From Drought Response to Drought Preparedness and Mitigation: Drought Monitoring for Extensive Livestock Farming in the Northern Cape

Report to the

Water Research Commission

by

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This is the final report of WRC project no. C2022/2023-00732.

Executive Summary

This report comprises two distinct parts. The first report, herein presented, details the research outcomes from the project. The second part, the project management report, addresses various administrative aspects, including capacity building, the financial management of the project, and the challenges encountered. Together, these reports encapsulate the comprehensive findings and administrative insights from the project, aiming to enhance drought preparedness and response strategies in the Northern Cape.

The project's main objectives were threefold:

i. The main aim of this project is to develop one of the most important building blocks for the National Drought Disaster Risk Reduction and Management Plan, namely, an indicator framework for drought monitoring for reference farms in the extensive livestock sector.
ii. The second aim is to develop a computerised reporting and data capturing system for extensive livestock reference farms based on the drought monitoring indicator framework.
i. The third aim is to develop contingency plans for the different drought categories for the extensive livestock sector.

The research outputs provide the necessary stimulus for the proper implementation of the national drought plan as follows:

i. It provide guidance for the development of contingency plans.
ii. This research opens the way for the implementation of a drought reference farm system in South Africa for all the different agricultural sectors.
iii. The drought plan also requires municipalities to report regularly on drought conditions within their municipal area and the development of a computerised reporting and data capturing system should also accommodate municipalities, which act as drought reference units.

The outcomes of this research are important building blocks in the implementation of the recently developed Integrated Drought Disaster Risk Reduction and Management Plan for South Africa.

This report is structured in six chapters, with each deliverable submitted during the project period as a separate chapter The six chapters are the following:

i. Chapter 1: Drought Indicators – A Study of the Literature
ii. Chapter 2: Farm Level Drought Indicators
iii. Chapter 3: Framework for Web-based Reporting
iv. Chapter 4: Web-based Drought Reporting Mechanism
v. Chapter 5: Drought Contingency Plans for the Extensive Livestock Sector
vi. Chapter 6: Conclusion

Chapter 1: Drought Indicators – A Study of the Literature

Chapter 1 focuses on the study of literature regarding drought indicators used globally and in South Africa. The chapter emphasises the importance of a drought strategy of shifting from merely responding to droughts to being better prepared and mitigating its effects, specifically in the context of extensive livestock farming in South Africa. The chapter highlights the adoption of a drought classification system by the National Joint Drought Coordinating Committee (NJDCC), classifying drought into five levels from D0 (dry period) to D4 (extraordinary drought).

Key topics in Chapter 1 include a historical overview of droughts, the proposed drought classification system, globally used drought indicators, and specific indicators relevant to the livestock sector. The chapter highlights the availability of over 60 remotely sensed drought indicators, many of which are utilised in South Africa through various national and international agencies.

Despite the resources available, a significant gap remains in the lack of an integrated system to consolidate and interpret this data for improved drought early warnings. The chapter concludes by recommending the development of such a system, leveraging existing tools and best practices from international examples like the US Drought Monitor and the Australian Drought

Map, and specifically proposes a ground-truth system for the livestock sector to validate remotely sensed data.

Chapter 2: Farm Level Drought Indicators

This chapter discusses the complex impacts of drought and emphasises the importance of understanding these impacts through a comprehensive monitoring system, particularly at the farm level. Here's a concise summary of chapter 2:

Drought has a devastating impact on all sectors, including society, economy, and environment. The direct effects are visible—empty dams, dry rivers, low groundwater, crop losses, and poor animal conditions. However, indirect impacts like high food prices, health issues, migration, and psychological stress are not as easily linked to drought. This complexity is due to the multiple causal and feedback loops among the environmental, economic, and social factors.

Recognising the inadequacy of standard weather and remotely sensed data alone, the chapter highlights the importance of developing farm-level monitoring systems. Traditional drought indicators do not adequately capture the economic and social impacts of drought, which vary significantly based on context such as vegetation, soil type, livestock, and individual farmer resilience.

The chapter highlights the development of a drought classification model for farm-level indicators, integrating weather data, vegetation and fodder conditions, animal health, soil moisture, water status, and the socio-economic impacts. This model aims to provide a practical framework for drought reporting and to serve as an early warning system for farmers, who may also benefit from indigenous knowledge for early drought detection.

The challenge remains in engaging enough farmers to participate in this reporting during all climatic conditions.

Chapter 3: Framework for Web-based Drought Reporting

Chapter 3 outlines the purpose and structure of a Drought Information Management and Communication System (DICMS), designed to enhance drought monitoring and early warning capabilities. The summary of chapter 3 is as follows:

The primary aim of the DICMS is to provide effective, timely, and reliable drought early warnings by integrating key drought indicators into a comprehensive system. This system is designed to deliver real-time data to various stakeholders, including government and private sector decision-makers, across all levels of governance, and the public, thereby facilitating informed decision-making and enhancing drought preparedness and response efforts.

The DICMS should feature geo-referenced, timely data that accommodates local, regional, and national variations in drought conditions. Chapter 3 describes such a system, which is composed of three main components namely (i) the main sub-chapter, (ii) an accompanying Excel document, and (iii) a reporting prototype. The main sub-chapter is structured into several sections that detail various frameworks for monitoring, analysing, and communicating drought information, as well as a proposal for a web-based, interactive communication system. The sub-chapters include an introduction, details on the drought monitoring and information system, the indicator framework, data capturing, data processing and communication framework, and a conclusion.

Chapter 4: Web-based Drought Reporting Mechanism

Chapter 4 details the development and implementation of the Drought Information Management and Communication System (DICMS), a transformative initiative to enhance drought monitoring and early warning through a robust web-based platform. Here’s a summary of chapter 4:

The DICMS integrates key farm-level and primary drought indicators like temperature, rainfall, vegetation condition, soil moisture, and hydrological data. This integration is facilitated by advanced reporting and communication tools built into the system. A notable feature of the proposed DICMS is its farmer-centric data collection application, designed to be intuitive and user-friendly. Farmers can report drought indicators directly from the field using mobile devices, promoting real-time, cost-effective data collection.

The system has evolved to include two separate but complementary web-based applications. One focuses on data collection from farmers, and the other on data visualisation to aid in modelling and analysis. This change was influenced by a strategic collaboration with the Agricultural Research Council (ARC), which hosts a pre-existing drought information website developed under a previous WRC initiative. This collaboration allows the DICMS to utilise ARC’s infrastructure and user base to enhance the functionality and reach of the drought monitoring system.

The ARC's website now serves a dual purpose: it continues its initial function of drought reporting and also supports the DICMS by hosting the new data collection website. This integrated approach ensures that the data collected is not only extensive but also geographically precise, enabling detailed analysis and insights on drought conditions that are relayed back to users. This system is pivotal in advancing drought monitoring and management, providing critical data that empowers farmers and decision-makers with the information needed to address drought impacts effectively.

Chapter 5: Drought Contingency Plans for Livestock Farmers

Chapter 5 reports on proactive livestock farming drought management practices in the Northern Cape (NC) Province. The main focus is on livestock farming, the dominant form of agriculture in the NC, which is significantly impacted by drought conditions.

The study aimed to develop indicator-based contingency plans for different levels of drought intensity (D0-D4) for livestock farmers to enhance their preparedness and resilience. A qualitative research method involving semi-structured interviews was employed, with data collected from leading livestock farmers or experts in the area through purposive and snowball sampling. The interviews were segmented into categories including biographic information, grazing land management, livestock management, financial management, and social management, facilitating easier coding and analysis of data.

Key findings suggest that experienced farmers in the Northern Cape generally accept drought as a regular aspect of their climate and have adapted their practices accordingly. These adaptations include maintaining conservative stocking rates to protect grazing land, reducing livestock numbers timely during drought conditions, being financially prudent, and relying on strong social networks for support.

The recommendations from the study include training participants on indicator-based drought categories and expanding the development of drought contingency plans to encompass business and municipal sectors. These measures aim to further reduce vulnerability and foster sustainable development practices in the region.

Conclusion

The primary achievement of this project is the establishment of a detailed indicator framework for drought monitoring, tailored specifically for reference farms in the extensive livestock sector. This framework not only enriches the National Drought Disaster Risk Reduction and Management Plan but also provides a model that can potentially be replicated across various agricultural sectors and provinces.

Additionally, the project has introduced a computerised reporting and data capturing system that replaces outdated paper-driven methods, thereby streamlining and enhancing the efficiency of data collection and drought monitoring. This system is poised to be adopted nationwide, offering real-time monitoring capabilities that are crucial for timely and effective drought response.

Furthermore, the development of contingency plans based on distinct drought categories provides a structured approach to managing drought impacts specifically in the livestock sector. These plans are a critical resource for farmers, enabling them to implement strategic measures to mitigate the adverse effects of drought based on varying levels of severity.

The research outputs from this project not only guide the development of similar contingency plans in other sectors but also underscore the necessity for a unified approach to drought management. This includes the integration of municipal reporting, which will further the reach and effectiveness of drought mitigation strategies.

Overall, the project's outputs are instrumental in advancing the Integrated Drought Disaster Risk Reduction and Management Plan for South Africa, setting a benchmark for future initiatives aimed at bolstering drought resilience across the country. The collaborative efforts, particularly with the Agricultural Research Council, highlight the potential for widespread adoption and implementation of these systems, ensuring that the insights and methodologies developed can benefit a broader spectrum of the agricultural community and beyond.

Project Achievements

Capacity Building

- J. le Roux: Masters Disaster Management – Graduated March 2024. Title: *Drought Contingency Plans Linked to Drought categories for the Livestock Sector.*
- Z. Dhladhla: Research phase. Title: *Predicting Meteorological Drought Categories Using Graph Neural Networks*

Knowledge Dissemination

- 6 Farmer Workshops – 86 farmers – 2022/2023/2024
- SANCID symposium – 2023
- IRM-UK / UFS Symposium – 2023
- ELSEDIMA International Conference – Cluj Napoca, Romania - 2023
- DWS National Water Symposium – 2023
- WRC Symposium, Umtata – 2023
- COGTA and Dept of Agriculture, Nelson Mandela Bay – 2023
- UNU-EHS / UFS PhD Block Course, Durban – 2023
- *Landbouweekblad* article – Largest farmer's magazine in SA – 2024
- Lectures to Post-Graduate Diploma and Master students – 2023/2024

Innovation

- Composite drought indicator combining primary and remotely sensed indicators
- Farm level drought indicator reporting tools
- Development of contingency plans linked to drought categories

Collaboration

- Northern Cape Department of Agriculture
- National Disaster Management Centre (NDMC)
- Northern Cape Provincial Disaster Management Centre (NC PDMC)
- Agricultural Research Council (ARC)
- Northern Cape Agri
- University of the Free State (UFS)

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To everyone involved, thank you for your dedication to advancing drought preparedness and resilience in South Africa. Your support and contributions have been invaluable.

Prof Andries Jordaan

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Acronyms

ADI	Aggregate Drought Index
Agric DI	Agricultural Drought index
ARC	Agricultural Research Council
ARDI	Agricultural Reference Drought Index
BFI	Base Flow Index
BMDI	Bhalme and Mooly Drought Index
CDD	Consecutive Dry Days
CDI	Combined Drought Indicators
CornDI	Corn Drought Index
CDP	Carbon Disclosure Project
CMI	Crop Moisture Index
CPA	Cumulative Precipitation Anomaly
CSA	Cumulative Streamflow Anomaly
CSDI	Crop Specific Drought Index
DAFF	Department of Agriculture Forestry and Fisheries (Changed to DARDLR)
DAI	Drought Area Index
DARDLR	Department of Agriculture, Rural Development and Land Reform
DEFF	Department of Environmental, Forestry and Fisheries
DEWS	Drought Early Warning System
DFI	Drought Frequency Index
DHSWS	Department of Human Settlement Water and Sanitation
DICMS	Drought Information Management and Communication System
DJDCC	District Joint Drought Mitigation Committee
DL	Dam Levels
DMU	Drought Mitigation Unit
DRI	Drought Reconnaissance Index
DRR	Disaster Risk Reduction
DSI	Drought Severity Index
DWS	Department of Water and Sanitation (Changed to DHSWS)
EDI	Effective Drought Index
ETDI	Evapotranspiration Deficit Index
FAO	Food and Agriculture Organisation
GIS	Geographic Information Systems

GL	Groundwater Levels
GRI	Groundwater Resource Index
GWP	Global Water Partnership
ha	Hectares
ICMS	Information and Communication System
IPCC	International Panel on Climate Change
JADTF (Australia)	Joint Agency Drought Task Force
KBDI	Keetch-Byran Drought Index
KPA	Key Performance Area
LSU	Large Stock Unit
LWCI	Leaf Water Content Index
MDPI	Modified Perpendicular Drought Index
MPDSI	Modified Palmer Drought Severity Index
MSDI	Multivariate Standardised Drought Index
NBR	Normalised Burn Ration
NDI	NOAA Drought Index
NDII	Normalised Difference Infrared Index
NDMC	National Disaster Management Centre
NDMF	National Disaster Management Framework
NDVI	Normalised Difference Vegetation Index
NDVIA	Anomaly of Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
NGO	Non-governmental Organisation
NIDIS (US)	National Integrated Drought Information System
NIWIS	National Integrated Water Information System
NJDCC	National Joint Drought Coordinating Committee
NMDI	Normalised Multiband Drought Index
NOAA	National Oceanic and Atmospheric Administration
NPO	Non profit Organisation
PAI	Palfai Aridity Index
PASG	Percentage of Average Greenness
PDSI	Palmer Drought Standardised Index
PerDI	Perpendicular Drought Index
PHDI	Palmer Hydrological Drought Index
PN	Percentage of Normal Precipitation

Q90	Low Flow Index
RAI	Rainfall Anomaly Index
RDI	Reclamation Drought Index
RecDI	Reconnaissance Drought Index (RecDI)
RSDI	Regional Streamflow Deficiency Index (RSDI)
RSDRI	Remote Sensing Drought Risk Index
SADC	Southern African Development Community
SAI	Standardised Anomaly Index (SAI)
SANSA	South African National Space Agency
SAWS	South African Weather Service
SCI	Soybean Drought Index
SDG	Sustainable Development Goals
SFDRR	Sendai Framework for Disaster Risk Reduction
SL	Streamflow
SLM	Sustainable Land Management
SMA	Soil Moisture Anomaly Index
SMDI	Soil Moisture Deficit Index
SMDI	Soil Moisture Drought Index
SMI	Soil Moisture Anomaly Index
SPEI	Standard Precipitation Evaporation Index
SPI	Standard Precipitation Index
SRSI	Standardised Reservoir Supply Index
SRWI	Simple Water Ratio Index
SSSI	Standardised Streamflow Index
SVI	Standardised Vegetation Index
SWI	Standardised Water Level Index
SWSI	Surface Water Supply Index
TCI	Temperature Condition Index
TSDI	Total Water Deficit Index
UN	United Nations
UNCCD	United Nation Convention to Combat Desertification
UNDP	United Nations Development Programme
UNISDR	United Nations International Strategy for Disaster Reduction
USDA	United States Department of Agriculture
USGS	United States Geographic Survey

USNDMC	United States National Drought mitigation Centre
VCADI	Vegetation Condition Albedo Drought Index
VCI	Vegetation Condition Index
Veg DRI	Vegetation Drought Response Index
VHI	Vegetation Health Index
VWMI	Vegetation Water Moisture Index
WASP	Weighted Anomaly Standardised Precipitation
WI	Water Index (WI)
WMA	Water Management Agency
WMO	World Meteorological Organisation
WUO	Water User Organization

Chapter 1: Literature Review

1.1 Introduction

Drought is a slow onset disaster of which it is difficult to determine the onset and the end of a drought. In addition, drought is the hazard affecting most people in South Africa (SA) and significantly impacts the economy. Therefore, drought monitoring and timely analysis of drought indicators are essential for early warning and implementing drought risk reduction contingencies. Accepting a drought classification system and indicator thresholds is the first step in drought management with a focus on mitigation and risk reduction on a national scale. The National Joint Drought Coordinating Committee (NJDCC) has already approved a drought classification system for South Africa. According to this classification, drought is classified into five classes: D0 to D4, where D0 is a dry period, and D4 is an extraordinary drought. In addition, thresholds for the most critical indicators were accepted and approved.

This report is the first deliverable in the project titled "From drought response to drought preparedness and mitigation: Drought monitoring for extensive livestock farming".

This report is a discussion of the following topics:

- A brief background to the history of drought and response measures implemented by the government.
- The proposed drought classification system for South Africa
- Overview of globally used drought indicators
- Drought indicators applicable to the livestock sector
- Proposed indicators
- Global best case examples of drought monitoring

We could identify more than 60 remotely sensed drought indicators globally, many of which are already used in South Africa. Through the South African Weather Service (SAWS) and the South African National Space Agency (SANSA), we have the capacity in South Africa to monitor drought progression through remotely sensed indicators in near-real-time. The indicator products are available to farmers, mainly from the SAWS, the Department of

Agriculture, Rural Development and Land Reform (DARDLR) through the Agricultural Research Council (ARC), and the Department of Human Settlement, Water and Sanitation (DHSWS), through the National Integrated Water Information System (NIWIS). Some of the catchment Management Areas (CMA) also provide some information. In addition, the private sector provides remotely sensed products, mainly to crop farmers, for use in precision agriculture, but these products are available only at a price.

Drought-related data is available in silos, mainly through the NIWIS, ARC, SAWS and a few global sources, and sometimes at a cost. The most significant drought indicators available to farmers are:

- Precipitation and temperature data in near-real-time monitored and distributed by the SAWS
- Hydrological indicators such as dam levels and stream flow for major dams and rivers available in near-real-time from the NIWIS
- Remotely sensed vegetation products such as NDVI, PASG, VCI communicated monthly through the UMLINDI report from the ARC
- Groundwater levels in near-real-time from the NIWIS
- Several international organisations such as EUSAT, NOAA, USGS, UNCCD and others provide remotely sensed products

A conspicuous gap in the drought monitoring system in South Africa is the lack of an integrated system with the capacity to combine and integrate all drought-related data and indices for improved drought early warnings. The US Drought Monitor and the Australian Drought Map are best-case examples from which we can build upon their systems and lessons learned. Therefore, there is no need to develop a new system for South Africa. Firstly, South Africa already has access to the required remotely sensed products for drought monitoring. Secondly, this research should develop a ground-truth system for the extensive livestock sector that validates the remotely sensed results.

The government should apply more effort to develop an integrated drought monitor and analysis capacity, considering drought's economic, environmental and social impacts.

Although not part of the objective of this research, we will advocate for an integrated drought monitor and analysis system.

1.2 Background

Dry periods and drought remain the major meteorological event with devastating impacts on the livelihoods of people in Africa and the globe (WMO, 2019). Drought is a slow onset disaster, and it is difficult to determine the onset and the end of a drought. Drought remains the hazard affecting most people in SA and significantly impacts the economy (Schreiner et al., 2018). The FAO reported that drought emerged by far the most destructive natural disaster costing farmers in the developing world billions of dollars each year. Globally, the cost of drought is estimated to be around US$80 billion annually. This does not include indirect impacts such as increased salinity, impact on water quality and socio-economic impacts resulting in migration and conflict (WMO & GWP, 2017). The risks associated with drought are the result of the hazard itself, the exposure to it, and the vulnerability of society, livelihoods, economy and ecosystems. The capacity of governments, society, economic sectors and organisations to manage droughts is equally crucial as vulnerability to drought (Vogt et al., 2018; Jordaan et al., 2020). Widespread, severe and multi-year droughts globally stimulate the need for improved drought monitoring and drought preparedness on a global and national scale. Despite the devastating effect of droughts, most disaster risk scientists, policymakers and practitioners focus on events such as floods, fires, and hurricanes, which have immediately visible impacts. In addition, climate change projections of a warmer climate might result in increased dry periods of higher intensity. Despite the large number of people affected on the African continent, we still cannot accurately predict when the next drought will happen and how severe it will be (WMO, 2019).

Drought is part of South Africa's history and helps shape its history. Hall (1949), as cited in Ballard (1986), reported three significant climatic changes with a trend of decreasing rainfall characterised by prolonged droughts from 1700 to 1750. That was followed by a wetter period until the late 1700s. Krige (1936) and Hall (1949), as cited by Ballard (1986), reported that the prolonged drought between 1800 and 1806, known in the Nguni language as "*Madhlatule*" (let one eat what he can and say nought), caused great distress and suffering for the northern Nguni. These droughts resulted in a famine of such magnitude that it led to a severe breakdown of social, political and economic institutions among Nguni pastoralists. Extraordinary drought during 1816 – 1817 also caused the "*Mahlatule*" famine and the "*Mfekane*", which was the primary catalyst for the social revolution that produced the Zulu Kingdom under Shaka (Ballard, 1986; SAHO, 2020). More than 2 million people died from starvation and conflict over cattle, grain, water and grazing. Other authors reported a "*continual decline in rainfall and progressive desiccation of lakes, rivers and springs from about 1800 to 1830, and numerous droughts in the 1820's and 1830's*" (Ballard, 1996; Garstang, Coleman & Therrell, 2014; HOSA, 2020). Reports from the Cape Colony, Botswana and Natal suggest regions that "suffered from severe and frequent droughts". For example, late eighteenth-century descriptions of the Beer Vlei near Willowmore portrayed it as an area of bushy grasses, swamps, springs and periodical rivers. In contrast, in the 1820s, Beer Vlei was described as "*completely dry, barren and desolate*" (Ballard, 1986).

The winter rainfall region of the Cape Colony also experienced extreme drought during the early nineteenth century. In 1801, a British official wrote; "*Inhabitants of the Cape have for some time past laboured under the scarcity of bread, owing to the almost total failure of the last crop*." In 1806, another official wrote of the successive failures of grain harvest from 1803 to 1805. Previously, the Cape Colony was a reliable source of food supply for ships, but they had to import food during the early nineteenth century because of successive droughts (Ballard, 1986, Cobbing, 1988).

Twentieth century extreme droughts in central SA recorded are 1914, 1916, 1923, 1933, 1941, 1946, 1949, 1964,1970, 1981, 1983 – 1985, 1991- 1992, 1995. Recent droughts recorded are the 2001- 2003 and 2015 – 2018 droughts (Kelso & Vogel, 2017; Nash, Klein, Endfield, Pribyi, 2019).

Droughts were always part of development in South Africa, with the government supporting farmers with drought aid or plans from as early as 1914. The "*Senate Select Committee*" report titled "*Droughts, Rainfall and Soil Erosion*", released in 1914, was the first formal enquiry into the impact of drought on Agriculture in South Africa during the twentieth century. As early, as 1916 "*De Droogt an Overstroming Noodleniging Wet No 28 van 1916*" provided for drought support to farmers. The Noordwester of 10 June 1923 reported as follows: "*De heer Crous was chairperson of the Droogte Onderzoek Kommissie*" The "*Drought Investigation Commission*" recommended that farmers should not receive animals, feed and fodder but instead supported in the following ways:

- Tax relief and postponement of Government tax
- Establishment of drought monitor committees
- Extension of Land Bank loans and interest relief
- Additional credit from Land Bank at very low-interest rates
- Support to Land Bank to support agricultural cooperatives
- Provision of additional credit facilities from commercial banks

Farmers were motivated to join small cooperatives with members between seven and a maximum of fifty. These Cooperatives received funding from the government through the Land Bank, and they could then lend that money to members to buy dairy cattle, oxen, ploughs and other equipment. The "*Drought Investigation Commission*" also realised and documented the need for change in natural resources- and livestock- management practices (*Noordwester*, 10 June 1923). During the following sixty years, eighty parliamentary acts rendered services to commercial farmers in response to drought and drought-related issues. These acts dramatically impacted the rural landscape's development, and the government emphasised soil conservation and protection of the natural resource base (Smith, 1993; Van Zyl, 2010).

The 1930s saw the initiation of State support to commercial farmers with intensified support during droughts. The 1940s saw commissions such as the "*Commission on National Provision Against Drought*" in 1941, which researched the spatial extent of drought relief measures. The "*Phase Drought Relief Scheme*" was initiated in 1946, and the "*Report on the Fodder Bank Committee*" was released in 1949 (Smith, 1993; Van Zyl, 2010).

The government supported and subsidised drought-evading strategies during the 1930s and 1940s (van Zyl, 2010). The movement of animals during 1933 from the drought-stricken Northern Cape province to the Free State province and the central and eastern Karoo is an excellent example of a drought-evading strategy. The *Noordwester* of 20 June 1933 reported on trucking more than fifty thousand sheep and goats during the second half of May 1933 from the Calvinia region. The government funded the railway transport for all animals.

The Agricultural Credit Board (ACB), founded in the 1950s, became a crucial vehicle to support farmers during and after severe droughts. Farmers who were not found creditworthy by commercial organisations received loans from the ACB to continue farming and recover from drought. As a result of land degradation caused by over-grazing, the government implemented the livestock reduction scheme from 1969 to 1978, probably the most successful drought prevention and mitigation scheme ever implemented in South Africa. The government subsidised farmers to reduce their stock numbers by one-third to farm at 66% of the recommended stocking rate. This was a volunteer scheme, and many farmers participated in the scheme with successful results (Smith, 1993; Van Zyl, 2010; Jordaan, Sakulski & Jordaan, 2011; Jordaan et al., 2017(a)). The subsidies for fencing and water provision and reticulation during the 1960s and 1970s also contributed tremendously toward properly planning agricultural rangelands (Smith, 1993; Van Zyl, 2010). Extension officers and technical staff during this period were influential in introducing proper farm planning and management with drought risk reduction in mind (De Bruin, 2010).

1.3 Drought Typology

Drought has no universal definition as droughts are region-specific, reflecting differences in climatic characteristics with different socio-economic and physical variables. However, some of the most common definitions are the following:

- The UNDP (2008) defines drought as *"the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems".*
- Knutson *et al.* (1998) define drought as "*a deficiency of precipitation from expected or "normal" that, when extended over a season or longer period of time, is insufficient to meet demands. This may result in economic, social, and environmental impacts. It should be considered a normal, recurrent feature of climate. Drought is a relative, rather than absolute, condition that should be defined for each region. Each drought differs in intensity, duration, and spatial extent".*
- The Director of the Commonwealth Bureau of Meteorology in 1965 suggested a broad definition for drought as *"severe water shortage".*

- Palmer (1965) states: *"Drought is an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply".*
- Chopra (2006) defines drought as *"a period of rainfall deficiency, extending over months or years of such nature that crops and pastures for stock are seriously affected, if not completely burnt up and destroyed, water supplies are seriously depleted or dried up and sheep and cattle perish."*
- McMohan and Diaz Arena (1982) define drought as *"a period of abnormally dry weather sufficiently for the lack of precipitation to cause serious hydrological imbalance and carries connotations of a moisture deficiency with a mass usage to water".*

All the above definitions only consider meteorological influences and have little reference to drought and dry periods' socio-economic and environmental impact. Wilhite & Glantz (1985), Wilhite (2000) and Castillo (2009) recognised the challenge for a universally accepted definition and categorised drought into four different categories with specific definitions. The four most common definitions describing the different types of drought are (i) meteorological drought, (ii) agricultural drought, (iii) hydrological drought and (iv) socio-economic drought.

- ***Meteorological drought:*** A precipitation deficiency threshold usually defines meteorological drought as a reduction in rainfall supply compared with a specified average condition over a specified period. Different indexes and methodologies are used to define the meteorological drought, such as the Standard Precipitation Index (SPI), the Standard Precipitation Evapotranspiration Index (SPEI), and the percentage of mean rainfall, rainfall deciles, and other indicators. The SPI is currently the most sophisticated index used worldwide to measure meteorological droughts.
- The lack of soil water for vegetation production commonly defines agricultural drought. It is a reduction in water availability below the optimal level required by a crop during each growth stage, resulting in impaired growth and reduced yields. Agricultural drought relates to an imbalance in the water content of the soil during the growing season, which, although influenced by other variables such as the crop water.

- ***Hydrological drought*** is generally determined by a departure of surface and subsurface water supplies from some average condition at various points in time. It occurs when there is a substantial deficit in surface runoff below normal conditions or when groundwater supplies are deposed. Hydrological drought reduces water supply for sewerage, household use, industrial use, irrigation, hydro-electrical power generation, and tourism.
- ***Anthropogenic drought*** is an "*artificial*" drought experienced because of human intervention and the lack of drought management planning. This drought occurs when the demand/supply ratio is larger than one because of increased water demand in relation to water supply or water availability. Population growth, unplanned development or poor maintenance of infrastructure can cause this. Examples are municipalities where water restrictions are not applied timely, excessive water leakages and new developments without water availability. Organisations such as municipalities then use the anthropogenic drought as an excuse to source disaster funding for regular expenditure or infrastructure maintenance that was supposed to be funded from the regular budget. Over-grazing and poor natural resource management on the farm level are also, in many cases, the cause of anthropogenic or artificial droughts.
- ***Socio-economic drought*** differs markedly from the other types of drought. First, it concerns the relationship between the supply and demand for some commodities or economic goods dependent on precipitation. It represents the impact of drought on human activities, including indirect and direct impacts. This relates to a meteorological anomaly or extreme event of intensity and/or duration outside the normal range of events considered by enterprises and public regulatory bodies in economic decision-making, thereby affecting production and the wider economy.

The different drought categories are illustrated in Figure 1.3.1.

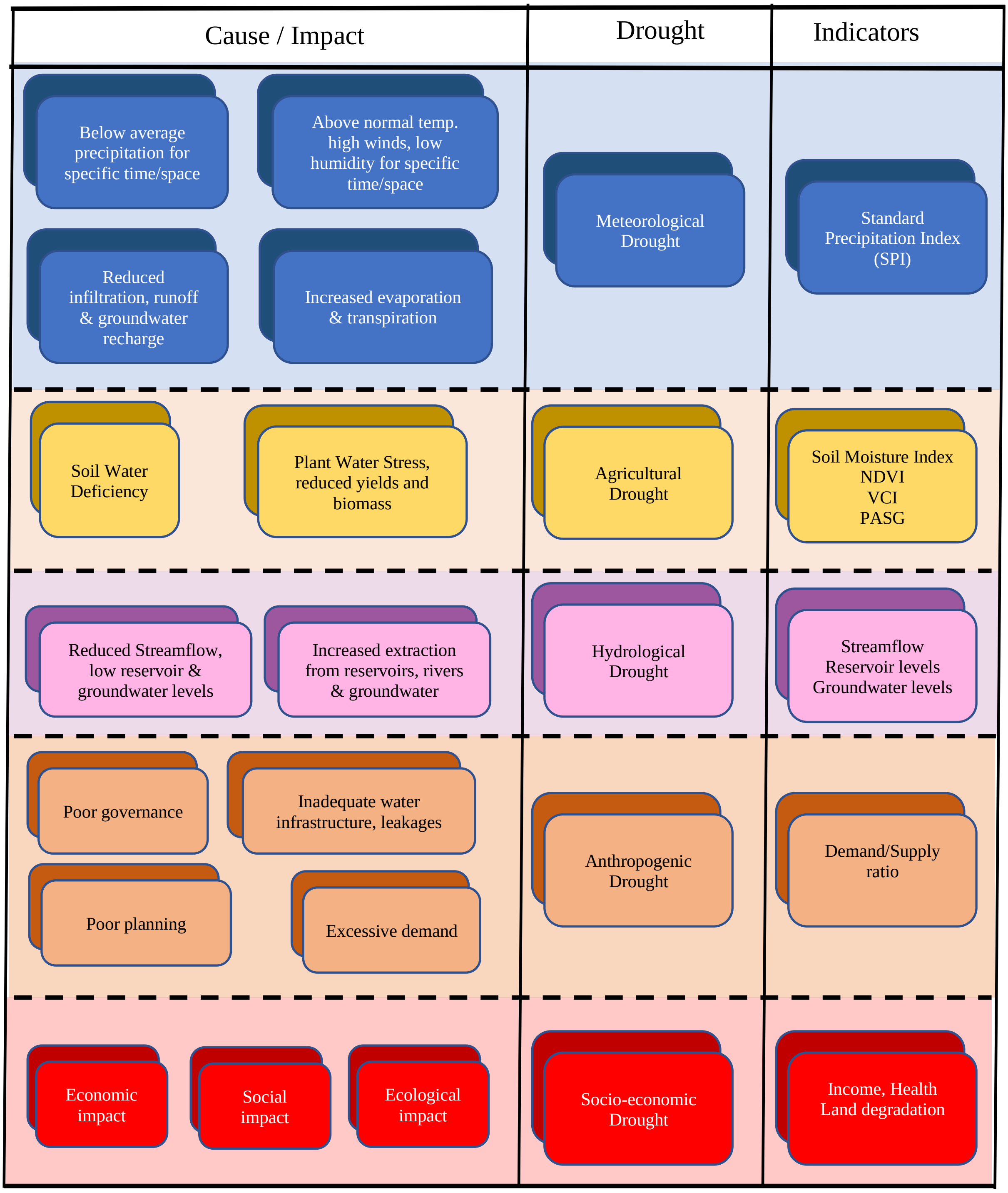


FIGURE 1.3.1: DROUGHT CATEGORIES
(Adapted from Wilhite and Glantz 1985; Wilhite, 2000; Castillo, 2009;and Jordaan, 2020)

Van Zyl (2006) also provides some alternative and practical definitions for drought types usually experienced and commonly used by farmers in South Africa. These are the following:

- ***False drought:*** This type of *"drought"* occurs when rainfall is slightly below the long-term average. However, due to overgrazing, the veld and fodder supply become prematurely depleted, giving the impression of a prevailing drought. In some cases, false droughts have been wrongly declared disaster droughts.
- ***Premature drought:*** This type of drought occurs when a chronic dry situation is so aggravated by overgrazing that a disaster drought is prematurely declared. In many instances, adjoining farms may differ widely as drought intensity is, in this case, a result of veld management practices and the exploitation of grazing capacity.
- ***Prolonged drought:*** A drought can be prolonged for months when high stock numbers are maintained. This results in a more or less chronic food shortage even after rains have fallen. Plants become severely damaged. It is also possible that areas which have been declared drought-stricken do not recover after moderate rainfall. After a few months, the drought could be even worse.
- ***Green drought:*** Green drought occurs when excessive grazing pressure is maintained in semi-dry periods. This causes food shortages even though the vegetation appears green and soil moisture reserves are favourable, or where natural causes such as rain showers during a drought promote a short spell of green growth but not enough to break the drought. A green drought can also occur where insects such as locusts severely attack plants and deplete the fodder to such a degree that it takes on the appearance of a drought situation. There is thus a shortage of fodder despite favourable climatic circumstances. The most common pests are locusts, the Karoo caterpillar and the commando caterpillar.
- ***Financial drought:*** Farmers exert pressure to obtain financial assistance to improve cash flow. Therefore, a region is sometimes declared drought-stricken even though a drought does not prevail. The declaration of such a region as a disaster drought area has a negative effect on the interpretation of rainfall records because drought is indicated when it does not exist.

Climate variability is a given fact, and the vegetation in a region results from a specific climate profile. It is important to remember that drought is a temporary anomaly, unlike normal arid and semi-arid climatic conditions, and one must distinguish between drought and aridity. Understanding the difference between these two concepts is essential for developing drought risk reduction plans, which are based on assessing drought risks (WMO, 2006). Water users should be conscious that weather fluctuates from wet to dry periods and, therefore, must adapt their practices to fit within the two extremes and cope with them.

Figure 1.3.2 illustrates the interaction between long-term production potential and climate profile. Within a specific climate profile, some years might receive above-normal rainfall with potentially above-average runoff and production. On the other hand, below-normal precipitation in other years might result in below-average production outputs and low runoff with low dam levels, stream flow and groundwater levels (IPCC, 2001; Jordaan et al., 2020). The ideal production and planning situation, though, is located between the two extremes since farmers can prepare with timely operational decisions and follow production systems and management practices that can cope with the extremes (see Figure 1.3.2).

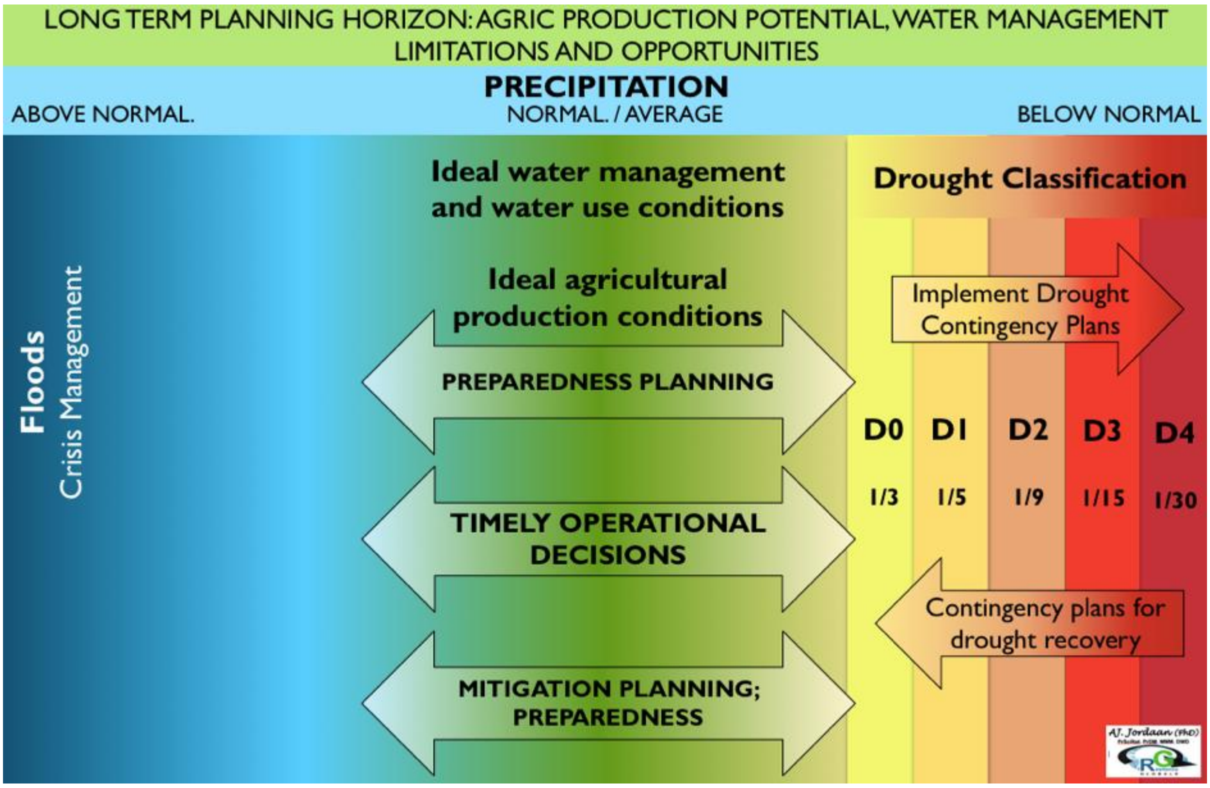


FIGURE 1.3.2: RELATION BETWEEN THE CLIMATE PROFILE, PRODUCTION LEVELS AND MANAGEMENT DECISIONS.
(Source: IPCC, 2001 adapted by Jordaan et al, 2020)

Issues to be updated and monitored during the *"normal"* climate period are drought early warning and the progression of drought. Monitoring dry conditions and drought allow farmers to make timely tactical decisions instead of reverting to crisis management during extreme climatic situations (See illustration in Figure 1.3.2). Framers should include drought planning as part of the standard management process. Drought categorisation linked to specific responses for each progressive category is an important risk reduction tool in the drought management tool kit.

1.4 Drought Classification

Drought is a slow onset disaster, and the government and farmers should manage it according to a standardised classification system. Drought monitoring and drought classification are possible through several well-developed indicators currently monitored by the SAWS, ARC, DWSWS and other organisations. The objective of drought monitoring and early warning is to warn stakeholders when there is a risk of dry periods or drought. As a result, reliable drought early warning will allow water users to prepare and increase resilience to potential water shortages, crop losses and food shortages. Drought early warning is essential for agriculture, water resource management and municipalities responsible for water provision.

Drought classification provides a sound basis for early warning strategy and the timely implementation of contingency plans based on the drought classification. Drought monitoring and drought assessment require integrating all information such as indices and impact indicators in a comprehensive framework. Drought monitoring through indices alone does not provide sufficient knowledge for drought classification. Additional information on the impact (vulnerability) of different sections (economic, social, environment) *is required to understand* the different drought classes (Wilhite *et al.*, 1997; Du Pisani, Fouche & Venter, 1998; Wilhite, 2000; Wisner *et al.*, 2004, Jordaan, 2011).

When to declare drought a disaster remains one of the most debated issues in disaster management. The 2015/2016 drought in South Africa is an example that illustrates the need for quantifiable indicators for drought classification and declaration. Five out of the nine provinces in South Africa declared the drought a provincial disaster. Nevertheless, it was never declared a national disaster even though the disaster management Act (Act 57 of 2002 and amended Act 16 of 2015) stipulates that a national disaster can be declared once more than one province is affected by drought or a disaster. The reasons provided by the National Disaster Management Centre (NDMC) for the non-declaration of a national drought disaster are not convincing. They do not consider the impact of the drought on the South African economy.

The declaration of drought disasters and how the government responded to droughts are amongst the most important contributors to increased resiliency if handled correctly. However, the lack of efficient relief causes increased vulnerability. The commercial and communal farming sectors are highly susceptible to the negative impacts of drought and the economy at large. Therefore, drought indicators should be quantifiable, easy to measure and understand, transparent and all-inclusive, meaning that one should be able to measure the hazard and its impact.

Drought disaster declaration is linked to drought classification. Previous research by Jordaan (2011) highlighted the difference in drought disaster thresholds for the different agricultural sectors. Communal farmers, for example, experience normal dry periods as disaster droughts because of land degradation and over-grazing, the lack of alternative resources, lack of water reticulation systems, lack of proper fencing, poor management and numerous other reasons. The threshold for disaster drought in the case of communal farmers is therefore not the same as thresholds for the commercial farming sector. Different agricultural systems and vegetation regimes also require different thresholds and indicators (Jordaan, 2011; Gerber, 2022). The period of drought occurrence is also important. For example, dry periods during the months of September to February in central South Africa can have a disastrous effect on the maise industry, while the livestock sector might experience the same dry period as a mild drought. Remotely sensed drought indicators might require different calibrations for regions with a low vegetation cover compared to regions with high vegetation cover or bushes and trees (Gerber, 2022); therefore, different thresholds and different indices for different systems. A “*one-fit-all*" indicator and threshold selection are not possible.

1.4.1 Drought Classification in South Africa

The National Department of Agriculture, Land Reform and Rural Development (NDALRRD) initiated a process in 2017 to provide a drought classification system for the agricultural sector (Jordaan et al., 2017). The drought classification system proposed by the Department is based on best practices from leading countries with drought management plans, such as the USA, Mexico and Australia. The proposed classification is aligned with the classification system used in the United States, Mexico and Australia. The United States Drought Monitor is probably the world’s most developed drought monitor system. They stated: *"This is what makes* *the U.S. Drought Monitor unique. It is not a model. The USDM relies on experts to synthesise the best available data from multiple sources and work with local observers to localise the information as much as possible. Numeric inputs are many: the Palmer Drought Severity Index, the Standardised Precipitation Index, and other climatological inputs; the Keech-Byram Drought Index for fire, satellite-based assessments of vegetation health, and various indicators of soil moisture from data assimilation systems and other models; and hydrologic data, particularly in the West, such as the Surface Water Supply Index and snowpack"* (USNDMC, 2016).

According to the DARDLR 2017 drought classification, drought is classified into five classes from a D0 to a D4 drought, as follows (Jordaan *et al*., 2017):

- D0 Dry period
- D1 Moderate drought
- D2 Severe drought
- D3 Extreme drought
- D4 Exceptional drought

The different drought categories and duration of different types of drought are illustrated in Figure 1.4.1.

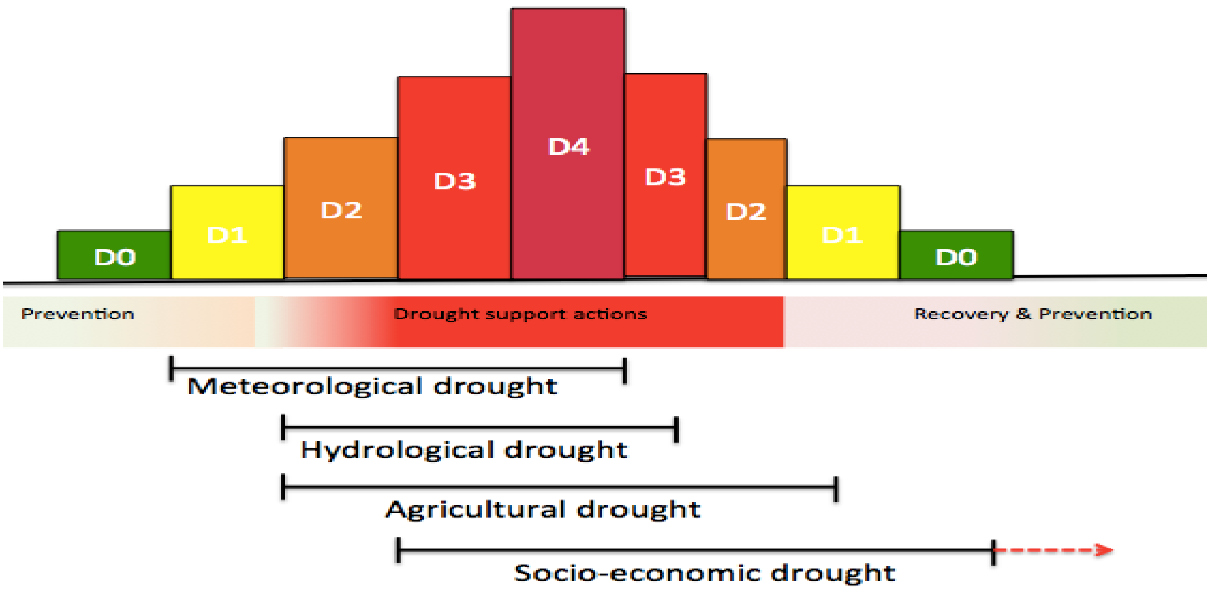


FIGURE 1.4.1: ILLUSTRATION OF DROUGHT CLASSIFICATIONS

Drought is a slow onset disaster with long-term consequences. The first rain during a D3 and D4 drought might end the meteorological drought but not the agricultural drought and especially not the socio-economic drought. The end of the hydrological drought also occurs only during the reservoirs' fill-up and increased stream flow. Therefore, the declassification of droughts needs to consider the lag effect of a particular drought; for example, grass takes months to recover after the first rains, and a drought's socio-economic impact is usually felt two or more years after the drought. In the case of D3 and D4 droughts, the impact is still visible five years after the drought, depending on the vegetation type and follow-up treatment. Livestock farmers reported that in the case of a D4 drought, most farmers do not recover fully, especially when they have to sell breeding stock and lack the resilience to withstand such a drought. Government safety nets must be activated in such cases to support the affected livestock sector. Disaster drought declaration for agricultural drought is imminent during drought phase D2. During a D2 drought, the communal and smallholder agricultural sectors require external assistance. Therefore, a disaster drought declaration is required for phases D3 and D4. Drought phase D4 might require extreme response and recovery measures to secure the long-term sustainability of the agricultural sector.

The description of the drought classification with potential agricultural impacts is summarised in Table 1.4.1.

TABLE 1.4.1. DESCRIPTION AND IMPACT OF DROUGHT CLASSES

Category	Description	Potential impacts
D0	Dry 1:3 year	Going into drought – Dry period: • Short term dryness • Limiting planting conditions • Limiting growth of crops or pastures • Smaller farm dam levels lower than usual • Some fountains stop flowing Coming out of drought – back to normal rainfall: • Some lingering water deficits • Pastures and crops not fully recovered • "Green drought" with young vegetation growth on pastures
D1	Moderate drought 1:5 year	• Streams, reservoirs or wells lower than normal • Some water shortages developing or imminent • Voluntary water restrictions requested • Some damage to crops • Soil moisture deficit for planting crops • Grazing conditions start deteriorating • Animals start showing feeding stress
D2	Severe drought 1:10	• Water shortages is common • Water restrictions imposed • Crop and pasture losses likely • Grazing conditions deteriorated • Animals show serious feeding stress • Groundwater levels going down at selected places • Disaster drought declaration imminent and required for certain sections of society
D3	Extreme drought 1: 15 year	• Widespread water shortages • Groundwater levels very low • Extreme measures to be imposed to limit negative impacts • Negative impact on regional economy • Businesses especially in rural towns under financial stress • Major crop and pasture losses • Severe shortages in natural grazing • Some sales of productive assets • Not enough feed and fodder for animals • Animals in poor condition • High fire alerts
D4	Exceptional drought 1:30 year	• Shortages of water in reservoirs, streams and wells creating water emergencies • Boreholes dried up with extremely low groundwater levels • Rivers dried up • Exceptional and widespread crop and pasture losses • Major sales of productive assets • Forced liquidation of farming enterprises and business in small towns • Potential food insecurity • Widespread economic impact - Impact on national economy • Extreme measures required with extreme response and recovery actions • Very high fire alerts

The indicators and indicator thresholds of the different drought classes is shown in Table 1.4.2.

TABLE 1.4.2. DROUGHT CLASSIFICATION AND INDICATOR THRESHOLDS

				Meteorological		Remote sensing				Hydrological			
Cat	**Description**	**Potential impacts**	**Freq.**	**% Of normal preciptn.**	**SPI**	**NDVI**	**PASG**	**1-month VCI**	**St Veg health Index**	**CPC Soil Moisture %**	**Dam levels zone Z score**	**Str. Flow Z score**	**Ground water level % Z score**
D0	Dry	Dry period: Short term dryness slowing plant Growth of crops and pastures; fire risk above average: some lingering water deficiencies: pastures and crops not fully recovered	1/3yr	<75%for 30days	-0,5 to -0,7		3month PASG <90%	< 90%	36-45	21-30	In the moderately low zone	21-30	60- 100
D1	Moderate drought	Some damage to crops & pastures: fire risk is high: Levels of streams, reservoirs or wells are low: Some water shortages are imminent and developing: voluntary water restrictions requested: early warning	1/5yr	<70%for 30days	-0,8 to -1,2		6-month PASG <90%	<80%	26-35	11-20	In the low zone Z= -0,8 to -1,2	11-20 Z= -0,8 to -1,2	40- 60 Z= -0,8 to -1,2
D2	Severe drought	Crop and pasture losses likely: Fire risk very high: Water shortages common: Water restrictions imposed: drought warning messages: Institutions to prepare for response mechanisms.	1/10yr	<65%for 180days	-1,3 to -1,5		12-month PASG <90%	<70%	16-25	6-10	In the very low zone Z= -1,3 to -1,5	6-10 Z= -1,3 to -1,5	30- 40 Z= -1,3 to -1,5
D3	Extreme drought	Major crop and pasture losses: Extreme fire danger: Widespread water shortages and restrictions compulsory: Extended duration with critical impact: Warning messages must be adhered to: disaster drought declaration: Institutions to implement active response actions.	1/20yr	<60%for 180days	-1,6 to -1,9		12/24-month PASG <80/90%	<60%	6-15	3-5	Water below the absolute minimum Z= -1,6 to -2	3-5 Z= -1,6 to -2	15- 30 Z = -1,6 to -2
D4	Exceptional drought	Exceptional and widespread crop & pasture losses: Exceptional high fire risk: shortages of water in reservoirs, streams and wells creating water emergencies. Water restrictions compulsory: Warning messages must be adhered to: Active response mechanisms: Impacts critical	1/50yr	<65%for 360days	-2 or less		12/24-month PASG <80%	<60%	1-5	0-2	Dams dry Z<-2	0-2 Z<-2	0- 15 Z<-2

1.4.2 Application of Drought Classification

The drought classification is essential because it provides the stimulus for implementing contingency plans for the different sectors. Figure 1.4.2 illustrates the climate profile in a region with climate extremes and the preparedness plan schedule. Timely tactical and operational decisions (preparedness) should happen during normal years, and implementation of contingencies should be activated during different drought classifications. Contingencies in a specific catchment will depend on the drought classification in the affected catchment. Also necessary are the contingencies after the end of the meteorological drought. Socio-economic and agricultural droughts might continue for years after the end of the meteorological drought. For example, grazelands often take years to recover to their former status after a multi-year drought. It is therefore also essential to develop drought recovery contingencies. The livestock sector is especially vulnerable because it might take years for livestock farmers to recover after droughts.

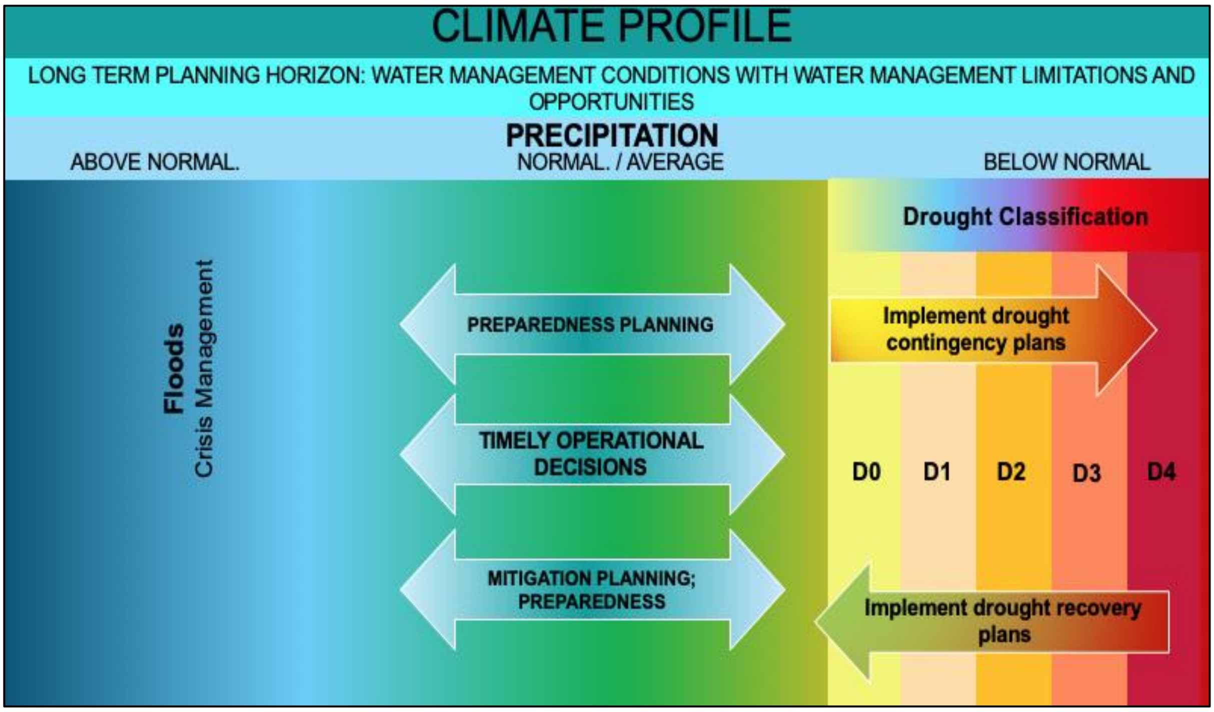


FIGURE 1.4.2: IMPLEMENTATION OF CONTINGENCY PLANS ACCORDING TO DROUGHT CLASSIFICATION
(Jordaan et al, 2017)

The challenge with the proposed drought classification system is the lack of an integrated real-time drought monitor system. Drought monitoring is conducted in silos by different organisations, but an integrated system is lacking. Table 1.3.3 summarises the drought information available to the public in South Africa. It is clear from the results that most of the information is presented in "*silos*" through the different line departments and organisations. Much of the information is also not user-friendly and lacks the integration for proper decision-making.

TABLE 1.4.3. DROUGHT INFORMATION AVAILABLE TO THE PUBLIC

Sector	Drought Information and Communication Systems
Agriculture, Rural Development & Land Reform	**The Department of Agriculture, Rural Development and Land Reform**, AgriSA, AFASA and all provincial agriculture departments briefed the Portfolio Committee on their readiness for the 2019/20 planting season. It was stated in the meeting that the Department provides the farmers with timeous early warning information, which includes prediction of the seasonal forecast, provision of daily extreme weather warnings, market information, as well as any helpful information and advisory services that will enable the farmers to cope well and thrive in all seasons (PMG, 2019). However, a web survey failed to identify the Early Warning System referred to during this meeting. **Agricultural Research Council (ARC):** Information seekers can log onto their website and obtain information such as agricultural economics and capacity development, animal sciences, crop sciences and research and innovation systems. For personalised information, users can register and obtain specific and relevant information. The ARC also has an ARC HUB App with information on the live weather report, crops, livestock production, training, experts in different fields etc. It is a great platform to support farmers and has a very good rating and reviews from users. In addition, the monthly UMLINDI report is a valuable source for drought monitoring and is basically the only source readily available on the web.
Human Settlements, Water & Sanitation	**National Integrated Water Information System (NIWIS)** In 2015, the Department developed a National Integrated Water Information System (NIWIS). The web-based system consists of a set of dashboards to enable managers to make a quick assessment of the water situation in South Africa. The NIWIS dashboards represent the data in an interactive manner that is user-friendly and easy to navigate and understand. The NIWIS is described as a living system that is designed to give an overview at the National level, Provincial or Water Management Area level, and, where possible, at the level of individual items (e.g. dams, weirs etc.). Below is an illustration of the dashboards: NIWIS dashboards are structured and subdivided into categories as follows: - Home – Home or Landing page - Climate and Weather – e.g. climate change - Disaster Management – drought status - DWS Human Resources – Human capital - Infrastructure – Dam safety regulation - Monitoring Networks – For example, surface water - -Water Ecosystems – Groundwater reserve - -Water Quality – drinking water quality - -Water Quantity – surface water storage - -Water Services – access to water - -Water Tariffs – raw water - -Other – contact us, help function, Useful links (Electronic Water Use Application and Authorization System (E-WULAAS), Hydrological Services - Surface Water (Data, Dams, Floods and Flows), National Groundwater Archive (NGA), National Register of Water Use (WARMS), Water Management System (WMS), Water Services Knowledge System (WSKS), External Links Council for Scientific and Industrial Research (CSIR), National Eutrophication Monitoring Programs (EONEMP), Water Information Network System (IHP-WINS), RAMOTSWA Information Management System, SADC HYCOS, Water Resources of South Africa, 2012 Study (WR2012), Water Research Commission (WRC)) (Department of Water and Sanitation 2015).

	The DHSWS NIWS system is probably the most valuable system for water management in SA but still lacks much information for drought monitoring. **Inkomati-Usuthu Catchment Management Agency** The agency helps improve decentralised water resource management decision-making with stakeholders. It manages, protects, uses, conserves and develops the nation's water resources. On their web page is a live infographic dam level monitor of 14 dams. In addition, there is a hydronet water control room and water quality and eco-status reports for water quality status. Furthermore, they actively disseminate information to the media through newsletters, brochures and media releases. **Breede-Gouritz Catchment Management Agency** Provides information for emerging farmers through a package comprising information about institutions in charge of water allocation, access land and grants. They also do roadshows for information dissemination, but a permanent repository is accessible through mobile phones, websites and tablet web. The web page shares catchment management strategies, community projects, dam levels, monitoring points,
Department of Forestry, Fisheries and Environment	The Department has websites with information relevant to the drought through the Branch on Forestry and Natural Resources Management with a Climate Change and Disaster Management Unit. Information in 2016 documents on drought indabas (Department Agriculture Forestry and Fisheries, 2020). The information available says little about drought. However, the South African Air Quality Information System (SAAQIS) provides information on air quality.
South African Weather Services	Customised products and services supplied by the SAWS are available to the public. They are: -WeatherSmart access – users can access the weather by dialing *120*7297# then selecting their area or date immediately. Weather information is available at a click. -Hydronet – web-based decision support system which provides reliable weather forecasts (including the 6-month seasonal forecast in a Grid format), real-time and historical weather data. -WeatherSmart Application - provides the user with location-based forecasts and other handy weather information for your immediate surroundings. In addition, it includes the following features and options: - Location-based forecasts - Severe weather warnings - Weather conditions and forecast for your current location - Search for and add other locations - A seven-day forecast for all your selected locations - Minimum & maximum temperature(s) - Wind direction(s) - Weather notices, warnings and alerts -Industry-Specific Weather Information – user requests weather and climate information for their particular industry. -Weather API – offered through SAWS AfriGIS partner. Users create their applications from various datasets provided. -SAWS is very active in its information dissemination through media releases and newsletters
Health Sector	The health sector's nearest effort to drought support is shown in an article by Wright, Chersich, & Mathee (2019) concerning the National Health Insurance (NHI) and climate change. This article impels South Africans to avoid health risks associated with climate change to benefit fully from the NHI. To help support this, they propose a Health Information System, which includes these components: - Paper-based data system to be replaced with a quality electronic data system for monitoring and analysis. - Data for engaging in research and modelling. Early-warning systems and better integration with the South African Weather Service

Some organisations should take responsibility for drought classification. Drought affects all sectors of society. Therefore, the NDMC should take responsibility for drought classification with the support of the organisations that host the data. Amongst the most significant data hosts are the SAWS, DHSWS and DARDLR. It is important to note that several indicators are essential for accurate classification. Therefore, the drought monitor system should be developed in such detail that each quaternary catchment is classified for meteorological drought, hydrological drought and agricultural drought.

