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

(DEWFORA)

A 7th Framework Programme Collaborative Research Project

Implementation of improved methodologies in comparative case studies

Final report for the Limpopo case study

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DOCUMENT INFORMATION

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SUMMARY

This document presents a Limpopo Case Study application of the DEWFORA Drought Early Warning Framework. The Limpopo Case Study was a pilot for the application of DEWFORA's drought early warning framework seeking improvements in the institutional framework, procedures and technical developments can be taken up and implemented by stakeholders. The following investigations were conducted:

Investigation	
(a) Detailed synthesis and synthesis of existing data	• All raw primary and secondary data for the Limpopo River Basin • Minimum quality control protocols for the Limpopo • Quality control and report on data quality • Archival and database of time series and spatial data to support work package 4 (WP4) and other WPs
(b) Situation assessment	• Existing monitoring, forecasting and early warning systems • Historical drought experiences, responses, mitigation and adaptation practices • Institutional assessment • Comparison with state of the art
(c) Refining of drought indicators forecasting and modelling	• SPI – modelling for various case sites as well as operationalization of SPI for lead-time forecasting of droughts • Dry spells analysis and modelling for various case sites • Sustainability, soil moisture modelling and risk analysis of various crops rainfed systems • Risk of failures of irrigated systems under different agro-ecological zone crop systems
	• Coupling meteorological, hydrological and agricultural forecasting tools into a water allocation model •
	• Local scale agricultural models for Limpopo river basin
	• Deviation from historical monthly and seasonal mean NDVI • Modelling and analysis of seasonal NDVI and rainfall drought indices
	• Statistical analysis of drought variability to inform a statistical forecasting model of hydrological drought
(d) Drought management:	• Downscaled and tailor made hydrological models for the Limpopo Case Study basin
	• Skill of regional hydrological models developed to forecast hydrological drought
	• Inventory of scientific and indigenous knowledge systems on drought management
	• Flow of information within the drought forecasting and early warning framework
(e) Capacity building	• Stakeholder meetings and workshops • Training workshop

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LIST OF ABBREVIATIONS

AGRHYMET	Regional Training Centre for Agro-meteorology and Operational Hydrology
CAMELIS	Capacity Added by Mending Early and Livelihoods Information Systems
CARE	Cooperative for Assistance and Relief Everywhere
CFU	Commercial Farmers Union
CGMS	Crop Growth Monitoring System
CICs	Community Information Centres
DESA	Drought Emergency in Southern Africa
DGH	General directorate of Hydraulics
DHA	Department of Humanitarian Affairs
DMC	Drought Monitoring Centre
DMN	National Directorate of Meteorology
DPA	Regional Directorates of Agriculture
DPPA	Disaster Prevention and Preparedness Agency
DWA	Department of Water Affairs
ENSO	El Niño – Southern Oscillation
EWRD	Early Warning and Response Directorate
EWWG	Early Warning Working Group
FAO	United Nations, Food and Agricultural Organization
FEWSNET	Famine Early Warning Systems Network
GOZ	Government of Zimbabwe
GOZ-NEPC	Government of Zimbabwe - National Economic Planning Commission
GWAVA	Global Water Availability Assessment
ILRI	International Livestock Research Institute
LEWS	Livestock Early Warning System
LIMCOM	Limpopo Commission
LIU	Livelihoods Integration Unit
LPCI	Livelihood Protection Cost Index
MINAGRI	Ministry of Agriculture
NDVI	Normalised Difference Vegetation Index
NGOs	Non-Governmental Organizations
PAPSTA	Support Project to the Strategic Plan for the Agriculture Transformation
PWSS SOF	Polokwane Water Supply System Stakeholder Operating Forum
RRC	Relief and Rehabilitation Commission
RRSP	Regional Remote Sensing Project
SADC	Southern Africa Development Community
SADC	Southern Africa development community
SAP	Early Warning System

SARCOF	Southern Africa Regional Climate Outlook Forum
SAWS	South Africa Weather Services
SWAT	Soil and Water Assessment Tool
SPI	Standard Precipitation Index
SSD	Secretariat for the Drought Disaster
UN	United Nation
UNDP	United Nations, Development Programme
USAID	United States agency for International Development
VAC	Vulnerability Assessment Committees
VCI	Vegetation Condition Index
VAM	Vulnerability Analysis Mapping
WB	World Bank
WHO	World Health Organization

1. INTRODUCTION

The development of the improved framework for drought monitoring, forecasting and early warning involved a number of core tasks which included a comprehensive situation assessment, development and testing of drought indices, evaluation of forecasts, use of models; scientific analysis, policy analysis, end user and stakeholder meetings and workshops under Work Packages 2 to 7. Some of this work was conducted on the Limpopo River basin is summarized in the document for completeness. Improvements in drought monitoring and forecasting capabilities, the institutional framework and policies were included in Deliverable 5.3, the framework and guideline document. The Limpopo River Basin (see **Figure 1-1**) was selected as a pilot catchment to test specific aspects of the improved drought early warning framework on the DEWFORA project and in particular the flow of information during a drought.

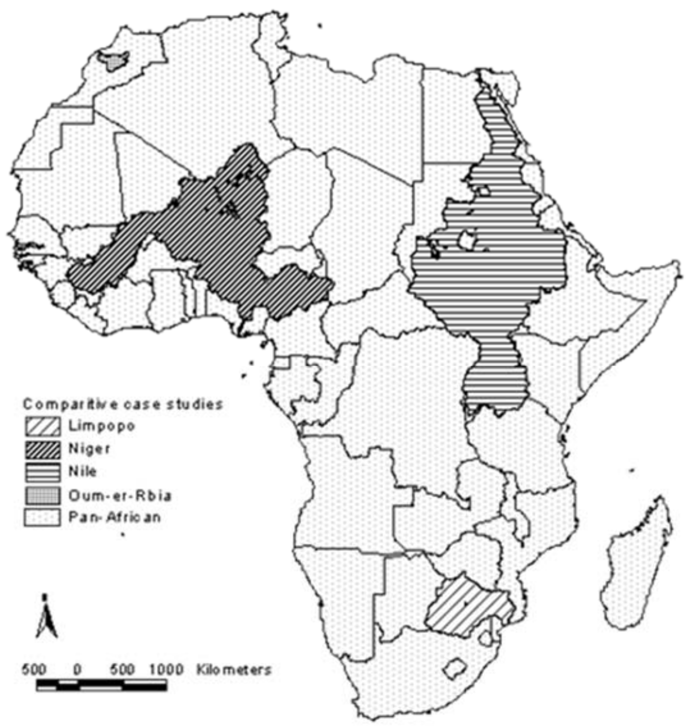


Figure 1-1: Location of the Limpopo River Basin in Africa

However in order to have adequate range of scales, climates and societies this investigation was extended to four geographical areas comprising countries in Northern Africa, Northern and Eastern Africa, Southern Africa and Western Africa. In this specific paper, our case study will be the Limpopo Basin located in Southern Africa. The Southern Africa region is shown in the Figure 1-2.

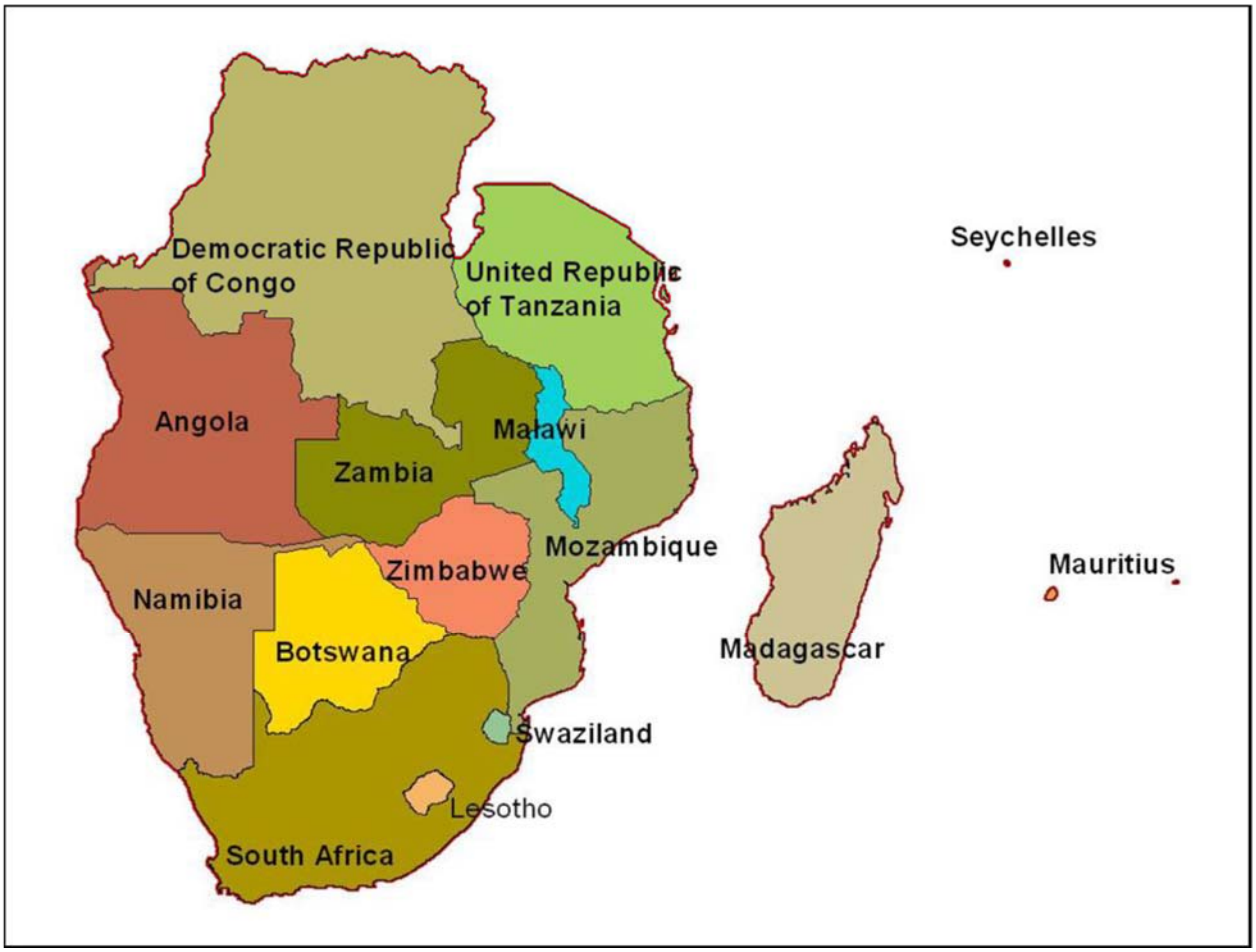


Figure 1-2 Countries in southern Africa.

According to the International Fund for Agricultural Development (IFAD), as cited by Benson, Thomson and Clay (1997), at least 60 percent of sub-Saharan Africa (SSA) is vulnerable to drought and probably 30 percent is highly vulnerable. Extreme drought in the Limpopo River Basin is a regular phenomenon and has been recorded for more than a century at intervals of 10-20 years. In the period 1980-2000, the SADC region was struck by four major droughts, notably in the seasons 1982/83, 1987/88, 1991/92 and 1994/95. This corresponds to an average frequency of once every four or five years, although the periodicity of droughts is not necessarily so predictable. FAO (1994) identified three drought cycles during the years 1960 to 1993 with lengths of 3.4, 7.1 and 5.8 years, respectively. Amplitudes were 0.38, 0.35 and 0.28 standard deviations, respectively.

In the case of the 1991/92 drought in southern Africa, estimates put the total number of people affected at 86 million, 20 million of whom were considered to be at serious risk of starvation. Botswana experienced several periods of prolonged drought affecting the entire country from 1981 to 1986 that were caused by a succession of below average rainfall years. The cumulative effect was devastating in terms of food and water availability and caused large-scale mortality in livestock and wildlife. This drought is widely regarded as the worst to affect Botswana in living memory. A second period of drought in 1991/92 also affected the entire country and caused widespread crop failure and livestock mortalities

The 1991/92 drought in Southern Africa, referred to as the "apocalypse drought" because of the magnitude of the problem, provides an unusually dramatic example of a large-scale natural disaster that resulted in very few deaths. Rains failed (or were late) across a wide region in 1991/92; the worst rainfall levels in over a century followed generally below-average rains across Southern Africa in 1989/90 and 1990/91. Grain yields in the ten states of the Southern African Development Community (SADC) were 56 per cent of normal (Green 1993). Regional stockpiles were woefully inadequate to cope with the shortage. The drought placed 17-20 million people at risk of starvation. Yet there were no famine-related deaths reported, except in Mozambique where there was an on-going civil war (Callihan et al. 1994).

1.1 OVERVIEW OF INVESTIGATIONS CONDUCTED

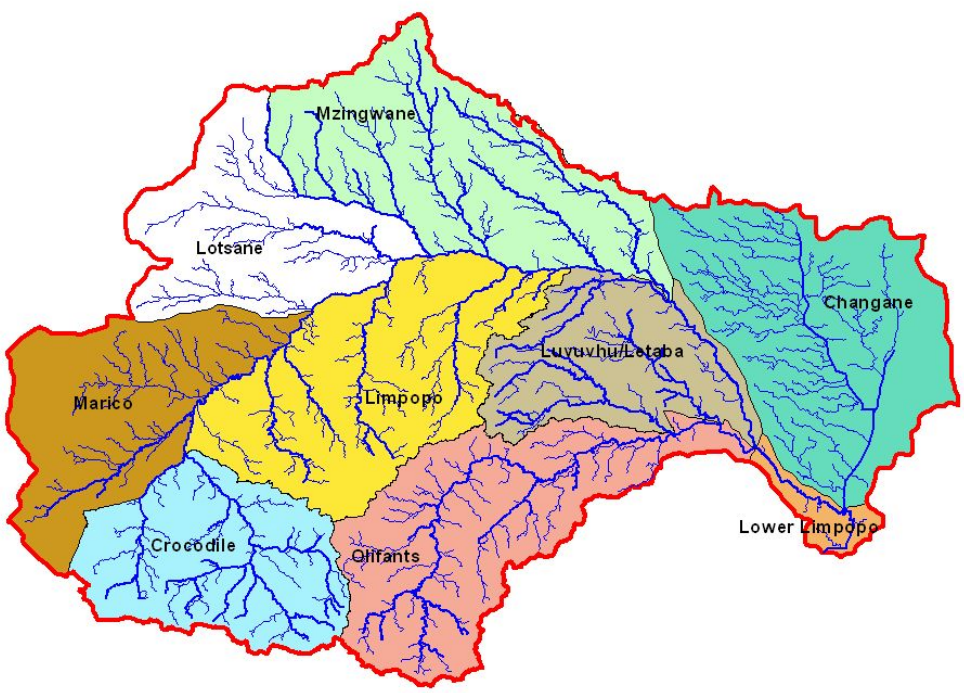


Figure 1-3: Location of the Mzingwane and Luvuvhu/Letaba Catchments

Baseline information about the Limpopo River Basin was collected and described in the Inception Report (Deliverable 6.1). Investigations and analysis in WP2 covered (a) existing drought early warning systems (Deliverable 2.1), institutional frameworks and drought mitigation and adaptation practices (Deliverable 2.2), drought warning experiences (Deliverable 2.3), and the gaps on monitoring and forecasting systems as well as mitigation and adaptation practices identified in Deliverables 2.4 and 2.5 respectively.

Improvements in the institutional framework and procedures from Work Package 5 were tested as well as the technical developments from Work Packages 3 and 4. Tests were conducted on the flow on information from the warning system through the institutional framework from regional to local scale. The Limpopo Case Study was therefore a pilot for the application of DEWFORA's drought early warning framework. Improvements in the institutional framework, procedures and technical developments put forward in this document can be taken up and implemented by stakeholders.

The following investigations were conducted:

Investigation		**Responsible Partner**	**Reference/ Comment**
(a) Detailed synthesis and synthesis of existing data	• All raw primary and secondary data for the Limpopo River Basin • Minimum quality control protocols for the Limpopo • Quality control and report on data quality • Archival and database of time series and spatial data to support WP4 and other WPs	*Waternet*	*Inception Report*
(b) Situation assessment	• Existing monitoring, forecasting and early warning systems • Historical drought experiences, responses, mitigation and adaptation practices • Institutional assessment • Comparison with state of the art	*WRNA*	*Covered in work by L Dlamini, B Chisadza, W Nyabeze, M Tumbare, M Chilundo, P Manguambe, A Muhate*
(c) Refining of drought indicators forecasting and modelling	• SPI – modelling for various case sites as well as operationalization of SPI for lead-time forecasting of droughts • Dry spells analysis and modelling for various case sites • Sustainability, soil moisture modelling and risk analysis of various crops rainfed systems • Risk of failures of irrigated systems under different agro-ecological zone crop systems	*Waternet and WRNA*	*Covered in work by Alemaw and L Dlamini*
	• Coupling meteorological, hydrological and agricultural forecasting tools into a water allocation model •	Waternet/ University of Botswana	B Alemaw

	• Local scale agricultural models for Limpopo river basin	*Waternet and CSIR*	*Covered in work by Alemaw and Emma*
	• Deviation from historical monthly and seasonal mean NDVI • Modelling and analysis of seasonal NDVI and rainfall drought indices		*Covered in work by Dlamini et al*
	• Statistical analysis of drought variability to inform a statistical forecasting model of hydrological drought	*GFZ*	M Seibert - GFZ, Deliverable 4.6 and 4.8)
(d) Drought management:	• Downscaled and tailor made hydrological models for the Limpopo Case Study basin	*IHE*	Maskey
	• Skill of regional hydrological models developed to forecast hydrological drought	*IHE*	P Trambauer, A Maskey
	• Inventory of scientific and indigenous knowledge systems on drought management	*WRNA*	*Covered in work by Chisadza et al*
	• Flow of information within the drought forecasting and early warning framework	*UEM*	*Taken over by Dinis Juizo (Addendum A)*
(e) Capacity building	• Stakeholder meetings and workshops • Training workshop	*Waternet*	*Report by J-M Onema*

The results from these investigations are presented in the next sections of the document.

Meteorological droughts

The drought of the early nineteen thirties reached maximum development during the 1932-1933 seasons with vast areas of the country severely affected whilst large areas were similarly affected during the 1948-1949 season. An interesting period is that from 1963-1964 to 1965-1966 where the influence of the Eastern Transvaal (now part of Mpumalanga and Limpopo provinces) escarpment is clearly apparent. The worst drought in the South Western Cape from a water resources point of view occurred during the 1972-1973 season. The event was very largely confined to the coastal regions and the southern interior with serious shortfalls in dam levels. Over most of the interior the early and mid-seventies were particularly wet with serious flooding during the 1974-1975 season. The present drought is seen to have developed over the Northern Transvaal during 1978-1979 and over Natal during 1979-1980.

Dry conditions began in the Limpopo Basin in 1965 to 1975. A serious drought began in the water year of 1981 up to 1987. The amount of rainfall received was relatively enough for the storage in dams that were available but the issue was with period at which the rain fell. There was no rainfall was experienced at crucial times of the year.

1.1.2 OVERVIEW OF METHODLOGY APPLIED IN DATA COLLECTION AND ANALYSIS

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) .This study has been carried out in coordination between the specialists of each region. In each region a watershed basin has been taken as a study case. The information was collected at an institutional level for each sector. It should be noted that in most cases the information collected at the institutional sector was insufficient to give the required responses for the project. Part of this was supplied with the information of the other countries sharing the basin. The table below presents the main team of the DEWFORA Project.

Table 1-1: The main team of DEWFORA Project.

Title	Inventory of institutional frameworks and drought mitigation and adaptation practices in Africa	
Lead Author	W R Nyabeze and Associates, South Africa	
Contributors	A Opere	ICPAC
	G Ouma	ICPAC
	O Lahlou	Institut Agronomique et Vétérinaire Hassan II
	S. B. Alaoui	Institut Agronomique et Vétérinaire Hassan II
	Y Imani	Institut Agronomique et Vétérinaire Hassan II
	C Ndayisaba	Institute of Scientific and Technological Research (Rwanda)
	K Mahmoud Attia	Nile Research Institute, Egypt
	H Farag	Environment and Climate Research Institute, NWRC, Egypt
	D Mulungu	University of Dar es Salam, Tanzania
	M Mohamed Elhag	University of Gezira, Sudan
	S O Dulo	University of Nairobi, Kenya
	M Chilundo	WR Nyabeze and Associates
	B Chisadza	WR Nyabeze and Associates
	L Dlamini	WR Nyabeze and Associates
	M Kubare	WR Nyabeze and Associates
	P D Manguambe	WR Nyabeze and Associates
	A Muhate	WR Nyabeze and Associates
	W Nyabeze	WR Nyabeze and Associates
	M Tumbare	WR Nyabeze and Associates
	M Diallo	Wetlands International/ Mali office
	B Kone	Wetlands International/ Mali office
	K Sanogo	Wetlands International/ Mali office
Distribution	PP: Restricted to other programme participants (including the Commission Services)	
Reference	Inventory of institutional frameworks and drought mitigation and adaptation practices in Africa	

2. CURRENT SITUATION IN THE LIMPOPO RIVER BASIN (*L DLAMINI, W NYABEZE-WRNA*)

On average the rainfall season starts in October as shown in **Figure 2-1** and by end of March most of the rainfall would have been received as shown in **Figure 2-2**. For a one month lead time an expectation of rainfall for rain fed agriculture can be assessed in August and issued in September. A forecast in December with a one month lead time can provide the expectation in February. The monthly time scale is adequate for most user requirements. However, farmers require daily rainfall data for the forthcoming month to determine planting date or schedule irrigation.

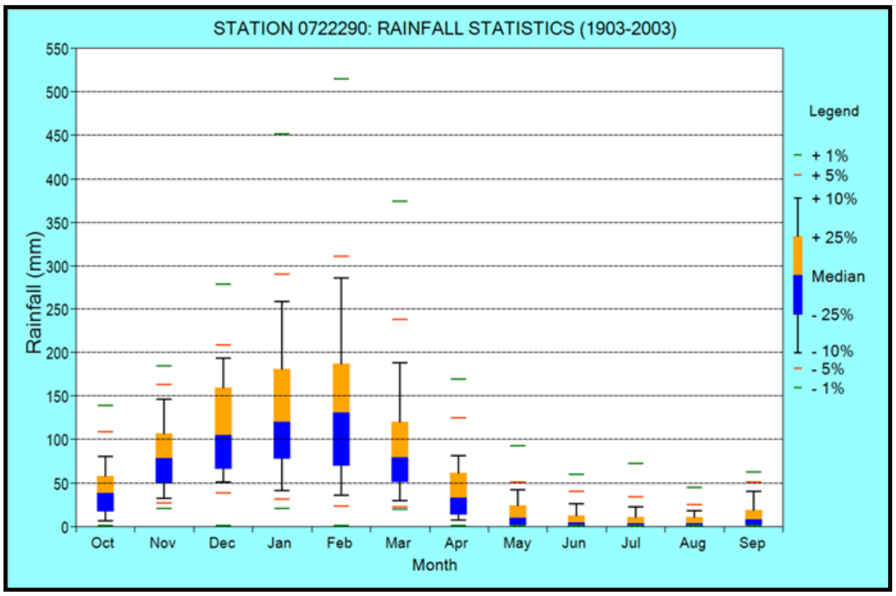


Figure 2-1: Distribution of total monthly precipitation

Source: HDAM Graphs, 2012

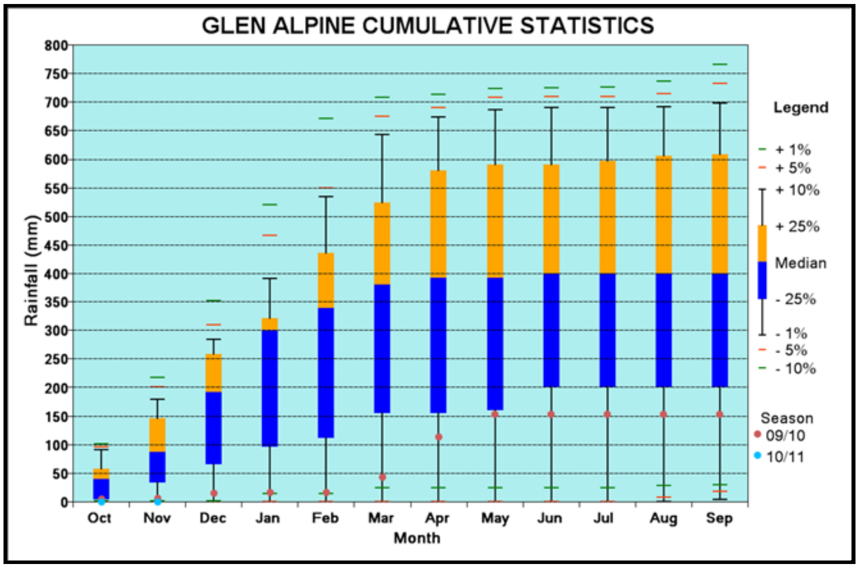


Figure 2-2: Cumulative distribution of total monthly precipitation

Source: HDAM Graphs, 2012

The Inception Report on the Limpopo Case Study (Deliverable 6.1) provides geographic information, status of ground and surface water development, historical water use, drought management practices including the issuing of early warnings, implementation of mitigation and adaptation interventions. The results from the situation assessment are summarized in this section. For more detailed information the reader is referred to DEWFORA deliverables 2.1 to 2.5.

The Limpopo basin is shared by four countries namely South Africa, Mozambique, Botswana and Zimbabwe. The area covered is around 415,000 km^2, which 19.3% is in Mozambique. The river rises in South Africa at an altitude of 1500m, with a total length of 1500 km. In Mozambique the main tributary rivers are the Elephants (the main tributary of the river, covering an area of approximately 68 km^2), covering in Mozambique an area of approximately 6900 km^2, and the Shangaan, which covers an area of 43 km^2 in Mozambique. The figure 2-3 below illustrates the Limpopo basin.

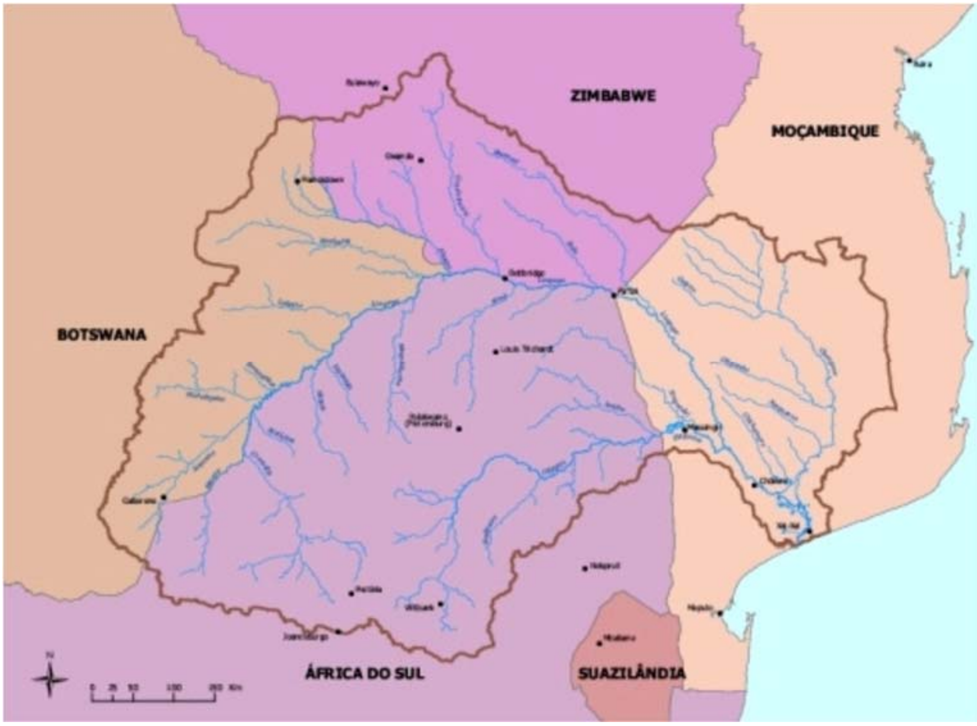


Figure 2-3: the Limpopo River Basin (INGC et al., 2003)

Geology and Soils

In Mozambique the Limpopo basin is characterized mostly by thick deposits of Pleistocene marine sediments, called “Mananga " , with a high percentage of coarse sand.

Vegetation

The dry climate of this area benefits the occurrence of savanna and dry ecosystems. But during the rainy season occurs grasslands.

Population and Socioeconomic Characteristics

Most of the Limpopo Basin in Mozambique covers the Gaza Province, with a small part in Inhambane Province. Thus, there is a greater concentration of the population at the Gaza side, respectively in the coastal where the climate is less arid.

Climate

In this region occurs two distinct seasons: the wet and warm season (October to March) and the dry and cool season (April to September). The wet season occurs when the Zone

Inter -Tropical Convergence (ITCZ) moves towards the South and the opposite in the dry season (INGC et al., 2003). The precipitation tends to decrease from the coast to the interior and the climate in this region is also influenced by phenomena El Niño and La Niña. The El Niño/La Niña refers respectively to abnormal heating or cooling of the sea surface in the equatorial Pacific Ocean.

Climatic Classification

As previously mentioned the climate in the region of Limpopo basin, varies from semi-arid to arid, respectively from the coast to the interior. The annual rainfall average at the Limpopo basin can vary from 1000 mm in the coastal area to 350 mm in the interior region. The wet season registers about 76-84% of the total annual rainfall and dry season around 26-24% of the total annual rainfall. The annual temperature average in this region is among 23 to 26 ° C with a decreasing gradient from the coast to the interior. The evapotranspiration also shows variation from the coast to the interior, like other climatic variables, particularly the temperature gradient. The highest values are recorded in the months of January and February and the lowest in June and/or July.

Surface Water

Regarding the runoff, the Mozambican Tributaries Rivers of the Limpopo basin contributes with approximately 10 % of the annual total runoff of the Limpopo River. The Limpopo River, is originally a perennial river, however it dry (eight months a year) due to increased abstractions from upstream countries (FAO, 2004).

In Mozambique the Elephants River is the only tributary that can be considered permanent, but in exceptional condition, it can dry. The other rivers, including the River Limpopo, Shangaan and Mwenezi are intermittent (Brito and Julaia, 2009). During its course in Mozambique there are 11 hydrometric stations in Limpopo. In Mozambique the drought is the most common and devastating disaster that has affected the Limpopo Basin. It is a phenomenon historically often with large impacts on populations. The Limpopo basin is very vulnerable because the rainfall is very irregular and unpredictable. The rainy season often starts as not predictions and when it occurs, the precipitation falls mostly concentrated in a few days (Brito and Julaia 2007).

In the Limpopo basin, several droughts have occurred at intervals of 7-11 years, and the lower intensity of the droughts that occur more regularly. The drought of 1991-92 was the worst in living memory and affected the entire basin and most of the southern African region (INGC et al., 2003).

Infrastructures

Massingir Dam

The Massingir dam was built during the period 1972 - 1977 on the Elephants River. The study for its construction started in 1924 and its main purpose was irrigation. The dam project aimed to irrigate an area of about 90.000hectares (including a part in the Chokwe Irrigation system and another system of Irrigation). The project also was proposed to: Intrusion control of the mouth of the lower Limpopo, the amortization of floods and produce electricity. It should be noted that not all objectives have been achieved as yet not been constructed centrally for the electricity production. The surface of the reservoir created by this structure is about 150 km^2 with a total storage capacity of 2844 hm^3, where 2 784 hm^3 (approximately 98%) correspond to the useful storage. It is an earth and concrete dam with a maximum height above the foundation of 46 m and an elevation 130 m crowning a full storage level of 125 m a level of 127.5m of maximum full level of minimum operation of 95 m. (http://www.ara-sul.co.mz/dam.asp?id=102 Ara Sul, 2013). The reservoir of the Massingir dam is shown on the figure 2-4.

Figure 2-4: The Massingir Reservoir (google maps).

Macarretane Dam

In order to regulate the flow and raise the water level in the Limpopo River to benefit the Chokwe irrigation scheme, given the importance of this, the weir was built Macarretane. The dam Macarretane is located a few kilometers (about 30 km) from the confluence of the tributary to the Limpopo Elephants. However, it is noted that the dam not seen yet achieved its main objectives now that despite the Chokwe Irrigation is one of the largest agricultural fields in the country (30 thousand ha), less than 40% is being used.

Figure 2-5: The Macarretane weir/dam, plan view (google Earth).

It is a reinforced concrete structure whose construction dates from 1955, with approximately 650 km in length crossing the Limpopo River. The structure is composed of 39 metallic gates which open automatically when the flow rate reaches or exceeds 2 500 m^3/s.

2.1 EXISTING DROUGHT FORECASTING AND EARLY WARNING SYSTEMS

A comprehensive list of drought monitoring, forecasting systems networks/ institutions for the Limpopo was developed and presented as factsheets (see Deliverable 2.1). This information can also be found on the Stakeholder Platform (www.dewfora.net).

2.1.1 Seasonal climate forecasts

The following three forms of seasonal climate forecasts are available in the Limpopo river basin:

(i) Southern Africa Regional Climate Outlook Forum (SARCOF) climate outlooks

(ii) Seasonal climate outlooks prepared by Meteorological Departments

(iii) Local knowledge forecasts applied by rural communities

The SARCOF climate outlook is issued once in September each year as a statement after a consensus workshop. National, regional, and international weather experts build a consensus seasonal forecast for the region. The process uses statistical and other climate prediction schemes to determined likelihoods of above-normal, normal and below-normal rainfall for each area. Above-normal rainfall is defined as lying within the wettest third of recorded (30- year, that is, 1971 -2000 mean) rainfall amounts; below-normal is defined as within the driest third of rainfall amounts and normal is the middle third, centred on the climatological median. The scientists also take into account the El Nino-Southern Oscillation (ENSO). A typical ENSO forecast is shown in **Figure 2-6.**

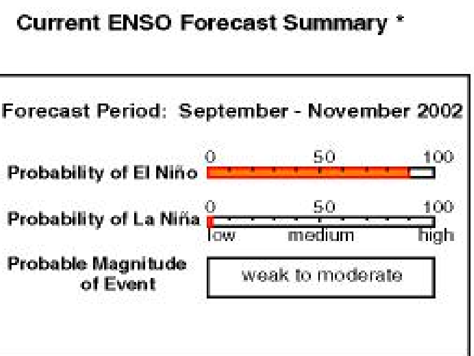


Figure 2-6: El Niño & Southern Oscillation (ENSO) forecast summary for July 2002

The outlook splits the rainfall season in two periods, Oct-Nov-Dec and Jan-Feb-Mar and provides an average forecast map for each period for above normal, normal and below normal. A typical SARCOF climate outlook is in the form shown in **Figure 2-7**. The colours on the map show near homogeneous regions and the three numbers in each box are the percentage chance of above normal, normal and below normal. It is a three-month ahead forecast as illustrated in **Figure 2-8**.