1.5 Drought Indicators

The term 'indicator' has its roots in the Latin words "*indicare*" (to point out, to show, to indicate) and "*index*", literally meaning "*anything used for pointing*" and "*the finger used for pointing*". Several modern languages have inherited the latter meaning. We have, for example, the English index finger, the French index, the Italian *dito indice*, the Spanish *dedo indice*, and the Portuguese *dedo indicador*. In the same way as a pointing finger, an indicator provides information and guidance. Indicators can provide warning signals and thus improve our ability to take early action, contain risks or solve existing problems. In addition, indicators assist us in making evidence-based decisions by allowing us to assess the success of a given policy in achieving its desired objectives (Eurostat, 2014).

Indicators are used in many areas of economic, social and environmental statistics as a valuable way to summarise and present information. Various types of indicators can be applied in many cases, ranging from simple, single-variable indicators to more complex composite indicators that bring together information from several different sources or areas into one standard measure. An indicator is a specific, observable and measurable characteristic of a specific phenomenon – drought in this case. Indicators are, in many cases, a quantitative expression of qualitative observations. Where practically possible, indicators should provide a good idea of the data required for measurement and the conditions for which the indicator is measured. As a result, indicators should be defined in precise, unambiguous terms that describe clearly and precisely what is being measured.

In most cases, each outcome should have at least one indicator. Such an indicator should be clear, focused and specific. Therefore, words such as *'increase", "decrease*", or "*improved*" do not belong to the concept of indicators.

Hammond *et al.* (1995) define indicators as *"quantifiable constructs that provide information either on matters of wider significance than that which is actually measured, or on a process or trend that otherwise might not be apparent".* Existing definitions and terms have been developed over time for different uses. The definitions of composite and sentiment indicators are not always understood in the same way. Furthermore, the indicators themselves may be based on different methods. The literature provides many definitions for indicators, indices and composite indicators (Cannon, 2004; Day, 2004; Vincent, 2004; IADB, 2005; Birkmann, 2006; Gbetibouo & Ringler, 2009). An explanation of each of these terms is necessary in order to avoid confusion.

Indicators are recognised as valuable tools for measuring trends and conditions for policy decisions, especially when it is not easy to measure the phenomena directly (Cannon, 2003; Damm, 2010). The use of indicators to monitor change in the status of people and communities has long been used in the social sciences as a recognised measurement method. In the 1830s, for example, social reformers in Europe, the UK and the USA had already used social statistics and indicators to monitor and improve health conditions amongst people (Gbetibouo & Ringler, 2009). Economic indicators such as GDP, GGP, unemployment rate and terms of trade emerged in the 1940s, with social and environmental indicators growing as a preferred measurement tool in the 1970s. The application of indicators that measure vulnerability to natural hazards has gained momentum since the 1990s due to decision-makers requesting more quantifiable vulnerability data (Dwyer *et al.,* 2004).

Different types of indicators are used to measure different things. The three main indicator categories are single indicators, sentiment indicators and composite indicators. However, sentiment indicators and composite indicators are not mutually exclusive categories. An indicator can be classified both as sentiment and composite indicator. An important consideration for both sentiment indicators and composite indicators is the presence or absence of a reference series, a series that an indicator aims to approximate or predict. Indicators with reference series may exhibit a leading, coincident or lagging relationship with the reference series (Eurostat, 2014).

A summary of some standard indicator definitions is shown in Table 1.5.1.

TABLE 1.5.1. SOME COMMON INDICATOR DEFINITIONS

Source	Definition
Gallopin, 1997	Indicators are variables which is an operational representation of an attribute of a system.
OECD/DAC, 2002	A quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, reflect changes connected to an intervention, or help assess the performance of a development actor
Dwyer et al., 2004	Indicators only indicate broad and complex social concepts
USAID, 2006	A variable whose purpose is to measure a change in a phenomena or process
European Commission	A description of the project's objectives in terms of quantity, quality, target groups, time and place
Birkmann et al., 2006	An index number is a measure of quantity relative to a base period. Indices are a statistical concept, providing an indirect way of measuring a given quantity or state, allowing comparison over time. An index's main point, however, is to quantify something that cannot be measured directly and to measure changes.
Cutter et al., 2008	Indicators are quantitative measures intended to represent a characteristic or a parameter of a system of interest.
International Institute for Sustainable Development, 2011	An indicator quantifies and simplifies phenomena and helps us understand complex realities. Indicators are raw and processed data aggregates, but they can be further aggregated to form complex indices.
MDF, 2011	An indicator can be defined as something that helps us understand where we are, where we are going and how far we are from the goal. Therefore, it can be a sign, number, graphic, etc. It must be a clue, a symptom, a pointer to something changing. Indicators are presentations of measurement. They are bits of information that summarise the characteristics of systems or highlight what is happening in a system.
Investors, 2011	An index is a statistical indicator representing the value of the securities which constitute it. Indices often serve as barometers for a given market or industry and benchmarks against which financial or economic performance is measured
Businessdictionary, 2011	An indicator is a measurable variable used to represent an associated (but non-measured or non-measurable) factor or quantity. For example, the consumer price index (CPI) serves as an aggregate indicator of the general cost of living, which consists of many factors, some of which are not included in computing CPI. Indicators are common statistical devices employed in economics.

(Source: Jordaan, 2011)

Adriaanse (1994) explains the different terms at the hand of an indicator pyramid illustrated in Figure 1.5.1.

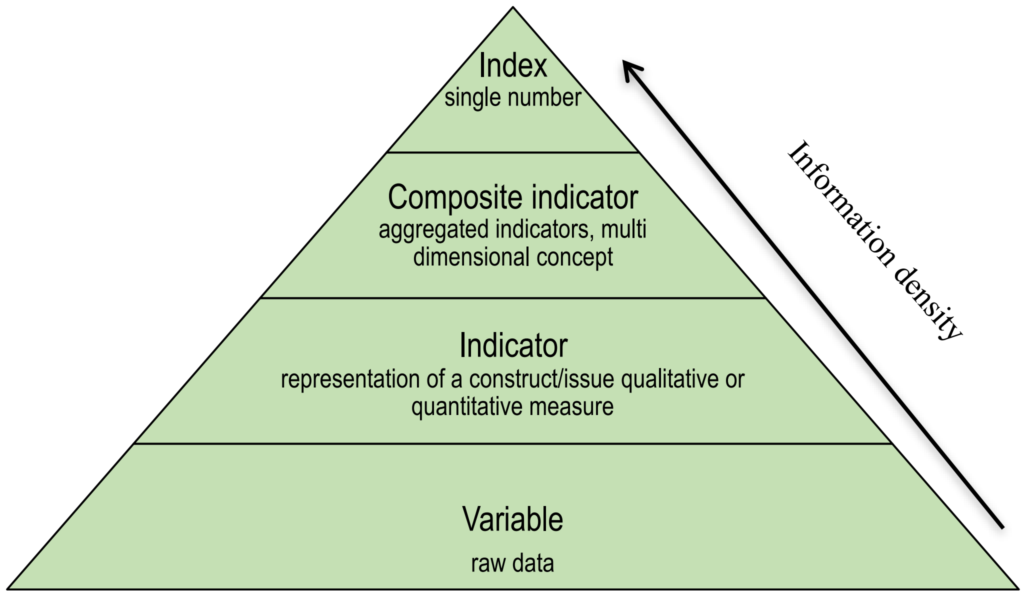


FIGURE 1.5.1: INDICATOR PYRAMID
(Source: Adriaanse, 1994)

In order to explain the *ranking* of the terms, raw data is used to develop an indicator. For example, low levels of education indicate social vulnerability or the lack of land ownership, and the absence of insurance products can be indicators of economic or financial vulnerability. Low levels of education plus unemployment rate plus livelihood deprivation, asset ownership, and low-income levels are called a composite or aggregated indicator for poverty, which then can be transformed into an index for social vulnerability. Similarly, the lack of insurance, no alternative income sources, no capital reserves, volatility of product prices and lower demand for products are aggregate indicators of economic vulnerability. Therefore, they can provide an index for economic vulnerability.

Characteristics of good indicators are (Gage & Dunn, 2009; Eurostat, 2014):

- **Measurable:** should be quantifiable using available methods and tools. In some cases, an index is used to quantify qualitative observations.
- **Precise:** operationally defined in clear terms
- **Reliable:** consistently measurable over time, in the same way by different observers
- **Valid:** an accurate measure of a phenomenon, behaviour, practice, or task that is the expected output, outcome or impact of the phenomenon (drought) or intervention
- **Timely:** provides a measurement at time intervals relevant and appropriate in terms of characteristics, impacts, programme goals and activities
- **Programmatically important:** linked to the programs or phenomenon or to achieving the objectives.

The following tables are some examples of different categories of indicators.

TABLE 1.5.2. USE OF INDICATORS FOR DESCRIPTION OR MEASUREMENT OF PERFORMANCE

Indicator	Description	Example
Descriptive or contextual, or situational	The indicator describes a situation or trend and further explains a phenomenon. It reflects the situation as it is, without reference to how the situation should be	Drought indicators such as SPI, NDVI, and stream flow. Describe the current state and impact of drought
Performance or normative	The indicator allows statements to be made describing the situation as better or worse. It shows progress, or the lack of it, towards established objectives and targets or the desired end-state	Lower than average crop yields, deteriorating veld condition

TABLE 1.5.3. ECONOMIC CYCLE FRAMEWORK INDICATORS

Indicator	Description	Example
Leading indicator	The indicator changes before a change are seen in general economic conditions and can be used to predict turning points in the business cycle.	The number of forced sales of animals also creates an expectation of meat scarcity and increased food prices.
Coincident indicator	The indicator changes (more or less) simultaneously with general economic conditions and therefore reflects the economy's current status.	Total number of animals sold during the first months of drought, characterised by increased food prices
Lagging indicator	The indicator changes after macroeconomic conditions have changed. Lagging indicators confirm economic trends that have already been predicted by leading indicators or shown by coincident indicators.	The number of job losses because of drought. Increased number of people experiencing food shortages

TABLE 1.5.4. DRIVING FORCES, PRESSURE, STATE IMPACT AND RESPONSE FRAMEWORK INDICATORS

Indicator	Description	Example
Leading indicator	The indicator describes the social, demographic or economic developments in societies and the corresponding changes in lifestyles and overall levels of consumption and production patterns.	The number of forced sales of animals also creates an expectation of meat scarcity and increased food prices
Coincident indicator	The indicator describes developments in the release of substances, physical and biological agents, the use of resources and the use of land.	Total number of animals sold during the first months of drought, characterised by increased food prices
Lagging indicator	The indicator describes the quantity and quality of physical, biological and chemical variables in a particular area	The number of job losses because of drought. Increased number of people experiencing food shortages

Drought classification is based on several indicators with thresholds for the different drought categories. Information sources for drought classification include (i) meteorological data and forecasts, (ii) drought impact indicators (remotely sensed indicators), (iii) available data, (iv) warning signals and (v) farm-level information required for ground-truthing of remotely sensed indicators. Drought indicators are classified as primary and secondary drought indicators. The primary indicators are those easy to monitor quantitatively through meteorological data, remotely sensed data and gauging stations. On the other hand, secondary indicators represent meteorological data and drought impacts reported from reference farms and other organisations (Jordaan *et al.*, 2017). Quantitative indicators should be monitored in real-time, considering that not one single drought index fits all needs to determine the different types of drought.

1.5.1 Implementing the use of drought indicators

Not all dry periods are droughts, and the impact of dry periods is different between different sectors. Therefore, the use of the prescribed indicators without the consideration of the sector-specific characteristics is foolish. Factors to consider before drought classification are the following:

Primary indicators: At least three of the indicators must have a threshold for at least a D2 drought, at which stage one can expect secondary indicators also to indicate a drought.

Secondary indicators: Grazing on the reference should display definite dry conditions, and the farmer should reduce animal numbers by 30%. Crops should reveal definite signs of water stress with potential crop losses of at least 40%.

Time of monitoring: The three-month SPI during the growing season can lead to a disaster drought for crop farmers. The same SPI value outside the growing season might only be regarded as a dry period with little impact. Reservoir levels are also linked to seasonality; for example, reservoirs with low water levels at the beginning of the rainy season are not a problem compared to empty reservoirs at the end of the rainy season, which could lead to water shortages. One needs to consider the seasonality and growing season of different crops and grazing on livestock farms with the classification of drought; therefore, the use of secondary indicators to ground-truth the impact of a dry period.

Sector differences: The difference between the communal farming sector and the commercial farmers in drought vulnerability and resilience is significant (Jordaan, 2011, Jordaan *et al.*, 2017). Communal farmers and the smallholder farming sector are extremely vulnerable to drought because of (i) over-grazing, (ii) land degradation, (iii) poor infrastructure and water reticulation on their land, (iv) no grazing management systems, (v) poor quality animals, (vi) lack of reserves, (vii) imperfect markets, (viii) lack of knowledge, and (ix) cultural beliefs (Jordaan, 2011). Communal farmers experience dry periods as droughts and report significant drought losses every third year. A D0 and a D1 drought could be disastrous for them while, on the other hand, most commercial farmers can manage a D2 drought. Figure 1.5.2 illustrates the dilemma at the hand of drought loss functions.

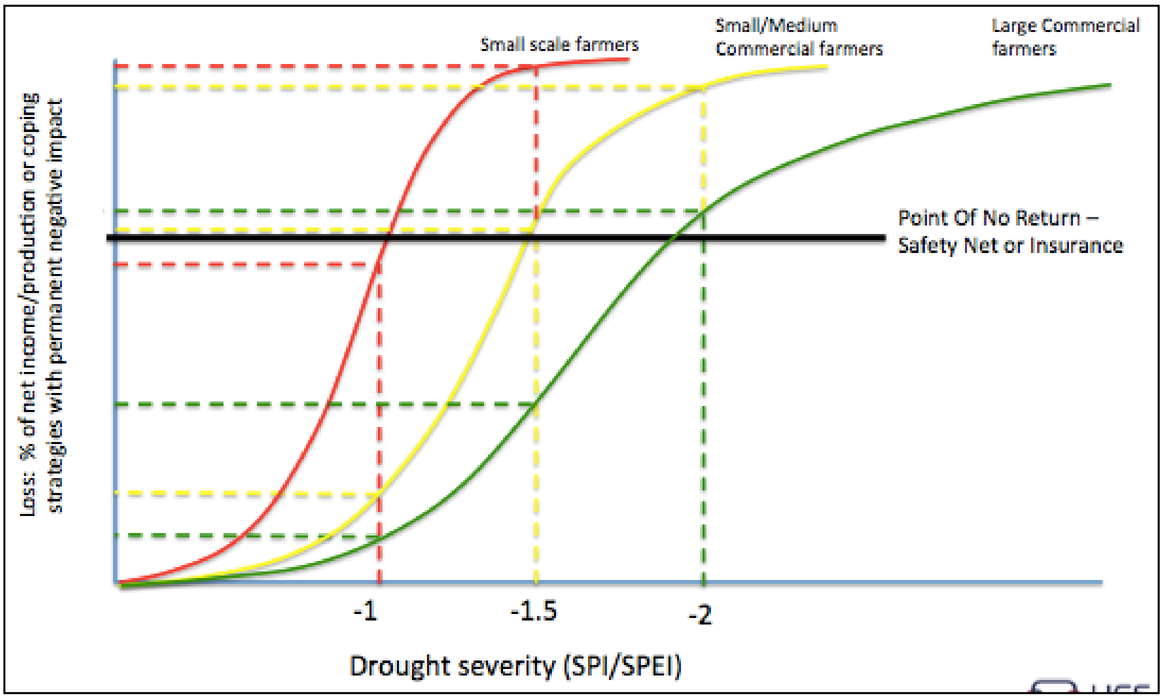


FIGURE 1.5.2: DROUGHT LOSS FUNCTIONS FOR DIFFERENT AGRICULTURAL FARMER CATEGORIES

Figure 1.5.2 illustrates typical drought loss functions for smallholder or communal livestock farmers, medium-scale farmers and large commercial farmers. SPI values are illustrated on the x-axis, and production loss is a percentage of their wealth normal production on the y-axis. Smallholder communal farmers already lose more than 50% of normal production at a 12-month SPI value of -1.2 and require safety net activation long before the larger and more resilient farmers. More than 2 million people are classified as smallholder farmers in SA, and 40% of domestic livestock in SA is owned by this sector (DAFF, 2014). These farmers produce mainly only enough for subsistence, but that in itself is significant in that they contribute to the total food production in South Africa. Furthermore, each one of these farmers, who migrated out of Agriculture because of drought, became an additional burden on the social security system in South Africa. Therefore, it is strategically important to provide safety nets to support smallholder and communal farmers with continued production.

Indications are that drought safety nets should be activated for communal farmers already at drought stage 2, which is characterised by SPI -1,2. Drought declaration and activation for commercial farmers is at drought D3 with SPI <-1,5. For livestock farmers, one should use the 12- and 24-month SPI, while the 6-month SPI during the growing season is more relevant for crop farmers. Obviously, one should also consider other indicators in conjunction with the SPI.

The resilience or the ability of a household to cope with shocks is a function of several factors. The available options such as distance from labour and produce markets (roads, large urban centres), nearby forests, water sources and tourism all influence the resiliency and coping strategies of communities (Watts, 1983; Richards, 1986; Corbett, 1988; Hutschinson, 1992; Rocheleau *et al.*, 1995; FEWS, 1999; de Waal, 2004; Smucker & Wisner, 2007; Erikson & Silva, 2009, Jordaan, 2011, Jordaan *et al.*, 2017). The level of own resources a household can draw for survival is also critical (Little *et al.*, 2006; De la Fuente, 2007; Dercon & Porter, 2007; de la Fuente, 2008; Jordaan, 2011).

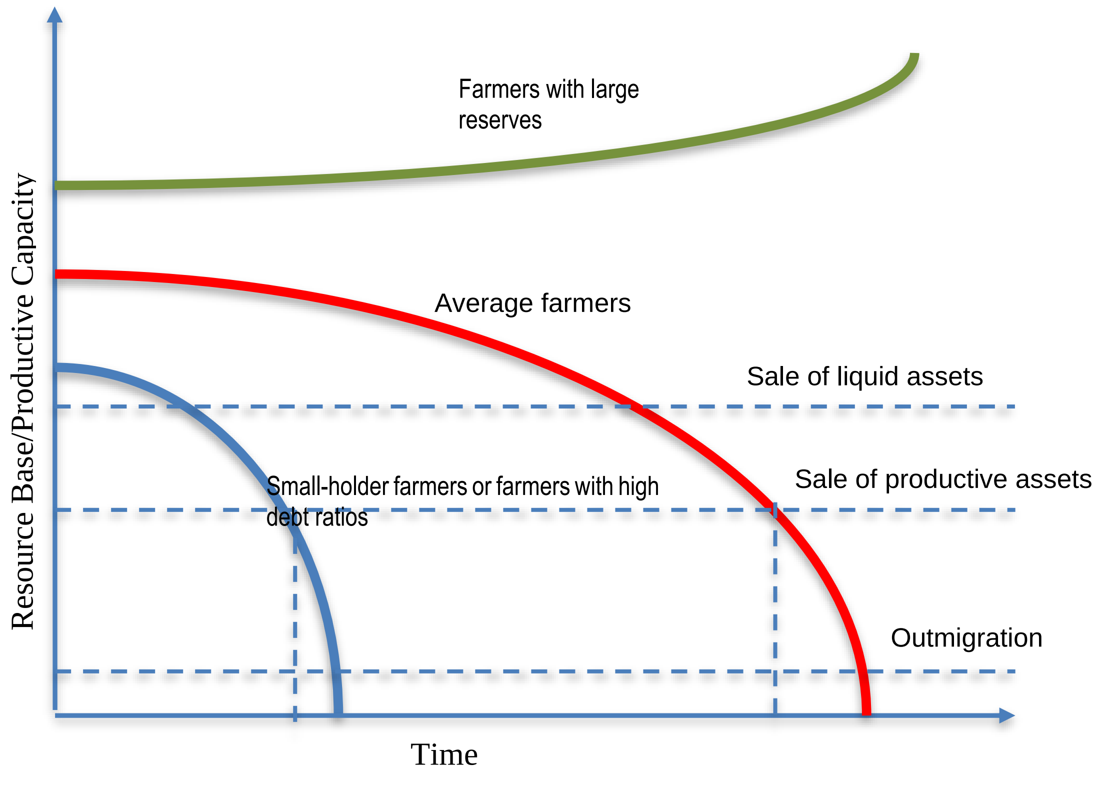


FIGURE 1.5.3: DROUGHT RESPONSE OF FARMERS AS A FUNCTION OF THEIR RESOURCE BASE
(Source: Author after FEWS (1999)).

Figure 1.5.3 compares the different thresholds of households with different levels of own resources. It is clearly illustrated in Figure 4.3 that households with different resource levels reach different thresholds at different times.

Illustrated in Figure 1.5.3 is that households with large resource levels (richer households), in many cases, managed to increase their resource base due to favourable prices for animals or other goods (FEWS, 1999; Erikson & Silva, 2009, Jordaan, 2011, Jordaan, 2016; Jordaan *et al.,* 2017). They are the only ones with capital and are in a position to exploit members of lower economic classes or smaller farmers (FEWS, 1999; Jordaan, 2011). Dercon & Porter (2007), De la Fuente & Dercon (2008) and Porter (2010) confirms previous findings from other researchers in Ethiopia, where the outcome of shocks varies dramatically among households with little resource base (poor households) compared to *"richer"* households.

Farmers with high debt ratios show the same characteristics as farmers with a low resource base since they are forced to service debts even in times of shortages and cannot withstand severe or extreme droughts.

1.5.2 List of drought indicators

Drought is a complex phenomenon with wide-ranging impacts on different systems and in different climates and geographic regions. Comparing drought between climate zones and different systems is very difficult (Hisdal *et al.*, 2004, Gerber, 2022). Therefore, the use of a single drought indicator is not desirable. Authorities in South Africa rely mostly on meteorological and vegetative indicators but even that could provide a false result. Gerber (2022) reported that the Department of Agriculture in the Northern Cape has already adjusted indicator thresholds unique to the arid Northern Cape.

Drought classification should rely on expert analysis that synthesises the best available data from multiple sources and work with local observers (farmers in this case) to localise drought information as much as possible. Numeric inputs for meteorological drought are (i) precipitation, (ii) temperature, (iii) wind speed, (iv) evapotranspiration, (v) transpiration and (vi) derived indicators such as the (vi) Standardized Precipitation Index (SPI), (vii) Standardised Evaporation Precipitation Index (SPEI), (viii) Percentage of Normal Rainfall, (ix) Deciles, and other meteorological indicators.

Remotely sensed indicators that measure the impact of meteorological dryness are (i) NDVI, (ii) PASG, (iii) VCI, (iv) SVHI, (v) CPC Soil Moisture Index, and other indices. These indicators represent agricultural drought. Hydrological drought indicators that require constant monitoring are (i) dam and reservoir levels, (ii) stream flow, and (iii) groundwater levels. Municipalities, industry and mining are more concerned about hydrological drought, and an essential indicator for municipalities and irrigation farmers is the demand/supply ratio. The demand/supply ratio is essential in that it is sensitive to factors controlled by people. Leakages in water infrastructure, for example, increase water demand and directly impact the demand/supply ratio.

Meteorologists and other specialists developed numerous indicators for drought, yet none of these satisfied the need under all conditions. Examples of these in alphabetical order are (i) crop moisture index (CMI) (ii) mean monthly rainfall deficit, (iii) per cent of mean precipitation, (iv) Palmer Drought Severity Index (PDI) (Palmer 1968; Alley, 1984; Karl & Knight, 1985), (v) PUTU suite of plant models (Fouche, de Jager & Opperman, 1985; Fouche, 1992), (vi) Rainfall Anomaly Index (Van Rooy, 1966), (vii) relative drought resistance method (Roux, 1993), (viii) rainfall deciles method (Erasmus, 1991), (ix) Roux expert system (Roux, 1991) (x) surface water supply index (SWSI) (Shafer & Dezman, 1982) (xi) reclamation drought index (xii) deciles (Gibbs & Mather, 1967) (xiii) Standard Precipitation Index (SPI) (McKee *et al.,* 1993) (xiv) Standard Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano *et al.,* 2010) (xv) ZA schrubland model (Venter, 1992), (xvi) Zucchini-Adamson models (Zucchini, Adamson & McNeill, 1991), and others which are not relevant in the context of this study (Du Pisani, Fouche & Venter, 1998; Wilhite, 2000; WMO, 2006; Vasilaides & Loukas, 2009).

Several indices measure the deviation of precipitation for a given period from historical norms. None of the major indices is inherently superior to the rest in all circumstances, yet some indices are better suited than others for certain uses (UNCCD, 2009). The Palmer Drought Severity Index (PDSI), for example, has been widely used by the US Department of Agriculture to determine when to grant emergency drought assistance and can be used when working with large areas of uniform topography such as the Karoo. However, areas with mountainous terrain and the resulting complex regional microclimates find it useful to supplement Palmer values with other indices such as the Surface Water Supply Index (SWSI), which takes snowpack and other unique conditions into account. The most commonly used index worldwide, though, is the Standardised Precipitation Index (SPI) and, where possible, the Standardised Precipitation Evaporation Index (SPEI) (UNCCD, 2009).

The SPI and SPEI are among the most important indicators to characterise meteorological droughts worldwide. This is because temperature and evaporation play a vital role in moisture deficit, and the SPEI provide a better indicator for drought than the SPI (Vicente-Serrano, Begueria & Lopez, 2010; Beguria *et al.*, 2010). On the other hand, Kim, Byun and Choi (2009) believe that the Effective Drought Index (EDI) is a better index than the SPI and SPEI since runoff during heavy storms is considered, which is not the case with SPI and SPEI.

The Department of Agriculture Fisheries and Forestry (DAFF) – currently, Department Forestry, Fisheries and Environment (DFFE) - with the approval of the National Drought Task Team, finalised drought hazard indicators to be used in the future (Jordaan *et al.*, 2015). Tables 1.5.5 to 1.5.10 provide a summary of available indicators that is easy to use and is used regularly by different countries. Indicator classification is done according to meteorological, remotely sensed vegetation indicators, hydrological and composite indicators. Globally more than sixty drought indicators are listed in the literature. The following are the acronyms for certain concepts used in the indicator list.

AWC	Available water content	Rad	Solar Radiation
CC	Crop coefficient	RD	Reservoir
CD	Crop data	S	Snowpack
ER	Eco region	Sat	Satellite
ET	Evapotranspiration	SF	Stream flow
GW	Groundwater	ST	Soil type
LC	Land cover	SWD	Soil water deficit
Mod	Modelled	T	Temperature
Multiple	Multiple indicators used	Td	Dew point Temperature
P	Precipitation	W	Wind data
PET	Potential Wind Data	Y	Yield data (crops)

Known drought indicators listed in publications are summarised in the following tables.

TABLE 1.5.5. METEOROLOGICAL INDICATORS

	Index	Input parameters	Additional Information
	Aridity Anomaly Index	P, T, PET, ET	Easy to calculate but not operationally used in SA
	Aridity Index	P, T	Easy to calculate. Can also be used for climate classifications
	Consecutive dry days (CDD)	P	Easy to calculate.
	Cumulative Precipitation Anomaly (CPA)	P	
	Crop Moisture Index (CMI)	P, T	Requires weekly values for both P and T
	China Z Index	P, T	Intended to improve on SPI. Simple to calculate
	Deciles (DECILES)	P	Easy to calculate. Used in Australia
	Drought Area Index (DAI)	P	
	Drought Frequency Index (DFI)	P	
	Drought Reconnaissance Index (DRI)	P, T	Requires monthly P and T data. Valuable to identify the onset and end of water deficit periods
	Drought Severity Index (DSI)		
	Effective Drought Index (EDI)	P	Requires daily effective precipitation (EP), daily mean EP, deviation of EP (DEP) and the standardized value of DEP.
	Effective Precipitation (EP)		
	Evapotranspiration Deficit Index (ETDI)	P, T,	Complex calculations with multiple inputs required
	Keetch-Byran Drought Index (KBDI)	P, T	Calculations are based upon the climate of the area of interest. Developed to identify drought in the early stages using a uniform method specific to the climate of the region. It is the net effect of evapotranspiration and precipitation in producing a moisture deficiency in the upper layers of the soil and also gives an indication of how much precipitation is needed for saturation of the soil and eliminating drought stress.

	NOAA Drought Index (NDI)	P	Best used for application in agriculture. A precipitation-based index in which the actual precipitation measured is compared with normal values during the growing season.
	Palmer Drought Severity Index (PDSI)	P, T, AWC	Complex calculations and requires serially complete data
	Percentage of Normal Precipitation (PN)	P	Easy to calculate. Used in South Africa together with SPI. Percent of normal is calculated by dividing a given precipitation by the normal. The time scale of the analysis can vary from a single month to a year
	Palfai Aridity Index (PAI)	P, ET	Ratio of the mean annual P and the mean annual ET. Higher values represent more humid areas.
	Rainfall Anomaly Index (RAI)	P	Requires serially complete data
	Reconnaissance Drought Index (RecDI)	P, PET	Combine P and PET in a single index. Similar to the SPEI
	Standardised Anomaly Index (SAI)	P	Requires P data at monthly, seasonal or annual time steps. Easy to calculate
	Standardised Precipitation Index (SPI)	P	Globally widely used. Most common indicator in SA.
	Standardised Precipitation Evaporation Index (SPEI)	P, ET	More accurate than SPI. Combine P and ET in same calculation
	Soil Moisture Anomaly Index (SMI)	P, T	
	Weighted Anomaly Standardised Precipitation (WASP)	P, T	Uses gridded data for monitoring drought in tropical regions. Might be applicable for use in high rainfall areas
	Z-Score	P	Simple to calculate but shorter time scale with large difference in mean and median might not be accurate. Also valuable for hydrological drought

TABLE 1.5.6. HYDROLOGICAL INDICATORS

	Index	Input parameters	Additional Information
	Base Flow Index (BFI)	SF, G.	Ratio of long-term baseflow to total streamflow and it represents the continuous contribution of groundwater to river flow.
	Cumulative Streamflow Anomaly (CSA)	Surface water demand and freshwater biota	The deficit anomaly indices provide more differentiated, spatial and temporal patterns that help to distinguish the degree of the actual drought hazard to vegetation health or the water supply.
	Dam Levels (DL)	Dam levels, daily/weekly	Dam levels
	Groundwater Levels (GL)	Groundwater levels, monthly	Actual groundwater level as a % from maximum
	Groundwater Resource Index (GRI)		
	Low Flow Index (Q90)		
	Normalised Difference Water Index (NDWI)		
	Palmer Hydrological Drought Index (PHDI)	P, T, AWC	Interpolation over large areas is challenging due to variations in soil types and different crops. Based on the original PDSI and modified to take into account longer-term dryness that will affect water storage, streamflow and groundwater. PHDI has the ability to calculate when a drought will end based on precipitation needed by using a ratio of moisture received to moisture required to end a drought.
	Palmer Z Index (Z-Index)	Streamflow or dam levels	
	Regional Streamflow Deficiency Index (RSDI)	Srtreamflow	
	Simple Water Ratio Index (SRWI)	Surface water	

	Standardised Reservoir Supply Index (SRSI)	Reservoir	Similar calculation as SPI using reservoir data
	Standardised Streamflow Index (SSSI)	Streamflow	Similar calculation as SPI using streamflow data
	Standardised Water Level Index (SWI)	Groundwater	Similar calculation as SPI using groundwater level data
	Streamflow (SL)		
	Surface Water Supply Index (SWSI)	Snow	Explicitly accounts for snowpack and its delayed runoff
	Total Water Deficit Index (TSDI)	Streamflow, Reservoir levels	A traditional assessment of hydrological drought is total water deficit, synonymous with the drought severity S. This severity is the product of the duration D, during which flows are consistently below some truncation level (e.g., the hydroclimatic mean), and the magnitude M, which is the average departure of streamflow from the truncation level during the drought period
	Water Index (WI)	Streamflow, Reservoir levels	

TABLE 1.5.7. VEGETATION INDICATORS

	Index	Input parameters	Additional Information
	Anomaly of Normalised Difference Vegetation Index (NDVIA)		
	Corn Drought Index (CDI)		
	Crop Specific Drought Index (CSDI)	T(min), T(max). P, W, SR, ST, Y	One of the first attempts to monitor and identify drought-related agricultural impacts using remotely sensed data. AVHRR data in the visible, infrared and near-infrared channels are all used to identify and classify stress to vegetation due to drought.
	Vegetation Water Moisture Index (VWMI)		
	Leaf Water Content Index (LWCI)		
	Modified Perpendicular Drought Index (MDPI)		

	Modified Perpendicular Drought Index (MDPI)		
	Normalised Burn Ration (NBR)		
	Normalised Difference Vegetation Index (NDVI)	AVHRR satellite data	
	Normalised Difference Infrared Index (NDII)		
	Perpendicular Drought Index (PerDI)		
	Soybean Drought Index (SCI)	T(min), T(max). P, W, SR, ST, Y	Specifically designed for soybean growth monitoring
	Standardised Vegetation Index (SVI)		
	Temperature Condition Index (TCI)	AVHRR satellite data	Using AVHRR thermal bands, TCI is used to determine stress on vegetation caused by temperatures and excessive wetness. Conditions are estimated relative to the maximum and minimum temperatures and modified to reflect different vegetation responses to temperature. Used in conjunction with NDVI and the Vegetation Condition Index (VCI) for drought assessment of vegetation in situations where agricultural impacts are the primary concern.
	Vegetation Condition Index (VCI)		
	Vegetation Condition Albedo Drought Index (VCADI)		
	Vegetation Health Index (VHI)	AVHRR Satellite data	One of the first attempts to monitor and identify drought-related agricultural impacts using remotely sensed data. AVHRR data in the visible, infrared and near-infrared channels are all used to identify and classify stress to vegetation due to drought.

TABLE 1.5.8. SOIL MOISTURE INDICATORS

	Index	Input parameters	Additional Information
	Agricultural Reference Drought Index (ARDI)	P, T	The ARID predicts the status of moisture availability in the soil. It uses a combination of water stress approximations and crop models to identify the impact on of water stress on plant growth, development and yield for specific crops.
	Soil Moisture Deficit Index (SMDI)	Modelled from various parameters	A weekly soil moisture product calculated at four different soil depths, including the total soil column, at 0.61, 1.23 and 1.83 m, and can be used as in indicator of short-term drought, especially using the results from the 0.61m layer.
	Soil Moisture Drought Index (SMDI)		

TABLE 1.5.9. COMPOSITE DROUGHT INDICATORS

	Index	Input parameters	Additional Information
	Aggregate Drought Index (ADI)	P, ET, S, R, AW,SP	Difficult to calculate. Requires large amount of data. Can be used in the context of multiple types of drought impacts. Looking at the total amount of water in a climate regime allows a better understanding of water availability to be made. Takes into account water stored as well as moisture that comes from precipitation.
	Agricultural Drought index (AgricDI)		
	Bhalme and Mooly Drought Index (BMDI)		
	Combined Drought Indicators (CDI)	P, SM, Veg Modelled and requires also satellite data	Composed of three warning levels (watch, warning and alert) by integrating three drought indicators: SPI, soil moisture and remotely sensed vegetation data. A watch is indicated when there is a precipitation shortage, a warning level is reached when the precipitation shortage translates into a soil moisture shortage, and a

			warning occurs when the precipitation and soil moisture deficits translate into an impact to the vegetation. For use in agriculture.
	Crop Specific Drought Index	P, T, S, RD, SF	Quality data of many variables needed. Challenging to use
	Multivariate Standardised Drought Index (MSDI)	P, SM Modelled	Uses information on both P and SM to identify and classify drought episodes by investigating P and SM deficits. It is helpful for identifying drought episodes where typical P-based indicators or SM-based indicators on its own may not indicate the presence of drought.
	Modified Palmer Drought Severity Index (MPDSI)		
	Normalised Multiband Drought Index (NMDI)		
	Palmer Drought Severity Index (PDSI)	P, T, ST	Calculated using monthly temperature and precipitation data along with information on the water-holding capacity of soils. It takes into account moisture received (precipitation) as well as moisture stored in the soil, accounting for the potential loss of moisture due to temperature influences.
	Reclamation Drought Index (RDI)	P, T, S, RD, SF	Similar to surface water supply index but also requires P and T data. Applicable in regions with snow as one of the water sources
	Remote Sensing Drought Risk Index (RSDRI)		
	Sperling Drought Index		
	Soil Moisture Anomaly Index (SMA)	P, T, AWC	Intended to improve on the water balance of PDSI. Can use weekly or monthly precipitation and potential evapotranspiration values in a simple water balance equation. It is intended to reflect the degree of dryness or saturation of the soil compared with normal conditions and to show how soil moisture stress influences crop production around the world.
	Surface Water Supply Index	P, R, S, SP	Many methodologies and derivatives are available, but comparisons between basins are subject to the method chosen

	United States Drought Monitor	Multiple	Interpretation of local and regional conditions is required
	Vegetation Drought Response Index	SPI, PDSI, % annual seasonal greenness, start of season anomaly, land cover, soil available water capacity, derived variables.	Developed as a drought index that was intended to monitor drought-induced vegetation stress using a combination of remote sensing, climate-based indicators, and other biophysical information and land-use data.

TABLE 1.5.10. INDICES DEVELOP WITHIN SOUTH AFRICA FOR SOUTH AFRICAN DROUGHT CONDITIONS

	Index	Input parameters	Additional Information
	PUTU Suite of Plant Models		
	Relative Drought Resistance Model		
	ZA Shrubland Model		
	Zucchini-Adams Drought Model		

1.6 Indicators Proposed for the Livestock Sector in South Africa

This section focuses on current and potential indicators useful for the extensive livestock sector. The first part deals with meteorological indicators followed by a discussion of remotely sensed indicators for drought.

1.6.1 Meteorological

Three indicators are currently in use in South Africa namely percentage of normal precipitation, precipitation deciles and the SPI. The SPEI is also discussed as it provides more accurate results by the inclusion of evapotranspiration in the equation for SPEI.

1.6.1.1 Precipitation expressed as percentage of the long-term mean

The long-term mean percentage precipitation is the most common and easiest way to indicate drought classification. Below the threshold of 75% for a certain period, the index may indicate meteorological drought. Depending on the period for which the deviation is calculated, it may serve as an indicator for both agricultural (12 months and less) and hydrological (24 months and more) droughts. The timing of deviation is crucial for rainfed crop framers. A low percentage of average precipitation combined with high temperatures during the growing season of specific crops might have disastrous results. On the other hand, a low percentage of average precipitation outside the growing season might not be as damaging.

An example of a percentage of normal precipitation is illustrated in Figure 1.6.1. The map in Figure 1.6.1 is part of a larger report named UMLINDI or on the web site www://drought.agric.gov.za produced monthly by the Agricultural Research Council (ARC). The percentage of normal precipitation are always linked to a specific period.

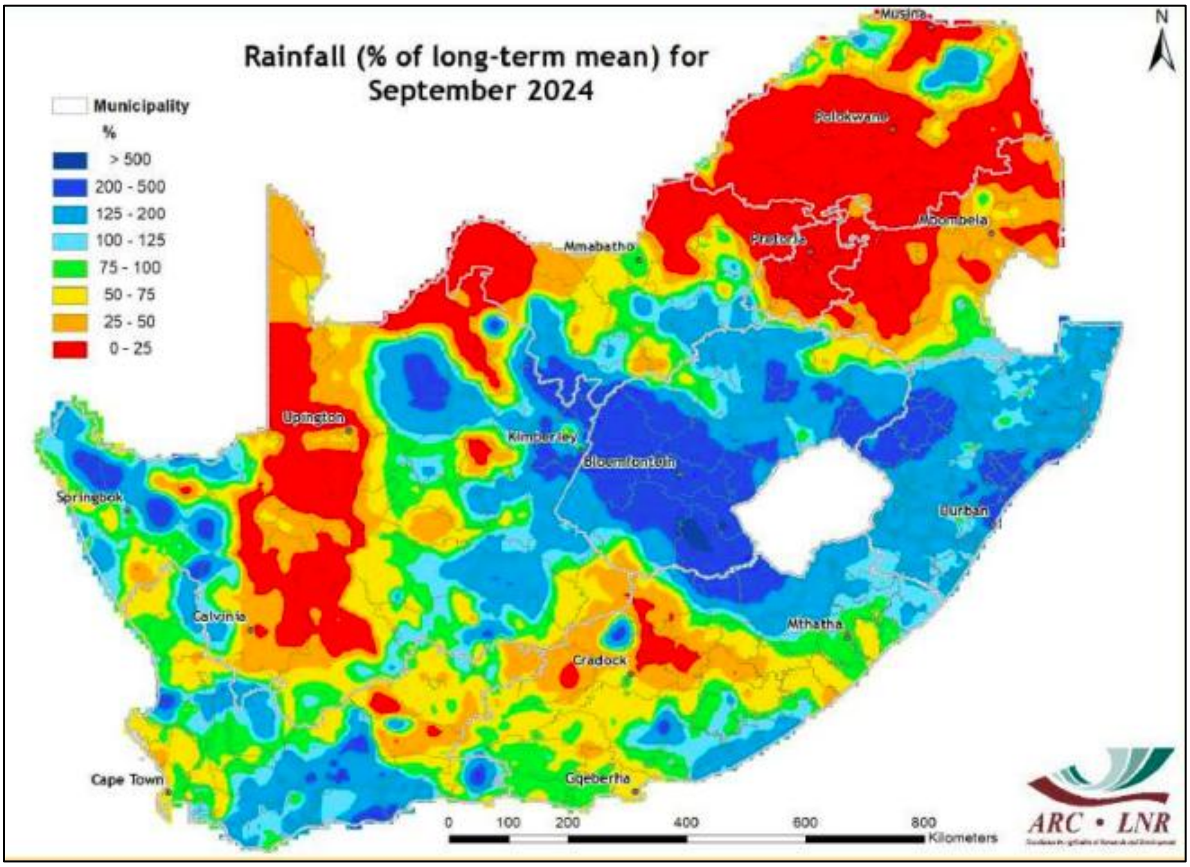


FIGURE 1.6.1: PERCENTAGE OF LONG TERM MEAN FOR SOUTH AFRICA, SEPTEMBER 2022
(Source: ARC, 2024)

The categories currently used are not fully aligned with the proposed drought classification system for South Africa and the decile system discussed in the following sub-section. The category 0% to 25% of average precipitation for a single month is not necessarily a reflection of drought. The decile categories for the proposed South African drought classification system are as follows:

- D0 drought (Dry period) = <75% of mean precipitation for 30 days
- D1 drought (Moderate drought) = <70% of mean precipitation for 30 days
- D2 drought (Severe drought) = <65% of mean precipitation for 180 days
- D3 drought (Extreme drought) = <60% of mean precipitation for 180 days
- D4 drought (Extraordinary drought) = <65% of mean precipitation for 360 days

Figure 1.6.2 shows the percentage of long term mean precipitation for the period April 2024 to September 2024. It is clear that the comparison of the longer-term data is more reliable for drought classification.

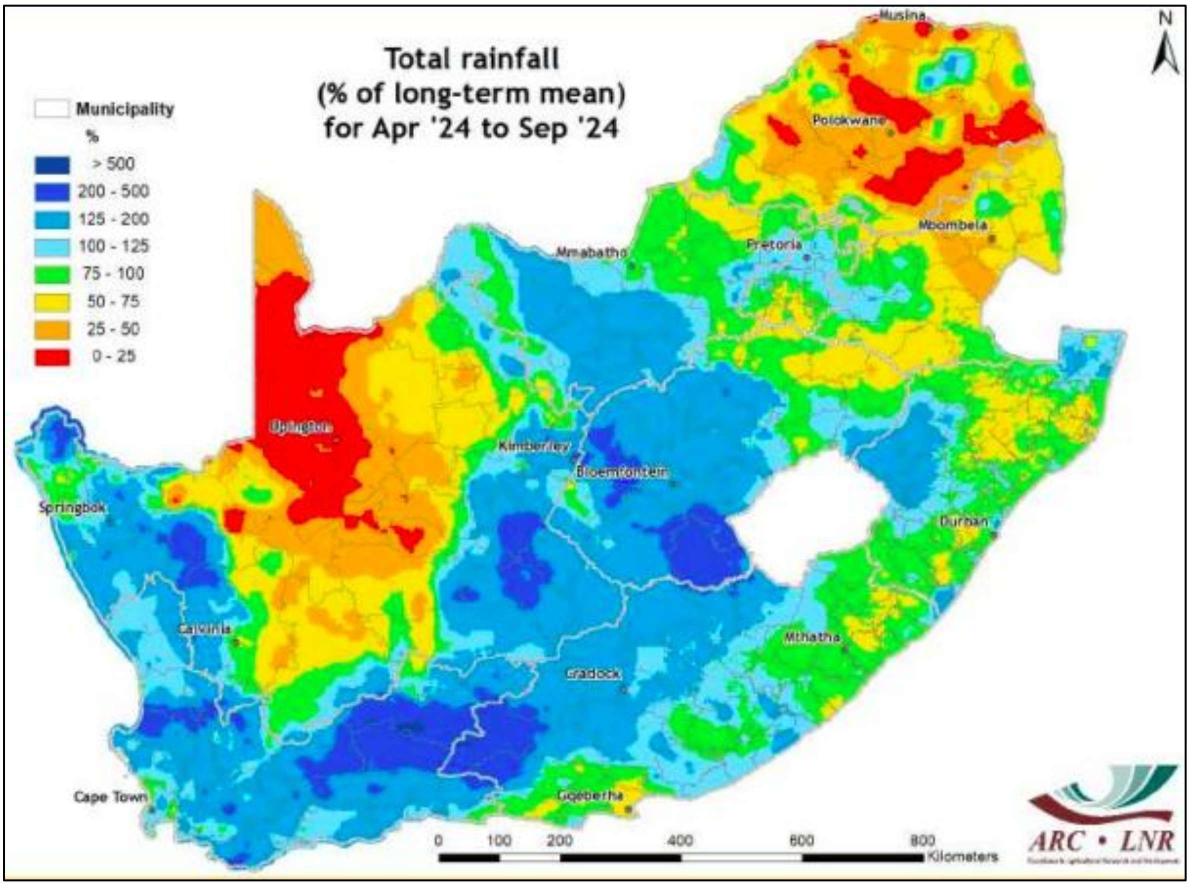


Figure 1.6.2: Percentage of long term mean precipitation for South Africa: April 24 – Sept 24
(Source: ARC, 2024)

The map in Figure 1.6.2 clearly shows that most of the Northern Cape (NC) received less than the mean rainfall from April 2024 to September 2024. This period covers the winter months and should not have a significant impact on vegetation growth if the province receive normal rainfall from September.

1.6.1.2 Precipitation Deciles

Precipitation deciles are used to express the ranking of precipitation for a specific period in terms of the historical time series. To calculate deciles, you first need to arrange the precipitation data, for example, precipitation totals, in ascending order (from lowest to highest). Next, divide the ranked data set into ten equal parts (i.e. ten blocks of 10%). So, for example, the first group (the lowest 10% of rainfall totals on record) would be in decile range one, the second group in decile range two, up to the highest 10% of rainfall totals being in decile range 10.

A rainfall total in decile range ten would be in the top 10%, higher than (at least) 90% of previous monthly observations. The highest total on record is at the very top of decile range 10, while the lowest total is at the bottom of decile range 1.

In applying the proposed drought classification system for South Africa, the following deciles approximately represent different drought classifications.

- Decile 1 = D4 drought (Extraordinary drought, only over longer periods)
- Decile 2 = D3 drought (Extreme drought only over longer periods)
- Decile 3 = D2 drought (Severe drought only over longer periods)
- Decile 4 = D1 drought (Moderate drought only over longer periods)
- Decile 5 = D0 drought (Dry or normal period only over longer periods)

The decile system to categorise precipitation is only useful when used over long periods in the same way as the percentage of long-term mean precipitation. Therefore, it is not an indicator of drought, mainly when determined for shorter periods such as one month.

The ARC also produces decile maps published monthly in the UMLINDI report and in the drought website. These maps only show the precipitation concerning the long-term mean for the previous month. An example of the precipitation decile map for September 2024 is shown in Figure 1.6.3. In the map, a value of five represents the median value for the time series. A value of 1 refers to the rainfall being low or lower than experienced in the driest 10% of a particular month historically (even possibly the lowest on record for some areas). In comparison, a value of 10 represents rainfall as high as the value recorded only in the wettest 10% of the same period in the past (or even the highest on record). It, therefore, adds a measure of significance to the rainfall deviation.

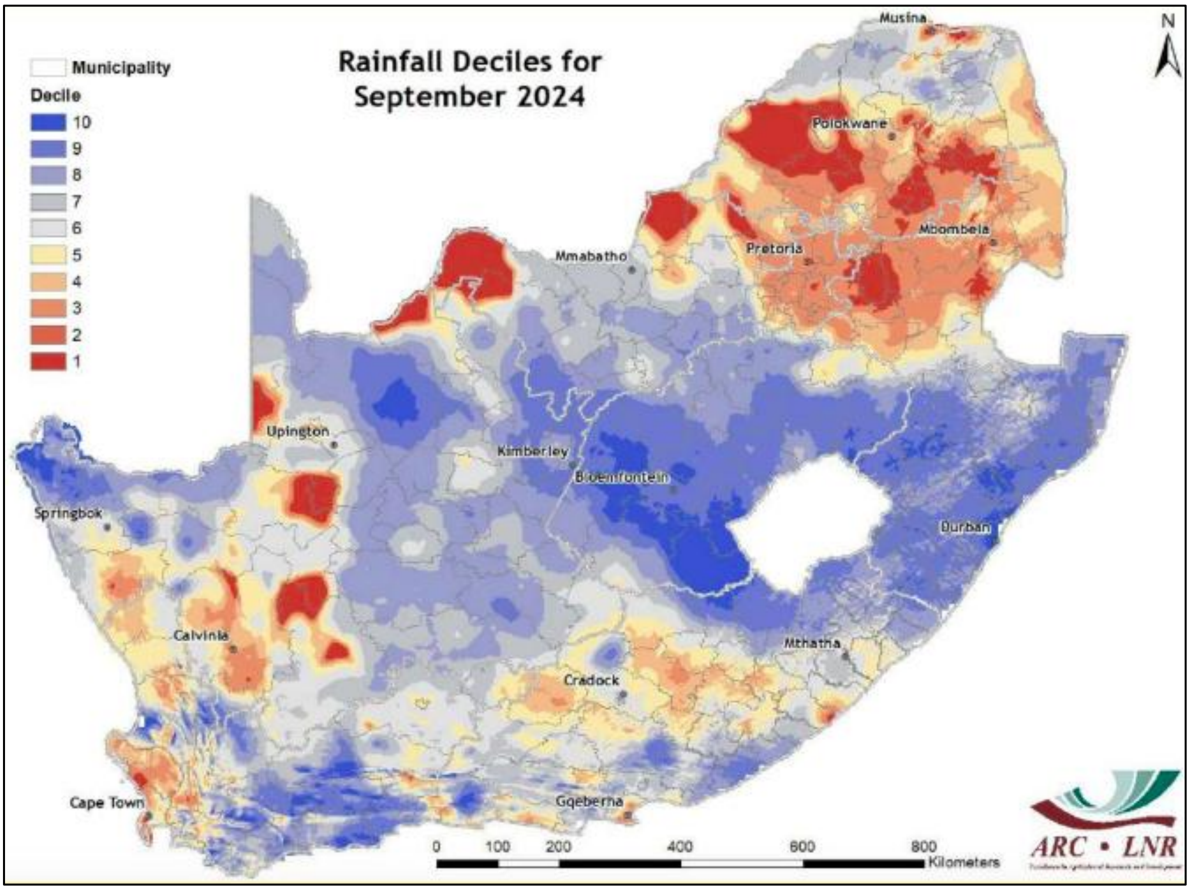


FIGURE 1.6.3: PRECIPITATION DECILE MAP FOR SOUTH AFRICA, SEPTEMBER 2024.
(Source: ARC, 2022)

1.6.1.3 Standardized Precipitation Index (SPI)

The SPI quantifies precipitation deficits at variable time scales and provides an indication of drought intensity and duration based on the historical distribution of rainfall. It has been applied with success in various parts of the world. Its simplicity and application over a wide range of climatic regions and all seasons make it an attractive tool for delineating drought conditions. The SPI has been used to track the evolution of drought at time scales ranging from 1-36 months or longer. Depending on the relevant period, the index can be used to identify both agricultural and hydrological droughts.

Noteworthy, however, is the time scale of measurement and during which season. The three-month and six-month SPI during the growing season is very important for crop farmers since a low three- and six-month SPI from November to March in the summer rainfall area can result in total crop losses. The 12-month and 24-month SPI is more relevant to livestock farmers, but a low six-month SPI during the growing season might also impact livestock farmers negatively.

The SPI and SPEI are globally the preferred indexes to be used for drought risk assessment (WMO, 2009), henceforth using the SPI and SPEI as the preferred meteorological indicators for drought classification. Therefore, the SPI and SPEI are discussed in detail in the following two sections. In order to understand the meaning of SPI and SPEI, one should also review some other definitions and concepts related to these indices. These are discussed below (McKee *et al.*, 1993; Western Regional Climate Centre, 2011):

- **Accumulated precipitation** – the total precipitation that has fallen during the indicated number of months through the end of the month displayed.
- **Accumulated Precipitation Departure** – the amount by which the indicated accumulated precipitation is above or below the long-term average for the same set of months. The local seasonal cycle of long-term average precipitation is automatically accounted for. A departure of 0 indicates that totals are precisely equal to climatological values.
- **Accumulated Precipitation Percent of Average** – the observed accumulated precipitation, over the time scale of interest and extending through the end of the last month indicated, divided by the long-term average precipitation, which would be expected to accumulate over the same set of months, and then multiplied by 100. A value of 0 indicates no precipitation at all, and a value of 100 per cent indicates that the amount is equal to the climatological average.
- **Percentile, or "Probability of Non-Exceedence"** – this quantity indicates how often a value of the magnitude observed is seen and its degree of "unusualness". A value of 0 means that zero per cent of the other values in the record does not exceed that value, or in other words, all other values exceed that value, so that the value in question is so low that it seldom, if ever occurs. A value of 50 indicates that half of the historical values are higher and 50 per cent are lower. A 75 indicates that 75 per cent of the values are as low as this value, or conversely, only 25 per cent of the values are higher than the given value. A value of 99 means that 99 per cent of the observed values are

lower, and this value is in the top one per cent of all values. Values near 50 are not unusual; values near 0 or 100 are very unusual.

Tom McKee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in 1993 to better represent wetness and dryness than the Palmer index (McKee *et al.,* 1993). In contrast to the Palmer index, which is based on a monthly water balance accounting scheme that involves precipitation, evapotranspiration, runoff and soil moisture, the SPI was developed to quantify a precipitation deficit for different time scales and different locations. In addition, it was designed to be an indicator of dry and wet periods that recognises the importance of time scales in analysing water availability and water use (McKee *et al.,* 1993; 1995; Keyantash & Dracup, 2002; Moreira *et al.,* 2008).

The advantage of the SPI and SPEI is that one can relatively easily analyse dry periods or anomalously wet periods at a particular time scale for any location in the world with daily precipitation records (McKee, 1995; Moreira *et al.,* 2008). The appropriateness and robustness of these indices to characterise dry periods have already been shown in several studies (Keyantash & Dracup, 2002; Paulo, Perreira & Matias, 2003; Paulo & Perreira, 2005; 2007; 2008, Moreira *et al.,* 2008). Drought, early warning and measurement of the onset of drought using drought indices received much research attention from scientists. Candelliere & Salas (2007), for instance, developed a stochastic approach to forecast monthly SPI values for different time scales. Mishra & Desai (2006) and Thyer, Frost & Kuczera (2006) also developed neural networks and stochastic models applied to precipitation time series data. The stochastic properties of the SPI time series data for predicting index class transitions were analysed using Markov chain modelling, and log-linear models were used for the same purpose (Paulo *et al.,* 2005; Moreira *et al*., 2008). Moreira *et al.* (2006) applied log-linear models to analyse class drought transitions and to search for the impact of climate change on drought severity and frequency.

The SPI has the following desirable traits (McKee *et al.,* 1993):

- First, SPI is uniquely related to probability.
- The SPI is typically distributed and is therefore valuable for monitoring dry and wet periods.

- Because of the normal distribution of SPI, the drier and wetter climate regimes are represented similarly.
- The precipitation data in SPI can be used to calculate the percent of mean precipitation for a specific period.
- Finally, the SPI calculations' precipitation data show the specific period's precipitation deficit.

The technique to calculate the SPI is discussed henceforth. Conceptually, the SPI is equivalent to the Z score often used in statistics as follows (Lloyd-Hughes & Sanders, 2002; Giddings, Soto & Rutherford, 2005):

$$Z = \frac{X - \hat{X}}{\sigma}$$

Where X= precipitation (observed or simulated)

X^= precipitation mean (observed)
δ = Standard deviation

Typical frequency distribution of precipitation for a given time scale is skewed with the mean precipitation larger than the median, in other words, not gaussian, but somewhat skewed towards larger values of precipitation (skewed to the right). The lower median than the mean is typical in arid and semi-arid regions such as the Karoo and the Northern Cape. That means that precipitation values are below the mean more than half of the time. Katz & Glantz (1985) found that precipitation frequency distribution for more extended time scales such as 24-month and 48-month time scales became more gaussian with skewness of near zero. Thom (1966) and Sakulski & Jordaan (2014) found the Gamma distribution to fit climatological precipitation time series well.

The Gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad \text{for } x>0$$

Where: $\alpha > 0$ α is a shape parameter

$\beta > 0$ β is a scale parameter
$x > 0$ x is the precipitation amount

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y}\, dy$$

$\Gamma(\alpha)$ is the gamma function

Calculating the SPI is done by fitting two parameters gamma probability density function to a calculated frequency distribution of precipitation totals for a data set. Two parameters, alpha and beta, of the gamma probability density function are estimated for each data set, for each month of the year, and for each time scale (three months, six months, 12 months, 24 months and 48 months) (McKee *et al.,* 1993, Sakulski, 2002, Jordaan & Sakulski, 2009).

Thom (1966), as cited by Sakulski (2002), suggested that the maximum likelihood solutions are used to estimate parameters alpha and beta optimally:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$$

$$\beta = \frac{x}{\alpha}$$

Where: $$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$$

n = number of precipitation observations

The resulting parameters are used to calculate the cumulative probability of an observed precipitation event for a specific month and time scale for a specific area. The cumulative probability is given as:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{-x/\beta}dx$$

If $t=x/\beta$, the equation becomes the incomplete Gamma function:

$$G(x) = \frac{1}{\Gamma(\alpha)}\int_0^x t^{\alpha-1}e^{-t}dt$$

As an Excel function, Gamma transform = GAMMADIST($x, \beta, \alpha, true$)

The gamma function is not defined for the value of *x=0*, and a precipitation distribution contains zero values, the cumulative probability therefore becomes:

$$H(x) = q + (1-q)G(x)$$

Where: *q* = probability of a zero value.

Thom (1966) estimated q by m/n if m is the number of zero values in a precipitation time series. The **Standardized Precipitation Index (SPI)** is then calculated by transforming the cumulative probability, *H(x)*, to the standard normal random variable *Z* with mean zero and variance one.

Abramovic & Stegun (1965) as cited by Sakulski (2002) proposed an easy way to calculate SPI using approximations. It converts cumulative probability to the standard normal random variable *Z*:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t_3} \right), \qquad 0 < H(x) \leq 0.5$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t_3} \right), \qquad 0.5 < H(x) < 1$$

Where: $$t = \sqrt{\ln\left(\frac{1}{(H(x))^2} \right)}, \qquad 0 < H(x) \leq 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{(1 - H(x))^2} \right)}, \qquad 0.5 < H(x) < 1$$

$c_0 = 2.515517$
$c_1 = 0.802853$
$c_2 = 0.010328$
$d_1 = 1.432788$
$d_2 = 0.189269$
$d_3 = 0.001308$

The SPI and SPEI represent the number of standard deviations above or below the mean (z-score). Since precipitation distribution is initially skewed, the above-mentioned is not exactly valid for the short time scales. The SPI and SPEI will have a standard normal distribution with an expected value of zero and a variance of one during the base period for which the gamma parameters are estimated. Drought risk assessment requires an index with a fixed expected value to compare the index values between different regions with different climate regimes (Katz & Glantz, 1985). The spatial and temporal dimensions of drought could be a challenge in developing a drought index because not only must an anomaly be normalised for location, but an anomaly must also be normalised in time to produce a meaningful estimate of drought. The SPI and SPEI accomplished both (McKee *et al.*, 1993; Giddings *et al.*, 2005; Kim *et al.*, 2009). The SPI is firstly normalised to a region or station because it accounts for the frequency distribution of precipitation and the accompanying variation in the region or at the station. Secondly, the SPI is normalised in time because it can be calculated at any number of time scales. In addition to that, no matter the location or time scale, the SPI represents a cumulative probability of the base period for which the gamma parameters were estimated (Sakulski, 2002; Giddings *et al.*, 2005; Kim *et al.*, 2009)

Figure 1.6.4 shows the standard normal distribution for SPI, and it illustrates that about 62% of the time, the SPI will be between 0.5 and -0.5, representing a normal climate condition. SPI between -0.5 and -0,79 is experienced about 31% of the time, representing a **D0 drought**, with 23% of the time between -0.8 and -1.2, which indicates a **D1 drought**. **Severe** or D2 droughts are normally experienced about 15% of the time. E**xtreme droughts (D3 droughts)** with values between -1.5 to -1.99 is experienced between 6% and 7% of the time. Extraordinary droughts (D4 droughts) are expected between 2% and 3% of the time.

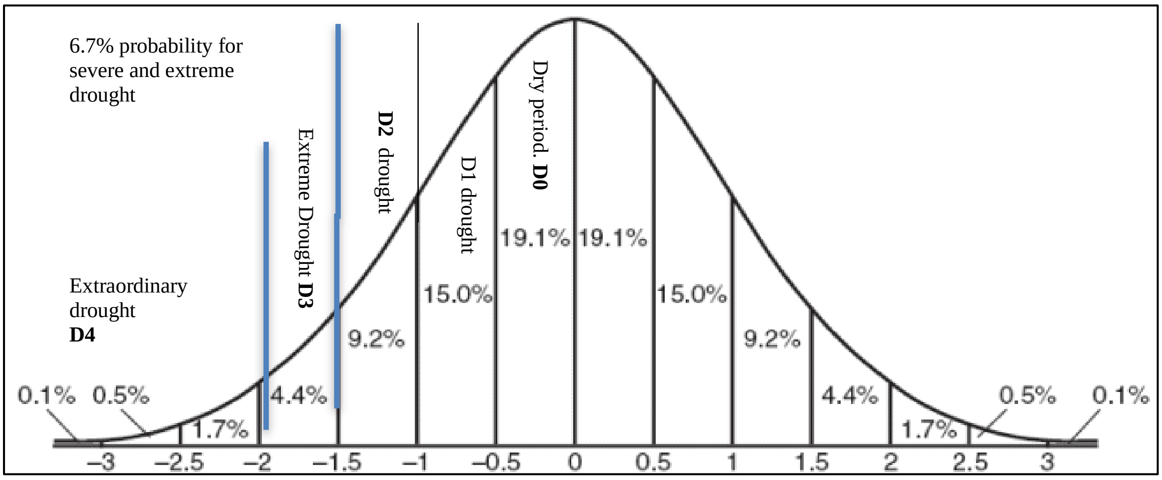


FIGURE 1.6.4: STANDARD NORMAL DISTRIBUTION WITH SPI AND SPEI

Since 1993, when McKee *et al.* (1993) introduced the SPI, several authors proposed slightly different categories (classifications) of dry and wet periods. According to McKee *et al.* (1993), a drought event for time scale x is defined as a period in which the SPI is continuously negative and the SPI reaches a value of -1.0 or less. The dry period begins when the SPI first falls below zero and ends with the positive value of SPI following a value of -1.0 or less. The problem with McKee's classification is that it does not provide a normal year classification with a slight deviation from the SPI of zero. One should expect slightly above zero or slightly below zero as normal. Agnew (2000) argues in strong language against this; in his words, he wrote: *"In McKee's classification, all negative indexes (SPI) are taken to indicate the occurrence of drought; this means for 50% of the time, drought is occurring. This is clearly nonsense!"* *McKee* arbitrarily defined drought intensity for values of the SPI with the following categories (McKee *et al.*, 1993; 1995):

- **0 to -0.99** **mild drought**
- **-1.0 to -1.49** **moderate drought**
- **-1.5 to -1.99** **severe drought**
- **less than -2.0** **extreme drought**

Agnew (2000) questions the values assigned by McKee *et al.* (1993) and raises the notion of *"persistent drought"*, which confuses drought with "*desiccation.*"[1]. Warren & Khogali (1992) distinguish drought from desiccation by arguing that (i) drought occurs when moisture supply is abnormal below average for up to two years and (ii) desiccation is a period of aridification brought about by decades of climate change. Therefore, coping mechanisms for desiccation require long-term measures such as resettlement and land-use change, while drought requires short-term measures. Agnew (2000) suggested alternative thresholds because of using different drought classes with the analysis of annual rainfall from the Sahelian region in West Africa, which is well known for its extreme droughts and the problem of changing the base averaging periods. Categories proposed by Agnew (2000) are:

- **higher than -0.5** **no drought**
- **-0.5 to -0.84** **moderate drought**

[1] Aridness or aridity

- **-0.84 to -1.28 severe drought**
- **-1.28 to –1.65 extreme drought**

Hayes (2000) proposes modifications to Agnew's categories by using 5%, 10% and 20% probability occurrences as guideline for his classification. He proposes the use of the term **dry** instead of **drought** because that is more appropriate for short time scales. Hayes (1999) links the term **extreme** to the 5% probability and **severe** a 10% probability. These categories are also the basis for the US monthly national SPI maps:

- **2.0 + extremely wet**
- **1.5 to 1.99 very wet**
- **1.0 to 1.49 moderately wet**
- **-0.99 to 0.99 near normal**
- **-1.49 to –1.0 moderately dry**
- **-1.99 to –1.5 severely dry**
- **-2.0 and less extremely dry**

The classification proposed by McKee (1993), Hayes (1999) and Agnew (2000) is proposed, and we propose the following for use in South Africa. The national drought plan provides SPI thresholds and drought classes, as shown in Table 1.6.1.

TABLE 1.6.1. DESCRIPTION AND THRESHOLDS OF DROUGHT CATEGORIES ACCORDING TO SPI VALUES

Drought type	Drought description	SPI value	Approximate % of time	Approximate Probability
	Normal climate	-0,49 to 0.5	≅62%	
D0	Dry period	-0,5 to -0,79	≅31%	≅1 in 3 years
D1	Moderate drought	-0.8 to -1.29	≅23%	≅1 in 5 years
D2	Severe drought	-1.3 to -1.49	≅15%	≅1 in 7 years
D3	Extreme drought	-1.5 to -1.99	≅6% to 7%	≅1 in 15 years
D4	Exceptional drought	<-0.2	≅2% to 3%	≅1 in 30 years

1.6.1.4 Standard Precipitation Evapotranspiration Index (SPEI)

Vicente Serrano, Beguiria & Lopez-Moreno (2010) developed the Standard Precipitation Evapotranspiration Index (SPEI) by considering evapotranspiration. The SPEI is based on precipitation and evapotranspiration data and has the advantage of combining a multi-scalar character with the capacity to include the effects of temperature variability on drought risk assessments.

The SPEI combines the sensitivity of the PDSI to changes in evaporation demand caused by fluctuation and trends in temperature with the simplicity of the calculation and multi-temporal nature of the SPI. Because of the inclusion of temperature and temperature trends, the main advantage of the SPEI above other indices is its ability to identify the role of temperature variability and evapotranspiration in drought risk assessments in the context of global warming (Vicente-Serrano *et al.,* 2010; Beguiria, Vicente-Serrano & Angulo-Martinez, 2010; Potop, 2011).

In order to understand the principles for SPEI calculation, one should understand evapotranspiration. Evapotranspiration is the most significant component of the hydrological budget after precipitation, and it varies according to weather, temperature and wind conditions. The impact of evapotranspiration becomes more significant during dry periods since it continues to deplete the limited remaining surface water supplies and soil moisture (Thornthwaite, 1948; Alley, 1994; Allen *et al.*, 1998; Wilhite, 2000; Vicente-Serrano *et al.,* 2010).

Evapotranspiration is the water lost to the atmosphere through evaporation and transpiration. Transpiration is the loss of water through the leaves of plants, and evaporation is the loss of water from open water bodies and the soil. The determinates for evapotranspiration include net solar radiation, surface water area, wind speed, density and type of vegetation cover, soil moisture, root depth, reflective land surface characteristics and season (Hanson, 1991).

Potential evaporation or potential evapotranspiration (PET) is defined as the amount of evaporation that would occur if a sufficient water source were available. Suppose the actual evapotranspiration is considered the net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture. In that case, PET is a measure of the demand side. Surface and air temperatures, insolation, and wind all affect this. Wilhite (2000) defines dry land as a place where potential annual evaporation exceeds annual precipitation.

The SPEI is based on the same calculation methodology for SPI. However, the calculation of potential evapotranspiration (PET) is also included since SPEI uses the monthly or weekly difference between precipitation and PET as a basis for calculation. Calculation of PET is the most difficult because of numerous parameters such as surface temperature, air humidity, incoming soil radiation, water vapour pressure and ground-atmosphere latent and sensible heat fluxes (Allen *et al.,* 1998; Vicente-Serrano *et al.*, 2010). The lack of reliable data for all the parameters forced scientists to use alternative methods for calculating PET. Vicente-Serrano *et al. (*2010) therefore propose the Thornthwaite method of calculating PET. Thornthwaite (1948) proposes the use of monthly mean temperature. Following Thornthwaite's method, PET is then calculated as follows (Beguiria *et al.,* 2010; Vicente-Serrano *et al.,* 2010):

In order to calculate Potential Evapotranspiration (PET) using the Thornthwaite method, first, the Monthly Thorthwaite Heat Index (i) calculation is required, using the following formula:

$$i = \left(\frac{t}{5}\right)^{1.514}$$

Where: t = mean monthly temperature.

The Annual Heat Index (I) is calculated as the sum of the Monthly Heat Indices (i):

$$\mathrm{I} = \sum_{i=1}^{12} i$$

Potential Evapotranspiration (PET) estimation is obtained for each month, considering a month is 30 days long and there are 12 theoretical sunshine hours per day, applying the following equation:

$$PET = 16K\left(\frac{10T}{I}\right)^{m}$$

Where T is the monthly mean temperature in °C; I is a heat index, which is calculated as the sum of 12 monthly index values i, being derived from the mean monthly temperature using the formula:

$$i = \left(\frac{T}{5}\right)^{1.514}$$

Where m is a coefficient depending on I, and K is a correction coefficient computed as a function of the latitude and month by:

$$K = \left(\frac{N}{2}\right)\left(\frac{NDM}{30}\right)$$

Where *NDM* is the number of days of the month and *N* is the maximum number of sun hours, which is calculated according to:

$$N = \left(\frac{24}{\pi}\right)\varpi_s$$

Where ω_s is the hourly angle of the sun rising, obtained as:

$$\varpi_s = \arccos(-tan\phi tan\vartheta)$$

Where Φ is the latitude and ϑ is the solar declination (both in radians):

$$\vartheta = 0.4093sen\left(\frac{2\pi J}{365} - 1.405\right)$$

Where J is the average Julian day of the month. With a value for *PET*, the difference between the Precipitation (*P*) and *PET* for the month *i* is calculated:

$$D_i = P_i - PET_i$$

The result simply measures the water surplus or deficit for the analysed month. The calculated D_i values are aggregated at different time scales, following the same procedure as for the SPI. Vicente-Serrano *et al.* (2010) found the selection of the most suitable statistical distribution to model the *D* series difficult, given the similarity among the four distributions

(Pearson III, Lognormal, Log-logistic, and General Extreme Value). They based the selection of the most suitable statistical distribution model on the behaviour at the most extreme values. They realised the Log-logistic distribution showed a gradual decrease in the curve for low values, and coherent probabilities were obtained for very low values of D, corresponding to 1 occurrence in 200 to 500 years. In addition, they found no values below the origin parameter of the distribution.

The probability density function of a three-parameter log-logistic distributed variable is expressed as

$$f(x) = \frac{\beta}{\alpha}\left(x - \frac{y}{\alpha}\right)^{\beta-1}\left(1 + \left(x - \frac{y}{\alpha}\right)^{\beta}\right)^{-2}$$

Where *α*, *β* and *γ* are scale, shape and origin parameters, respectively, for *D* values in the range (*γ* > *D* < ∞). Parameters of the Log-logistic distribution can be obtained following different procedures. Vicente Serrano *et al.* (2010) follow Ahmed *et al.* (1988), who found the L-moment procedure the most robust and straightforward approach. Vicente Serrano *et al.* (2010) further follow Singh *et al.* (1993), who reported that when L-moments are calculated, the parameters of the Pearson III distribution are obtained as follows:

$$\beta = \frac{2w_1 - w_0}{6w_1 - w_0 - 6w_2}$$

$$\alpha = \frac{(w_0 - 2w_1)\beta}{\Gamma(1 + 1\beta)\Gamma(1 - 1\beta)}$$

$$y = w_0 - \alpha\Gamma(1 + 1\beta)\Gamma(1 - 1\beta)$$

Where Γ(*β*) is the gamma function of *β*. The probability distribution function of *D* according to the Log-logistic distribution is then given by:

$$F(x) = \left[1 + \left(\frac{\alpha}{x} - y\right)^{\beta}\right]^{-1}$$

Where Γ(*β*) is the gamma function of *β*. The probability distribution function of *D* according to the Log-logistic distribution is then given by:

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1W + d_2W^2 + d_3W^3}$$

Where: $W = \sqrt{-21n(P)}$

For $P \leq 0.5$, P being the probability of exceeding a determined D value, P=1-F(x). If $P>0.5$, P is replaced by $1-P$, and the sign of the resultant SPEI is reversed. The constants are: $C0$=2.515517, $C1$=0.802853, $C2$=0.010328, $d1$=1.432788, $d2$=0.189269, $d3$=0.001308.

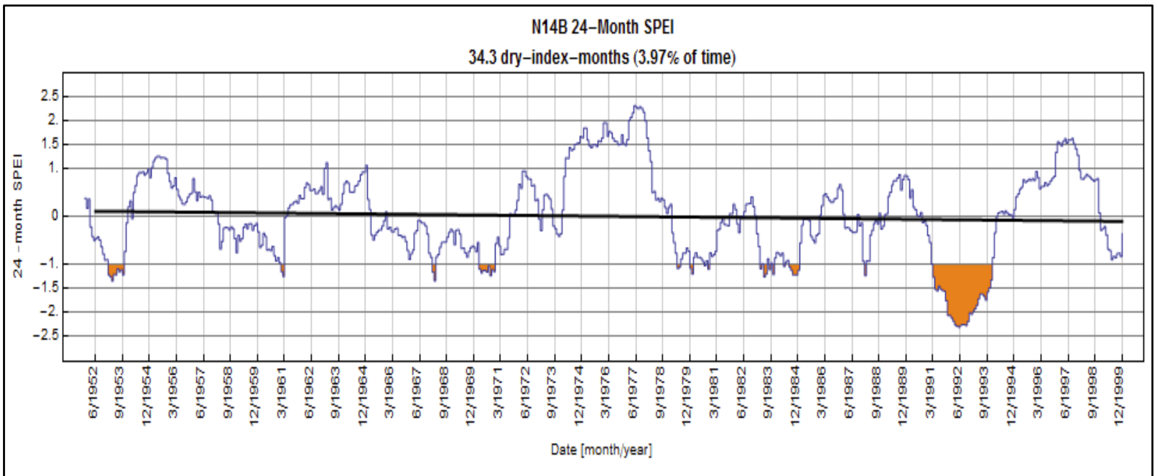
The average value of the SPEI is 0, and the standard deviation is 1. Like the SPI, the SPEI is a standardised variable that can be compared with other SPEI values over time and space. An SPEI of 0 indicates a value corresponding to 50% of the cumulative probability of *D*, according to a Log-logistic distribution.

Scientists, in general, agree that precipitation is the most critical variable in explaining drought and that it should always be included in the calculation of drought indices (Alley, 1984; McKee *et al.,* 1993; Sakulski, 2002; Breguiria *et al*., 2010; Vicente-Serrano *et al.,* 2010; Hayes *et al.,* 2011; Jordaan, 2011; Jordaan et al., 2011; Jordaan & Sakulski 2004; Jordaan *et al*., 2014). On the other hand, the inclusion of a variable that accounts for climatic water demand is not always acceptable since its role in drought conditions is not always well accepted and understood. Hu & Wilson (2000) and Vicente-Serrano *et al.* (2010) argue that temperature, and evapotranspiration, play a major role in explaining drought variability in drought indices. They argue that evapotranspiration determines soil moisture variability and vegetation water content, which directly affects agricultural droughts commonly recorded by short time-scale indices. Narasimhan & Srinivasan (2005) and Vicente-Serrano *et al.* (2010) conclude that evapotranspiration-based indices show better results than precipitation-based indices for short-term agricultural droughts.

Vicente-Serrano *et al.* (2010) find little difference between precipitation-based indices such as SPI and evapotranspiration indices such as sc-PDSI and SPEI where temporal trends in temperature do not exist. Furthermore, they find that the inclusion of PET only affects the index when PET differs from average conditions, for example, in global warming scenarios.

Khan, Gabriel & Rana (2008) found a low correlation between shallow groundwater fluctuations and short-term SPI values. However, they found a good correlation between groundwater fluctuations at 6-, 12- and 24-month SPI values. This supports the *a-priory* expectation that groundwater and reservoir levels are better measured with long-term (12-, 24- and 48-month SPI or SPEI) values.

For example, the 12-month SPEI for tertiary catchment N14B shown in Figure 1.6.5 clearly shows one extreme dry period with SPEI <-2 during 1981 - 1982. The same Figure shows these different dry periods' duration, intensity and severity. Severity is a function of duration and intensity, and the SPEI provides a methodology for easy calculation of drought severity.

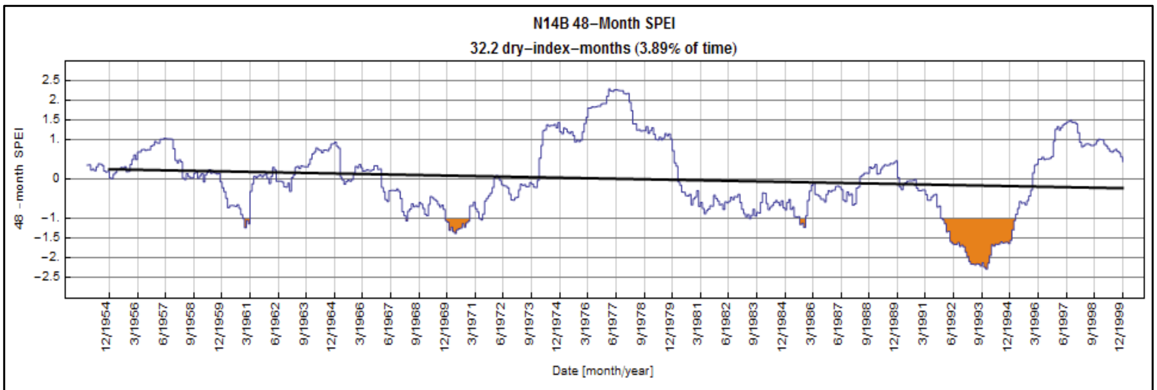


Indicative linear trend: 0.111666 - 0.000366687 x , p-Value=0.1094

Dates	{Apr 1991, May 1991}	{Jul 1991, Sep 1993}
Duration	2	27
Intensity	1.52	1.94
Severity	3.04	52.38

FIGURE 1.6.5: 24-MONTH SPI GRAPH FOR TERTIARY CATCHMENT N14B
(Sakulski & Jordaan, 2014)

The longer period (24-month; Figure 1.6.5 and 48-month; Figure 1.6.6) of the SPEI calculation smooths the graph, and only the long-term severe and extreme droughts become visible. Therefore, the application of the SPEI in drought risk assessment becomes simple when analysing the mentioned SPEI graphs. The calculation of frequency (probability) and severity of dry periods and droughts is now very easy.



Indicative linear trend: 0.251262 - 0.000864747 x , p-Value=0.0004

Dates	{Apr 1992, Dec 1994}
Duration	33
Intensity	1.83
Severity	60.39

FIGURE 1.6.6: 48-MONTH SPI GRAPH FOR TERTIARY CATCHMENT N14B
(Sakulski & Jordaan, 2014)

Drought frequency or probability is an important indicator when comparing different regions for drought risk. Since the SPEI equation transfer the data as a normal distribution, one should expect the probability for severe droughts to be < 0.67 and extreme droughts to be < 0.23. In other words, to simplify the argument, one could expect approximately seven severe droughts for every 100 years and three extreme droughts every 100 years if the 12-month SPEI was calculated. The probability for extreme and severe droughts or dry periods remains the same for the 3- and 6-month SPEI, but one should keep in mind that probability was calculated for 3- and 6-month periods; in other words, the probability for severe drought according to the 3-month SPI is 7 out of (100 X 3 = 300/12 = 25) 25 years and for the 6-month SPI 7 out of 50 years.

Figure 1.6.7 shows the exceedance probability for the example catchment D13F. Again, the strength of the SPI and SPEI technique is illustrated here in that one can see how easy it is to calculate the probability for drought at values less than zero and wet periods with positive values from 1 to 2,5 at the top of the graph (McKee *et al.*, 1993; Guttman, 1999; Hayes *et al.*, 1999; Wilhite, 2000 (a); Hayes, 2011).

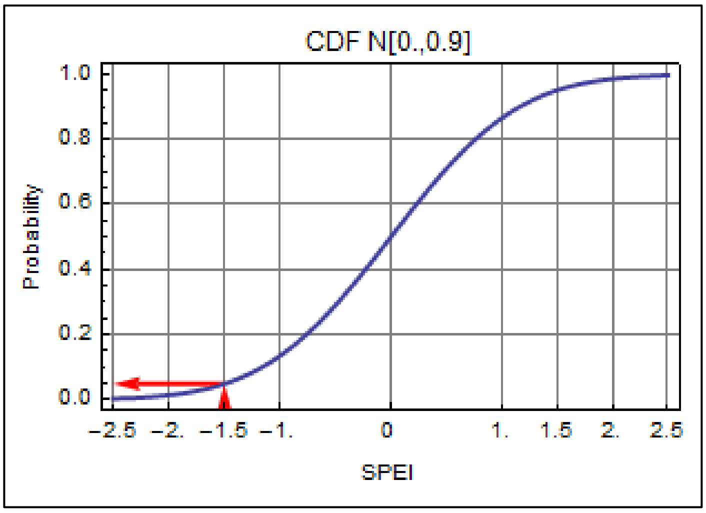


FIGURE 1.6.7: TWELVE-MONTH EXCEEDANCE PROBABILITY FOR SPEI -1,5 FOR D13F
(*Sakulski & Jordaan, 2014)*

The questions to be answered in drought risk assessment are (i) which of the 6-, 12-, 24- or 48-month SPEI or SPI values represent disaster droughts for what sectors, and (ii) at what SPEI or SPI value should disaster droughts be measured; is it at <-1.5 (extreme (D3) drought) or <-2.0 (extraordinary (D4) drought)? Necessary for the extensive livestock sector is the 6-month SPI during the growing and rainy season and the 12-month, 24-month and longer time series. The longer time series SPI or SPEI results are indicators for multi-year droughts, which might indicate disaster droughts that affect not only the vegetation but also groundwater levels, streamflow and dam levels.

The ARC's UMLINDI report provides the 6-, 12-, 24- and 36-month SPI for South Africa (see Figures 1.5.8 (a,b,c,d)). These maps are extremely useful for drought management because they show multi-year droughts and assist with increased interpretation. The following are some of the conclusions from the SPI maps.

i. The 6-month SPI map represents the previous growing season in the summer rainfall regions. From the 6-month SPI, it is clear that the NC experienced severely wet conditions during the growing season, which supported vegetation growth. The 12-month SPI looks similar to the 6-month SPI, which is expected since it also includes the winter months with usually very little to zero precipitation.

ii. The 12-month SPI shows moderate to severe drought conditions for Richtersveld in the far north-western part of the NC. This region is extremely arid and also mainly a winter rainfall area.

iii. The 24- and 36-month SPI maps show extremely drought conditions in the southern region of the Eastern Cape (EC). Even the 6- and 12-month SPI maps show mild to moderate drought conditions for this area. Therefore, one can expect a hydrological drought with low dam and groundwater levels in the Nelson Mandela Bay region.

iv. The 24- and 36-month SPI maps show wet conditions for most of the NC, and one can expect that vegetation cover and groundwater levels to be recovered after the 2015 – 2019 multi-year drought.

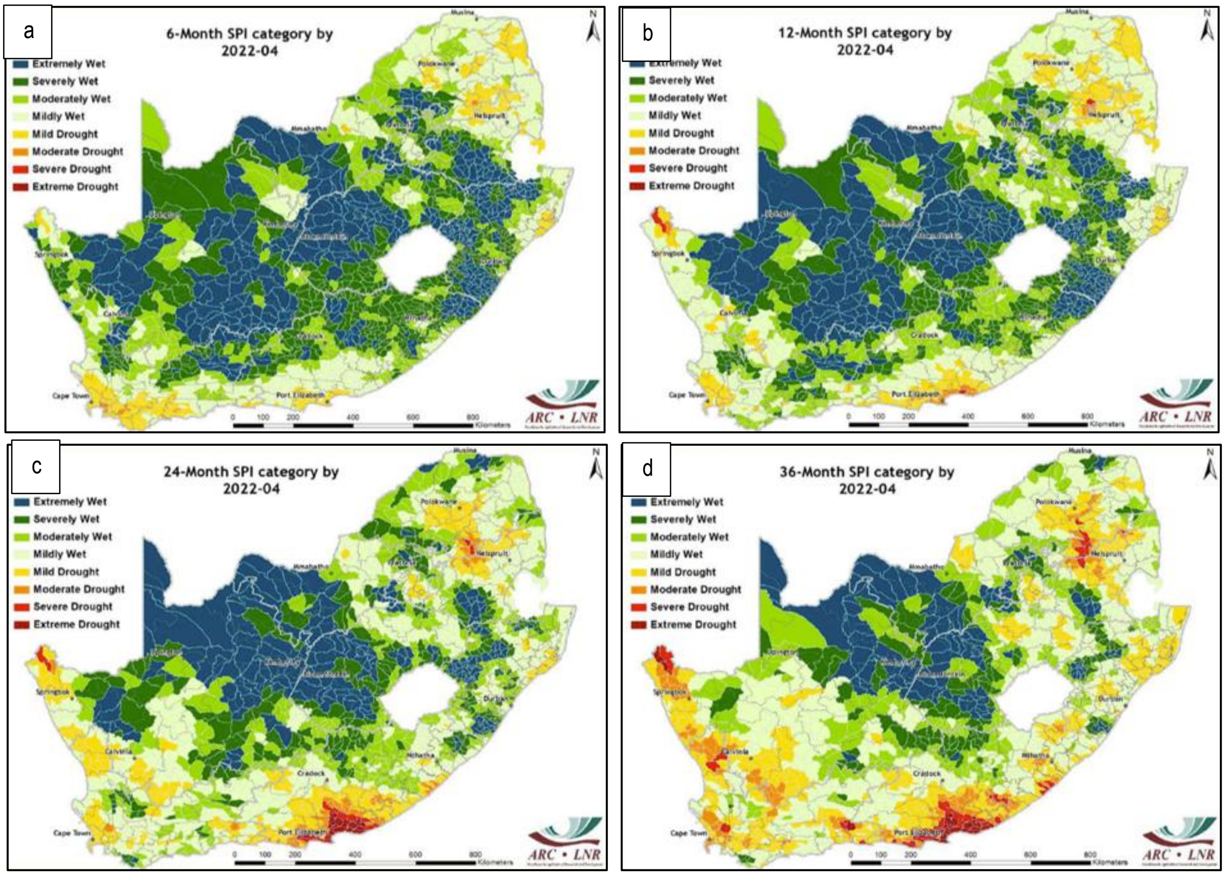


FIGURE 1.6.8: SPI MAPS FOR DIFFERENT TIME-SCALES
(Source: ARC, 2022)

1.6.1.5 Meteorological indicators developed in South Africa

1.6.1.5.1 Rainfall Anomaly Index

This technique was developed by Herbst *et al.* (1966) and used rainfall as the source of input data. The technique indexed the current rainfall as a variance from the mean precipitation of historical periods of extremes of low precipitation by calculating the effective precipitation for each month and allowed for the carry-over effect of a surplus or deficit in precipitation from previous months using a series of weighting factors. The mean monthly deficit was then calculated from the difference between actual and mean Precipitation (Du Pisani *et al.*, 1998).

1.6.1.5.2 Erasmus Rainfall Deciles Method

Developed by Erasmus (1991) and based on the same principles as deciles developed by Gibbs and Mather (1967). Erasmus used drought intensity profiles for 400 individual rainfall stations and ranked the cumulative frequency distribution of moving three-monthly rainfall totals into decile ranges. The current drought intensity was then calculated, ranked and compared with specific decile ranges.

1.6.1.5.3 Relative Drought Resistance Model

The Relative Drought Resistance Model (RDR) developed by Roux (1993) used total rainfall over a predetermined period as an input data source. He calculated the meteorological status by expressing total precipitation for a predetermined period before the drought as a percentage of the long-term average precipitation for a corresponding time. The period to be considered was calculated from the RDR of the area. The principle of this methodology was that the higher the mean precipitation and the lower the annual variance, the less drought tolerant the vegetation and *vice versa* and the sooner one could expect a drought.

1.6.1.5.4 Zucchini-Adams Model

The Zucchini-Adams model developed by Zucchini and Adamson (1991) uses daily, weekly, monthly or annual rainfall as an input data source. The model is characterised by the half-life of an exponentially decaying factor such as rainfall. The exponential function describes the decay in the benefit associated with precipitation as the time from the precipitation event increases.

1.6.2 Remotely Sensed Vegetation Indicators

The remotely sensed indicators reflect the results of meteorological droughts if interpreted correctly. However, vegetation type and external factors such as over-grazing and wildfires might impact the results of some of the remotely sensed indicators. As a result, interpretation of remotely sensed data in some cases requires ground-truthing and adjustments. The Northern Cape, for example, had to adjust NDVI and other vegetation thresholds to reflect drought conditions in areas with different vegetation cover. More about the adjustments in the next section.

This section discusses the most critical remotely sensed indicators that apply to the extensive livestock sector.

1.6.2.1 Normalised Difference Vegetation Index (NDVI):

(Source: https://land.copernicus.eu/global/products/ndvi)

The first and most commonly used remotely sensed indicator in South Africa is the NDVI. NDVI is a remote sensing-based index that measures vegetation conditions (Rouse *et al*. 1974). NDVI uses the advanced high-resolution radiometer (AVHRR) reflected red and near-infrared channels to calculate if the vegetation is healthy or unhealthy and sparse (e.g., suffering from drought or insect infestation).

Under healthy conditions, chlorophyll absorbs light, reflecting less R. Lower R values result in higher NDVI values. Conversely, unhealthy plants reflect higher R resulting in lower NDVI. Therefore, NDVI has extensively been used as a base index for several remote sensing indices that similarly measure vegetation conditions, e.g., the Vegetation Condition Index (VCI) (Kogan 1990).

Reflectance from Sentinel-3/OLCI in seven Red and Near-infrared (NIR) bands is first atmospherically corrected. Then 10-daily BRDF normalised reflectance is computed from 30 days of input reflectance. The four narrow Red and three narrow NIR are averaged into a broad Red and NIR band, which are then used to calculate the NDVI. Uncertainty is calculated by error propagation of the uncertainty of the seven input top-of-canopy (TOC) reflectance. The number of observations is calculated as the minimum of the number of observations used for BRDF correction over the 7 TOC reflectance bands.

The equation for NDVI is as follows:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Where: NDVI = Normalised Difference Vegetation Index
NIR = Near-infrared spectral reflectance
R = Visible red spectral reflectance

For many years, the NDVI has been widely used by the bio-geophysical community to monitor the vegetation state and disturbances to address a large range of applications, including forestry, agriculture, food security, and water management. For example, the NDVI was among the first remotely sensed drought indicators applied in South Africa.

NDVI values range from +1.0 to -1.0. Areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs, grasslands, or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage. The negative value of an NDVI index refers to a lack of vegetation and other types of land use, such as built-up areas. Furthermore, a zero value indicates bodies of water, whereas positive values refer to different types of vegetation rates (Sun, J. et al., 2011; Morawitz et al., 2006).

NDVI values can be averaged over time to establish "normal" growing conditions in a region for a given time of year. Further analysis can then characterise the health of vegetation in that place relative to the norm. When analysed through time, NDVI can reveal where vegetation is thriving and under stress, as well as changes in vegetation due to human activities such as deforestation, natural disturbances such as wildfires, or changes in plants' phenological stage (USGS, 2018).

The NDVI maps in Figures 5. (a) and (b) illustrates the 16-day NDVI difference for the period 30 March 2022 to 15 April 2022 compared to the NDVI for the period 14 March 2022 to 30 March 2022 (a) and the 16-day NDVI difference for the period 30 March 2022 to 15 April

2022 compared to the same period in 2021. These maps show an improvement in vegetation growth in most parts of the country. However, it says nothing about drought classification since the NDVI results shown in Figure 1.5.9 are only a comparison of the NDVI for the same period a year ago and do not provide a comparison with the long-term mean NDVI.

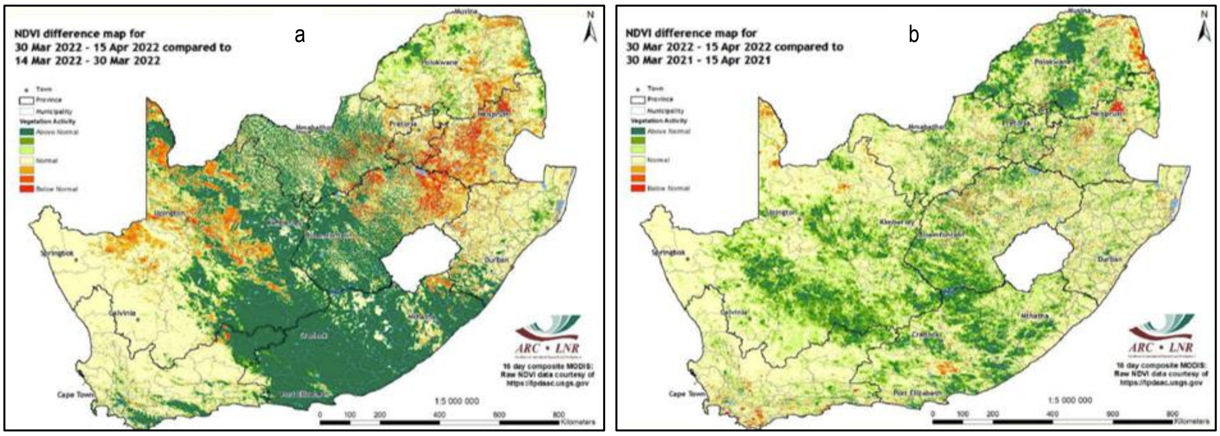


FIGURE 1.6.9: (A) & (B): 16-DAY NDVI MAPS FOR 30 MARCH 2022 TO 15 APRIL 2022
(Source: ARC, 2022)

1.6.2.2 Standard Difference Vegetation Index (SDVI)

The Standardised Vegetation Index (SVI) provides information about the relative vegetation condition compared to the years being analysed. As weather conditions influence the state of vegetation, the SVI can also be utilised as a drought index and for regular drought monitoring to facilitate the early identification of a slow-onset drought. The SVI is based on satellite Vegetation Indices (VI), such as the Normalised Difference Vegetation Index (NDVI) or Enhanced Vegetation Index (EVI), indicating the estimated vegetation condition. Vegetation Indices mostly explore the difference in reflectance radiated in the visible Red and near-infrared waveband for determining the health or stress of plants as well as the density of plant growth.

The SDVI originates from the NDVI anomaly concept developed by Peters *et al.* (2002). The SDVI describes the probability of variation from the normal NDVI over multiple years of data on a weekly time step. The SVI is a z-score deviation from the mean in units of the standard deviation, calculated from the NDVI or EVI values for each pixel location of a composite period for each year during a given reference period. The equation below shows the general calculation of the SVI:

$$Z_{ijk} = \frac{VI_{ijk} - \mu_{ij}}{\sigma_{ij}}$$

where Z_{ijk} is the z-value for the pixel i during week j for year k, VI_{ijk} is the weekly *VI* value for pixel i during week j for year k whereby both the NDVI or EVI can be utilised as *VI*, μ_{ij} is the mean for pixel i during week j over n years, and σ_{ij} is the standard deviation of pixel i during week j over n years.

The key strengths of the SDVI are as follows (UNSPIDER, 2022):

- The SDVI provides a valuable analysis tool for assessing vegetation condition trends and monitoring areas affected by drought as it compares the vegetation condition of a point at the same time of a year with the respective points of time in the other years included in the analysis. The user can, therefore, estimate whether the state of the vegetation in the period of interest is unusually good or bad compared to other years.
- The SDVI allows clear visualisation of relative vegetation greenness at each pixel location. In addition, it indicates the deviations of the present vegetation condition from the mean vegetation condition in a specific pixel deriving from the z-score as outlined above.
- The computation of the SDVI is not restricted to the commonly utilised NDVI, which makes the SDVI more variable. Depending on the area of interest, the user can further derive the SDVI from other Vegetation Indices, such as the Enhanced Vegetation Index (EVI), with improved sensitivity over dense vegetation conditions compared to the NDVI.
- For example, the temporal and spatial coverage of the SDVI for regular drought monitoring depends on the underlying vegetation index and the satellite data used. Furthermore, the NDVI values can be acquired by the Advanced Very High-Resolution Radiometer (AVHRR) sensor with a resolution of 1.1 km and a total global coverage twice a week. Next, to this fast temporal ability, the NDVI values

can be analysed since the launch of the AVHRR in 1981, allowing a relative comparison of the vegetation condition over almost 40 years employing the SDVI.

The fundamental limitations of the SDVI are the following (UNSPIDER, 2022)

- The Vegetation Indices, on which the SDVI is based, do not differentiate between different types and characteristics of vegetation. Therefore, the SDVI can only provide a relative comparison of the vegetation condition while the assessed deviation from the mean vegetation condition cannot be translated into an absolute deviation of, for example, the plant height. Therefore, neither can the SDVI be interpreted for absolute quantification of agricultural damage.
- The SDVI is a good indicator of vegetation response to short-term weather conditions. However, if interpreted as a drought index, it must be considered that other climatic, hydrologic or agricultural conditions apart from drought can also cause reduced vegetation vigour. For example, relatively poor vegetation conditions may be induced by over-grazing, flooding, unseasonable coolness, or wildfires. Therefore, ground data must also be included in the analysis to better interpret the vegetation trend in a specific region.
- The SDVI measures the vegetation response to the drought hazard, but it cannot be used to quantify the magnitude of a drought hazard.

The SDVI map for South Africa for the period 30 March to 15 April 2022 compared to a 20-year mean is illustrated in Figure 1.6.10. According to the SDVI, most of central, eastern and northern South Africa show above normal vegetation growth from the mean, except the western part of NC, the whole WC and the southern part of EC. Drought conditions are shown in the Richtersveld, the southern part of EC, and a small region in Mpumalanga.

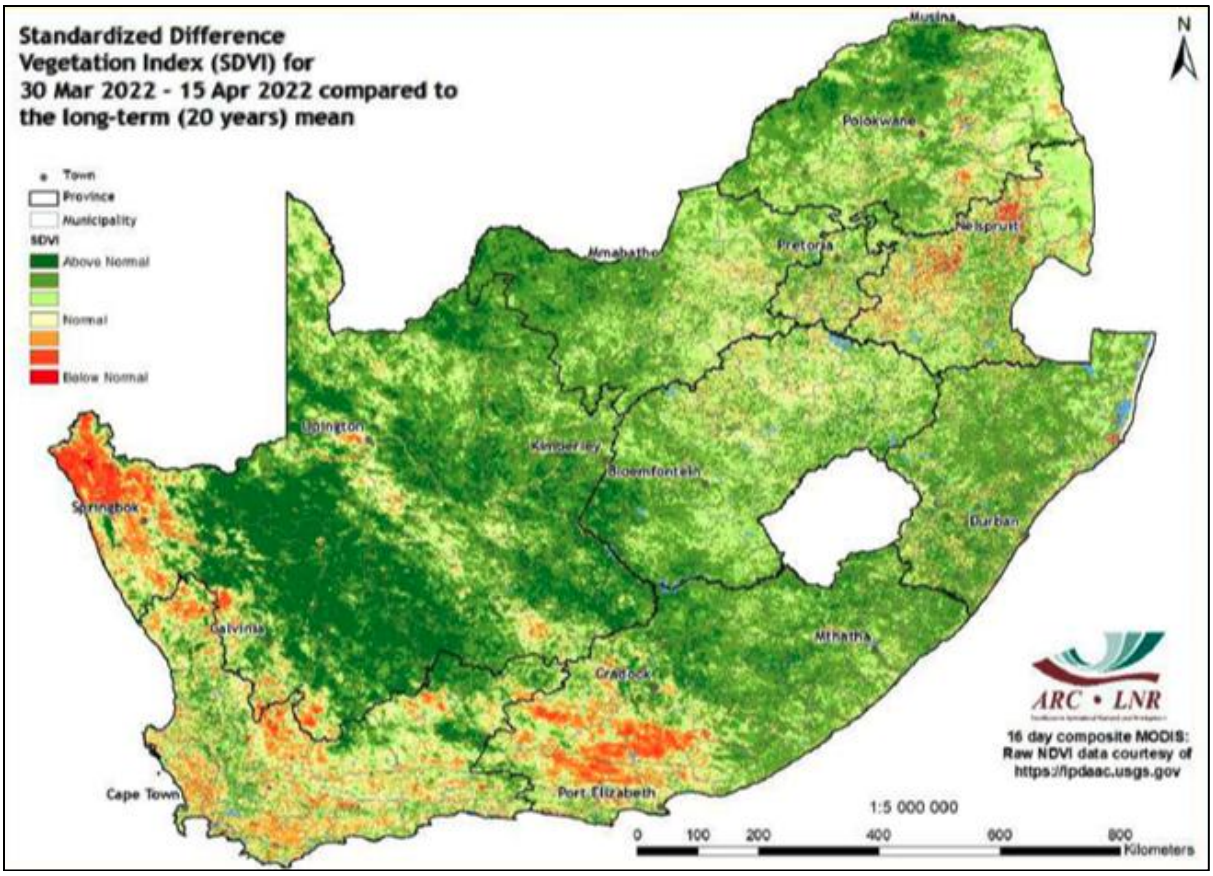


FIGURE 1.6.10: SDVI FOR THE PERIOD 30 MARCH 2022 TO 15 APRIL 2022 COMPARED TO 20-YEAR MEAN
(Source: ARC, 2022)

1.6.2.3 Vegetation Condition Index (VCI)

The VCI is an indicator of the vigour of the vegetation cover as a function of the NDVI minimum and maximum encountered for a specific pixel and a specific period, calculated over many years. The Vegetation Condition Index (VCI) compares the current NDVI to the range of values observed in the same period in previous years. The VCI is expressed in percentage and shows where the observed value is situated between the extreme values (minimum and maximum) from the previous years. Lower and higher values indicate bad and good vegetation conditions, respectively.

The algorithm for VCI computed the minimum and maximum values of NDVI for every dekade in the time series. Current NDVI is compared to these historical references every 10 days.

$$VCI = \frac{NDVI - Min}{\mathrm{Max} - \mathrm{Min}} * 100$$

Where: VCI = vegetation Condition Index
NDVI = Normalised Difference Vegetation Index
Min = Extreme minimum NDVI value from previous years
Max = Extreme maximum NDVI value from previous years

The VCI normalises the NDVI according to its changeability over many years and results in a consistent index for various land cover types. It is an effort to split the short-term weather-related signal from the long-term climatological signal as reflected by the vegetation. Therefore, the VCI is a better indicator for drought detection than the NDVI due to its ability to compare current and long-term vegetation conditions. In addition, it is a better indicator of water stress than the NDVI.

The VCI in the NC for 30 March 2022 to 15 April 2022 compared to the long-term mean is illustrated in the May UMLINDI report and shown in Figure 1.5.11.

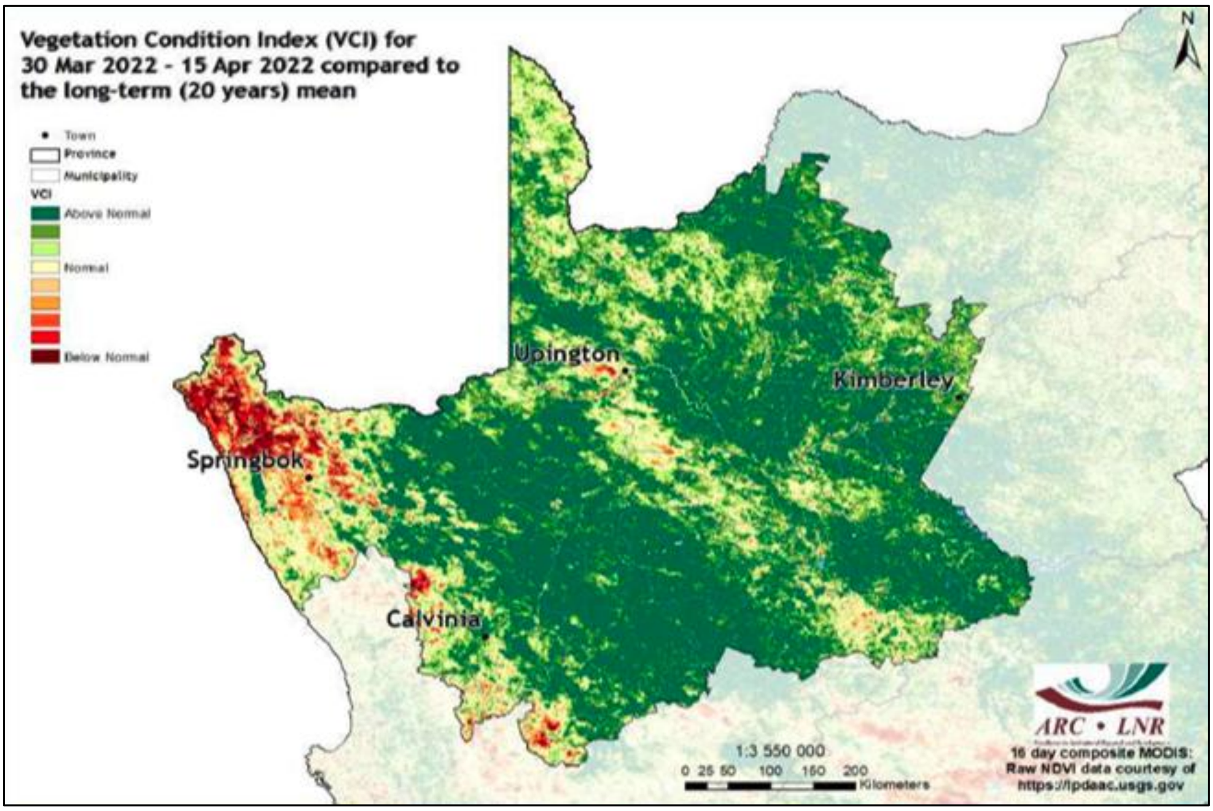


FIGURE 1.6.11: VCI FOR THE NC FOR THE PERIOD 30 MARCH TO 15 APRIL 2022 COMPARED TO THE LONG-TERM MEAN
(Source: ARC, 2022)

The VCI map in Figure 1.6.11 supports the results from the SDVI as shown in Figure 1.6.10, and the drought category is also in line with the proposed drought classification.

1.6.2.4 Percentage of Average Seasonal Greenness

(PASG) is an index representing the cumulative vegetation activity during a specific period relative to the long-term average. PASG is the cumulative NDVI compared to long-term cumulative NDVI, expressed as a percentage. The amount is expressed as a percent of the historical average. A PASG value of 100% means that the current seasonal greenness is equal to the long-term mean historical greenness, and this is indicative of normal or average vegetation conditions. PASG values less than 100% indicate below-average greenness (poorer than normal vegetation conditions) that may be linked to some form of stress (for example, drought, flooding, fire, hail damage, or pest infestation – damage caused by locusts currently a plaque in the NC serves as an example). PASG values greater than 100% indicate higher than average greenness, reflecting above-normal vegetation conditions. PASG values are not calculated for a location until the start of the season has occurred. The equation for the calculation of PASG is as follows:

$$PASG = \frac{Current\ SG}{Mean\ SG\ for\ the\ season} * 100$$

Where SG is calculated as a daily integration of the NDVI curve between the start of the season and the current date.

Figure 1.6.12 illustrates the UMLINDI PASG map for 27 December 2021 to 15 April 2022 compared to the long-term mean. The PASG clearly show the positive vegetation growth (greenness) in the NC compared to the long-term mean. The PASG map also confirms the drought conditions in the Nelson Mandela Bay region in the southern EC.

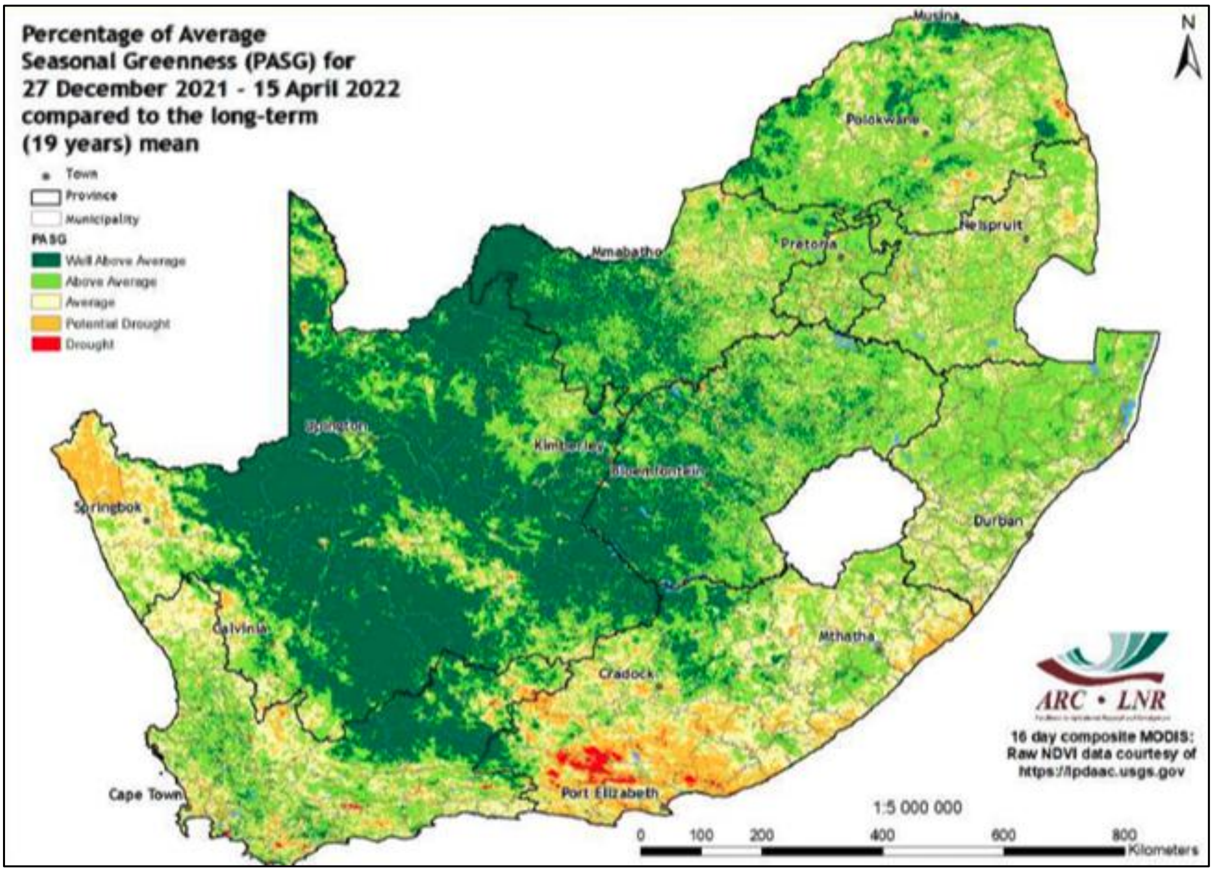


FIGURE 1.6.12: PASG FOR PERIOD 27 DECEMBER 2021 TO 15 APRIL 2022 COMPARED TO LONG-TERM MEAN
(Source: ARC 2022)

1.6.2.5 Vegetation Health Index

The Center for Satellite Applications and Research (STAR) at the National Oceanic and Atmospheric Administration (NOAA), USA, produces satellite-based global vegetation health products, including the vegetation health index (VHI). VHI is a proxy characterising vegetation health or a combined estimation of moisture and thermal conditions. Vegetation health is often used to estimate crop conditions and anticipated yield.

The NOAA products are available in near real-time and are downloadable at https://www.drought.gov/data-maps-tools/noaa-star-global-vegetation-health-products.

For example, the VHI for South Africa on 15 June 2022 is illustrated in Figure 1.6.13.

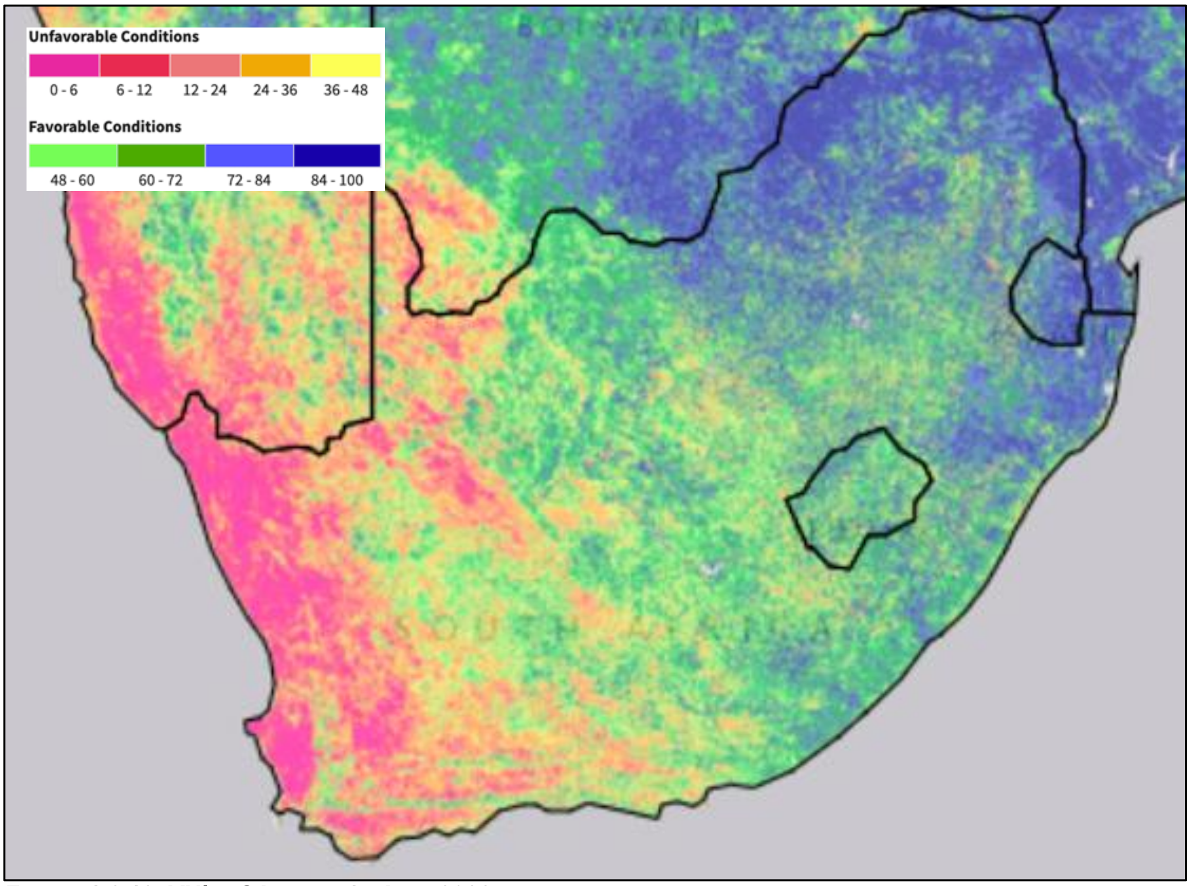


FIGURE 1.6.13: VHI IN SA AS ON 15 JUNE 2022
(Source: NOAA STAR)

If the indices are below 40, indicating different levels of vegetation stress, crop and pasture production losses might be expected; if the indices are above 60 (favourable condition), plentiful production might be expected. Comparing the NOAA images (which are near real-time) with the ARC's UMLINDI images, it is clear that vegetation health in most of the western part of South Africa has already deteriorated, primarily due to winter conditions.

1.6.2.6 Vegetation Productivity Index

The Vegetation Productivity Index (VPI) assesses the overall vegetation condition by referencing the current value of the NDVI with the long-term statistics for the same period. The VPI is a percentile ranking of the current NDVI value against its historical range of variability. For example, values of 0%, 50% and 100%, respectively, indicate that the current observation corresponds with the historical minimum (worst vegetation state), median (normal) or maximum (best situation) ever observed.

Historical reference statistics (mean, standard deviation, percentiles) of NDVI are computed every year. Current NDVI compared to these historical references every ten days. VPI computed as probability of occurrence.

Like other indicators of difference between current and historical vegetation indicator values (e.g. VCI), VPI is mostly used qualitatively to detect and spatially delineate anomalies in vegetation condition and growth, both in extension and intensity. This is particularly useful in monitoring the ongoing growing season (e.g. early warning purposes).

1.6.2.7 Enhanced Vegetation Index

EVI is similar to Normalized Difference Vegetation Index (NDVI) and can be used to quantify vegetation greenness. However, EVI corrects for some atmospheric conditions and canopy background noise and is more sensitive in areas with dense vegetation. It incorporates an "L" value to adjust for canopy background, "C" values as coefficients for atmospheric resistance, and values from the blue band (B). These enhancements allow for index calculation as a ratio between the R and NIR values while reducing the background noise, atmospheric noise, and saturation in most cases.

$$EVI = G * \frac{NIR - R}{NIR + C1 * R - C2 * B + L}$$

Where: EVI = Enhanced Vegetation Index
G =
NIR = Near-infrared spectral reflectance
R = Visible red spectral reflectance
C1 = Coefficient for atmospheric resistance
C2 = Coefficient for atmospheric resistance
B = Values from the Blue Band
L = Value to adjust for canopy background

1.6.2.8 Leaf Area Index

The Leaf Area Index is defined as half the total area of green elements of the canopy per unit of horizontal ground area. The satellite-derived value corresponds to the total green LAI of all the canopy layers, including the understory, which may represent a significant contribution, particularly for forests. Practically, the LAI quantifies the thickness of the vegetation cover.

LAI is recognised as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).

1.6.2.9 Fraction of Green Vegetation Cover

The Fraction of Vegetation Cover (FCover) corresponds to the fraction of ground covered by green vegetation. Practically, it quantifies the spatial extent of the vegetation. Because it is independent of the illumination direction and is sensitive to the vegetation amount, FCover is an excellent candidate for replacing classical vegetation indices for monitoring ecosystems.

1.6.2.10 Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)

(Source: https://land.copernicus.eu/global/products/fapar)

The FAPAR quantifies the fraction of the solar radiation absorbed by live leaves for the photosynthesis activity. Then, it refers only to the green and alive elements of the canopy. The FAPAR depends on the canopy structure, vegetation element optical properties, atmospheric conditions, and angular conFigureuration.

FAPAR is recognised as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS). Daily FAPAR, at 300m resolution, is estimated by applying a Neural Network on instantaneous Top-of-Canopy reflectances from Sentinel-3 OLCI (v1.1 products) or daily Top-of-Aerosol input reflectances from PROBA-V (v1.0). Temporal smoothing and small gap filling are applied to the instantaneous LAI estimates, discriminating Evergreen Broadleaf Forest (EBF) and no-EBF pixels. Temporal compositing is adapted to provide a near-real-time (10-daily) estimate and successive updated estimates until a consolidated value is reached after about two months.