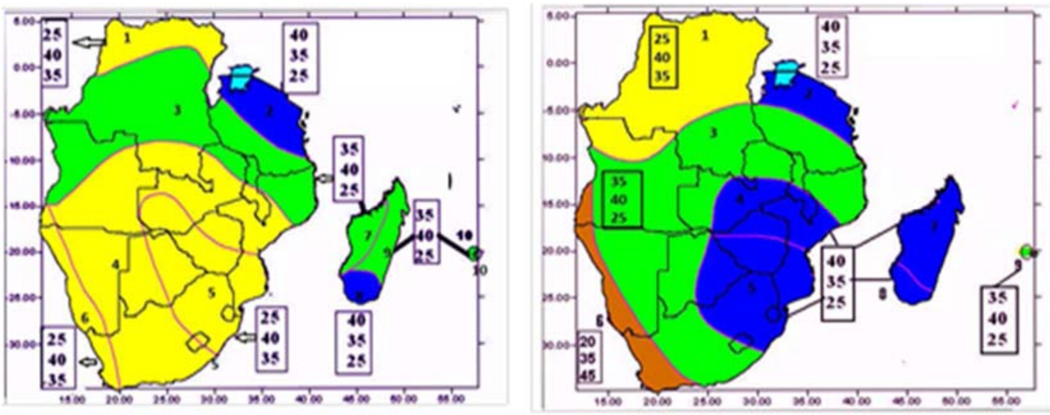


Figure 2-7: Rainfall forecast for October-November-December 2011 and January-February –March 2012

Source: SARCOF 15 statement

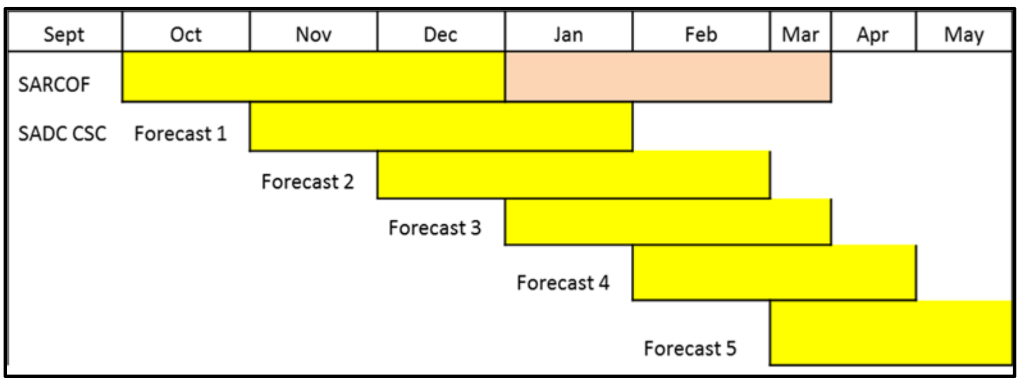


Figure 2-8: Current practice SARCOF and SADC Climate Services Schedule

The SADC Climate Services Centre (CSC) complements this effort by producing three month-ahead forecasts starting with Nov-Dec-Jan. These forecasts can be used for evaluating the SARCOF forecasts and reviewing decisions as necessary.

The South Africa Weather Services (SAWS) has moved from using a downscaling global system to the region (atmospheric modelling) to the ECHAM 4.5 Ensemble prediction system for climate forecasting. Enhanced Probabilities is considered to be more than 45% probability for a specific category (i.e. above or below normal). For the areas that do not show an indication of more than 45% probability, the forecasts are considered to be uncertain. Every mid-month the South Africa Weather Services (SAWS) issues maps of rainfall and maximum and minimum temperatures as three 3-month forecasts. A typical SAWS climate outlook is in the form shown in **Figure 2-9**. The colors on the map also show near homogeneous regions and the three numbers on the legend are percentages chance of occurrence. Each forecast comprises two maps, one for each category.

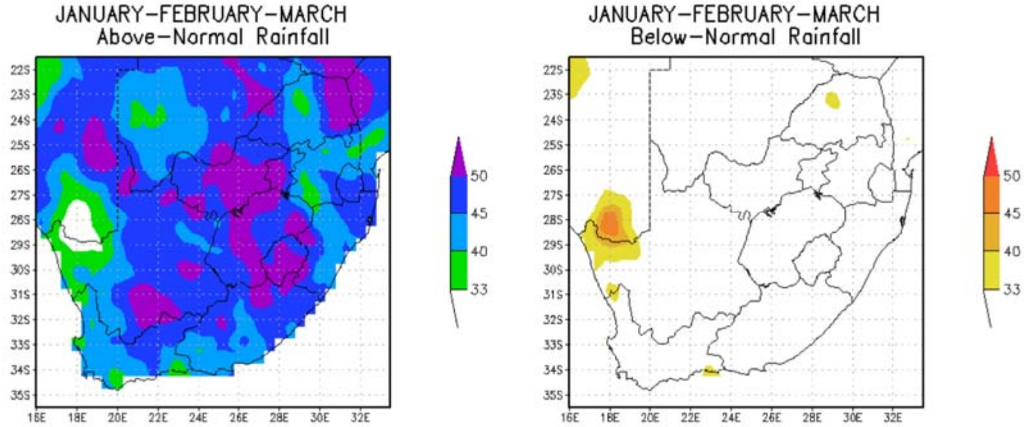


Figure 2-9: Rainfall forecast for January –March 2012

Source: SAWS

The SAWS also generates Standard Precipitation Indices (SPI) and provides them in map form as shown in **Figure 2-10**.

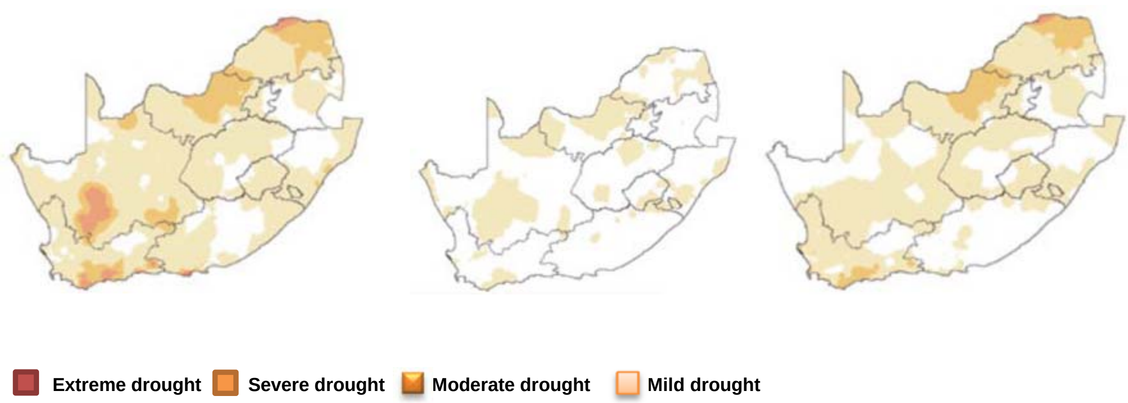


Figure 2-10: Standardized Precipitation Index (SPI) for South Africa, November 2005 (left); September to November 2005 (middle); June to November 2005 (right)

Source: South African Weather Service

On average, Dec-Jan-Feb is the wettest period (**see** Figure 2-11) therefore for a seasonal outlook the first relevant forecasts is the one produced in September and the one produced in November (review) would be the last relevant forecast (**see** Figure 2-11). The forecast have a lead time of three months. The forecast for the next month is expected to improve on the second and third blocks of the previous month forecast. Users are expected to review their decisions based on this information.

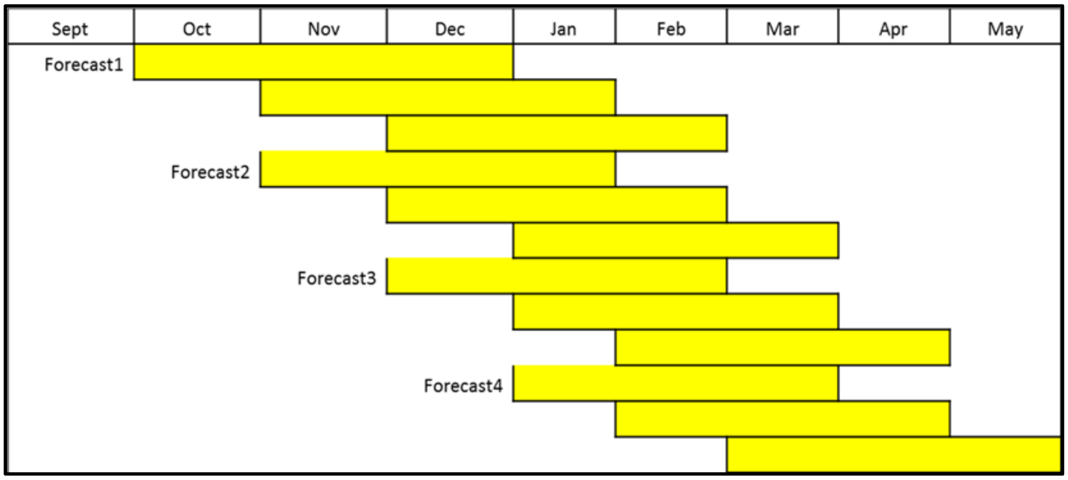


Figure 2-11: Current practice SAWS Schedule

The following are included in the local indigenous and knowledge drought forecasting systems in the Limpopo River Basin:

- The sun, moon and wind
- Trees and plants
- Insects, birds and animals

Table 2-1 shows some of the warnings and the possible implications.

Predictor/ signal	Description/Interpretation	Implications
Cry of Cuculus solitarius bird	The cry of Cuculus solitarius bird between August and November is a sign of the beginning of the wet season	Farmers prepare farming inputs upon the cry of the bird.
Abundance of some wild fruits	The abundance of some wild fruits that include Vanguer birrea during the period of December to February is taken as a sign of imminent famine	Harvest from previous season is preserved. Wild fruits and vegetables are also collected and preserved
Cry of frogs	The cry of frogs during the summer season (September to March) is taken as a sign of approaching rainfall.	Farmers prepare their farming inputs in readiness to plough
The position of the moon	When the moon is slightly tilted to the west and the crescent is facing down during the periods of August to December it is taken as imminent sign of rainfall within a week.	Farmers prepare their farming inputs in readiness to plough and plant

Abundance of certain insects	The abundance of butterflies, locusts and grasshoppers during the farming season is taken as a sign of imminent drought and famine	Harvest from previous season is preserved and preserved

Table 2-1 Warnings from Indigenous and Local Knowledge Systems

2.1.2 Forecasting water availability

Water managers forecast availability of water using rainfall and storage trajectories. The most common current approach on rainfall superimposes forecast rainfall on statistics of historical rainfall to establish the deviation from "normal". Dam operators and water resource managers want to know the forecast storage or stream flow at the beginning or end of each month. The current practice in South Africa is to consider storage at the end of the rainfall season and produce forecast trajectories which consider abstractions and probable inflows. For the Limpopo River basin this typically takes place at the beginning of April or May. Drought operating rules or water restriction rules are applied to keep the storage above the minimum operating levels.

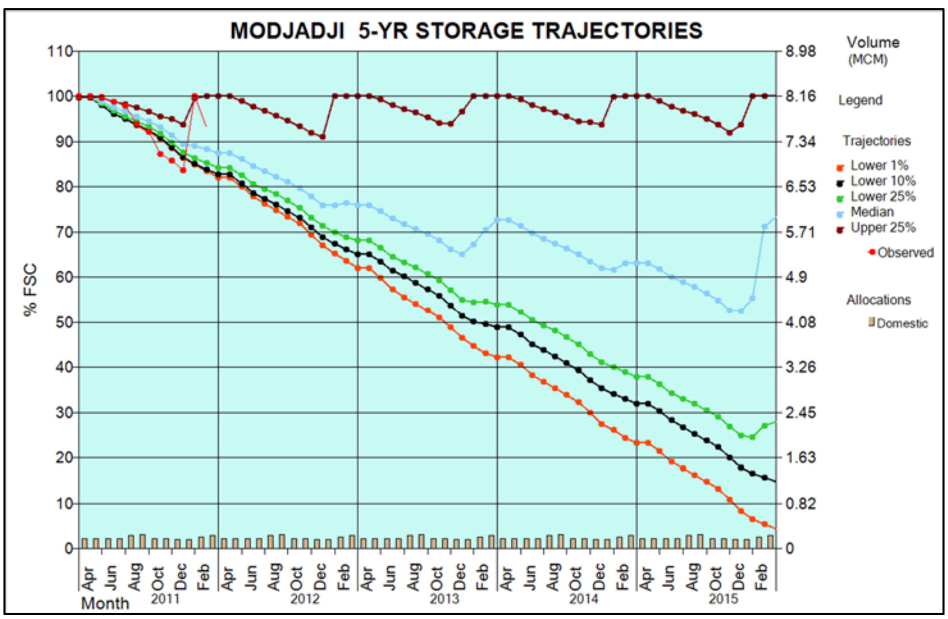


Figure 2-12: Example of reservoir trajectories

Source: HDAM Graphs, 2012

The thresholds for decision making will be defined based on analysis of trajectories and possible impact on users. The purpose of these thresholds is for stakeholders to initiate mitigation activities, as well as adaptation strategies. WRNA publishes information on operating rules and forecast storage trajectories on the web page www.wrmew.com.

2.1.3 Drought hazard mapping

Indices are used to map drought hazard and the most common ones are decile rainfall, Water Satisfaction Index (WSI), Normalised Difference Vegetation Index (NDVI) and Standard Precipitation Index (SPI). The Famine Early Warning System Network (FEWSNET) provides information on food deficits through its vulnerability assessment network.

2.1.4 Users of drought early warning information

Direct users of drought early warning information include social and economic organizations, local communities, the fishing industry, hydrological services, departments responsible for water management - planning, development and operation of water infrastructure, research agencies, catchment management agencies/water authorities, departments of agriculture, directorates responsible for communicating drought forecasts to users, disaster management organisations, municipalities/district councils, directorates responsible for communicating drought forecasts to users, UN agencies, large irrigation water users, NGOs and USAID FEWSNET.

2.1.5 Key findings

Key findings of this review can be summarised as follows:

- The forecasting and early warning systems available are not adequately maintained
- Existing infrastructure including drought forecasting systems, advanced models and software is generally inadequate compared to user requirements
- The number of scientist/specialists involved in designing and developing early warning and forecasting systems is very low compared to, Australia, the United States of America (USA) and countries in Europe.
- Although locally collected data is also useful for regional, continental and global forecasting and early warning systems, the data collection systems are deteriorating. Data is not readily available
- Infrastructure to process and share information is inadequate
- Poor support for researchers, meteorologists, technology transfer, farmers, policy makers, and communities to perform their roles more effectively
- The application of early warning systems such as seasonal climate outlooks and monthly updates is generally poor

- Methods for integrating scientific (broad scale) and traditional (local scale) drought forecasting and monitoring are not well developed.
- Challenges on monitoring drought include the following:
    - Meteorological and hydrological data networks are often inadequate in terms of the density of stations for all major climate and water supply parameters. Data quality is also problematic because of missing data or a short length of record;
    - Data sharing is inadequate between government agencies and research institutions;
    - Indigenous knowledge systems are poorly documented and validated
    - High costs limits application of data in drought monitoring, preparedness, mitigation and response. Rainfall, temperature data and the derived parameters are costly, as the national meteorology agencies, which are public institutions, charge high fees even if the data is required by education and research institutions.

2.1.6 Comparison of existing monitoring and early warning systems with "state-of-the-art"

This section provides a summary of the gap analysis in WP2 Deliverable 2.4. The Group on Earth Observations defines a "state of the art" early warning system as: "a web-based, real-time Geographic Information System GIS server with a distributed database federation, used for hydrologic alerts in drought conditions..." Monitoring, forecasting and early warning systems in the USA, Australia and Europe are provided as examples of "state-of-the-art" systems. The section looks at the institutional alignment and framework requirements for drought monitoring and early warning systems.

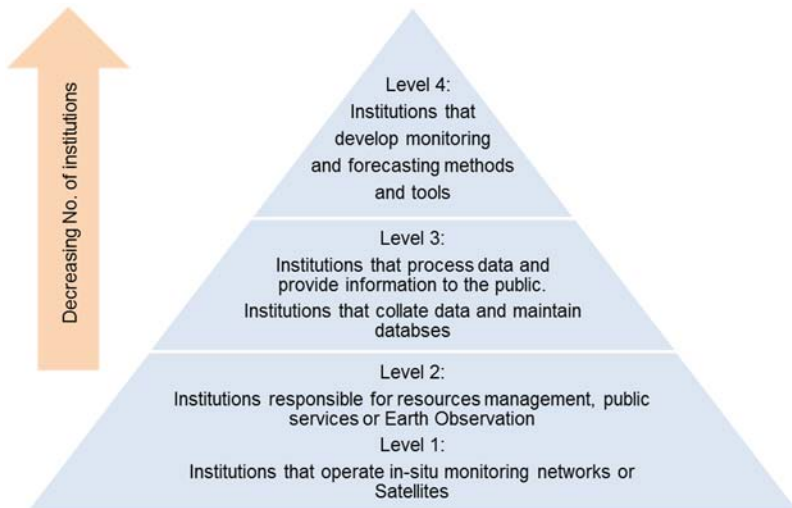
(a) Institutional alignment

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

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

- Level 4: Institutions that develop monitoring and forecasting methods and tools.

These levels are illustrated below.



In Southern Africa the number institutions involved in drought monitoring, forecasting and early warning is very small and they tend to try to work at all of the four levels.

(b) Configuration of drought monitoring and early warning systems versus user requirements

The focus of the analysis in this document is on the outputs, inputs and resources of the systems in Africa in order to understand the gap that exists between them and the 'state of the art". The main users of drought monitoring and forecasting systems and their requirements are summarised in section 2.4 and Deliverable 2.3.

The main challenges for drought forecasting and early warning systems in Africa are as follows:

- Early warning information where it exists is delivered on an occasion basis. End users do not get information in suitable format at the time they need it. Systems for disseminating or delivery or exchange of information in a timely manner are not well developed or inexistent, limiting their usefulness for decision support;
- Early warning information is often too technical, limiting its use by decision makers and farmers. End users are not involved in product verification. There are no customer's/users networks to ensure product verification and service feedback;

- Early warning information is often unreliable on the seasonal timescale and lacks specificity, reducing their usefulness for agriculture and other sectors;
- Drought impact assessment methodologies are not standardized or widely available, which limits the formulation of regionally appropriate mitigation and response programs;
- Drought indices are generally inadequate even for detecting the onset and end of drought;
- Integration of information into government structures is poor and focuses on emergency response rather than long-term planning;
- Users are not aware of early warning products that they can use.

The following observations were also made in this deliverable:

- The forecasting and early warning systems available in Africa are not adequately maintained; recalibration and troubleshooting of the systems are also inadequate;
- The limited involvement of scientist/specialists in Africa in designing and developing early warning and forecasting systems means that local knowledge is not incorporated in "state of the art", which results in unreliable products downscaled to regional and local levels;
- Locally collected data is also useful for regional, continental and global forecasting and early warning systems. The current approach to financing data collection is therefore not appropriate;
- Capacity is required at all levels (researchers, meteorologists, technology transfer, farmers, policy makers, communities, etc) for effective interpretation and usage of forecasting and early warning products.

2.2 DROUGHT EXPERIENCES IN THE RIVER BASIN

Drought is a recurrent phenomenon in the Limpopo River basin as depicted by local inhabitants from many centuries ago. However, due to the reliability of the data and documentary this study is focused on specific drought years from around 1920s from readily available literature (**see Deliverable 2.2**). The spatial coverage of drought varies each year. Hit count of drought reports shows that 1921/22 to 1950/51, drought was reported somewhere in the basin for up 10 successive seasons; 1951/52 to 1980/81-up to 10 successive seasons, 1981/82 to 2008/09 - up to 7 successive seasons. Even if the frequency varies for specific localities, droughts are one of the main natural hazard in the Limpopo River Basin

2.2.1 Drought incidents captured in literature

Table 2-2 shows the hit count of drought incidences available from literature for the period 1921/22 to 2008/2009. The years when drought was not reported are excluded in order to reduce the length of the table.

Table 2-2 Consecutive drought years in the Limpopo basin (1961/62 to 2008/9)

	Total No of drought years	1 year continuou s drought	2 year continuou s drought	3 year continuou s drought	4 year continuou s drought	5 year continuou s drought	> 5 years
1961/62 1970/71	5	1			1		
1971/72 1980/81	4	4		1			
1981/82 1990/91	7	4	2		1		1
1991/92 2000/01	4	3	2				
2001/02 2008/09	5	3	2				
Total	**25**	**15**	**6**	**1**	**2**	**0**	**1**

The spatial distribution of drought in the basin is shown in **Figure 2-13** obtained from Nyabeze (2004). The blue areas represents the threshold below which drought was experienced and the rest of the shading shows worsening drought conditions from green, yellow, brown to dark brown. 1986/87 was a severe drought covering most of the sub-catchment but 1991/92 drought was more severe and extended.

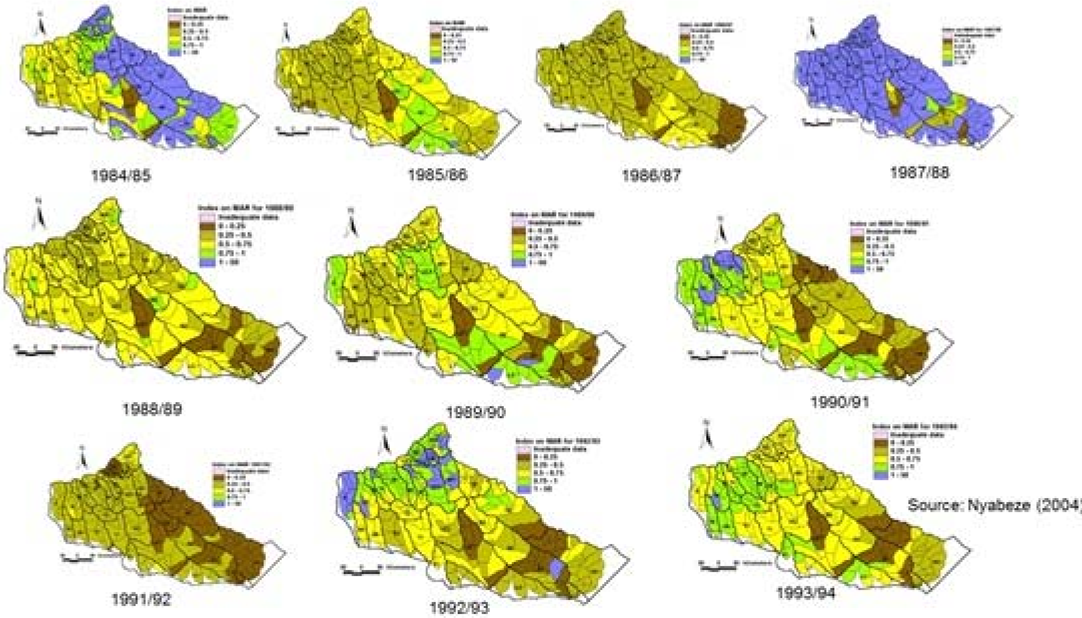


Figure 2-13: Drought Experiences in the Limpopo River Basin

In the period 1984-1994 the basin was struck by four major droughts, notably in the seasons 1986/87 and 1991/92. FAO (1994) identified three drought cycles during the years 1960 to 1993 with lengths of 3.4, 7.1 and 5.8 years. Amplitudes were 0.38, 0.35 and 0.28 standard deviations, respectively.

The 1992 drought was very severe especially for southern parts of Zimbabwe including the Limpopo River basin as shown in Figure 2-13

Figure 2-14: Drought Experiences in the Limpopo River Basin

Competition for water is often experienced during droughts as illustrated in Figure 2-14.

The spatial extent of drought is well documented at national and administrative scale. This is informed by the need to map of drought impacts in terms of food shortage and people affected. In direct, contrast mapping of drought at catchment scale, the hydrological unit as not well documented.

Since 1975 after the independence Mozambique has been affected by long period of drought which results in stagnation of the national economy contributing for high levels of vulnerability of Mozambican citizens (SETSAN, 2005).Every year droughts affects the country, the most frequency and severity are verified in the southern and central region. The agriculture is the first sector that suffers the direct consequences followed by other sectors of economy. According to INGC *et al*. (2003), the most dramatic droughts during the last two decades (1980 to 2008) are listed in table below.

Table 2-3: Major drought in Mozambique 1980 – 2008 (INGC et al. 2003).

Year	**Affected Area**	**Number of people affected**
1980	South and Central	No data available
1981-83	South and Central	2.46 million
1983-84	Most country	No data available
1987	Inhambane	8,000
1991-92	Entire country	1.32 million
1994-95	South and Central	1.5 million
2002-06	43 South and Central Districts	800,000 million

Table 2-4: Frequency of drought occurrences. (MICOA 2006).

Region	**Province**	**Number of consecutive drought years**	**Return period (years)**
North	Niassa	6	5.0
	Cabo Delgado	5	6.0
	Nampula	6	5.0
Central	Tete	5	6.0
	Zambézia	6	5.0
	Sofala	9	3.3
	Manica	5	6.0
South	Inhambane	5	6.0
	Gaza	5	6.0
	Maputo	5	6.0

The experience of Southern Africa during the 1991/92 drought is not a complete success story. Mozambique fared less well than other Southern African countries, in part because donors were reluctant to send food aid from fear that with the existing conflict situation the food could be stolen and not reach displaced people (Ayisi 1992). Largely owing to the ongoing civil war production also did not rebound with the good rains in 1992/93 to the same extent as it did in neighboring nations.

Another, less severe, drought afflicted the region in 1994/95, and farmers who might otherwise have been able to cope were pushed into bankruptcy, since they were already in debt from the 1991/92 drought. Nevertheless, the experience during the worst drought in over a century clearly shows that drought does not have to lead to famine. The physical and biological causes of production shortfalls are in no way the sole determinants of food shortage. They must always be viewed against an institutional background dedicated to preventing and alleviating shortage.

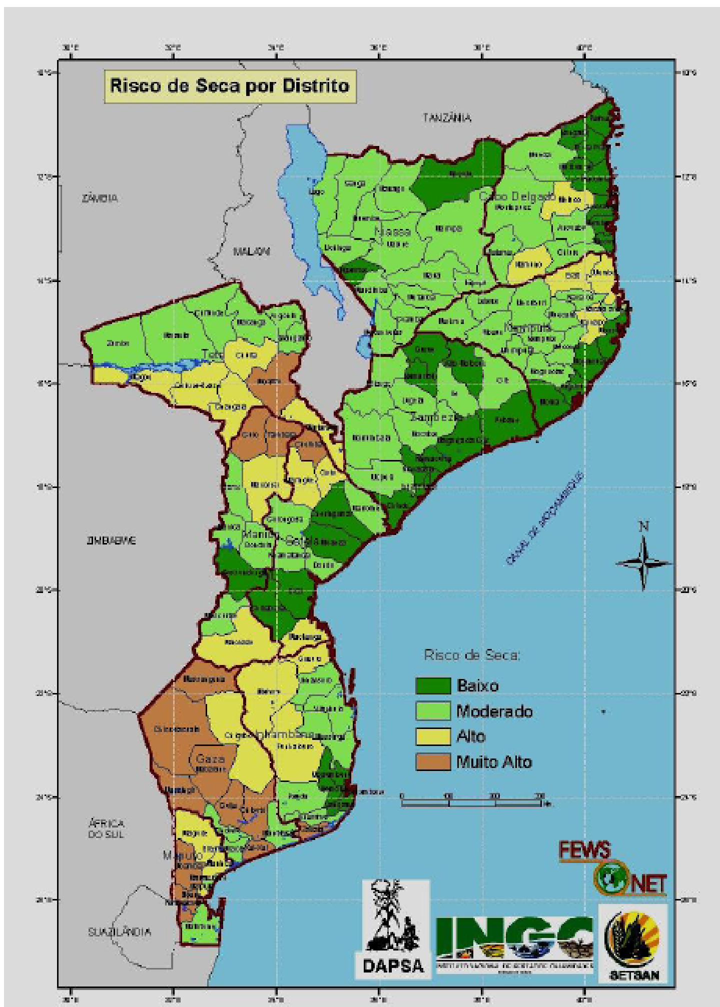


Figure 2-15: Drought prone zones in Mozambique (MICOA 2007).

Classification of drought periods in the history of Southern Africa

The periods shown in Table below can be identified in the history of Southern Africa as both meteorological and hydrological droughts.

Drought period		Type of drought	Spatial coverage
From	To		
1964	1970	Meteorological and agricultural	SADC
1981	1984	Meteorological and agricultural	SADC
1987	1988	Meteorological and agricultural	SADC
1991	1995	Meterological, Hydrological and Agricultural	SADC
2002	2005	Meteorological and agricultural	SADC

2.2.2 Drought mitigation

The most common drought mitigation action implemented in the basin is **food aid**. The following table presents a summary of the actions identified.

Mitigation Actions	Southern Africa -Limpopo Basin			
	Botswana	Mozambique	South Africa	Zimbabwe
Food aid	X	X	X	X
Boreholes, wells and small dams		X	X	X
Harvesting of rainfall water	X		X	X
New drought tolerant crops	X	X		X
Horticulture		X	X	X
Drought relief program		X	X	X
Saving livestock		X	X	X
Livestock vaccination campaigns		X	X	X
Agroforestry		X	X	X
Livestock watering points			X	X
Controlled grazing		X	X	
Livestock feeding programs		X	X	
Water use efficiency			X	X
Local seed production			X	X
Giving priority to drinking water		X		X
Rescheduling of farmers' credits		X	X	
Diversification of income sources			X	X
Fruit production		X	X	
Irrigation management			X	X
Irrigation systems		X	X	

Mitigation Actions	Southern Africa -Limpopo Basin			
	Botswana	Mozambique	South Africa	Zimbabwe
Importing and subsidizing drilling				x

Other drought mitigation actions include use of lowlands, debt forgiveness, restrictions on summer crops, public awareness campaigns and cloud seeding. Local traditions and knowledge systems for drought mitigation include:

- Prayers for rain
- Rain queen
- Rain emissaries
- Offerings for rain

There are different types (distinguished by role) of institutions involved in drought mitigation. The most common actions being agriculture extension services, food aid, policy, advocacy and water supply. The following table presents the spread of roles amongst the institutions identified. Agriculture extension services, food aid and funding are well established roles. Drought forecasting is also included.

Type of Institutions/Role	Limpopo Basin			
	Botswana	Mozambique	South Africa	Zimbabwe
Agriculture Extension Services	1	2	3	3
Food Aid	1	2	1	4
Funding	1	1	4	2
Water Infrastructure Development	1	2	1	1
Forecasting	1	1	1	1
Management of Water Infrastructure		2	1	1
Policy	1	1	1	1
Advocacy	1	1		1
Early Warning			1	1
Water Supply (tankering etc)			1	1
Total	7	12	14	16

Table 2-5 Guidelines on drought actions to mitigate drought impacts

Water Users	Response Area	Response
Rainfed Crop Producers	Soil choice	o Choose suitable soil type. o Roughen the soil surface to minimize evaporation.

		o Minimize compaction by reducing the passing of heavy machinery in the field. Land preparation: o Avoid, where possible, soils with pronounced plough pans. o Use a ripper to break plough pans and increase access of roots to stored water and nutrients. o Do not expand land under crop production unnecessarily. o Prioritise fallow land.
	Crop choice and planting	o Choose drought resistant cultivars or drought tolerant crops as a precautionary measure. o Provide flexibility and diversification. o Stick to normal planting window if appropriate and follow the weather and climate forecast regularly. o Consider staggered planting-spreading over weeks. o Do not experiment with new and unknown cultivars and also avoid unnecessary capital investments. o Always practice crop rotation. o Planting in a controlled environment (e.g. green house) is advisable where possible.
	Crop management	o Adjust planting density accordingly. o Consider mulching to minimize evaporation. o Control weeds regularly. o Consider a conservative fertilizing strategy during dry conditions. o Consider organic fertilization. o Scout for pests and diseases regularly and control where necessary
Irrigation Farmers		o Remove all weeds containing seeds, but keep other vegetative rests on the land because that will reduce evaporation. o Check and repair all tools and machinery. o Irrigate during cool conditions to avoid evapotranspiration. o Avoid over irrigation because that can create problems e.g. water logging and diseases. o Adhere to the water restrictions when issued.
Domestic and Home Garden Water Users		o Conserve existing water supplies. o Eradicate water weeds. o Limit water waste and losses. o Repair leaking pipes. o Re-use water and retain high quality. o Harvest water during rainy days.
Stock Farming		o Provide lots of drinking points. o Provide phosphorous licks freely. o If grazing is in danger, herd animals into pens where different animals can be segregated and fed separately. o Herd management should be aimed at maximizing animal condition during the growing season as it affects the degree at which animals lose/gain weight and condition during the dry periods. o Decide in advance when to switch the animals to different levels of feeding. o Sell mature livestock as soon as they reach marketable condition. o Treat the rangeland as a valuable asset. o Build fodder reserves in years of good rainfall. o Always practice rotational grazing. o Retain nucleus of best cows aged 4 to 6 years. o Diseases- Local veterinary services.

		o Always consider relevant vaccinations and control outbreak of diseases.
Grazing		o Subdivide your grazing area into camps of homogeneous units (in terms of species. Composition, slope, aspect, rainfall, temperature, soil and other factors) to minimize area selective grazing as well as to provide for the application of animal management and veld management practices such as resting and burning. o Determine the carrying capacity of different plant associations. o Calculate the stocking rate of each, and then decide the best ratios of large and small animals, and of grazers or browsers. o Provide periodic full growing-season rests (in certain grazing areas) to allow veld vigor recovery in order to maintain veld productivity at a high level as well as to maintain the vigor of the preferred species. o Rested veld forms an important source of cheap feed during winter for dry stock with appropriate protein supplementation. o Do not overstock at any time. o Eradicate invader plants. o Periodically reassess the grazing and feed available for the next few months, and start planning in advance. o Spread water points evenly. o Cut forage early to stimulate re-growth. o Provide suitable licks to make coarse, dry range grasses more palatable

These advisories issued by Agricultural Department monthly are broad guidelines and should be interpreted considering the local aspects of the region such as soil types, cultural preferences and farming systems. The basic strategy to follow would be to minimize and diversify risk, optimize soil water availability and to manage the renewable resources (rain water and grazing) to uphold sound farming objectives. The districts/ municipalities should further simplify, downscale and package the information according to their language preference and if possible use local radio stations and farmers' days in disseminating the information.

There institutions that are on the formal institutional frameworks for drought mitigation can be distinguished by role, the most common actions being food aid, funding and advocacy as shown in the following table.

Type of Institutions/Role	Limpopo Basin			
	Botswana	Mozambique	South Africa	Zimbabwe
Food aid	1	3	3	4
Funding	1	3	2	2

Advocacy	1	1	1	1
Policy		1	1	1
Agriculture Extension Services	1	2		
Forecasting		1		
Total	**4**	**11**	**7**	**8**

2.2.3 Drought adaptation

Communities in the basin are engaged in adaptation activities to be able to cope with future droughts and climate change, depending on duration and magnitude of deficit. This is being done through changes in processes, practices, and structures to moderate potential impacts of future drought. The most common actions being construction of water infrastructure, water harvesting, traditional/cultural practices, improved dryland farming practices, crop monitoring, capacitation of farmers and control of deforestation. The following table presents a summary of the actions identified.

Adaptation Actions	**Limpopo Basin**			
	Botswana	**Mozambique**	**South Africa**	**Zimbabwe**
Construct small scale dams	X	X	X	X
Water harvesting	X	X	X	X
Multi-activity agriculture	X	X	X	X
Improved dry land farming practices	X	X	X	X
Crop monitoring	X	X	X	X
Control of deforestation	X	X	X	X
Capacitation of farmers	X	X	X	X
Cultural practices	X	X	X	X
Construction of large dams	X		X	X
Expansion of protected areas	X		X	X
Water rationing	X	X	X	
Water conservation	X		X	
Resource Management	X	X	X	
Management of water networks	X		X	X
Crop diversification	X	X	X	
Inter-basin water transfers			X	X
Managing wildlife	X		X	
Management of ground water			X	X
Drought early warning systems	X		X	
Management of water resources			X	

Adaptation Actions	Limpopo Basin			
	Botswana	Mozambique	South Africa	Zimbabwe
Recycling of water			X	

The same actions were identified as climate change adaptation actions.