FAPAR plays a critical role in ecosystems' energy balance and carbon balance estimation. It is one of the surface parameters that can be used in quantifying CO2 assimilation by plants and releasing water through evapotranspiration. The systematic observation of FAPAR is suitable to reliably monitor the seasonal cycle and inter-annual variability of vegetation photosynthetic activity over terrestrial surfaces.

The FAPAR is used as input to several primary productivity models based on simple light use efficiency considerations. For example, the Dry Matter Productivity is derived from the FAPAR. Then, FAPAR is used for operational crop monitoring and yield forecasting.

1.6.3 Hydrological Indices

Hydrological indicators cover surface water and sub-surface water, but for indicator categorisation, we will discuss sub-surface water in a separate section. This section focuses on streamflow and reservoir and dam levels. Hydrological indicator data is available on the National Integrated Water Information System of the DHSWS.

1.6.3.1 Reservoirs and dams

The extensive livestock sector is not as sensitive to dam and reservoir levels as the irrigation sector, but dam levels provide useful information for drought categorisation. The livestock sector is more dependent on smaller dams and reservoirs for animal drinking water, but data for farm dams are unavailable on the NIWIS. Therefore, the importance of secondary or farm-level indicators that should provide on-farm drought conditions.

Figure 1.6.14 shows the NIWIS interactive map of the major rivers and dams in South Africa. It is possible to view the historical and current dam levels of all the major dams in the country.

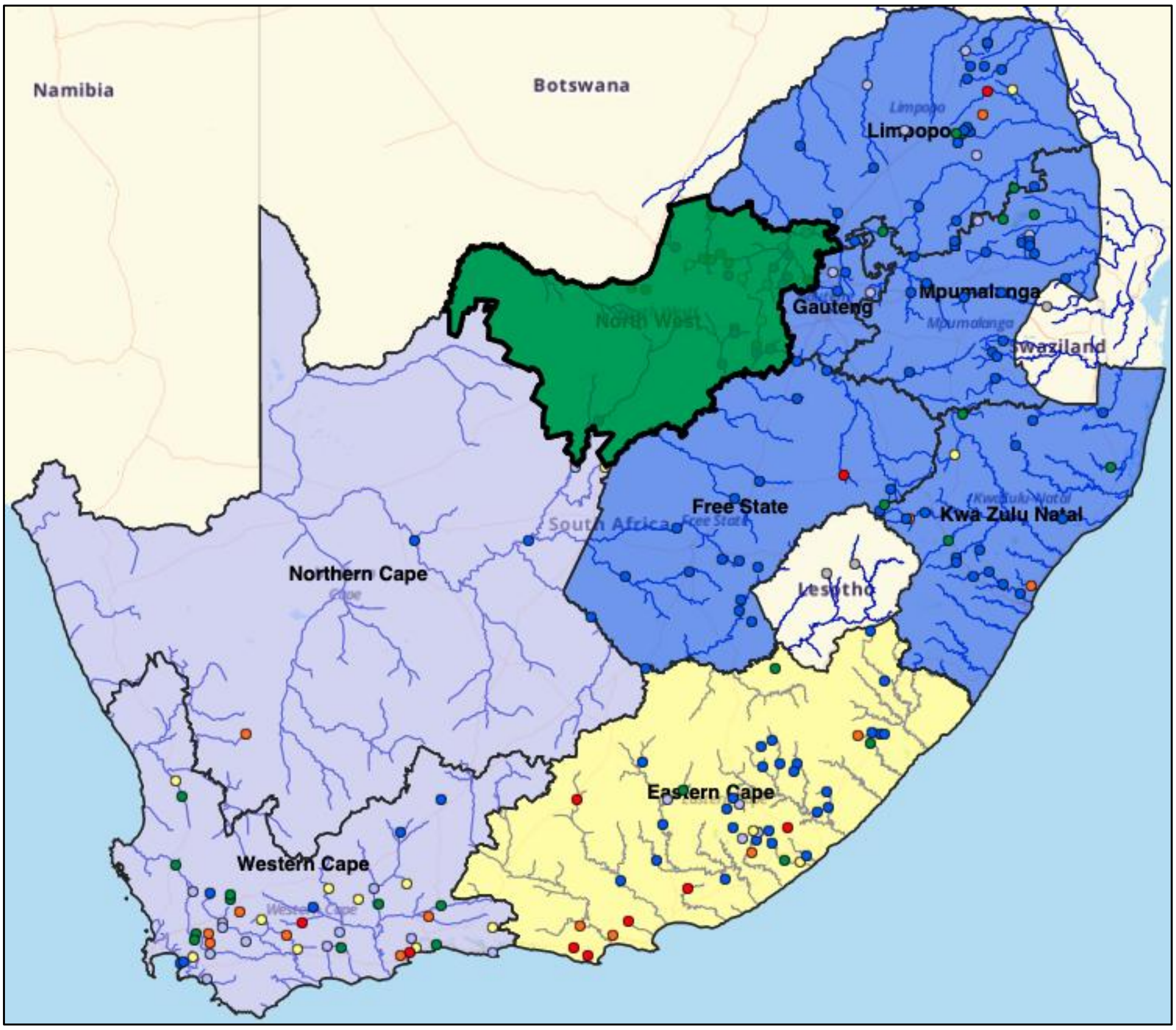


FIGURE 1.6.14: NIWIS INTERACTIVE MAP OF ALL RIVERS AND MAJOR DAMS IN SOUTH AFRICA.
(Source, NIWIS, 2022)

Figure 1.6.15 is an example of the NC surface water storage for October 2021 to September 2022. Again, storage levels are significantly higher than the 2020/2021 water storage levels for the same period.

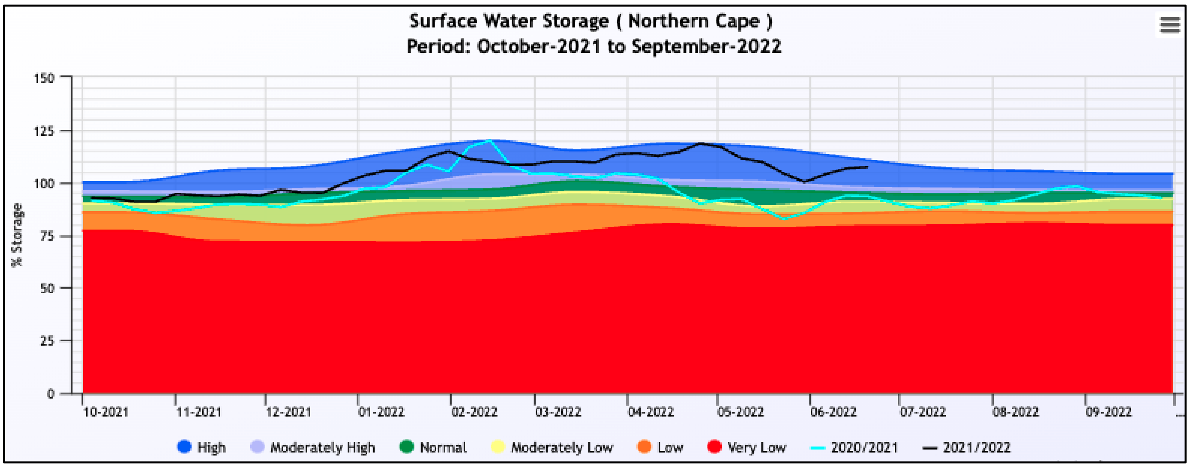


FIGURE 1.6.15: SURFACE WATER STORAGE IN THE NC
(Source, NIWIS, 2022)

Figure 1.6.16 shows the historical surface water storage levels from January 2014 to April 2022. The illustration clearly shows the deficient water storage levels from 2016 to 2017 and from 2019 to 2000.

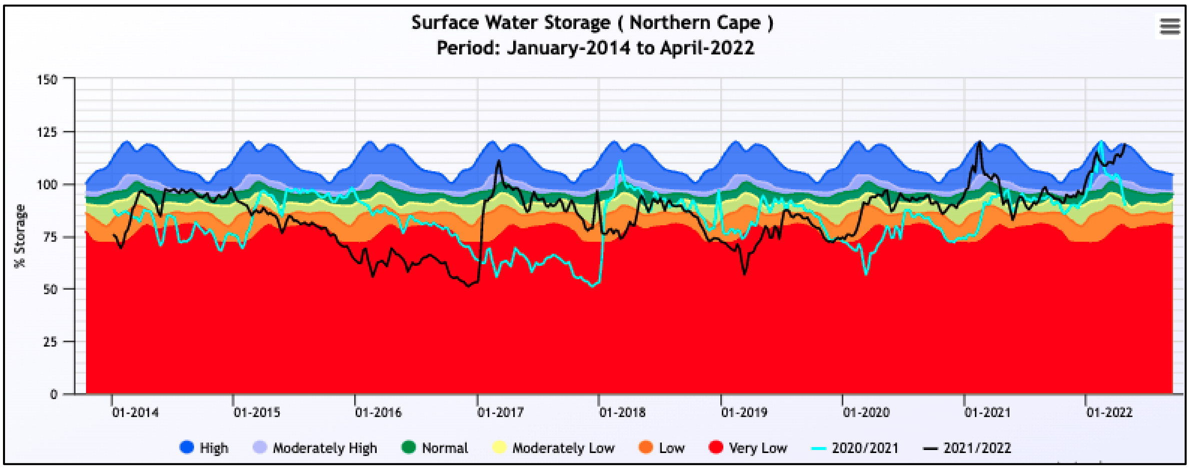


FIGURE 1.6.16: HISTORICAL SURFACE WATER STORAGE FOR THE NC
(Source: NIWIS, 2022)

Information is also available from the NIWIS for the five largest dams in the NC (See Figure 1.6.17). Information includes the name of the dam, date of measurement, the total capacity of the dam in Mm^3, the current amount of water in the dam in Mm^3, percentage of total capacity the previous year at the same time, and percentage capacity previous week, the current percentage of total capacity.

⊟ **Northern Cape (5 Dams)**						
Spitskop Dam	20-Jun-2022	57.8	57.8	102%	100%	100%
Douglas Weir	20-Jun-2022	16.2	19.1	110%	118%	118%
Karee Dam	20-Jun-2022	0.9	0.1	14%	10%	14%
Boegoeberg Dam	20-Jun-2022	20.6	37.9	48%	184%	184%
Vaalharts Weir	20-Jun-2022	50.7	42.1	89%	81%	83%
Northern Cape	**20-Jun-2022**	**146.3**	**157.1**	**93%**	**107%**	**107%**

FIGURE 1.6.17: DAM STORAGE CAPACITY AND WATER LEVEL IN THE NC
(Source: NIWIS, 2022)

1.6.3.2 Streamflow

Streamflow is equally important as storage water levels. The NIWIS provides near real-time hydrographs for all major rivers in South Africa. Livestock farmers near rivers also depend on rivers since many produces feed and fodder under irrigation as reserves for dry periods. Monitoring rivers and streams is therefore also an essential indicator for drought classification. Examples of hydrographs from the NIWIS are shown in Figures 1.6.18 to 1.6.20.

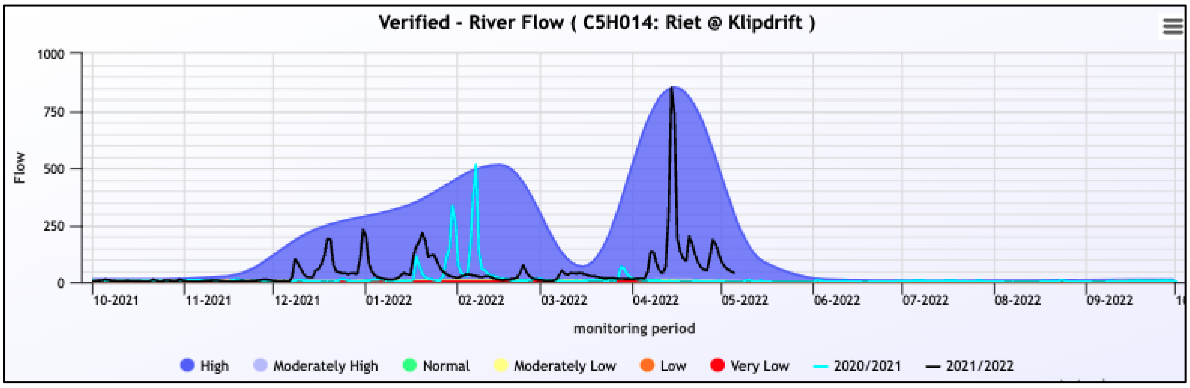


FIGURE 1.6.18: CURRENT SEASONAL HYDROGRAPHS FOR RIET RIVER AT THE KLIPDRIFT MONITOR SITE

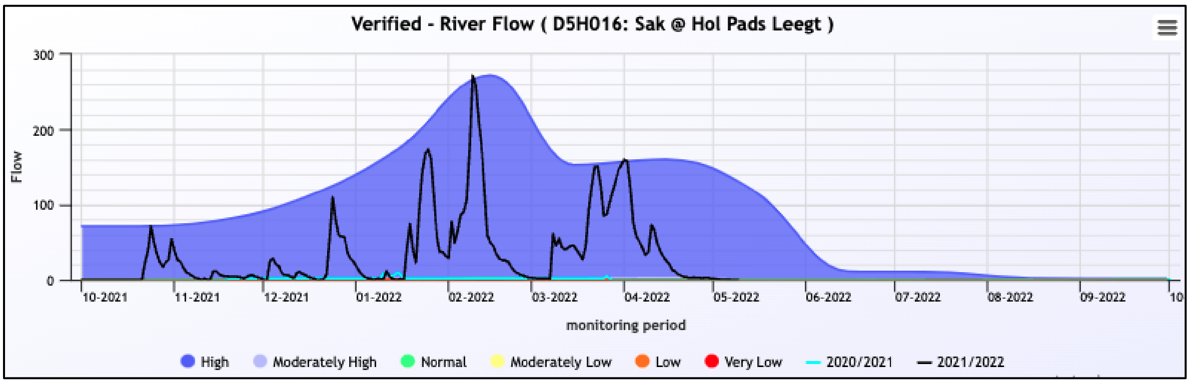


FIGURE 1.6.19: CURRENT HYDROGRAPH FOR THE SAL RIVER AT THE HOL PADS LEEGTE MONITOR SITE
(Source: NIWIS, 2022)

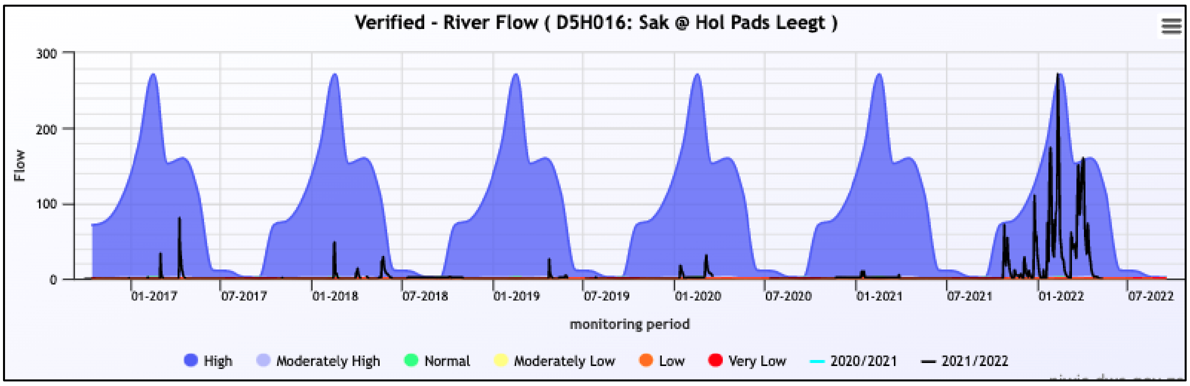


FIGURE 1.6.20: CURRENT HYDROGRAPH FOR THE SAL RIVER AT THE HOL PADS LEEGTE MONITOR SITE
(Source: NIWIS, 2022)

1.6.4 Soil moisture and groundwater indices

1.6.4.1 Soil Moisture

Soil moisture and groundwater are not the same concepts. Soil moisture is commonly expressed as the amount of water in mm of water depth in one meter of soil. For example, when 120mm water is present in one-meter depth soil, then the moisture content is 120mm/m soil. Soil moisture is also expressed as a percent of volume. For example, if 120mm moisture is measured in one-meter depth and the one-meter surface is (1^3 meters) soil, the percent moisture content is 12%, calculated as $^{0.12}/_{1}$*100= 12%. Thus, a moisture content of 120mm/m corresponds to a moisture content of 12%.

Soil moisture is an important drought indicator if used in combination with other indicators. Soil water is the most limiting plant growth factor on semi-arid rangelands. Grazing management influences the effectiveness of precipitation and soil moisture. The amount of precipitation that infiltrates the soil is directly linked to adequate plant cover and soil compaction (See Figure 1.6.21).

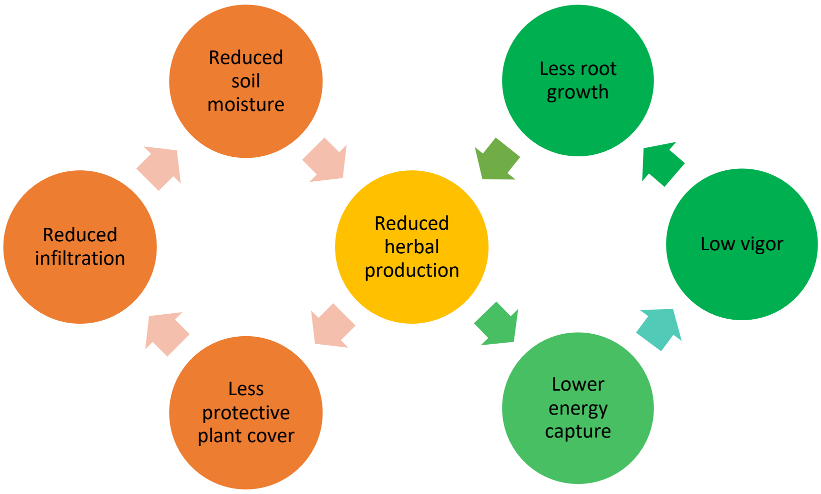


FIGURE 1.6.21: INTERACTION BETWEEN VEGETATION COVER AND SOIL MOISTURE

Reduced protective plant cover and soil compaction increased runoff during heavy precipitation. Over-grazing, therefore, might lead to artificial droughts. Analysis of remotely sensed vegetation and soil moisture data might lead to wrong conclusions in the absence of secondary ground-truthing.

Global soil moisture data to the public is available on the USGS website, the EUEMSAT for registered users and the United Nations Soil (UN-SPIDER) website. The South African National Space Agency (SANSA) have access to remotely sensed soil moisture data, but we could not find access to any of the products at a catchment scale. However, the NASA disaster dashboard (https://maps.disasters.nasa.gov/arcgis/apps/MapSeries/index.html?appid=ab7723584fe847449faaa2e62d3bef74) and the NOAA Global Drought Data dashboard at (https://experience.arcgis.com/experience/5dceec104a384df094e65af12a274959/) have some excellent near-real-time products.

The following is available on the NASA and NOAA disasters and drought dashboards:

- Root zone soil moisture
- Relative soil moisture: Top 10cm, daily
- Relative soil moisture: Top 20cm daily
- Soil moisture, 3 day composite
- Soil moisture anomaly, 3 day composite
- Shallow groundwater
- Evaporative stress index (5km, 4 weeks)
- Evaporative stress index (5km 12weeks)

Soil moisture data is based on radar backscatter measurements of the Advanced SCAT thermometer (ASCAT) aboard the EUEMSAT MetOp satellite. An example of soil moisture maps from the USGS website is shown in Figure 1.6.22.

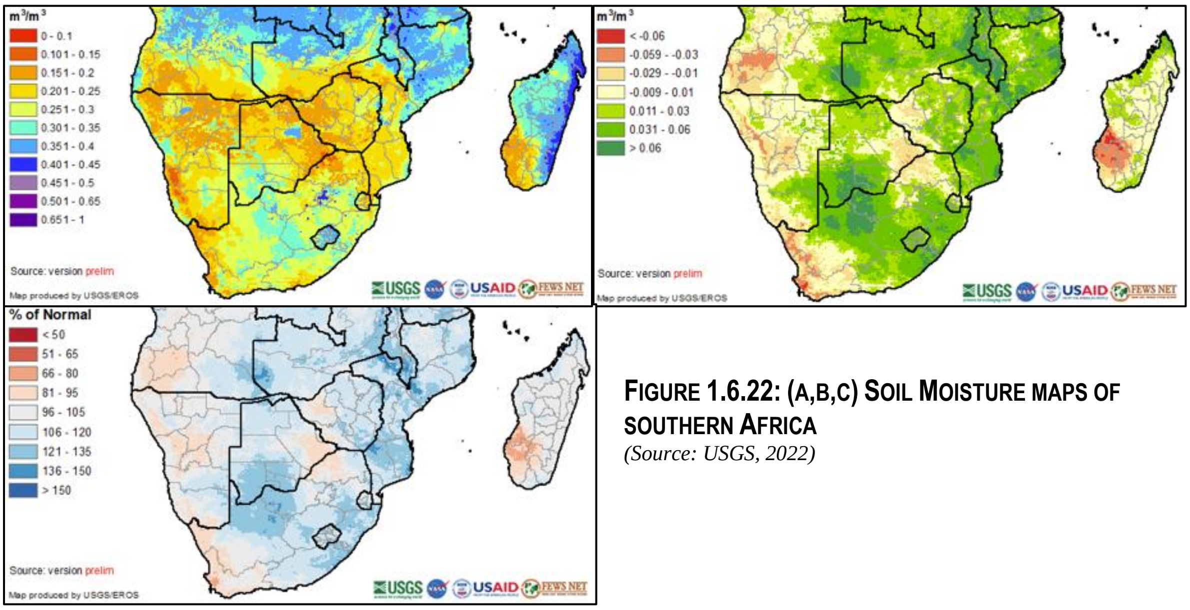


FIGURE 1.6.22: (A,B,C) SOIL MOISTURE MAPS OF SOUTHERN AFRICA
(Source: USGS, 2022)

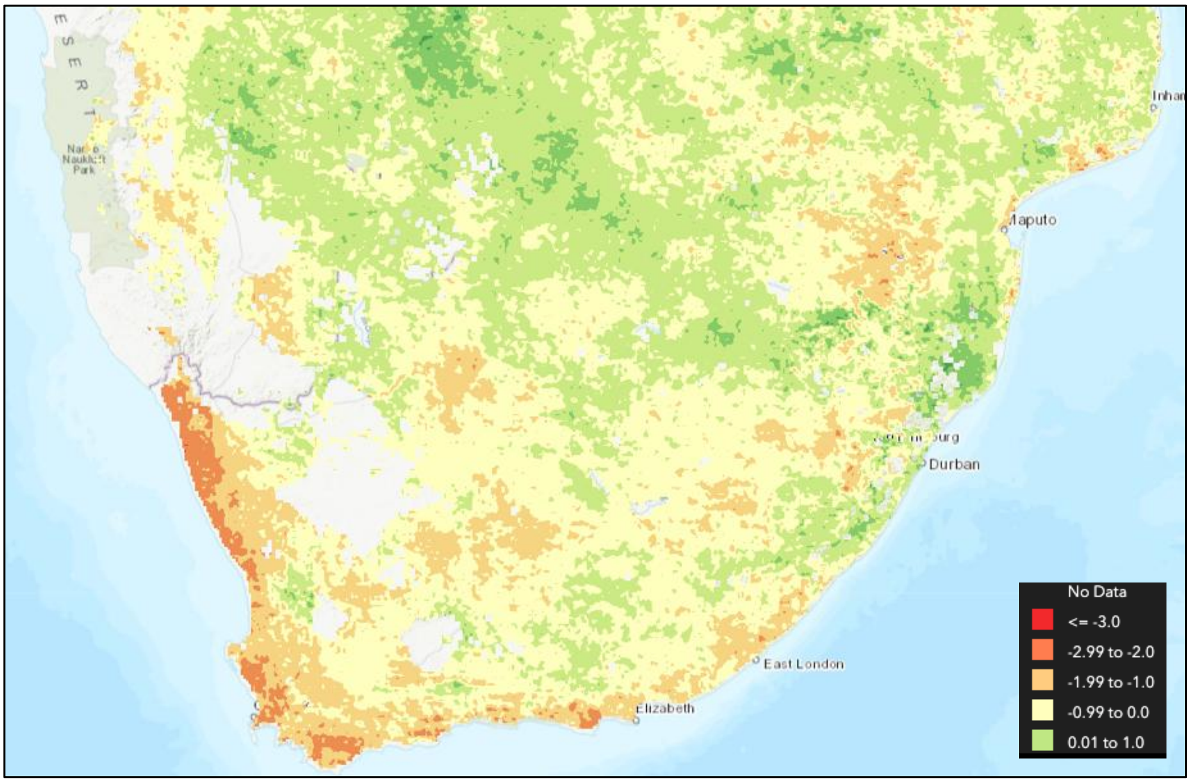


Figure 1.6.23: Evaporative stress index for South Africa, 15 June 2022

(Source: NOAA, SAT)

The evaporative stress index used by NASA and NOAA is not fully aligned with the proposed drought classification system for South Africa (See Figure 1.6.23). However, soil moisture indices are already aligned with the South African drought classification system. The proposed evaporative stress indices and soil moisture thresholds for the different drought types are as follows:

TABLE 1.6.2. PROPOSED SOIL MOISTURE THRESHOLDS FOR DIFFERENT DROUGHT CATEGORIES.

Drought classification	Drought description	Evaporative stress index	% soil moisture
D0	Dry period	<=-0.89 to 0	21% - 30%
D1	Moderate drought	<=-1.59 to -0.9	11% - 20%
D2	Severe drought	<=-2.29 to -1.6	6% - 10%
D3	Extreme drought	<=-2.99 to -2.3	3% - 5%
D4	Exceptional drought	<=-3.0	>3%

1.6.4.2 Groundwater

Groundwater usually refers to all subsurface water beneath the water table in soils and geologic formations that are fully saturated. This definition excludes soil pore water in the vadose or unsaturated zone. The water table marks the upper surface of groundwater systems. The water table may be deep or shallow and may rise or fall depending on many factors. Heavy rains may cause the water table to rise, or heavy pumping of groundwater supplies may cause the water table to fall. Water in aquifers is brought to the surface naturally through a spring or can be discharged into lakes and streams. Groundwater can also be extracted through a borehole drilled into the aquifer. A borehole is a pipe in the ground that fills with groundwater. This water can be brought to the surface by a pump. Shallow boreholes may dry if the water table falls below the bottom of the well. Some boreholes, known as artesian boreholes, do not need a pump because of natural pressures that force the water up and out of the borehole. Groundwater supplies are replenished or recharged by rain. People can face severe water shortages because groundwater is used faster than it is naturally replenished.

The livestock sector depends mainly on groundwater for animal drinking and small irrigation for feed and fodder, a drought mitigation strategy (Jordaan, 2011). Groundwater, therefore, directly impacts drought risk in the livestock sector. Groundwater is affected in various ways by a drought, and the components and characteristics of groundwater that are affected are:

- Groundwater recharge (water that infiltrates and replenishes the aquifer)
- Groundwater discharge (into surface water bodies, springs or sea)
- Groundwater storage (total volume of water withheld within the aquifer)
- Groundwater levels (level of the water table in the aquifer)

Groundwater availability fluctuates less seasonally, making groundwater a good buffer against drought. Groundwater is often available during earlier parts of a drought when surface water has run out. Only in later stages of drought will groundwater storage and availability diminish as a result of a continued drought. Hence, groundwater level can be used as a drought indicator, but only to a certain degree, because the available groundwater may not represent the current recharge. It should be noted that during drought, it is often boreholes that fail, not aquifers.

After a drought event, groundwater may be short in supply even after rainfalls start and therefore, it tends to react with a time lag relative to rainfall and surface waters, both at the onset of drought and at the end of a drought. This is illustrated in Figure 1.6.24.

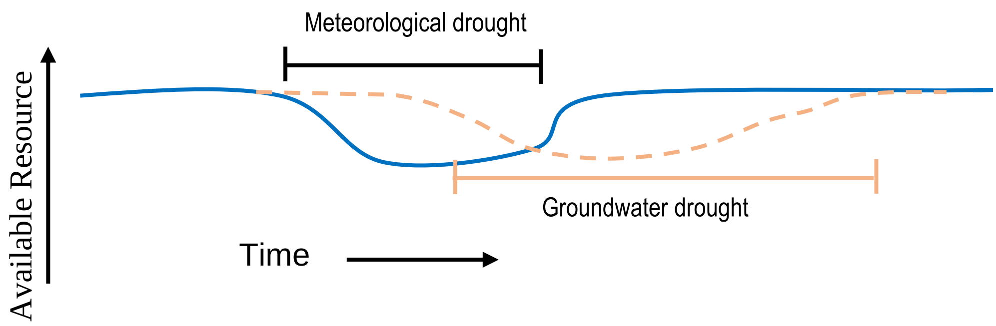


FIGURE 1.6.24: SEQUENTIAL RESPONSE AND RECOVERY FUNCTIONS OF GROUNDWATER AND SURFACE WATER TO DROUGHT.

A potential method of calculating drought based on groundwater level is the same methodology used for calculating SPI. In this case, one would use the current groundwater levels and compare them with the mean groundwater levels during the corresponding long-term historical levels. Again, one would require at least 30 years of historical data for accurate calculation. The Z score also provides an alternative way of calculation. Further research is required to determine the Z score and SPI equation as alternatives.

Groundwater information is available to the public on the National Integrated Water Information System (NIWIS), maintained by the Department of Human Settlement, Water and Sanitation (DHSWS). Groundwater levels are monitored and provided in reports that indicate percent of highest water levels (total capacity) (DWSWS, 2022).

The groundwater reserve is shown for each quaternary catchment (See Figure 1.6.25).

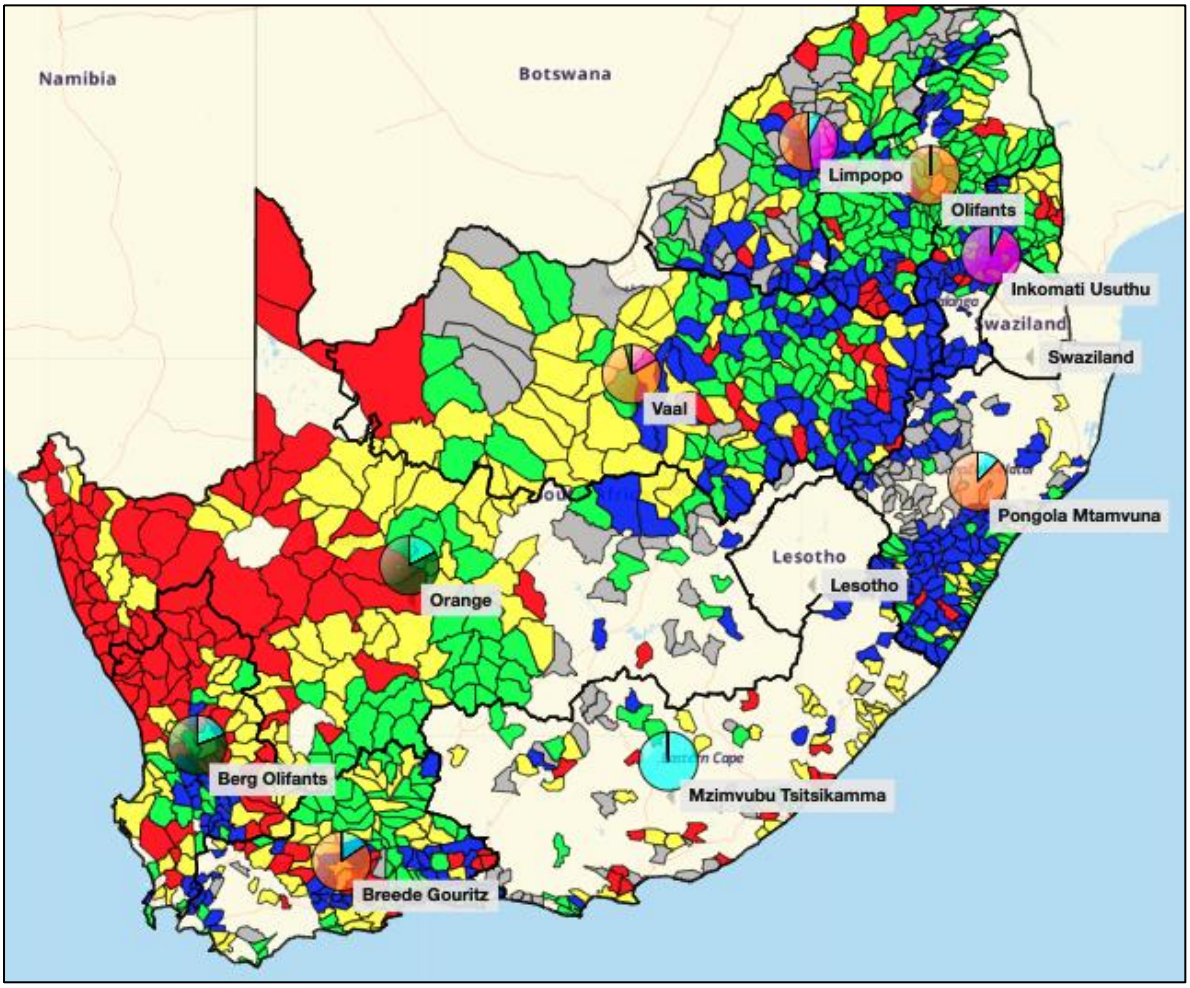


FIGURE 1.6.25: GROUNDWATER RESERVE IN SOUTH AFRICA PER QUATERNARY CATCHMENT
(Source: NIWIS, 2022)

The monitor sites in the NC are illustrated in the map in Figure 1.6.26. Unfortunately, the whole province is not fully covered.

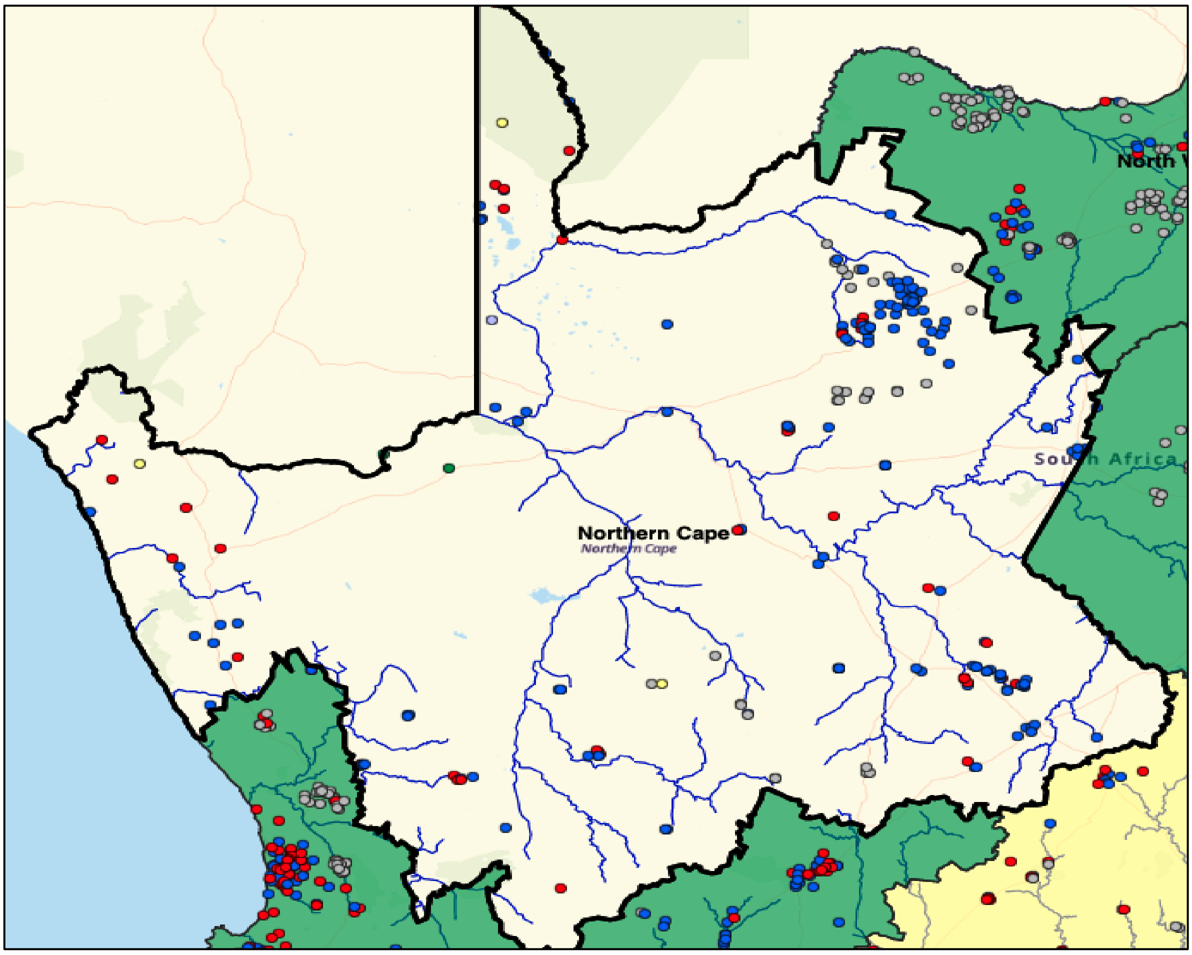


FIGURE 1.6.26: GROUNDWATER MONITOR SITES IN THE NC
(Source: NIWIS, 2022)

The groundwater status for the province is also illustrated as shown in Figure 1.6.27.

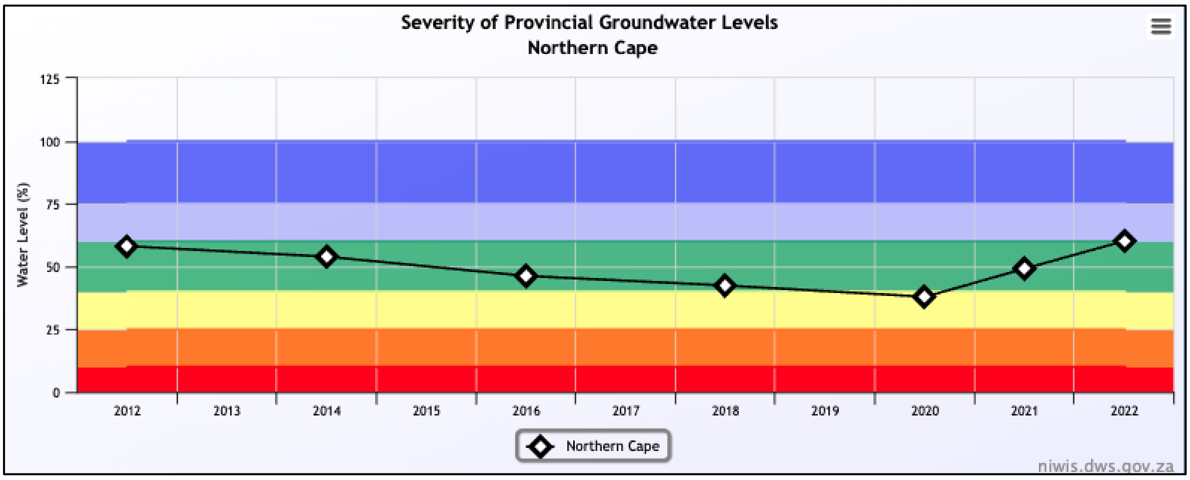


FIGURE 1.6.27: GROUNDWATER STATUS IN NC, JUNE 2022
(Source: NIWIS, 2022)

The groundwater status for individual monitor sites is also available by selecting a monitor site on the map. For example, the result for the Prieska site is illustrated in Figure 1.6.28.

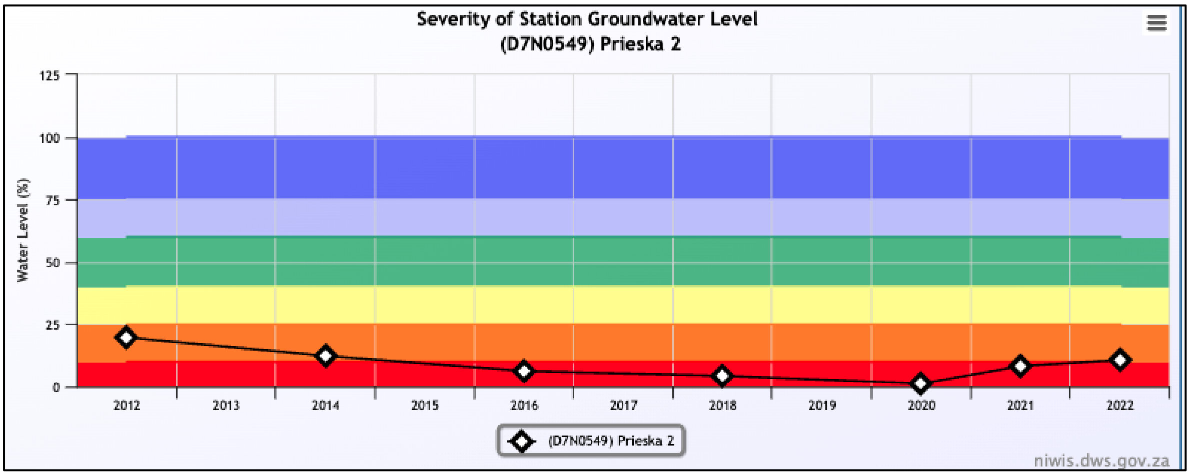


FIGURE 1.6.28: GROUNDWATER STATUS AT PRIESKA MONITOR SITE, JUNE 2022
(Source: NIWIS, 2022)

The groundwater level for the Bothaskop site near Kuruman is shown in Figure 1.6.29.

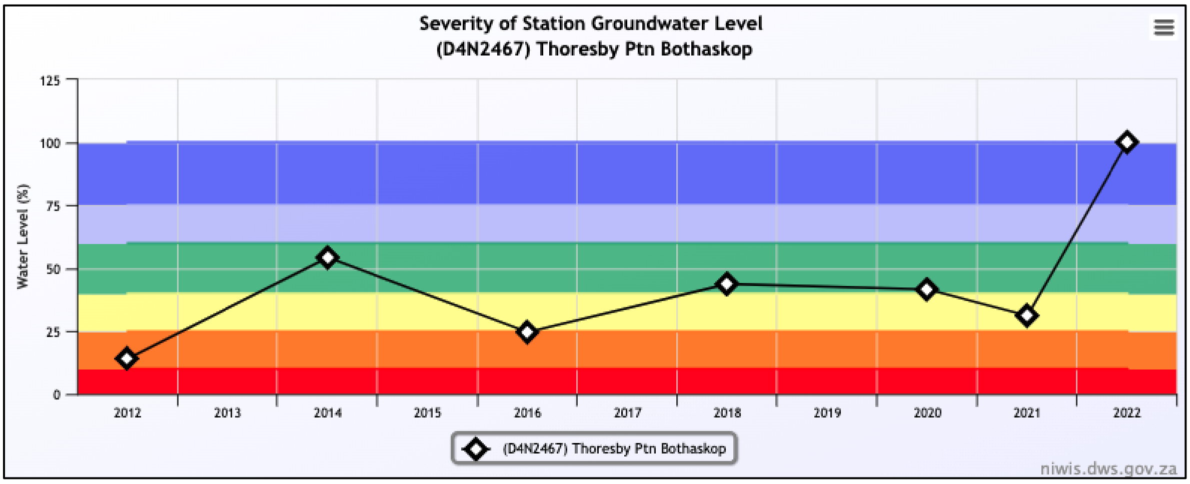


FIGURE 1.6.29: GROUNDWATER STATUS AT BOTHASKOP (NEAR KURUMAN) MONITOR SITE, JUNE 2022
(Source: NIWISS, 2022)

The above illustrations show that groundwater recharge in Prieska is extremely low with low water levels despite above-average precipitation during the 2021/2022 rainy season. On the other hand, excellent groundwater recharge is shown at the Bothaskop (near Kuruman) monitor site due to good precipitation, runoff and water recharge since 2021.

1.6.5 Indices developed in South Africa

South African scientists developed several drought indices with a specific focus on the arid regions of the Karoo and Eastern Cape. Most of these indices were developed before the availability of remotely sensed indices. Remote sensing technology today provides excellent signals for drought, and most of the South African indices are replaced by more accurate technology. Noteworthy, however, from the earlier indices is the integration of primary and secondary data as prescribed in the Roux expert system and the PUTU Suite of Plant Models. Both of these indices use meteorological data together with on-farm data to determine drought classification, aligned with the objective of this research to integrate primary and secondary (on-farm) indicators in a computerised reporting system.

1.6.5.1 Roux Expert System

The Roux expert system proposed by Roux (1991) uses subjective values for various agricultural variables as input data. The data gathering is done through a questionnaire where farmers and experts have to classify certain variables such as (i) rangeland physical condition and health, (ii) availability of planted pastures or crops for feeding and (iii) livestock condition and status of drinking water for livestock. Then, respondents choose alternatives that describe the current circumstances best and the scores are processed to a drought index (Du Pisani *et al.*, 1996).

1.6.5.2 PUTU Suite of Plant Models

Developed by Booysen (1983) and further refined by Fouche *et al.* (1985) and Fouche (1992), this model depends on daily rainfall data, temperatures and irradiance as well as soil and clay content. These models are dynamic process-driven rangeland production models that consist of various sub-routines such as water balance, carbohydrate metabolism, plant phenology, etcetera. The model includes establishing long-term yield profiles for 350 rainfall stations by ranking the cumulative distribution functions of grassland yields in descending order. Current drought intensity is then assessed by comparing the rangeland production at any given time against the long-term cumulative distribution function.

1.6.5.3 ZA Shrubland Model

The ZA shrubland model was adapted from the meteorological model of Zucchini and Adamson (1991) for arid and semi-arid shrublands. The model is based on the carry-over effect of rainfall as influenced by the amount of rainfall and temperature. The model weights the effective cumulative precipitation over consecutive six-month periods with the cumulative mean effective precipitation. Current drought intensity is assessed by weighing the current rainfall with historical values (Du Pisani *et al.*, 1998).

1.6.6 Useful Drought Information Products Already Available

Several open source websites already provide useful drought monitoring and drought indices. These should be linked to a South African drought monitor.

Some of these are discussed in the following sections:

1.6.6.1 CSIR Green Book

Web address: https://greenbook.co.za/

The green book website developed by the CSIR and other organisations as a valuable tool to obtain a snapshot of drought risk and other risks to municipal level. It also provides future projections under climate change and population change projections but it is not a dynamic tool available for real time drought monitoring. Its real value is in the information available per municipality and in future projected changes in risk profiles.

1.6.6.2 FAO AQUASTAT Global Information System on Water and Agriculture

Web address: http://www.fao.org/aquastat/en/

This information tools offers the following:

i) Standardised data and information to measure progress and to substantiate decisions
ii) Tools to generate own analysis and conclusions
iii) Capacity development to improve understanding and monitoring of water resources, water use, and irrigation management

Data is available globally and South African data is available down to micro-scale for some data sets. Data, metadata, river basin profiles, regional analysis, maps, tables, spatial data, guidelines and other tools are available on

i) Water resources; intercanal and transboundary
ii) Water use by sector, source and wastewater
iii) Irrigation locations, area, typology, technology, crops
iv) Dam locations, height, capacity and surface area
v) Water related organisations, policies and legislation

1.6.6.3 AQUEDUCT Water Risk Atlas

Web Address: https://www.wri.org/aqueduct

Aqueduct provide two sets of tools, which can be used globally. These are the:

i) Aqueduct water risk tool that maps and analyses current and future water risks across locations. The water risk tool provides excellent information at country and catchment level about water stress, water depletion, interannual variability, seasonal variability, groundwater table changes, riverine flood risks, coastal flood risks, drought risk, untreated connected wastewater, coastal eutrophication potential, drinking water and sanitation.
ii) Aqueduct country rankings, which compare national and sub-national water risks. The overall score for SA is 2.89 meaning medium to high water stress score with the agricultural sector as 3.16, domestic water at 2.43 and industrial water at 2.55. Score between 2 and 3 indicates medium to high water stress and score >3 indicate high water stress.
iii) Also, of great value is the projection tool of aquaduct where projection up to 2040 are available under 3 scenarios for water stress, seasonal variability, water supply and water demand.

1.6.6.4 FEWSNET (Famine Early Warning Systems Network)

Web address: https://fews.net/

The primary objective of FEWSNET is to monitor food security for different regions in the world. Various tools and projects available on the FEWSNET web page are useful for drought monitoring in the region and in South Africa. FEWSNET provides data and interactive maps on agro-climatology, livelihoods, markets and trades, nutrition, food security and weather and climate data. The website also provides useful links to NOAA and USGS, which have useful tools for drought monitoring.

An important link with various tools and products with spatially visible results on weather and climate data as well as various agricultural remotely sensed indicators is available at https://earlywarning.usgs.gov/fews/search,

1.6.6.5 NOAA Climate Prediction Centre

Web address: https://www.cpc.ncep.noaa.gov/products/international/

Wide range of weather and climate forecasting products are available for all regions and countries in the world.

1.6.6.6 Climate Engine

Web address: https://clim-engine.appspot.com/climateEngine

Allows users to make maps of different climate features

1.6.6.7 Global Drought Information System

Web address: https://www.drought.gov/gdm/

1.6.6.8 International Water & Climate Atlas

Web address: https://www.iwmi.cgiar.org/resources/world-water-and-climate-atlas/

An interactive service is available from which meteorological and climate data as well as drought indicators can be downloaded. The data can be downloaded for specific sites.

1.6.6.9 Sentinel Hub

Web address: https://www.sentinel-hub.com/

This is a very useful site for generating real time and historical maps base on images from a complete archive of Sentinel-1, Sentinel-2, Sentinel-3, archives of Landsat 5,7 and 8, Envisat, Merit, Proba-V and GIBS products; All open source and free to use. Various layers are available. Information for drought management such as soil moisture, NDVI, PASG, VCI and water status are daily updated. Subscription at a very reasonable price is available for commercial use.

1.6.6.10 Australian National Drought Map

Web address: https://map.drought.gov.au/

The Australian drought map is one of the best-case examples of drought monitoring. Much of the remotely sensed information required for drought management – even for SA - is available on the Australian drought map. (See discussion in Chapter 7).

1.6.6.11 USNDMC

Web address: https://droughtmonitor.unl.edu/

The United States National Drought Monitor located at the University of Nebraska and funded by NOAA and USDA is another best-case example of an integrated drought monitor and early warning system. (see discussion in Chapter 7).

1.7 Input Data for Drought Monitoring

The implementation of the monitor system, better expressed as a drought information management and communication system, should inform the drought classification for each quaternary catchment, which in turn provides the thresholds for activation of contingency plans. Some of the products required for drought classification, monitoring and early warning are discussed in Chapter 5. In addition, this chapter provides a summary of the data and information required to support the drought monitor products (outputs).

Indicators drive drought monitoring with indicator thresholds that indicate the different levels of drought. It is therefore imperative that drought classification and the different indicators and indicator thresholds are considered the primary sources of information required for drought monitoring. Necessary for drought monitoring are historical data, current drought situation and projections. Several indicators are helpful for drought analysis and monitoring. These include, amongst others, the following:

1.7.1 Meteorological indicators

Meteorological indicators are available from the SAWS, ARC, and other sources and should be updated daily.

i. Precipitation
ii. Maximum temperature
iii. Minimum temperature
iv. Actual temperature
v. Wind
vi. Evaporation (mm/day)
vii. Reference crop evapotranspiration (mm/day)
viii. Evaporation and evapotranspiration ratios can be calculated from the mentioned indicators.
ix. SPI (3 -, 6-, 12-, 24-, 36-, 48-month)
x. SPEI (3-, 6-, 12-, 24-, 36-, 48-month)
xi. Drought Index

1.7.2 Hydrological indicators

Hydrological indicators are available primarily from the Department of Human Settlement, Water and Sanitation and other sources. Primary indicators to be monitored and updated weekly are:

i. Dam levels (Actual & Z-score compared to the same time)
ii. Base flow (mm/day)
iii. Stream flow (m^3 & Z-score compared at the same time)

iv. Groundwater levels (Z-score compared to the same time)
v. Surface runoff (actual and comparison to the long-term mean)
vi. Demand/supply index per municipality
vii. Demand/supply index per irrigation scheme

1.7.3 Remotely sensed ecological indicators

Remotely sensed indicators are available from SANSA, research institutions, and various open-source websites. It is possible to update the following daily:

i. NDVI
ii. VCI
iii. PASG
iv. NHVI

1.7.4 Remotely sensed soil indicators

i. Soil moisture (topsoil)
ii. Soil moisture (10cm – 40cm)
iii. Soil moisture (total)
iv. Soil moisture deviation from the mean
v. Groundwater level (actual)
vi. Groundwater levels (deviation from the mean)

1.7.5 Socio-economic indicators for drought resilience and vulnerability in agriculture

Socio-economic indicators are essential for monitoring resilience and vulnerability to drought. It is also helpful to illustrate such indicators per quaternary catchment or municipality. Socio-economic information is available from various sources such as the Department of Social Development, Statistics SA, DARDLR, research organisations and other sources.

The following are examples of socio-economic indicators that are useful for the determination of drought resilience per catchment or municipality

i. # of people in farming
ii. Age and gender profile of farmers and farm workers
iii. Education level of farmers
iv. # of farmers per quaternary catchment or municipality
v. # of farm labourers
vi. No non-farm labourers
vii. Unemployment rate
viii. Youth unemployment rate
ix. Alternative job opportunities
x. The debt ratio of farmers
xi. # bankruptcies amongst farmers because of previous droughts
xii. Farmers household stress
xiii. The average income of farmers and farm workers
xiv. Economic dependency on farming
xv. # people in the quaternary catchment
xvi. In and out-migration of people linked to agriculture
xvii. # people dependent on social grants
xviii. % communal land
xix. Internet connectivity
xx. Average household size of farmers and farm labourers
xxi. # of children from farms in primary and secondary schools
xxii. Primary health services available to farms
xxiii. Health services available such as Doctors per 1000 people or hospitals
xxiv. Available social services to the farming community

1.7.6 Secondary / ground-truth indicators

Best practice experience globally, however, teaches us that more indicators are required to ground-truth the information obtained from remotely sensed sources. The primary indicators mentioned above should catalyse drought classification, but municipalities, water managers, farmers, and others should ground-truth the information. For example, the United States drought monitor sometimes utilised up to more than 50 drought indicators as a composite indicator for drought monitoring and drought impact (US Drought Monitor, 2015).

Therefore, we recommend a system of secondary indicators that should support the primary ones mentioned above. The secondary indicators serve as a source to confirm what is evident from remote sensing and meteorological data and to provide real-time information on actual conditions at the local level. Various sources are available as secondary indicators, but we propose a reference farm system for agricultural-related droughts as an initial phase.

The secondary indicators to be utilised in conjunction with the primary indicators include but are not limited to the following:

- Rainfall and temperature (on the farm)
- Vegetation condition and availability
- Animal conditions
- Actual soil moisture content
- Groundwater levels
- Surface water levels

1.7.6.1 Reference farms

Quantitative measurement of the secondary indicators is a challenge but a requirement for quantitative drought classification. Political pressure and qualitative opinions influenced drought declarations in the past. In order to ensure proper drought monitoring at the farm level, a system of reference farms should be implemented. At least one-reference farm should be selected for each quaternary catchment. The objective with reference farms is to formalise and implement a system on the selected farms based on practical experience and research over a long period of drought management. Reference farms are those particular farms chosen in a catchment area where a farmer is prepared to collect and supply data on rainfall, carrying capacity, veld condition and other scientific information according to specific terms and conditions. In collaboration with DAFF, the provincial departments of agriculture, the disaster management centres and organised agriculture. Data should be submitted regularly via the Internet on a web-based system. This data should be analysed, processed and used as a source for drought monitoring and early warning.

Furthermore, the reference farm system can contribute to calculating the carrying capacity for the different catchment areas. Reference farms must have typical characteristics of the selected catchment. One acknowledges that rainfall is not always the same on all farms in a specific catchment, and cognisance should be taken of thunderstorms and localised showers.

The natural resources on the reference farm must be representative of the specific catchment. The most significant natural resources are veld type, water supply, soil type, geographical features, and the farming system. The farmer (owner or lessee) (called participant) must be willing and able to keep records and provide data weekly. The participant must apply good agricultural practices according to the norms and climate conditions of the specific region. In addition, the participant must be connected or have access to the Internet to provide and upload data regularly.

Participants in the drought monitor and early warning project must:

- Supply daily meteorological data on at least a weekly basis. The possibility of automatic meteorological data capturing mechanisms should be discussed with SAWS.
- Supply an inventory of all animals and movement of animals in terms of progeny, sales and purchases on the farm, i.e. sheep, cattle, horses, donkeys, ostriches and game (Values according to the present Meisner tables or as reviewed.)
- Adhere to the carrying capacity according to the norms of DAFF over a twelve-month cycle. As a farmer who applies good agricultural practices, he/she will under-graze some years and over-graze others depending on the condition of the veld and climate conditions. Therefore the carrying capacity will be exceeded for some years etc. Of course, the baseline veld condition on a specific farm differs from others, and not all farms have the same carrying capacity, but sound agricultural principles apply.
- Comply with good farming practice (veld management system).
- Comply with the protocols provided by the drought monitor unit.

The secondary indicators on the reference farms (rainfall, temperature, grazing and animal condition, surface and groundwater levels) can now be used as a basis for drought classification in conjunction with the primary indicators.

1.7.6.2 Other sources of secondary indicators

Other organisations responsible for the monitoring and provision of data on secondary indicators are the DALRRD), DHSWS and DEFF. In addition, municipalities and Traditional leaders as custodians of agricultural land should also be included as sources of secondary data for drought classification.

1.7.6.3 Future research on secondary indicators

Specific guidelines and thresholds for secondary indicators are not available. Consequently, that is one of the sub-objectives of this research project, and the following deliverable should provide more clarity on the secondary drought indicators.

1.8 Global Best-Case Examples

Lately, several organisations have developed global drought monitor initiatives with access to information on different websites. But unfortunately, these websites do not provide sufficient information at the micro-scale. Some of the best-case examples of micro-scale drought monitoring are the United Stated drought monitor and the Australian drought monitoring systems. The following section describes the highlights of these systems.

1.8.1 United States National Drought Monitor Centre (USNDMC)

https://droughtmonitor.unl.edu/ https://www.drought.gov/drought/node/

The USNDMC is another best-case example for drought monitoring. Up to 50 indicators are used to monitor drought conditions in the United States. The USNDMC is located at the University of Nebraska, and the principal funder is the Federal Department of Agriculture in the United States (US). The USNDMC update drought conditions weekly and provide a nationwide drought monitor map based on more than 50 indicators. Additional information supporting the drought monitor map is also available online, and the public can download all data and statistical analysis used to develop the drought monitor map. An example of the drought monitor map dated 8 September is shown in Figure 1.8.1.