There are four different types (distinguished by role) of institutions that are involved in drought adaptation namely water infrastructure development, water infrastructure development, agriculture extension services and policy as shown in the following table.

Type of Institutions/Role	Limpopo Basin			
	Botswana	Mozambique	South Africa	Zimbabwe
Policy	1	1	1	4
Agriculture Extension Services	1	2	1	1
Water Infrastructure Development	1	1	1	1
Management of Water Infrastructure		2	1	1
Total	**3**	**6**	**4**	**7**

The reliance on the internet, published materials and contacts for information limited the historical droughts, mitigation and adaptation actions, and institutional frameworks for drought mitigation and adaptation in Africa that could be identified particularly at national and local levels. The information presented here is thus not exhaustive however additional information is expected from other stages of Work Package 2 and Stakeholder Platform(s).

2.3 DROUGHT WARNING AND RESPONSE EXPERIENCES

This section provides a summary of the drought early warnings and responses identified in WP2 Deliverable 2.3. A distinction is made in this section between drought and famine early warning.

2.3.1 Drought early warnings issued

A list of drought warnings issued for historical droughts in the basin, obtained available from literature is shown in **Table 2-6**

Table 2-6: List of Drought warnings from historical experiences

Drought Period	Drought type	Warning(s)	Lead time for warning
1991/92	Meteorological, Agricultural Hydrological	Warm ENSO phase Rainfall forecast	1st warning - 6 months ahead (issued March 1991)

Drought Period	Drought type	Warning(s)	Lead time for warning
		Harvest and food deficit estimates Warnings issued by the Regional early Warning System (REWS)	2nd warning – during drought period December 1991) **3rd warning –declaration of a disaster on 6 March 1992**
1993/94	Meteorological Agricultural	Harvest and food deficit estimates Rainfall forecast & Warm Enso phase Warnings issued by the REWS	(October 1993)
1997/98	Meteorological Agricultural	Harvest and food deficit estimates - FAO Rainfall forecast Warm ENSO phase	1st warning - April 1997 2nd warning June 1997
2002/03	Meteorological Agricultural	Harvest and food deficit estimates - FAO Rainfall forecast	April 2002 May 2002

(a) The 1991/92 Drought:

In 1991 climatologists, predicted the meteorological drought based on their El Niño modelling (Cane et al. 1994). As early as March 1991, the SADC Regional Early Warning System (SADC REWS) had predicted a substantial, region-wide grain shortfall (around 3 million tonnes) for the marketing year (1991-92) preceding the drought. The SADC Food Security Bulletin for December 1991 alerted governments and the donor community of this adverse change in growing conditions and issued tentative assessments of the likely impact on the forthcoming grain harvest in a number of countries.

(b) The 1993/94 Drought:

As early as October 1993, the DMC issued a forecast for the season based mainly on the observed and expected trend in the El Niño Southern Oscillation, normal rainfall was predicted across most of the SADC region for the period October to December 1993; some deficits were forecasted for the latter half of the season (January to April 1994). Unlike the situation during the 1991–92 drought, when drought warnings were either not received or not taken seriously, warnings about potential rainfall shortages during the 1993–94 season were disseminated to most key users and the media (Unganai 1994).

(c) The 1997/98 Drought

In December 1997, SARCOF issued a midseason forecast update covering January through March 1998 as shown in Figure 2-16. The forum's consensus forecast was for normal to below-normal rainfall for much of the area. Rainfall was expected to be below normal over much of South Africa, Botswana, and southern Namibia; normal to below normal over northern Namibia, north eastern South Africa, Zimbabwe, southern Zambia, and southern and central Mozambique; normal to above normal over far southern South Africa; and above normal over northern Tanzania. Rainfall over other areas was expected to be near normal.

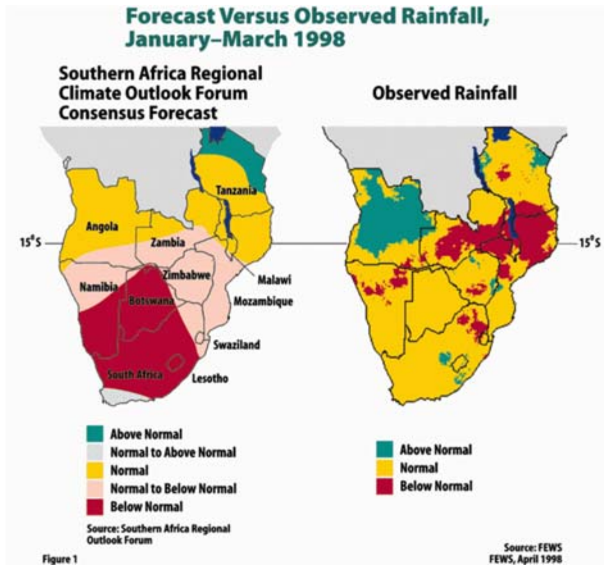


Figure 2-16: Forecast versus observed rainfall January to March 1998

(d) The 2002/2003 Drought

In late 2000 FEWS NET began to publish monthly reports on the food security situation in the SADC region, using the internet as the primary means of dissemination. By drawing on the work of the national Vulnerability Assessment Committees (VACs), collaborating closely with the Regional VAC (RVAC) and posting these reports on the web every month during the crisis, FEWS NET complemented these monthly reports with bi-monthly and also produced “Executive Overviews” to summarize information in an actionable form for decision makers. The July 2002 assessment was published by FEWS NET as a Position Paper; assessments in September and December 2002 were published by SADC RVAC as Regional Food Security Assessment Reports. Warnings were first made public in April 2002, before the harvest had even begun in some areas.

In Mozambique, mitigation actions implemented are as follows:

- Vegetative material;
- Input fairs;

- Agro-pastoral fairs;
- Horticulture;
- Local seed production;
- Fruit production;
- Irrigation systems;
- Use of lowlands;
- Construction of small dams and water reservoir;
- Irrigation management;
- Veterinary assistance;
- Foment of Animal breeding;
- Foment of animal traction;
- Pasture management;
- Milk production;
- Pisciculture;
- Junior farm school (JFFLS);
- School kitchen-garden;
- Nutrition and HIV/AIDS;
- Improved barns;
- Hunger alert dossier (FAF);
- Combat against plagues and diseases.

During the decade 20's to early 80's, there were no records of droughts in Mozambique. Table 2-7 shows the occurrence of droughts since the decade 80 until the year of 2008.

Table 2-7: Drought occurrence in the last years.

Year	Occurrence	Year	Occurence
1981/82	X	1994/95	X
1982/83	X	1995/96	X
1983/84	X	1996/97	
1984/85	X	1997/98	
1985/86		1998/99	
1986/87		1999/00	
1987/88	X	2000/01	
1988/89		2001/02	
1989/90		2002/03	X
1990/91		2003/04	X
1991/92	X	2004/05	
1992/93		2005/06	X
1993/94		2006/07	X

2.3.2 Famine early warnings

A summary of the famine warnings issued in the past is given in **Table 2-8**

Table 2-8 Monthly drought reports or warnings for 2002/03 drought

Month, Year	Title of Monthly Report/Warning	Key Content of Monthly Report
February 1991	Agro-met bulletin fore	18.5 % less for maize yield compared to the previous year.
March 1991	Agro met bulletin	Crop harvest lower than the three year average from 1987/88 to 1990/1991
July 1991	Agro met bulletin	Low maize stock level y Dec 1991
November 1991	National Early Warning unit (NEWU)	Critically low food stocks.
April 2002	*FEWS NET Monthly Report*: "Production Shortfalls Imminent"	Maize production by country in 2001 and 2002 compared to five year average; special focus on problems in Zimbabwe; assessment of South Africa's ability to cover the regional deficit
May 2002	*FEWS NET Monthly Report*: "Food Security Crisis Deepens"	Graph of regional production plus stocks (total availability) vs. consumption over past eight years, showing largest deficit since 1995; discussion of how to fill the gap, including mention of U.S. white maize availability; assessment of transport corridor capacity to handle imports.
June 2002	*FEWS NET Monthly Report*: "Shortages, Higher Prices in Region"	Report on FAO/WFP CFSAM. First quantitative estimate of import needs (3.18m MT), embedded in text of report; discussion of price rises in some markets of Malawi and Zimbabwe.
July 2002	*FEWS NET Monthly Report*: "Regional Cereal Shortage, Import Challenge" *FEWS NET Position Paper*: "Is a Famine Developing in Southern Africa?"	Maps and table of estimated import requirements for 11 countries in region. Report on WFP Regional Emergency Operation (EMOP) for six most affected countries (Mozambique, Malawi, Swaziland, Lesotho, Zambia, Zimbabwe), SADC FANR monitoring and response plans, and UN Consolidated Appeal. First use of regional map on front page with (qualitative) summaries of food security situation for key countries
September 2002	*FEWS NET Monthly Report*: "Imports Lag, International Response Inadequate" *First SADC RVAC Regional Food Security Assessment Report*:	Updated import requirements, and progress towards meeting them; statement on GM maize controversy in region. Regional map for six most affected countries on front page, with number affected and import requirements; report on results of first rolling food security assessment, including information on wasting, coping mechanisms; prospective information through end of current season; section for decision makers.
October 2002	*FEWS NET Monthly Report*: "Assessments Point to Rising Needs"	Updated import needs and "slow progress" in filling them; Child wasting estimates from national VACs; climate forecasts for current growing season.
December 2002	*FEWS NET Monthly Report*: "Food Security Prospects Worrisome" *Second SADC RVAC Regional Food*	Update on "poor rainfall performance" for current growing season and likely impact on continuing

	Security Assessment Report	crisis; Update on "large remaining cereals gap" that will be "difficult to fill". Updated regional map with number affected and import needs; food aid progress and plans; review of market prices; HIV/AIDS impacts on food security; statement that "in general wasting levels are still not a cause for concern" but noting "scanty data".
February 2003	*FEWS NET Monthly Report*: "Signs of Improving Food Security Conditions"	Report on anticipated 2003 harvest and likely import needs; report on most recent vulnerability assessments

2.3.3 Responses to drought early warnings issued

(a) The 1991/92 Drought:

By December 1991, several individual governments had received information that the upcoming harvest would be below normal due to drought. Rainfall had stopped in many places and plants were experiencing moisture stress. Many users of early warning information ask why the 1991-92 drought could not have been foreseen if Regional Early Warning Systems (REWS) are useful. The answer lies in the fact that REWS do not predict weather conditions. The 1991-92 growing season started well in most parts of southern Africa. It was not until the end of 1991 that indications of a prolonged dry spell began to surface. Although by this stage it was already clear that, because of wilting and delayed planting, the maize harvest was going to be reduced, there were still prospects for recovery if the rains returned in the following few weeks. However rains did not return in January or February 1992, which are the critical rainfall months for the southern African maize crop. The SADC Food Security Bulletin for December 1991 alerted governments and the donor community of this adverse change in growing conditions and issued tentative assessments of the likely impact on the forthcoming grain harvest in a number of countries. During the next three months, dry conditions intensified and, by March 1992, the full impact of the drought on grain production had become apparent.

(b) The 1993/94 Drought:

Responses to initial warnings concerning the depletion of grain stocks over the 12-month period leading up to the drought were generally slow and late. It was not until such stocks had dropped to critical levels that reactions were initiated, by which time it was already too late to avoid the maize shortages which hit countries like Zambia and Zimbabwe during the early part of 1992 (Pawadyira and Ndlovu 1993).Perhaps because of the critical stock position at the time, responses to the drought alert were much swifter. First indications of a concerted reaction came as early as January 1992, well before the full impact of the (still ongoing) drought could be assessed, when the SADC Food Security Sector Coordinator was directed by SADC Ministers to consult closely and urgently with member states, with a view to:

- assessing the extent of food shortages;
- evolving a common strategy to address the problem; and
- convening, if necessary, a Donor's Conference.

In addition, it is important to recognize that, while all these activities were going on, individual countries - notably Zambia and Zimbabwe - had already begun to identify sources for their commercial maize imports. As it turned out, this was to have a significant bearing on the food security situation in these countries during the following months.

(c) The 1993/94 Drought:

Before the end of December 1993, Tanzania had declared the drought a national disaster. The period from about January to February 1994 saw a gradual shift in the rainfall pattern. The deficits that were widespread north of the 18th parallel were cleared in a short time as heavy rains battered those areas. In its updated forecasts, the DMC predicted further improvement to the north and diminished rainfall to the south. From about mid-February 1994, a dry spell that extended into the entire month of March 1994 hit most of southern Zambia, southern Malawi, eastern Botswana, most parts of Zimbabwe and Mozambique.

(d) The 1996/97 and 1997/98 Drought:

During the winter months of July and August 1997, the Zimbabwe the Commercial Farmers' Union (CFU) in Zimbabwe incorporated discussions of El Niño into its "field-day" activities in the different regions, reinforcing the probabilistic nature of the prediction. Occurring in July and August 1997, these deliberately coincided with times at which commercial farmers were buying their seed for the upcoming season. The general advice the CFU provided in coordination with the Meteorological Services Department in Harare, was to plant early to take advantage of the predicted good early season rains, and to plant short-season varieties to avoid the likely late season drought. Farmers working with CFU agronomists at the field-day meetings generated location-specific recommendations about what particular varieties to plant. Most farmers incorporated these recommendations into their planting decisions. Using the information was more difficult in the smallholder sector, especially among communal land farmers in drier regions of the country, where “below-normal” rainfall implied a high likelihood of crop failure.

(e) The 2002/2003 Drought

There has been some complaint that initial reactions by governments and donor agencies to the warnings in April 2002 were skeptical, thus delaying immediate action (Mano et al 2003, Save the Children 2003, SADC Food Security Network 2002e, and SADC Regional Vulnerability Assessment Committee 2002). The WFP launched its Emergency Operation (EMOP) between April and June 2003, stating that “approximately 13 million people in the SADC Region would be facing a severe food crisis over the next nine months”. By May 2003, the FAO/ World Food Program (WFP) Crop and Food Supply Assessment Missions had estimated that 1.2 million metric tons of food aid would be required to help fill the gap in the SADC Region. These data were reported in the June 2003 report, along with an estimated food gap of nearly 3.2 million metric tons. By September 2003, RVAC was estimating that 14.4 million people in the SADC Region required an additional 1 million metric tons of food aid to cover a total food gap of 3.3 million metric tons. By December 2003, the estimated number of affected persons had climbed to 15.25 million. Throughout the crisis, the food gap and progress towards meeting it were highlighted, and other relevant information (such as the GM maize controversy) was presented.

(f) The 2006/2007 Drought

The 2006/07 drought was also linked to El Nino conditions. In Zimbabwe the drought was declared a national disaster in March 2007 (Chronicle 2007; IRIN 2007) and this obliged the government to provide relief services to people in need by either using its own resources or appealing to international relief agencies (Chigodora 1997; FAO/WFP 2002)

2.3.4 Users of drought warnings and flow of information

The direct users of drought warnings identified on this study are listed in **Table 2-9.**

Table 2-9: List of direct users of drought warnings

Stakeholders and Interest Groups	Interpretation of warnings	Particular interest

Department of Water Affairs	Use of El Nino and La Nina, also the historical dam inflow data and water allocation relative to the dam level	Dam Management
Department of Agriculture	Seasonal forecast issued by South African Weather Services for the below normal to above normal rainfall	Drought Management
Municipalities	Warnings are given by the department of water affairs for any availability of water	Water Distribution
Catchment Management Areas	No warnings issued	Water Management
Water Users Association	Some application of self-restrictions is applied by some water users or practice physical observation of stream	Water Availability
Disaster Management Centres	Seasonal forecast issued by South African Weather Services for the below normal to above normal rainfall	Drought Management
Lands, Agriculture & Rural Resettlement: AGRITEX, MSD	Communicating the warning to farmers Interpreting the warning to a product that can be useful to farmers. Offering advice on appropriate methods & ways to tackle the impending situation.	Custody of agricultural policy
Finance and Economic Development.	Costing the extent of drought in monetary terms. Lobbying for aid or funding.	Macro-economic growth and stability
Local Government and National Housing.	Mainly use the information to ensure coordination of drought management.	Civil protection, coordinates government social protection programmes, drought relief and emergencies .Coordinates and oversees all local government administration and leadership
Public Service, Labour and Social Welfare	Assessment of community vulnerability levels. Putting in place timely welfare programmes to assist affected communities.	Maintaining welfare and implementation of social safety nets and welfare programmes
Food and Nutrition Council.	nutritional status of infants and other people	Development and monitoring of policies, strategies and programmes for addressing food and nutrition security
Parliamentary Portfolio, Committee on Lands, Agriculture, Water Development, Rural Resources and Resettlement, Presidents Office	Timing of declaration of the drought. Mobilising funding Appealing for funding	The Committee monitors the general performance of the executive (government) and undertakes specific investigations for information of Parliament.
Farmers:		
Small holder farmers	Nature of the season	
Commercial farmers		
Local rural leaders:		
Traditional leaders.	Community governance	
Agribusiness.		
GMB.	Sourcing grain	Acquisition (from local and external sources), storage and distribution of grain to ensure national food security
AGRIBANK.	Funding relief programme for the agriculture sector including: • Milling Companies	Long-term viability and maximizing dividends

	• Livestock Feed Processors • Seed producers.	
Consumers.		
Both rural and urban communities	Stocking of food reserves	
Media	Ensuring warning is disseminated to the people. Production of progress reports.	Provision of timely and accurate information.
NGO: (Local and International)		
Christian Care, World Vision, Care International, Africare, World Lutheran Federation ORAP, Plan International, Catholic Relief, Save Children UK, Save Children USA	Preparation and provision of relief. Lobbying for relief fund. Reporting. Carrying out vulnerability assessment	Advancing food security and social well-being of communities Economically empowering local Communities. Securing and maintaining funding from sponsors
International Donors (Development partners):		
USAID, DFID, GTZ, NORAD, AUSAID, Canada CIDA	Provision of relief fund	Promoting poverty reduction at community levels through efficient and effective use of donor resources
FAO, WFP	Provision of food aid	Estimation of food deficits and food relief requirements

Figure 2-17 shows the flow of information and data in the existing formal monitoring, forecasting and early warning system. The advent the internet broad band, cellular networks and community radios has opened up communication channels making it easier for users to access information from ay sources.

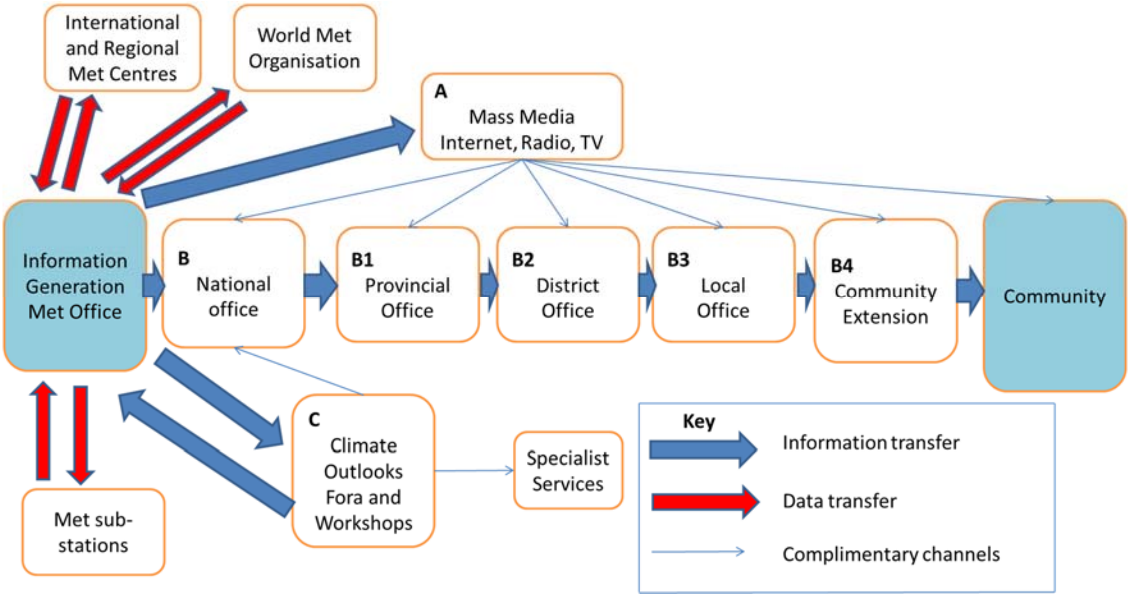


Figure 2-17: Drought monitoring forecasting and early warning data and information flow

2.3.5 Key findings

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

- Meteorological and hydrological data networks are often inadequate in terms of the density of stations for all major climate and water supply parameters. Data quality is also a problem because of missing data or an inadequate length of record;
- Data sharing is inadequate between government agencies and research institutions, and the high cost of data limits their application in drought monitoring, preparedness, mitigation and response;
- Information delivered through early warning systems is often too technical and detailed, limiting its use by decision makers;
- Forecasts are often unreliable on the seasonal timescale and lack specificity, reducing their usefulness for agriculture and other sectors;
- Drought indices are sometimes inadequate for detecting the early onset and end of drought;
- Drought monitoring systems should be integrated, coupling multiple climate, water and soil parameters and socio-economic indicators to fully characterize drought magnitude, spatial extent and potential impact;
- Impact assessment methodologies, a critical part of drought monitoring and early warning systems, are not standardized or widely available, hindering impact estimates and the creation of regionally appropriate mitigation and response programmes;
- Delivery systems for disseminating data to users in a timely manner are not well developed, limiting their usefulness for decision support.

2.3.6 Gap analysis -existing institutional frameworks

This section provides a summary of the gap analysis depicted in WP2 Deliverable 2.5 which compares "state of the art" and current practices on drought mitigation and adaptation and organizational structures for drought management. Mapping of institutions and their interactions is important. Institutional changes (through social, political, cultural or other changes) can increase or reduce vulnerability of communities to drought, limit and/or facilitate mitigation and adaptation.

Drought mitigation considers – "the reduction in the classification of a drought in terms of frequency and magnitude of risks and resulting from reduction of the potential impact of a drought". Therefore mitigation practices can be considered as all the actions that contribute to the reduction of drought effects on the environment, human wellbeing and economic activities. Drought adaptation refers to the process of being able to survive in a drought condition. It refers to changes in processes, practices, and structures to moderate potential impacts of future drought" therefore adaptation practices can be considered as the measures/actions/strategies capable of reducing regional vulnerability to future droughts.

(a) Lessons from global practices

From the European experience, the "state of the art" institutional framework for drought management corresponds to the existence of a specific drought committees (at local and national level in the member states), with both political and technical responsibilities in drought management. These committees coordinates actions with regional and local bodies responsible for water resources management and/or civil protection. It can be a permanent organisation or a body just constituted when a drought situation is declared. The organisational arrangements at different levels from local to regional are elaborated. In the U.S., the "state of the art" institutional framework is closely related to the existence of drought plans at all scales of the society, from the farmer's ranch through city boards and state governments. These state plans define the institutional framework relevant for that particular locality by defining the roles and responsibilities of all stakeholders in the onset or event of a drought. In some cases, this might include a drought committee, but that is not always the case. In Australia, in the past decade, a lot has happened with respect to drought policy at the national, state, basin and city level. Additionally, farmers have a large role to play in adapting to drought and have an increasing responsibility for managing the risks arising from climatic variability.

(b) Current practice in the Limpopo River Basin

Here, most of the institutions involved in drought mitigation and adaptation are not found on the formal frameworks. This affects development of plans, efficient and timely implementation of actions especially at local level. Therefore, here is a high potential for improvement here. The following weaknesses also exist:

- Division of responsibilities among many governmental jurisdictions and lack of one department which takes overall responsibility. Lack of coordination and integration, duplication and conflicts of interests that emerge among them
- Lack of structures for managing drought at the local level
- lack of equipment and technology to increase the credibility of information

- inadequate financial resources
- Involvement of the private sector is very low
- lack of technical capacity, insufficient human resources and inadequate training
- Weak science-policy interface. No clear drought management policies and drought mitigation plans

NGOs play a significant role in drought mitigation in the Limpopo River Basin, however they suffer from the following:

- Activities are projected for specific areas only and funds rely on good will donations, they try to cover a wide range of activities but are limited in numbers of personnel which means that they cannot deal with extended drought mitigation and adaptation programs.
- Sustainability of interventions not guaranteed.
- Do not have distribution network and rely on government and other NGOs to implement programs
- Inadequate spatial resolution of drought impact assessment, sampling/selection methodologies are generally weak and
- They tend to engender a culture of dependency from relief efforts

According to MICOA (2006), in Mozambique there is not a specific Institutional Framework for droughts, there is only a Framework for mitigation which is used for all disasters phenomena. The Ministry of Agriculture (MINAG) and the Technical Secretariat of Food. Table 2-10 shows the entities involved in drought mitigation actions.

Table 2-10: List of Institutions in Mozambique.

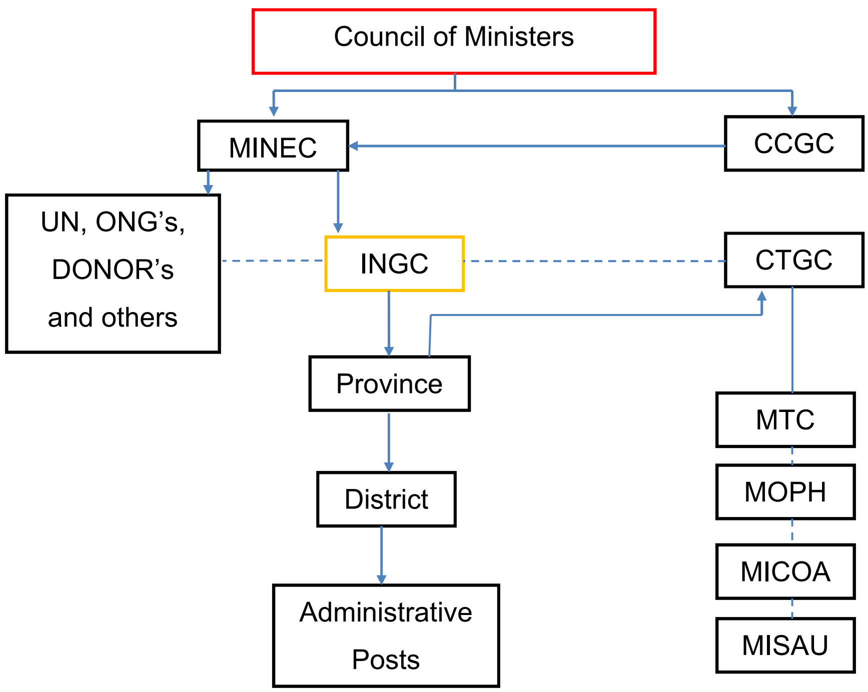
Instittution	Contacts/Email	Responsability
National Institute for Disaster Management (INGC) – (CCGC – Coordinator committee of disasters management, CTGC – Technical committee for disasters management)	Marta Manjate (coordinator) Address: Maputo Mozambique Telephone: +25801490222 Fax: +25801490222 Mobile: +258825929546 Email: martamanjate@yahoo.com http://www.ingc.gov.mz	Responsible for all issues related with mitigation of disasters in the country, with focus on natural disasters like cyclones, drought. Coordinates disaster management efforts with and receives support from public and private institutions. Conduct mitigation efforts (such as collection and analysis of data); Undertake preparedness measures (e.g. awareness campaigns); Coordinate disaster response (including distribution of food, tents, and other supplies)
National Meteorological Institute (INAM)	Mr. Berino Francisco Silinto Address: Rua de Mucumbura Nr. 164 P.O.Box 256 Maputo Mozambique Phone: + 25821493193 Fax: +25821491150 Mobile: +258842263890 Email: berino_s@inam.gov.mz http://www.inam.gov.mz	Weather monitoring throughout the country and responsible for early warning on imminent tropical storms or meteorological changes that potentially threaten the country.
Ministry for Coordination of Environmental Affair (MICOA) – (DNGA – National Directorate of Environmental Management)	Mr. Custodio Mário - DNGA .Av Acordos de Lusaka No. 2115 Maputo - C.P. 2020 Mozambique Telephone: + 258 21466495 Fax: + 258 21465849 Mobile: +258828632120 Email: custodiomaphossa@yahoo.com.br	Development of appropriate policies and laws that will ensure the sustainability of resource use. Coordinating and fulfillment the intersectorial view of correct use of natural resources (Implementation of the strategy and action plan for prevention Drought). Strategy and Mitigation Action Plan for Biodiversity Conservation in Mozambique under the Biodiversity Convention; Strategy and Action Plan for Preventing and Combating Soil Erosion Preparation of National Action Programme for Adaptation (NAPA) under United Nations Convention on Climate Change; Assessment of National Needs and Capacity; Self-assessment of overall management of the environment; Action Plan to Combat Drought and Desertification in the Framework of the United Nation together on combating drought and desertification and establishment of youth organizations aimed to conserve the environment
Ministry of Agriculture (MINAG)	Mr. Eusébio M. Tumuitikile Praca dos Herois Mocambicanos Maputo-C.P. 1406 Mozambique Telephone: +250-21-49-1785; +258-21-46-0011 Fax: +258-21-49-9673; +258-21-46-0055 Mobilr: +2588206003 Email: muitikile@gmail.com http://www.minag.gov.mz	Farmers awareness on possible occurrence of droughts and promotions of relief and mitigation actions. Acquisition and distribution of seeds (tolerant/resistant to drought), movement of animals from highly drought risk zones to better locations.
Ministry of Public Works and Housing (MOPH) – (DNA – National Directorate of Water)	Av. Karl Marx 606, Maputo-C.P. 268 Mozambique Telephone: +258-21-430028 Fax: +258-21-421369 www.mop.gov.mz	Development and implementation of the water resources management plans and enforcement tools. Management of the Water Sector in the country.

Instittution	Contacts/Email	Responsability
Ministry of Transport and Communications (MTC)	Av. Martires de Endereco Inhaminga.336- Maputo- C.P. 276, Mozambique Telephone: +258-21-430152/5 Fax: +258-21-431028/424109 http://www.mtc.gov.mz	NA
Red Cross Mozambique (CVM)	Av. Agostinho neto 284 – Maputo Telephone:+258214977/490943/498139 Fax: + 25821497725 Email: cvm@redcross.org.mz	Assists vulnerable groups in collaboration with Government agencies (MINAG, MISAU and INGC), Implements, but prior to disaster, plans activities and focuses on promoting access to water and food; In post-disaster phases, supports the provision of health care The CVM is responsible to improve the living conditions of vulnerable populations; Preventing and alleviating human suffering wherever it exists; Mobilize the strength of a growing number of volunteers, particularly young people
Technical Secretariat for Food Security and Nutrition (SETSAN)	Mrs: Francisca Cabral Av. das FPLM nº 2698 - Recinto do IIAM (Pavilhão novo), Maputo, Moçambique Telephone: (+258 - 21) 461874 – Fax: (+258 - 21) 462403 / 461850 Mobile: +258823943820 Email: fcabral@setsan.org.mz http://www.setsan.org.mz	Working group comprising professionals from various ministerial sectors, including nongovernmental organisations. Supports the establishment of food and nutritional security in the country
Famine Early Warning System Network FEWSNET	FEWSNET Mozambique Maputo Av. das FPLM nº 2698 - Recinto do IIAM Tel : + 25821460588 Mozambique@fews.net http: //www.fews.net	Improvement of the early warning system (droughts and floods); Support to contingency plans for response preparations to disasters; Improvement in use of information for disasters prevention. Improved early warning system; Improved access and use of integrated information notice to disaster risk reduction; Identification and correction of gaps in information on vulnerability and disasters; Support for contingency plans for disaster preparedness and response and providing information and analysis of disaster with a view to an effective emergency planning strategies.
World Food Programme (WFP)	Avenida do Zimbabwe, 1302 Maputo, Mozambique Tel:+258-21-482200 Fax:+258-21-491719 Email: WFP.Maputo@wfp.org	Have interventions in provinces more vulnerable to droughts and floods: WFP activities are oriented to: □ Food distribution; □ Provision of supplementary food to children with less than 5 years of age; □ Food distribution in schools; and; □ Implementation of emergency programmes, including □ issues related to HIV/AIDS.
United Nations Development Programme - Mozambique (UNDP)	Mr. Gustavo Mahoque Mobilel: +258 82 483 5680 Email:gustavo.mahoque@undp.org Av. Kenneth Kaunda, 931; P. O. Box 4595, Maputo Tel: +258 21 481 400 Fax: +258 21 491 691	Involved mainly in the field of capacity building oriented to emergency situations associated to natural disasters (drought). Some of UNDP activities are: • Preparation of a national plan for disasters and establishment of a support network through NGOs and local governments, for strengthening of community initiatives for disasters prevention;

Instittution	Contacts/Email	Responsability
	E-mails: registry.mz@undp.org or undpmz@undp.org or procurement.mozambique@undp.org	• Establishment of a fund for local and community support for mitigation of natural disasters; • Improvement of geographic and demographic information in risk areas.
United Nations Children's Fund – Mozambique (UNICEF)	Mr. Arild Drivdal Email: adrivdal@unicef.org Tel: +258-21 481 121 1440, Zimbabwe Avenue P.O.Box 4713 Maputo – Mozambique Tel: +258-21 481 100 Fax: +258-21 491 679 Email: maputo@unicef.org http://www.unicef.org	Coordinates assistance on health care for children and teenagers. Through: • Training provision to distrital and provincial directorates in matters related to planning, management and improvement of the health care services; • Establishment of a structure which enables community participation in health assistance; and • • Dissemination of the appropriate approach about the necessary assistance to children and teenagers.
Ministry of Health (MISAU)	Mrs. Julaya Mussa (Técnico) Av. Eduardo Mondlane 1008 Maputo-C.P. 264 Mozambique Telephone: =258-1-427131/2/4 Mobile: 828526780 Email:juhamica@yahoo.com.br www.misau.gov.mz	Provides access to preventative and curative health services in drought and flood prone areas as well as relief assistance.

Institutional frameworks in Mozambique

Security and Nutrition (SETSAN) with support of FAO have developed a preliminary Mitigation Action Plan. The purpose of the action plan is to establish basic means to overcome the adverse drought conditions by improving the ability of households to cope and adapt, based on local recommendations and experiences. Although the plan does not contemplate direct food assistance, some activities are implemented through *food-for-work* and other intervention programs in coordination with local authorities (FEWS NET, 2005).



The main adaptation actions implemented for each of the identified droughts are as follows:

- Strengthening the early warning system;
- Strengthening capacities of agricultural producers to cope with climate change and variability;
- Reduction of climate change impacts in coastal zones;
- Management of water resources under the framework of climate change for the reduction of droughts and flood impacts along the hydrological basins Experiences drought in the Limpopo River basin Mozambique.

2.3.7 Opportunities to improve current practice

The following opportunities exist with the current situation:

- the framework for mobilization of government agencies exists
- substantial resources can be brought together
- institutional structures for water management and development as well as health and sanitation exist
- the need for strategies to manage and mitigate drought is generally appreciated
- the need for drought early warning systems is appreciated

Stakeholders play a major role in drought management as they can share experiences, as well as identifying linkages amongst themselves. Institutions can draw some experiences gained in tackling previous droughts. This provides an opportunity to address the weakness and failures encountered. Other possible interventions include:

- Better focus of resources. Improve distribution of roles. New agencies/role players are required.
- Training and public awareness campaigns: especially in situations where the country is approaching a drought season
- Effective transfer of information to policy- and decision-makers
- Improved implementation of responsibilities assigned to different bodies at different levels
- Improve the link between relief efforts and development programmes

3. FRAMEWORK INVESTIGATIONS (LINKED TO WORK PACKAGES 3, 4 AND 5)

This chapter described the investigations conducted on the Limpopo River basin related to the various work packages. The objectives of the investigation, methods and results are described.