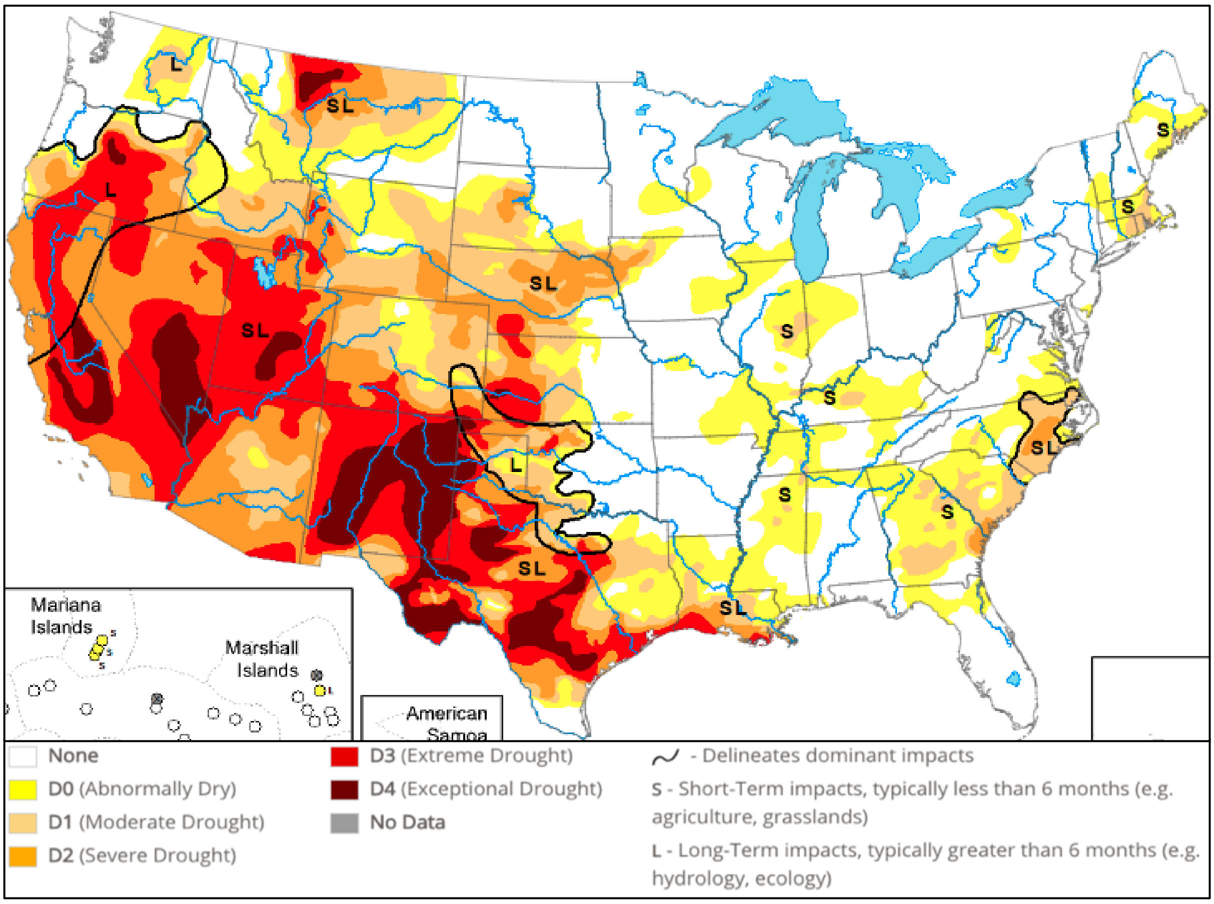


FIGURE 1.8.1: US DROUGHT MAP, 22 JUNE 2022
(Source: USNDMC, 2022)

Additional information in support of the drought monitor map is discussed in following sections:

1.8.1.1 Data

All data are available in table format or as illustrations on graphs or maps. In addition, the following data types are available open-source and for use by the public.

1.8.1.1.1 Time Series Data

Time series data is especially useful for comparing current conditions with previous periods. Time series drought data is available as raw data and illustrations on a graph. The illustrations of the data are available at (i) national level, (ii) climate zone, (iii) State (province in SA), (iv) county (district in SA), (v) river catchments, (vi) water management areas, (vii) urban areas, (viii) agricultural production system regions, and (ix) numerous other regions.

An example of a time series drought graph is shown in Figure 1.8.2.

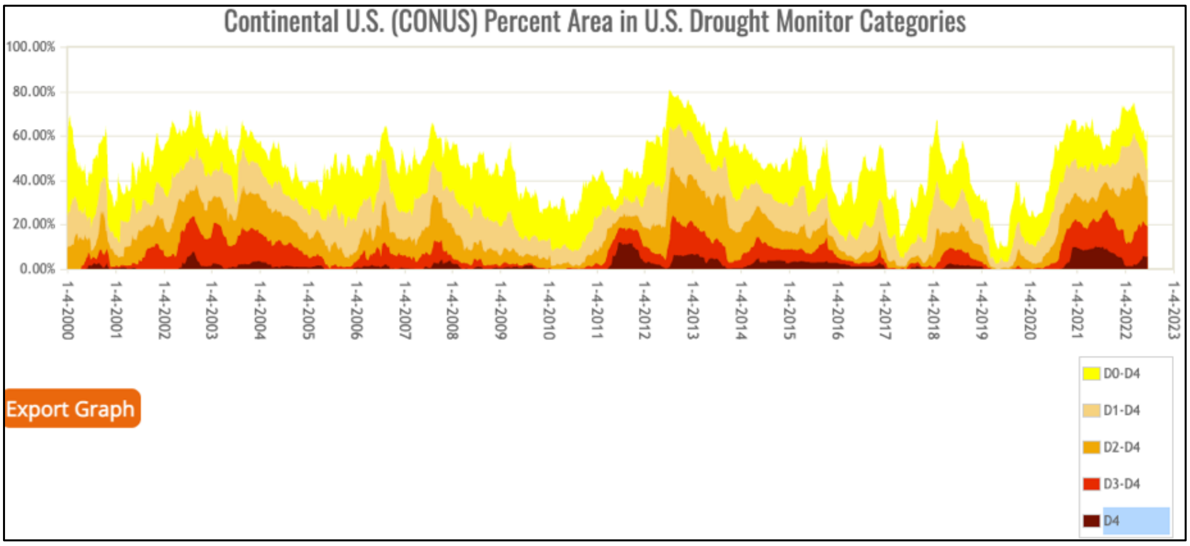


FIGURE 1.8.2: TIME SERIES DATA COMPARING DROUGHT TYPES FROM 2000 – 2022
(Source: USNDMC, 2022)

1.8.1.1.2 Tabular Data Archives

The tabular data archives provide specific information on percentage of areas classified in the different drought classes. This information is also available for all geographic regions as discussed in time series data. It is important to note that the South African drought classes are the same as the US drought classes; from D0 to D4.

An example of the tabular data available is shown in Table 1.8.1.

TABLE 1.8.1: TABULAR DATA OF DROUGHT CONDITIONS PER REGION

Percent Area in U.S. Drought Monitor Categories

Show 25 entries Search:

Week	None	D0-D4	D1-D4	D2-D4	D3-D4	D4	DSCI
2022-06-21	37.51	62.49	45.38	32.86	19.13	5.62	166
2022-06-14	42.78	57.22	44.54	32.76	19.63	5.59	160
2022-06-07	41.68	58.32	47.57	34.37	19.62	5.43	165
2022-05-31	41.58	58.42	49.30	36.98	20.14	5.52	170
2022-05-24	38.01	61.99	50.66	39.15	20.94	5.96	179
2022-05-17	36.86	63.14	52.54	39.90	21.61	5.77	183
2022-05-10	38.78	61.22	53.02	39.76	19.97	4.27	178
2022-05-03	36.11	63.89	53.77	40.48	18.52	4.16	181
2022-04-26	35.88	64.12	54.20	42.29	19.73	3.56	184
2022-04-19	34.18	65.82	55.38	42.99	20.24	2.82	187
2022-04-12	32.56	67.44	56.73	43.23	19.37	2.58	189
2022-04-05	30.71	69.29	57.30	43.22	17.51	2.13	189
2022-03-29	30.47	69.53	57.97	41.27	17.14	1.85	188
2022-03-22	28.12	71.88	58.27	40.80	16.54	1.76	189
2022-03-15	25.75	74.25	60.98	42.40	17.04	2.08	197
2022-03-08	24.87	75.13	61.11	41.83	14.95	2.04	195
2022-03-01	26.46	73.54	59.17	39.97	13.31	1.18	187
2022-02-22	26.63	73.37	57.52	36.28	12.18	1.23	181
2022-02-15	27.42	72.58	57.06	36.35	11.85	1.24	179
2022-02-08	28.83	71.17	55.47	35.40	11.32	1.34	175
2022-02-01	27.79	72.21	55.24	36.52	12.22	1.34	178

(Source: USNDMC, 2022)

The DSCI value indicated are the total drought severity and drought coverage index for a specific region.

1.8.1.1.3 Data Download Available

Detailed and weekly uploaded data are available for the following:

i. **Comprehensive statistics:** Download data for all U.S. Drought Monitor categories for each week of the selected period and location. Data options are the percent of the area, total area, percent of the population and total population. Spatial scale choices include national, State, County and urban areas, and many more.

ii. **Statistics by threshold:** Choose a place, time, and Drought Monitor level, and get the proportion of an area that meets your chosen criteria. One can also specify a minimum or maximum threshold as a proportion of the area.

iii. **Weeks in drought:** Find out how many weeks, consecutive or total, each county in a state has been in a certain level of drought.

1.8.1.1.4 GIS data

All drought monitor shapefiles are available from 2000. All data was updated weekly. An example of the shapefiles and metadata available is shown in Table 1.8.2.

TABLE 1.8.2. SUMMARY TABLE INDICATING TYPE OF SHAPEFILE AVAILABLE

2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000

Download all Drought Monitor shapefiles for 2022.

Date	KMZ	Shapefiles		GML	WMS	Statistics		
Current	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-06-21	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-06-14	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-06-07	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-05-31	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-05-24	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-05-17	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-05-10	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-05-03	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-04-26	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-04-19	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-04-12	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County
2022-04-05	KMZ	SHP	Impacts	GML	WMS	U.S.	State	County

(Source: USNDMC, 2022)

KMZ files are spatial datasets formatted for Google Earth. GML files are spatial datasets formatted using the Geographic Markup Language. Each WMS file contains one Drought Monitor layer based on the cleaned shapefiles projected to the WGS84 projection.

1.8.1.1.5 Meta Data

The Excel files contain the percent area statistics for the given week. The Drought Monitor classes are cumulative---if a region is in D2, it is also in D1 and D0. The statistics provided on the site represent those cumulative values. For example, Region A has 75% in D0, 50%

in D1 and 10% in D2. Therefore, 25% (75%-50%) of Region A is in D0 only; 40% in D1 and D0; and 10% in D2, D1 and D0.

Each file contains four worksheets:

- one containing values for the whole US
- one containing values for the contiguous US (CONUS)
- one containing values for each State
- and one containing values for each county.

Column headers are included.

1.8.1.1.6 FSA livestock eligibility tool

This section provides the necessary guidelines for livestock farmers to test if they qualify for assistance if they experience specific drought conditions. Drought classification per region is the primary consideration for eligibility.

1.8.1.1.7 Drought Impacts by State

The drought impact by State provides potential impacts for each State according to the different drought classifications. An illustration of the different impacts is shown in Tables 1.8.3 and 1.8.4. Table 1.8.3 show an example of the potential impacts for a D4 drought for Nebraska.

TABLE 1.8.3. D4 DROUGHT IMPACTS FOR NEBRASKA

Category	Historically observed impacts
D0	Rangeland conditions decline
D1	Pasture and crop growth are stunted
	Surface water levels decline
D2	Crop yields are low; ethanol production decreases and plants begin to close
	Fires increase; firework restrictions are possible
	Roadside haying begins
	Well levels are dropping; mandatory surface water irrigation restrictions are implemented; water use is high
D3	Hay is scarce and expensive; producers are selling cattle early and culling; horses are abandoned
	Pavement is cracking
	Fish kills claim thousands of fish; drought-tolerant trees are dying
	Water temperatures are high; Platte River is dry in sections; water recreation is limited
	Groundwater use increases; new irrigation wells are drilled
D4	Crop germination is stunted; high levels of nitrate are found in corn
	Auctions have record number of cattle
	Wildfire season is destructive and costly
	Severe case of EHD is observed in deer population; deer hunting is down
	Municipality water supply is low; trade navigation is hindered on major rivers due to low flow and obstructions

(Source: USNDMC, 2022)

Table 1.8.4 show an example of the potential D4 drought impacts for Nevada.

It is important to note that potential impacts are region-specific, but the drought categories are the same. The indicator thresholds for a D3 or D4 drought in Nebraska are the same as indicator thresholds for a D3 or D4 drought in any other State.

TABLE 1.8.4: D4 DROUGHT IMPACTS FOR NORTH DAKOTA

Category	Historically observed impacts
D0	Crop germination is poor
	Grass fires increase
D1	Crops and pastures are water stressed; farmers are encouraged to have a drought plan
	Fire danger increases
	Grasshopper infestation occurs
	Pond and creek levels begin to decline; more nesting areas are available for birds
D2	Soil moisture is low; pasture and rangeland is dry; crop conditions are poor; hay yields are low; cattle are sold
	Open burn and firework restrictions are implemented; fire activity intensifies
	Conditions are dusty; air quality is poor
	Fertilizer sales are low at elevators
	River flow is decreased; stock dams are low
D3	Crops stop growing; pastures go dormant, emergency haying of conservation areas is authorized
	Blue-green algae blooms cause cattle death
	Large wildfires burn
	Fairs have fewer entries; public meetings are scheduled with government officials to discuss drought
D4	Wheat is baled for hay; numerous tests are conducted on water nitrate level and quality and high nitrate levels in forage; farm service agency increases staffing; producers cull cattle
	Wildfires are immense; rural/volunteer fire departments are stressed; rural fire departments run out of funding
	Fewer hunting permits are issued
	Local economy is at a standstill

(Source: USNDMC, 2022)

Links are available to the *"Drought Monitor Classification Scheme"* with more detailed information on drought classification and drought indices.

1.8.1.2 Maps

Maps for various time scales and for all geographical regions and regional types are available for download. Amongst others these include:

1.8.1.2.1 Compare different weeks

Compare two U.S. Drought Monitor weeks side by side.

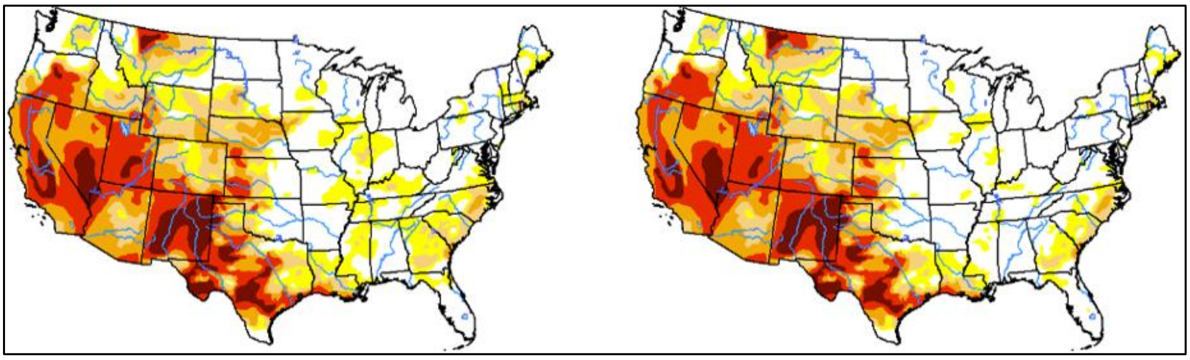


FIGURE 1.8.3: COMPARISON OF DROUGHT US MAPS BY WEEK (14 JUNE 2022 AND 21JUNE 2022)
(Source: USNDMC, 2022)

1.8.1.2.2 Comparison slider

Displays the USDM maps from two selected dates, and allows the user to determine which is displayed by using a slider bar

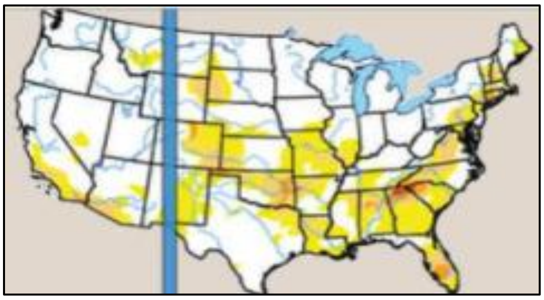


FIGURE 1.8.4: COMPARISON US SLIDER MAP
(Source, USNDMC, 2022)

1.8.1.2.3 Map archives

View any map format for a selected week. Weekly historical maps are available since 2000.

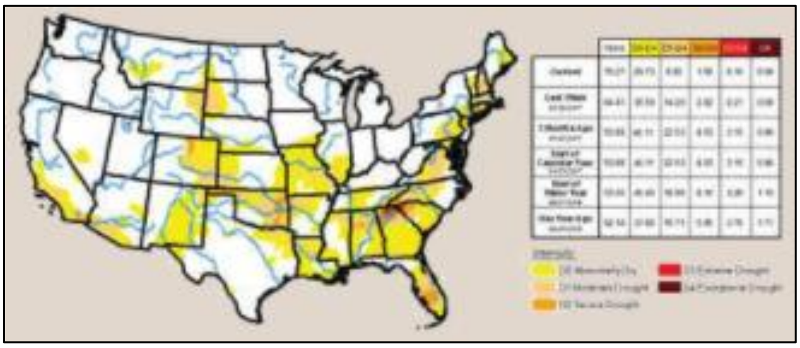


FIGURE 1.8.5: EXAMPLE OF US MAP ARCHIVES
(Source: USNDMC, 2022)

1.8.1.2.4 Change maps

View a series of change maps for a selected week.

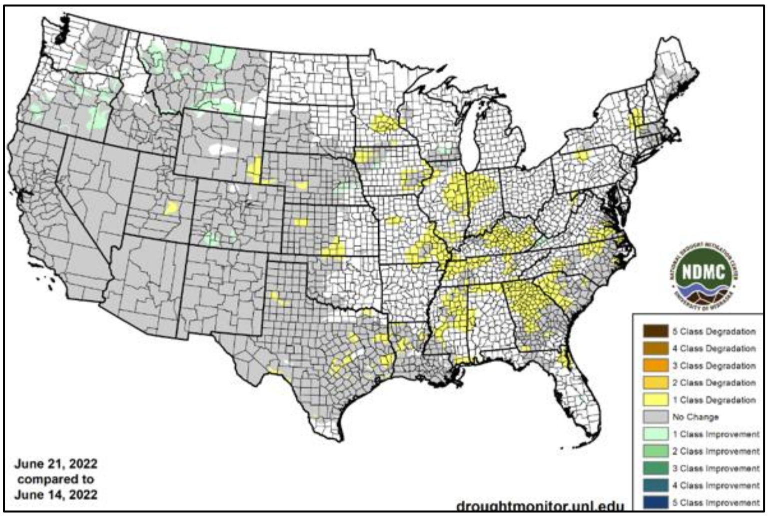


FIGURE 1.8.6: EXAMPLE OF US DROUGHT CHANGE MAP
(Source: USNDMC, 2022)

1.8.1.2.5 Animations

View an animated series of maps or download animated GIF files.

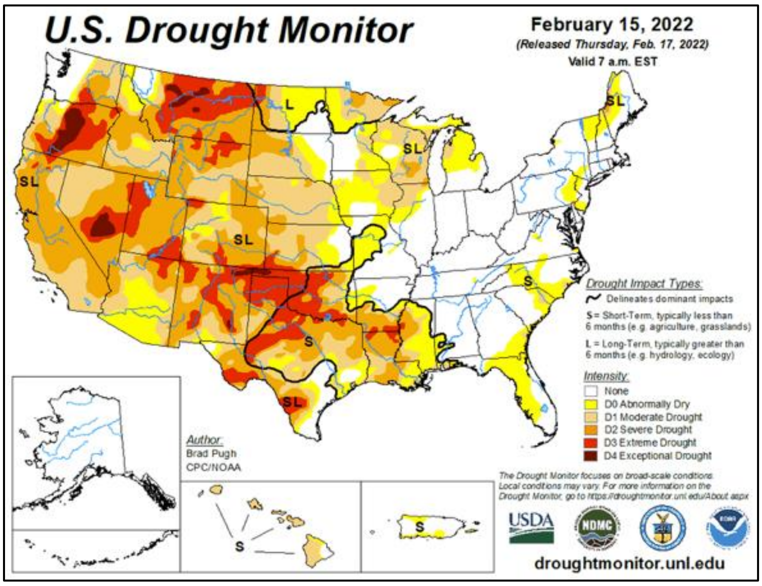


FIGURE 1.8.7: EXAMPLE OF TIME SERIES US DROUGHT ANIMATION MAP
(Source: USNDMC, 2022)

1.8.1.2.6 Custom map requests

Request a custom U.S. Drought Monitor map.

FIGURE 1.8.8: SELECTION PANEL FOR MAP REQUEST
(Source: USNDMC, 2022)

1.8.1.3 Additional Information

Additional information regarding the data available for monitoring and early warning include the following:

1.8.1.3.1 Drought Classification

This section explains how the drought classification system works and what indicators are used for drought classification

1.8.1.3.2 Drought severity and drought coverage Index:

This section provides the drought classification and drought coverage index as a single numeric value for any given time and geographical area

1.8.1.3.3 Statistics explanation:

Statistics are calculated weekly for the U.S. Drought Monitor by two different methods that are referred to as "*cumulative,"* which is how it is done from the beginning, or *"categorical*," meaning the report on one category at a time. Explanation of each method is illustrated in Table 1.8.5.

TABLE 1.8.5. SUMMARY EXPLANATION OF STATISTICS USED FOR DROUGHT CLASSIFICATION

	Absolute Values	Cumulative Statistics	Categorical Statistics
Area, Absolute	Sq miles in drought	Reports areas from D0 through D0-4	Reports areas one drought category at a time
Area, Proportional	% of area	Reports areas from D0 through D0-4	Reports areas one drought category at a time
Population, Absolute	People in drought	Reports population from D0 through D0-4	Reports population one drought category at a time
Population, Proportional	% of people (in area)	Reports population from D0 through D0-4	Reports population one drought category at a time

(Source: USNDMC, 2022)

Cumulative statistics

The cumulative U.S. Drought Monitor statistics combine drought categories for a comprehensive percent of area in drought. For example, the D0-D4 category shows the percent of the area that is classified as D0 or worse.

Week	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
2015-05-26	0.00	100.00	90.63	34.38	9.32	0.00

Categorical statistics

The categorical U.S. Drought Monitor statistic is the percent of the area in a certain drought category, and excludes areas that are better or worse. For example, the D0 category is labelled as such and only shows the percent of the area experiencing abnormally dry conditions.

Week	None	D0	D1	D2	D3	D4
2015-05-26	0.00	9.37	56.24	25.07	9.32	0.00

1.8.1.4 Education and Tutorials

The section dealing with education and tutorial provide valuable linkages as well as detailed information on the following:

i. What is the US Drought Monitor
ii. Who makes the map
iii. What does the map show

iv. What data are used to make the map
v. How are the drought categories assigned
vi. What is the timeline for production
vii. Where can I find the US Drought Monitor
viii. How can I contribute
ix. Who uses the US Drought Monitor

1.8.1.5 Current Conditions

Interactive maps are also available for current conditions and the user can select 17 different products to be displayed for different geographic areas.

The products available on display are the following:

i. Objective blend of drought indicators
ii. Weekly maps of drought indicators and indices
iii. Vegetation drought response index (VegDRI)
iv. National Weather Service Precipitation analysis
v. US drought impact reporter
vi. Weekly weather and crop bulletin
vii. Palmer drought severity index (PDSI)
viii. Crop moisture index
ix. Standardised precipitation index (SPI)
x. Percent of normal rainfall
xi. Current streamflow
xii. Mountain snowpack
xiii. Soil moisture
xiv. US and global soil moisture monitoring
xv. STAR – Global Vegetation Health products
xvi. Fire danger maps
xvii. Other current conditions information

Several links are available with weather related and other information.

1.8.1.6 Outlooks

The outlook section also provides interactive maps with a wide variety options to select type of information and geographic area. Products to display include:

i. Monthly US drought outlook
ii. Seasonal US drought outlook
iii. Climate outlooks
iv. Soil moisture forecasts
v. Current 3- to 7-day outlooks
vi. Current 6- to 10-day outlook
vii. National fire weather outlook
viii. Western Water Supply outlook

1.8.1.7 Partnership

The US drought monitor is located at the University of Nebraska with major partnerships between the University of Nebraska, US Department of Agriculture, US Department of Commerce and National Oceanic and Atmospheric Administration (NOAA).

1.8.2 The Australian National Drought map

[https://map.drought.gov.au/about.html and https://map.drought.gov.au/]

The National Drought map provides:

i. a framework of geospatial data services to support analysis, decision making, planning and reporting functions,
ii. a simple intuitive way to visualise spatial information from a standard data set,
iii. easy access to authoritative spatial data,
iv. facilitates the sharing of data from different sources and enhanced collaboration.

The National Drought Map provides a range of data sources to help identify areas suffering from drought or dry conditions. To identify areas suffering from poor conditions the

"*Australian Landscape Water Balance*" data set provided by the Bureau of Meteorology provides daily information on rainfall and soil moisture deficiencies.

http://www.bom.gov.au/water/landscape/#/sm/Actual/day/-28.4/130.4/3/Point////2020/3/16/

Farmhub is another service linked to the National drought map. The Farmhub link provided farmers with drought related information. https://farmhub.org.au/

The type of information geographically available on the Australian National Drought Map is illustrated in Figure 1.8.9. Rainfall maps and maps for soil moisture at different levels are available. Farmers can make informed decisions based on this information. Future projections for crop yields and grazing potential can be derived from such information

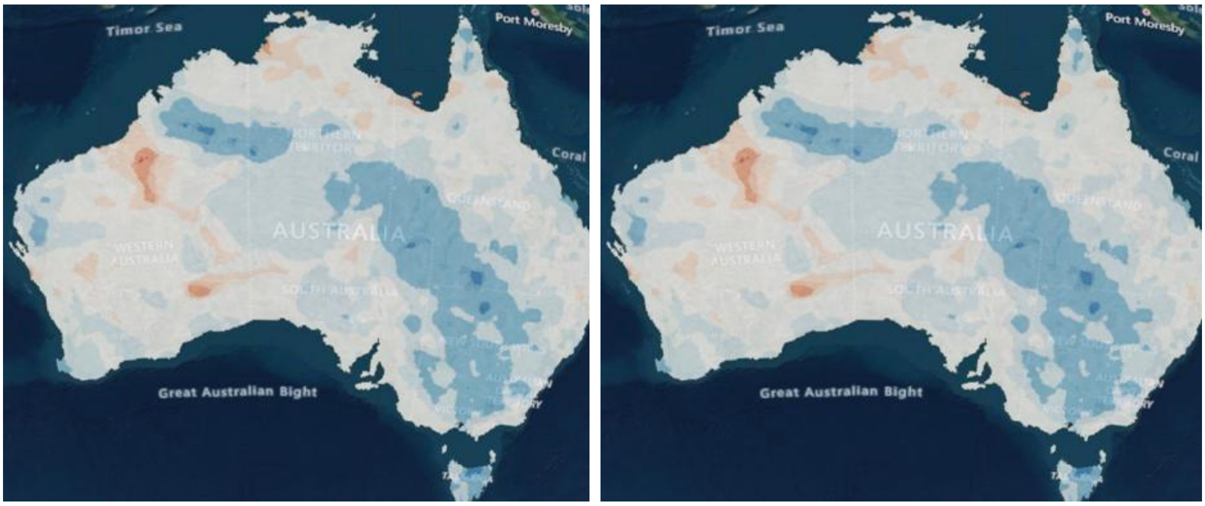


FIGURE 1.8.9(A): MONTHLY RAINFALL MAP AND (B) ROOT ZONE SOIL MOISTURE MAP FOR AUSTRALIA
(Source: Australian National Drought Map, 2022)

Socio-economic information is also available. This provide drought and water managers to determine drought vulnerability and drought resilience. Additional information regarding drought relief is also captured.

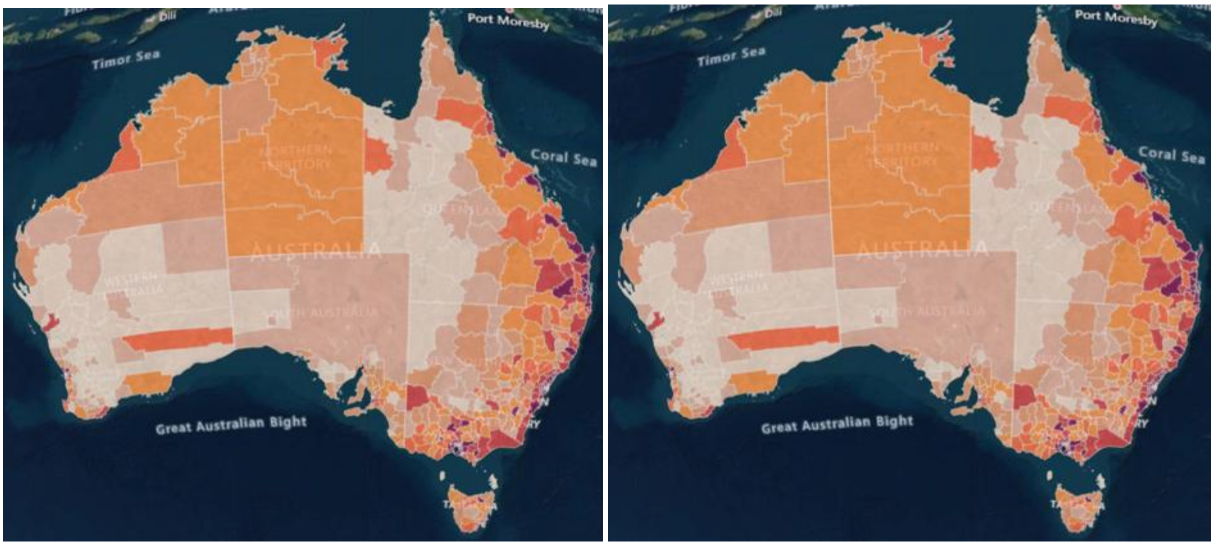


FIGURE 1.8.10 (A): FARMER CONCENTRATION AND (B): DROUGHT RELIEF PAYMENTS TO FARMERS
(Source: Australian National Drought Map, 2022)

See Figure 1.8.10 (a) for number of farmers per district and Figure 1.8.10 (b) for drought relief support per district. Figure 1.8.11 (a) illustrates # of farmers that receive drought relief per district while Figure 18.11 (b) illustrates the # of farm workers affected by drought.

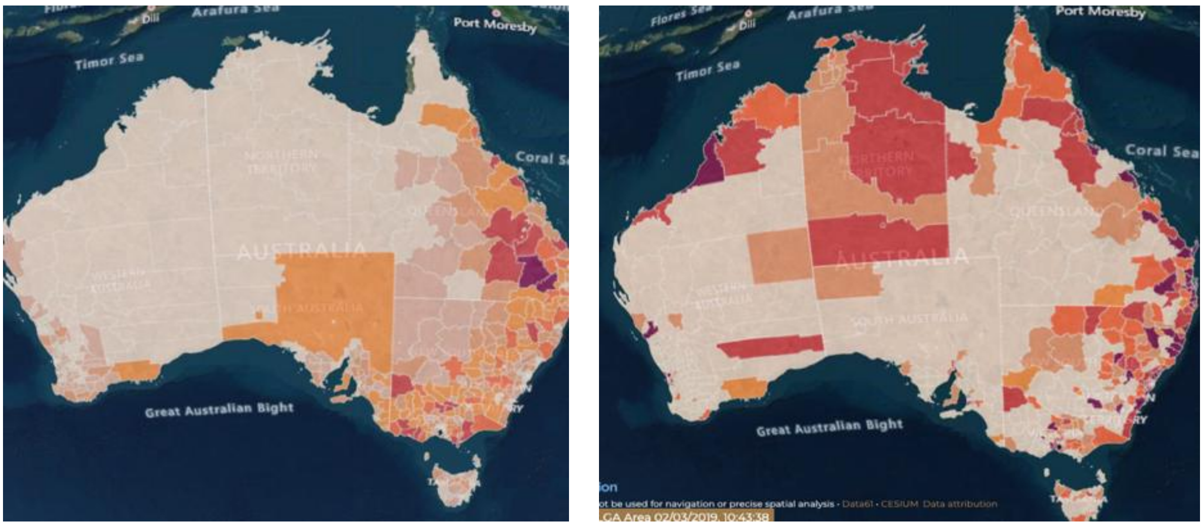


FIGURE 1.8.11 (A): # FARMERS RECEIVED DROUGHT RELIEF (B) # OF FARM WORKERS
(Source: Australian National Drought Map, 2022)

Numerous other indicators important for drought risk monitoring are available on the Australian Drought Map, which is a best-case example for a drought information management system. South Africa can learn from the Australian example.

A summary of the drought information available and spatially illustrated on the Australian drought map are the following:

i. Australian Landscape Water Balance
   a. Rainfall, month to date
   b. Rainfall, year to date
   c. Root zone soil moisture, month to date
   d. Root zone soil moisture, year to date
ii. Catchment Scale Land Use
   a. Catchment scale land use (18 class classification)
   b. Catchment scale land use (Agricultural Industries)
   c. Catchment scale land use (Agriculture)
   d. Catchment scale land use (Primary classification)
   e. Catchment scale land use (Secondary classification)
iii. Disaster Events *(drought is not considered a disaster in Australia – rather an extreme event with extreme impacts)*
   a. Financial year bushfire boundaries
iv. Drought communication program
   a. Drought communities' program eligible councils
v. Farm Businesses
   a. Farm management deposits
      i. Industry holdings per state and territory
      ii. National holdings
      iii. State and territory holdings
   b. Number of farmers across Australia by local government authorities
vi. Farm families and Individuals
   a. Centrelink Mobile Service Centre locations over time
   b. Previous drought payments per LGS area
   c. Farm households allowance current demand against State and Territories

d. Farm household case officers
e. Private boarding schools
f. Public boarding schools

vii. Health

a. General practitioners
b. Headspace centres
c. Medicare benefits schedule mental health data
d. Medicare offices
e. Primary health networks
f. Primary health networks mental health data
g. Psychologists
h. Rural adversity mental health program
i. Social workers

viii. National Boundaries

a. ASGS remoteness area (2011, 2016,2018, 2020, 2022)
b. Australian drainage divisions
c. CDP regions
d. Commonwealth electoral divisions (2011, 2016, 2019, 2022)
e. Local government areas (2011, 2017, 2018, 2019, 2020, 2022)
f. Natural resource management areas
g. Postal areas (2011, 2016, 2018, 2020, 2022)
h. State electoral divisions
i. State suburbs
j. State and territories
k. Tourism regions

ix. National Drought and Flood Agency

a. National drought and flood recovery regions

x. NSW Combined Drought Indicator

xi. Queensland Drought Declarations

a. Shires fully drought declared
b. Shires partly drought declared

xii. Rural Financial Counselling Services

a. Rural financial counselling services offices
b. Rural financial counselling services regions

xiii. Satellite images
a. Hotspots
b. 10m pixels
c. 25m pixels
d. 25m pixels – 16-day composite
e. 25m pixels – daily
f. Multi sensor blended – daily

xiv. Social and Economic
a. Aboriginal and Torres Strait Islander people
b. Age profile
c. Average household size
d. Business entry active exit
e. Dwellings with internet connection
f. Employed persons
g. Estimated residence population
h. Household stress
i. Industry of employment
j. Insolvencies
k. Labour force participation
l. Own unincorporated business income
m. Personal income
n. Population projections
o. Selected pensions or allowances
p. Single parent families
q. Socio-economic disadvantage
r. Unemployment rate
s. Vocational or higher education qualifications
t. Young people earning or learning
u. Youth unemployment rate

xv. Bureau of Meteorology – Historical Rainfall and Temperature

a. Monthly rainfall, 1910 – 2022
b. Annual rainfall, 1910 – 2022
c. Monthly minimum temperature, 1910 – 2022
d. Monthly maximum temperature, 1910 – 2022
e. Annual minimum temperature, 1910 – 2022
f. Annual maximum temperature, 1910 – 2022

xvi. Vegetation cover
a. Vegetation fractional cover: PV, NPV, BS – monthly
b. Total vegetation cover: PV + NPV – monthly
c. Vegetation cover anomaly – monthly
d. Vegetation cover – deciles

xvii. Place names

The Australian drought map is interactive and it is possible to zoom to the meso- and in most cases, to the micro-level.

1.8.3 Conclusion

The examples of Australia and USA is extremely valuable, it is interactive and simple to understand. Without re-designing a new system, one can copy most of the products available from the Australia and USA examples.

1.9 Conclusion

Drought is a slow onset disaster of which it is difficult to determine the onset and the end of a drought. In addition, drought is a hazard affecting most people in SA and significantly impacts the economy. Drought monitoring and timely analysis of drought indicators are essential for early warning and implementing drought risk reduction contingencies. The acceptance of a drought classification system and indicator thresholds is the first step in drought management on a national scale. The uniqueness of hazards requires alternative management strategies. For example, managing fast onset hazards such as floods compared to slow-onset hazards such as drought. Flooding, for example, is expected during the rainy season and high precipitation. On the other hand, drought is experienced throughout the year at different geographic locations.

Comparing drought between climate zones and different systems is very difficult (Hisdal *et al.*, 2004, Gerber, 2022). Therefore, the use of a single drought indicator is not desirable. More than sixty drought indices are published in the literature. These indices are grouped as meteorological, vegetation, soil, and hydrological. Authorities in South Africa rely mostly on meteorological, vegetative and hydrological indicators, but that alone is insufficient for proper drought monitoring and classification. Gerber (2022) reported that the Department of Agriculture in the Northern Cape has already adjusted indicator thresholds unique to the arid Northern Cape.

The objective of drought monitoring and early warning is to warn stakeholders when there is a risk of dry periods or drought. As a result, reliable drought early warning will allow farmers and the agricultural sector to prepare and increase resilience to potential water shortages, production losses and food shortages. Drought classification provides a sound basis for early warning strategy and the timely implementation of contingency plans based on the drought classification. Drought monitoring and drought assessment require integrating all information such as indices and impact indicators in a comprehensive framework, but indices alone do not provide sufficient knowledge for drought classification. Additional information on the impact (vulnerability) of different sections (economic, social, environment) *is required to understand* the different drought classes (Wilhite *et al.,* 1997; Du Pisani, Fouche & Venter, 1998; Wilhite, 2000; Wisner *et al.,* 2004, Jordaan, 2011).

The National Joint Drought Coordinating Committee (NJDCC) has already approved a drought classification system for South Africa. According to this classification, drought is classified into five classes: D0 to D4, where D0 is a dry period, and D4 is an extraordinary drought. In addition, thresholds for the most critical indicators were accepted and approved.

The drought monitor system proposed for South Africa consists of primary and secondary indices. Primary indices are currently monitored by the SAWS, ARC, DWSWS and other organisations. Secondary indicators are farm-level indicators to be developed through this research.

This report focuses on the primary indicators. Essential meteorological indicators are precipitation, temperature, and the SPI produced monthly by the SAWS and the ARC.

Important remotely sensed vegetation indicators produced by the ARC through the UMLINDI report are the NDVI, VCI and PASG. Soil moisture data is available to the public on the USGS and NOAA websites. Hydrological data is available in near-real-time from the NIWIS. Thresholds for the different indicators are not aligned with the proposed drought classification system. Most index categories provide for four classes of drought instead of five. Therefore, alignment to the proposed drought classification system is required. We intend to facilitate such a process during this research.

Drought-related data and information is currently available and classified according to administrative boundaries. However, drought does not respect administrative boundaries, and it is imperative to monitor drought and classify drought conditions according to water catchment areas. For example, hydrological drought requires a system where the specific water catchment area is considered in sync with meteorological indicators. Likewise, agricultural drought risk monitoring and assessment should follow quaternary catchments, and groundwater drought risk assessment should follow the groundwater recharge area for a specific source.

A conspicuous gap in the drought monitoring system in South Africa is the lack of an integrated system with the capacity to combine and integrate all drought-related data and indices for improved drought early warnings. The US Drought Monitor and the Australian Drought Map are best-case examples from which we can build upon their systems and lessons learned. Therefore, there is no need to develop a new system for South Africa. Firstly, South Africa already has access to the required remotely sensed products for drought monitoring. Secondly, this research should develop a ground-truth system for the extensive livestock sector that validates the remotely sensed results.

Drought-related data is available in silos, mainly through the NIWIS, ARC, SAWS and a few global sources, and sometimes at a cost. The government should apply more effort to develop an integrated drought monitor and analysis capacity, considering drought's economic, environmental and social impacts. Although not part of the objective of this research, we will also advocate for an integrated drought monitor and analysis system.

References

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. (2009). Crop Evapotranspiration: Guidelines for Computing Crop Requirements. Irrigation and Drainage (9), 897-905.

Alley, W.M. (1984). The Palmer Drought Severity Index: Limitations and Assumptions. journal of Applied Meteorology, 23, 1100-1109.

Agnew, C.T. (2000). Using the SPI to identify drought. Drought Network News (1994-2001). National Drought Mitigation Centre, University of Nebraska, Lincoln, USA.

Booysen, J., (1983). Towards a better understanding of drought, Karoo Regional Newsletter, Autumn 1983, p. 11-14.

Beguria S., Vicente-Serrano S.M., Lopez-Moreno J.I, Angulo M. & El Kenawy A. (2010). A new gridded product for the analysis of drought variability and drought impacts. 10th EMS Annual Meeting, 8th European Conference on Applied Climatology (ECAC).

Du Pisani, L. F. (1998). Assessing rangeland Drought in South Africa. Agricultural Systems, 57 (3), 367-380.

Du Pisani, L.G., Fouché, H.J. and Venter, J.C., 1998. Assessing rangeland drought in South Africa. Agricultural systems, 57(3), pp.367-380.

Erasmus, J.F. (1991). Methodologies for Drought Monitoring Using Meteorological Data. PhD Dissertation, University of the Free State, Bloemfontein, South Africa.

Eurostat, (2001). Towards a harmonised methodology for statistical indicators Part 1: Indicator typologies and terminologies. Publications Office of the European Union, Luxembourg. ISBN 978-92-79-40322-4, ISSN 2315.0815, doi:10.2785/56118, Cat. No: KS-GQ-14-011-EN-N.

Fouche, H.J. (1992). Simulation of the Production Potential of Veld and the Quantification of Drought in the Central Free State. PhD Dissertation, University of the Free State, Bloemfontein, South Africa.

Fouche, H.J., de Jager, J.M. & Opperman, D.P.J. (1985). A Mathematical Model for Assessing the Influence of Stocking Rate on the Incidence of Droughts and for Estimating the Optimal Stocking Rates. Journal of the Grassland Society of Southern Africa, 2 (3), 4-6.

Gage, Anastasia and Melissa Dunn. (20090. "Monitoring and Evaluating Gender-Based Violence Prevention and Mitigation Programs." U.S. Agency for International Development, MEASURE Evaluation, Interagency Gender Working Group, Washington DC.

Gerber H., (2022). Personal Communication (April, 2022).

Gibbs, W.J. & Maher, J.V. (1967). Rainfall deciles as drought indicators. Bureau of Meteorology Bulletin, 48.

Guttman, N.B. (1998). Comparing the Palmer drought index and the Standardized Precipitation Index. Journal of the American Water Resources Association (34), 113-121.

Guttman, N.B. (1999). Accepting the Standardized Precipitation Index: A Calculation Algorithm. Journal of the American Water Resources Association (35(2)), 311-322.

Hanson, R.L. (1991). Impact of Climate Change and Land use in the southern United States. Retrieved from: Geochange: http://geochange.er.usgs.gov/sw/changes/natural/et/ [Accessed 25/05/2022]

Hayes, M.J. (2011). What is Drought? Retrieved March 25, 2011 from National Drought Mitigation Centre (USA): http://www.drought.unl.edu/Planning/Monitoring/ComparisonofIndicesIntro/Deciles.aspx

Hayes, M., Wilhite, D.A., Svoboda, M. & Vanyarkho, O. (1999). Monitoring the 1996 drought using the Standardized Precipitation Index. Bulletin of the American Meteorological Society, (80), 429-428.

Hu, Q. & Wilson, G.D. (2000). Effect of Temperature Anomalies on the Palmer Drought severity Index in the Central United States. International Journal on Climatology, 20, 1899-1911.

Ji, L. & Peters, A.J. (2003). Assessing Vegetation Response to Drought in the Northern Great Plains Using Vegetation and Drought Indices. Remote Sensing and Environment, 87 (1), 85-98.

Jordaan, A.J. (2011). Drought Risk Assessment for the Northern Cape. PhD Thesis. University of the Free State, Bloemfontein, South Africa.

Jordaan, A.J., Sakulski, D & Jordaan, A.D. (2011). Drought Risk Assessment for Northern Cape Province. Department of Agriculture and Rural Development. Kimberley: Unpublished Report.

Jordaan, A.J. 2016. When is a Dry Period a Drought: Drought Not the Same for All Farmers. African Drought Conference: Enhancing Resilience to Drought Events on the African Continent. Windhoek, Namibia. 15-19 August 2016.

Jordaan, A.J., Makate, D., Mashego, T., Ligthelm, M., Malherbe, J., Mwaka, B., Olivier, W., Symington, W. & van Zyl, K.1 , 2017. Drought Indicators for South Africa, in Jordaan, A.J. (Ed) *Vulnerability, Adaptation to and Coping with Drought: The Case of Commercial and Subsistence Rain Fed Farming in the Eastern Cape*; Vol II, WRC Report Nr TT 716/2/17. ISBN 978-1-4312- 0885-2. Pretoria. PP 6.47–6.55.

Jordaan AJ, Mlenga D, Muyambu F, Mdungela N, Phatudi-Mphahlele B, Mashimbye C, & Shawababa S. (2017). Drought Risk Assessment, Vulnerability, and Resilience: Literature Review. Vulnerability, Adaptation to and Coping with Drought: The Case of Commercial and Subsistence Rain Fed Farming in the Eastern Cape. Research Report WRC, Pretoria.

Jordaan, AJ, Sakulsji, DM, Maybuye, C & Mayumbe, F. (2028). *Measuring Drought Resilience Through Community Capitals*, in Zommers, Z & Alverson, K. (eds) Resilience: The Science of Adaptation to Climate Change. ELSEVIER. ISBN 9780128118917. eISBN 9780128118924.

Katz, R.W & Glantz, M.H. (1985). Anatomy of a Rainfall Index. Monthly Weather Review.

Karl, T. & Knight, R.W. (1985). Atlas of Monthly Palmer Hydrological Drought Indices (1931-1983) for the Contiguous United States. Historical Climatology, Series 3-7, National Climatic Data Centre, Asheville.

Kogan, F.N. (1990). Application of vegetation index and brightness temperature for drought detection. Adv. Space Res. 15(11), 91-100

McKee, T.B., Doesken, N.J. & Kleist, J. (1993). Drought monitoring with multiple time-scales. 9the Conference on Applied Climatology, (pp. 233-236). Dallas, Texas.

Morawitz, D.F., Blewett, T.M., Cohen, A., & Alberti, M. (2006). Using NDVI to assess vegetative land cover change in central Puget Sound. Environmental monitoring and assessment,114(1-3), 85-106.

Narasimhan, B. & Srinivasan, R. (2005). Development and Evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Index (ETDI) for Agricultural Drought Monitoring. Agricultural and Forest Meteorology (133), 69-88.

NIWIS, 2022. National Integrated Water Information System, Department of Human Settlement, Water and Sanitation, Pretoria. South Africa. https://www.dws.gov.za/niwis2/

NOAA, 2022. National Oceanic and Atmospheric Administration, Department of Commerce, USA. https://www.noaa.gov/

Palmer, W.C. (1968). Keeping track of crop moisture conditions, nationwide: The new crop moisture index. Weatherwise, 21, 156-161.

Peters, A.J., Walter-Shea, E.A., Ji, L., Vina, A., Hayes, M. and Svoboda, M.D., (2002). Drought monitoring with NDVI-based standardized vegetation index. Photogrammetric engineering and remote sensing, 68(1), pp.71-75

Peters, E., (2003). Propagation of drought through groundwater systems - Illustrated in the Pang (UK) and Upper-Guadiana (ES) catchments. Ph.D. thesis, Wageningen University, The Netherlands.

Potop, V. (2011) Evolution of drought and evaporation and its impact on corn in the republic of Moldovia. Theory for Applied Climatology, 105: 469 -843.

Roux, P.W. (1991). South Africa Devises Scheme to Evaluate Drought Intensity. Drought Network News, 3 (3), 18-23.

Roux, P.W. (1993). Relative drought Resistance Indices for the Karoo Region. Karoo Agric, 5 (2), 25-28.

Sakulski, D. (2002). An Integrated Database Driven Technique for Multi-Dimensional Drought Analysis for South African Catchments. PhD Thesis, Faculty of Engineering, University of Witwatersrand, Johannesburg, South Africa.

Sakulski, D. & Jordaan, A.J. (2011). Disaster Risk Atlas for South Africa. Retrieved 2011 from http://dimtecrisk.ufs.ac.za/nc. (Website not operational anymore)

Smucker, T.A. &. Wisner, B. (2007). Changing Household Responses to Drought in Thakara, Kenya: Vulnerability, Persistence and Challenge. Retrieved June 27, 2011, from Wiley Online Library: http://onlinelibrary.wiley.com/doi/10.1111/j.1467-7717.2007.01035.x/pdf

Sun, J., Wang, X., Chen, A., Ma, Y., Cui, M., & Piao, S. (2011). NDVI indicated characteristics of vegetation cover change in China's metropolises over the last three decades. Environmental monitoring and assessment,179(1-4), 1-14.

Thornthwaite, C.W., 1948. An approach toward a rational classification of climate. Geogr. Rev. 38, 55–94

UNSPIDER, (2022). United Nations Office for Outer Space Affairs, UNSPIDER Knowledge Portal. Standardised Vegetation Index. https://www.un-spider.org/node/11416

UNCCD. (2009). Brief note on the Inter-Regional Workshop on Indices and Early Warning Systems for Drought. United Nations, UNCCD. Lincoln, Nebraska: SECRETARIAT OF THE CONVENTION TO COMBAT DESERTIFICATION.

USGS, 2022. Monthly soil moisture (10-40Cm) https://earlywarning.usgs.gov/fews/product/313

USGS, 2018. NDVI, the foundation of remote sensing phenology. https://www.usgs.gov/special-topics/remote-sensing-phenology/science/ndvi-foundation-remote-sensing-phenology

Van Rooy, M.P. (1965). A Rainfall Anomaly Index Independent of Time and Space. Notos, 14, 43-48.

Venter, J.C. (1992). Drought Characterization Based on Karoo Schrubland Productivity. South African Journal of Science, 88 (3), 154-157.

Vicente-Serrano S.M., Gouveia C., Camarero J.J., Beguería S., Trigo R., López-Moreno J.I., Azorín-Molina C., Pasho E., Lorenzo-Lacruz J., Revuelto J., Morán-Tejeda E. & Sánchez-Lorenzo A. 2013. Response of vegetation to drought time-scales across global land biomes. Proceedings of the National Academy of Sciences of the United States of America 110 (1): 52-57.

Wilhite, D.A. (2000). Drought Planning and Risk Assessment: Status and Future Directions. Annals of Arid Zone. (39), 211-230.

Zucchini, W., Adamson, P.T. & McNeill, L. (1991). A Family of Stochastic Models for Drought. South African Journal of Plant and Soil, 8 (4), 206-211.

WMO & GWR, (2016). World Meteorological Organization (WMO) and Global Water Partnership (GWP), Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.

Chapter 2: Farm Level Indicators

2.1 Introduction

Drought is only understood when we understand the impacts of drought. Drought affects all sections of society, business, government, the ecology and the environment in various ways. Understanding the vulnerability and potential resilience of the different sectors and their relation to each other provides valuable lessons to develop resilience for future droughts.

Drought impacts are evidenced in various forms, and the level of impact is directly linked to the capacity of the government, private sector and society to deal with droughts. Traditionally, drought was associated with agriculture in South Africa, but population growth, migration, and the increased demand for urban water resulted in water shortages and drought conditions for urban areas. The most evident impacts of drought in South Africa are tangible impacts such as empty dams, dry river beds, low groundwater levels, crop losses, lack of vegetation growth, dry landscapes, dust storms, high animal mortalities and low production output. However, the indirect and intangible impacts are not always linked to drought. These are high food prices, job losses, health impacts, psychological stress, migration and population decline in affected regions, bankruptcies, water conflict, low economic growth and the trauma of witnessing the damage to livestock, crops, soil and vegetation, amongst other impacts.

Drought impacts are not measurable through remotely sensed and meteorological data, so developing a farm or local-level drought monitor system is needed.

2.2 Why farm-level drought indicators

The South Africa Weather Service (SAWS) provides impact-based weather warnings, but the truth is that meteorological events have different impacts on different sectors. The variation of drought impacts on different sectors is, in some cases, much higher than hazard threats such as floods and fires. For example, grape farmers in the Northern Cape prefer meteorological drought during the harvest months of November and December. This is because dry weather, just before and during harvest time, promotes good quality grapes while rainfall damages grapes.

One should also interpret indicators such as the SPI with consideration of the different sectors. For example, the 3-month SPI of -1,5 during the rainy season might have a disastrous impact on rainfed crop production, while it might have a minimal effect on livestock farming. On the other hand, the 12-month, 24-month and 36-month SPI are indicators more suitable for the livestock sector. Reservoir levels are also linked to seasonality; for example, reservoirs with low water levels at the beginning of the rainy season are not a problem compared to empty reservoirs at the end of the rainy season, which could lead to water shortages. One needs to consider the seasonality and growing season of different crops and grazing on livestock farms with the classification of drought; therefore, the use of farm-level indicators to ground-truth the impact of a dry period. Therefore, the use of standardised indicators without the consideration of sector-specific characteristics is foolish.

The difference in drought resilience and the use of standardised indicators between commercial and communal livestock farmers are already discussed in Deliverable 1.

Although the remotely sensed indicators provide information on vegetation condition, soil moisture and other drought impacts, it is not always a true reflection of the actual farm-level situation. For example, over-grazing and wildfires might send false signals regarding drought impact.

Economists have long been critical of meteorological definitions of drought, mainly when used to develop policy responses targeting social and economic outcomes (Nelson et al. 2007; Hughes et al. 2022). Such measures are imperfect proxies for agricultural impacts and do not reflect the economic and social effects. Drought impacts in agriculture depend on various factors beyond annual rainfall, timing and intensity, temperature and evaporation. They can vary significantly with the context, for example, vegetation, soil, livestock, farm technology, on-farm infrastructure, management skills, etc. Economic and social effects also depend on the context, particularly the capacity of the farmer and communities to adapt to drought shocks (Nelson et al., 2010a; Nelson et al., 2010b; Hughes et al., 2022). Ultimately, indicators should be linked to specific conditions and systems. No single indicator can measure drought from the perspective of all people, locations or time periods. Of more practical value are drought indicators developed for specific applications which can measure the effects of drought on policy-relevant outcomes, such as farm incomes (Nelson et al., 2007; Hughes et al., 2022).

2.3 Farm-level and Drought Impact Indicators

The impact of drought is complex, with multiple causal and feedback loops that require understanding the interactions between the environment, economy and social impacts. Therefore, monitoring drought and drought impact is impossible utilising weather and remotely sensed data only. Therefore, the importance of developing a system of farm-level monitoring.

Farm-level drought indicators aim to support the primary indicators available from the SAWS, NIWIS, Dept of Agriculture and other sources, and, secondly, as an early warning system for the farmers themselves. Nor even meteorologists, with all their sophisticated equipment, can accurately predict the onset of a drought. Drought is not evident during the initial stages but becomes easily detected after reaching full impact. However, good managers who adapted to occasional drought conditions recognise early signs of a pending drought, and they can act timeously. Indigenous knowledge, in most cases, provides crucial early warning signals and farmers, understanding some of the natural events, can prepare timeously for pending droughts.

2.3.1 Drought Indicators Based on Indigenous Knowledge

Zuma-Netshiukhwi et al. (2013) define "traditional prediction" as "environmental indicators that are locally used to read its signs and then to interpret the weather or climate conditions". Initially, scientists were sceptical about the value of traditional prediction, but the reality is that communities developed traditional knowledge over centuries by closely observing natural phenomena. However, more recently, scientists have acknowledged the value of traditional prediction and the importance of validating and documenting this knowledge (Lebel, 2013; Jordaan et al., 2017; Salite, 2019)

Nature and the behaviour of animals and insects are major early warning indicators for farmers. For example, Jordaan et al. (2017) reported that communal farmers in the Eastern Cape use the following signs as traditional drought predictions:

- Snakes moving the same direction - drought when they move downhill and rain when they move uphill
- Bees flying in a specific direction – drought
- Frogs making much noise in the afternoon – rain
- Horses are jumping playfully – rain.
- A kaleidoscope of butterflies flying together – a good season.
- Army of locusts moving in the same direction – drought.
- Lower than usual lamb percentages amongst sheep – drought expected
- Large swarms of locusts – drought

Commercial livestock farmers in South Africa agreed with the findings of Jordaan et al. (2017) among communal farmers. They add the following:

- Increased number of whirlwinds
- Height of finch’s nests in willow trees; High – expect a rainy season; Low – expect drought.

Chisadza et al. (2013), Kagunyu et al. (2016), and Balehegen et al. (2019) identified the following drought early warning signs in Zimbabwe, Ethiopia and Kenya:

- Early and significant flowering of Mopane (Colophospermum mopane) trees
- Late flowering of Umtopi (Boscia albitrunca) trees
- Intestines of slaughtered animals are black
- Extremely hot weather
- Some trees shed leaves before normal times
- Sound and movement of birds

- Specific patterns in the stars
- Wind direction

Farmers have developed traditional early warning systems over many years and centuries, but some regions might have specific natural prediction signs. Therefore, farmers must be sensitive to natural phenomena and accurately document early warning signals. That way, good managers' environmental awareness might be able to develop farm-specific early warning signs. The challenge remains that the traditional and natural prediction signs indicate pending droughts or the beginning of a drought. No research has been done to link natural (traditional) drought predicters to a drought classification system, which is the core of the national drought plan.

2.3.2 Rangeland vegetation

Extensive livestock farmers depend upon the production of rangeland vegetation to feed free-ranging livestock. In actual fact, livestock farmer's approach should be to market forage produced on the farm through livestock. When following such an approach, the farmer will focus on the quality of rangelands in the first place and therefore ensure the principles of sustainable and conservation agriculture are applied. Natural resources such as vegetation, soil and water are the most critical assets on any farm. When planning for drought, the importance of rangeland vegetation became obvious. Therefore, farmers need to understand the interactions between soil, plant and animals and its socio-economic impacts as principles for drought management.

Reduced precipitation reduces soil moisture content, especially when combined with high temperatures and winds. Reduced soil moisture results in reduced herbage production, which leads to less protective plant cover, and reduced water infiltration, which then exacerbates the reduction of soil moisture. On the other hand, reduced herbage production results in lower energy capture, low growth vigour and less root growth, and in its turn, reduced herbage production. The outcome of less herbage production is reduced animal production, which in its turn, lead to reduced profits, high debt, social stress and a potential outmigration of the farmer from agriculture.

Drought stress hampers plant biomass production, quality and energy. The cumulative effect of drought severely affects the plant's morphological, physiological, biochemical and molecular attributes, adversely impacting photosynthetic capacity. Some plants cope better with water scarcity than others. Drought resistance plants evolve complex resistance and adaptation mechanisms, including physiological and biochemical responses (Ings et al. 2020; Suleiman et al. 2021). Barker & Caradus (2001) concluded that plant drought resistance is a meaningless term since drought measurements have no linear effect on plants. Measurements for drought intensity, according to them, could be water potential (-MPa), water deficit (MM) or soil water content (g/g, cm3/cm3, %). They further concluded that plant water reserves are trivial compared to the environment's demand and that all plants are incapable of resisting drought. In defence, it is also true that plants vary in tolerance to the intensity and duration of drought (Snyman & Fouche, 1991; Vetter, 2009; Suleiman et al., 2021).

The growth stage, age, plant species, and drought severity and duration influence plant responses to drought. In turn, resistance mechanisms to drought vary among plant species. Therefore, plants can reduce resource utilisation and adjust their growth to cope with adverse environmental conditions like drought. Water stress effects on plants are summarised in Table 2.3.1.

TABLE 2.3.1. WATER STRESS EFFECTS ON PLANTS

Morphological changes		Physuiological changes		Biochemical changes
• Dwarf plants • Early maturity • Leaf area reduction • Leaf extension limited • Leaf rolling • Stomatal position • Leaf waxiness • Leaf hairs • Leaf moment • Leaf angle • Leaf orientation • Small leaf size • Less leaves • Leaf longevity reduction • High root to shoot ratio • Reduction in shoot length • Reduction in plant height		• Closure of stomata • Photosynthesis stops • Oxidative stress increase • Cell wall integrity changes • Reduction in leaf water potential • Decrease in stomatal conductance • Internal CO2 reduction • Growth stops • Decrease in transpiration rate • Enhance WUE • Reduction in RWC • High proline accumulation • Translocation ceases • Assimilation stops • Capillary moment ceased • Guard cells activated • Internal temp increases		• Rubisco efficiency ceased • Photochemical efficiency declined • ROS production • Oxidative damage • Antioxidant defense • ABA generation • Chlorophyl contents decreased • High proline accumulation • Polyamine generation • Antioxidative enzymes increases • Carbohydrate production • ABA accumulation

Source: Seleiman, et al. 2021

Rangeland drought resilience is more than only plant resistance. Ecosystem resilience is defined as the amount of perturbation a social or ecological system can absorb without shifting to a qualitatively different state. It has emerged as a prominent concept in ecosystem ecology and, more recently, as a conceptual framework for understanding and managing complex social-ecological systems (Vetter, 2009). Ensuring drought resilience is, therefore, a complex challenge involving not only drought-resistant plants but also their management.

Figure 2.3.1 clearly illustrates the influence of rangeland management on the effectiveness of precipitation. Over-grazing can cause drought-like conditions even with average precipitation. Snyman & Fouche (1991), after 12 years of research on the impact of veld condition on run-off and water-use efficiency, concluded that veld condition, rather than rainfall appeared to be more important for controlling run-off and water-use efficiency.

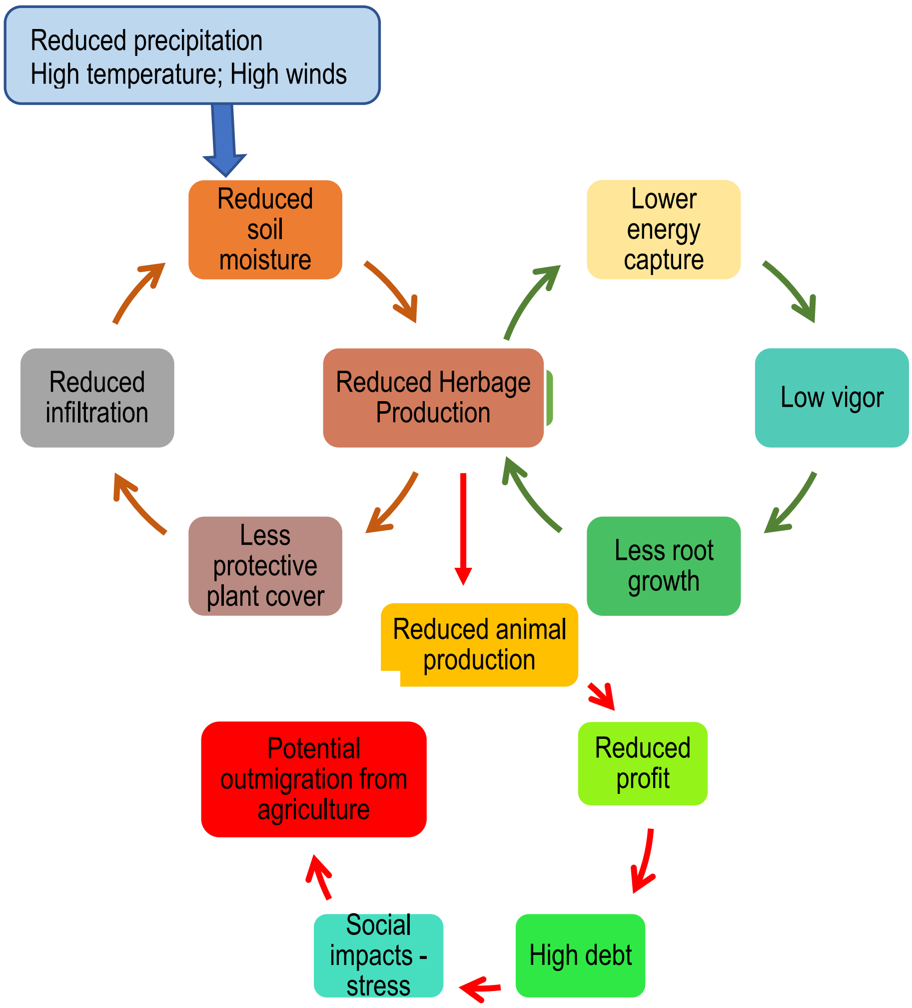


FIGURE 2.3.1: DROUGHT IMPACT CYCLE FOR EXTENSIVE LIVESTOCK FARMERS
Source: Illustration by Jordaan

Although rangelands are adversely affected by drought regardless of condition, over-grazed ones in poor condition are more adversely affected and take much longer to recover after a dry period than good quality ones. The main reasons for this are (Howery, 1999):

i. Improved rangeland condition is normally associated with adequate vegetation cover to prevent accelerated soil erosion.
ii. Better soil stability improves the capacity to retain soil moisture and grow the kinds and amounts of plant species they are inherently capable of.
iii. Better rangeland conditions mean higher plant diversity with different growing seasons and rooting habits (e.g. deep-, medium- and shallow-rooted plants). This increases opportunities for plant communities to exploit the various soil moisture and temperature regimes across arid and semi-arid rangelands.

The degree to which grazelands deteriorate depends on grazing intensity, frequency and timing. Livestock owners can control each of these factors, but it remains a challenge on communal land. The phrase "intensity of grazing" refers to the number of animals and duration of grazing on a particular piece of land, in other words, the stocking rate.

"*Frequency of grazing"* refers to the number of times individual plants are grazed during the growing season. Frequency is closely related to intensity because the probability of the same plant being grazed twice increases with higher stocking rates. Plants grazed continuously have no opportunity to grow new leaf material between successive defoliations and become stressed. Continuous grazing, for example, on communal land, has a detrimental impact on grazeland vigour, resulting in artificial (man-made) droughts even during normal precipitation.

"Timing of grazing" deals with the time of the year that plants are grazed and their physiological and morphological stage of development. Plants are much more sensitive to grazing from the late boot to the early heading stage. But again, communal land around towns and cities is grazed right through the year with zero time for vegetation to recover.

Vegetation cover is an important drought risk reduction mechanism, and the absence of good vegetation cover renders the farmer extremely vulnerable to drought conditions. This explains why communal farmers experience normal dry conditions as drought.

2.3.3 Water – surface water and groundwater

Water supply in sufficient quality and quantity is critically important for livestock production. If animals do not meet their water requirements, they may refuse to eat, become sick, experience lower production and ultimately die. Access to cool, clean drinking water is essential to keep an animal's internal body temperature within normal limits. Water temperature affects rumen temperature and, thus, blood temperature, which affects brain centres that control feed consumption (USNDMC, 2022). Water quality is also negatively affected during drought. With water shortages and empty dams and pools, water might become toxic with the following common water quality problems affecting livestock production (UCDavis, 2022):

- High Nitrogen content (nitrates and nitrites).
- High concentrations of minerals (excess salinity).
- Bacterial contamination.
- Heavy blue-green algae growth.
- Accidental spills of petroleum pesticides and fertilisers.

Water consumption of livestock increases with higher water temperatures. For example, as water temperature increases from 21OC to 35 OC, water requirements for animals will increase 2.5 times. The amount of water livestock needs depends on the animal type and production stage. For example, the daily water intake of beef cattle when the temperature is 35OC is approximately as follows:

- Cows – 68 litres for nursing calves; 58 litres for bred dry cows and heifers
- Bulls – 76 litres
- Growing cattle – 36 litres for 181 kg animal; 48 litres for a 272 kg animal; 57 litres for a 363 kg animal
- Finishing cattle – 54 litres for a 272 kg animal; 66 litres for a 363 kg animal; 78 litres for a 454 kg animal; 91 litres for a 544 kg animal.

Water vulnerability to drought depends not only on the type of animal, size and production stage; The amount of water available on a specific farm, its catchment area, the water: animal ratio and management skills all determine water vulnerability. Therefore, it is impossible to develop a standardised indicator threshold for water vulnerability on all farms. In addition, water storage capacity differs on different farms, catchment areas, and water sources.

The ratio between groundwater and surface water to animal numbers is also important and differs from farm to farm. Therefore, each farmer should develop their own farm-specific water availability thresholds for the different drought classes.

Things to consider include the following:

- Water reticulation system.
- Surface water storage capacity
- Catchment area for surface water storage infrastructure
- Number of boreholes
- Reliability of groundwater sources

2.3.1.1 Surface water in the Northern Cape (NC)

The water storage capacity in the NC is 147.3 million m^3, with the Vaal and Orange rivers the major sources of surface water. There is a total of 436 towns and settlements in the NC, with 316 dependent on groundwater. Except for the Orange and Vaal rivers, all other rivers are classified as ephemeral, with no visible flow most of the time. As a result, these streams are not reliable water sources, especially during dry periods. As a result, the livestock sector mainly depends on groundwater, with only a handful of farms having small farm dams. Therefore, reporting on surface water is not as important as groundwater reporting.

2.3.1.2 Groundwater in the Northern Cape

The limited number of water resources in the Northern Cape has resulted in increased emphasis being placed on groundwater. Groundwater supply of acceptable quantity and quality is the lifeline of most of the livestock farms in the NC. Groundwater is defined as water found in the subsurface in the saturated zone below the water table and includes all water occurring in the saturated zone. Groundwater is present at different depths everywhere in the NC (See Figure 2.3.2). The water table may rise or fall depending on drought, heavy rains or over-abstraction of the groundwater. Water in aquifers is brought to the surface through springs, discharge in rivers or lakes or borehole pumping. The use of boreholes is the most common method on livestock farms to abstract water from aquifers. Almost every farm in the NC is dependent on groundwater for both domestic and stock watering. Unfortunately, there are no abstraction volumes available, but in terms of quantities of water, stock farming has a relatively small influence on the regional groundwater resources. Mining in certain areas, especially around Sishen and north of Kuruman, significantly impacts groundwater levels in its close vicinity (Dennis, 2011). Farmers located closer to these mines complained about groundwater shortages during droughts. Depending on the daily rainfall distribution, two years with the same annual rainfall may give different recharge values.

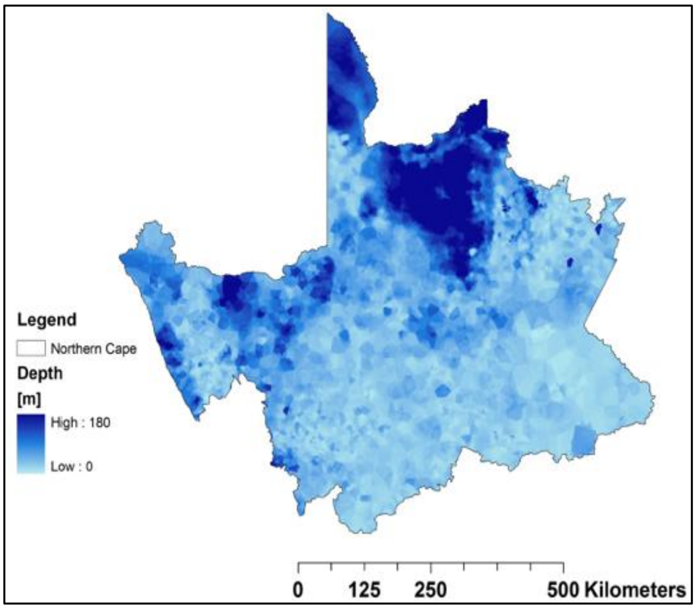


FIGURE 2.3.2: AQUIFER DEPTHS IN THE NC
Source: Dennis, 2011

Annual runoff and recharge totals are more sensitive to short-term rainfall distribution than annual total rainfall, especially in semi-arid regions (Eilers et al., 2007). Therefore, an extended period of medium-intensity rainfall is more likely to lead to significant recharge than either a period of high-intensity rainfall, which leads to increased runoff or a period of low-intensity rainfall, most of which will evaporate.

Dennis (2011) completed a drought sensitivity report for groundwater in the NC. She applied the DART methodology, which focuses on typical parameters used in sustainability studies, but also accommodates water quality due to water quality deterioration with a drop in water levels over time as the salt load will concentrate. DART stands for:

- D – Depth to water level change
- A – Aquifer type
- R – Recharge
- T – Transmissivity

D – depth to water level change

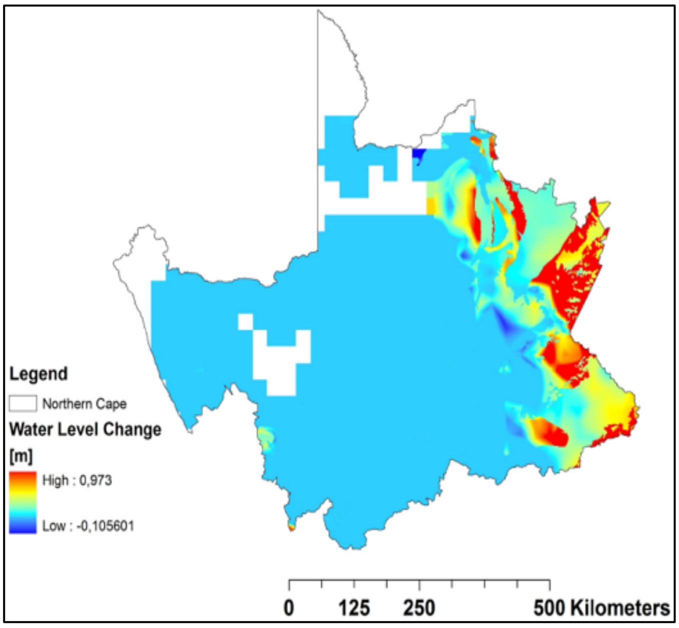


FIGURE 2.3.3: DEPTH TO WATER LEVEL CHANGE
Source: Dennis, 2011

Dennis (2007) calculated water level change for different drought scenarios following the relationship between water level, recharge and storage coefficient:

$$\Delta Water\ level = \frac{\Delta Recharge}{Storage\ coefficient}$$

Change in water level for most of the extensive livestock areas is very low except in the eastern part of the NC with higher precipitation. It is important to note that the map in Figure 2.3.3

does not show the aquifer depth; the focus is on water table change due to drought. The reason for the greater change in water table depth is a result of higher recharge capacity in the east.

A – Aquifer type = Storage coefficient

The storage coefficient was derived using the geohydrological maps of South Africa in conjunction with the classification of aquifer types shown in Table 2.3.2.

TABLE 2.3.2: AQUIFER TYPE

Aquifer type	Storativity
Fractured	0.001
Fractured & Intergranular	0.005
Karst	0.01
Intergranular	0.1

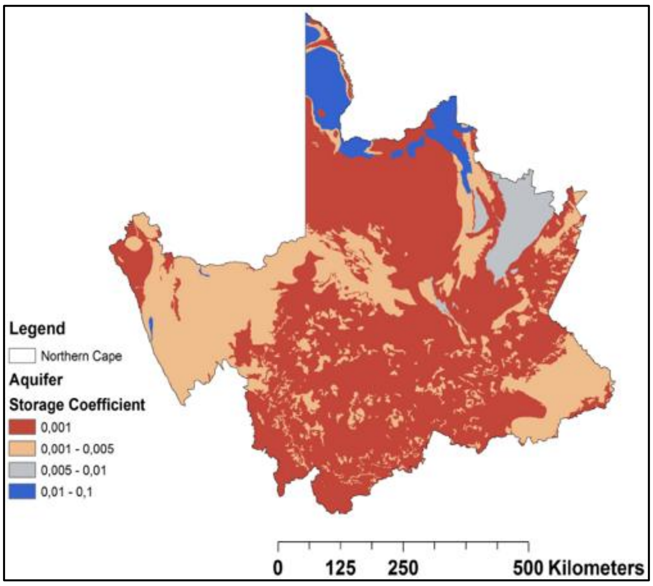


FIGURE 2.3.4: AQUIFER STORAGE COEFFICIENT
Source: Dennis, 2011

R - Recharge

The relationship clearly shows that the recharge is the driving force of the water level since the storage coefficient is a static parameter. Furthermore, recharge is a function of both precipitation and slope. Therefore, Dennis (2011) formulated a recharge model based on the parameters above to accommodate monthly recharge Figures based on monthly precipitation.

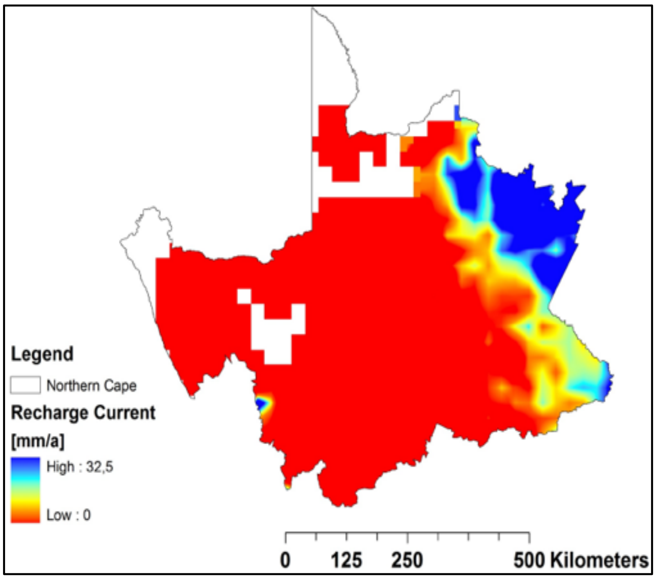


FIGURE 2.3.5: RECHARGE
Source: Dennis, 2011

T - Transmissivity

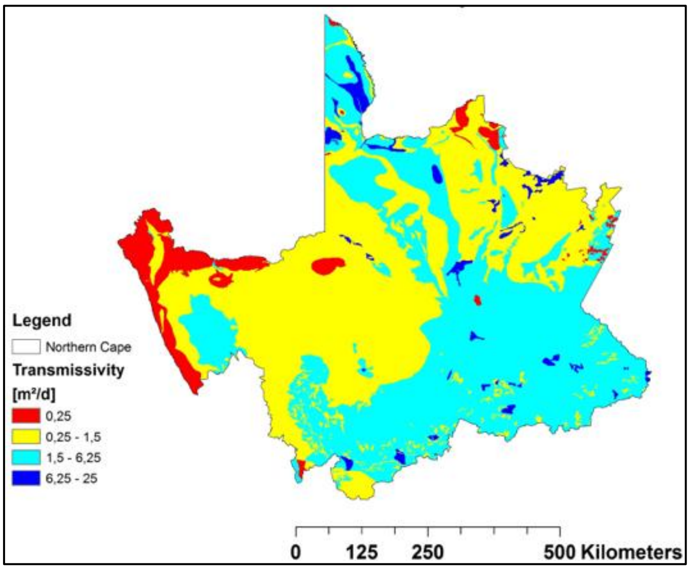


FIGURE 2.3.6: TRANSMISSIVITY
Source: Dennis, 2011

Transmissivity measures the ease with which groundwater flows in the subsurface. The transmissivity map was produced using the geohydrological maps of South Africa and translating the yield values to transmissivity values using a factor of five. This led to transmissivities in the range of 0.25 – 25m^3/d.

DART result

Table 2.3.3 shows the resulting ranges, classification and associated weights to calculate the DART index with a maximum score of 10. Higher values represent more resilience against drought and climate change projections.

TABLE 2.3.3. DART INDEX CALCULATION

D		A		R		T	
65%		15%		15%		5%	
Range	Rating	Range	Rating	Range	Rating	Range	Rating
-5 - 0	0 - 10	0 – 0.1	0 - 10	0 - 10	0 - 10	0 - 25	0 - 10
Rating =(2*Range = 10		*Rating = 100*Range*		*Rating = Range*		*Rating = 0.4 Range*	

The DART index indicates relatively good resilience against drought with most values six to seven. Small areas north of Kuruman shows a higher index of eight.

The groundwater risk assessment concluded that groundwater withdrawals as a fraction of total water withdrawal might increase where surface water become scarcer.

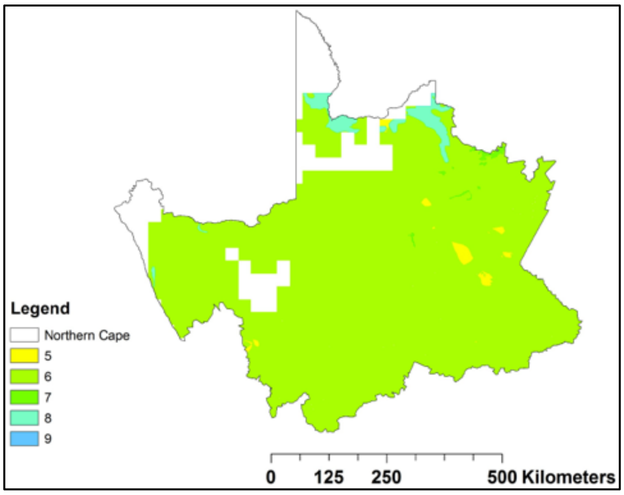


FIGURE 2.3.7: DART INDEX
Source: Dennis

The Council of Geo-Sciences (2011) also develop a groundwater vulnerability map (Figure 2.3.8). They also used the DART index but added two additional parameters, namely Soil media (Sg) and the vadose zone (IR) impact. In addition, they also apply different weightings to the different parameters as shown in Table 2.3.4.

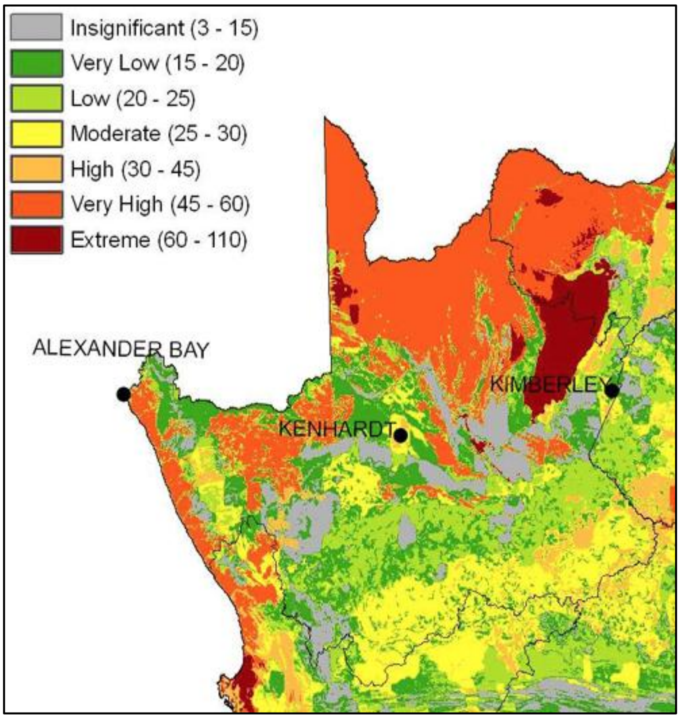


FIGURE 2.3.8: GROUNDWATER VULNERABILITY
Source: Council of Geo-Sciences, 2011

TABLE 2.3.4. PARAMETERS & WEIGHTS

Parameter	Weight
Depth to groundwater	5
Recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of vadose zone	5
Hydraulic conductivity	3

Farmers should note that increased groundwater withdrawals are not sustainable if quantities are not much less than groundwater recharge to avoid harmful reductions in baseflow to surface water bodies and large drawdowns of the groundwater table. Many livestock farmers introduced Lucerne or other fodder sources under pivot irrigation as a drought resistance strategy. Unfortunately, these additional withdrawals might have a negative impact on the DART index on a specific farm or catchment.

The DART index is very similar for the NC. Therefore, the decisive factor that determines groundwater drought resilience is the DART index/abstraction ratio. Some farmers might have a large ratio if they do not over-withdraw water from groundwater aquifers. The principle is similar to over-grazing. Farmers who over-withdraw water from groundwater aquifers might experience normal dry periods as droughts with low groundwater levels.

Reporting groundwater levels according to the drought classification remains a challenge in the short term. However, with time, the reporting system will gather more data for increased calibration.

2.3.4 Soil moisture

Soil moisture is the total amount of water, including water vapour, in unsaturated soil. Soil moisture represents the water in land surfaces that is not in rivers, lakes, or groundwater but instead resides in the soil's pores. Surface soil moisture is the water in the upper 10 cm of soil. In contrast, root zone soil moisture is the water available to plants—generally considered to be in the upper 200 cm of soil (AMS Glossary of Meteorology, 2022).

Soil moisture content can have significantly different implications depending on soil type, depth, location, season, vegetation cover, etc. For example, the same absolute value of soil moisture can indicate a serious drought in the higher rainfall eastern parts of SA, while it represents normal soils in the Northern Cape. Interpreting soil moisture data requires assessing and maintaining a range of other "*metadata,",* particularly soil characteristics. It also means that more than one unit of measure may be needed to adequately describe conditions, including not only "*volumetric water*" (the volume of water present) but also anomalies, daily ranking percentages, etc. The importance interaction of soil moisture with vegetative growth is already discussed in 3.2.

2.3.5 Social impact of drought and corresponding indicators

The social impact of drought is, in most cases, not a direct impact of drought and not always tangible. However, social impact is closely linked to economic impact. Significant social impacts occur as a result of reduced income for farmers and rural businesses, increased rural poverty, job losses, increased workloads on individuals, health and welfare issues, the need to seek alternative income, declining educational access, increased workload for women in far rural areas who have to walk long distances to collect water and overload on service providers. In addition, drought impacts are gender-specific, and men and women experience drought differently due to different responsibilities.

Increased poverty and lower household income have led to increased isolation of farm family members due to longer working hours for men and less money available to travel. In some cases, drought leads to separation due to the requirement of a family member to seek alternative income elsewhere.

Nicholls, Butler, & Hanigan (2006) reported an increase of 8% in suicides during drought periods and Lorenz, Conger, & Montague (1994) and Coelho, Adair, & Mocellin (2004) also reported higher levels of anxiety and depression during droughts in the US and Brazil respectively. Drought studies in California suggested a strong correlation between periods of drought and the perception of the physical and mental health among inhabitants (Barreau et al., 2015). Mental health is complex and varies with social, cultural and family norms and values and the financial status of individuals and households. Vins, Bell, Saha, & Hess (2015) developed causal process diagrams for drought based on published papers on the impacts of drought on health. Figure 2.3.9 illustrates the mental health outcomes of the economic effects of drought.

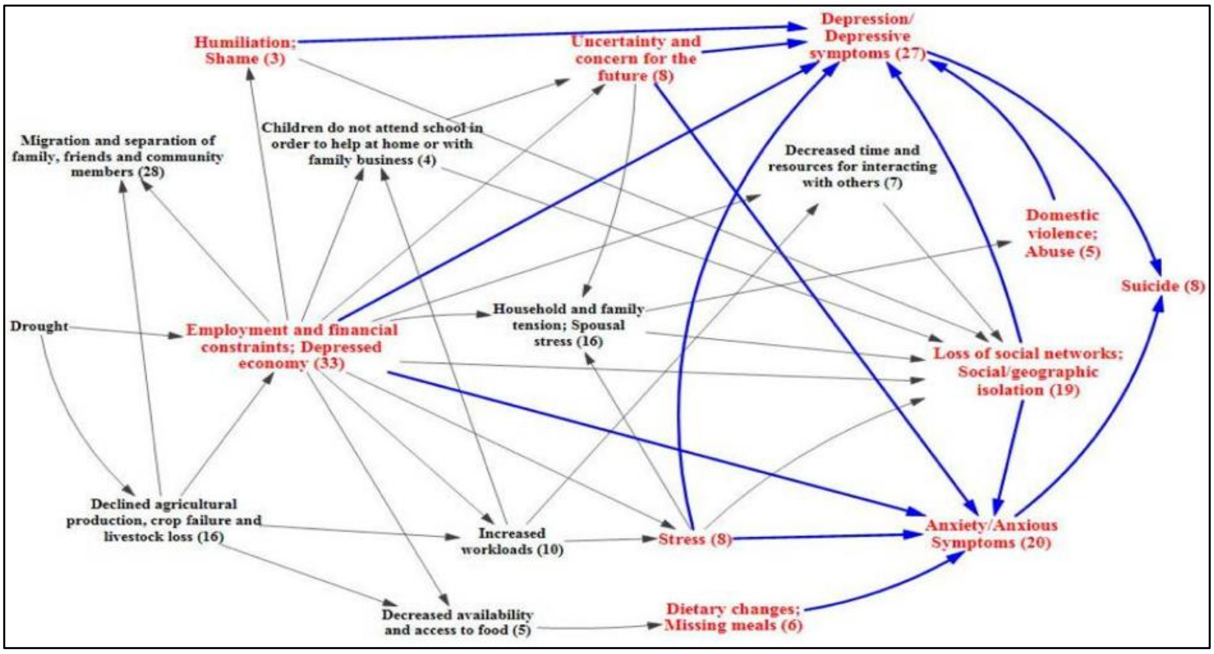


FIGURE 2.3.9: MENTAL HEALTH OUTCOMES OF ECONOMIC EFFECTS OF DROUGHT
Source: Vins et al, 2015

Financial constraints, a depressed economy and job losses might lead to anxiety, stress, humiliation, or shame (when people cannot provide for daily needs). These characteristics, combined with stress in its turn, lead to depression and, ultimately, suicide.

The migratory effects of drought on mental health are illustrated in Figure 2.3.10. Again, the pattern is evident in that drought can result in outmigration from agriculture or the sector affected by drought. Outmigration because of drought lead to the loss of social networks, a new social environment, altered family, community and social structures and eventually to anxiety, depression and potential suicide.

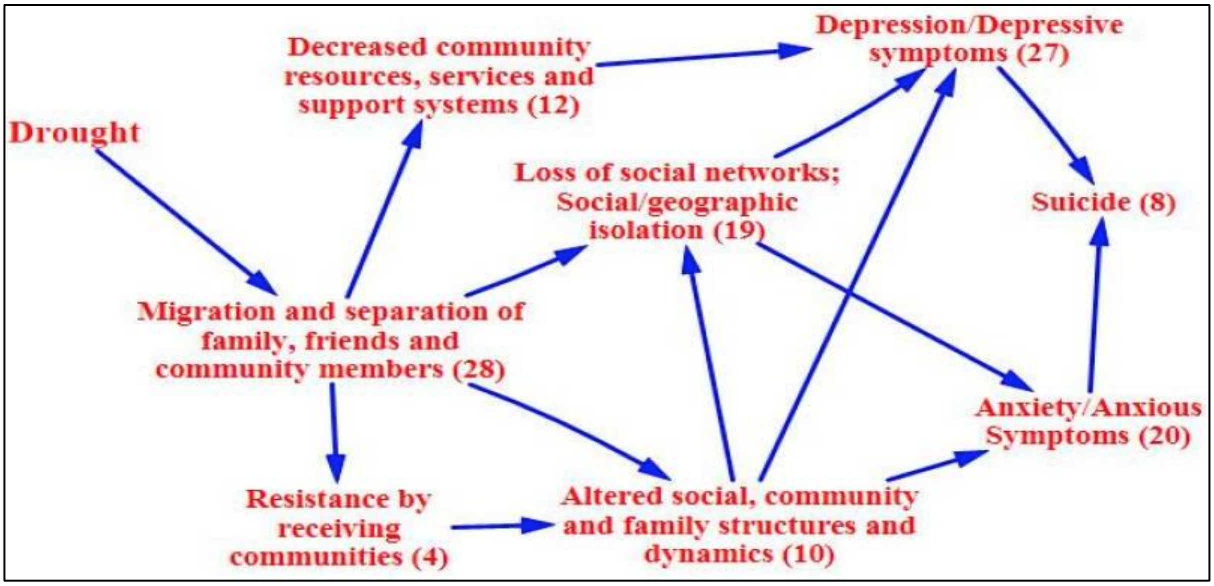


FIGURE 2.3.10: MIGRATORY EFFECTS OF DROUGHT UPON MENTAL HEALTH
Source: Vins et al, 2015

The mental health outcomes related to the environmental degradation of a household is illustrated in Figure 2.3.11.

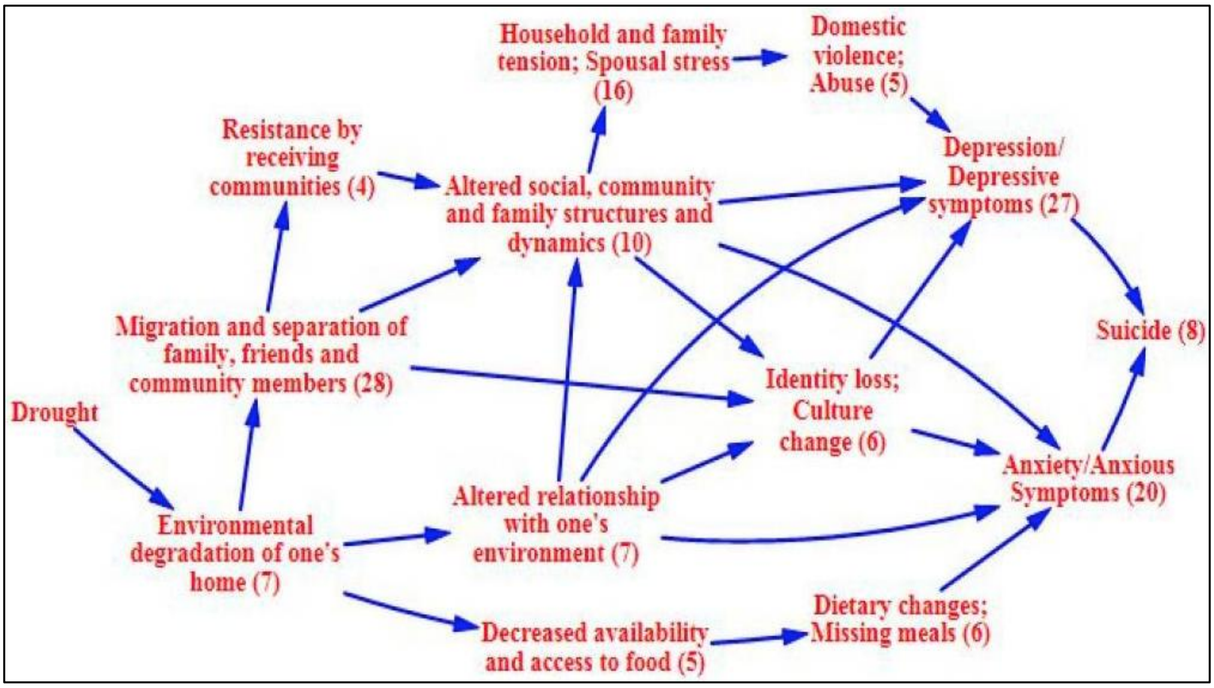


FIGURE 2.3.11: MENTAL HEALTH OUTCOMES RELATED TO THE ENVIRONMENTAL DEGRADATION OF A HOUSEHOLD
Source: Vins et al, 2015

Not all populations and communities experience and react to drought similarly. Individuals or communities apply various mechanisms to deal with the mental health effects of drought. Table 2.3.5 summarises populations' vulnerable characteristics, protective factors, and coping mechanisms.

TABLE 2.3.5. VULNERABILITIES, PROTECTIVE FACTORS AND COPING MECHANISMS FOR MENTAL HEALTH EFFECTS OF DROUGHT

Vulnerable characteristics	Protective factors	Coping mechanisms
• Rural & remote populations • Farming & agricultural dependent population • Indigenous populations • Perceived stigma associated with mental health issues • Lack of knowledge surrounding mental health issues • Lack of knowledge regarding availability of mental health support • Previous mental health issues or adverse life events • Exposure to an extended period of more intense or severe drought	• Social support, social capital and sense of community belonging • Shared knowledge and community preparedness regarding availability and access to services • Mental health literacy • Government assistance and initiatives available	• Employing practical solutions & active methods, including planning for the future • Psychological methods, including positive thinking, acceptance & reframing of the problem • Utilising social support and talking about the problem • Distracting oneself from the problem • Taking a break • Turning to religion • Alcohol and substance use • Denial and avoidance of the problem

Factors with the highest publication scores are:

- Employment and financial constraints and depressed economy (33);
- migration and separation from family, friends and community members (28);
- depression and depressive symptoms (27);
- anxiety and anxious symptoms (20);
- loss of social networks and social and geographic isolation (19);
- declined agricultural production, crop failure and livestock loss (16);
- household and family tension and spousal stress (16);
- decreased community resources, services and support systems (12)
- altered social community and family structures and dynamics (10);
- increased workloads (10)
- stress (8);
- suicide (8);
- uncertainty and concern for the future (8);
- altered relationship with one's environment (7);
- environmental degradation of one's home (7);
- decreased time and resources for interacting with others (7);
- dietary changes and missing meals (6)
- identity loss and cultural change (6);
- decreased availability and access for food (5);
- domestic violence and abuse (5);
- children do not attend school in order to help at home or family business (4);
- resistance by receiving communities (4);
- humiliation or shame (3)

The causal processes for mental health outcomes to drought is illustrated in diagram, Figure 2.3.12.

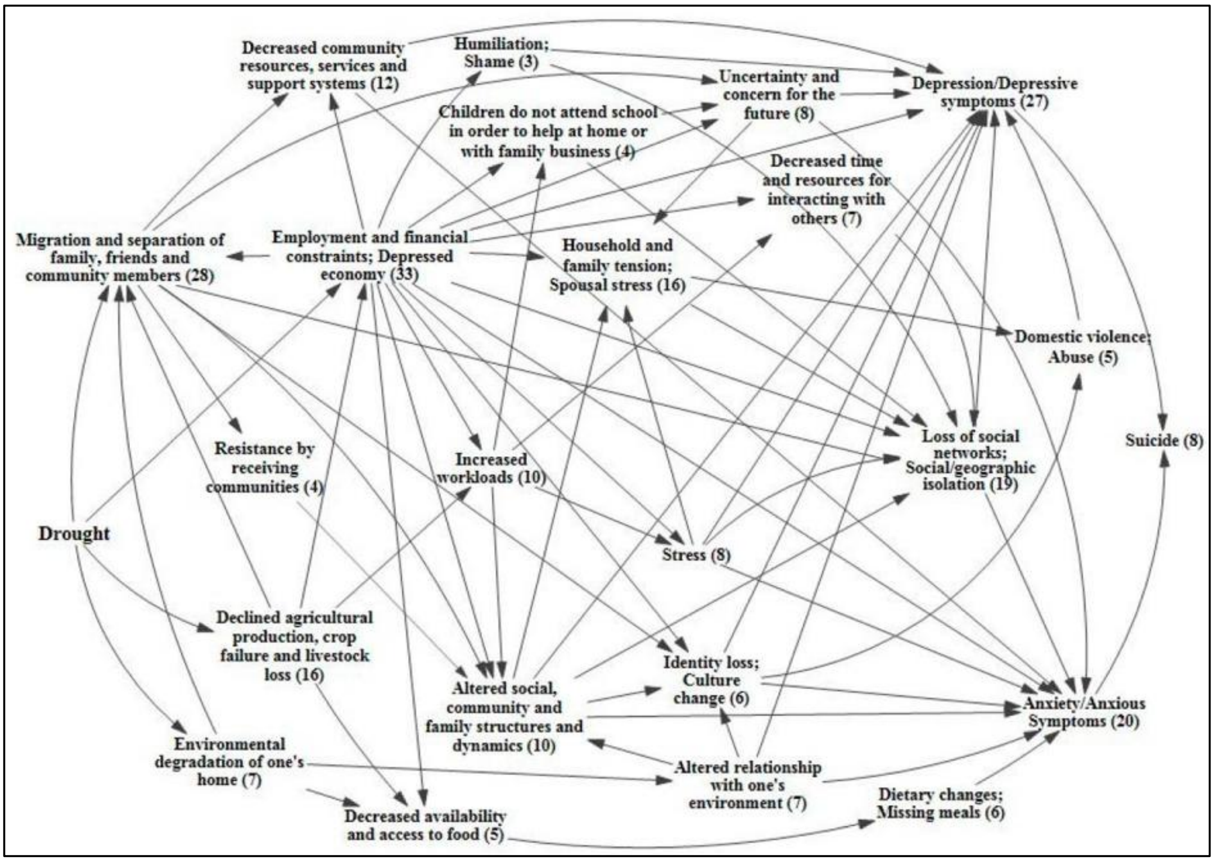


FIGURE 2.3.12: CAUSAL PROCESSES DIAGRAM FOR MENTAL HEALTH OUTCOMES OF DROUGHT
Source: Vins et al, 2015

2.3.6 Economic impact of drought and corresponding indicators

A substantial body of literature confirms drought's adverse economic impact. Drought and water scarcity impact all levels of economic activity, and a downtrend characterises droughts in economic growth at national and regional levels. Economic impacts range from direct impacts such as reduced agricultural production, reduced activity in the total agricultural value chain, delays in industrial production processes, reduced business activity in rural towns, increased water treatment costs and disruptions in energy production.

The 2015 Carbon Disclosure Project (CDP) water disclosure report reported a loss of R841 million estimated by only ten companies in the Vaal catchment area due to the 2015/2016 drought. Direct drought loss because of water stress was R610 million; ecosystems impact R128 million; additional flooding impact R35 million (CDP, 2016). Reports and publications on drought impacts in South Africa primarily focused on drought impacts in the agricultural sector. As a result of the 2015/2016 drought, the government established a drought committee in terms of Section 7 of the Marketing of Agricultural Products Act (Act 47 of 1996). The committee was instituted following approval by the Minister of Agriculture, Forestry and Fisheries. The committee documented the impacts of the 2015/2016 and 2017/2018 droughts.

The committee reported far-reaching implications for farmers and the broader economy. Projections showed that crop farmers affected by the 2015/2016 drought would only yield positive cash flow positions again in 2019 if normal climate conditions characterised the following years. Calculations showed that Net Farm Income (NFI) for maise farmers in the Northern Free State were 218% less than the 2014 base year and the only way farmers could survive was to restructure their debt to longer periods and even under good scenarios, they will only recover four years later. Smallholder farmers were also severely affected by the 2015/2016 drought. The Smallholder maise area decreased by 33% in the 2015/2016 season due to unfavourable planting conditions.

Drought in the winter rainfall area of the Western Province also showed decreased production of agricultural products. Winter cereal production decreased by 32% for wheat, 21% for barley and 4% for canola. Stone fruit production declined by 9% to 20%, and table grape production by 13%. Simulations for apple and pear producers showed negative NFI for 2018, and they estimated that these farmers would take at least five years to recover financially. Wine producers also experienced a drop of 17% in production during the 2018 drought.

Drought also affected the livestock sector with prolonged and severe droughts in the Northern Cape, Eastern Cape and Western Cape. The national sheep flock has reduced dramatically due to successive and prolonged droughts. In some cases, farmers in the Northern Cape and Eastern Cape had to sell all their animals, and those farmers might never recover financially and ultimately migrate out of agriculture. Maré & Willemse (2016) established that more than 40 000 cattle died in KZN in 2015 due to drought, which increased red meat prices due to lack of supply. In a study of 350 livestock farmers, Maré, Bahta & van Niekerk (2018) and their own calculation found that average cattle herd numbers declined by 14.7% and sheep numbers declined by 12.2% from 2013 to 2016 as a result of the 2015/2016 drought. Table 2.3.6 shows the decline in herd numbers per province for both cattle and sheep.

TABLE 2.3.6. AVERAGE HERD NUMBERS AND % CHANGE IN NUMBERS DUE TO DROUGHT FOR SELECTED PROVINCES FOR CATTLE AND SHEEP.

Province	Cattle: Ave herd size	% decline Cattle	Sheep: Ave herd size	Sheep: % decline
Limpopo	322	-32.2%	333	-34.5%
North West	1087	-17.7%	685	-15.5%
KwaZulu-Natal	1042	-5%	1752	-1%
Free State	544	-16.9%	2197	-3.5%
Northern Cape	256	-33%	2408	-26.7%
Western Cape	176	-4.3%	2433	-6.8%
Eastern Cape	540	-8.2%	2612	-13.8%
Total Ave	566	-14.7%	1774	-12.2%

Source: Maré, Bahta & van Niekerk (2018) and own calculation.

What is interesting from the results shown in Table 8.1 is that the requirement or guideline to reduce livestock numbers by 30% during extreme drought was only met in Limpopo and Northern Cape. KwaZulu-Natal reported a decline in numbers of only 5% for cattle and 1% for sheep implying that livestock mortalities in KwaZulu-Natal reported in other reports mainly come from the smallholder sector – the same author reported deaths of 40 000 cattle in KZN in 2015 (Mare & Willemse, 2016). The Free State and Eastern Cape, two of the provinces declared a state of drought disaster, also reported significantly lower percentages for declining sheep and cattle numbers than expected.

The agricultural sector in the Western Cape lost more than R5 billion due to the 2017/2018 drought, which directly impacts the national economy in that Western Cape contributes more than 22% to the national agricultural GDP. The Western Cape is also the largest exporter and earner of foreign capital due to exports.

Drought causes additional strain on the fiscus in supporting drought relief to communities and farmers. Drought also increases the import bill in that South Africa needs to import food items such as maise and wheat and protein sources such as meat, eggs and chicken during drought. Local shortages of produce also push up prices, which in turn push up the consumer price index. Given that the Reserve Bank uses interest rates to control inflation, this generally leads to higher interest rates, which affect the entire economy.

Vins, Bell, Saha, & Hess (2015) developed causal pathways to illustrate drought's economic and social effects. The authors analysed publications on drought impacts and developed different causal pathways for drought based on the number of publications linked to specific drought impacts. The causal diagrams developed by Vins et al. (2015) illustrate the link between economic and social impacts.

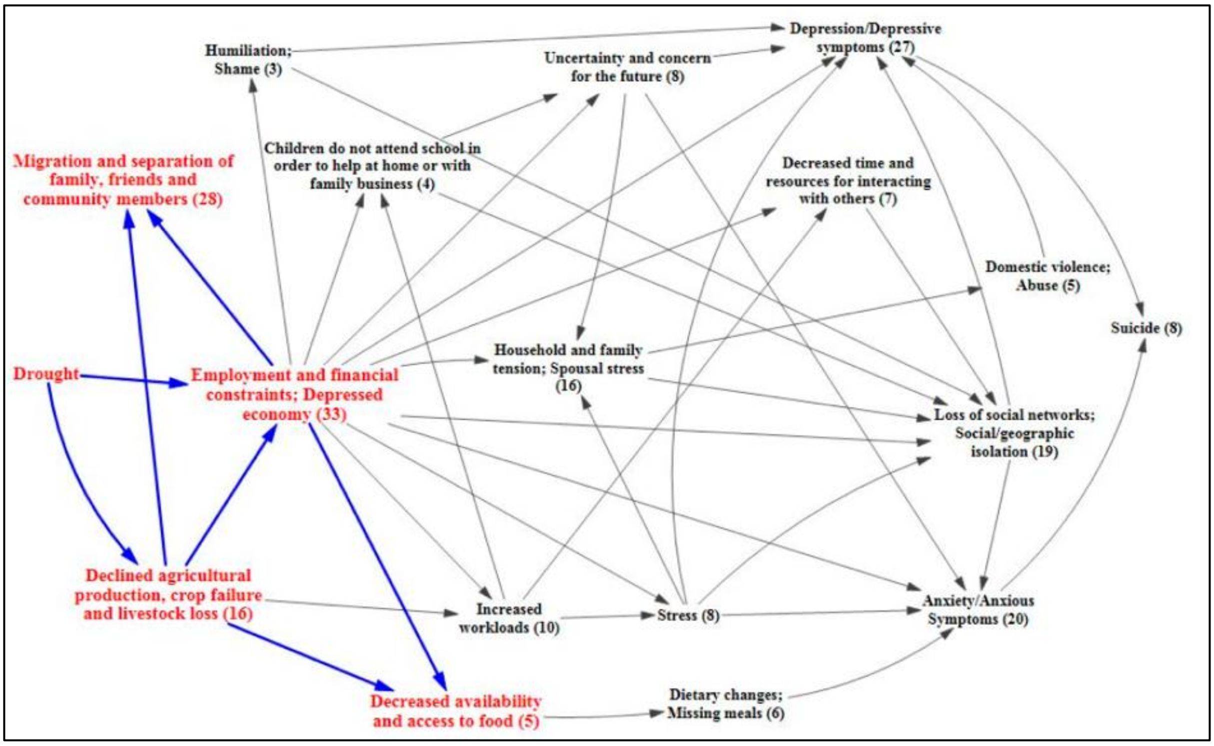


FIGURE 2.3.13: DIRECT ECONOMIC EFFECTS OF DROUGHT
Source Vins et al, 2015.

The direct economic effects are illustrated in Figure 2.3.13 in red. Direct economic effects are;

- migration and resultant separation from family, friends and support structures
- declined production due to crop failures and livestock loss
- financial constraints
- depressed economy
- unemployment
- decreased availability and access to food

The intermediary factors of economic pathways are illustrated in Figure 3.14. The link between to social impact of drought and the economic impact is clearly illustrated in the diagram in Figure 2.3.14.

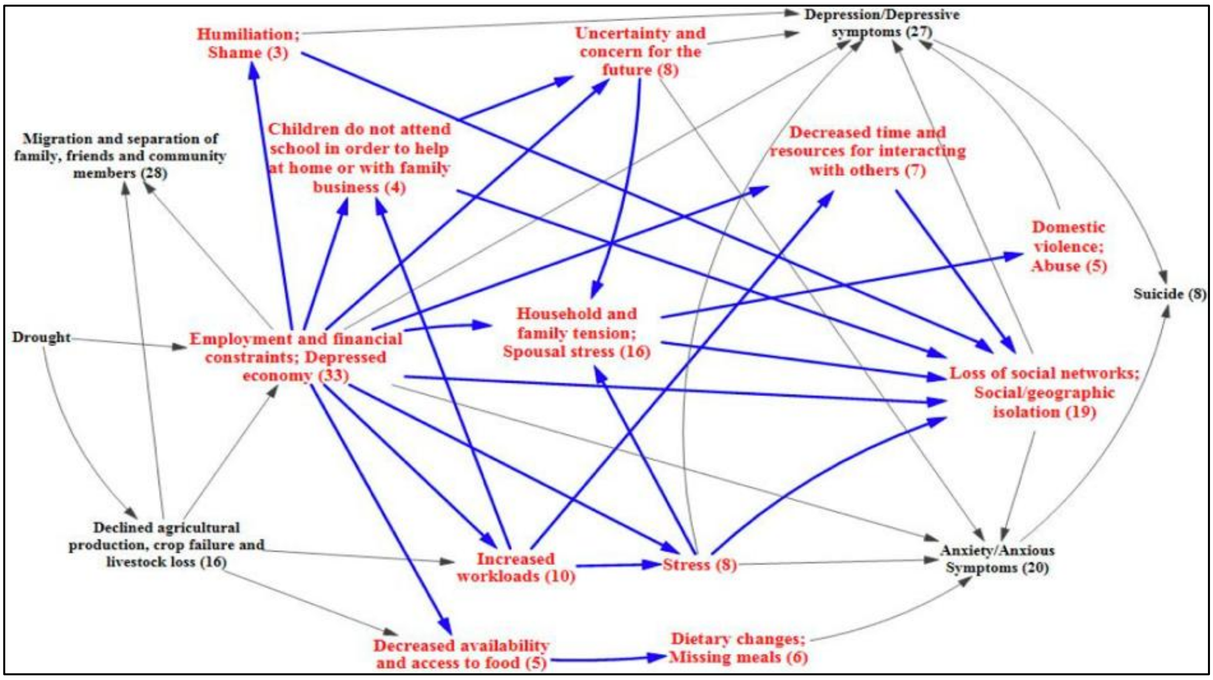


FIGURE 2.3.14: INTERMEDIARY FACTORS OF ECONOMIC PATHWAY
Source Vins et al, 2015

Financial constraints and a depressed economy lead to;

- humiliation or shame
- decreased availability and access to food
- household and family tension
- spousal stress
- uncertainty and concern for the future
- stress
- increased workloads
- less social interaction
- loss of social networks
- domestic violence

2.4 Characteristics of drought classes

This chapter listed the most obvious impacts and indicators for the different drought classes.

2.4.1 D0 drought

The D0 drought is a short dry period, which might be temporary, or it may indicate the start of a prolonged and more severe drought. This type of drought is typically the 1 in the 3-year dry period. Farm-level characteristics are the following:

- Short-term dryness
- Daily evapotranspiration has exceeded precipitation for several days
- Limiting growth of pastures
- New plant growth has withered at the soil surface
- Grass leaves are curled during the midday and afternoon
- Smaller farm dam levels are lower than usual
- Some fountains stop flowing
- Short-term weather forecasts indicate hot and dry days

2.4.2 D1 drought

The D1 drought is the moderate drought expected with a frequency of about 1 in 5 years. The D1 drought might be a seasonal drought or an indication of a prolonged extreme drought. Normally, there is no reason for farmers to panic during a D1 drought, but they should be prepared for a progression of drought under El Nino conditions with a seasonal forecast of below-average rainfall. Characteristics of the D1 drought are the following:

- Daily evapotranspiration has exceeded precipitation for a number of several days
- Grazing conditions deteriorating
- Blades of grass remain curled throughout the day, and the blue-grey tint of the sward is peppered with tan-coloured leaf tips and new growth that has withered at the soil surface

- Tyre tracks made by tractors and vehicles remain apparent a day or more after they were made
- Rainfall is unlikely within the next two weeks, especially during an El Nino year
- Streams, reservoirs and wells lower than normal
- Soil moisture deficit for planting dryland forage
- Water shortages developing or imminent
- Animals start showing feeding stress
- Slight increase in the supply of older and poor conditioned animals at auctions and abattoirs

2.4.3 D2 drought

The D2 drought is a severe drought with a frequency of about 1 in 8 to 10 years. The SPI values for a D2 drought are normally between minus 1.2 and minus 1.5. This is the category of drought where farmers should reduce animal numbers. Typical characteristics of this drought are the following:

- Daily evapotranspiration has exceeded precipitation for several several weeks
- Grazing conditions deteriorating
- Forage growth has slowed dramatically and has stopped in areas with poor-quality soil
- Groundwater levels going down at selected places
- Smaller farm dam water levels are much lower than usual
- Most fountains stop flowing
- Streams, reservoirs and wells significantly lower than normal
- Animals are grazing the forage noticeably faster than the rate forage is growing
- Animals show feeding stress
- Supply of animals at auctions and abattoirs increases relative to previous weeks and years
- The market price for culled animals decreased slightly
- No forecast of rain in short to medium term

- Regular high-fire alerts

2.4.4 D3 drought

The D3 drought is typically when farmers advocate for a disaster declaration. This drought category causes severe economic loss, and the frequency is more or less 1 in 12 to 15 years. The SPI values for precipitation are normally lower than minus 1.5. The D3 drought is characterised as follows:

- Daily evapotranspiration has exceeded precipitation for several weeks
- Extremely hot conditions compare to the long-term mean temperature
- Grazing conditions extremely deteriorated
- Zero forage growth is taking place
- Severe shortage in natural grazing
- Not enough feed and fodder for animals
- Animals show serious feeding stress
- Not possible to keep animals with progeny on natural grazing alone
- Widespread water shortages
- Groundwater levels are very low
- Most farm dams at very low levels
- Small farm dams empty
- In some places, farmers have to transport water to animals
- Significant increase in the supply of animals at auctions and abattoirs
- In limited cases, the sale of core breeding stock
- Some sales of productive assets
- Significant decrease in animal prices
- A dramatic increase in feed and fodder sales at agri-businesses and cooperatives
- Farmers stop with capital expenditures
- Negative impact on the regional economy
- Labour retrenchments in some places

- Regular high-fire alerts

2.4.5 D4 drought

The D4 drought is an exceptional drought with a frequency of more or less one in 30 years. Some refer to this category of drought also as a catastrophic drought. Few farmers can sustain this drought without external support or drastic changes in the structure and operation of their businesses. The economic impact of a D4 drought is usually felt at a national level and almost always signifies increases in food prices and inflation. Some of the characteristics of the D4 drought in the livestock sector are the following:

- Daily evapotranspiration has exceeded precipitation for several months
- Scorching conditions compare to the long-term mean temperature
- Exceptional and widespread pasture losses
- Grazing totally deteriorated
- The remaining leaves of grass stay tightly curled throughout the day and are almost completely tan-coloured and withered
- Total shortages of natural grazing
- Zero vegetation production is taking place
- Soil is dry with no moisture
- Animal conditions are extremely poor
- Core breeding stock have to be kraaled for survival
- Total water shortages
- Almost all farmers have to transport water for animals
- Almost all farm dams are empty
- Streams, rivers and fountains are totally dry
- Rainfall is unlikely within the next few weeks or prior to the total exhaustion of available feed supplies
- Most animals already sold during the D3 drought
- Increased supply of poorly conditioned breeding stock at auctions and abattoirs

- Extremely poor prices for breeding stock
- Extremely negative impact on the regional economy
- Significant sales of productive assets
- Regional businesses close down
- Increased labour retrenchments
- Increase in unemployment in rural areas
- Debt consolidations by farmers and rural businesses
- Increase in farmer bankruptcy applications

2.5 Model for drought determination

We developed a draft model for illustrative purposes to explain to farmers what the farm-level information might look like. The framework to be developed as part of deliverable four is based on the draft model presented here. We categorise the farm-level drought indicators as shown in Table 2.5.1.

TABLE 2.5.1. INDICATOR GROUPING AND NO. INDICATORS

No	Indicator group	No of indicators
1	Meteorological / weather	3
2	Grazing and fodder data	6
3	Animals	10
4	Water	4
5	Soil	4
6	Social	8
7	Economic	9
	TOTAL	**44**

Since not all indicators are equally important, we propose a weighting of each and group of indicators. We will determine the weights or importance of the different indicators through consultation with farmers and expert inputs. The model will calculate the total score for all the indicators and apply the required weights, and the total score should indicate a drought class. The higher the score, the drier it is.

Calculating the drought score as follows:

Indicator group = $\sum_{i=1}^{n} a_i w_i$

Where

- n = number of indicator scores
- a_i = score for individual indicator
- w_i = weight for individual indicator

and

Drought score = $\sum_{i=1}^{n}((SPI, Veg, M, P, A, Wat, S, Soc, E)Wn)$

Where:

- SPI = SPI derived index score
- Veg = Remotely sensed derived vegetation score
- M = On-farm derived score for meteorological indicators
- P = On-farm derived score for pastures and fodder
- A = On-farm derived score for animals
- Wat = On-farm derived score for water
- S = On-farm derived score for soil
- Soc = Derived score for social indicators
- E = Derived score for economic indicators

Each of the indicators are classified according the different drought classes with a corresponding score as follows:

- D0 drought – 5
- D1 drought – 15
- D2 drought – 40
- D3 drought – 80
- D4 drought – 100

The following sections show the different indicators for each indicator group. Tables 2.5.2 to 2.5.7 are screenshots taken from the model in Xcel.

2.5.1 Meteorological indicators from SAWS – SPI

The template for the SPI scores are shown in Table 2.5.2. Note that consideration is given to different SPI time periods and exacerbating factors are also considered.

TABLE 2.5.2. SPI SCORING TEMPLATE

		D0 drought	D1 drought	D2 drought	D3 drought	D4 drought		W	
	Score	**10**	**40**	**60**	**80**	**100**	**82**		**74**
		> minus 0.7	Minus 0.7 to -1.19	Minus 1.2 to -1.49	Minus 1.5 to -1.99	<-2	**68**		**62**
Rainfall								1,00	
	3-month SPI				1		80	0,05	4
	6-month SPI				1		80	0,05	4
	12-month SPI			1			60	0,30	18
	24-month SPI			1			60	0,30	18
	36-month SPI			1			60	0,30	18
Exacerbating factors		<5%	6% - 10%	11% - 20%	21% - 30%	>30%			
	Exacerbating factors	1,00	1,10	1,20	1,3	1,40	1,20		
	Rainfall efficiency lower than normal		1				1,10		
	Wind impact above normal			1			1,20		
	Temperature above normal				1		1,30		

2.5.2 Remotely sensed: Vegetation, soil & hydrological

The template for the remotely sensed data is shown in Table 2.5.3.

TABLE 2.5.3. SCORING TEMPLATE FOR REMOTELY SENSED DATA

Vegetation		**10**	**40**	**60**	**80**	**100**	**55**		**56**
		<90%	80%-89%	70%-79%	60%-69%	<60%		1,00	
	NDVI			1			60	0,20	12
		3-month<90%	6-month<90%	12-month<90%	12-month<80%	24-month<80%			
	PASG		1				40	0,20	8
		36-45	26-35	16-25	6--15	<5			
	SVHI			1			60	0,20	12
		<90%	80%-89%	70%-79%	60%-69%	<60%			
	VCI			1			60	0,40	24
Soil moisture		**10**	**40**	**60**	**80**	**100**	**80**		**80**
							0		
	CPC soil moisture (top soil)	21%-30%	11%-20%	6%-10%	3%-5%	<3%			
					1		80	0,60	48
	CPC soil moisture (> 40 cm)	21%-30%	11%-20%	6%-10%	3%-5%	<3%			
					1		80	0,40	32
Hydrological data		**10**	**40**	**60**	**80**	**100**	**53**		**42**
	Dam levels	>60%	41%-60%	31%-40%	16%-30%	<15%			
			1				40	0,05	2
	Stream flow	>60%	41%-60%	31%-40%	16%-30%	<15%			
					1		80	0,05	4
	Groundwater level	>60%	41%-60%	31%-40%	16%-30%	<15%			
			1				40	0,90	36

2.5.3 Meteorological / weather (on-farm)

The SPI is the primary indicator provided by the SAWS, ARC and SANSA. Rainfall data from the SAWS and ARC are modelled in most cases and are not always a true reflection of farm-level weather conditions. The model, therefore, requires the following farm- or catchment-level data:

- Rainfall
- Temperature as a deviation from the long term average
- Cloud cover
- Whirlwinds

The example template is shown in Table 2.5.4.