3.1 IMPROVED DROUGHT INDICATORS FOR THE LIMPOPO RIVER BASIN AND MAPPING OF DROUGHT VULNERABILITY

Vulnerability to drought varies spatially and is determined by natural factors, like the intensity and magnitude of the drought hazard that lead to its susceptibility, and by social factors that lead to exposure, coping capacity and adaptive capacity. The social factors that define vulnerability to drought – for example number of people exposed, per capita water availability, water use trends, technology, policies, etc – change over time, therefore vulnerability also changes. As result, subsequent droughts in the same region will have different effects, even if they are identical in intensity, duration, and spatial coverage, because societal characteristics evolve through time.

A suite of indicators may be used to characterize drought vulnerability. Ideally, the indicator values may define thresholds. Defining critical thresholds is very complex. A threshold is the value at which action is initiated – and not necessarily that at which problems occur. In some literature this leads to two types of threshold – the one is called an action or operational threshold, the other a result threshold. *Vulnerability* is a measure of the consequences suffered by a system exposed to a hazard. Under the DEWFORA approach, vulnerability is considered to be a function of susceptibility and coping capacity.

In order to characterize drought vulnerability in the context of drought early warning systems, it is useful to distinguish between two types of indicators: 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. Diagnostic indicators include information relative to the recent past. The spatial and temporal resolution that can be achieved with diagnostic indicators is high and their uncertainty is usually low, since they are mostly based on observations. Predictive indicators are developed to anticipate climatic conditions. They may also be based on recent observations, but they include a modeling component to make predictions about the future. Typically, they are applied over large areas and at low temporal resolution. Their uncertainty is also greater than that of the diagnostic indicators, because they involve uncertain modeling, either of physical or statistical nature, or both. Their early warning potential is high.

Traditional drought indicators based on the characterization of drought hazard should be extended to consider water uses and users, and estimate the impact of drought on a wider sector of society. The focus on drought vulnerability implies an approach based on the probabilistic characterization of drought impacts. This requires not only a probabilistic characterization of drought occurrence, but also an analysis of the cascading effects of drought on water uses, water users and society as a whole. The goal would be to identify thresholds at which response measures should be applied. The definition of the threshold values should achieve a balance between the frequency of activation of response measures and the effectiveness of the application of the measures. If drought measures are adopted too early, users are frequently confronted with unnecessary restrictions. If the adoption of measures is delayed, it may be too late for them to be effective.

Vulnerability indicators describe social-based responses: anticipation, adaptation and reaction to drought. Vulnerability indicators are essential to implement effective drought early warning system. Their focus is on drought impacts on society. The structure of vulnerability indicators is very diverse, since they have to cover a wide range of impacts across different sectors. In some cases, drought vulnerability indicators are very specific for a given water use and may use simple proxy variables to characterize drought impacts. In other cases they are global, and aim at characterizing the global coping capacity of society in a large region.

The approach proposed has large value from the operational standpoint, since it links the hazard with the propagation of drought effects across water resources, water sectors and society. Nevertheless it is advisable that drought monitoring to concentrate the efforts on the first variables in the time chain in order to anticipate drought impacts. For this reason, diagnostic drought indicators based on precipitation are widely used for drought monitoring.

They take advantage of the delay of the socioeconomic response function to drought and allow for the adoption of timely measures early on.

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 gain time and can come closer to drought impacts in their analysis. The focus on drought vulnerability requires the development of new drought indicators that are tailor made for a given drought impact. This requires information about the dependency of regional and local communities on water use. In addition to hydro meteorological values, other variables that influence drought impacts can be included in the analysis. This simplifies the difficult task of identifying threshold values of indicators at which drought problems arise.

DROUGHT HAZARD INDICATORS

Drought severity may be characterized according to its intensity, duration, time of onset, and exposure.

Climatic indices are important elements of any monitoring and assessment system because their purpose is to simplify complex interrelationships between many climate and climate related parameters. Indices make it easier to communicate information about climate anomalies to diverse user audiences and permit scientists to quantitatively assess these anomalies in terms of their intensity, duration, and spatial extent. This allows for the analysis of the historical occurrence of drought and its probability of recurrence, information that is extremely useful for planning and design applications in agriculture and numerous other sectors. An adequate drought index should:

- Provide criteria for declaring the beginning and the end to a drought;
- Represent the concept drought in a particular region'
- Correlate to quantitative drought impacts over different geographical and temporal time scales.

Drought indices are typically single numbers that are calculated including observed and proxy data related to water supply and provide a comprehensible synthesis of a situation for the decision maker that may be more useful than raw data. The use of a particular index to characterize drought depends on the objectives of the analysis and the study region. Most water supply planners find it useful to consult one or more index before making a decision.

Meteorological drought indices respond to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by these indices ends without taking into account stream flow, lake and reservoir levels, and other longer-term hydrologic impacts. Meteorological drought indices do not take into account human impacts on the water balance, such as irrigation. Hydrological drought indices take into account water management and stream flow, lake and reservoir levels, and other longer-term hydrologic impacts.

3.1.1 Regional Standardized Precipitation Index (SPI) in the Limpopo River Basin (*B Alemaw - University of Botswana/Waternet*)

(a) Objectives and study area

This investigation covered the whole of the Limpopo River Basin and its objectives were as follows:

- Regionalization of drought in the Limpopo basin
- The determination of homogenous drought regions
- Assessment of drought duration and severity
- Construction of spatial maps of drought severity and SAF curves
- Preview of implications to agricultural, vegetation and hydrological drought
- Objectives and study area

(b) Stakeholders involved

The following stakeholders were involved in the study:

- AMESD SADC THEMA ACTION
- SADC
- Local agricultural offices
- Meteorological office
-

(c) Study methodology

The study methodology was as follows:

- Regionalization of drought in the Limpopo basin for developing local response strategies
- Determine drought duration and severity using SPI and stochastic modelling approach
- Clustering by Fuzzy C-Means (FCM) clustering method (modified K-means algorithm)
- grouping of sites using the clustering algorithm
- minimized total intra-cluster variance function
- Rainfall Factors: elevation, longitude, latitude and median monthly rainfall.
- Construction of spatial maps of drought severity and SAF curves for each homogenous region

(d) Results

The following results were obtained from the investigation:

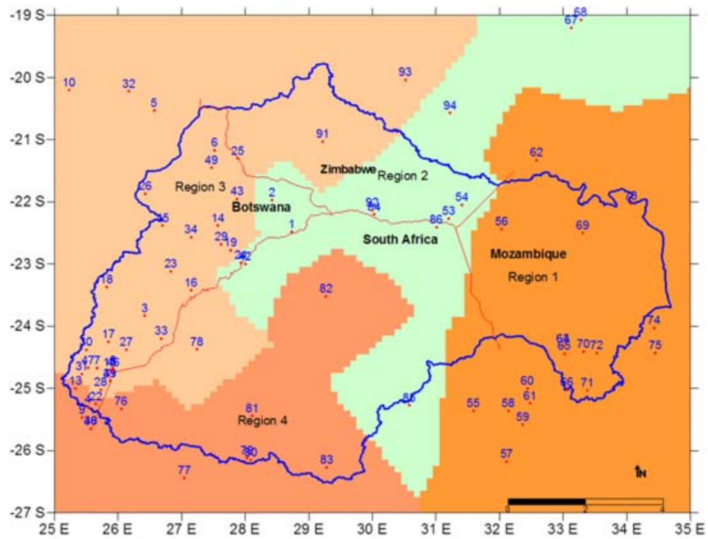


Figure 3-1: Meteorological stations used in the study and homogeneous regions

Homogeneous regions are identified by using the Fuzzy C-Means clusters in the space of site characteristics of the median of monthly precipitation. After that, the Limpopo River Basin is divided into 4 homogeneous regions (Figure 3-1). The four homogeneous regions appear to be similar to be similar to the basins general aridity map. Aridity index that depends on the ratio of annual precipitation to Potential Evapotranspiration, it is generally a long term characteristic.

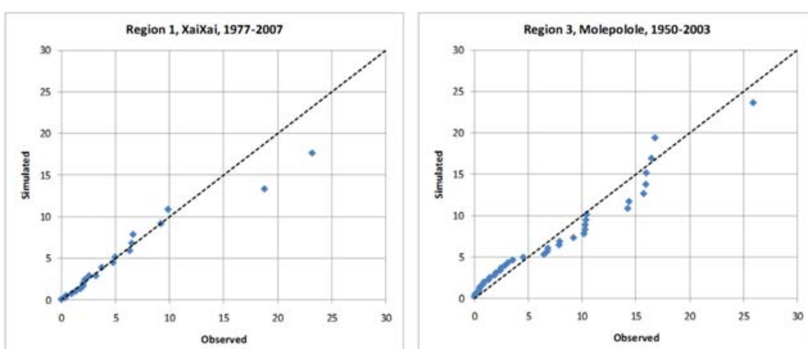


Figure 3-2: Comparison between observed and simulated DSI (Drought Severity Index) in two homogenous regions

The Severity-Area-Frequency (SAF) curves for each homogeneous region are constructed at different aggregation periods of SPI (3, 6 and 9 months). All the distributions fitted well and passed the K-S test at the 90% confidence level at all the homogenous regions (Figure 3-3 and Figure 3-4).

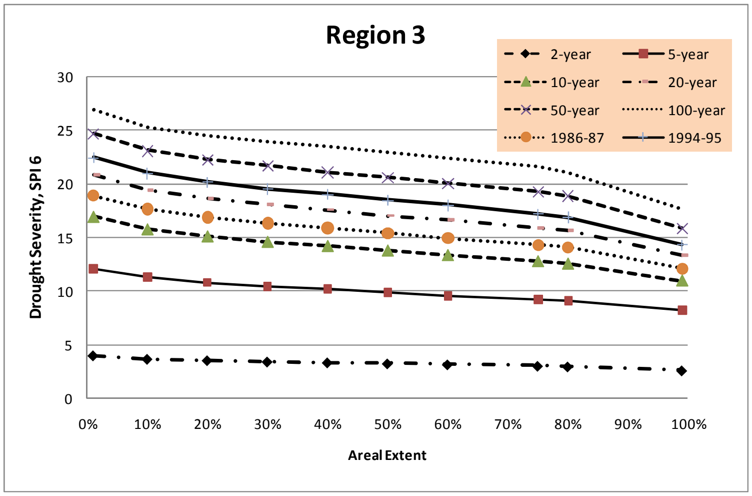


Figure 3-3: Drought Severity-Area-Frequency (SAF) curves of SPI 6 for Region 3 for 1986-87 and 1994-95 drought years

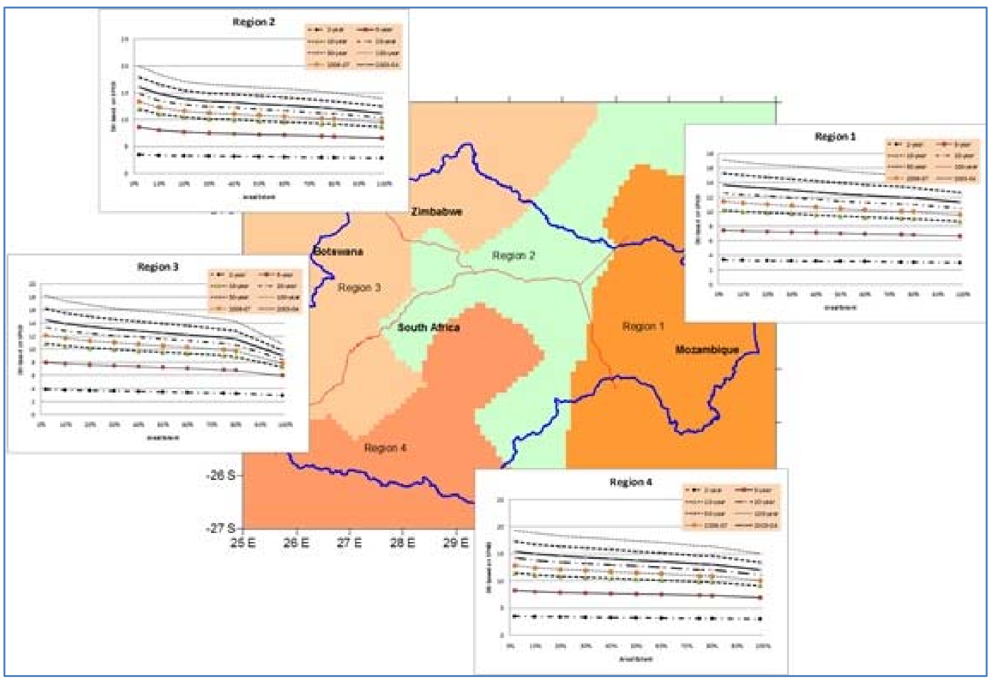


Figure 3-4: Regional Severity-Area-Frequency (SAF) curves of SPI 3

As for short-term droughts, the drought severity in Region 3 is higher than in the other regions, while Region 4 is an exception where the droughts tend to be of lower severity. For the medium-term droughts, the drought severity in region 1 is higher than the other regions while Region 3 is an exception where drought severity is lower.

The Region 1 is where the Limpopo Delta is located. The Delta is one of the highly economically important region from the mainly agriculture perspectives, a high risk of medium-term drought will undoubtedly pose higher risk for sustainable development of the regional socio-economy and also for the regional social stability. In this sense, considerable concerns should be attached to effective and integrated water resources management with focus on the entire basin.

The regional sums of the SPI values were used to extract the SPI for each region. The regional distribution in terms of the mean of the regional drought severity is illustrated in Figure 3-5.

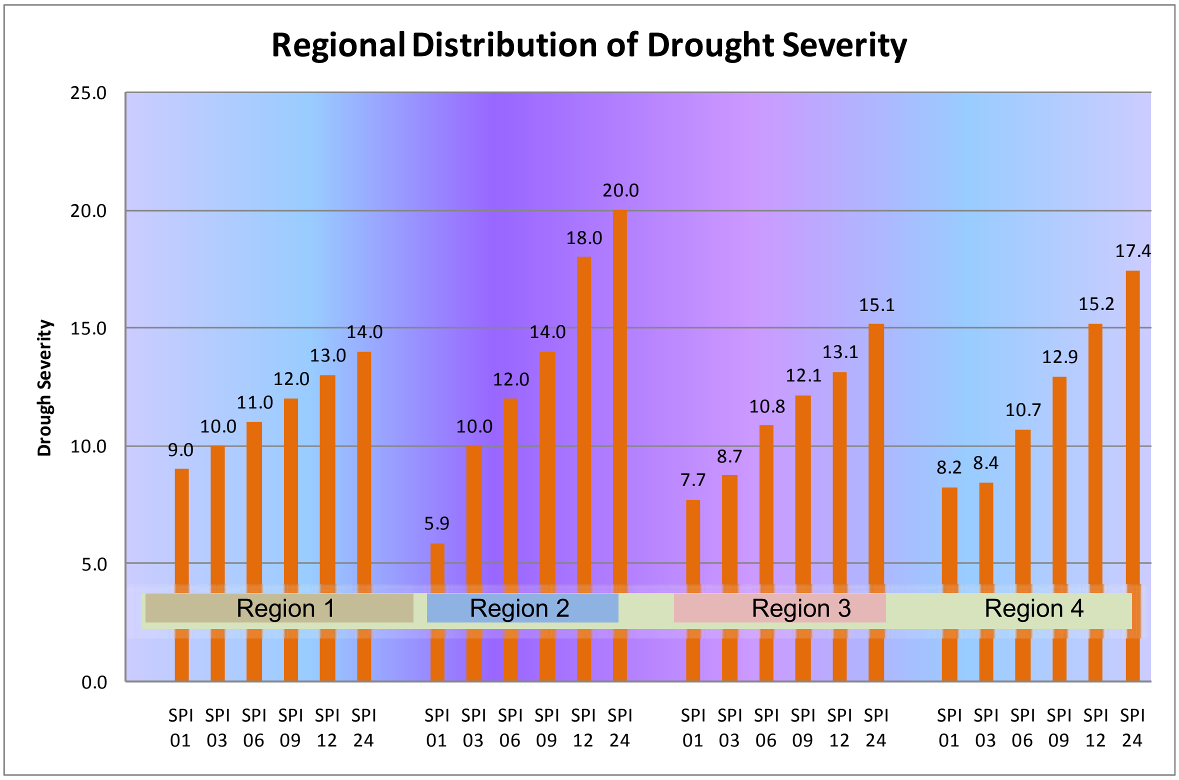


Figure 3-5: Aggregated mean regional distribution of drought severity computed from running sums of SPI for different time scales

A spatial analysis of drought characteristics in the Limpopo basin was is undertaken in this section to evaluate its regional implications to water management challenges. Here, duration frequency and severity are investigated. A set of drought severity-area-frequency (SAF) curves were constructed and analyzed. The entire Limpopo River Basin is subdivided into four homogeneous regions owing to topographic and climate variations in the basin which was based on K-means Clustering algorithm.

Using the medium range time series of the Standardized Precipitation Index (SPI) as an indicator of drought conditions, for each homogeneous region monthly and annual SAF curves and maps of probability of drought occurrence were produced.

The results indicated localized severe droughts in higher frequencies while only moderate to severe low frequency droughts may spread over wider areas in the basin. The approach can used to develop improved drought indicators, to assess the relationship between drought hazard and vulnerability and to enhance the performance of methods currently used for drought forecasting.

Preliminary correlation results with hydrological and vegetation or agricultural drought indices are presented as a means of a validation of the specific drought regimes and their localized impact in each homogeneous region. In general, this preliminary investigation reveals that the western part of the basin will face a higher risk of drought when compared to other regions of the Limpopo Basin in terms of the medium-term drought. The Limpopo basin is water stressed and livelihood challenges remain at large, thus impacts of droughts and related resilience options should be taken into account in the formulation of regional sustainable water resources development strategies

3.1.2 Modelling of standardised precipitation index using remote sensing for improved drought monitoring (***L Dlamini, J Ndiritu,*** ***A Ramoelo,*** ***W Nyabeze*** *- WRNA*)

(a) Objectives and study area

The Standardized Precipitation Index (SPI) is the only method used by the South African Weather Services (SAWS) to assess drought conditions in the country. The current method is limited by the coarse spatial scale it uses (as shown in Figure 3-6) which fails to show local features of droughts. The current spatial scale is due to the diminishing number and sparse distribution of available rainfall stations.

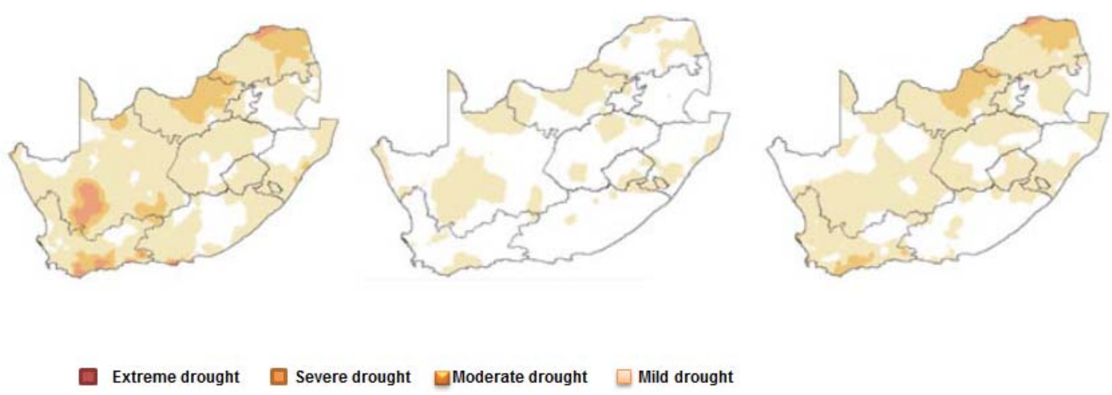


Figure 3-6:Standardised Precipitation Index (SPI) based drought maps for South Africa, November 2005 (left); September to November 2005 (middle); June to November 2005 (right)

Source: South African Weather Service

The study area is shown in **Figure 3-7**

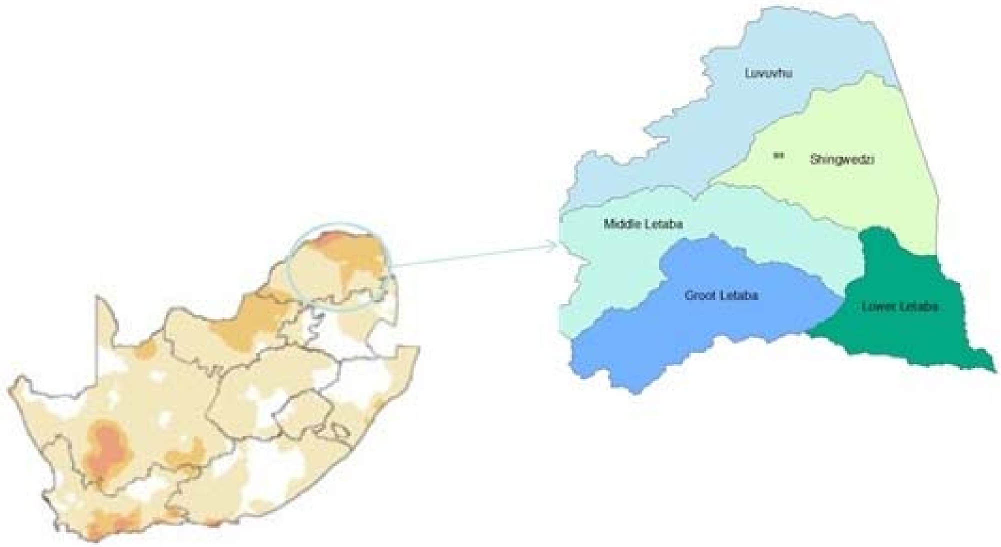


Figure 3-7: Study Area

Figure 3-8 shows the sparse distribution of available rainfall stations in the study area namely the Luvuvhu/Letaba Water Management Area (WMA) in 2011. This WMA is within the Limpopo Basin. The sparse distribution of rainfall stations therefore makes it difficult to determine reliable meteorological data based indices.

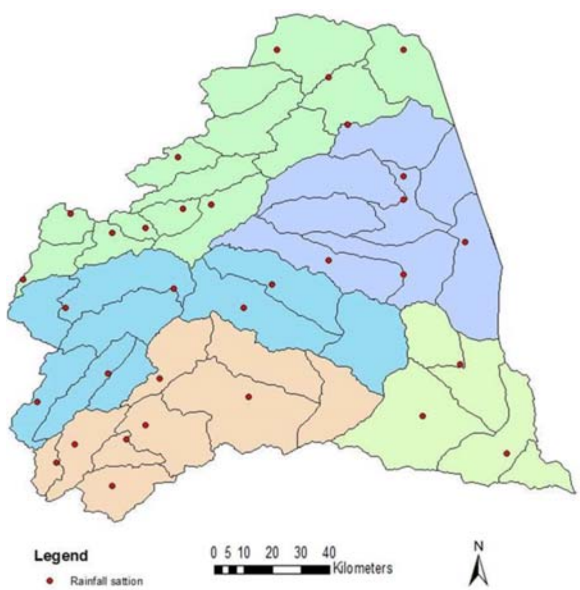


Figure 3-8: Operational rainfall stations in Limpopo in the year 2011

The objective of this study was to answer the following question: **How can the SPI information be supplemented by means of NDVI, VCI and topographical attributes for locations**

without rainfall data? The main objective of this study was to develop a method to estimate the SPI for catchments with limited rainfall observations using data for selected sub-catchments of the Luvuvhu/Letaba Water Management Area.

(b) Study methodology

Landsat images were used to determine vegetation cover during the same periods at the locations of the rainfall stations. These values were used to formulate and calibrate a model for SPI and determined the dryness of the area relative to the SPI value of the same point. The schematic presentation of the methodology shown in Figure 3-9: involved the meteorological data process to determine the SPI (meteorological drought), the remote sensing data for determining NDVI and VCI (agricultural drought). GIS analysis was used to determine Aspect and Slope.

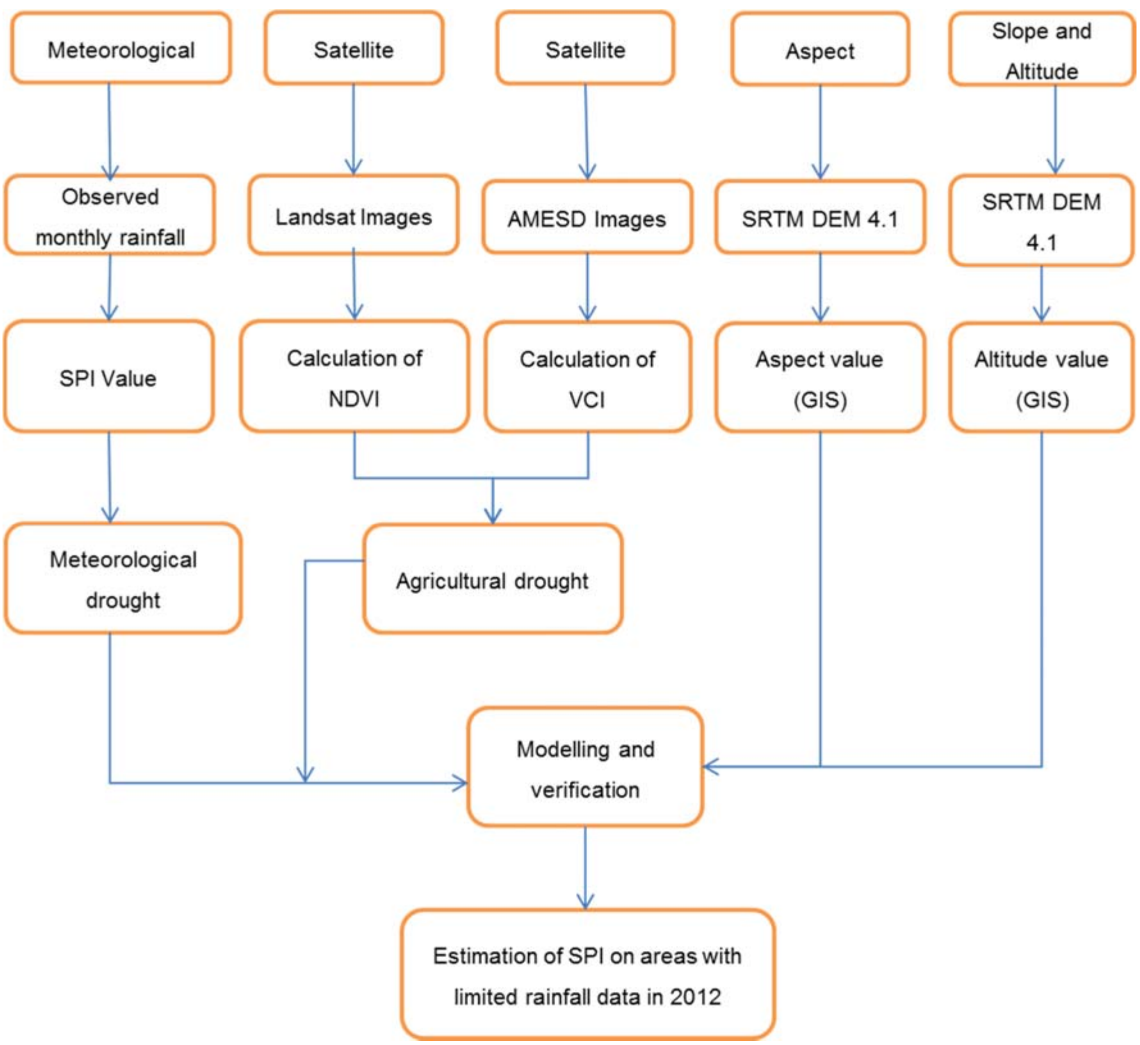


Figure 3-9: Schematic presentation of Methodology

Multiple regression techniques were used to verify if there was a correlation between the SPI, NDVI, VCI, Aspect, Altitude and Slope in the Luvuvhu WMA between 1983, 1984, 1991 and 1992. The SPI, NDV, VCI, and Aspect were then used to produce SPI maps with a finer spatial resolution. This information could be applied for drought-related decision making at local/community level. Figure 3-10 shows the correlation of NDVI values from a 180m x180m grid with those from the station pixel of 60m x60m. This was done for thirty rainfall stations. The coefficient of determination (R^2) is for the average NDVI value in the grid compared with the pixel value where the rainfall station is located. The same process was done for stations with the grid size increased as shown in Figure 3-11.

(c) Results

A higher correlation was found around pixels close to the rainfall station as shown in Figure 3-11. As one moves further away from the station, the correlation decreases. A high R^2= 0.878 was achieved on a 180m x 180m grid and the value of R^2 decreased as the grid increased. Depending on the level of accuracy that may be needed for decision making a choice for tolerable R^2 value can be made. This will allow for possible errors resulting from the downscaling of information.

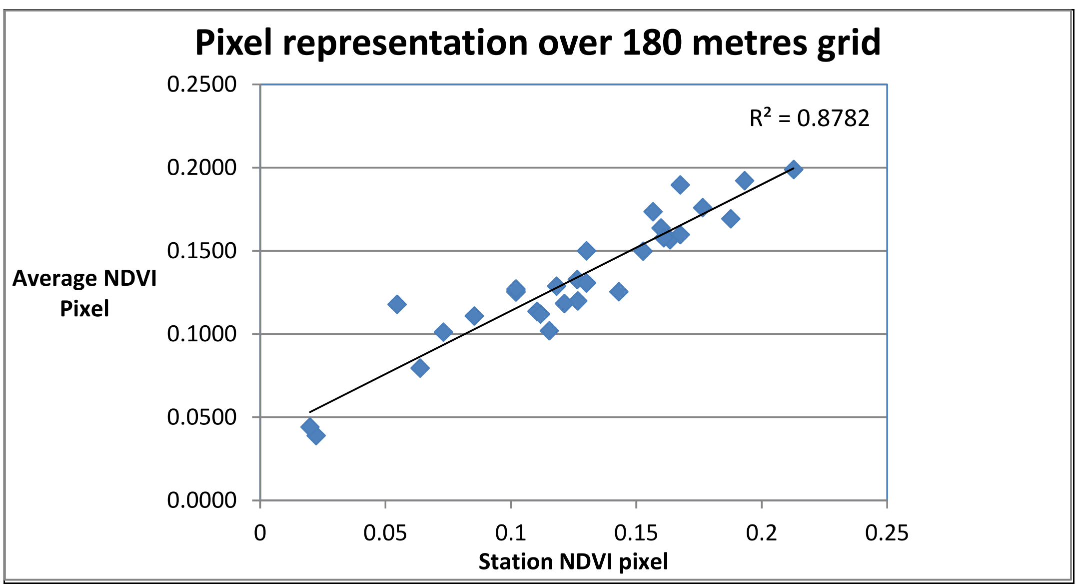


Figure 3-10: 180m NDVI pixel correlation

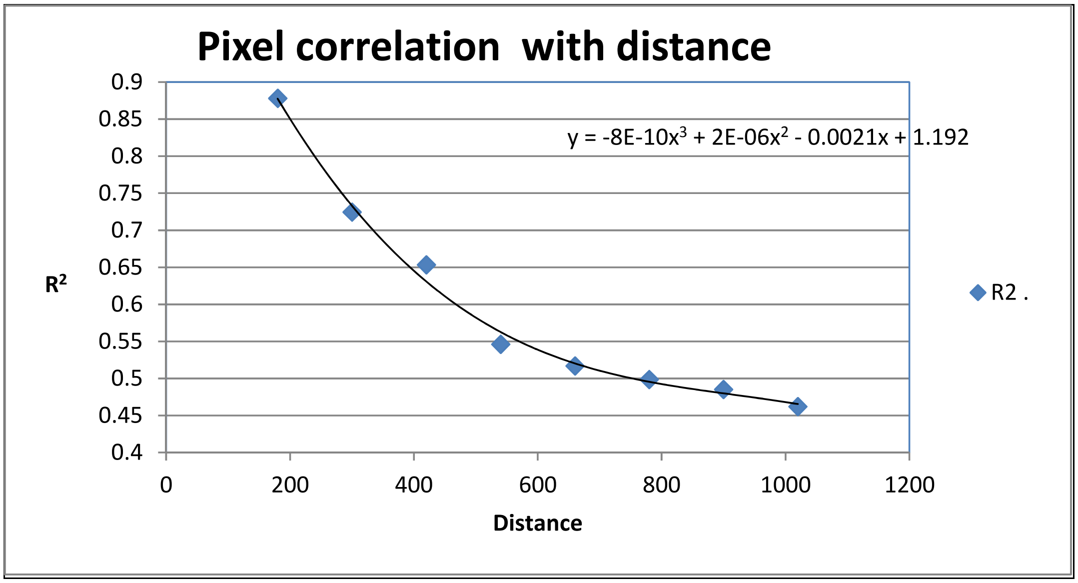


Figure 3-11: Pixel correlation with distance

The periods were divided into the wet and dry season. Uni-variate analysis was run on the model and yielded the relationships of SPI/NDVI and SPI/VCI. Multi-variate analysis was run on the model to predict β_0, β_1, β_2, β_3 and β_4 after bootstrapping to give improved coefficients. Figure 3-12 shows wet season performance per year while Figure 3-13 shows dry season performance per year. The variables fitted into linear regression to predict the SPI per season were then assessed to develop a robust model. This was achieved by analysing the R^2 and RMSE for each season per year. The years that yielded a better relationship between the variables and SPI were 1983, 1984 and 1991 (for the wet season) and 1984, 1991 and 1992 (for the dry season). The identified years were then used to develop a more robust model as shown in Figure 3-14. As stepwise multiple regression model was used, the model rejected elevation (DEM) as a significant parameter. This may be as a result of low altitude variation within the area of study. Alternatively, it may be that drought conditions are regional and affect areas independently of their attitude.