TABLE 2.5.4. METEOROLOGICAL DATA

Meteorological / weather		D0 drought	D1 drought	D2 drought	D3 drought	D4 drought	34	1,00	38
		Weather conditions near normal	No indication of rainfall in short term. Slightly above average temperatures	Evapotransipartion higehr than precipitation for numebr of days. No rain expected.	Extremely hot conditions. High evapotranspiration . Regular whirlwinds with dust and dust storms. Extremely high fire danger	Exceptionally hot conditions. Daily evapotranspiration exceeded precipitation for months			
	Weather conditions deviation from the mean	<10%	11%-20%	21%-40%	41%-75%	>76%			
	Score	5	15	40	80	100			
	Higher temperatures		1				15	0,10	2
	Less cloud cover for days			1			40	0,05	2
	More whirlwinds			1			40	0,05	2
	Precipitation difference from mean			1			40	0,80	32

2.5.4 Grazing / fodder

The grazing and fodder indicators were discussed in detail in section 4.2. Indicators useful for drought classification are shown in Table 5.5. Grazing indicators are:

- Plants wilted more than normal
- Grazing capacity loss
- Production loss
- More reserve feed and fodder used
- Additional licks provided
- Additional feed and fodder purchased

TABLE 2.5.5. GRAZING AND FODDER DATA

Grazing/fodder		D0 drought	D1 drought	D2 drought	D3 drought	D4 drought	54	1,00	61
		Grazing more or less normal. No need to provide additional fodder	Grazing conditions start deteriorating. Have to feed animals with offspring. Increased lcik demands			Zero vegetation growth. No natural grazing available. Reserve feed and fodder depleted			
	General condition/situation regarding grazing and fodder and feeding - % deviation	<10%	11%-20%	21%-40%	41%-75%	>76%			
	Score	5	15	40	80	100			
	Plants wilted				1		80	0,10	8
	Grazing capacity loss				1		80	0,20	16
	Production loss				1		80	0,40	32
	Reserve feed and fodder used		1				15	0,20	3
	Feed and fodder purchased		1				15	0,10	2

2.5.5 Animals

Animal behaviour and condition provide excellent indicators for drought classification. The animal indicators are sub-divided into three sub-sections as follows:

- Condition and productivity
    - Animal condition loss
    - Number of animals kraal feeding as a result of drought
    - Less wool yield
    - Less weight of progeny at weaning
- Animal numbers
    - Fewer animals on the farm out of own decision
    - Forced sales of animals as a result of drought
    - The forced sale of core stock
- Animal progeny and mortality
    - Less progeny
    - Increased mortalities of older animals
    - Increased mortality of young animals

The reporting template for animals is shown in Table 2.5.6.

TABLE 2.5.6. ANIMAL DATA

Condition & productivity		General condition of animals more or less normal	Clear signs that pregnant and older animals starting to suffer on natural grazing.	Animals on natural grazing shows serious stress. Forced sales of unproductive animals. Mortalities high because of drought	Condition of animals on natural grazing extremely poor. Have to kraal most productive animals. Mortalities as a result of drought very high.	Only core stock left and sometimes forced sales of core stock. Large numbers of animals receives kraal feeding. Very high mortalities because of drought			
	Score	**5**	**15**	**40**	**80**	**100**			
	General condition/situation regarding animals - % deviation	<10%	11%-20%	21%-40%	41%-75%	>76%			
	Animal condition loss				1		80	0,20	16
	Kraal feeding because of drought		1				15	0,08	1
	Less wool yield			1			40	0,02	1
	Less weight of progeny at weaning		1				15	0,05	1
Animal numbers		No forced reduction in numbers	Small forced reduction in animal numbers. Increased sales of unproductive animals are immenent.	Sales of all unproductive and older animals. Over supply of animals at auctions.	Unproductive and older animals already sold. Start selling productive animals with poor condition. Over supply of animals at auctions.	Keep only corebreeding stock. All ather animals sold. Under supply of animals at auctions.			
		<10%	11% - 20%	21% - 30%	30% - 60%	>61%			
	Less animal number as mitigation			1			40	0,05	2
			1				15		0
	Sales of core stock	1					5	0,20	1
	Forced animal sales		1				15	0,05	1
Animal mortalities and progeny	% deviation from normal	Normal (<5%)	Above normal (6-10%)	High (11-20%)	Very high (21-30%)	Exceptional high (>31%)			
	Increased mortalities of young animals as a result of drought		1				15	0,15	2
	Increased mortalities of older animals as a result of drought	1					5	0,15	1
	Less progeny		1				15	0,05	1
							0		0

2.5.6 Water

Almost all livestock farmers in the NC depend on groundwater as the primary water resource. Groundwater is affected only during D3 and D4 droughts. The water indicators proposed for drought monitoring are:

- Groundwater levels
- Dam levels
- Rivers and streams
- Water availability to animals

See Table 2.5.7 for the Xcel model.

TABLE 2.5.7. WATER DATA

Water		D0 drought	D1 drought	D2 drought	D3 drought	D4 drought	50	1,00	60
		Water situation more or less normal	Clear signs of a reduction in water reserves. Slightly under normal	General reduction in water reserves. Streams, fountains and groundwater levels starting to dry up. Possible lower groundwater table	Some farmers have to transport water for animals. Far below average	Critical water shortages. Significant number of farmers have to transport water for animals			
		Normal	Below normal	Significantly below normal	Critically low	Crisis / no water			
	% below normal	<9%	10%-30%	31%-50%	51%-70%	>71%			
	Score	**5**	**15**	**40**	**80**	**100**			
	Groundwater levels			1			40	0,40	16
	Dams			1			40	0,05	2
	Rivers and streams			1			40	0,05	2
	Water availability to animals				1		80	0,50	40

2.5.7 Soil

Soil moisture determines vegetation growth and the interaction between soil moisture and vegetation growth is explained in Figure 3.1. The template for soil moisture scoring is shown in Table 2.5.8.

TABLE 2.5.8. TEMPLATE FOR SOIL SCORING

Soil		D0 drought	D1 drought	D2 drought	D3 drought	D4 drought	80		80
		Normal	Slightly dry	Dy	Extremely dry	Exceptional;ly dry. Zero moisture at any depth			
	Score	**5**	**15**	**40**	**80**	**100**			
	Dryness				1		80	1,00	80

2.5.8 Social impact

The use of social impact for drought monitoring is not commonly discussed in the literature and is ignored during drought response programs. However, social resilience is an essential element in the survival of farmers during droughts. Indicators identified to measure the impact of drought on the social environment are the following:

- Higher stress levels
- Cancellation of family holidays
- Labour retrenchments
- Struggle to pay children’s school fees
- Stress in family relations

- Withdraw from social events
- Reduce social involvement in the community
- Consider suicide

The Xcel proforma is illustrated in Table 2.5.9.

TABLE 2.5.9. SOCIAL IMPACT SCORING

Social / personal		D0 drought	D1 drought	D2 drought	D3 drought	D4 drought	43		19
		No	Maybe but improbable	Probable	Highly probable	Definitely yes			
	Score	5	15	40	80	100		1,00	
		<10%	11%-20%	21%-40%	41%-75%	>76%			
	Higher Stress levels			1			40	0,05	2
	Cancellation of family holidays		1				15	0,04	1
	Labour retrenchments		1				15	0,20	3
	Struggle to pay children's school fees			1			40	0,05	2
	Stress in family relations		1				15	0,05	1
	Withdraw from social events		1				15	0,04	1
	Withdraw from leadership positions		1				15	0,04	1
	Family separation			1			40	0,20	8
	Consider suicide	1					5	0,23	1
	Migrate away from farm	1					0	0,10	0

2.5.9 Economic indicators

The ultimate impact of drought is on the region's finances and economy at the national level. In addition to farmers, banks, cooperatives, agricultural businesses and auctioneers can also provide information on the economic impact of drought. Some of the most important economic indicators for drought are the following:

- Reduce and stop capital expenditure
- Increased sales of licks
- Increased feed and fodder sales
- Farmers use savings to buy animal feed and fodder
- Sales of liquid assets
- Consider debt consolidation
- Getting behind with instalments
- Sales of off-farm assets (holiday homes)
- Farmers stop buying new vehicles
- Businesses in local towns are suffering financially

The reporting template for the economic indicators is shown in Table 2.5.10.

TABLE 2.5.10. ECONOMIC IMPACT SCORING

		D0 drought	D1 drought	D2 drought	D3 drought	D4 drought			
Economic		No	Maybe but improbable	Probable	Highly probable	Definitely yes	**62**	**1,00**	**62**
	Stop capital expenditure		1				15	0,05	1
	Use savings to buy animal feed				1		80	0,10	8
	Consider debt consolidation				1		80	0,10	8
	Sales of liquid assets				1		80	0,20	16
	Sales of fixed non-farm assets			1			40	0,20	8
	Businesses at local town suffering			1			40	0,10	4
	Getting behind with instalments				1		80	0,10	8
	Farmers stop buying new vehicles					1	100	0,05	5
	Seek alternative income			1			40	0,10	4
							0		0

2.5.10 Chapter conclusion

The xcel model is useful to quantitatively classify a specific drought class. Extension officers and disaster management staff will find it a useful tool for drought classification. However, it is important to note that the values attached to the current model is arbitrary allocated after discussions with experts. More research is required to fine-tune the model and we plan to submit a more robust model as part of the drought reporting

2.6 Information flow

This section provides a concept proposal on how the system should operate. Figure 6.1 is an illustration of the communication and reporting linkages between the different stakeholders. The national drought monitor unit receives information for the primary indicators from the SAWS, ARC, SANSA and other sources. This information is then supplemented with information from reference farms or local entities reporting on farm-level social and economic drought indicators. The information is then combined, geo-referenced and analysed by the Drought Monitor Unit, which provides the drought class for each quaternary catchment.

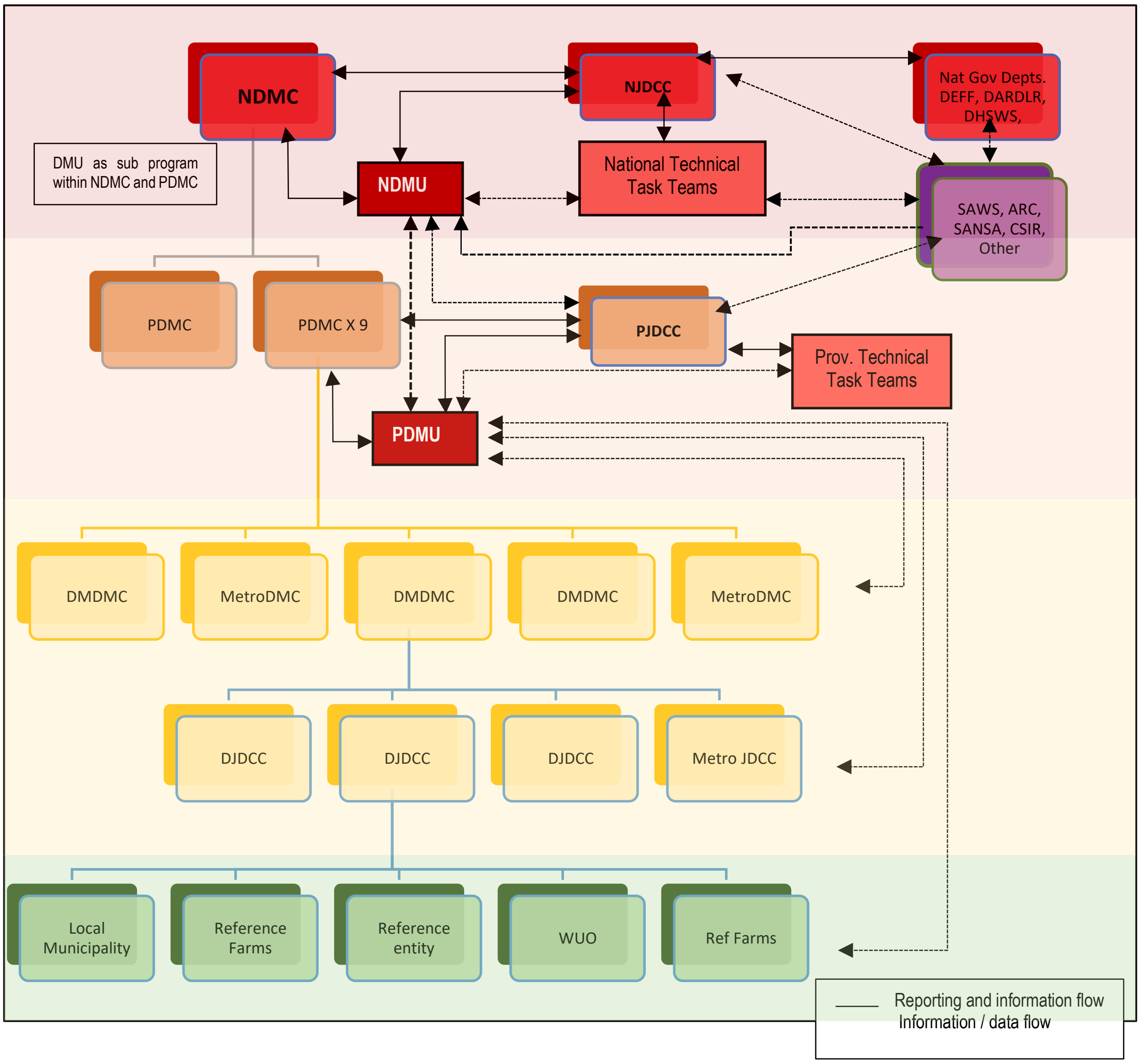


FIGURE 2.6.1: PROPOSED INSTITUTIONAL STRUCTURE FOR A DROUGHT INFORMATION AND COMMUNICATION SYSTEM

Reference farmers will report through a web-based application on smartphones or a computer. Therefore, it is important to keep the reporting system simple and short. Farmers will not participate if they have to provide large amounts of information or specific information such as animal numbers or financial loss. A simple reporting template is illustrated in Table 2.6.1.

TABLE 2.6.1. PROPOSED REPORTING TEMPLATE

	Actual	N-50%	N-30%	N-15%	Normal	N+15%	N+25%
Rainfall		X					
Temp/evapotransp.			X				
Veld condition				X			
Animal condition				X			
Dam & stream levels			X				
Groundwater levels					X		
Planting conditions		X					
Crop condition			X				
Yield potential				X			

Details of the drought information management system do not fall within this project's scope, and further research is required to develop such a system for South Africa.

2.7 Conclusion

Developing a system of farm-level reporting from reference farms in all the quaternary catchments is a good academic plan included as part of the latest Integrated National Drought Risk and Response plan. Yet, the practicality is that not all farmers are willing to participate in such a system. Northern Cape Agri (NC Agri) initiated such a project many years ago, yet they did not manage to obtain the support of a critical number of participating farmers. The success of the NC Agri reporting system is based on personal relations built over many years between staff from the Department of Agriculture and farmers. According to information from senior management in the Department, the staff managing the reference farm system will leave the Department during 2023 with no staff succession planning in place.

Building trust and new relations might take many years to rebuild. The government must support the NC Agri initiative, which should serve as a template for extending to other provinces. During our discussions with the NC Dept of Agriculture, they indicated their support for continuation of the reference farm drought reporting system. However, they should prove it through tangible support to NC Agri and farmers participating in the system.

Through this project, we endeavour to develop and fine-tune the reporting system with practical guidelines and the necessary programming, but implementation remains the responsibility of the NC Dept of Agriculture, the NC Disaster Management Centre and farmers. However, extension officers and disaster management staff will find the program useful for future quantitative drought classification and limit the qualitative assessment of droughts.

References

Balehegn M., Balehey S., Fu C. & Liang W. 2019. Indigenous weather and climate forecasting knowledge among Afar pastoralists of north eastern Ethiopia: Role in adaptation to weather and climate variability. Pastoralism: Research, Policy and Practice, (2019) 9:8. https://doi.org/10.1186/s13570-019-0143-y.

Barreau T, Conway D, Haught K, Jackson R, Kreutzer R, Lockman A, Minnick S, Roisman R, Rozell D, Smorodinsky S, Tafoya D,Wilken JA. 2015. Physical, mental, and financial impacts from drought in two California Counties, 2015. *Am J Public Health 2017; 107(5):783–90.*

CDP. 2016 *South Africa Water 2016: Risks and Targets.* https://www.nbi.org.za/wp-content/uploads/2016/12/CDP-Water-South-Africa-2016-Infographic-3-Risks-and-Targets.pdf

Chisadza B., Nhapi I. & Nyabeze W. 2013. Useful traditional knowledge indicators for drought forecasting in the Mzingwane Catchment area of Zimbabwe. Disaster Prevetion and Management – August 2013. DOI: 10.1108/DPM-10-2012-0109.

Coelho, A., Adair, J., & Mocellin, J. 2004. Psychological responses to drought in northeast Brazil. *International Journal of Psychology, 38, 95–103.*

Howery, L. 1999. *Rangeland management before, during and after drought.* Cooperative Extension, University of Arizona.

Hughes N., Soh WY., Boult G. & Lawson K. 2022. Defining drought from the perspective of Australian farmers. *Climate Risk Management* 35(100420). Science Direct, Elsevier.

Ings J, Mur LA, Robson PR, Bosch M. 2013. Physiological and growth responses to water deficit in the bioenergy crop Miscanthus x giganteus. *Front Plant Sci. 2013 Nov 25;4:468.* doi: 10.3389/fpls.2013.00468. PMID: 24324474; PMCID: PMC3839294.

Jordaan AJ., Sakulski DM., Muyambo F., Schwababa S., Mdungela N,. Phatudi-Mphahlele B., Mashimbye C., Mlambo D., Fadeyi O., Miya T., Bahta Y., Owusu-Sekyere E. & Schulze RE. 2017. *Vulnerability, Adaptation to and Coping with Drought: The Case of Commercial and Subsistence Rain Fed Farming in the Eastern Cape*. WRC Report number: TT 716/2/17. ISBN 978-1-4312-0885-2

Kagunyu A., Wandibba S. & Wanjohi JG. 2016. The use of indigenous climate forecasting methods by the pastoralists of Northern Kenya. Pastoralism: Research, Policy and Practice (2016) 6:7 DOI 10.1186/s13570-016-0054-0

Lebel L (2013) Local knowledge and adaptation to climate change in natural resource-based societies of the Asia-Pacific. *Mitig Adapt Strateg Glob Change* 18(7):1057–1076.

Lorenz, F. O., Conger, R. D., & Montague, R. 1994. Doing worse and feeling worse: Psychological consequences of economic hardship. In R. D. Conger & G. H. Elder Jr (Eds.), *Families in troubled times. Adapting to change in rural America* (pp. 167–186). New York: Aldine de Gruyter.

Maré, F., Bahta, Y.T. & Van Niekerk, W. 2018. The impact of drought on commercial livestock farmers in South Africa, *Development in Practice, 28:7, 884-898, DOI: 10.1080/09614524.2018.1493091*

Maré, F. & Willemse, J. 2016. *Expected implications of the 2015 drought on the red meat industry*. Unit in Livestock Economics, Department of Agricultural Economics, University of the Free State.

Nelson, R., Kokic, P., Crimp, S., Meinke, H., Howden, S.M., 2010a. The vulnerability of Australian rural communities to climate variability and change: Part I: Conceptualising and measuring vulnerability. *Environ. Sci. Policy* 13 (1), 8–17.

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H., Howden, S.M., de Voil, P., Nidumolu, U., 2010b. The vulnerability of Australian rural communities to climate variability and change: Part II: Integrating impacts with adaptive capacity. *Environ. Sci. Policy* 13 (1), 18–27.

Nicholls, N., Butler, C. D., & Hanigan, I. 2006. Inter-annual rainfall variations and suicide in New South Wales, Australia, 1964–2001. *International Journal of Biometeorology, 50, 139–43.*

Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: associations with observed temperature and

Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: associations with observed temperature and precipitation trends, irrigation, and climate beliefs. *Global Environ. Change 39, 133–142.*

Nieuwoudt, T. 2019. *Grazing management in drought prone areas*. Stockfarm (38-39).

Salite, D. 2019. Traditional prediction of drought under weather and climate uncertainty: analyzing the challenges and opportunities for small-scale farmers in Gaza province, southern region of Mozambique. *Natural Hazards 96(1289-1309)*. https://doi.org/10.1007/s11069-019-03613-4.

Seleiman MF, Al-Suhaibani N, Ali N, Akmal M, Alotaibi M, Refay Y, Dindaroglu T, Abdul-Wajid HH, Battaglia ML. Drought Stress Impacts on Plants and Different Approaches to Alleviate Its Adverse Effects. *Plants (Basel).* 2021 Jan 28;10(2):259. doi: 10.3390/plants10020259. PMID: 33525688; PMCID: PMC7911879.

Snyman, HA. & Fouche, HJ. 1991. Production and water-use efficiency of semi-arid grasslands of South Africa as affected by veld condition and rainfall. *Water SA, January 1991*. https://www.researchgate.net/publication/284239558.

UC Davis. 2022. Assessing water quality for livestock under drought conditions. University of California Davis. https://lawr.ucdavis.edu/cooperative-extension/irrigation/drought-tips/assessing-water-quality-livestock-under-drought-conditions

USNDMC. 2022. Water and Heat stress. United States National Drought Mitigation Centre. https://drought.unl.edu/ranchplan/DuringDrought/WaterandHeatStress.aspx

Vetter, S. 2009. Drought, change and resilience in South Africa's arid and semi-arid rangelands. *South African Journal of Science, 105(1-2).* DOI: 10.1590/S0038-23532009000100017.

Vins, H., Bell, J., Saha, S., & Hess, J. J. 2015. The Mental Health Outcomes of Drought: A Systematic Review and Causal Process Diagram. International journal of environmental research and public health, 12(10), 13251–13275. https://doi.org/10.3390/ijerph121013251

Zuma-Netshiukhwi G, Stigter K, Walker S. 2013. Use of traditional weather/climate knowledge by farmers in the South-western Free State of South Africa: agrometeorological learning by scientists. *Atmosphere 4(4):383–410*.

Chapter 3: Framework for Web-based Reporting

3.1 Introduction

Inculcating a culture of drought adaptation to drought-resistant strategies requires acquiring and sharing reliable, relevant and credible information. The information must be up-to-date and in a format ready for decision-making. Such information is pertinent to implementing drought risk reduction strategies. Therefore, information and communication are crucial elements of risk reduction strategies. The Sendai Framework for Disaster Risk Reduction (SFDRR), the Sustainable Development Goals (SDGs) and the Paris Agreement on Climate Change (COP21) highlighted the importance of early warning and risk assessments through information and communication systems (UNISDR 2015; UNFCC 2015; UNDP 2015). The four priorities of action in the SFDRR, the SDGs' 17 global goals, and the 12 crucial areas to combat climate change set by COP21 are data-driven and require information and communication to achieve them. Disaster Managers argue that the government must lead in managing data and information for national risk reduction priorities (Jones, Wynn, Hillier, & Comfort, 2017). As such, drought mitigation and prevention in South Africa contributes to fulfilling the 2030 global goals by exploring the benefits of information management and communication systems (IMCS).

The main objective of this chapter is to provide a framework and content for drought information management and communication that will support the capacity for drought early warning and monitoring for the livestock sector in the Northern Cape. In support of the main objective, the framework (i) identify and propose the combination of current drought information systems into an integrated system that can serve all stakeholders in the province, (ii) identify information products required for early warning and informed drought risk management, (iii) identify the drought information and data requirements for the drought information products, and, (iv) recommend an integrated and interoperable system that allows for information collection, information and data sharing and analysis for effective drought risk reduction and response.

3.2 Drought Information Management and Communication

3.2.1 Introduction

The main objective of a DICMS is to provide effective drought early warning and monitoring through a comprehensive system that collects and integrates information on the key indicators of drought to make usable, reliable, and timely drought forecasts and assessments of drought, including assessments of the severity of drought conditions and impacts.

Implementing the Drought Information Management and Communication System should inform the drought classification for each quaternary catchment, which in turn provides the thresholds for activating contingency plans. In addition, this chapter discusses the data and information required to support the drought monitor products (outputs).

Drought monitoring is driven by indicators with indicator thresholds that indicate the different levels of drought. It is, therefore, imperative that drought classification and the different indicators and indicator thresholds are considered the primary sources of information required for drought monitoring. In addition, important for drought monitoring are historical data, current drought situation and projections.

This chapter provides the generic outlay and principles for a drought information and communication system.

3.2.2 Characteristics of the Drought Information and Communication Management System (DICMS)

The DICMS should communicate drought forecasts, drought conditions, and drought impacts on an ongoing basis – preferably in real-time - to decision-makers in the government and the private sector at all levels of governance and the public. Such a system should engender better informed and timely decisions, leading to better preparedness and reduced impacts and costs due to drought. The DICM should include geo-referenced, timely (where possible real-time) data, information, and products that reflect local, regional, and national differences in drought conditions.

The integrated DICMS should build on existing climate projections, forecasting, drought assessment programs and collaboration models. The integrated drought information and communication system must provide:

i. Spatially related real-time drought, climate, weather and related information on interactive maps
ii. Spatially related real-time drought, climate, weather and associated data in table format
iii. Spatially related historical drought information and data
iv. Data-driven visualisation of drought-related impacts
v. Spatially associated data and information on drought indicators
vi. Spatially associated data and information on drought vulnerability and resilience indicators

In addition, the DICM should be able to integrate sector-specific indicators required for sector-specific decision-making.

3.2.3 Understanding Information and Communication Management

The application technology allows real-time drought monitoring and ground-truth mechanisms through a web-based reporting and processing system. Up-to-date, geo-referenced information and drought analysis reports and projections should be available as open-source information to all sectors of society. Cheung & Lee (2007) define a Web-based Information System (WIS) as computer applications constructed using Internet Web technologies to deliver user information and services. The primary purpose of such multimedia technology and software systems is to publish and maintain data through the use of hypertext-based methods. Using today's fast broadband connections, users can stream content to a computer, cellphone, television etc. The most important indicator for a successful WIS is *"user satisfaction"*, an indicator the proposed system should consider.

The National Disaster Management Framework (NDMF) (2005) defines Information Management and Communication System (IMCS) as "*...a system that enables the receipt, analysis, storage, dissemination and exchange of information in support of integrated disaster* *risk management."* Ultimately, the purpose of such a system is to target primary interest groups for them to make informed decisions. Furthermore, Geographical Information Systems (GIS) that display applications and multimedia communication capabilities should be an integral system element. Any system comprises people, hardware, software programs, and procedures to collect, process, transmit and disseminate data and information (Demiryurek, Erdem, Ceyhan, Atasever, & Uysal, 2008). Eventually, the processing and programming of data and information occur when people understand and analyse the data and information.

The requirement to differentiate between Information Technology and Information Systems is of crucial importance. IMCS is technology-based and supported by numerous other processes. The distinction is shown by Florida Tech (2020) and Juneja (2019), who demonstrated that Information Systems are, in fact, an umbrella term for the systems, people and processes that are designed to create, store, manipulate, distribute and disseminate information. Information Systems entirely depend on Information Technology such as computers, computer programs, apps and other technological devices or programs. Therefore, these authors define Information Technology as the hardware, software, databases and networks supporting business goals.

The structure of the typical drought information communication management system is illustrated in Figure 3.2.1 (Jordaan & Kunguma, 2020).

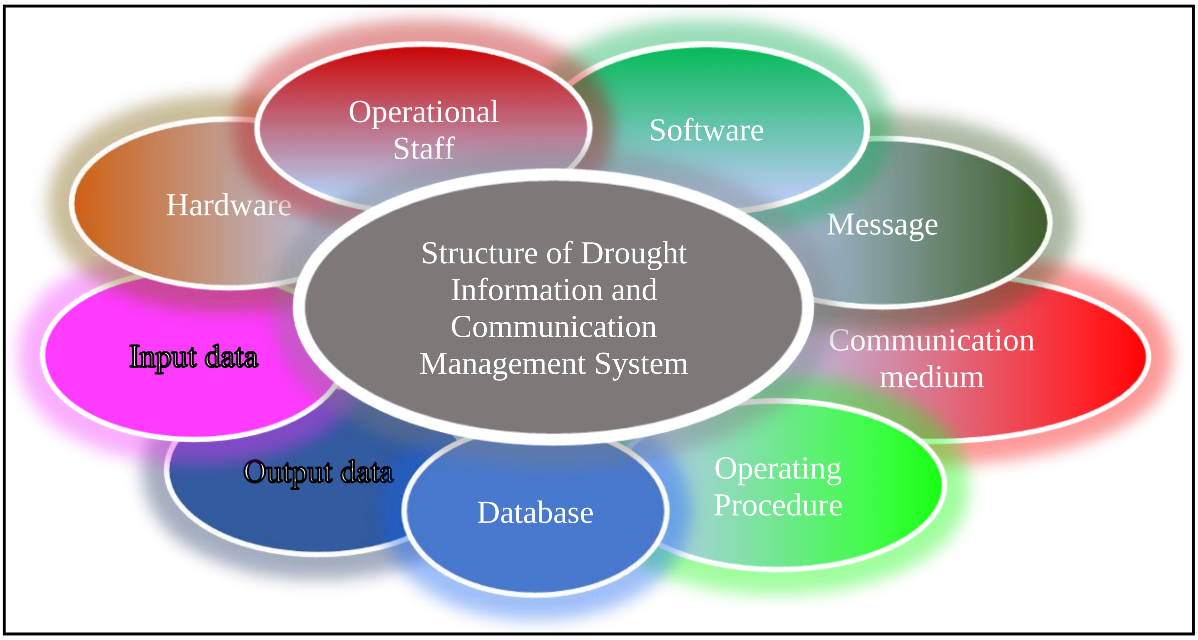


FIGURE 3.2.1: ELEMENTS OF A DROUGHT INFORMATION AND COMMUNICATION MANAGEMENT SYSTEM
(Source: Jordaan & Kunguma, 2020)

A typical Drought Information and Communication System consist of four major elements, namely (i) data and information, (ii) communication, (iii) the system, and (iv) the management of the system.

i. Information consists of raw data and processed data that assist in monitoring, early warning, predictions and projections
ii. Communication is the means and process of communicating the results to all stakeholders and public
iii. The system is made up of inputs, processing, output and feedback and control
iv. Management consists of planning, control, maintenance and administration of the system as well as information

The drought DICMS consists of the following major elements:

i. Operational staff
ii. Computer hardware, inclusive displays
iii. Software
iv. Input data

v. Output data
vi. Database
vii. Operating procedures
viii. Message
ix. Communication channels

All of these elements are integrated and depend on each other. Systems design aims to produce the design specifications for the integrated drought information system that will satisfy the requirements for an integrated drought information management system. Specifications should be detailed enough to become inputs to the programming stage that follows the design. The design process is usually broken down into three phases:

i. Conceptualisation phase. This plan focuses on the conceptualisation and logical design phase. Therefore, it does not include technical aspects such as computer programming and hardware, which should be dealt with during the physical design phases.
ii. Logical design phase - produces the general specification of the resources that will make up the system.
iii. Physical design - produces a complete, detailed specification of the named program components, called modules, which are to be programmed, and of the databases to be maintained by the system.

Figure 3.2.2 illustrates the linear flow of managing an information management system.

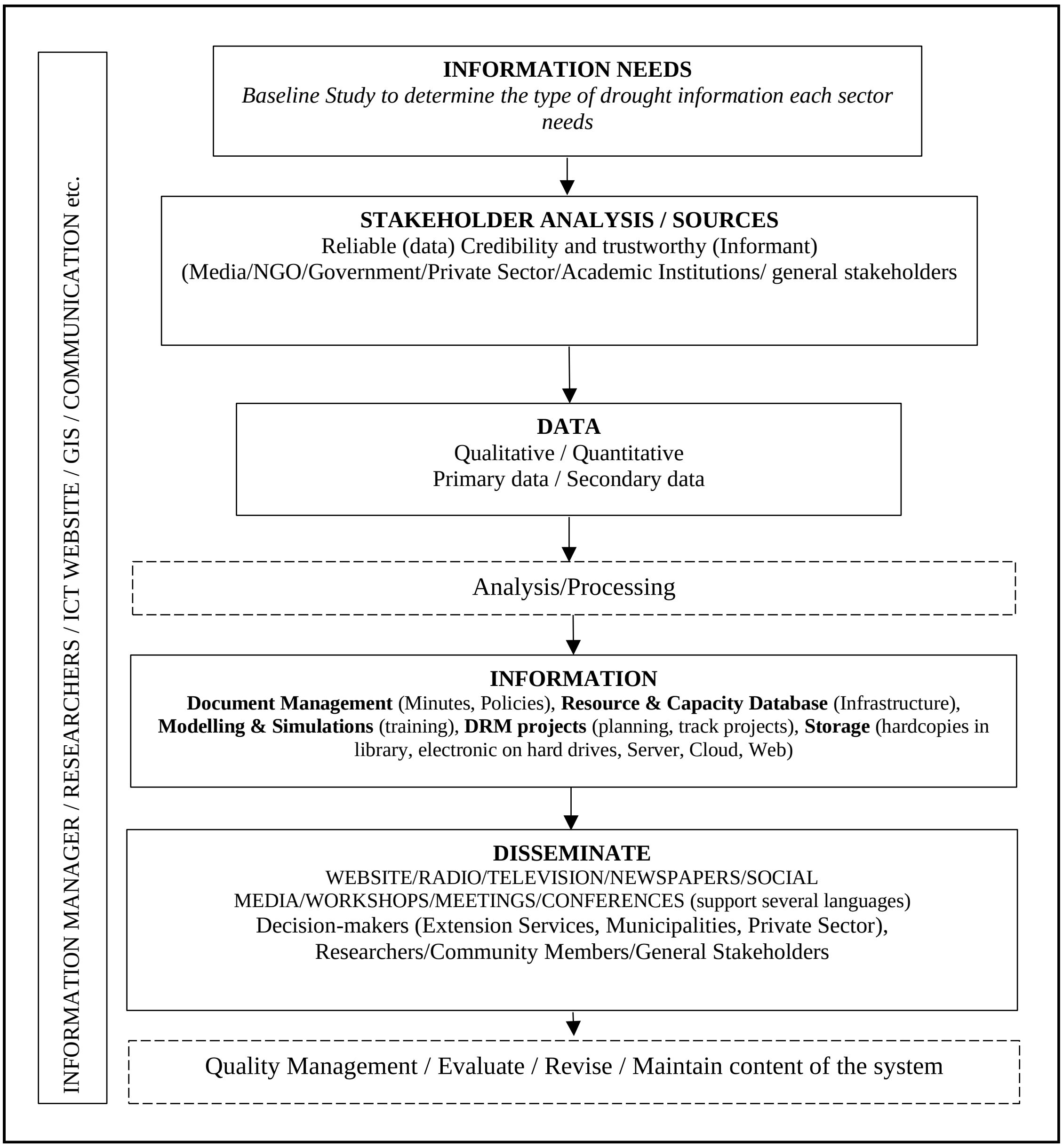


FIGURE 3.2.2: GENERIC INFORMATION MANAGEMENT AND COMMUNICATION SYSTEM
Source: (Kunguma 2020, adopted from the Republic of South Africa, 2005)

All steps need to be supported and monitored to yield the system's full benefits (Sharman; Rao; Upadhaya & Cook-Cottone 2010:13). There should also be a collaborative platform among various individuals, groups and organisations to share information, make decisions and synergise response.

The conceptualisation of the system is the first phase and includes the development of a framework for the drought information system. Existing systems are a good point of departure with already available best practice examples in support, such as the Australian Drought Monitor and the USNDMC.

The following need to be addressed during the conceptualisation phase:

i. Objective of a drought information and communication management system
ii. Stakeholder analysis
iii. Type of information products required
iv. Type of information and data required and how to obtain information and data
v. How to integrate information and data into useful products
vi. How and who will analyse the information and data and package it in a user-friendly format for specific sectors
vii. How to communicate information and early warning products
viii. How to maintain the system
ix. How to fund the system

The following are important in the design and development of the system itself:

i. Operational staff
    a. Subject matter specialists
    b. GIS experts
    c. IT experts
    d. Administration
ii. Computer hardware and software
    a. Hardware and systems software platforms for the application.
    b. Programs that will constitute the application and the modules that will make up the programs.
    c. Specification of individual software modules
    d. Design of the database
    e. Design of user interfaces

i. Operational procedures
   a. Procedures for system use.
   b. Procedures for analysis
   c. Procedures for data capturing
   d. Procedures for communication
   e. Maintenance procedures
ii. Monitoring and evaluation

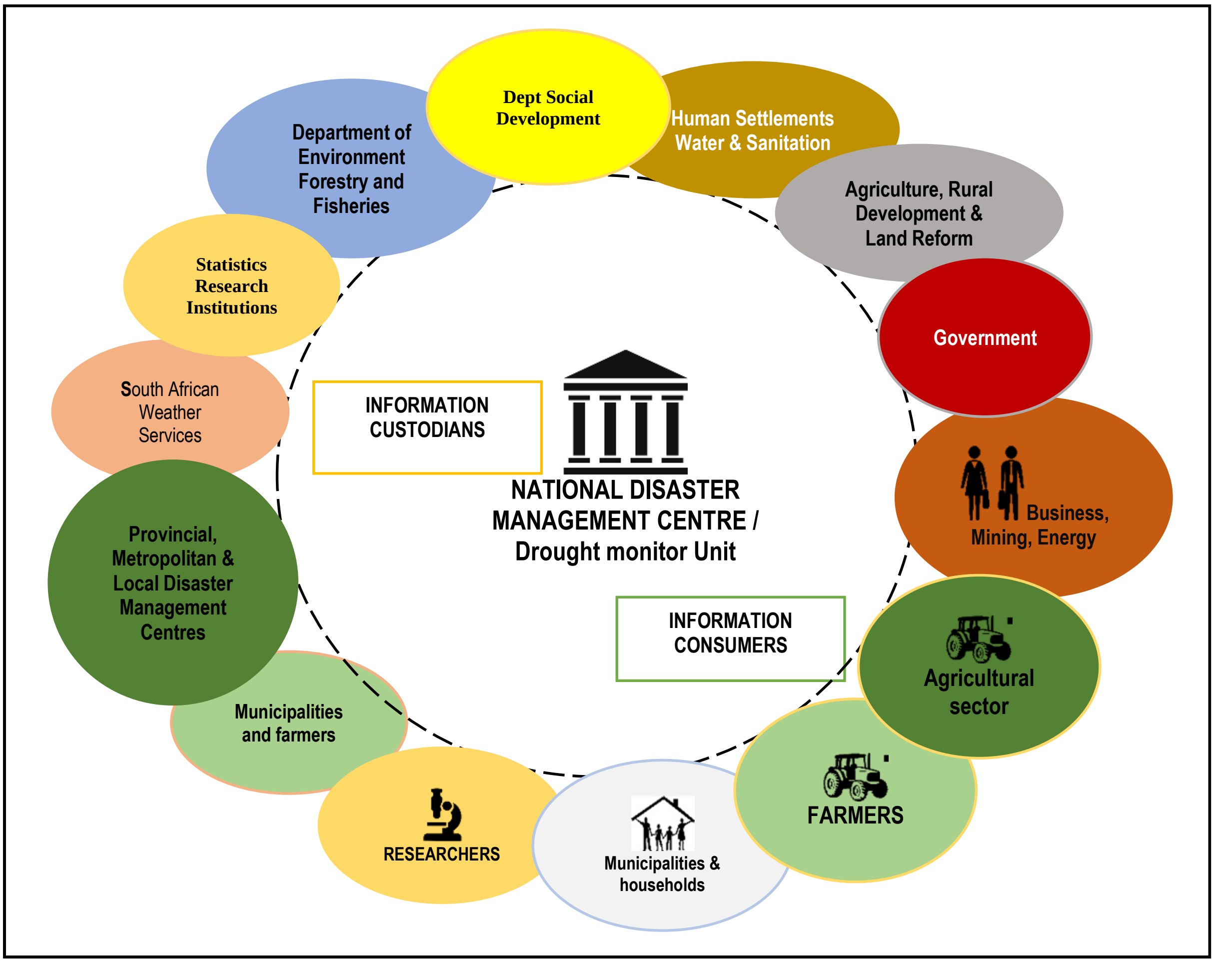
3.2.4 Stakeholder Analysis/Sources

Understanding the capacity and needs of stakeholders is an essential step in designing any information management system. According to Freeman (2004), a stakeholder is an individual or group that can be affected or affect the achievement of an organisation's purpose. Like Freeman's definition, the definition provided by the Merriam-Webster Dictionary (2019) is *"a stakeholder is a person or organisation who has an interest or investment in something and is impacted by the course of its action".* Moreover, whoever owns a problem should be a co-owner of the solving process (Reed, Graves, Dandy, Posthumus, Klaus, Morris, Prell, Quinn, Stringer (2009). With these definitions in mind, one can relate to the disaster management ideology, where disaster management is multi-disciplinary and multi-sectoral (Republic of South Africa 2002: 45). Everyone and every organisation in South Africa are a drought stakeholder since all are affected by the impacts of droughts. Freeman (2010) wrote, *"prioritising and developing specific programs for each stakeholder group assists in implementing the stakeholder ideology and drought risk management".*

The literature refers to some stakeholders as information custodians with other information consumers. However, in an integrated information management system, all stakeholders are information custodians and consumers. The SAWS, DHSWS, DARDLR, DEFF, STATSSA and others are traditionally viewed as information custodians, but these organisations also require data and information to develop projections and information packages. On the other hand, farmers, municipalities, businesses, researchers and others are traditionally viewed as information users, which is not the case in an integrated information management system.

Farmers, for example, need to confirm and provide actual ground truth information on what is visible on the remotely sensed indicators such as NDVI, PASG, VCI, soil moisture etc. Farmers must report on planting conditions, vegetation conditions, etc. Municipalities, for example, also have to report on water demand. Information flow in an integrated system is two-directional, with all stakeholders in one way or another, information custodians and information users. The diagram in Figure 3.2.3 illustrates some of the major stakeholders relevant to the functioning of the DICM.

FIGURE 3.2.3: STAKEHOLDER MAP



(Jordaan & Kunguma, 2020)

Having identified the information custodians and users, it is imperative to identify their roles and responsibilities in providing drought-related information and what type of data is required.

Table 3.2.1 summarises stakeholder analysis for a DIMCS for livestock farmers in the Northern Cape.

TABLE 3.2.1. ROLES AND RESPONSIBILITIES OF DROUGHT INFORMATION STAKEHOLDERS

	Information Custodians	Roles and responsibilities
1	National Disaster Management Centre	-Provides capacity to analyse data and information from different sources -Coordinate information from different sources -Develop a methodology for data collection and analysis; -Research projects which include national drought data collection and analysis; -Maintain the national drought data repository; -Disseminate information through the identified conduits.
2	Provincial Disaster Management Centre	-Consolidate provincial-level information -Research projects which include national drought data collection and analysis; -Conduct provincial drought risk assessments; -Support the NDMC with drought data from the province.
3	South African Weather Services	-Provides drought weather/climate-related information and data t; -Collaborates with stakeholders in disseminating information. -Provides weather-related information to the public and stakeholder organisations
4	Department of Environment, Forestry & Fisheries (Climate Change & Disaster Management Unit)	-Provides information on practices that affect the environment and forests, -Provides climate change risk reduction strategies.
5	Human Settlements, Water & Sanitation – National Integrated Water Information System	-Links the NIWIS with the DICM system; -Provides information on water status in dams, rivers and groundwater (e.g. water quality, drought status etc.).
6	Catchment Management Agencies	-Provides information on the dam levels, streamflow, water demand and catchment management strategies
7	Agriculture, Rural Development & Land Reform (National and Provincial)	-Provides agricultural-related information on agricultural finance, markets, training, current technologies etc. -Share information and data with other stakeholders on the crop and veld conditions -Share information and data on production trends and conditions, including horticulture, livestock, crops, fruit production etc.
8	Agriculture, Rural Development & Land Reform – Agricultural Research Council (ARC)	-Provides the NDMC with information on crop and livestock production, training, industry experts for advice, current research etc. -Share data and information on weather-related data with other stakeholders
9	South African National Space Agency (SANSA)	-Provides access to data retrieved from monitoring the Earth and surrounding environment. The collected data ensures that navigation, communication technology and weather forecasting services function as intended.
10	Media (Television, Radio and Newspaper)	-Provides general information about drought risk reduction strategies, public perceptions, drought impacts on households, institutions etc.
11	Municipal Drought Monitor Committees	-Coordinate information from farmers (reference farms) -Drought conditions sent to the Province
12	Farmers on reference farms	-Provide ground-truthed, on-farm drought information -Provide socio-economic drought information
13	Agri-businesses	-Provide economic drought information -Provide purchase trends as a result of drought amongst farmers
14	Banks & Financial organisations	-Provide financial trends as a result of drought

International organisations such as FAO, World Bank, USGS, FEWSNET, Africa Drought Monitor, Sentinel HUB and others are also custodians of valuable information. An Integrated drought information management system should tap into all available sources to analyse and provide up-to-date information to water users or information users. Much information is already available, and the challenge is integrating and analysing available information for integrated drought monitoring and management.

3.2.5 Key Requirements for the DIMCS

The table below shows the key requirements for the development and successful operation of the system.

TABLE 3.2.2. KEY PERFORMANCE AREAS FOR THE SUCCESSFUL OPERATION OF THE SYSTEM

Area of consideration	Description
Drought Monitor Unit	Full-time operational capacity with daily and weekly updates of information
Useful links	The Web-page must provide useful links to other Information Systems
Easy-to-use reporting system	Reporting, especially from farmers, should be simple and not time-consuming
Automated processing	Data integration and processing should be automated and real-time
People	Information Manager, Information Officials, Researchers, Subject specific experts, Communication Officials, IT Officials and GIS Officials
Sector relevant data	The web page system must include a form that users can fill in to obtain sector-specific information
Quality Management	The information must be verified (accurate and trustworthy); it must be applicable and relevant in that the NDMC must know exactly what information the users need and that the information contributes to decision-making. Accommodate different languages. Quality Management can, therefore, be carried out through the Drought Committee, checklists, regular meetings with the information officials and other stakeholders and feedback from the users.
User manual	Develop a user manual for aiding the user on how the DICM system functions and where to access the system's different functions. The manual helps improve interaction with the DICM system.
Funding	Funding is a cross-cutting issue in all the elements of the System
Training	Training of key information officials on research methods, information management and communication with skills
Infrastructure	Internet access, electricity (generator etc.), Storage Volts, technology.
Policies & Procedures	Like information security; communication procedures before, during and after a drought occurrence; Maintenance plans, Monitoring plans, Evaluation plans and Various Templates (examples are Drought Risk Assessment Template, Drought Risk Reduction Projects & Programs Assessment Template, Drought Situation Report Template and Drought Recovery Assessment Template)

3.2.6 Institutional structures

Figure 3.2.4 illustrates the communication and reporting linkages between the different stakeholders. The national drought monitor unit receives information for the primary indicators from the SAWS, ARC, SANSA and other sources. This information is then supplemented with information from reference farms or local entities reporting on farm-level social and economic drought indicators. The information is then combined, geo-referenced and analysed by the Drought Monitor Unit, which provides the drought class for each quaternary catchment.

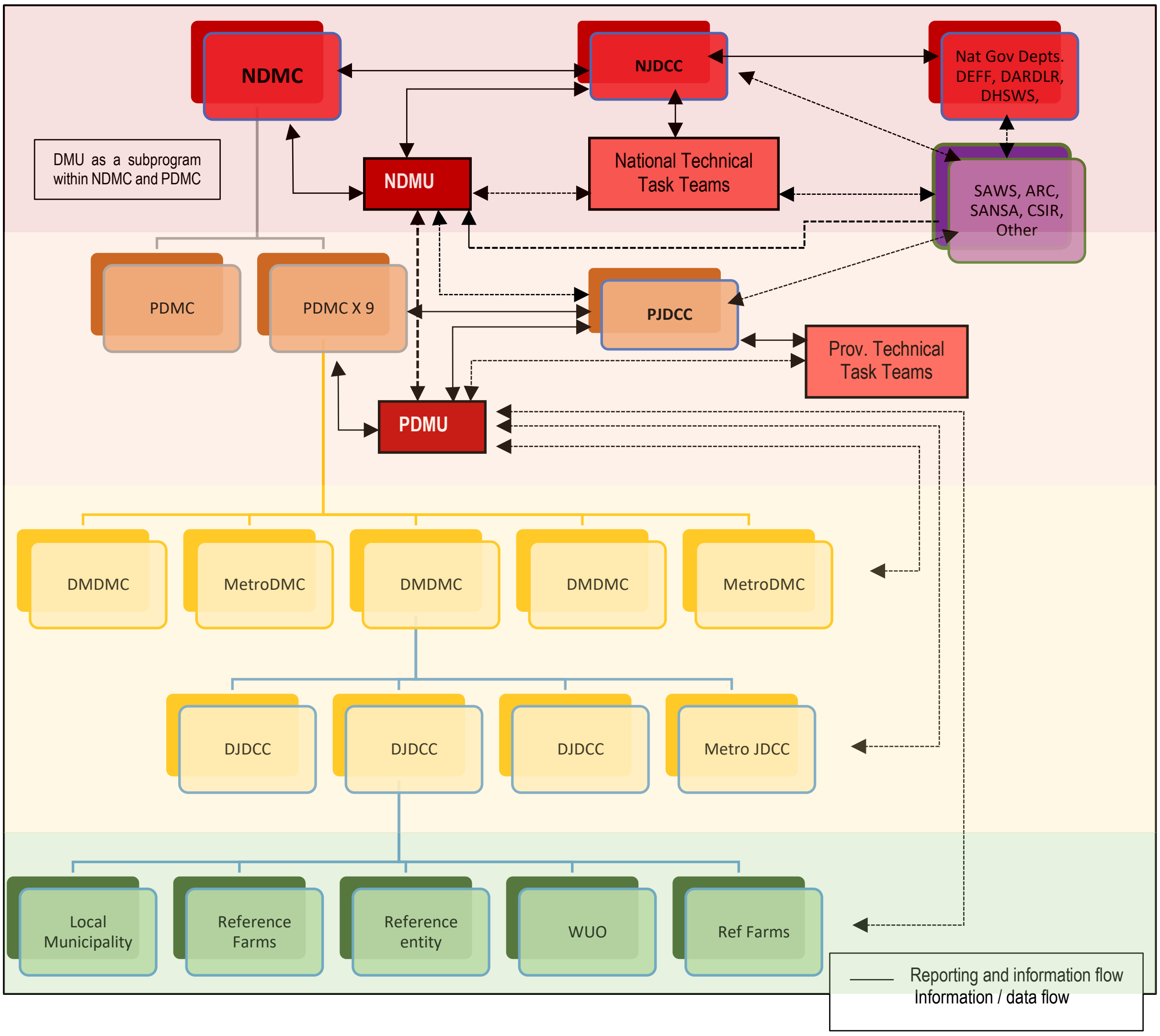


FIGURE 3.2.4: PROPOSED INSTITUTIONAL STRUCTURE FOR A DROUGHT INFORMATION AND COMMUNICATION SYSTEM
Source: Jordaan, 2018

3.2.7 Reference Farms

Reference farms, also called monitor farms, are a key element of drought management because they provide information and the opportunity to benchmark drought resilience. The following section deals with the characteristics and contributions of reference farms.

3.2.7.1 Objectives

The objective is to formalise and implement a system of reference farms based on practical experience and research over a long period of drought management. Reference farms are those particular farms chosen in a catchment area on the basis that a farmer is prepared to collect and supply data on rainfall, carrying capacity, veld condition and other scientific information according to specific terms and conditions in collaboration with the Provincial Department of Agriculture Rural Development and Land Reform (DoARDLR). Data will be submitted regularly via smartphone apps or a web portal via the Internet to a web-based analysis system. This data will be analysed, processed and used for drought classification and early warning.

The DoARDLR is responsible for capturing, processing and analysing the data and advising decision makers as an early warning message on the deterioration of veld and drought conditions and declaring drought as a disaster as part of the Disaster Management Act, 2002.

Furthermore, the system of reference farms can contribute to an effective determination of carrying capacity for the different catchment areas and could act as a stimulus for farmers to farm on a sustainable basis and to use risk mitigation measures.

3.2.7.2 Geographic selection

Reference farms must be as representative of a specific climate zone as possible. However, one acknowledges that rainfall is not always the same on all farms within a specific region. To ensure proper provincial cover, the quaternary catchments should be used as the preferred region for sampling reference farms. At least one reference farm should be sampled from each quaternary catchment.

3.2.7.3 Profile of Reference farms

The reference farm's natural resources must represent the specific catchment. The most notable natural resources are veld type, water supply, soil type, geographical features, and farming system.

The farmer (owner or lessee), called the participant, must be willing and able to keep records and provide data weekly. Furthermore, the participant must apply good agricultural practices according to the norms and climate conditions of the specific region. In addition, the participant must be connected or have access to the Internet to provide and upload data regularly.

3.2.7.4 Responsibility of participants

Participants in the drought monitor and early warning project must:

i. Supply daily meteorological data on at least a weekly basis.
ii. Supply information on the deviation from the norm of animal conditions and numbers due to drought.
iii. Adhere to the carrying capacity according to the norms of the PDoARD and DAFF over a twelve-month cycle. As a farmer who apply good agricultural practices, they will under-graze some years and overgraze other years, depending on the condition of the veld and climate conditions. Therefore the carrying capacity will be exceeded for some years etc. Of course, the baseline veld condition on a specific farm differs from others, and not all farms have the same carrying capacity, but sound agricultural principles apply.
iv. Comply with good farming practices (e.g. veld management system) as approved by the PDoARDLR.
v. Comply with the protocols provided by the service provider and the PDoARDLR.

Extension Officers and the Soil Conservation Committees will play a vital role in the roll-out of the scheme and overseeing measures.

3.2.7.5 Functioning

Participants will have to upload the prescribed information to the early warning research unit through an app every week and a prescribed web-based programme every month. By default, the system will automatically remind participants of any non-compliance. This could have a detrimental effect on those farms coupled with the particular reference farm, as they are also dependent on the results obtained through the scheme, and it might jeopardise the outcome of the advice to the decision-makers as far as financial assistance is concerned in case of required drought assistance.

Reference farmers will report through a web-based application on smartphones or a computer. Therefore, it is important to keep the reporting system simple and short. Farmers will not participate if they must provide large amounts or specific information such as animal numbers or financial loss. A simple reporting template is illustrated in Table 3.2.3.

TABLE 3.2.3: PROPOSED REPORTING TEMPLATE

	Actual	N-50%	N-30%	N-15%	Normal	N+15%	N+25%
Rainfall		X					
Temp/evapotransp.			X				
Veld condition				X			
Animal condition				X			
Dam & stream levels			X				
Groundwater levels					X		
Planting conditions		X					
Crop condition			X				
Yield potential				X			

Details of the national drought information management system do not fall within this project's scope, and further research is required to develop such a system for South Africa.

3.2.8 Indicator Framework

Framework in programming is a tool that provides the required components or solutions that are customised to support the development process. In the context of this study, the framework consists of 4 sub-components, namely the sub-framework for drought indicators, a reporting framework, a data processing framework and the communications framework. The drought indicator framework is explained in this section, the reporting framework in section four, the data processing framework in section five and the communications framework in section six.

The indicator framework consists of primary and secondary indicators. The primary indicators are available from SAWS, SASSA, ARC and other organisations with access to remotely sensed data, while the secondary indicators are the farm-level indicators.

The indicator framework consists of the indicator categories and sub-categories, as shown in Table 3.3.1.

TABLE 3.3.1: DROUGHT INDICATOR CATEGORIES AND SUB-CATEGORIES

Composite indicator	Indicator class	Indicators
Weather and Climate	Precipitation	SPI, SPEI, % of normal, Deciles
	Temperature	Degree C compared same historical time
	Evapotranspiration	mm per unit time
Vegetation	NDVI	Comparison from the long-term mean, same historical time
	PASG	Comparison from the long-term mean, same historical time
	SVHI	Comparison from the long-term mean, same historical time
	VCI	Comparison from the long-term mean, same historical time
Soil moisture	Soil moisture top 40cm	Mm water/moisture per depth unit
	Soil moisture > 40 cm	Mm water/moisture per depth unit
Hydrological	Stream flow	Comparison from the same historical time
	Dam levels	% from full, Comparison from same historical time
	Groundwater levels	Metres; Comparison from the same historical time

Thresholds for the primary indicators are shown in Table 3.3.2.

TABLE 3.3.2: PRIMARY INDICATORS AND THRESHOLDS

				Meteorological		Remote sensing					Hydrological		
Cat	**Descript.**	**Potential impacts**	**Freq.**	**% Of normal precepts.**	**SPI**	**NDVI**	**PASG**	**1-month VCI**	**St Veg Health Index. SVHI**	**CPC Soil Moist. %**	**Dam levels - zone Z score**	**Stream Flow Z score**	**Ground water level % Z score**
D0	Dry	Dry period: Short-term dryness slowing plant Growth of crops and pastures; fire risk above average: some lingering water deficiencies: pastures and crops not fully recovered	1/3yr	<75%for 30days	-0,5 to -0,7	-0,25 to - 0,39	3month PASG <90%	< 90%	36-45	21-30	In the moderately low zone	21-30	60- 100
D1	Moderate drought	Some damage to crops & pastures: fire risk is high: Levels of streams, reservoirs or wells are low: Some water shortages are imminent and developing: voluntary water restrictions requested: early warning	1/5yr	<70%for 30days	-0,8 to -1,2	-0,4 to 0,64	6-month PASG <90%	<80%	26-35	11-20	In the low zone Z= -0,8 to -1,2	11-20 Z= -0,8 to -1,2	40- 60 Z= -0,8 to -1,2
D2	Severe drought	Crop and pasture losses likely: Fire risk very high: Water shortages common: Water restrictions imposed: drought warning messages: Institutions to prepare for response mechanisms.	1/10yr	<65%for 180days	-1,3 to -1,5	-0,65 to - 0,79	12-month PASG <90%	<70%	16-25	6-10	In the very low zone Z= -1,3 to -1,5	6-10 Z= -1,3 to -1,5	30- 40 Z= -1,3 to -1,5
D3	Extreme drought	Major crop and pasture losses: Extreme fire danger: Widespread water shortages and restrictions compulsory: Extended duration with critical impact: Warning messages must be adhered to: disaster drought declaration: Institutions to implement active response actions.	1/20yr	<60%for 180days	-1,6 to -1,9	-0,8 to - 0,99	12/24-month PASG <80/90%	<60%	6-15	3-5	Water below the absolute minimum Z= -1,6 to -2	3-5 Z= -1,6 to -2	15- 30 Z = -1,6 to -2
D4	Exceptional drought	Exceptional and widespread crop & pasture losses: Exceptional high fire risk: shortages of water in reservoirs, streams and wells creating water emergencies. Water restrictions compulsory: Warning messages must be adhered to active response mechanisms: Impacts critical	1/50yr	<65%for 360days	-2 or less	<-1	12/24-month PASG <80%	<60%	1-5	0-2	Dams dry Z<-2	0-2 Z<-2	0- 15 Z<-2

The number of secondary or farm-level indicators is shown in Table 3.3.3.

TABLE 3.3.3: INDICATOR GROUPING AND NO. INDICATORS

No	Indicator group	No of indicators
1	Meteorological / weather	3
2	Grazing and fodder data	6
3	Animals	10
4	Water	4
5	Soil	4
6	Social	8
7	Economic	9
	TOTAL	**44**

The frame for farm-level or secondary indicators is shown in Table 3.4. Table 3.4 shows composite indicators, indicators and measurement criteria.

TABLE 3.3.4: SECONDARY INDICATORS

Indicator group	Indicators	Indicator measurement
Vegetation	Plants wilted	% of normal same historical time
	Grazing capacity loss	% of normal same historical time
	Production loss	% of normal same historical time
	Reserve feed and fodder used	% of normal same historical time
	Feed and fodder purchased	% of normal same historical time
Animal condition, numbers & mortalities	Animal condition loss	% of normal same historical time
	Kraal feeding because of drought	% of normal same historical time
	Sales of animals	% of normal same historical time
	Sales of core stock	% of normal same historical time
	Less animal number	% of normal same historical time
	Forced animal sales	% of normal same historical time
	Mortalities of young animals as a result of drought	% of normal same historical time
	Mortalities of older animals as a result of drought	% of normal same historical time
Water	Groundwater levels	% of normal same historical time
	Dams	% of normal same historical time
	Rivers and streams	% of normal same historical time
	Water availability to animals	% of normal same historical time
Soil	Dryness first 40cm	% of normal same historical time
	Dryness >40cm	% of normal same historical time

The socio-economic impact of drought is the culmination of drought impacts, which is caused by a combination of below-normal precipitation, extreme heat and high winds. The climatic condition directly affects plant and animal, which, in turn, impact the farmers' socio-economic state. It is, therefore, also essential to utilise socio-economic indicators as a measurement tool for drought severity. The most critical socio-economic indicators identified are summarised in Table 3.3.5.