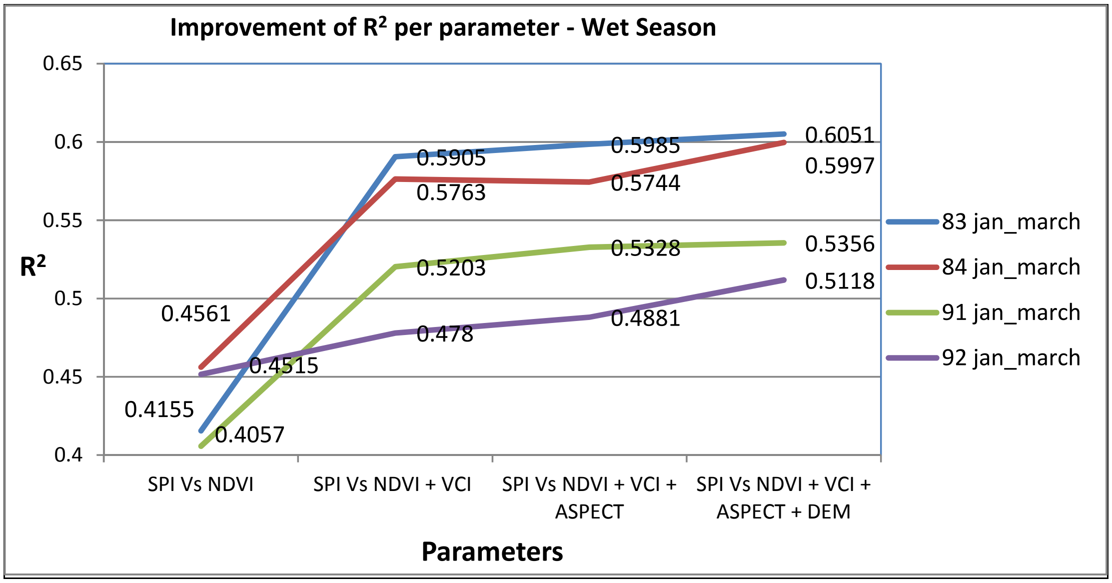


Figure 3-12: Performance of wet season SPI modelling

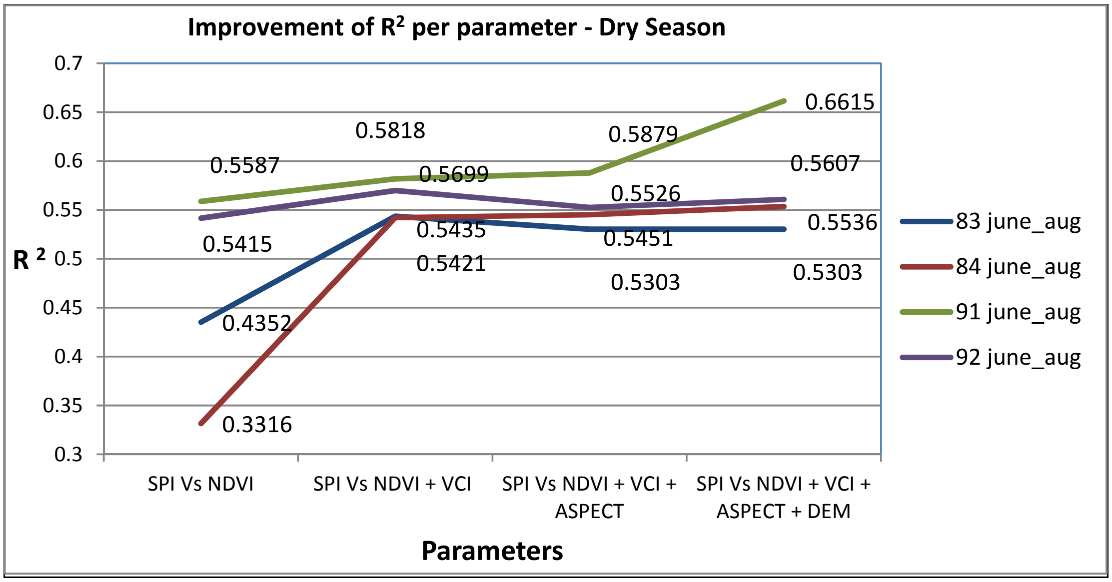


Figure 3-13: Performance of dry season SPI modelling

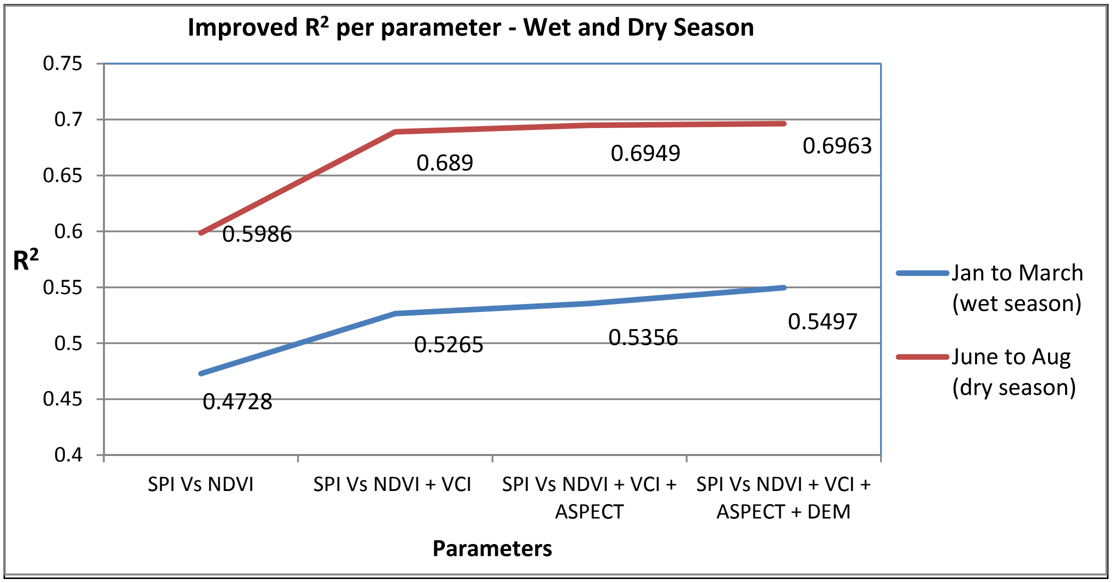


Figure 3-14: Performance of improved wet and dry season SPI modelling

Figure 3-12 shows that for the wet season in 1983, 1984 and 1991 there was better correlation (R^2 = 0.605, 0.600 and 0.536, respectively) for the SPI and NDVI, VCI, Aspect and DEM except for 1992. For the dry season (Figure 3-13) better correlation was observed in 1984, 1991 and 1992 (R^2 = 0.554, 0.662 and 0.561 respectively). Improved results from the model were achieved when the wet season (January to March) and dry season (June to August) for the years selected were used to develop a single model for each season (Figure 3-14). This was done by using the years that performed better in the specific season.

A better correlation (R^2 = 0.696) was achieved for the dry season. For the wet season, R^2 = 0.550 was achieved. A significant agreement can be observed between the SPI, NDVI, VCI, Aspect and Elevation for the dry season. This may suggest the following:

- Different atmospheric dynamics influence drought at different seasons of the year.
- Vegetation is responsive over a three month period (indicating a brief time).
- The relationships between precipitation, vegetation indices and topographical attributes would provide a better insight into drought onset and severity.

Different models were run in the different order of adding variables. The results show a better correlation of the SPI with the VCI. When the topographical attributes are added to the model, it becomes less significant. A strong relationship exists between the SPI and the NDVI. Furthermore, as topographical attributes are added, the results improve. On the other hand, the opposite was observed with the VCI.

Variations in vegetation indices can help to establish the effect of climatic factors on local vegetation. The variations will be of less practical value for large scale planning (e.g. SADC mitigation measures) but would help for local/community purposes since it would provide better insight into drought onset and severity. A SPI of -2.269 in 1992 recorded severe dry conditions, which were only last seen in 1969 and 1972 whist in 1983 and 1984 the dry season was close to as normal as other years during the dry season. During the following wet season a SPI of -1.189 was observed. Moderately dry conditions were identified in 1983. A SPI value of -1.606 was identified in 1992, which characterises a very dry condition (even though it is a wet season). These results are in agreement with the literature review and show that severe dry conditions were experienced during these years as confirmed by the SPI values.

The 1983 wet season had a 0.6 NDVI value, which is average green for a wet season. (This is expected to have a closer to 1 NDVI value in order to show green). These images agree with the SPI values for the same periods, expect for the years that show positive SPIs due to late rainfall (it was a drought year). In 1984 both seasons were drier as compared to the average of the same period. Satellite based vegetation indices (NDVI) show 1991's wet season as the worst dry period. It also shows that the dry season was moderately dry. The 1992 images show severe dry conditions for the wet season. Also, in the 1991 wet season, some areas received good rainfall and showed green. The dry season was however severely dry for the whole study area. The year 1992 was better than all the years as there were more green areas. Despite this, some areas still remained dry during the wet season.

This study reveals that seasonality has a very significant effect on the relationship between the SPI, NDVI, VCI, Aspect and Elevation. High correlations were observed during the dry season, but were much lower during wet season. Therefore, considering the whole area of study, the correlation between the SPI, NDVI, VCI, Aspect and Elevation is, in general, higher in areas with a low vegetation cover/activity (low average NDVI values). This could indicate that areas with a low vegetation cover/activity are more prone to the effects of drought than areas with a higher vegetation cover. The reason for this is that plants are more sensitive to water availability in their reproductive growth stage. The topographical attributes have an impact on the correlation between the parameters. For the dry season in 1991, elevation increased R^2 from 0.588 to 0.662. For the wet season in 1984, R^2 increased significantly from 0.574 to 0.600. For a robust model during the wet season, R^2 improved from 0.473 to 0.550, which was not too significant. For the dry period R^2 improved from 0.599 to 0.696. This showed a significant improvement on the value of R^2 as the attributes were added into the model. Aspect has more influence on the correlation than elevation. This could be attributed to the size of the catchment, which was used for this study as it does not have significant variation on Altitude.

After the statistical regression analyses for the model development were achieved, the model needed to be validated using a period not used in the regression analysis. Year 2012 was selected for this with field work conducted in the catchment area at Tzaneen, Mandlakazi, Ga-Modjaji, Thohoyandou and Giyani (Figure 3-15). These five communities were selected as they fall in different quaternaries and have different agricultural activities including significant commercial and subsistence farming. The field observation was done using meetings and visiting the fields with the farmers, the Water User Association, Water Managers from Tzaneen Dam, the Vhembe Municipality, Mopani Municipality and the Provincial Disaster Management Centre.

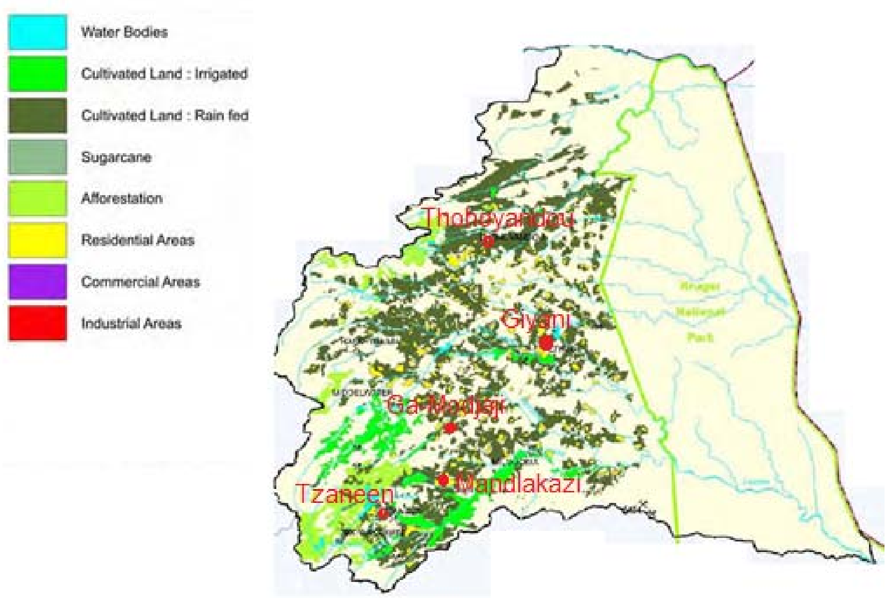


Figure 3-15: Land use map showing locations selected to verify SAWS and model-based SPI

Figure 3-16 and Figure 3-17 show the NDVI maps for the area of study for selected periods of year 2012. Figure 3-18 and Figure 3-19 show the VCI maps for the area of the study for the same periods.

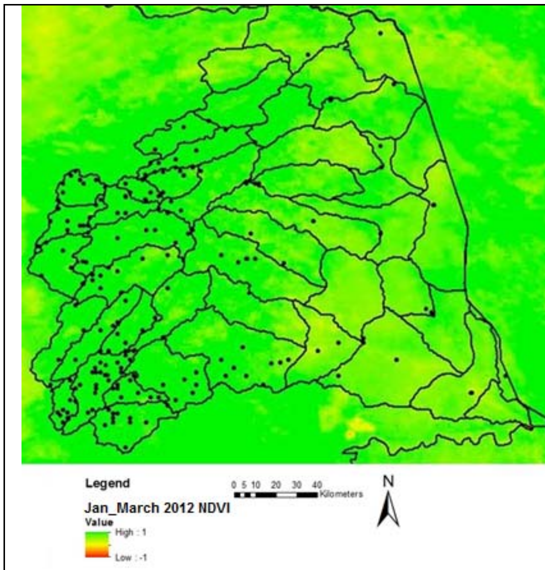


Figure 3-16: NDVI January to March 2012

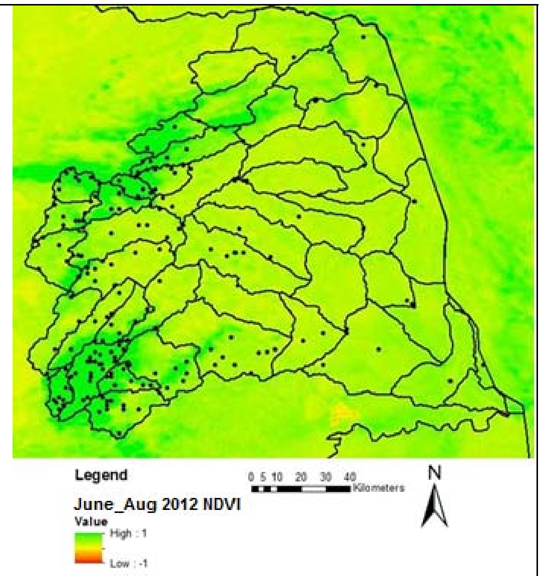


Figure 3-17: NDVI June to August 2012

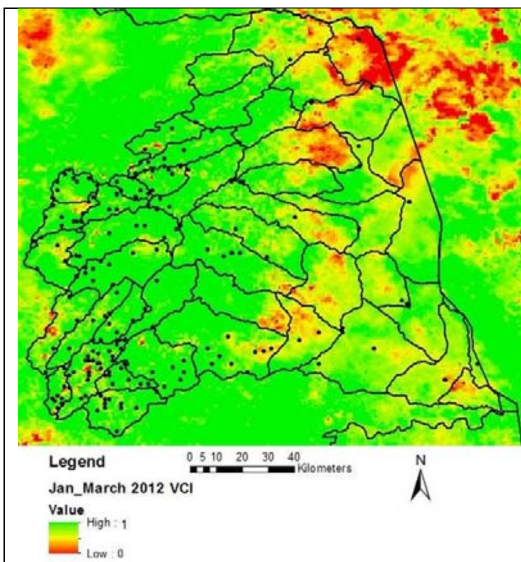


Figure 3-18: VCI January to March 2012

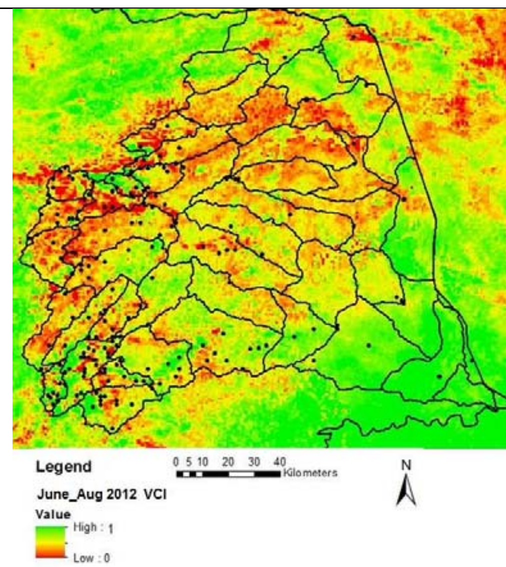


Figure 3-19: VCI June to August 2012

Using the NDVI and VCI images for 2012 and the SPI model developed, model-based SPI maps for the wet season and dry season were obtained as shown on Figure 3-20 and Figure 3-21. The SPIs were then classified using the same classes used by SAWS to obtain Figure 3-22 and Figure 3-23.The classification is:

- 0.2 and below – extremely dry;

- 0.21 to 0.35 – severely dry;
- 0.36 to 0.4 – moderately dry;
- 0.41 to 0.49 – somewhat dry;
- 0.5 to 0.65 – normal conditions;
- 0.66 to 0.8 – wet conditions;
- 0.81 and above – extremely wet conditions.

Areas with the same classification were mapped together based on a grid of 3 kilometres which is the estimated size of the smallest local community within the Limpopo. This obtained Figure 3-24 and Figure 3-26 which allowed reasonable comparison with the SAWS maps for the same periods.

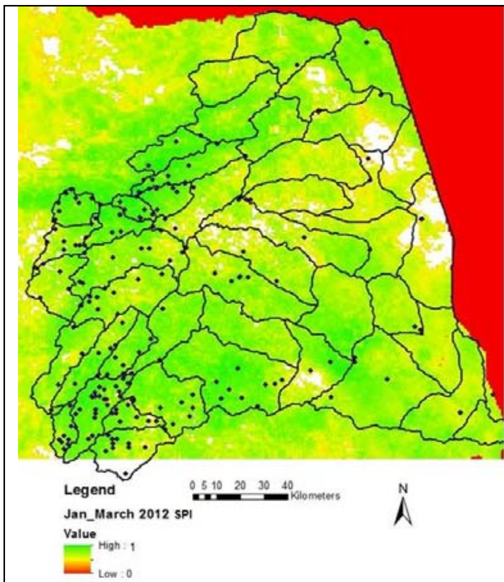


Figure 3-20: SPI January to March 2012

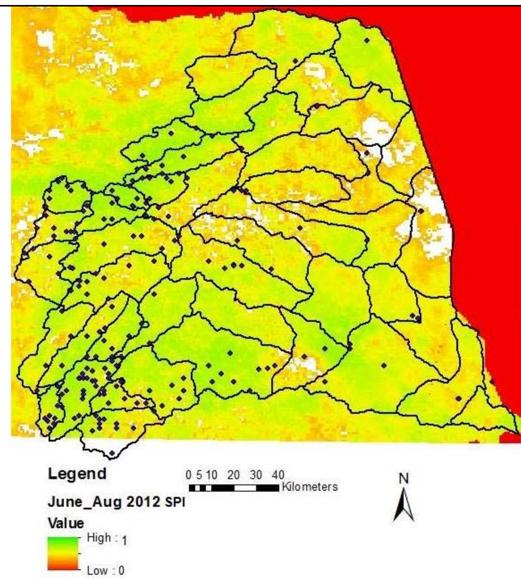


Figure 3-21: SPI June to August 2012

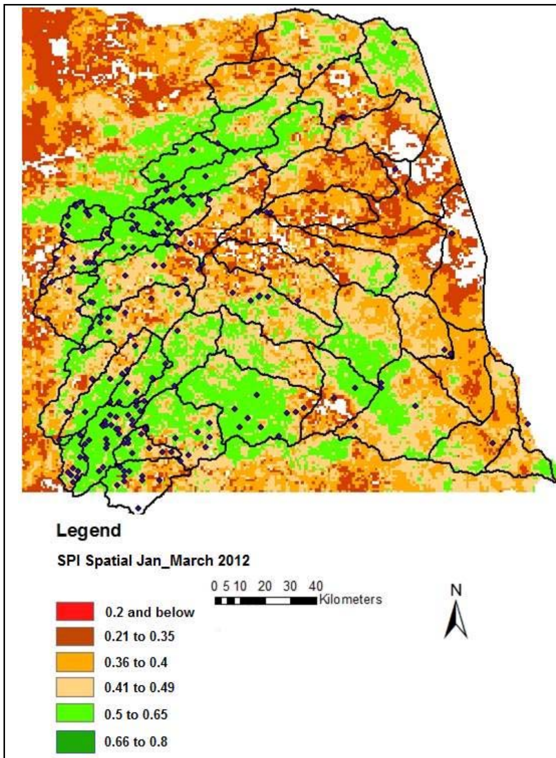


Figure 3-22: Classified SPI January to March 2012

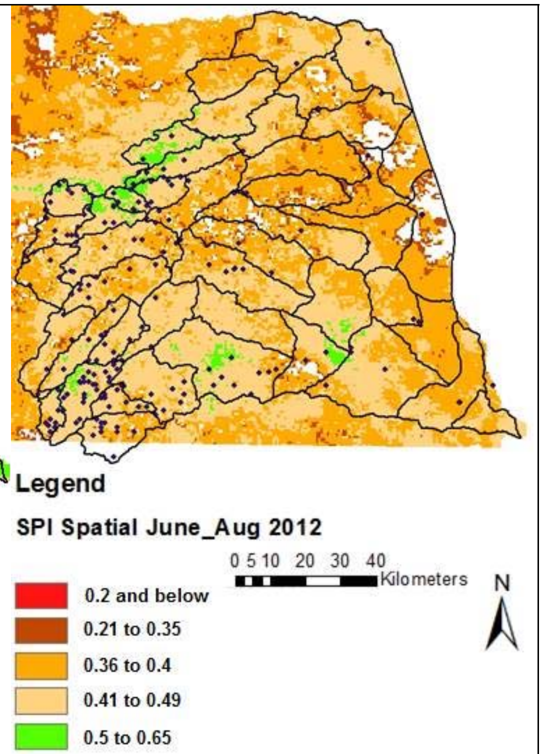


Figure 3-23: Classified SPI June to August 2012

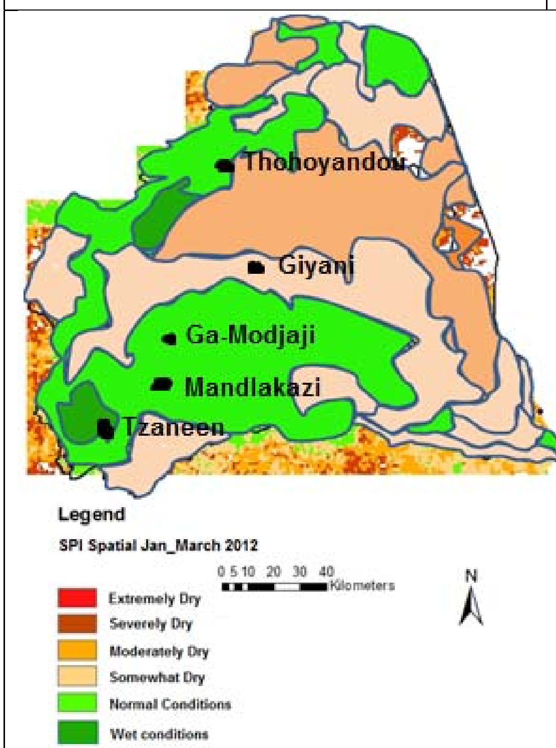


Figure 3-24: Classified areas within 3km - SPI January to March 2012

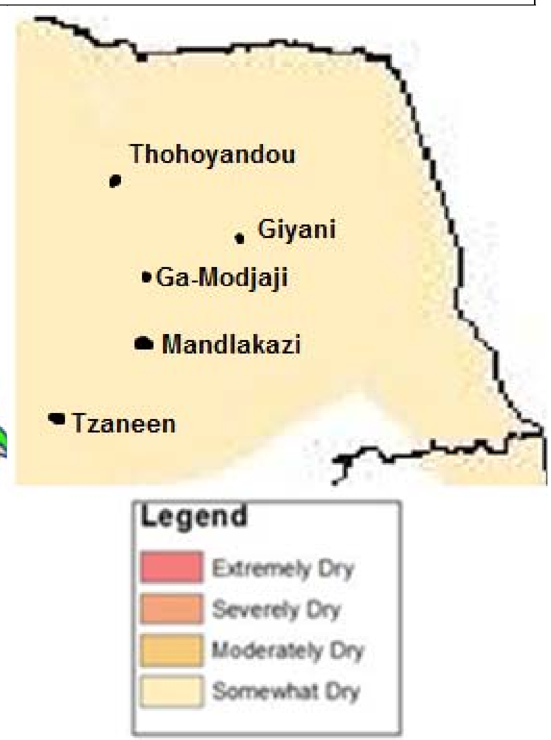


Figure 3-25: SAWS SPI January to March 2012

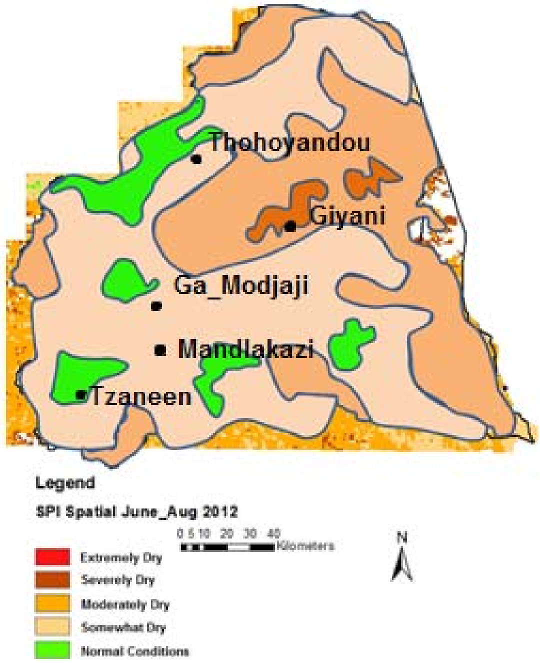


Figure 3-26: Classified areas within 3km - SPI June to August 2012

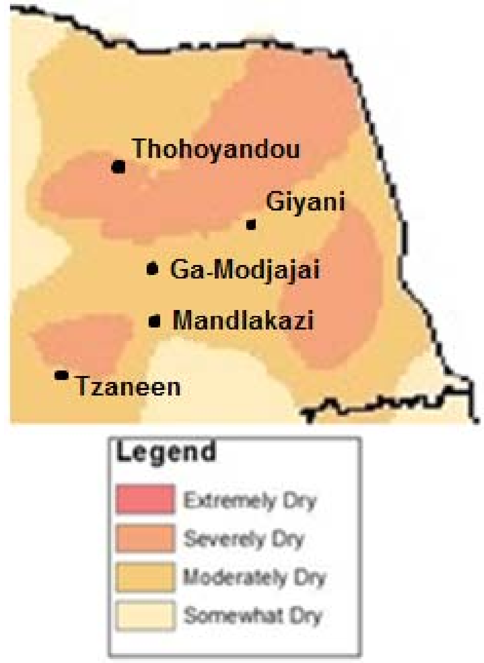


Figure 3-27: SAWS SPI June to August 12

An assessment of how well the SPI regression model and the SAWS maps agree with the field observations of the drought conditions in the selected sites is carried out for the wet and the dry season of year 2012.

Figure 3-26 and Figure 3-24 reveal that there is a significant difference in the SAWS SPI and that developed from the model. During the wet season, three areas agree with the model results and two areas agree with both model and SAWS results, for the dry season two areas agree with model results, one with SAWS results, one with model and SAWS results and one that does not agree with any of the results. This shows five areas in agreement with the model and field observation results, four areas that agree with both SAWS/model and field observation results and one that with no agreement.

The wet season shows a somewhat dry condition for the entire study area from the SAWS SPI map (Figure 3-25). On the other hand, the model shows normal to wet conditions, and only the Giyani areas show somewhat dry conditions. According to the SAWS, moderately to severely dry conditions were experienced during the dry season in the area of study. When visited during the wet and dry seasons respectively in 2012, the Water User Associations pointed out that SAWS' long range forecast and drought maps, which are available online, were the only available information, which could be used for early drought warning. Makuleke village in

Mopani experienced severe dry weather conditions and over 300 cattle died (SABC, 21/12/2012). This statement was confirmed by the model results of severe drought in the area.

The seasonal pattern of rainfall and NDVI combined with the VCI, Aspect and Slope, suggest that the north-western and south-western part Luvuvhu/Letaba Water Management Area received higher rainfall than the rest of the catchment in the wet season of 2012. The South African Weather Services' results portray the same conditions throughout the catchment area which did not agree with field observations. This can be attributed to the smaller number of rainfall stations available in the western part of the catchment area.

(d) Conclusions

In this study, drought condition maps based on the modelled SPIs were obtained on a grid of 3x3 km. These matched the field observations reasonably well and considerably better than the drought monitoring maps provided by the South African Weather Services (SAWS) which are based on data from sparsely located rainfall stations. By using the SPI model, it is therefore possible to zoom into local/community scale and determine the severity of drought with more confidence.

3.2 IMPROVED METEOROLOGICAL, HYDROLOGICAL AND AGRICULTURAL DROUGHT FORECASTING FOR THE LIMPOPO RIVER BASIN – LINKED TO WORK PACKAGE 4

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

The Limpopo Basin (Southern Africa) focuses on improving existing drought monitoring and forecasting capabilities, as well as institutions, policies, guidelines and procedures for management of the scarce water resources in the basin

Institutional structure; Water management; Only source of water for millions of people, shared basin; Improve the flow of information; Mental model; Regional analysis because the shared basin has to have a good coordination structure; To give the gap analysis, to look into the institutional set-up; Provide recommendations for improving institutional structure; Include several types of end-users and analyze how the issued warnings flow through the institutional structure; Agricultural drought forecasting

Based on Precipitation, stream flow, crop yields, management rules, institutional response, adaptive capacity, exposure, Social response.

3.2.1 Coupling meteorological, hydrological and agricultural forecasting tools into a water allocation model (*B Alemaw - Waternet/University of Botswana*)

(a) Objectives and study area

- Coupling of meteorological, hydrological and agricultural drought forecasting tools into a water allocation model in the Limpopo basin
- Assessment of drought resilience of crop production under meteorological drought in the Limpopo basin
- Assessment of drought duration and severity
- Construction of spatial maps of drought severity and SAF curves
- Preview of implications to agricultural, vegetation and hydrological droughts Assessment of agricultural droughts
- Assessment of hydrological droughts

(b) Stakeholders involved

- AMESD SADC THEMA ACTION
- SADC
- Local agricultural offices
- Meteorological office

(c) Study methodology

- Sustainability analysis of crop resilience using a soil water accounting water balance model
- Determination of crop productivity with ensembles of historical climate
- Hydrological impacts and reservoir risk analysis to meet domestic, agricultural demands needs and under different societal, operational as climate change scenarios

(d) Results

Major meteorological drought and related impacts involve the following aspects:

- SPI– modelling for various case sites
- Sustainability, soil moisture modelling and risk analysis of various crops rainfed systems: risk, resilience, vulnerability indices
- Risk of failures of irrigated systems under different agro-ecological and crop systems

There is clear evidence showing that soil fertility constraints often constitute the primary limiting factor to crop growth also in drylands (Klaij and Vachaud, 1992). Drought impact can be assessed from crop- soil-water simulations of long-term meteorological variables especially using crop specific water accounting (SMACS) models (Alemaw et al. 2006). A more recent relies on the assessment of availability of soil moisture which is an integrating variable for the underlying hydroclimatic and agronomic factors of rainfed agricultural areas. The risk level for sustenance of rainfed systems can be determined as a probability at which soil moisture (S) drops below a given moisture threshold (SWP +dt) during the crop's LGP. The risk factor for the entire growing period (simulation period) of crops under rainfed conditions can be calculated as defined as:

$$r\,[\%] = \frac{n}{T} \times 100\%$$

Where n is the number of days in which actual soil moisture S, drops below the critical soil moisture threshold (SWP + dt) during the total number of days (T) of the entire cropping period. In a period of years of analysis considered, T in days becomes the product of the number of the simulated years and the length of the growing period (LGP) in days.

The risk factor here is the same as the probability of failure which refers to the proportion of days to the total number of days or the length of the growing period (LGP), within which the simulated soil moisture drops below the amount which is set at p times the readily available soil moisture content (SFC - SWP). If other agricultural conditions such as land management and nutrient availability are not altered, then this risk factor integrates the prevailing hydroclimatology, soil moisture availability and crop-soil-water conditions, to assess sustainability of various crops under rainfed conditions.

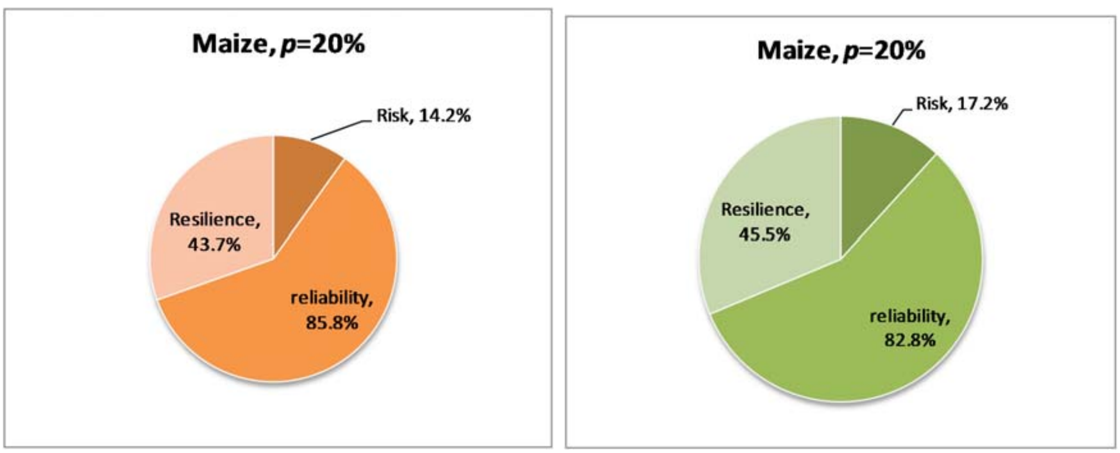
For assessment of soil moisture reliability and sustainability of rainfed systems, we recommend a set of indices that are used as quantitative measures, details of which are presented in Alemaw, 2012. The indices measure reliability, risk of failure and resilience for classifying and assessing the sustainability of rainfed agricultural systems. Reliability is a measure of frequency or probability that a system is in a satisfactory state meeting a given criterion. Resiliency generally indicates a measure of how quickly a system recovers from failure once failure has occurred. The computational scheme for these indices in this study is almost similar to that of Hashimoto et al. (1982), Maier et al. (2001), and Fowler et al. (2003), specifically tailored for analyzing risks and sustainability of rainfed systems and a different criterion.

Defining a criterion (C) as the minimum required soil moisture from a rainfed agricultural system, the daily soil moisture depth (d_t) can be classified as a satisfactory state (A) or a failure state (B), i.e.,

$$S_t \geq C \quad \begin{cases} \text{then} \quad d_t \in A \quad \text{and } Z_t = 1 \\ \text{else} \quad d_t \in B \quad \text{and } Z_t = 0 \end{cases}$$

Where Zt is a generic indicator variable. The daily available moisture content simulated in the SMACS model was used as a criterion and, thus, system failure occurs when soil moisture is below the criterion at any given day.

Daily simulations from climatic data of 1961-2001 were made for two districts in Region 3 of the Limpopo basin, considering commonly grown crops: maize, sunflower, and sorghum. For the same crop generally Bobonong District displayed higher risk, lower reliability and resilience compared to Palapye. Risk, reliability and resilience of maize simulated from the entire 1961-2000 daily record and taking the actual cropping length, at available soil moisture factor, p=20% for Palapye District and Bobonong Districts is shown in Figure 3-28.



(a) Palapye District (b) Bobonong District

Figure 3-28: Risk, reliability and resilience of maize with available soil moisture factor, p=20% in two districts of Region 3 (Alemaw 2012a)

3.2.1.1 Assessment of agricultural droughts in the Limpopo Basin

Results and general summary:

Detailed investigations of agricultural droughts are conducted for the following conditions:

- Crop production systems – based on agricultural statistical data analysis
- Cereal yields especially in rainfed systems

- Sustainability of rainfed crop production in the Limpopo range lands

Other important aspects are:

- Livestock production systems– based on agricultural statistical data analysis
- State of cattle feed supply
- Grazing land availability
- Animal feeding balance,
- Imports of animals and animal products such as milk

Sub-study summary:

Water requirement satisfaction index (WRSI) is relatively a relevant index to monitor agricultural drought. WRSI is an indicator of crop performance based on the availability of water to the crop during a growing season. The WRSI was generated by a crop water balance model, SMACS model. SMACS stands for Soil moisture accounting crop specific model (Alemaw et al., 2006). It was applied using the following criteria.

Table 3-1 WRSI-based drought severity class

WRSI (%)	**drought severity class**
80- 100	No drought
70-79	Slight drought
60-69	Moderate drought
50-59	Severe drought
<50-59	Very Severe drought

Within the SMACS model, WRSI was calculated as the ratio of seasonal actual evapotranspiration (AET) to the seasonal crop water requirement (WR) i.e.

$$WRSI = (ETa / WR)x100$$

In which WR is reference crop evapotranspiration (ETo) calculated from the Penman-Monteith model using the crop coefficient (Kc) to adjust for the growth stage of the crop, WR = ETo * KC. Whereas, ETa represents the actual amount of water withdrawn from the soil water reservoir where shortfall relative to potential evapotranspiration (PET) is calculated by function that takes into account the amount of soil water in the reservoir. Soil water content was estimated through simple mass balance equation where the total volume was defined by the water holding capacity or available soil moisture content (WHC=FC-PWP) of the soil.

The impact of agricultural drought on crop production can be largely expressed by yield reduction. For this, yield reduction due to water deficiency was computed within SMACS model software. Yield reduction was calculated from water balance output combined with an empirical formula developed by Doorenbosch and Kassam (Hoefsloot, 2008) which recommends a formula Yr=100-((1-(1-A/B) Ky) 100) in which A is the actual evapotranspiration, B is the total water requirement without water stress, and Ky is a crop dependent stress indicator.

The agricultural statistics database mainly for Region 3 was also used to analyse the implications of drought to crop yield. Figure 3-29 shows a variation of national crop production and its yield. It can be clearly evident how the droughts of 1991, 1992 and 1994 have affected agricultural yield. It can also be noted that the consequence of a particular drought year will have a pronounced effect in that year’s or later year’s yield.

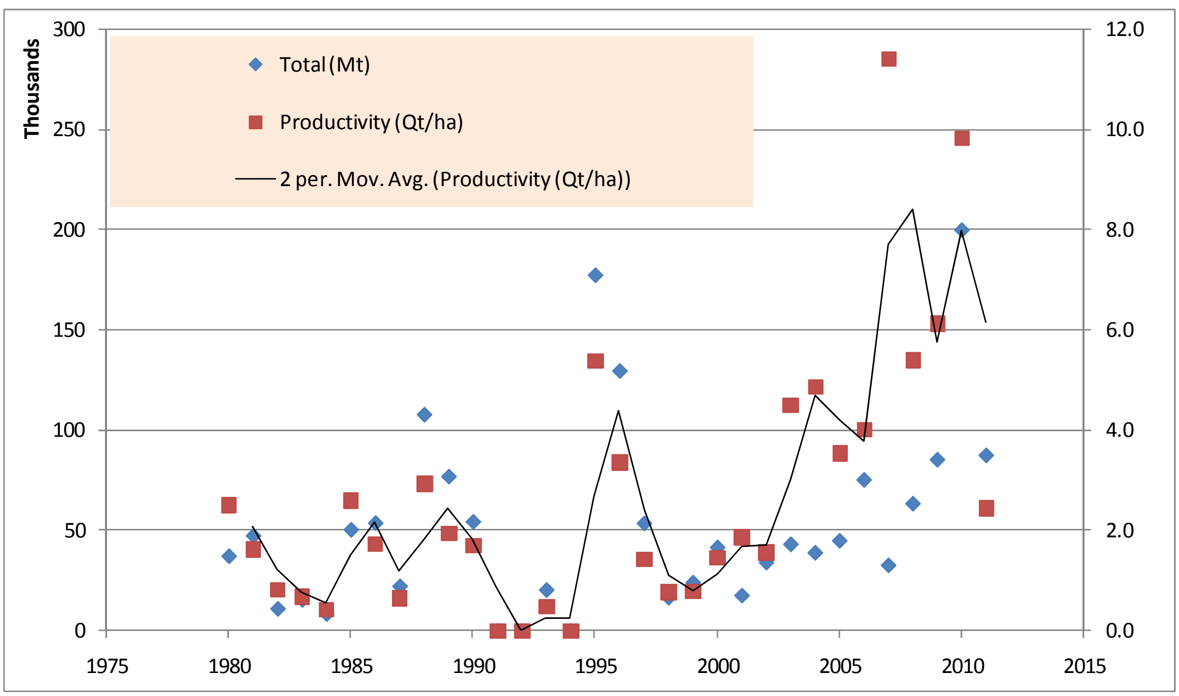


Figure 3-29 Crop production and yield data (Region 3)

3.2.1.2 Assessment of hydrological droughts

Results and sub-study summary:

Small dams are vital sources of water supply in the Limpopo basin for domestic purpose, agricultural use and livestock watering among others. Drought and climate variability is always posing challenges to availability and adequacy of water for meeting the various water needs. Sustainability of small reservoirs and water development in the Limpopo Basin is an issue which needs to be tackled from human and climate change perspective. The challenge is to make the dams and reservoirs more reliable and resilient to unpredictable factors. The control of floods and sedimentation also appears to be the dominant problem in the lower reach of the Limpopo River. In a study conducted recently (Alemaw et al., 2011), an assessment of climate change impact on the water resources of the Limpopo Basin was undertaken with the main indicators of water economy, projected over the coming decades, which will be influenced not only by climate, but first of all by the population and economic growth and technological progress.

The role of small reservoirs and agricultural dams for climate change adaptation is quite an experience in the Limpopo basin. The problem is how big a dam should be for it to be more reliable and have more resilience to provide its intended yield to its users under the influence of climate change, recurrent droughts and operational policies. In this study, we pursued two objectives. The first is to demonstrate through modelling study to determine the optimal required and available storage of agricultural and other multipurpose dams of varied sizes – attesting to possible rainwater harvesting through small reservoirs under current needs for agriculture, environmental and other uses. The second purpose of the exercise is to show how the different human and climate factors influence the dam operation and the reliability in meeting the multiple goals of water use and development as well as adaptation to climate change in the basin.

Climate Change impacts in the Limpopo basin

Considering the water cycle as the one important element in the global change dynamics, the principal input variables to the hydrological and water systems are precipitation and temperature projections under climate change conditions which are determined with some degree of variability and inconsistency. These leave major uncertainties in quantitative projections of changes in hydrological characteristics for a drainage basin (Kundzewicz et al., 2007).

For instance, the climate change scenarios in terms of temperature and precipitation changes simulated using MAGICC/SCENGEN (Hulme et al., 2000) and other recent modifications for the IPCC Third Assessment Report (TAR) and Fourth Assessment Report (FAR) depict wide differences in the projections. The rainfall and temperature simulations of 20 GCMs based on MAGICC/SCENGEN 5.3 which are described in Widgley (2008) show varied degrees of changes in the basin for the 2050s and leaves unexplained uncertainty for those projections.

Against the baseline 1971-2000 climatology, three specific GCM model projections in 2050 (CNRM, GFDL and UKHADCM3) were considered (modified from Alemaw & Chaoka, 2006). The corresponding water balances of simulated runoff for Lotsane River in Botswana, which is a Tributary River of the Limpopo drainage basin is shown in Figure 3-30. The runoff for 2050s and the baseline period were simulated using a coupled GCM-monthly water balance model. The latter is based on the Thornthwaite's water balance model which is given in McCabe and Markstrom (2007). It is quite clear that the simulated water balances show a mix of generally declining discharge during the dry quarters by the three scenarios, and increase during the rainy season, quarter Q2 (January, February, March), by the CNRM GCM under the assumed global change SRES emission scenarios.

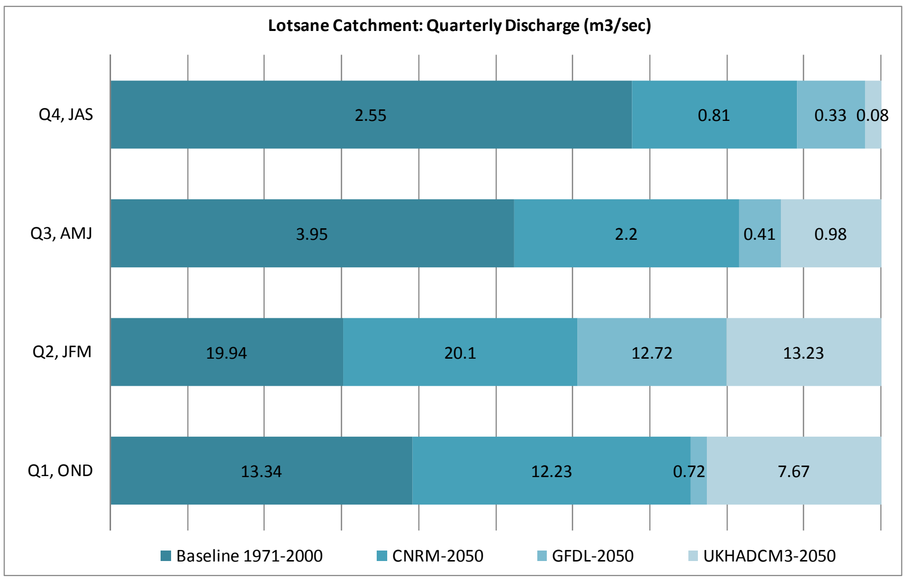


Figure 3-30: Projected quarterly discharge of Lotsane River for the baseline period of 1971-2000, and the 2050 using 3 GCM scenarios - simulated using a coupled GCM and a monthly water balance model (source: Alemaw 2012b)

Resilience and reliability of dams in the Limpopo basin

For this river which has a dam with a reservoir capacity of 38 MCM, and other two dams in the Limpopo basin namely Shashe and Letsibogo dams, located in Shashe and Motloutse rivers, whose capacity are 93 and 61 MCM, respectively, the reliability and resilience of the dams under different operational requirements and allowing an environmental flow requirement of 20% of the mean monthly flows is shown in Figure 3-31. The reliability and resilience indices were as defined and computed based on the methodology first provided by Hashimoto et al. (1982) and Maier et al. (2001).

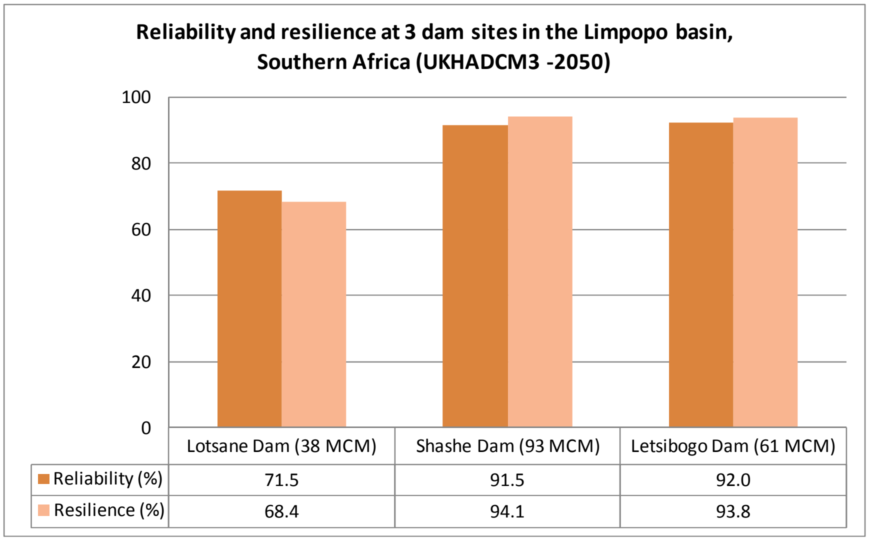


Figure 3-31: Reliability and resilience for the baseline period and the 2050 for the UKHADCM3 GCM scenario simulated using a coupled-GCM-hydrological-reservoir operation model. Small reservoirs proved to be less reliable and less resilient compared to the larger counterparts in the Limpopo basin. Details are provided in Alemaw et al 2011 and a recently published book (Alemaw, 2012b).

The reliability and resilience for the baseline period and the 2050 for 3 GCM scenarios are simulated using a coupled-GCM-hydrological-reservoir operation model to incorporate the effect of climate changes in the operation and management of water resources in the dam whose operational requirements depend on the expected water withdrawal, environmental flow releases, and accommodation of competitive water demands while meeting other socioeconomic realities on the ground. In this case study, if the operational requirements for using water for agriculture is envisaged besides the current domestic water use and if the releases are changed to meet various targets, obviously the reliability and resilience of the dam will alter accordingly. The decision to go for more storage dams in these rivers, for adjusting operational rules, for joint use of the surface water from the dam with other sources such as groundwater need further detailed ground studies encompassing of social, economic and investment priorities and options for communities and decision makers to make decisions on appropriate water supply management systems.

With or without climate change, it is shown in this manuscript that the size of water harvesting structures determines the ability of communities for coping with water shortages. The challenge in the Limpopo basin and the role of small reservoirs is with no doubt to allow and promote Flexible Water Storage Options to improve water access and overcome frequent hydrological droughts. Details are presented in Alemaw et al., (2011) and a recently published book (Alemaw, 2012b).

3.2.2 Statistical analysis of drought variability to inform a statistical forecasting model of hydrological drought (M Seibert - GFZ, Deliverable 4.6 and 4.8)

This section presents the objectives, study methodology, results and conclusions from the statistical analysis and statistical seasonal forecasting of drought.

(a) Objectives

The objective of this investigation was to conduct a statistical analysis of the complex relationship of drought in the Limpopo basin with climate anomalies, for example El-Niño. El-Niño is known to cause drought in Southern Africa it is a central factor for statistical methods of rainfall prediction.

(b) Study methodology

In order to achieve the task described above several statistical methods were employed. For details on the methods we would like to refer interested readers to the Deliverable 4.6 and Deliverable 4.8 of the DEWFORA project (DEWFORA, 2012).

First, principal component analysis was used to extract spatial patterns recurring when the Limpopo basin was affected by drought. With that method it was possible to analyse whether the spatial distribution of drought within the Limpopo basin was related to external atmospheric large scale drivers. This was achieved by a correlation analysis of drought pattern occurrence with climate anomaly indices on the hand and global sea surface temperatures in the other hand. The correlation to global sea surface temperatures was performed to test relationships to regions with modes of variability not covered by the climate anomaly indexes. In particular, regions in closer proximity to southern Africa were tested.

Second, for the identification of potential predictors a number of climate and circulation anomaly indices were compiled and complemented with teleconnected ocean regions in the proximity of Southern Africa. Regions were selected based on the correlations mentioned above and from composites analysis of sea surface temperature fields. The latter puts a drought specific focus upon sea surface temperature during drought events in the Limpopo basin by calculating the average condition during the 12 months preceding droughts. Hence, the regions defined in the composites are likely to have predictive power. Therefore ocean regions with anomalies were selected and prepared as potential predictors in statistical models.

Third, in the statistical forecasting approach followed here, two different methods were compared: multiple linear models and artificial neural networks (ANN). These methods have in common that they are able to relate multiple predictors (input) to one predictand (output) variable. The difference between these methods is the nature of the relationships simulated by the models. Multiple linear models simulate linear relationships only, whereas artificial neural networks can also simulate nonlinear behaviour which is particular suited for atmospheric processes. The predictors were the Ocean region time series, described above and the predictand was the runoff at the Blue Nile runoff station Khartoum. Hence, the first step was to identify potential predictors for drought in the Limpopo basin. Second, best predictors were chosen. Third, the models were set up with these predictors and drought forecasting performance was compared.

(c) Results

The preliminary analysis assessed the complexity of spatial drought variability. The application of principal component analysis aimed at understanding spatial variability. Spatial precipitation anomaly fields were dissembled to dominating patterns. The dominating spatial patterns in rainfall anomalies can be reduced to five patterns which accounted for 74 % of the total variation (Figure 3-32). They were analysed in an attempt to relate them with atmospheric anomalies and sea surface temperature (SST) anomalies. The correlations with climate anomaly indeces - even El-Nino – were low and rarely exceeded 0.3. Hence, no specific pattern could be related to El-Nino. Is more likely that the global anomalies the greater region of southern Africa on the whole. The spatial pattern then depend on other factors and every drought event very likely is a unique combination of many factors of influence that affect the drought genesis.

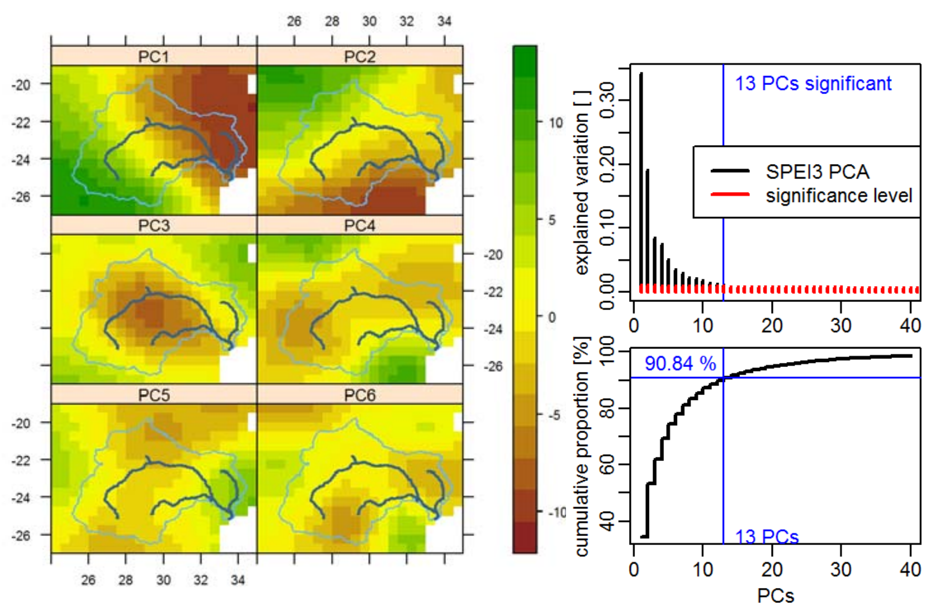


Figure 3-32: Decomposition of spatial rainfall variability into dominant patterns.

In the search for other ocean regions that influence drought patterns, the correlation with global sea surface temperatures was performed. Correlations were low as well with values rarely exceeding 0.3. Several region could be identified though, which were included in the list of potential predictors. Teleconnected ocean regions were identified by composites analysis. The composites of seas surface temperatures preceding drought in the Limpopo basin early in the rainy season are presented in Figure 3-33. Positive anomalies in the Indian Ocean and negative anomalies were observed in the Atlantic. In combination with further composite analyses a list of Ocean regions were compiled (see Figure 3-34 and Figure 3-35).

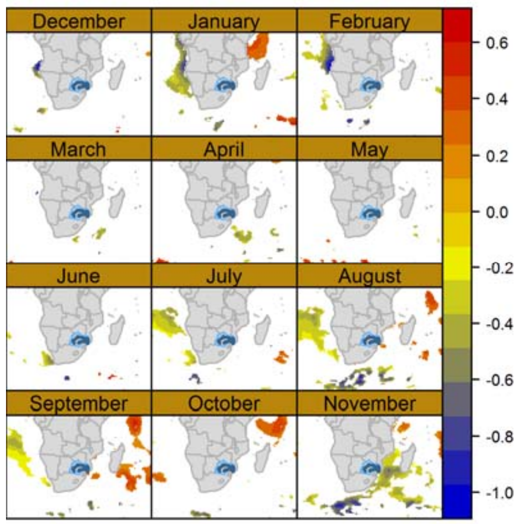


Figure 3-33: Sea surface temperature anomalies during the 12 months preceding a drought early in the rainy season (drought during October to December).

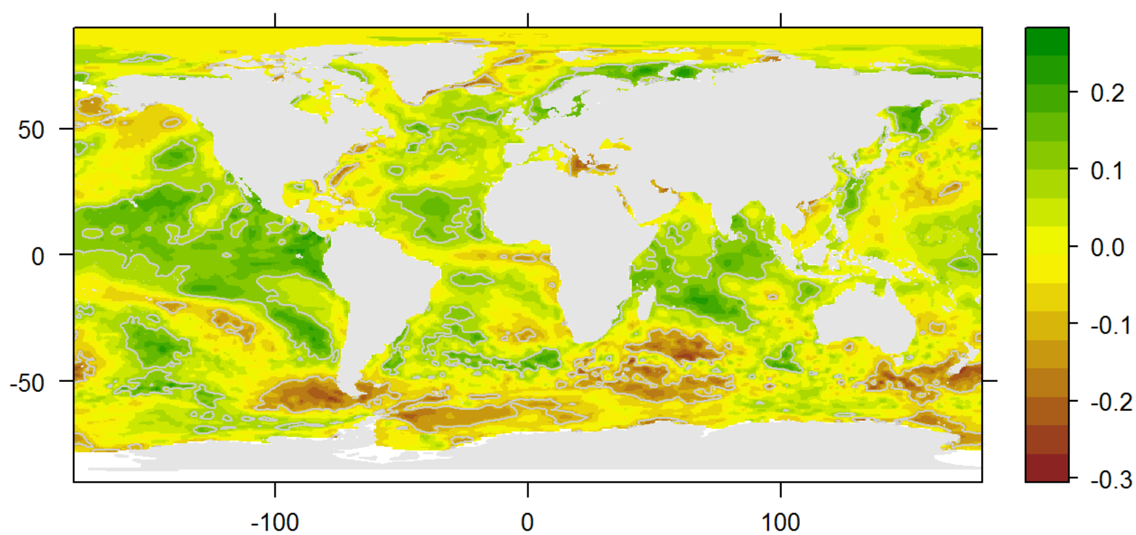


Figure 3-34: ERA-Interim SST anomaly correlation with PC1 loadings of SPEI in 3 month aggregation (Limpopo basin). Grey contours denote 0.95 level of correlation significance.

From that extensive list of teleconnected ocean regions, skillfull predictors were selected for multiple linear models with a suitable automated routine. Linear models and artificial neural networks were calibrated using the selected predictor set. For station Combomume the most important predictors included El-Niño indexes but also a region in the southern Indian Ocean and regions in the Atlantic. The linear models were outperformed by artificial neural networks when it comes to fitting the calibration data set. This showed, that the fit to the observations was better, when non-linearity was employed for the simulation. The coefficients of determination show the quality of a model fit and it shows, that the linear model was able to explain 59 % of the total variation, whereas the artificial neural networks reached up to 91 % (
Table 3-2). The artificial network was particularly better at simulating the very extreme values Figure 3-356.

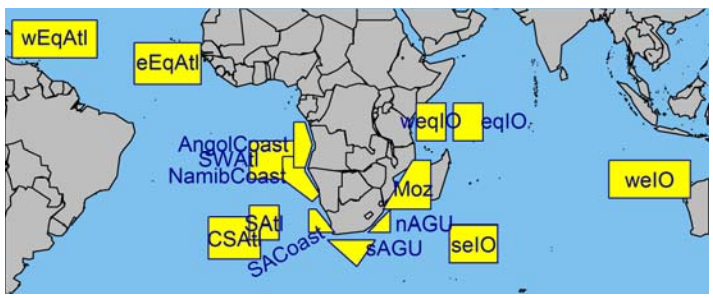


Figure 3-35: Teleconnected regions established by correlation and composites analysis.

Table 3-2: Station Combomume (Mozambique): Performance of statistical models for three month ahead forecast of rainy season runoff; coefficient of determination (R^2), root mean squared errors from calibration data (ALL) and from cross validation (CV).

Station	run	MLM	ANN-10	ANN-3
Combomume	R^2	0.59	0.91	0.82
	ALL	0.78	0.33	0.47
	CV	0.88	0.85	1.15

However, it was proven that the linear models provided more robust results in an early warning scheme, which was tested by cross validation. The artificial neural networks most probably suffered from overfitting for a small dataset as it was available for the analysed stations. The station “Combomume” was predictable to a degree which delivered a valuable early warning with three months lead time. The estimation of drought probabilities calculated from the linear model allowed the simulation of operational early warnings. Under the assumption that a drought would be triggered, a drought probability threshold of 0.4, the 80 % of the droughts would be warned ahead and only 20 % of the alarms would be false alarms. However, the results at other stations were less promising. There are many potential reasons for the weak performance. First, the predictability of rainfall variability in southern Africa is generally low due to non-linear processes (Mwale et al., 2007). Second, runoff measurements are sometimes unreliable and some stations' time series had extreme values that may be affected. Third, runoff is regulated and affected by management. The main properties of runoff time series are affected by much more than just the meteorological signal. Catchment properties, memory of the system and management strongly affect the runoff response. For example, a memory effect of past drought might introduced by dam operation. After an extreme drought, the dam storage have to be replenished so the runoff may be reduced and appear as a drought even when the meteorological conditions are normal. These long term effects of drought can have an influence on the runoff. All these factors are not taken into account by the statistical approach presented here.

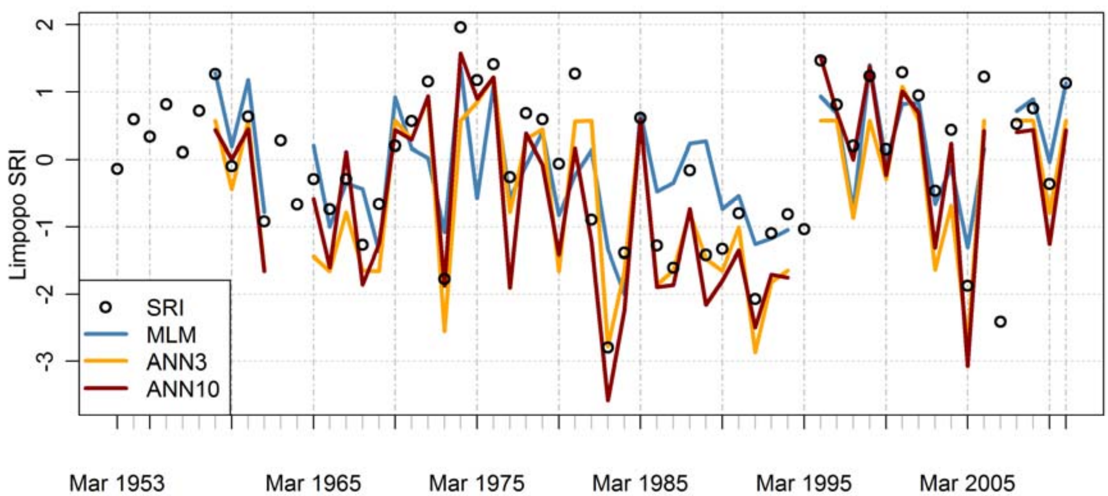


Figure 3-36:: Statistical seasonal models for streamflow at station Combomume (Mozambique): Fitted forecasts models of standardised rainy season runoff (SRIONDJFM) three month ahead in June by a multiple linear model (MLM) and artificial neural networks (ANN3 and ANN10).

(d) Conclusions

In conclusion of the work regarding statistical analysis and forecasting of drought we would like to stress two points:

- The spatial patterns of drought **within** the Limpopo basin show little to no relation to global scale climate anomalies. We would like to emphasize that there is no question that global scale anomalies have an impact on drought. However, our analysis showed that none of the dominant modes in spatial drought patterns could be linked to El-Nino or other kind of oceanic influence exclusively.

- At individual stations statistical seasonal forecasts can reach adequate skill for supplementing early warning systems. Suitable stations drain from larger catchments and have to present long and complete high quality observations. Consistent and qualitative monitoring on the ground in necessary to improve the available information and modelling techniques used.

3.2.3 Downscaled and tailor made hydrological models for the Limpopo Case Study basin (*__P Trambauer, A Maskey__ - IHE*)

This work is described in more detail in Deliverable 4.7 (DEWFORA, 2012).

(a) Objectives and study area

The main objective of this work was to model streamflow and hydrological drought indicators for selected river reaches in the Limpopo River basin, for the period 1979-2010 using a distributed physically based model.

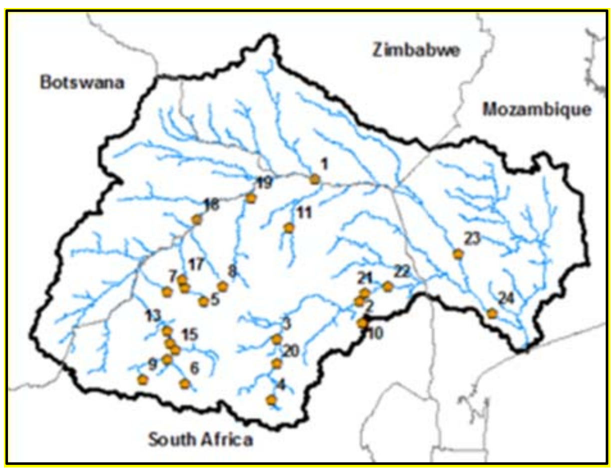


Figure 3-37: Study Area -Limpopo river basin- and hydrometric stations considered

(a) Stakeholders involved

This work was supported with data from CSIR and ARA SUL. Additional data was obtained from the DWA web page www.dwa.gov.za and from Water Research Commission in South Africa.

(b) Study methodology

The PCR-GLOBWB hydrological model was selected from 11 global hydrological models namely: (i) WaterGAP, (ii) PCR-GLOBWB (iii) Macro-scale-Probability-Distributed Moisture Model (Mac-PDM), (iv) Water Balance Model (WBM, (v) Lund-Postdam-Jena model (LPJ), (vi) Soil and Water Assessment tool (SWAT), (vii) SWIM, (viii) HBV (ix) Global Water Availability Assessment method (GWAVA) (x) WASMOD-M and (xi) LISFLOOD

PCR-GLOBWB, GWAVA, HTESSEL, LISFLOOD and SWAT show higher potential and suitability for hydrological drought forecasting in Africa. The selection criteria and results are described in Deliverable 4.5. PCR-GLOBWB is a grid-based model of global terrestrial hydrology. It is essentially a leaky bucket type of model applied on a cell-by-cell basis. The model calculates for each grid cell (0.5 x 0.5 degrees) for a daily time step. PCRGLOBWB was used to simulate the discharge with a GCM ensemble mean as forcing data. The resulting discharges were compared with the Global Runoff Data Center (GRDC) discharge data. The model was modified and applied at a finer resolution (0.05 x 0.05˚) for the Limpopo river basin. The simulation was carried out for the past 32 year-period (1979-2010) on a daily time step. All the meteorological forcing data used are based on ERA-Interim (ERAI) reanalysis dataset from ECMWF, and the precipitation data used was corrected with GPCP v2.1 (product of the Global Precipitation Climatology Project) to reduce the bias with measured products (Balsamo et al., 2010).

(c) Results

The following figures provide a comparison of the simulated discharge from the PCR-GLOBWB hydrological model with the measured runoff data for flow gauge station number 24 (see Figure 3-37). This station was selected because it has a very large drainage area.

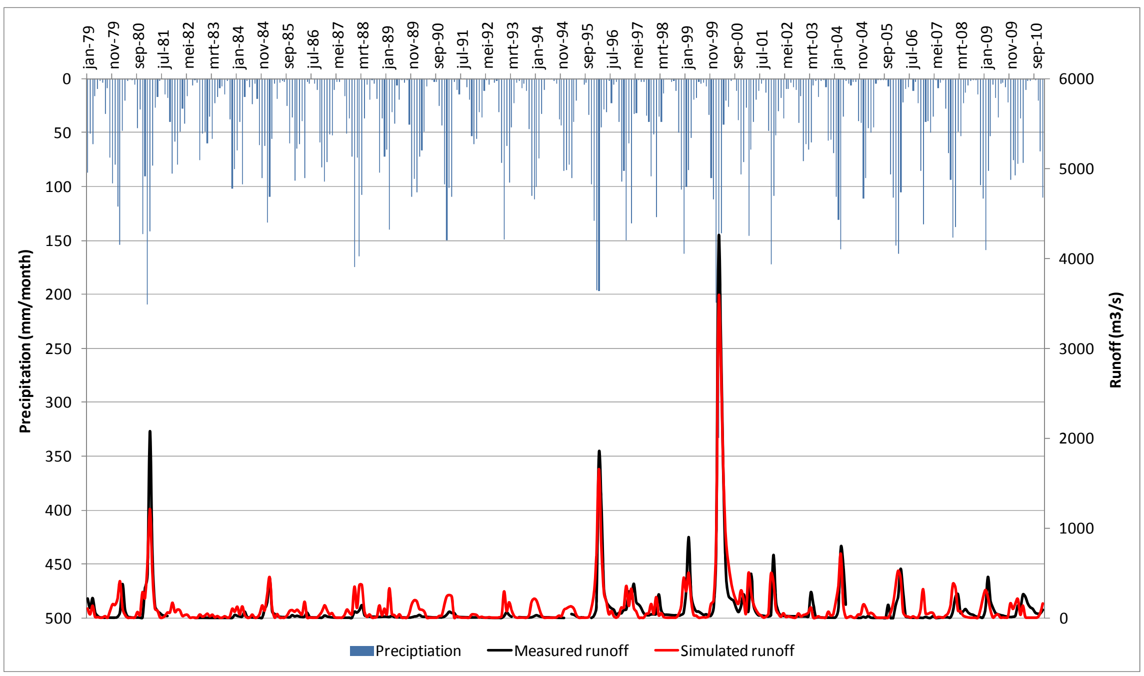


Figure 3-38: Runoff at gauge 24 (ARA- SUL: St No. E35)

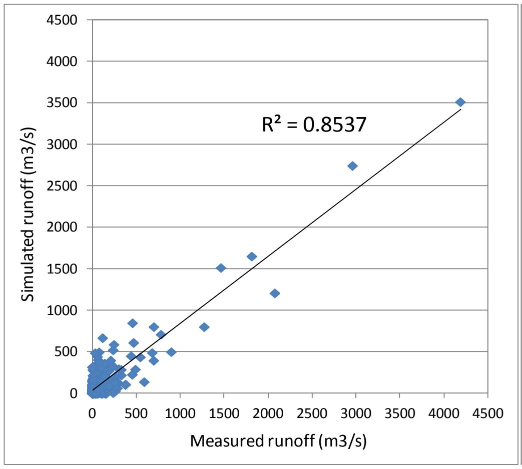


Figure 3-39: Fit between measured and simulated runoff at gauge 24 (ARA- SUL: St No. E35)

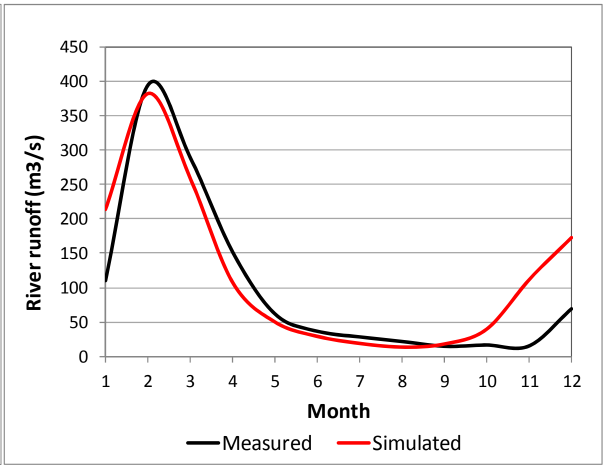
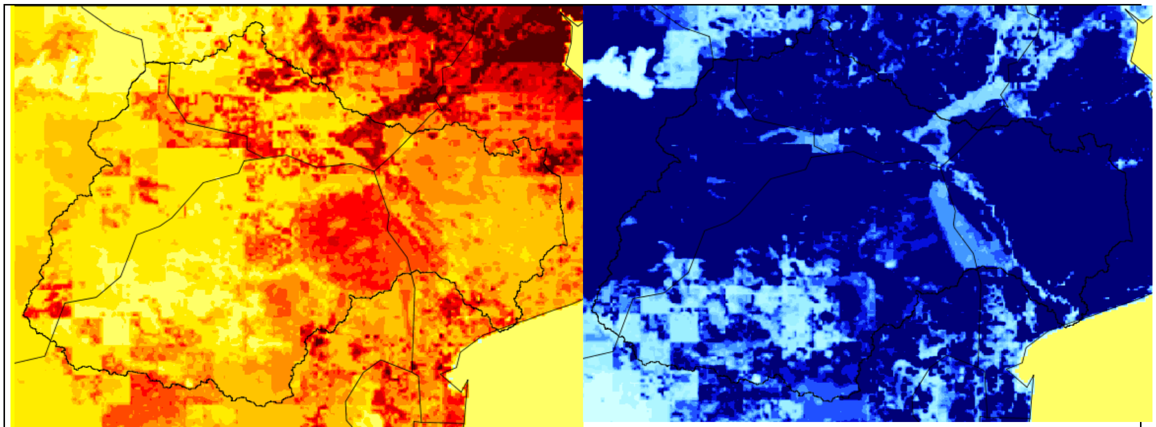


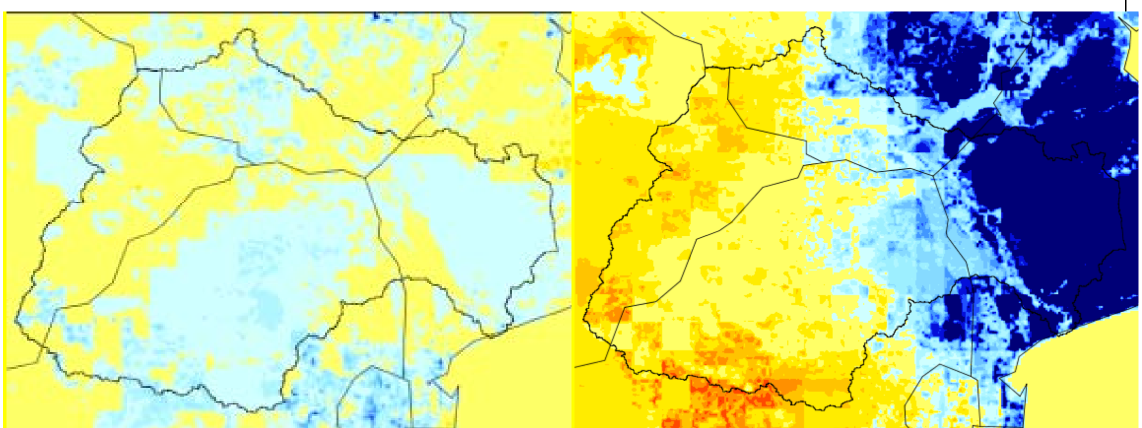
Figure 3-40: Mean annual runoff at gauge 24 (ARA- SUL: St No. E35)

The main purpose of this model is drought forecasting. One of the model outputs was the daily ‘root stress’, which is a spatial indicator of the available soil moisture in the root zone and the stress of the plants in the case of drought. This indicator ranges from 0 to 1, where 0 indicates that the soil water availability in the root zone is at field capacity, and 1 indicates that the soil water availability in the root zone is null and the plant is therefore under stress. The root stress indicator was computed as anomaly of its long term average at a monthly time step. Figure 3-41 presents the anomaly of root stress for four particular hydrological years in the Limpopo river basin. Root stress anomalies of 0.5 indicate that the root stress of that month is around 50% higher than the long term average of that month and root stress anomalies of -0.5 indicate that the root stress of that month is around 50% lower than the long term average of that month. High positive anomalies can be observed for the drought of 1991-92 and high negative anomalies can be observed for the flood of 2000.



a) Month of the most severe drought in the recent history in the Limpopo basin (March 1992)

b) Month of a particular wet year in the Limpopo basin (April 2000)



c) Month of a "normal" year in the Limpopo basin (Nov 1997)

d)Spatial variability of Root stress anomaly in the basin

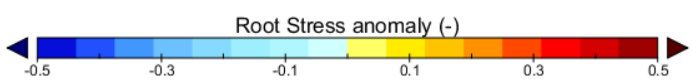


Figure 3-41: Root stress anomaly in particular months in the Limpopo river basin

Moreover, a commonly used indicator for hydrological droughts is the Standardized Runoff Index (SRI) varying between 2.0 (extremely wet) and -2.0 (extremely dry). As an example, Figure 3-42 shows the 6 months SRI results for the simulated flow of Station 24. The major droughts appear to be identified reasonably well (1982-83, 1991-92) with SRI values smaller than -1.5. Moreover, the extremely wet year of 2000 is very visible with SRI higher than 2.0.

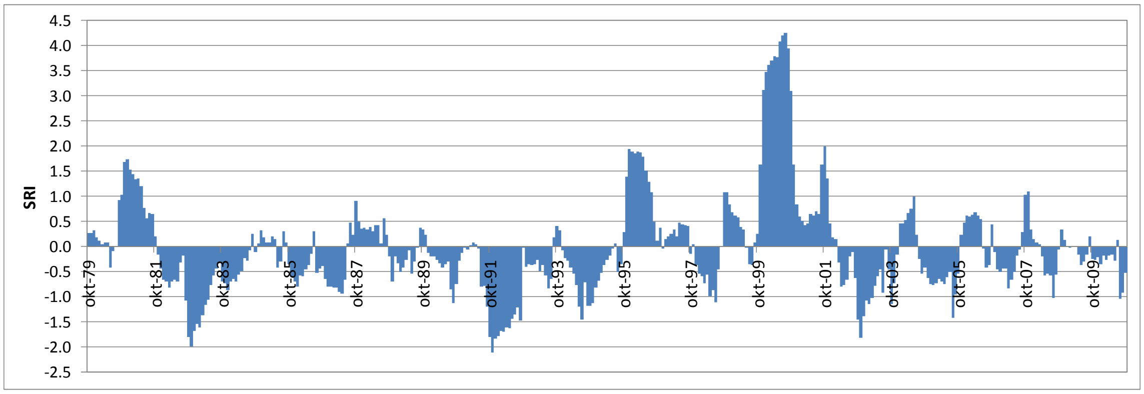


Figure 3-42: 6 months simulated SRI for station 24 (ARA- SUL: St No. E35)

For further details on the set up of the hydrological model and additional results refer to Deliverable D4.7 (DEWFORA, 2012).

3.2.4 Skill of regional hydrological models developed to forecast hydrological drought (*P Trambauer, A Maskey – IHE*)

This section summarizes briefly the results of the Deliverable D4.8 (DEWFORA, 2013) which explores the potential to improve and supplement hydrological drought early warning systems for the Limpopo case study. Two different approaches for hydrological drought forecasting are presented namely: a) a statistical seasonal forecast, and b) a dynamic multi ensemble seasonal forecast.

(a) Objectives and study area

The objective of this investigation was to provide the necessary information for decision makers regarding seasonal hydrological forecast for the Limpopo river basin.

(b) Stakeholders involved

Water Managers in the Limpopo river basin and farmers were involved in the study.

(c) Study methodology

The PCR-GLOBWB hydrological model for the Limpopo river basin (see section 3.2.3) was coupled with the output of the global atmospheric model ECMWF-System 4. The system is tested in a hindcast mode for the period 1981 to 2010 to allow for testing prior to its use in pre-operational real-time forecasts. This system seeks to provide operational guidance to farmers and water mangers within the basin at the seasonal time scale by predicting the availability of water for irrigation and water supply, which are the most important water uses in the basin.

The approach followed in this forecasting system is summarized in Figure 3-43. It starts obtaining the meteorological seasonal forecast from ECMWF together with some necessary "pre-processing" of the data. The hydrological model (embedded in the Delft-FEWS forecasting shell (Werner et al., 2013)) simulates the forecasted seasonal hydrology obtaining predicted streamflows and other hydrological variables.

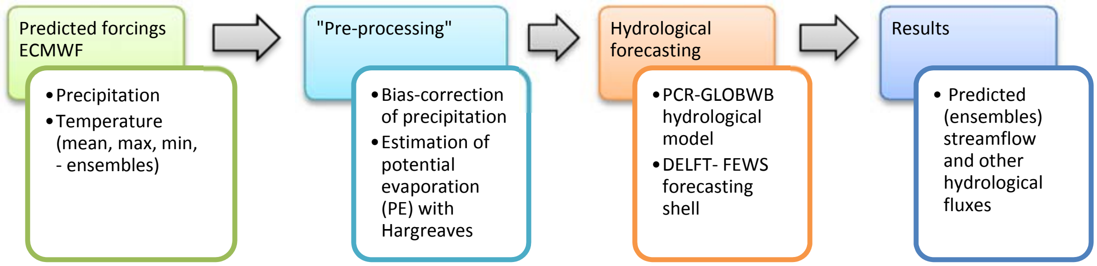
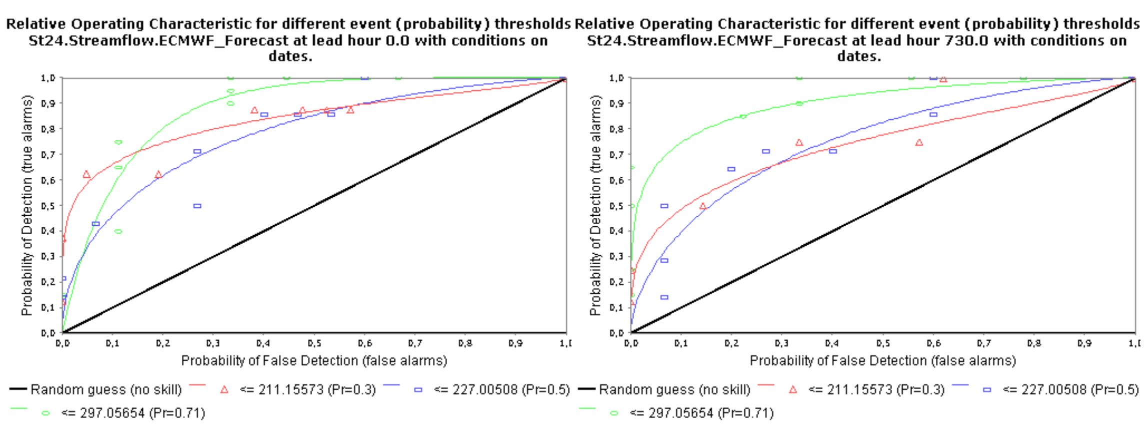


Figure 3-43: Approach followed in this forecasting system for the Limpopo river basin

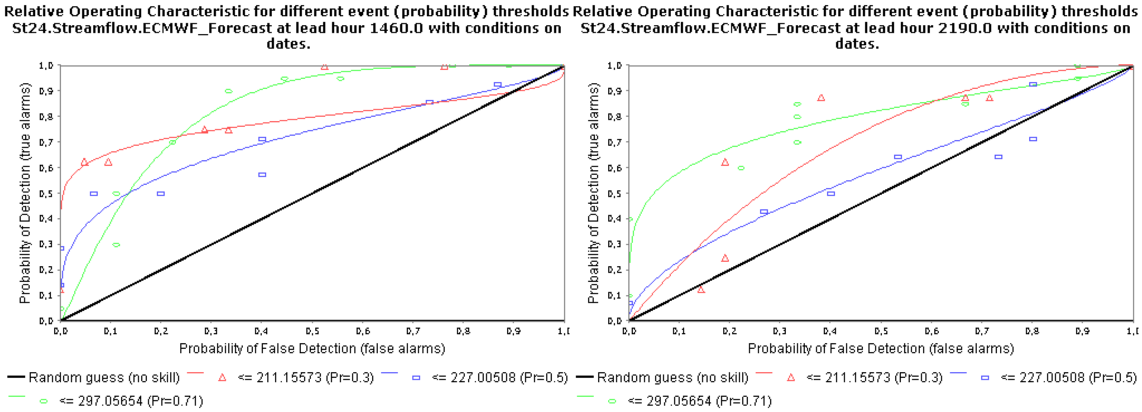
General verification skill scores are selected to measure the skill or quality of the different forecast ensembles to predict drought indices and streamflow (as simulated by the hydrological model). The verification was performed against the simulations and the resulting skills were relative to sample climatology. A preliminary assessment of the forecasted Water Level Anomalies in the reservoirs (as an indicator that is potentially meaningful to the local end users in the basin) was undertaken in this study by testing the forecast for two particular years. Finally, the improvement of the ECMWF seasonal forecast S4 compared to the Ensemble Streamflow Prediction ESP forecast (Day, 1985) for selected seasons was measured.

(d) Results

The ROC diagram, which plots the hit rate or Probability of detection (POD) versus the false alarm rate or probability of false detection (POFD), was used here as a tool for drought detection and determination of the skill of categorical forecasts. The skill of the streamflow seasonal forecast was analyzed for different verification periods and lead times. Figure 3-44, for example, shows the ROC curves for streamflow forecasts (station 24, see Figure 3-45) issued for the same 3-montly period Dec-Feb, with forecasts issued from September to December respectively (four different lead times, from zero to three months). The figure shows that in general the score tends to decrease with lead time.



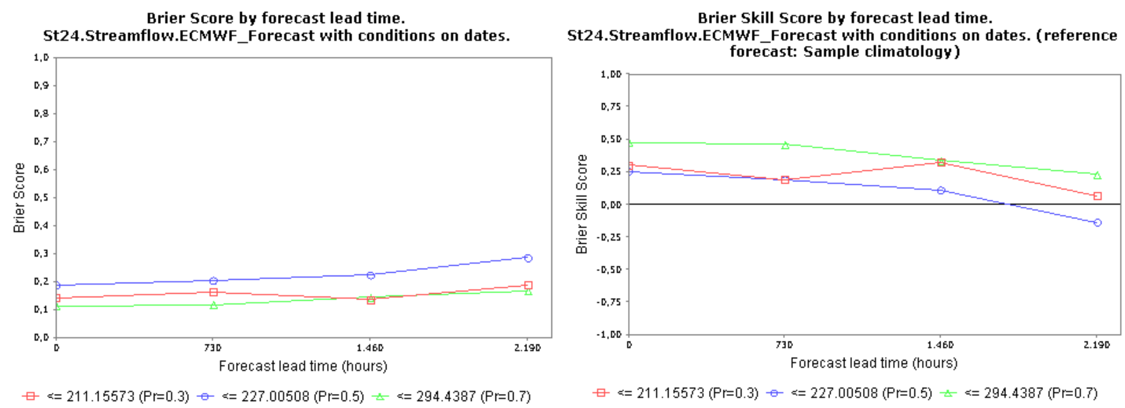
a) Forecast issued in December b) Forecast issued in November



c) Forecast issued in October d) Forecast issued in September

Figure 3-44: ROC diagrams for the average 3-months runoff (Dec- Feb) in station 24 for a lead time of: a) zero months, b) 1 month, c) 2 months, and d) 3 months

Figure 3-45 presents other verification metrics, the Brier Score (BS [0-1]) and the Brier Skill Score (BSS [-∞ to 1]) for the average 3-months runoff (Dec- Feb) in station 24 for different thresholds and lead times. The figure shows higher skill in the forecast of droughts (Pr=0.3) and the 70 percentile flows than the mean streamflow conditions (Pr=0.5). For the case of droughts (Pr=0.3), lead times up to two months present some skill, while a lead time of three months present almost no skill. The predictive skills of these forecasts, which worsen with lead time, are higher than using the climatology.



a) b)

Figure 3-45: a) Brier Score and b) Brier Skill score for the average 3-months runoff (Dec- Feb) in station 24 for different thresholds and lead times

A preliminary assessment of the forecasted anomaly of the water level (WLA) in a reservoir for a particularly dry and a particularly wet year suggests that the forecasted water level anomaly in the reservoirs could be a potential indicator with significant value for the decision makers in the Limpopo river basin concerning available water for irrigation during the season.

The evaluation of the forecasts for some selected seasons when a drought or flood actually occurs suggests that using ECMWF S4 seasonal meteorological forecast improves the hydrological forecasts and offers a clearer signal compared to the use of the ensemble streamflow prediction (ESP). These selected seasons suggest that seasonal forecasts based on numerical weather prediction models can offer better seasonal hydrological forecasts than ESP.

3.2.5 Local scale agricultural models for Limpopo river basin (*E Archer van Garderen, W. Landman – CSIR)*

(a) Objectives and study area

The intention of developing local scale agricultural models for the Limpopo basin was to use existing climate information products developed as part of DEWFORA as a basis for development of impacts and applications modeling for the agricultural sector. Agriculture is a critical contributor to both the formal and informal economy in the Limpopo Basin (see 2001 Inception Report); and as a result, tailored modeling and forecasting in this area has significant potential utility.

As mentioned earlier, the Limpopo comprises a multi-country basin, with highly committed water resources, and an active agricultural sector. The agricultural sector here ranges from large-scale commercial farming (e.g. citrus farming in the South African Lowveld) through to small-scale, or emerging agriculture (e.g. subsistence livestock and cropping in the Save River catchment in Zimbabwe). It is also the site of past work on tailored forecasting and applications modeling for the agricultural sector. The work undertaken here forms part of this body, available for operational use.

(b) Stakeholders involved

Work here was undertaken by the CSIR, in partnership with ECMWF, South Africa's Agricultural Research Council (ARC), and the Limpopo Provincial Department of Agriculture, who also helped host the DEWFORA field trip to Limpopo in February 2013 (where visits included small-scale co-operative dairy farming; and maize trials in collaboration with small-holder maize producers). Further livestock modelling (co-funded through other initiatives) is also underway in partnership with the ARC, Indigo Development and Change, the Heiveld Co-operative Livestock Working Group and the University of the Witwatersrand.

(c) Study methodology

In the case of crop modeling, statistical methods are applied in Deliverable 4.10 (DEWFORA, 2012) in order to develop prediction models for crop (yellow and white maize) yields of the

Limpopo Basin. In the case of livestock modeling, heat stress thresholds for cattle are currently being used, and are being derived empirically for small-stock (using data loggers; co-funded through START). In the case of forage modeling for livestock, dry matter productivity time series have been derived for the SADC region, and best predictors are currently being isolated (co-funded through the NRF). Crop results are available (see below); while livestock results are in progress.

(d) Results

The cross-validated downscaled yields over the Limpopo basin are shown in Figure 3-46 below. Five lead-times, with one month in between consecutive lead-times, are considered: L0 is for forecasts initialised in December in order to produce DJF 850 hPa geopotential height fields, and L4 for forecasts initialised in August. The figure shows that significant forecast skill is mainly restricted to the Rustenburg agricultural district. Further details may be found in Deliverable 4.10 (DEWFORA, 2012) report 'Local scale agricultural models for Limpopo and Oum er-Rbia river basins', dated February 2013.

Initial work in the area of heat stress modelling for livestock indicates that heat stress begins in most breeds above a threshold of 78 THI, while high producing dairy cows have a comfort threshold at 72 THI (Archer van Garderen 2011); thus provided thresholds for tailored forecasting for the cattle sector in Limpopo (Winsemius *et al* in progress). Tailored forecasting for small-stock is still in development, using empirical testing as part of a sister project.

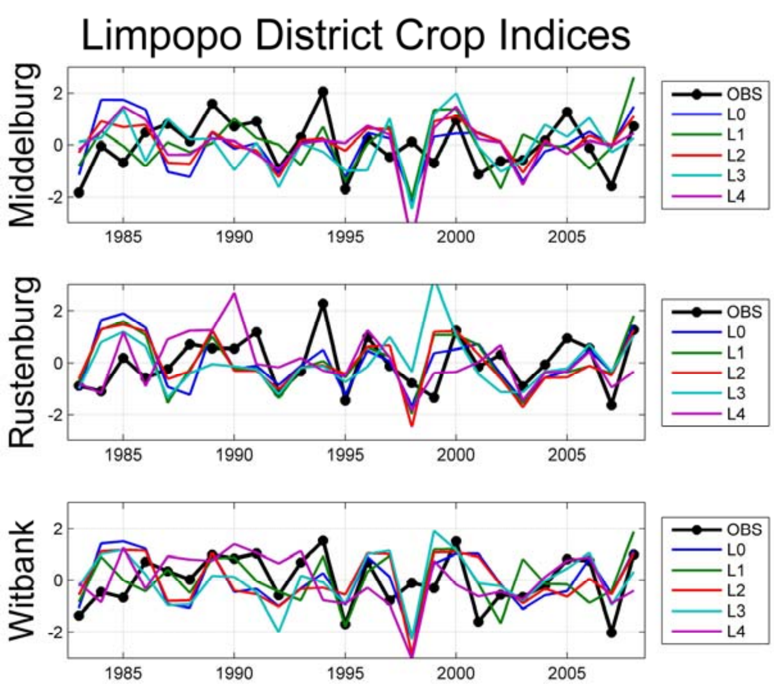


Figure 3-46: Agricultural district yield indices (normalised values) over the Limpopo basin vs. cross-validated (5-year-out) downscaled hindcasts for all lead times. The harvest years are shown along the x-axes.

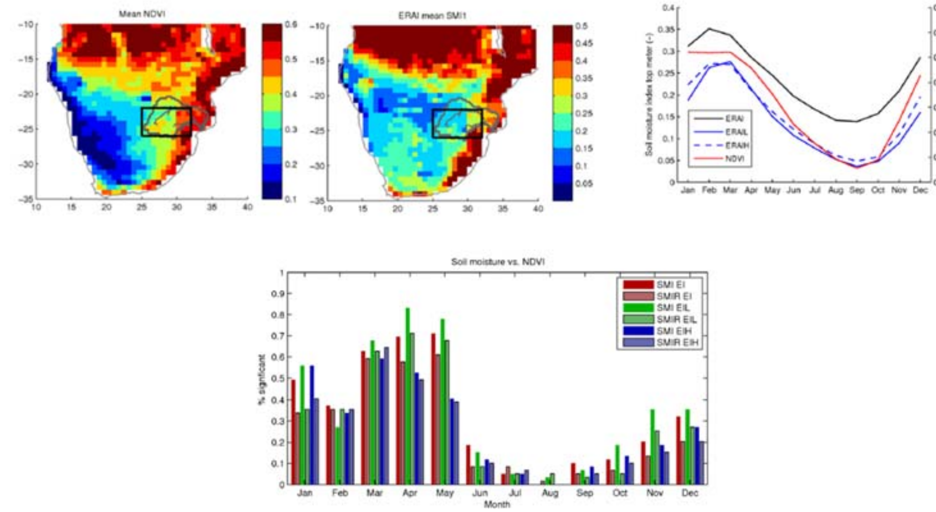


Figure 3-47: Soil Moisture vs NDVI

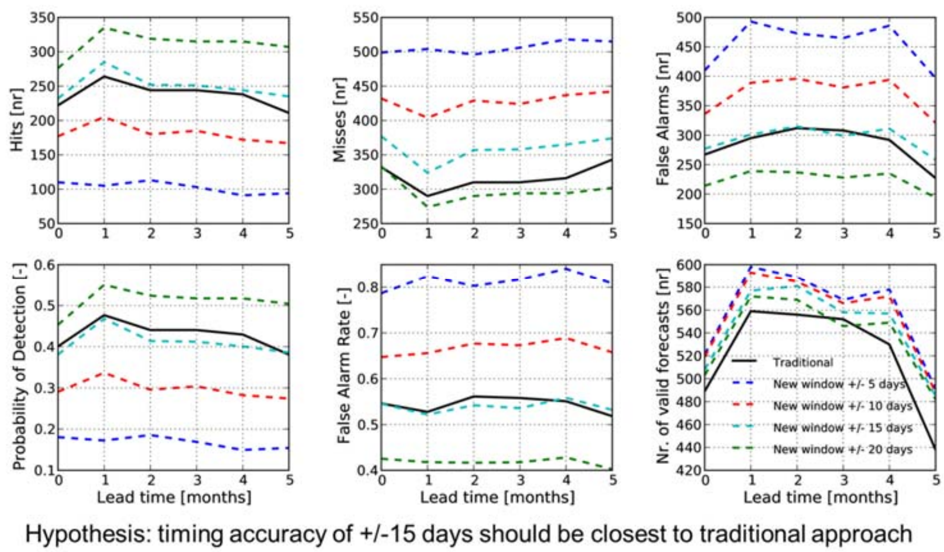


Figure 3-48: Synthetic experiment – prediction > 10-day dry spells

The results of the synthetic experiment (Figure 3-48) show no significant increase/decrease in skill in time. This is because we use synthetic forecasts that should not have any increase/decrease in skill over lead time. Initial conditions do not contain significant information. The forecasts are more valid forecasts because within one month, several observation-forecast pairs may be formed. In the traditional method, a month is either an event or not. This amount increases with decreasing window of opportunity, clearly shown in graph.

3.3 IMPROVING FLOW OF INFORMATION ON DROUGHT EARLY WARNING IN THE LIMPOPO RIVER BASIN – LINKED TO WORK PACKAGE 6

Refer to Addendum A for investigations conducted on improving information flow from regional to national and local scales in the Limpopo River Basin. Addendum A considers monitoring (drought characterization) and forecasting science identified/developed on the DEWFORA study and its suitability for application in the Limpopo River basin. In trying to answer the question how can society in the Limpopo River Basin benefit from forecasts, it assesses the improvements in institutional frameworks, institutional responsibilities, and communication lines for drought responses.

4. IMPROVING PERFORMANCE OF DROUGHT FORECASTING AND EARLY WARNING IN THE LIMPOPO RIVER BASIN

4.1 LINKING INDIGENOUS KNOWLEDGE SYSTEMS TO FORMAL FORECASTING METHODOLOGIES (*B Chisadza/M Tumbare/W Nyabeze- WRNA*)

(a) Objectives

The main objective of this investigation was to develop a GIS based drought early warning and forecasting system taking into account indigenous knowledge in Limpopo Basin area in Zimbabwe and the specific objectives were as follows:

- To identify traditional drought indicators in the Mzingwane catchment.
- To validate and assess the performance of the traditional drought indicators using 2012/13 season.
- To compare selected traditional drought indicators parameters and specific meteorological parameters.
- To identify and analyse possible linkages between traditional drought forecasting and scientific forecasting.

(b) Methodology

In this section rainfall, wind, temperature and vegetation (NDVI) data over the past 30 years was reviewed. This data was analyzed to establish trends related to past drought events and threshold levels to indicate drought. The Meteorological Services Department (MSD), Agritex and ZINWA were the primary data sources. Records were reviewed to assess the effectiveness of the previous drought early warnings and forecasts for selected past drought events

A total of 101 structured questionnaires, were administered to different households in 8 wards in four districts in the catchment. Eight focus groups (FDGs) were conducted in different villages of the district. Interviews with key informants such as the elderly (greater than 45 years) and Chiefs were used to collect additional data as it was evident in the FDGs that local traditional knowledge is not general knowledge, but to a larger extent related to the length of time a person has been living in an area, direct experience and socio cultural understanding of the persons. These data collection methods were employed for triangulation purposes. Triangulation served as a tool for cross checking the authenticity and validity of the various data sets generated through a focus group discussions, key informant interviews; structured questionnaires and field observations. Data was analysed using Ms Excel and the Statistical Package for Social Scientists (SPSS) to come up with descriptive statistics (frequencies and cross tabs) representing the four different smallholder districts. Cross tabulations were performed and associations between categorical variables assessed.

A validation exercise was carried out during the 2012/13 season to assess the accuracy and applicability of the traditional drought indicators identified during the 2011/12 season. A drought validation template and personal interview with selected farmers was used to collect information on forecast for the season. Figure 4-1 shows the validation timelines followed for the validation exercise. The template elicited on the following information:

- Observed changes on the traditional drought indicators and dates when the observations were made.
- Interpretation of the changes/Observations
- Combined forecast by all the indicators
- Observed estimated rainfall and intensity after the forecast
- Any decisions made by the farmer based on the observations

Figure 4-1: Traditional knowledge drought indicators

Both traditional drought forecasting data and scientific data for the 2011/12 and 2012/13 seasons were collected and analysed to test the possible trends and patterns as well as similarities in drought prediction mechanisms and the subsequent droughts forecasts. This analysis was done for the specific parameters in Table 4-1.

(c) Results

Table 4-1: Traditional indicators used in Mzingwane Catchment based on trees and plants

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

Table 4-2: Traditional indicators used in Mzingwane Catchment based on insects, birds and animals

Local name	*English name*	*Scientific name*	*Observation*	*Period when observed*	*Prediction*	*Comments*
1.Inkomo	Cattle		Breed less and abortion		Drought year	Long term
4.Macimbi	mopane moths/ worms	*Coimbrasia belina*	Less in numbers	April	Drought year	
5.umalulwani	bats	*Chiroptera*	Frequently flying	Rainy season	Imminent rains	Short term
6.inkanku	Jacobin Cuckoo	*Clamator jacobinus*	Sings a lot	Rainy season	Abundant rains imminent	Long term
7.amagen'a	Ants		Moving in a file and loading grass and food to their holes	Rainy season	Short term	Short term
8.isingizi	Ground hornbill	*Bucorvus leadbeateri*	Sings a lot	May to June	Normal rain imminent	Short term
9.intotoviyane	locust	*Caelifera*	Seen in large numbers	Aug to Oct	Normal to above rainfall season	Long term
10.ikonjani	Blue swallow	*Hirundo atrocaerulea*	Appearance	November to December	Imminent rains	Short term

Table 4-3: Traditional indicators used in Mzingwane Catchment based on sun, moon and wind

Local name	*English name*	*Scientific name*	*Observation*	*Period when observed*	*Prediction*	*Comments*
1.Isikhudumezi	heat	n/a	Too much heat	Aug-Oct	Imminent rainfall	Short term
2.Umoya	Southerly winds	n/a	blowing	Sept to October	Drought	seasonal
	West to east winds	n/a	blowing	July to Sept	Normal rains	Both short term and long term
3.inyanga	Moon	n/a	Big circle around the moon	Jul to Sept	Abundant rains	Seasonal
4.isavunguzane	Whirl wind	n/a	Blowing a lot, high frequency of occurrence	Aug to Sept	Abundant rains	Seasonal
5.ungqwaqwani	frost	n/a	If it doesn't appear	June to July	Drought	Seasonal
6.Amazolo	Morning dew	n/a	Appear in the morning	Nov to Dec	Imminent rains in a day to three days	Short term
N.B. For the signs that reflect good rains, if the signs do not show, then it becomes a sign of drought.						

About 66% of the respondents who used traditional drought forecasting methods in Mzingwane Catchment area said they could accurately predict weather conditions using LTK indicators. Multiple indicators were used at the same time for better drought prediction.

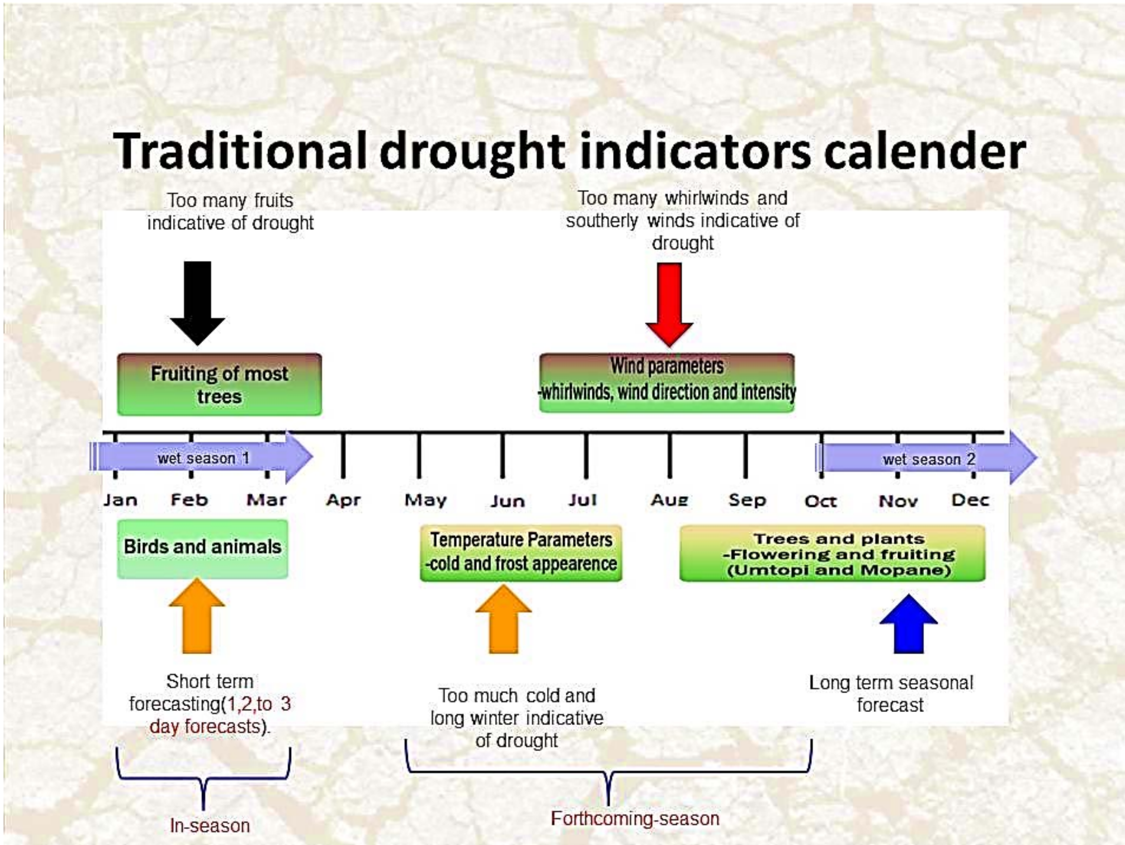


Figure 4-2: Traditional drought indicators calendar for Mzingwane catchment developed from Tables 4-1, 4-2, and 4-3

Figure 4-2 shows the traditional indicator calendar for the Mzingwane Catchment area. Periods when specific indicator signs can be noted and thus provide drought forecasts and early warning are shown on the calendar. For example, most fruiting and flowering of trees is noted between end of August and early January. Among the earliest indicators of the upcoming season are the starting date, intensity, and duration of the cold dry period

The validation of the results is presented in Table 4-4.

Table 4-4 Summary of Forecast for 2012/13 season

Period of Validation visit	Forecasted period	Traditional drought forecast	Scientific forecast/MSD	Actual	Comments
Before rainfall onset(October 2012)	October November December(OND)	Normal to above Normal rains	Normal rainfall with a slight tendency towards below normal.	Normal to above normal rains were observed in most parts of the province, with some parts experiencing flooding in December.	
Mid-season (Early March 2013)	January February March(JFM)	Normal rains to below normal rains	*normal to below normal rainfall*	Below normal rainfall , frequent dry spells	
End of Season/post season(May 2013)	March April May(MAM)	Normal to Below normal season	*normal to below normal season*	Normal to Below normal season	

Traditional drought forecasting indicators predicted more accurately the forecast for OND than the meteorological forecasts from Meteorological Services Department of Zimbabwe (MSD) as shown in table 4-4, and Figure 4-3 and Figure 4-4 for the Mzingwane catchment area. Overall forecast for JFM for the catchment was the same for both the scientific and traditional, though in the end the observed rains were below normal for the whole catchment. Both the traditional and meteorological forecast accurately predicted an overall normal to below normal season. The major difference with the both forecast was that traditional forecast could accurately predicted specific area forecasts, while meteorological forecast provided a blanket forecast for the region. For example, while there was a dry spell during the JFM, around mid-January to mid-February, forecast from traditional forecast for Mangwe (Shashe sub catchment) accurately predicted rains during this dry spell period.

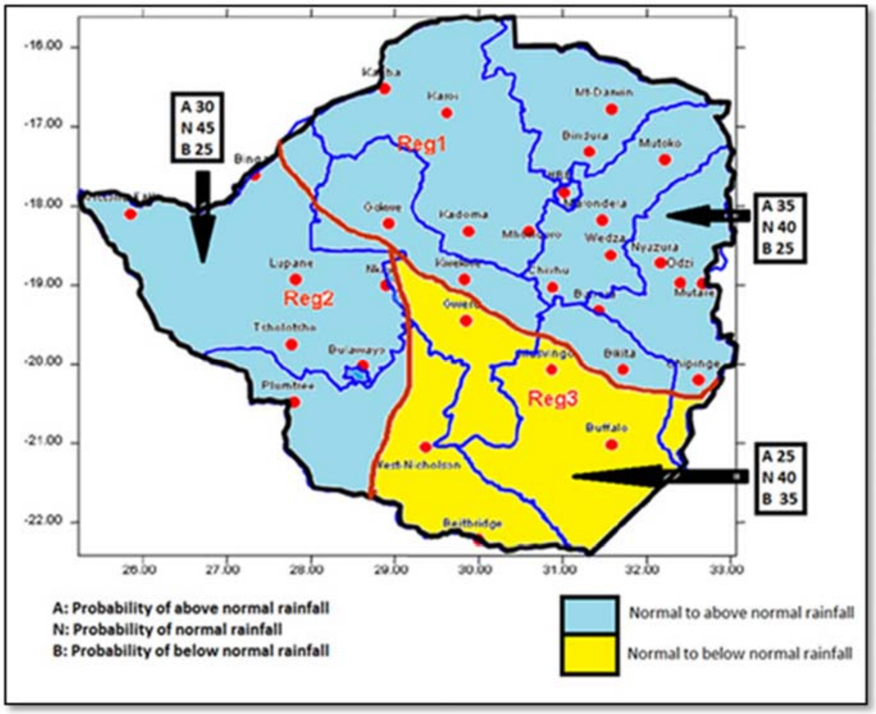


Figure 4-3: Rainfall Outlook for October to December 2012 showing generally normal to below normal rainfall over the southern parts of the country. Source :(MSD, 2012)

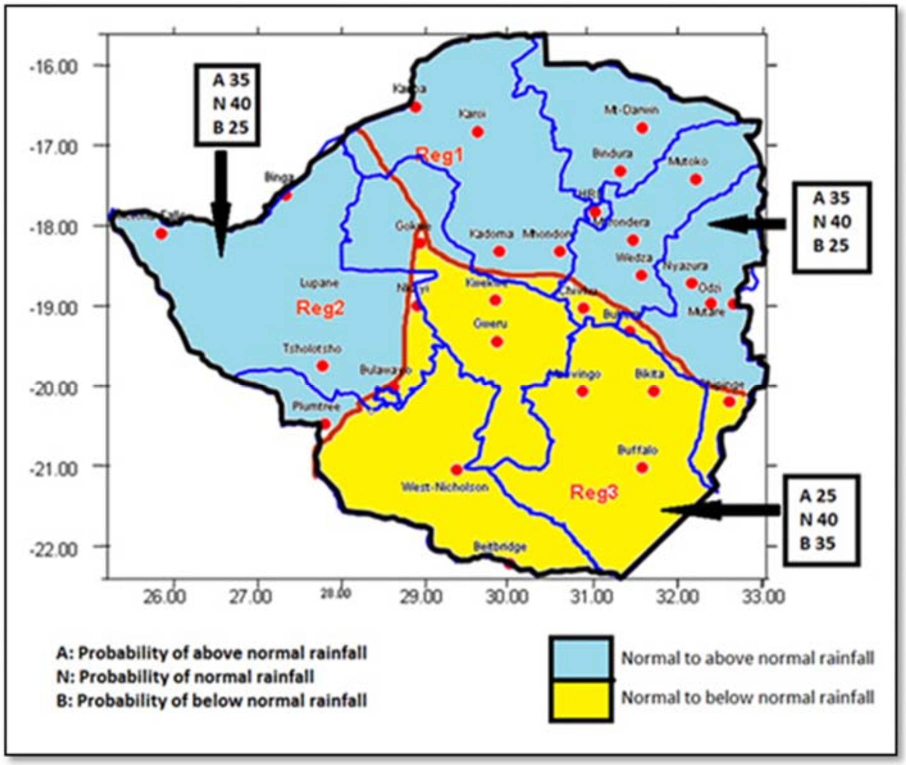


Figure 4-4: Rainfall Outlook for January to March 2013 showing generally normal to below normal rainfall over the southern parts of the country. Source:(MSD, 2012)

Table 4-5 shows the corresponding parameters used in making comparison of scientific and traditional drought forecasting parameters. Seasonal rainfall prediction using Umtopi and Mopane trees was compared with seasonal rainfall prediction using meteorological forecast. Traditional data was classified into three groups for each parameter, i.e. above normal, normal and below normal. This was derived from the level of observed data, for example tree fruiting was classified as above normal fruiting, normal fruiting and below normal fruiting. From the analysis, it was shown that there was a correlation between various levels of observed fruiting data and the corresponding forecasts to that of meteorological forecast. The analyses carried out also showed strong correlation between traditional plant and tree indicators with resulting conditions captured by NDVI and indices based on wind and temperature.

Table 4-5 Parameters Used in comparison between scientific and traditional forecasts

Scientific Parameters	**Local traditional knowledge Parameters**
Seasonal rainfall	Plants and trees (Umtopi and Mopane)
Wind direction and intensity	Wind
NDVI images	Plants and trees (Umtopi nad mopane)

The investigation conducted on this study is also captured in three research papers as follows:

i) Opportunities and challenges in drought monitoring, early waning and forecasting in the Mzingwane catchment area.

This paper presents an assessment of opportunities and challenges in drought monitoring and forecasting in Mzingwane catchment area. It also gives an outline of the existing methods and knowledge of communities and institutions in monitoring and forecasting droughts in the Mzingwane catchment area. Internet research, key informant interviews, and focus group discussions were used in data collection. Data from results from semi structured interviews with 101 respondents in the Mzingwane catchment was used. Perceptions of local communities (respondents) on both scientific and traditional forecasting methods were also assessed. This paper also describes the institutional frameworks in drought monitoring, early warning and forecasting in the catchment, and drought history.

ii) Useful traditional knowledge indicators for drought forecasting in the Mzingwane catchment area of Zimbabwe

This article identifies documents and analyses local traditional knowledge (LTK) indicators used in drought forecasting in the Mzingwane Catchment in Zimbabwe, and assesses the possibility of integrating traditional drought forecasting, with the scientific forecasting to improve applicability of meteorological drought forecasts at local level. Communities in the Mzingwane Catchment regard local traditional knowledge forecasting as their primary source of seasonal climate forecast and a large number of people (62%) use LTK indicators in combination with meteorological forecasts to make farming decisions. It was found that plant phenology is widely used as an indicator by the local communities in the four districts for drought forecasting. Early and significant flowering of Mopane trees (Colophospermum mopane) from September to December has been identified to be one of the signals of poor rainfall season in respect to quantity and distribution and subsequent drought. Late and less significant flowering of Umtopi trees (Boscia albitrunca) from September to December also signals a poor rainfall season. Formal meteorological forecasters do not rely in LTK indicators in their forecasts products. These formal forecasts have a coarse spatial resolution which limits their application by communities'. It is therefore recommended that combinations of some of the traditional methods and timely, easily understood meteorology-based forecasts would enable better accuracy of predictions. This will in turn allow communities in Mzingwane Catchment to buffer their livelihoods against the adverse effects of climate variability and ensure sustainable rural development.

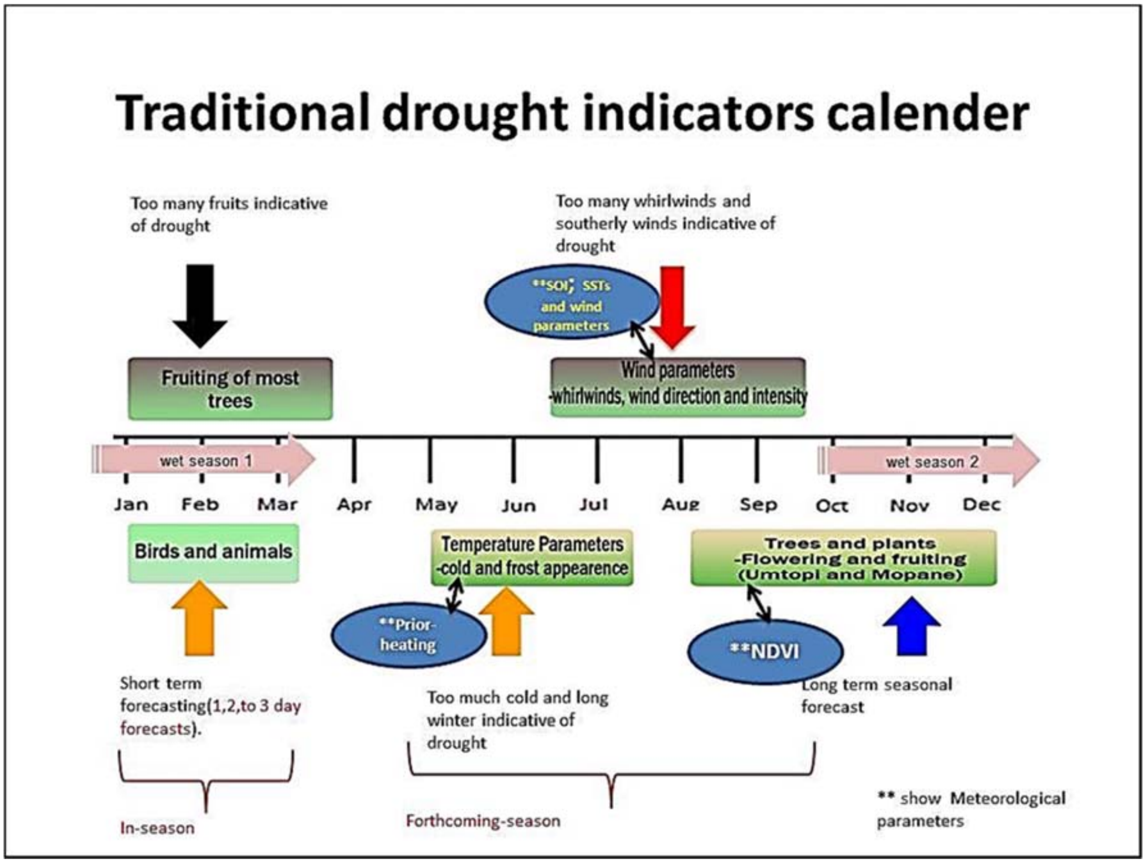


Figure 4-5: Traditional drought calendar for drought indicators

Figure 4-5 shows the traditional indicator calendar for the Mzingwane Catchment area. Periods when specific indicator signs can be noted and thus provide drought forecasts and warning are shown on the calendar. For example, most fruiting and flowering of trees is noted between end of August and early January. The calendar also shows potential areas of linkage with meteorological forecasts.

iii) Assessing performance of local knowledge drought forecasting systems in the Limpopo river basin in Southern Africa

This paper examines how local people in the Mzingwane Catchment, a part of the Limpopo River Basin located in Zimbabwe, forecast droughts using observations and interpretation of the local environment and how these forecasts relate to those produced by ”scientific” drought forecasting (SDF) methods. SDF methods apply Global Circulation Models (GCMs) but downscaling to local level has proved to be a huge challenge mainly because of inadequate calibration data, failure to accommodate local climate circulation systems and variations in geophysical conditions. Local knowledge drought forecasting (LKDF) systems accommodate these aspects but they are poorly documented, lack scientific validation and their applicability over large areas has not been tested. It is therefore important to document LKDF systems and try to validate them by comparing them with GCM based forecasting systems in order to improve acceptance levels and confidence to scientists and users of drought forecasts. Data was collected through observations and interviews with local people to identify the indicators based on the following local environment indicators: plants, wind, birds and domestic animals and temperature. The relationship between the present value of an indicator and the forecast future drought condition was documented. Two sets of comparisons were conducted namely the hind-cast comparison where the LKDF system results were evaluated against what the season turned out to be and forecast comparison where local LKDF system results were compared with downscaled GCM forecasts. The hind-cast comparison applied seasonal rainfall, wind, NDVI and temperature data collected from the Meteorological Services Department. The data collected was for 2011/12 and 2012/13, the period of this study mainly because lack of historical data for LKDF systems. The forecast comparison evaluated the LKDF system results with the seasonal and monthly outlook forecasts provided by SARCOF, the SADC Climate Services Department and the Zimbabwe Meteorological Services Department. The main objectives of this study were (i) to document LKDF system drought indicators (ii) to compare LKDF system drought indicators with selected drought indicators (a hind cast comparison) and (ii) to compare the LKDF system results with downscaled GCM forecasts.

Results shows strong correlation between traditional plant and tree indicators with resulting conditions captured as NDVI and indices based on observed rainfall, wind and temperature. Traditional forecasts performed better than downscaled GCM forecasts at local level for the 2012/13 season. The challenge on the LKDF systems however, was to isolate, enumerate and then verify the parameters which were mainly based on personal opinions of the forecasters. This concurs with Chang'a et al., (2010) who pointed out that LTK is mainly based on relative and local experience, lack of benchmarking makes it difficult to be harmonized and integrated into a conventional forecasting system These challenges can be resolved by affording LKDF more attention and support through their adoption by drought forecasting agencies.

(d) Conclusion

Local traditional knowledge drought indicators that are used by some local communities in forecasting droughts in the Mzingwane Catchment have been identified and documented. A calendar was developed to provide a framework to implement, monitor and review LTK indicators. Traditional drought indicators accurately predicted the 2012/13 season. There are linkages between specific LTK indicator parameters and scientific parameters. The study showed that there is a potential to use this framework to integrate traditional knowledge indicators with meteorological parameters such as wind and plants and trees. It was also noted that increased climate variability reduced the accuracy and the reliability of traditional drought forecasting.

The actual framework for calamities mitigation in Mozambique (see Figure 1) involves the Ministries Council, the Minister of Foreign Affairs and Cooperation (MINEC), the Coordinator Council for Calamities Management (CCGC), the National Institute for Calamities Management (INGC), the Technical Council for Calamities Management (CTGC), the Ministry of Agriculture, the Ministry for Coordination for Ambiental Action (MICOA) and Ministry of health. The inter-sectorial activities are coordinated by the CTGC which is represented by the ministries, ONG's and the United Nations and gives support to INGC.

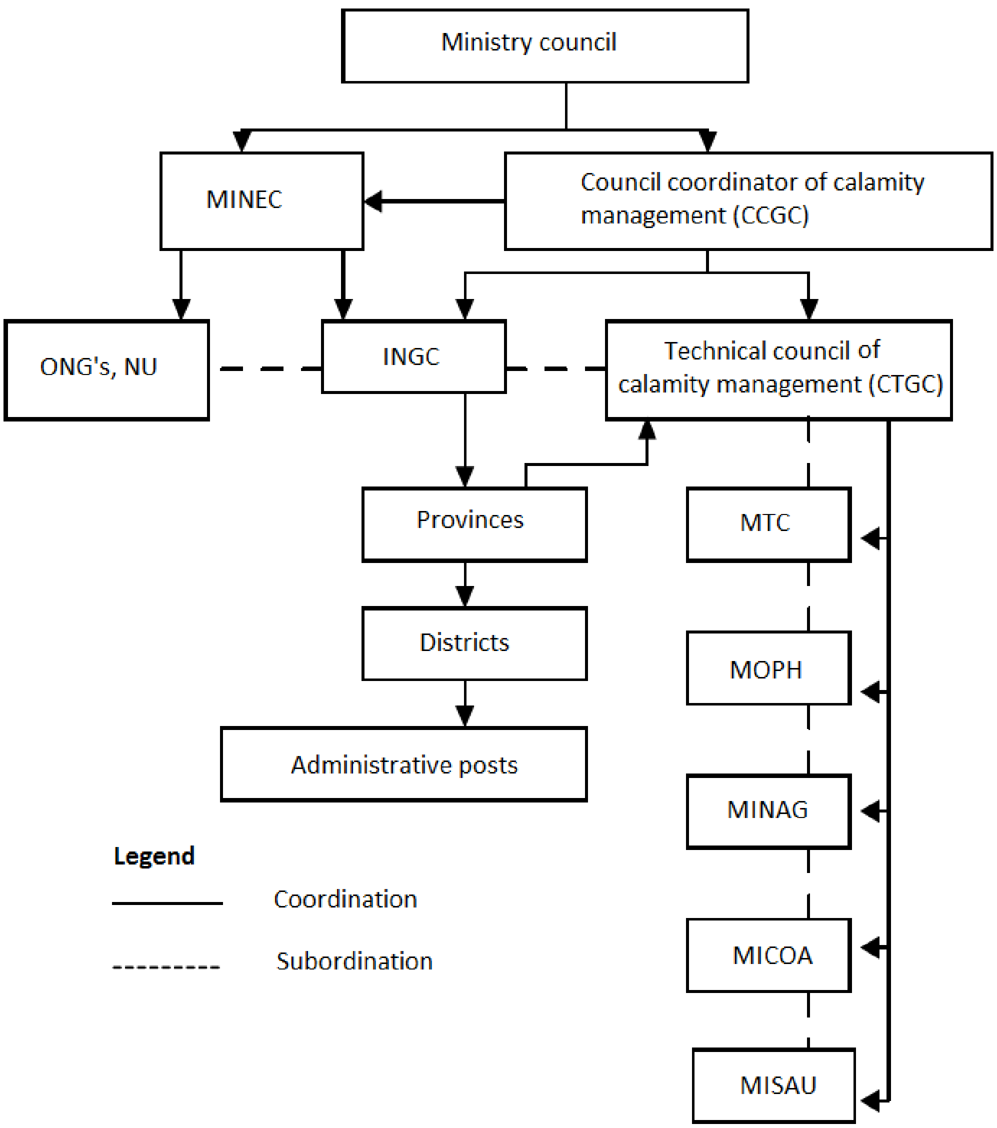


Figure 4-6 - Framework for calamities mitigation

The CCGC in coordinated by the prime minister. In each province of the country there is a provincial committee for disasters management (CPGD) responsible for the coordination at a provincial level.

MICOA (Ministry for Coordination of the Ambiental Action) is responsible for the development of strategic plans for protection of the environment, rational use of the natural resources and well-being of the society. It is also responsible for the climatic change effects in Mozambique, in particular for the plan of action of droughts and desertification.

INGC (National Institute for Calamities Management) is coordinated by the CCGC and it is responsible for the politics and strategies to prevent and mitigate calamities, for example to propose to the ministry council the creation of emergency funds, it is also responsible for the approval of the programs to provide humanitarian assistance for the victims and the divulgation of the information in case of droughts prediction.

INAM (National Institute of Meteorology) is responsible for the exploration of the climatic resources. It is in charge of the planning, installation and maintenance of the meteorological stations; registering and publication the observation results.

ONG's

SETSAN (Technical Secretary of Food Security and Nutrition) is responsible for the rehabilitation of key infra-structures and the restoration of agricultural products.

CVM (Red Cross of Mozambique) is an institution composed by volunteers and responsible for the prevention and alleviation of the population in case of need.

PMA (World food programme) works in partnership with national and international institutions in particular in the regions more vulnerable to droughts, they distribute food for the most vulnerable people. Besides the distribution of food, they monitor the state of vulnerability and food insecurity in cooperation with FAO.

In the actual framework for drought mitigation in Mozambique there is a gap in terms of coordination between the government institutions, the science available and the societal capacities. There is a need of improvement in the communication between these 3 sectors.

5. INFORMATION SHARING, STAKEHOLDER PARTICIPATION AND CAPACITY BUILDING – LINKED TO WORK PACKAGE 7

Users of drought monitoring and early warning information typically want answers to the following questions:

What will the season look like?

How bad is this drought?

When is this drought going to end?

Scientific advances identified on this project can provide improved information relevant to users, while acknowledging that there is still room for improvement. Work Package 7 (WP7) endeavoured to share information, provide short professional training and engage with relevant stakeholders. This was achieved through a series of meetings, training events and a regional end-user workshop in case study areas to discuss the results and obtain feedback from end-users.

5.1 STAKEHOLDER PARTICIPATION AND INFORMATION SHARING

5.1.1 Presentations to Polokwane Water Supply Stakeholder System Operating Forum (***L Dlamini - WRNA***)

A presentation to introduce the DEWFORA to the Polokwane Water Supply System Stakeholder Operating Forum (PWSS SOF) was made on 11 August 2011. The stakeholders welcomed the project and it was pointed out that the project comes at the right time since it addresses issues that are not linked to ongoing similar researches in the region. It will add value to the challenges that trans boundary institutions are trying to address. The custodians of the final product would be the various institutions currently trying to provide early warning information to users such as the SAWS and DWA. Updates were made at subsequent PWSS SOF meetings geld on the following dates: 02 November 2011, 11 February 2012, 31 May 2012, 25 October 2012, 06 May 2013. The following table list stakeholders involved:

Name	Organisation
Mr L. I.A. Nyatlo	DWA Limpopo Regional Office – Chairperson
Dr B.Mwaka	DWA Planning Systems
Mrs C. Ntuli	DWA Planning Systems
Mr T. Nditwani	DWA National Water Resources Planning
Mr T. Mbotho	DWA Planning Systems

Name	Organisation
Mr F. Morteza	DWA Planning Systems
Mr P. Venter	DWA National Water Infrastructure Branch Tzaneen
Mr W. du Toit	DWA Limpopo Regional Office
Mr N. D. Manyama	Limpopo Development Agency
Mr L. Majadibodu	Lepelle Northern Water
Dr W. R. Nyabeze	WR Nyabeze and Associates
Mr L. Dlamini	WR Nyabeze and Associates

The following main highlights from the stakeholder engagements:

- Many organisations mushroom during droughts and disappear when there are no droughts, with no clear description of what exactly they do regarding drought early warning and forecasting,
- There is need to have more organisations with capacity and resources to deal with long-term adaptation measures
- There need to strengthen capacity both human resource and IT infrastructure in processing drought forecasting data to provide early warning information usable to farmers.

5.1.2 Meetings and presentations (*L Dlamini – WRNA, J-M Onema - Waternet*)

The project was introduced the LIMCOM at meeting in Beline, Mozambique. Other stakeholders engaged during the case study investigations include the South Africa Weather Services (SAWS), CSIR, World Vision, USAID, and USAID FEWSNET in South Africa and USAID FEWSNET in Mozambique, the Meteorological Services Department in Zimbabwe and the INAM in Mozambique, SADC Climate Services in Mozambique

Additional activities that were conducted as part of stakeholder engagement and information sharing for the Limpopo case study are reported below:

- A meeting with SADC secretariat on actors involvement in the Limpopo basin was convened on April 19, 2012 in Gaborone, Botswana
- The following day, 20 April 2012 a meeting with AMESD project on drought management and collaboration in the Limpopo basin was staged in Gaborone, Botswana.
- During the world water week held in Stockholm, August 22-26, 2011 the DEWFORA project summary was part of the research brochure distributed to the conference delegates.

- The DEWFORA project was showcased during the Global water Partnership Southern Africa (GWP-SA) general assembly and meeting of partners that took place in Johannesburg September 13-14, 2011.
- From September 19 to 24, DEWFORA flyers where disseminated to the SADC council of water Ministers and their permanents secretaries who met in Maseru, Lesotho.
- DEWFORA flyers were also disseminated during the FANRPAN Annual Regional Food Security Policy Dialogue in Swaziland 19-23 Sept, 2011
- Synergies with related projects – Dissemination of the DEWFORA project to the CGIAR Challenge Programme on Water and Food (CPWF) especially during the third International Forum on Water and Food (IFWF3) held in Tshwane, November 14-18, 2011
- WaterNet made a presentation of the DEWFORA project during the side event organised by the European Commission under the EU-Africa Scientific Cooperation on Climate Change at COP 17 in Durban on November 28, 2011.
- WaterNet distributed DEWFORA flyers during Rio+20 conference on sustainable development in Brazil in June 2012.
- WaterNet and WRNA made a presentation to the 16th Southern African Regional Climate Outlook Forum (SARCOF-16) meeting held in Harare 13-24 August 2012

5.1.3 End user workshop (*J-M Onema - Waternet*)

An end user workshop was held as a one-day side-event of the 13th WaterNet-WARFSA-GWP symposium which was held in Johannesburg, South Africa from October 31 to November 2, 2012. The specific objectives of the workshop were as follows:

- Introduce and discuss the progress and expected outcomes of the DEWFORA project in relation to the Limpopo Basin
- Sharing progress and results from the Limpopo case study to get feedback for further analysis.
- Local and regional dissemination of project progress and results
- Create interaction between project partners and end-users to facilitate knowledge exchange.
- Present and discuss the developed structure and services of the stakeholders platform that will be implemented to provide continuous communication with end-users.

The following stakeholders attended the workshop:

- Organizations and agencies affiliated to basin countries of the Limpopo and the respective governments. Mainly sectorial agencies with the mandate of capacity development and implementation of national drought policies, management (including land, water and agriculture development) as well as the development of preparedness plans including monitoring and prediction;

- University and Research Institutions with interest and capacity in drought forecasting, assessment and management
- Regional and national organizations, agencies and institutions engaged in monitoring, prediction, and providing early warning of drought and taking preventive actions;
- Non-governmental organizations and government agencies responsible for the implementation of drought response activities at various levels.

5.2 CAPACITY BUILDING (*J-M Onema - Waternet*)

A short professional training course is scheduled to take place from August 27-30, 2013 at Birchwood Hotel and conference Centre in Johannesburg, South Africa. The course will focus on the Implementation of Drought Early Warning Systems and Developing the Institutional Framework for Effective Response in Africa with an emphasis on the Limpopo case study. The course will introduce participants to the state-of-the art in the implementation and management of the drought early warning systems, focusing on the methods used to develop frameworks for improving drought early warning systems to provide more effective drought mitigation measures, how to develop plans and strategies for strengthening preparedness, increasing resilience, and enhancing adaptation to drought in Africa at local, national, and trans-boundary scales. The course is jointly organized and facilitated by WaterNet and Universidad Politecnica de Madrid (UPM), in collaboration with some of the DEWFORA project partners: WR Nyabeze and Associates (WRNA), UNESCO-IHE, Universidade do Porto (UPORTO), Council for Science and Industrial Research, South Africa (CSIR).

The following table list stakeholders involved:

The following programme was followed during the workshop:

Day 0, 26 Aug	**Internal project meeting**
All day	Meeting with project coordinators Objectives and expected results of the training workshop / reviewing workshop agenda & coordination on roles and facilitation ...
Day 1, 27 Aug	**Drought early warning systems concepts**
8:30 – 9:00 h	**1.1. Opening ceremony** *WaterNet*
9:00 – 9:15 h	**1.2. Workshop Objectives and Review of the agenda** *UPM*

Country	Surname	Name	Organisation	Position
Country	Surname	Name	Organisation	Position
Botswana	Mabala Ikanyeng	Letsatle	Ministry Of Agriculture	Principal Agricultural Engineer
Democratic Republic of Congo	Bahal"okwibale	Mulengera Patrick M	Food and Agriculture Organization of the United Nations (UN FAO) – Regional Office for Africa	Consultant – Climate Change Researcher on indigenous and community adaptation strategies in Central and East Africa
Germany	Masiyandima	Mutsa	Water Management Specialist	Africarice
Ghana	Kilasi	Stephen Joseph	Institute Of Statistical, Social And Economic Research (ISSER), University Of Ghana	PhD Student (Development Studies) Assistant Lecturer
Lesotho	Lekhooana	Lisema	Water Commission	Principal Technical Officer (Planning, Monitoring And Evaluation)
Kenya	Kiluva	Veronica Mwikali	Masinde Muliro University of Science and Technology	Lecturer, Disaster Preparedness and Engineering Management Department.
Kenya	Fundi	Lucy Wamuyu	Water Resources Management Authority Thiba Sub Regional Office	Surface Water Officer
Kenya	Kimithi	Michael Mutinda	National Drought Management Authority	County Drought Information Officer
Kenya	Dulo	Simeon Otieno	Department of Civil and Construction Engineering	Senior Lecturer
Madagascar	Tatafasa	Carles Olivier	Ministry of Environment and Forest	Collaborateur
Mauritius	Goolaup	Premchand	Mauritius Meteorological Services	Deputy Director, Operations

9:15– 10:00 h	**1.3.**
10:00 – 10:30 h	**1.4. Introducing the Participants of Workshop**
10:30 – 11:00 h	Coffee break

Mauritius	Nowbuth	Manta Devi	Department of Civil Engineering, Faculty of engineering, University of Mauritius	Head, Civil Engineering department
Malawi	Chavula	Geoffrey	University of Malawi – The Polytechnic	Senior lecturer in Water Engineering
Malawi	Vanya	Charles Langton	Department of Climate Change and Meteorological Services	Principal Meteorologist
Mozambique	Macuacua	Eurico Braz Carlos	Tongaat Hulett Açucareira de Xinavane	Irrigation Extension Manager
Mozambique	Raiva	Isaias Gabriel António	National Institute of Meteorology of Mozambique (INAM)	Technician (Researcher)
Nigeria	Adeboye	Omotayo Babawande	Department of Agricultural and Environmental Engineering, Obafemi Awolowo University	Lecturer
Swaziland	Manyatsi	Absalom Mganu	University of Swaziland, Faculty of Agriculture	Professor
Sudan	Fadul Bashir	Eiman	Hydraulic Research Centre	Assistant Professor
Tanzania	Mulungu	Deogratias Maganga Mohamed	University of Dar Es Salaam; Department of Water Resources Engineering	Lecturer, Postgraduate and Research Coordinator, Dept of Water Resources Eng.
Uganda	Nsubuga	Twine Teddy	Joint Efforts to Save the Environment (JESE)	Program Manager-Natural Resources
Uganda	Deus	Bamanya	Uganda Meteorological Department	Meteorologist
Zambia	Lombe	Maiba	Freelance	Environmental Engineer
Zimbabwe	Chinyepe	Andrew	Scientific and Industrial Research and Development Centre (SIRDC)	Research Scientist
Zimbabwe	Mare	Albert	Zimbabwe National Water Authority	Catchment Manager

11:00 – 12:00 h	**1.5. Drought management and preparedness** Components FEWS in DEWFORA *UPM*
12:00 – 1:00h	**1.6. FEWS some examples of application** *UPM*
1 :00– 14:30 h	Lunch
14:30 – 15:00 h	**1.7. Introducing the Case Studies in DEWFORA- WaterNet** WRNA
15:00 – 16:00 h	**1.8. Defining practical issues** How can DEWFORA concept be adapted to different countries? Involvement of stakeholders, information, knowledge, institutional roles and coordination *WRNA*
16:00 – 17:30	**1.9. Discussion (and refreshment)** Practical discussion with stakeholders on the development of FEWS (3 groups) *All participants, (coordinators)*
Day 2, 28 Aug	**Drought monitoring, risk and technical aspects**
8.30 – 9:30 h	**2.1. Discussion** Reporting to plenary of the previous day discussion *All participants, (coordinators:)*
9:30 – 10:30 h	**2.2. Monitoring, forecasting and early warning** Options, data needs and limitations *CSIR*
10:30 – 11:00 h	Coffee break
11:00 – 12:00 h	**2.3. Data and monitoring** Role of effective data gathering, analysis, monitoring and prediction *UPM*
12.00 – 13:00 h	**2.4. Risk based drought indicators** Technical aspects to define risk levels, practical demonstration *WRNA*
13:00 – 14:30 h	Lunch
14:30 – 16:00 h	**2.5. Discussion (and refreshment)** Developing a monitoring system for the lake. Indicating proper indicators, data sources, information dissemination *All participants, (coordinator)*
Day 3, 29 Aug	**Drought early warning systems and links to policy**
8:30 – 9:30 h	**3.1. Management of agricultural water demand during drought** *WaterNet*
9:30-10:30	**3.3 Linking drought indicators to actions**

	How such monitoring system should be linked to policy and actions?; Examples *CSIR*
10:30 – 11:00 h	Coffee break
11:00-12:00	**3.2. Options of modeling in agriculture** *CSIR*
12:00 – 13:00 h	**3.4. Managing water availability** *WaterNet*
13:00 – 14:30 h	Lunch
14:30 – 16:30 h	**3.6. Discussion (and refreshment)** Possible measures in the case studies *All participants, (Coordinator)*

Day 4,30 Aug	**Practical development of drought early warning systems**
8:30-10:30	**4.1. The drought early warning systems, virtual exercise** *UPM*
10:30 – 11:00 h	Coffee break
11:00 – 1:00 h	**4.2. Round table: Presentation and discussion of the challenges and opportunities for developing drought early warning systems in Africa** *All participants*
1:00 – 14:30 h	Lunch

The specific objectives of the workshop were as follows:

- Introduce and discuss the progress and expected outcomes of the DEWFORA project in relation to the Limpopo Basin
- Sharing progress and results from the Limpopo case study to get feedback for further analysis.
- Local and regional dissemination of project progress and results
- Create interaction between project partners and end-users to facilitate knowledge exchange.
- Present and discuss the developed structure and services of the stakeholder's platform that will be implemented to provide continuous communication with end-users.

The following stakeholders attended the workshop:

- Organizations and agencies affiliated to basin countries of the Limpopo and the respective governments. Mainly sectorial agencies with the mandate of capacity development and implementation of national drought policies, management (including land, water and agriculture development) as well as the development of preparedness plans including monitoring and prediction;

- University and Research Institutions with interest and capacity in drought forecasting, assessment and management
- Regional and national organizations, agencies and institutions engaged in monitoring, prediction, and providing early warning of drought and taking preventive actions;
- Non-governmental organizations and government agencies responsible for the implementation of drought response activities at various levels.

6. SUMMARY OF MAIN FINDINGS FROM THE CASE STUDY AND RECOMMENDATIONS

In this section the main findings from investigation on the Limpopo Case Study are listed. The following differences were noted on the situation Southern Africa compared to Global and European experiences with respect to institutions science and technology.

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

6.1 IMPROVING EXISTING INSTITUTIONAL FRAMEWORKS AND INSTITUTIONAL CAPACITY

6.1.1 Capacity building to strengthen drought early warning and preparedness

- What are the capacity building needs?
- Capacity is required at all levels (researchers, meteorologists, technology transfer, farmers, policy makers, and communities) to perform their roles more effectively
- The forecasting and early warning systems available are not adequately maintained
- The limited involvement of scientist/specialists in designing and developing early warning and forecasting systems.
- Although locally collected data is also useful for regional, continental and global forecasting and early warning systems, the data collection systems are deteriorating.
- Data is not readily available
- Infrastructure to process and share information is inadequate
- Outline of capacity building programme

6.1.2 Policies and research for drought mitigation and adaptation

- What are the policy gaps?
- In order to improve drought mitigation and adaptation, there is a need to improve on the following areas:
- Training and public awareness campaigns: increased public awareness in situations where the country is approaching a drought season
- Effective Transfer of Information to Policy- and Decision-makers: To facilitate and improve a close link between relief efforts and development programmes, different bodies at different levels need to be assigned and adhere to specific responsibilities at different levels.
- Communities in South Africa are engaged in activities to be able to survive future droughts and climate change, depending on duration and magnitude of deficit. This is being done through changes in processes, practices, and structures to moderate potential impacts of future drought
- More institutions identified are not found on the formal framework hence a need exists to improve on such. Stakeholders play a major role in drought management as they can share experiences, as well as identifying linkages amongst themselves. Institutions can draw some experiences gained in tackling previous droughts. This provides an opportunity to address the weakness and failures encountered
- Policy actions to reduce social vulnerability
- Research on indices, thresholds and actions
- Research on alert mechanisms and thresholds

- Research on risk levels across water dependent users/ecosystems vs mitigation and adaptation actions

6.2 IMPROVING MONITORING, FORECASTING AND EARLY WARNING SYSTEMS

- identification of the shortcomings in the existing systems vs. state of -the art
- Timing and reliability of early warning
- Improved application of climatological information for early warning
- Improved research on ENSO and other climate teleconnections
- Research on local climate
- Improved links between global and local climate research.
- Improved early warning systems e.g. seasonal climate outlooks: (i) South African Weather Services, (iii) SARCOF and (iii) practices form the Department of Water Affairs
- Integrating scientific and traditional monitoring and forecasting

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