TABLE 3.3.5: SOCIO-ECONOMIC INDICATORS

Indicator	Measurement
Higher Stress levels	Scale 0 - 100
Cancellation of family holidays	Scale 0 - 100
Labour retrenchments	Scale 0 - 100
Stop capital expenditure	Scale 0 - 100
Use savings to buy animal feed	Scale 0 - 100
Consider debt consolidation	Scale 0 - 100
Sales of fixed non-farm assets	Scale 0 - 100
Businesses in local town suffering	Scale 0 - 100
Consider suicide	Scale 0 - 100

Since not all indicators are equally important, the weighting of each individual and group of indicators is applied. As discussed in Chapter 5, the model calculates the total score for all the indicators and applies the required weights. The total score indicates the drought class. The higher the score, the drier it is.

3.2.9 Conclusion

Developing a system of farm-level reporting from reference farms in all the quaternary catchments remains a challenge. The practicality is that not all farmers are willing to participate in such a system. Northern Cape Agri (NCAgri) initiated a similar paper-driven project many years ago, yet they did not manage to obtain the support of a critical number of participating farmers. The success of the NCAgri reporting system is based on personal relations built over many years between staff from the Department of Agriculture and farmers. According to information from senior management in the Department, the staff managing the reference farm system will leave the Department during 2023 with no staff succession planning in place.

Building trust and new relations might take many years to rebuild. The government must support the NCAgri initiative, which should serve as a template for extending to other provinces. During our discussions with the NC Dept of Agriculture, they indicated their support for continuing the reference farm drought reporting system.

Through this project, we endeavour to develop and fine-tune the reporting system with practical guidelines and the necessary programming. Still, implementation remains the responsibility of the NC Dept of Agriculture, the NC Disaster Management Centre and farmers. However, extension officers and disaster management staff will find the program useful for future quantitative drought classification and limit the qualitative assessment of droughts.

3.1 Farm-level Data Collection Framework

3.3.1 Introduction

The main objective of the data collection application is to create a platform where farmers can report on farm-level indicators. A framework of the indicators that will be tracked on a farm level is being finalised. The farmers will be the primary users of the data collection application.

The application will provide a better platform for data collection timeously and in a cost-effective way. Users will be able to perform reporting on the indicators live in the field because of the portability and ease of use for mobile devices. In addition, using mobile devices makes the system much more accessible to most farmers since a good majority have access to mobile devices.

The system will collect information using surveys that users can answer easily. This will make it easier for the user to report on the indicators. This means of collecting data will be accessible in an application that the users will use on their mobile devices. The application will be cross-platform and multi-lingual; thus, it will be inclusive for different users and accessible across different mobile platforms.

The data that will be collected will be stored and used for analysis to monitor drought. The analysis will be communicated back to the users. However, the application will be focused on data collection. The system design and functionality will be discussed in this chapter, along with the development process and tools.

3.3.2 System Requirements

There is a need to develop an application that farmers can use to report on the conditions of the indicators on a farm level. The application should be simple and easy to use on farms without complicated processes. This would encourage the usage of the application. In addition, the application should be accessible to farmers in their farming environment where connectivity issues might be prevalent.

The proposed application will be accessible from a mobile device. Thus, enabling accessibility of the application at any time and anywhere. This is needed for cases where the farmers might need to have the application open while observing the conditions of the indicators in real-time. Furthermore, mobile devices are portable and can be easily used anywhere.

The mobile application will communicate with a backend database that will be used to store all the data coming from the mobile application when farmers report on the indicators. Therefore, there will be a need for the mobile device to be connected to the Internet to be able to transfer all the data to the backend system via the Internet.

The mobile application will allow farmers to report on a defined frequency. There will be a need to also report on a detailed level for all indicators over a specific longer period. Farmers will get notifications on the devices when they need to report. This will help ensure that the needed data is acquired timeously.

The design of the reports will be easy to complete for farmers. They will be presented as a survey based on the indicator groups. The farmers will have to select the condition of each indicator on the list of presented options. This will save them time in interpreting the indicators. Farmers will have to register their details, such as the location of the farm and other details to be specified. This data will allow for the identification of the farm, and the data can be geographically referenced.

There will also be an administrator account that will be allowed to access the data stored in the database. This will allow the administrator to download the data in a specified format for analysis. The administrative user can also modify the indicators and indicator groups. This will allow the administrator to modify the application user interface without having to make changes in the code logic.

3.3.3 Data Requirements

The application will be built to collect the data from farmers. The data will be kept in a relational database as a persistent storage. The data will be stored in database tables. Each indicator group will represent one table. Then each column in a table will represent each indicator. The rows in the tables will represent data entries from the farmers.

Data provided by the farmers based on the indicators will have to be stored in persistent storage to allow usage of the data in the future. Therefore, the application will be built to send all data to the backend database that will be hosted in an internet-connected environment. Thus, the data will be transferred to the database by communicating with a public-facing application programming interface.

The database will be relational. Thus, the data will be stored in a structured format on relational tables. The data can be accessed for analysis by querying the databases directly. It is an optional feature to make the data accessible in a specific format by downloading it from the application administrator account.

3.3.4 Users

The system will have two kinds of users. There will be an administrator user and a normal user(farmers). The two users will have different system interfaces with different capabilities. In addition, the users will have separated privileges and accesses based on their use of the system.

The system administrator user will have separate and more privileged access. They will be able to perform operations that other users cannot perform, such as reading the data on the database.

The system administrator will be allowed to download the data in their chosen format suitable for analysis. The user will be allowed to change the indicators in the indicator groups by adding or removing indicators. This effectively means the system administrator will be able to change the user interface that is presented to the normal system user.

The end-users of this system will be farmers. They will be able to access the system using mobile devices. The user must have either an Android or iOS device to install the application. The users will also need to register the details of their farm, such as names and geo-location. This will allow the system to associate a specific farm to its user.

3.3.5 System Functionality

The data will be collected from the users through weekly and monthly surveys. Users will be able to answer surveys on their mobile devices. Surveys will be available for users' mobile applications that can be accessed with mobile or web applications. Each survey will be linked to each user who is associated with a specific farm. Details about the user will be collected in the system's initial use. Users must register to use the application by submitting all the information related to their farm and geo-location data.

3.3.6 System Requirements

The system will be accessible to the public as a mobile application and web application. Users will need internet-connected devices to be able to access the surveys. The cost of data that the end user will need to connect to the applications will not be expensive because the only data that will be transferred between the system and the user will be survey data that can be formatted to lightweight formats such as JSON.

Users will need an Android device with Google Play Store or an iOS device with App Store installed to download the application. A mobile browser could also be used to access the surveys. The user must log in to these applications with credentials to get their surveys.

The mobile device requirements will be communicated when the application has been built. The requirements such as device memory, storage size, processing speed and others can only be determined when the application has been built.

3.3.7 System Design

3.3.7.1 Backend Design

The requirements for the systems are to be cross-platform, multi-lingual, and be able to process data with CRUD (Create, Read, Update, Delete) operations. The system will be able to work on web browsers with various screen sizes. The system will also support mobile devices, specifically Android, iOS, and Windows. The system is designed to be cross-platform, which creates the need to decentralise it from one platform. As a result, it must function independently of each platform. A smart design option is to build a web API that the applications on different platforms can consume. This design will also make the system scalable in the future. The design is shown in Figure 3.3.1.

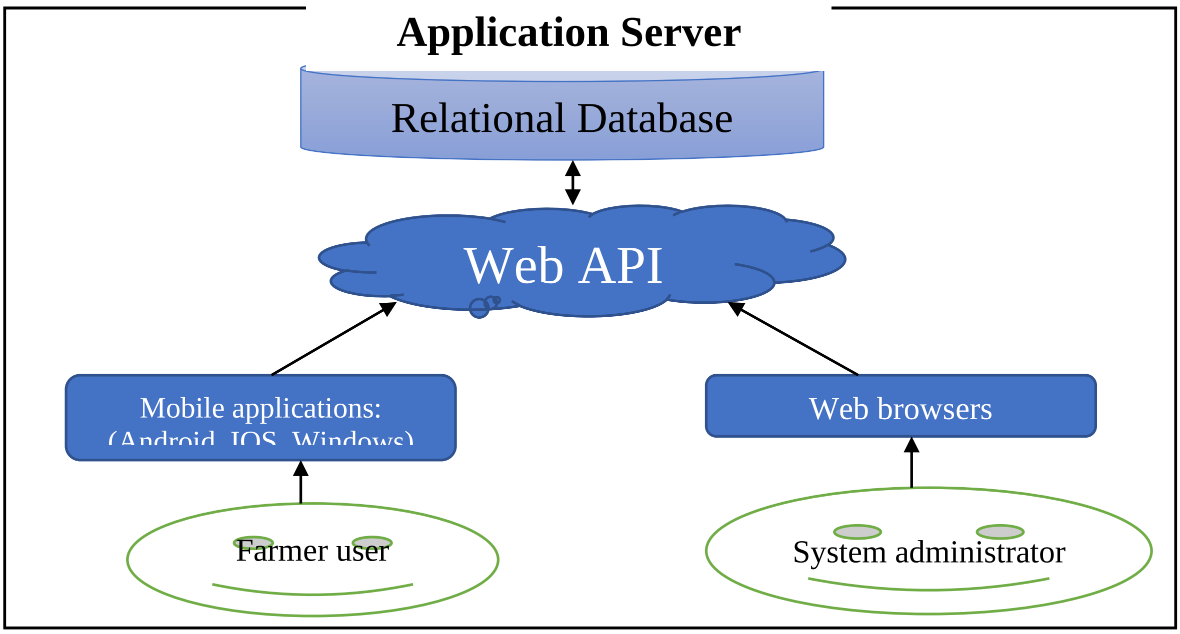


FIGURE 3.3.1: DROUGHT MONITORING SYSTEMS DESIGN
Source: Designed by Dhladla

3.3.7.2 End-user Interface

The primary design is in Figure 3.3.2. Please note the designs are not final. They are only meant for prototyping. The user will be faced with the screen shown in Figure 3.4.2 when they open the application for the first time.

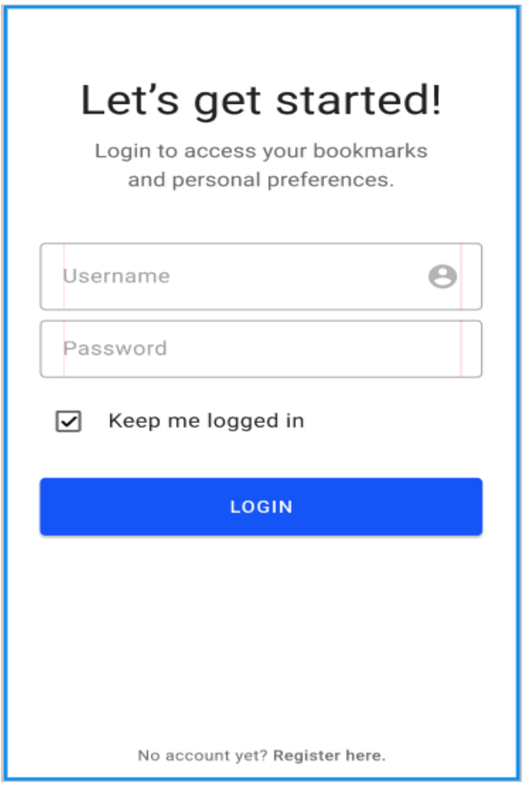


FIGURE 3.3.2: LOGIN SCREEN

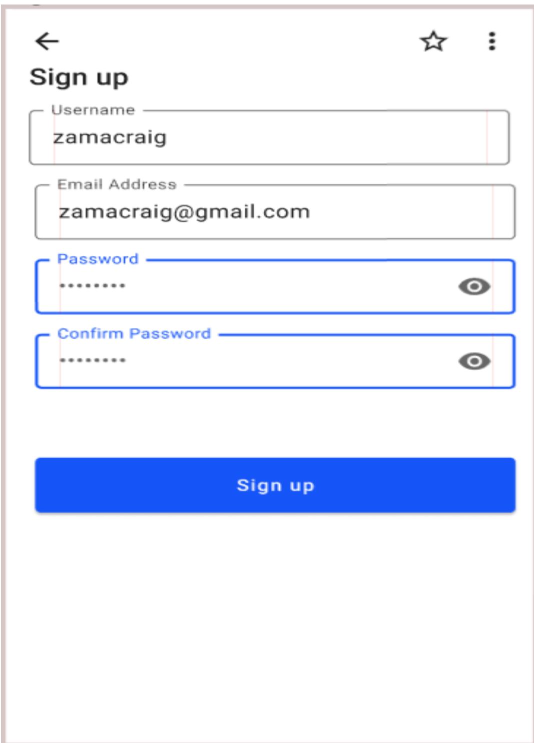


FIGURE 3.3.3: CREDENTIAL SCREEN

The user will be able to log in with their credentials. In case the user is using the application for the first time. They will need to register as shown in the screen illustrated in Figure 3.3.3.

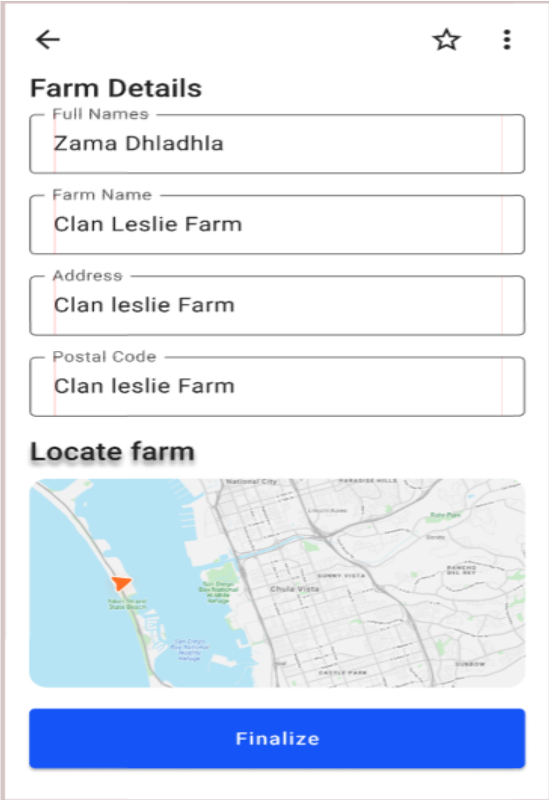


FIGURE 3.3.4: FARM DATA SCREEN

Users will be able to complete farm-level data such as GPS coordinates, or they can indicate the farm's location on a map. Additional farm-level data might include veld type, farm size, topography, type of farming, irrigation availability and water sources.

Farm data screen is shown in Figure 3.3.4.

Users will be able to take a survey at the time that suits them, and they will be reminded of outstanding surveys in red, as shown in Figure 3.3.5. Users can answer a survey by just clicking on it. Then they can save and submit a survey when they are finished answering.

FIGURE 3.3.5: SURVEY FREQUENCY

3.3.8 Reporting Matrix for Reference Farmers

Actual data is sometimes difficult to communicate, and farmers are often reluctant to communicate information such as animal numbers, animals sold, progeny etc. Meteorological data, however, is easy to share, and most farmers hold accurate precipitation records. Of course, farmers should communicate actual information where possible, but it is also useful to have information based on the experience and perception of farmers regarding certain indicators. An example of a potential reporting matrix is shown in Table 3.3.6. The matrix provides actual data and a comparison of indicators relative to the normal. The reporting matrix is the basis of the reporting app, and it should be easy for farmers to report and capture on the geo-referenced database.

TABLE 3.3.6 : EXAMPLE OF REPORTING MATRIX FOR REFERENCE FARMS

	Actual	N-50%	N-30%	N-15%	Normal	N+15%	N+25%
Rainfall		X					
Temp/evapotransp.			X				
Veld condition				X			
Animal condition				X			
Dam & stream levels			X				
Groundwater levels					X		
Planting conditions		X					
Crop condition			X				
Yield potential				X			

Reference farmers will have the choice to report on indicators applicable to their specific sector. The information obtained from the reference farms (secondary indicators) will confirm or reject the information already visible on remote sensing and meteorological information (primary indicators). As shown in the example matrix, more indicators can be added as the drought monitor system is improved for better monitoring.

The reporting interface on the app is illustrated in Figure 3.3.6.

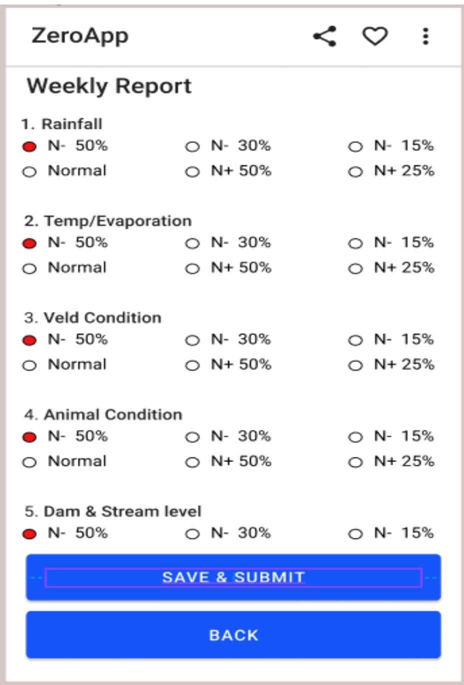


FIGURE 3.3.6: DATA REPORTING SCREEN

3.3.9 System Development

There are options still being reviewed for the development of the system. The option will be considered on factors such as affordability, usability, development ease, scalability, flexibility, and other factors that will be important for the project to be successful. The options will be to develop the system using open source or develop it with a third-party system as a licensed service.

3.3.9.1 Open-Source Development

3.3.9.1.1 Web API

The web API can be developed using ASP.NET Core 6. The web API can use the RESTful architecture. Independent applications can consume this API. The evolution of the API will be independent of the development of the user applications. This would enable the scalability of the system in the future. The Web API consumers can be independent web applications or any mobile application.

The Web API will be able to perform CRUD operations, allowing for storing data on a backend database (Relational or Nonrelational). The Web API can also be hosted on a cloud service. Data can be updated, created, read, or deleted on the backend database using the API endpoints.

3.3.9.1.2 Web Application – Desktop browsers, Mobile browsers

Web applications will be built independent of the API they will consume. The web application will support multiple screen sizes. This will make it responsive to different screen landscapes. The web application will be built using razor pages in the MVC Architecture. The razor pages will handle formatting on the web application for the front-end user. The application can be accessed using a specific URL accessible to the users.

3.3.9.1.3 Mobile Applications – Android, iOS, Windows

The mobile applications will be built for multiple mobile platforms, namely Android, iOS, and Windows OS. The applications will be built independently of the web API. The applications will all be built using Xamarin. Xamarin will allow for the building of applications using C#. The application user interface will be built using one interface that will be mapped to all the different mobile interfaces.

3.3.9.2 Licensed Product Development

ArcGIS Survey123 is a simple solution for creating surveys. Easily collect data using smart forms and quickly analyse results. ArcGIS Survey123 is a simple and intuitive form-centric solution for creating, sharing, and analysing surveys in three easy steps.

Create smart forms with skip logic, defaults, support for multiple languages, and much more. Collect data easily via the web or mobile devices in any environment and with minimal training. Analyse results quickly to make actionable decisions. Fully integrated with the ArcGIS platform, you can gather data using your computer or any mobile device in the field, even when offline, and then securely upload it to ArcGIS for further analysis.

The ArcGIS Survey123 mobile app can be downloaded from the Apple App Store (iOS), Google Play and the Amazon Appstore (Android), or the Microsoft Store (Windows). Full use of the app requires ArcGIS credentials.

3.3.9.3 Conclusion

The data collection application will be developed for farmers as the primary users. The system will collect information by using surveys. Users will have to report on indicators by answering the survey regularly. The information received from the users will be stored in a database server where it will be accessible for analysis.

The decision on which platform will be used to develop the system is still undergoing consideration. All factors that will have an impact on the success of the project are being considered. The outcome of the development stage will be the same regardless of which platform will be chosen. The decision will be made timeously for the development to begin in time.

3.4 Data Analysis Framework

3.4.1 Introduction

The main objective of the analysis framework is to provide a structured solution for coherently integrating data from multiple sources. It also outlines how the analysis of the data will be conducted. Finally, the framework will give an overview of how the analysis will be communicated with data visualisation tools.

Data of different granularity and nature will be received from various sources. The data will need processing to generate an analysis-ready dataset. This will be performed during the data integration step. The sparseness of the data will need to be integrated into one dataset that will be used in the analysis phase.

The data from multiple sources is related on a geographical level. All the sources have their data geo-referenced to a region. This allows the ability to integrate the data on its geographical nature. The final dataset used for analysis should be rich in information from multiple sources.

The data analysis will be communicated via data visualisation tools by means of graphical representations. Graphical objects such as maps and graphs will be used to explain the analysis results in an easy-to-understand presentation. In addition, all analyses will be geo-referenced; thus, a specific analysis can be associated with a particular geographical region.

The main objective of the analysis is to use the data from all the sources in order to identify drought categories by geographical regions. Different levels of droughts will be associated with specific regions. Thus, this will be used as an alerting system for identifying drought levels and administering proper responses.

3.4.2 Data Requirements

The system will be highly dependent on all the data from the various sources. Each source will enrich the data for analysis. The data will be expected from different sources in a particular format. Thus, the data quality is highly important to ensure the most accurate analysis. Data from the various sources must all be geo-referenced and grouped in quaternary catchments. The data must represent a specific quaternary catchment. This will allow the data visualisation on a map for easy communication with farmers and other users.

The data will need to be consolidated into a single dataset. Then calculations will be performed on the data to convert it to a format where each quaternary catchment can be classified by its drought category (See Excel sheet on drought calculation). The data coming from multiple sources will be numerical.

3.4.2.1 Information Flow and Data Sources

Data will be collected across the different sources, and it should be geo-referenced and numerical to allow for quantitative drought calculations. The data formats from the source's original sources might differ, but it should be transformed into a format suitable for calculating the drought index.

3.4.2.2 Information and Data Flow

The diagram in Figure 3.4.1 shows the flow of data from the various sources.

The arrow shows that communication is always a two-directional flow in order to either submit instructions or receive data. The black and red arrows in the illustration depict data flow, while the yellow and green depict instructions and requests to the source.

Remotely sensed data is transmitted to the SAWS and SANSA for weather, vegetation, and soil conditions. The South African Weather Service (SAWS) and the Agricultural Research Council (ARC) obtain additional weather information from weather stations, while the National Integrated Water Information System (NIWIS) monitor and obtain information from water measurement systems in rivers, dams and boreholes.

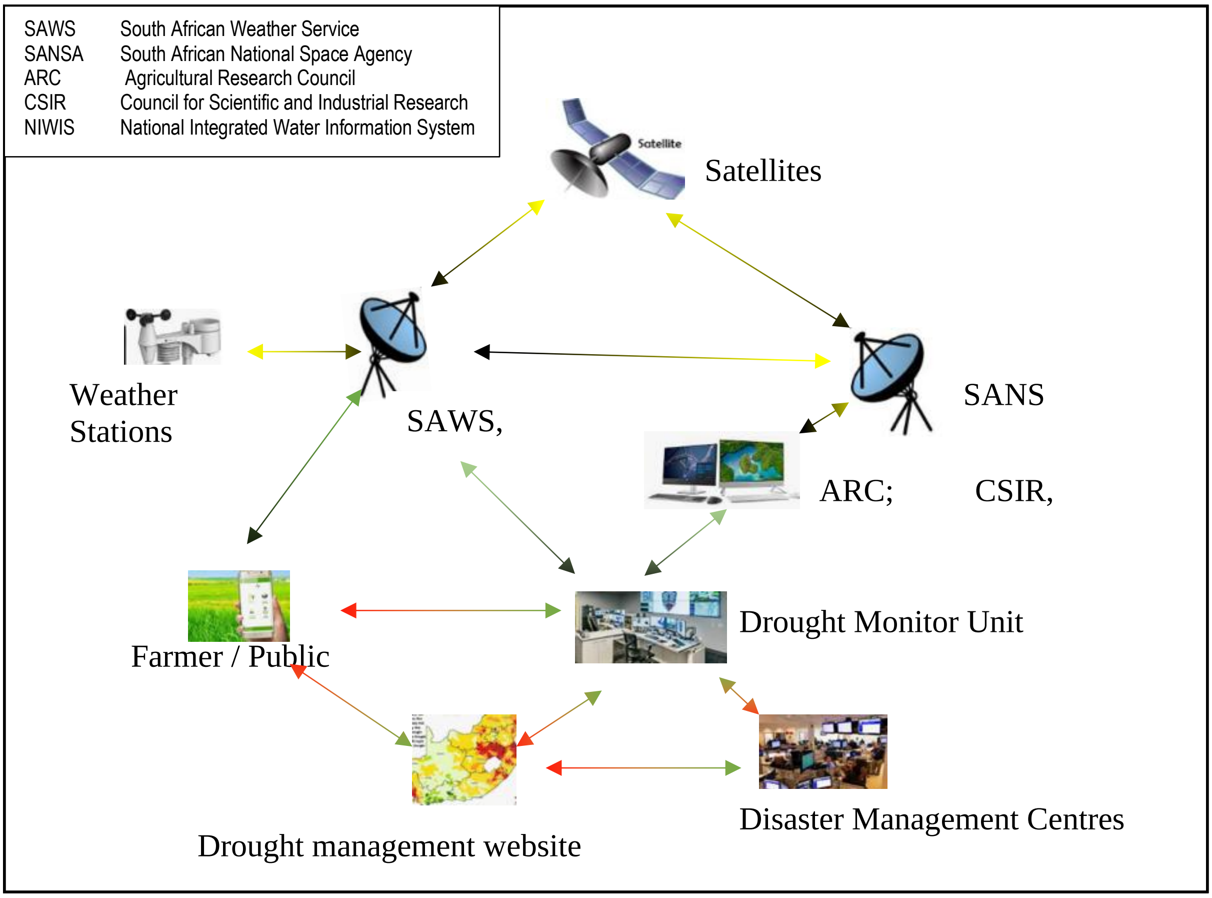


FIGURE 3.4.1: ILLUSTRATION OF DATA AND INFORMATION FLOW
Source: Designed by Jordaan

In practice, information flow and analysis will take place as follows:

i. SAWS and ARC to provide meteorological data to DMU either in raw data or as a processed product such as SPI, or SPEI. It's essential to have information per quaternary catchment and indicators such as 3-month, 6-month, 12-month, 24-month, 36-month and 48-month SPI or SPEI since the application is essential for different sectors. For example, the 6-month SPEI during the rainy season is vital for crop production, while the 12-month and 24-month SPEI are necessary for the extensive livestock sector. Again, 24-, 36- and 48-month SPEI might be required for perennial plants such as fruit trees under dryland conditions and can indicate groundwater levels.

ii. Hydrological data such as stream flow, dam levels and groundwater levels are available from DHSWS. Hydrological data analysis is important to determine demand/supply ratios for municipalities and analyse pending drought conditions for municipalities. Irrigation agriculture is the largest single water user in SA, and hydrological data is equally essential for the irrigation sector. The DMU should have a complete picture of water availability in SA and should be able to provide guidelines for activating drought contingency plans according to the drought classification.

iii. Remote sensing data is available from the South African Satellite Agency. The DMU should develop the capacity to create maps at the quaternary catchment level of at least the NDVI, VCI, PASG, SVHI and soil moisture index. In addition, remotely sensed data for the indicators mentioned are available on several open-source websites, such as Sentinel Hub.

iv. Secondary information from reference farms will supplement the primary indicators. The DMU should compare the information obtained from reference farms and municipalities with primary indicator information before making a drought classification for a specific catchment.

v. Reference units (farms, municipalities, water authorities, traditional authorities) should communicate information as mentioned via a cell phone app every week to the provincial DMU.

vi. Municipalities as landowners will communicate municipal information via an app weekly to the provincial DMU.

vii. The provincial DMUs should consolidate information per province, make their provincial analysis and send information to the national DMU.

viii. The information should be updated and communicated on a weekly basis.

The DMU heavily depends on the support from national government line departments such as Agriculture and Rural Development, Human Settlement, Water and Sanitation, Environment, Forestry & Fisheries, SAWS, and other organisations for information, data and funding. International organisations such as FEWSNET, WHO, UNISDR, WMO, FAO, RCMRD and others should also be linked to the disaster mitigation centre for information and data exchange.

3.4.2.3 Data and Information Sources for a National Drought Monitor System

The drought monitor system proposed as part of this project is only the first phase and focuses on the livestock sector in one province. A more comprehensive drought monitoring system for all sectors in the whole of South Africa should be the outcome of more research. An all-inclusive drought monitor system could obtain data and information from sources, as summarised in Table 3.4.1.

TABLE 3.4.1: INFORMATION SOURCES DROUGHT INDICATORS

Organisation	Data / Information
SAWS	Climate data / information Meteorological data / information Short term forecasts Medium-term forecasts Seasonal forecasts Meteorological Indices such as SPI, SPEI, deciles,
DHSWS	Hydrological data Stream flow Groundwater levels Dam levels Water demand/supply ratio per municipality Water demand/supply ratio per irrigation scheme Catchment level water supply and water demand
DARDLR incl. ARC	Remotely sensed indicators - NDVI, PASG, VCI, Soil moisture – top soil and deeper Crop conditions Livestock conditions General farming conditions Production outlooks per sector Updating *"Abstract for Agricultural Statistics"*
SANSA	Remotely sensed products as required by different organisations
DSD	Demographic data Employment data Data on # people dependent on pension payments # People dependent on agriculture Profile of people dependent on agriculture
DEFF	Wetland status Land degradation status Invasive species challenges Fire danger Index FireFigurehting readiness (Working on Fire)
STATSSA	Socio-economic information Demographic information per municipality per region Demographic information on # people per sector Business activities per sector per region

3.4.4 Data visualisation

The analysis will be associated with specific regions, such as quaternary catchments. This creates a need to be able to interpret the analysis with the representation of its geographical data. The data visualisation will be focused on communicating the analysis in an easy-to-understand way, such as maps or graphical visuals, such as graphs and pictures. The visuals will be interactive; thus, it will enhance understanding of the analysis. Regions will be shown on the maps. The ability to interact with the map to get details about specific regions with regard to drought will make the visuals interactive.

3.5 ARC/GIS as an option

3.5.1 Introduction

ArcGIS already has open-source capabilities with the required attributes for a drought monitoring system. The project team will also investigate the best possible solution.

3.5.2 About ArcGIS/ArcGIS Online

ArcGIS Online is a cloud-based mapping and analysis solution. Use it to make maps, analyse data, share and collaborate, access workflow-specific apps, maps and data from around the globe, and tools for being mobile in the field. Your data and maps are stored in a secure, private infrastructure and can be conFigured to meet your mapping and IT requirements.

3.5.3 What you can do with ArcGIS Online

Work with smart, data-driven styles to explore and visualise 2D and 3D data. Share your maps with anyone, anywhere or keep them private. Work collaboratively with your colleagues to build maps, scenes, apps, and notebooks. Access intuitive analysis tools that help you better understand your data.

3.5.4 Create maps, scenes, apps, and notebooks.

ArcGIS Online includes everything you need to create web maps, apps, and notebooks. Through Map Viewer, Map Viewer Classic, and 3D Scene Viewer, you can access a gallery of base maps and innovative styles for exploring and visualising your data. You also have access to templates and widgets for creating web apps to publish to ArcGIS Online. Using ArcGIS Notebooks, you can also access Python resources to perform analysis, automate workflows, and visualise data.

3.5.5 Share and collaborate

You can share content with others inside and outside your organisation. You can set up groups that are private and by invitation only or public groups that are open to everyone. You can also set up collaborations with other organisations to share and work with each other's content. Different ways to share maps and content include embedding them in web pages, blogs, web apps, and social media. Use focused apps to collaborate with colleagues in the field, office, or community.

3.5.6 Manage data

Add, manage, and share your own data. You can publish your data as web layers on ArcGIS Online. This frees up your internal resources since these web layers are hosted in Esri's cloud and scale dynamically as demand increases or decreases. You can add your layers to maps and allow others to use them as well. Finally, you can publish your data directly from ArcGIS Pro or ArcGIS Online and share the data with others.

3.5.7 Be mobile in the field

ArcGIS Online supports field activities. Take advantage of the built-in tools and apps to collect data, navigate, coordinate, and monitor projects. Create map areas for taking maps offline. Set up synchronisation so offline editors can get the latest updates to the map. Access your organisation from ArcGIS Companion, a mobile app that allows you to explore content, view groups, and more on the go.

3.5.8 Explore and analyse data

ArcGIS Online includes interactive maps that allow your entire organisation to explore, understand, and measure your geographic data. Access ArcGIS Living Atlas of the World, a dynamic collection of maps, scenes, data layers, imagery, analytics, and apps from the ArcGIS community. Use the analysis tools included in Map Viewer Classic to reveal new patterns, find suitable locations, enrich your data, find out what's nearby, and summarise your data. You can also leverage ArcGIS API for Python using ArcGIS Notebooks to run data science scripts to get insight into your data.

Once the user submits the required data, data will be stored in a temporary database. The purpose of storing data in a temporary database is to perform quality assurance (QA) to ensure that data are in accordance with the required standards. The database will already store all the necessary drought indicator's related parameters. Those data types are, relatively speaking, static data, with a low update frequency. A system will have an algorithm to process users' data and calculate all required drought indicators. Calculation results will be presented in the form of a map(s) and tables and be presented to the users in the form of a web-based application.

3.5.9 Information dissemination

A good communication system is a system with the potential to send and receive messages. Having proposed that the system should be Web-based in acknowledgement of the 4IR, then an electronic communication system like the *“Full-Duplex”* would be ideal. A *“Full-Duplex”* communication system is a dedicated channel or medium where users can communicate and send messages simultaneously. South Africa has moved from analogue (wired) to digital (wireless), which also supports the recommended electronic information management and communication (Mzekandaba, 2019). Barker (2013:104) defines communication as a strategic process involving interactive, integrated message sending and receiving.

Comprehensive and integrated information dissemination for the NC should ensure a broad provincial outreach. Figure 3.5.2 illustrate communication flow with a web platform as the central point of communication.

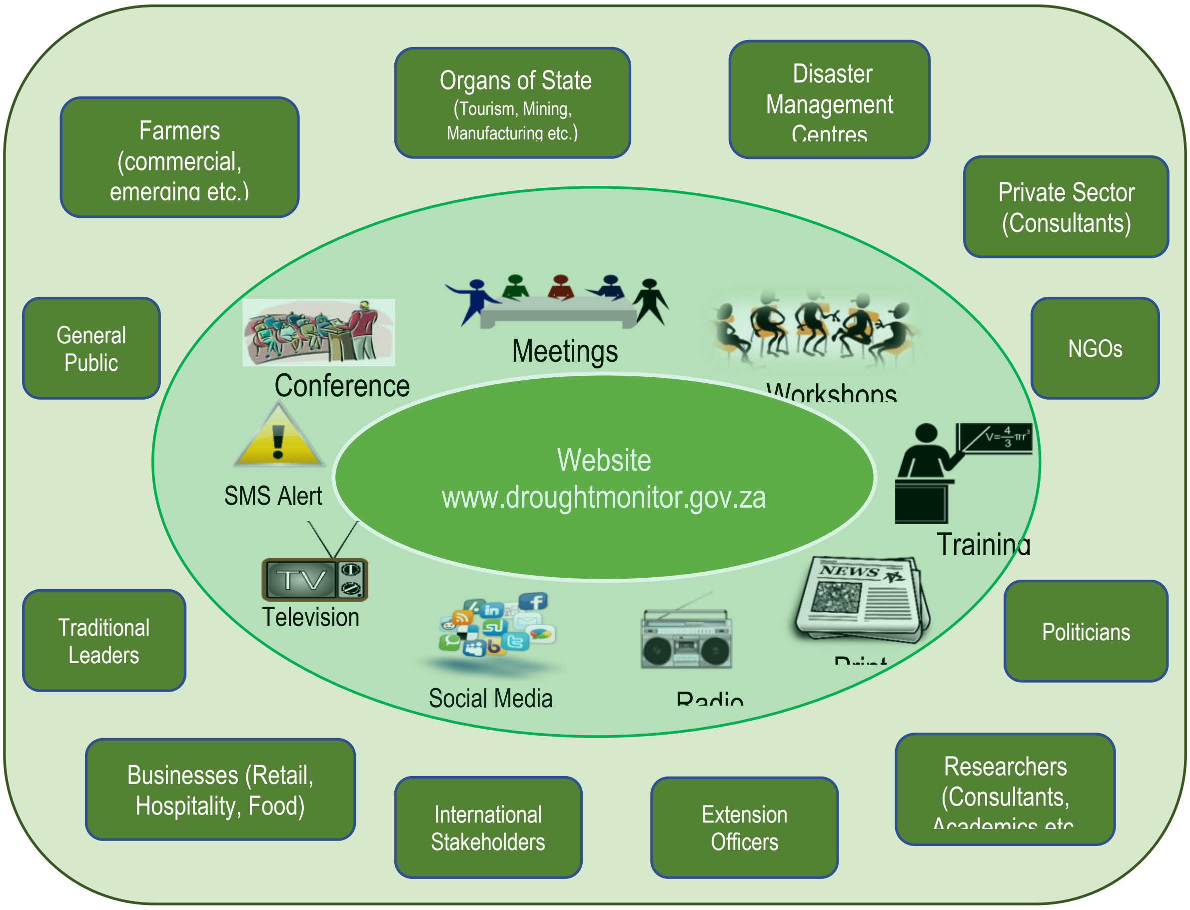


FIGURE 3.5.2: INFORMATION DISSEMINATION PROCESS TO STAKEHOLDERS
Source: Adapted from Kunguma, 2020

Using satellite technology for communication is equally important to remotely sensed data and information. For example, drought monitoring and early warnings are best communicated using geospatial illustrations and maps with options to select different geographic areas and indicators. In addition, communication technology provides numerous opportunities for effective and speedy communication through an interactive web-based system. An interactive web platform allows stakeholders to select information according to their specific needs. Linked to the web platform are other communication channels such as social media, printed media, radio, and television. The human factor, however, remains central in that personal networks could be decisive in understanding and interpreting messages and information packages.

Important to note are the essential elements of an effective information dissemination strategy. First, opinion leaders persuade and model appropriate behaviour in the target audience. Second, targeting is specifically significant in this situation where drought affects people differently. Third, the users' willingness to accept and act on information is important to the system's design (Duggan & Banwell, 2004). Other important factors to take note of are as follows:

i. Since a Web-based Information System is proposed, the knowledge management functions should be incorporated, such as Frequently Asked Questions, Inquiry Forms for sector-specific information requests, Push Notification, Live Chat or Chatbots, Factsheets, Infographics, Social Media Links and Registration for SMS Alerts.
ii. Information disseminated must be simple and clear, with no jargon,
iii. It must be relevant, trustworthy and demonstrate value through the decisions made by the users
iv. There should be a balance between electronic and non-electronic information dissemination (through television, newspapers, conferences, workshops, roadshows, e.t.c) to accommodate a wide reach to all stakeholders with or without access to the Internet

3.5.10 Conclusion

The Excel model provides the framework for indicator classification and is useful to quantitatively classify a specific drought class. Extension officers and disaster management staff will also find it a useful tool for drought classification.

3.6 Conclusion

Drought is a slow-onset disaster in which it is difficult to determine the onset of a drought and the end of a drought. In addition, drought is the hazard affecting the NC livestock sector the most, negatively impacting the provincial economy. Drought monitoring and timely analysis of drought indicators are essential for early warning and implementing drought risk reduction contingencies. Accepting a drought classification system and indicator thresholds is the first step in drought management at a provincial and national scale. The uniqueness of drought management requires an alternative system to managing fast-onset disasters such as floods. Flooding, for example, is expected during the rainy season and high precipitation. On the other hand, drought is experienced throughout the year at different geographic locations.

Because of the uniqueness of drought, an alternative structure is required to monitor and manage drought throughout the year. This report proposes a specialised Drought Mitigation Unit as a separate program within the PDMC or NC Provincial Department of Agriculture. The DMU will require support from the various data custodians such as SAWS, DHSWS, DARD, DEFF, SANSA and research organisations. The DMU should act as a *"one-stop-centre"* for drought monitoring and early warning in the province. Water management and drought is an interdepartmental responsibility, and proper monitoring and management is only possible in a coordinated manner with seamless data and information sharing in place. The development of the DMU at the provincial level alone is not sufficient, though.

National and other provinces also need to develop the capacity to gather data and information on drought at the provincial and national levels. In support of the DMU, a system of reference units (farms, municipalities, water managers) is proposed. Reference farms should be selected according to strict criteria and represent each quaternary catchment. The reference units should be responsible for weekly reports on water-related and drought issues. Municipalities, reference farmers and water management authorities will report specific data and information to the provincial drought units and the DMU, who will analyse data together with meteorological and remotely sensed data. Data analysis will be done by a team of experts from different line departments and regions, and the DMU will prepare weekly sector and regional-specific advisories and outlooks.

The products available to the different sectors should include meteorological data such as temperature, precipitation wind speed, evapotranspiration and analysis of meteorological data using the different SPI and SPEI time scales. Remotely sensed data includes NDVI, PASG, VCI, SVHI and soil moisture at different depths. Hydrological data such as dam levels, stream flow and groundwater levels are equally crucial for bulk water management organisations, municipalities and irrigation farmers. All the data should be available spatially to the quaternary catchment level. The DMU should develop an interactive website with current and historical data from which users can also analyse. The website should also contain links to alternative open-source websites such as SAWS, NIWMS of DHSWS, SAWX, CopernicusHUB, USGS, FEWSNET, AquaDuct, Climate Engine, AQUASTAT of the FAO and other drought-related data sources.

Potential actions for implementation of the proposed system are summarised as follows:

i. Obtain support for the establishment of the DMU at the NC PDMC or Provincial Department of Agriculture
ii. Appoint somebody with the PDMC or Agriculture to drive the implementation process
iii. Secure support from stakeholders
iv. Address potential policy implications
v. Determine staff structure
vi. Identify hardware and software requirements
vii. Budgeting
viii. Determine funding structure and secure funding agreements from other stakeholders
ix. Develop interactive data capturing and processing system
x. Develop web platform – part of the current project
xi. Develop reporting apps – part of the current project
xii. Work through regional structures and identify reference units (farms, municipalities, water managers)

xiii. Training of staff and reference units

References

Barker, R., 2013. Strategic integrated communication: an alternative perspective of integrated marketing communication. South African journal for communication theory and research, 39(1), pp. 102-121.

Cheung, C. M., & Lee, M. K. (2007). The structure of Web-Based Information Systems satisfaction: an application of confirmatory factor analysis. Web Information Systems and Technologies, 257-273.

Demiryurek, K., Erdem, H., Ceyhan, V., Atasever, S., & Uysal, O. (2008). Agricultural information systems and communication networks: the case of dairy farmers in the Samsun province of Turkey. Information Research, 1-11.

FloridaTech. (2020, 02 10). Information Systems vs. Information Technology. Retrieved from Florida Tech: https://www.floridatechonline.com/blog/information-technology/information-systems-vs-information-technology/

Freeman, R.E. (2004) The Stakeholder Approach Revisited. Zeitschrift für Wirtschafts-und Unternehmensethik, 5, 228-241.

Jones, P., Wynn, M., Hillier, D., & Comfort, D. (2017). The Sustainable Development Goals and Information and Communication Technologies. Indonesian Journal of Sustainability Accounting and Management, 1, 1-15. https://doi.org/10.28992/ijsam.v1i1.22

Jordaan AJ., Sakulski DM., Muyambo F., Schwababa S., Mdungela N,. Phatudi-Mphahlele B., Mashimbye C., Mlambo D., Fadeyi O., Miya T., Bahta Y., Owusu-Sekyere E. & Schulze RE. 2017. *Vulnerability, Adaptation to and Coping with Drought: The Case of Commercial and Subsistence Rain Fed Farming in the Eastern Cape*. WRC Report number: TT 716/2/17. ISBN 978-1-4312-0885-2

Kunguma, O. (2020). South African Disaster Management Framework: Assessing the status and dynamics of establishing information management and communication systems in provinces. Bloemfontein: University of the Free State Unpublished PhD.

Mzekandaba, S. (2019, July 23). SASSA web site remains down after hack. ITWeb. https://www.itweb.co.za/content/rxP3jqBpVJ27A2ye

Reed, M., Graves, A., Dandy, N., Posthumus, H., Klaus, H., Morris, J., . . . Stringer, L. C. (2009). Who's In and Why? a typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management, 90(5), 1933-1949.

Republic of South Africa 2002: 45.Disaster Management Act. Act 45 of 2002.

UNDP. 2013. Community Based Resilience Assessment (CoBRA) Conceptual Framework and Methodology. http://www.seachangecop.org/sites/default/files/documents/ 2013%2004%20UNDP%20CoBRA%20Conceptual%20Framework%20and%20Methodology.pdf

UNISDR. 2005. *Hyogo Framework for Action 2005-2015.* United Nations, International Strategy for Disaster Reduction, Kobe, Japan.

Chapter 4: Web-based Drought Reporting Tool

4.1 Introduction

The primary goal of a Drought Information Management and Communication System (DICMS) is to enhance the effectiveness of drought early warning and monitoring by establishing a comprehensive web-based system. This system is designed to gather and consolidate data concerning key drought indicators, ensuring the generation of reliable, timely, and actionable drought forecasts and assessments. These assessments encompass evaluating the severity of drought conditions and understanding their impacts.

The implementation of the DICMS plays a critical role in informing the classification of droughts within each quaternary catchment area. This classification, in turn, serves as the basis for determining the thresholds that trigger contingency plans. Furthermore, this report delves into the essential data and information necessary to support the outputs of the drought monitoring process.

Drought monitoring revolves around key indicators and their associated thresholds, which signify varying levels of drought severity. Therefore, the focal points for effective drought monitoring are the classification of droughts based on specific indicators and their corresponding thresholds. Additionally, historical data, current drought conditions, and future projections play a vital role in the context of drought monitoring.

<u>Data collection for drought monitoring</u>

The primary aim of the data collection application is to establish a user-friendly platform tailored to farmers, enabling them to report farm-level drought indicators efficiently. Farmers will serve as the primary user base for this data collection application.

This application promises enhanced data collection capabilities, offering timely reporting at a lower cost. Its design ensures that users can easily report on indicators directly from the field using mobile devices, providing real-time reporting convenience. Moreover, mobile device accessibility ensures that the system accommodates a wide range of farmers, given the widespread availability of mobile technology.

The data collection process will employ user-friendly surveys, simplifying indicator reporting for users. The application, designed to be cross-platform, ensures inclusivity across various mobile device platforms.

Collected data will serve as a valuable resource for drought monitoring and analysis, with the findings communicated back to users. However, this report will primarily focus on the system's design, functionality, development process, and tools used in creating this resource.

4.2 Development Progress and Expectations

This section provides a summary of DICM requirements and deliverables thus far.

4.2.1 Required Characteristics of a DICMS

The Drought Information Management and Communication System (DICMS) should facilitate the continuous dissemination of drought forecasts, ongoing drought conditions, and the impacts of drought, ideally in real-time. This information should reach decision-makers at all levels of government, including the private sector, as well as the general public. The aim is to enable well-informed and timely decision-making, ultimately enhancing preparedness and mitigating the adverse effects and costs associated with drought events.

The integrated DICMS should leverage existing climate projection, forecasting, and drought assessment programs, as well as collaborative models. This integrated system should offer the following components:

i. Real-time spatially linked information regarding drought, climate, weather, and related factors through interactive maps.
ii. Real-time spatially linked data pertaining to drought, climate, weather, and related variables presented in tabular form.

iii. Historical drought information and data with geographical references. iv. Data-driven visual representations of the impacts stemming from drought events.
iv. Spatially linked data and information concerning drought indicators.
v. Spatially linked data and information pertaining to indicators of vulnerability and resilience in the context of drought.

Furthermore, the DICMS should possess the capability to integrate sector-specific indicators essential for sector-specific decision-making processes.

4.2.2 Collaborating with the ARC

The core product originally envisioned for this project has undergone a significant transformation, driven by well-founded motivations, which we will outline below. However, it's important to note that the project's fundamental requirements have remained unchanged. Consequently, the new product(s) still align with the initial requirements. The objective remains constant, and it is now be achieved through the development of two complementary products that collectively provide the necessary functionality.

Initially, the plan was to create a unified application that would handle both data collection from farmers and data virtualisation for modelling outcomes. In the revised approach, we have opted to separate these two primary functions into distinct products, each taking the form of a website. The first website will focus on facilitating data collection from farmers, while the second website will be dedicated to data visualisation. Both websites will be accessible to users.

Motivations for this change in the system stem from our collaboration with the Agricultural Research Council (ARC). ARC already maintains a drought information website designed for reporting on various drought indicators, developed as part of an initiative for the Water Research Commission (WRC). This existing infrastructure and user base presented a compelling case for collaboration. The ARC's website is public-facing and actively used by farmers and other stakeholders. This collaboration streamlines our efforts to provide the public with a reporting platform for drought-related data. (ARC drought monitor: www.drought.agric.gov.za).

In this partnership, ARC has generously offered to host the reporting website on their infrastructure, simplifying the integration of our resources. Users who register on the reporting website will also gain automatic access to the ARC website's analysis of the drought indicator reports they submit.

The decision to separate the two websites arose from the differing data requirements for user registration on the ARC website and the need for georeferencing reporting data. While the ARC website already boasts a user base, we require geographical information for all reporting users to associate their data with specific geographical farms within quaternary catchments accurately.

ARC possesses the necessary infrastructure to host both websites. Our team developed the reporting website, which coexist on the ARC infrastructure alongside the website developed by ARC for the reporting needs. ARC will make additional modifications to their website to accommodate the visualisation of farm-level indicator data that farmers will be providing them. This collaborative effort ensures that both websites work in harmony to deliver valuable insights on drought conditions to users.

4.3 System Requirements

The system requirements for a web-based reporting and communication tool for drought monitoring, considering the provided background, can be outlined as follows:

i. **User-Friendly Interface:** The application should feature an intuitive and user-friendly interface, ensuring ease of use for farmers. It should minimize complicated processes to encourage adoption and usage.

ii. **Accessibility:** Given the farming environment's potential connectivity issues, the application must be accessible even in areas with limited internet connectivity. Offline capabilities or data-saving mechanisms should be considered.

iii. **Mobile Compatibility:** The application must be compatible with mobile devices, allowing farmers to access it anytime and anywhere. Mobile devices are preferred due to their portability and ease of use in the field.

iv. **Internet Connectivity:** To transfer data to the backend database, the mobile application will require internet connectivity. This connectivity is crucial for real-time data transmission and storage.

v. **Reporting Frequency:** Farmers should be able to report on indicators with flexibility in terms of frequency. The application should also support detailed reporting over extended periods, ensuring comprehensive data collection.

vi. **Notification System:** Implement a notification system within the application to remind farmers when reporting is required. Timely reporting is essential for accurate and up-to-date data.

vii. **Survey-Based Reporting:** Design reports in a survey format based on indicator groups. Farmers should easily select the condition of each indicator from a predefined list of options. This approach simplifies the reporting process and saves farmers time in interpreting indicators.

viii. **User Registration:** Farmers should register their farm details, including location and other specified information. This data will facilitate farm identification and allow for geospatial referencing of the collected data.

ix. **Administrator Account:** Include an administrator account with access to the backend database. This account enables data retrieval in a specified format for analysis. Additionally, administrators should have the capability to modify indicators and indicator groups to adapt the application's user interface without requiring changes in the code logic.

Incorporating these system requirements will ensure the development of a robust web-based reporting and communication tool for drought monitoring, catering to the needs of farmers while facilitating efficient data collection and analysis.

4.4 System Development

4.4.1 Architecture

The delivered product consists of two websites that share a common infrastructure and environment, facilitating seamless resource integration. The following diagram provides a visual representation of the integration between the two websites and how resource sharing is accomplished.

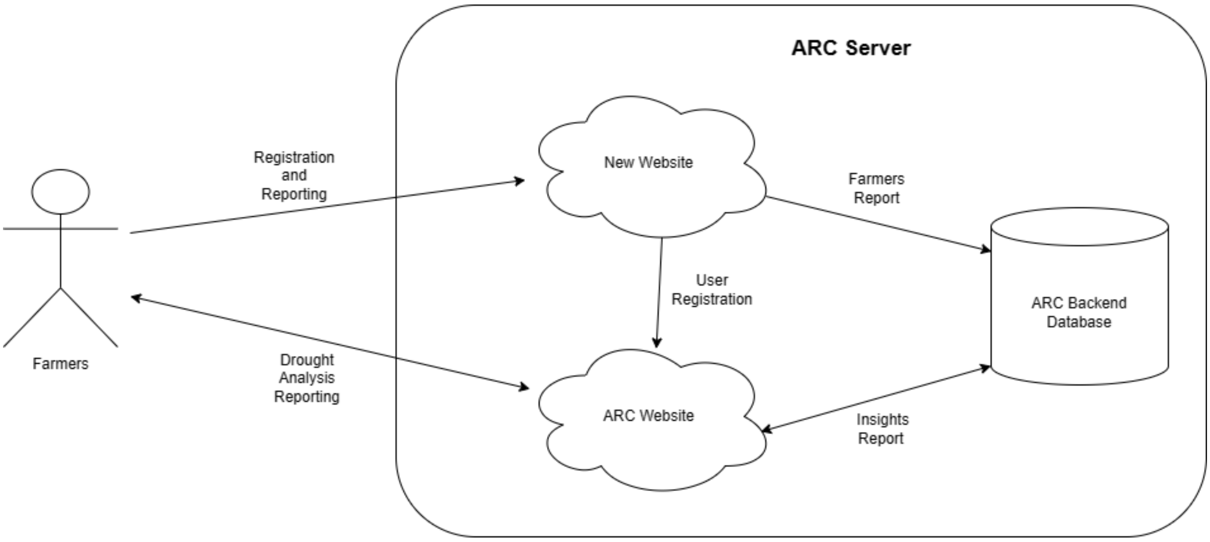


FIGURE 4.4.1: WEBSITE INTEGRATION

4.4.2 Development Process

The development process was divided into the steps below.

4.4.2.1 Plan

The document sets expectations and defines common goals that aid in project planning. This step was done earlier on during the year. The documentation that set the expectations and standards was submitted. This included details of the deliverables to be expected at each milestone in the project.

4.4.2.2 Design

During this phase, we thoroughly analysed and comprehended the project requirements, aiming to identify the most effective solutions for creating the desired product. It's worth noting that this phase accounted for over 65% of the total time and effort invested in the development process. We encountered multiple potential approaches for implementing the solution, ultimately opting to combine our resources and collaborate on the development of a product that would seamlessly integrate with the ARC. This strategic decision allowed us to leverage existing infrastructure and expertise, enhancing the overall efficiency and effectiveness of the project.

4.4.2.3 Implementation

The Implementation phase is inherently iterative in nature. We've successfully completed the initial functional build of the website, but it's important to note that this step allows for ongoing refinements and enhancements. These improvements may be necessitated by user feedback or issues identified during rigorous testing procedures. Currently, we are actively engaged in consultations with key stakeholders, including the Northern Cape Department of Agriculture, the Red Meat Producers Organisation (RPO), Northern Cape Agri and the National Wool Growers Association (NWGA), with the aim of implementing the reporting system at the farm level.

Our plan envisions a four-month period during which farmers will actively participate in testing the system, providing us with essential insights for further refinement. This thorough testing and feedback process will culminate in an official launch, which is aligned with the original project plan, and will take place through a national symposium. It's crucial to emphasise that we have already developed the minimum viable product (MVP), and the current focus is on rigorous testing and seamless deployment of the website to ensure its readiness for widespread use.

4.4.2.4 Test

This crucial step involves comprehensive testing of the websites to ensure they align with the functional requirements established during the initial planning phase of the development process. Quality analysis, a pivotal component of this step, encompasses rigorous error testing to identify and rectify any issues that may compromise the system's performance and reliability.

The ongoing nature of this phase is pivotal, as it allows for continuous refinement based on valuable user feedback. Over the next four months, we will actively engage with users, seeking their input and evaluating their experiences while using the websites. This iterative process ensures that any shortcomings or areas for improvement are promptly addressed, guaranteeing that the final product is not only robust but also user-friendly and aligned with the needs and expectations of our target audience.

4.4.2.5 Deploy

The deployment phase includes several tasks to move the latest website build copy to the production environment online. Other tasks include packaging, environment conFigureuration, and installation. This task is currently underway and the ARC IT team are working on deploying the website to their server and we are awaiting feedback from them.

4.5 Technical Details

Accessibility Requirements: The reporting website has been designed to ensure cross-platform accessibility. This means that users can access the website seamlessly on both mobile devices and computers, regardless of the operating system they use. To utilise the website, users simply need to have a web browser installed on their device. For optimal compatibility with the websites, we recommend using browsers such as Safari, Firefox, Google Chrome, and Microsoft Edge. Users who do not have these browsers installed on their devices can easily download and install them.

Data Requirements: The reporting website serves as a vital tool for collecting two primary categories of data: user information and farm-level indicator reporting data. All collected data are securely stored in the back-end database. The website's core function is to gather reporting data critical for drought analysis. During the user registration process, individuals will be prompted to provide specific details, including their geographical location and other relevant identifying information. These details are integral for several reasons, such as accurately modelling drought conditions within a particular geographic area and verifying the authenticity of the submitted data. Below, we outline the database table structure that will house user details.

4.5.1 User Details

This table captures comprehensive user information, enabling precise identification of the user conducting the reporting and their respective geographical location. This information plays a pivotal role in enhancing the accuracy of drought modeling for specific regions and validating the data submitted by users.

TABLE 4.5.1: DATA BASE TABLE - USERDETAIL

Column	Type	Default Value	N...	Character Set	Collation	Privileges	Extra	Comments
email	varchar(100)		NO	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
id	int		NO			select,insert,update,references	auto_increment	
isactive	int	0	NO			select,insert,update,references		
password	varchar(100)		NO	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
username	varchar(100)		NO	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
farmname	varchar(130)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
farmsize	int		YES			select,insert,update,references		
firstname	varchar(100)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
lastname	varchar(100)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
latitude	varchar(20)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
longitude	varchar(20)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
phonenumber	varchar(16)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
regionname	varchar(100)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
reset_token_expires_at	datetime		YES			select,insert,update,references		
reset_token_hash	varchar(64)		YES	utf8mb4	utf8mb4_0900_...	select,insert,update,references		

Database table name: userdetail

Column Meta data:

- *Id - Unique user identifying ID*
- *Username – User chosen username*
- *Password – Password has of from the chosen user password*
- *isactive - flag indicating if user account is active*
- *email - user email address*
- *firstname – user first name*

- *lastname – user last name*
- *phonenumber – users phone numbers*
- *farmname – the name of the farm*
- *regionname – regional name (Province or district)*
- *farmsize – farm size in hectors*
- *longitude – farm longitude coordinate*
- *latitude – farm latitude coordinate*
- *reset_token_hash – token hash for password resetting and account activation*
- *reset_token_expires_at – token hash expiration date and time*

4.5.2 Reporting Data

The process of data collection hinges on active participation from farmers as they provide essential information. This system offers farmers the capability to submit two distinct types of reports. These reports include a weekly report on farm-level indicators and a more comprehensive monthly report, which delves into finer details.

Weekly reports are designed to be submitted on a weekly basis, whereas monthly reports entail a more in-depth examination of various parameters. It's important to note that each report can only be submitted once for a specific reporting period. However, users do have the option to submit reports for missed periods by indicating this preference before commencing the survey. Given the disparities in the data collected for these two types of reports, the system efficiently segregates and stores this information in two distinct tables within the backend database. Below, we provide insight into the metadata and structural composition of these database tables:

i. **Weekly Report Data Table:** This table is designated for storing the data obtained from farmers' weekly reports. It serves as a repository for essential information pertaining to ongoing farm conditions and indicators.
ii. **Monthly Report Data Table:** In contrast, the monthly report data table serves as a repository for more comprehensive data gleaned from farmers' monthly reports. This table accommodates the additional details and insights gathered during this reporting cycle, offering a more comprehensive view of farm-level conditions and indicators.

4.5.2.1 Weekly Report

TABLE 4.5.2: TABLE NAME WEEKREPORT

Column	Type	Default Value	Nullable	Character Set	Collation	Privileges	Extra	Comments
animalcondition	int		NO			select,insert,update,references		
cropconditions	int		NO			select,insert,update,references		
damstreamlevels	int		NO			select,insert,update,references		
groundwaterlevels	int		NO			select,insert,update,references		
plantingconditions	int		NO			select,insert,update,references		
rainfall	int		NO			select,insert,update,references		
reportid	int		NO			select,insert,update,references		
temp	int		NO			select,insert,update,references		
timestamp	varchar(30)		NO	utf8mb4	utf8mb4_0900_...	select,insert,update,references		
userid	int		NO			select,insert,update,references		
veldcondition	int		NO			select,insert,update,references		
yieldpotential	int		NO			select,insert,update,references		

Database table name: weekreport

Column meta data:

- *userid – Unique user id that identify the user*
- *reported – Unique report id*
- *timestamp – date for the reporting period*
- *rainfall – flag for rainfall indicator*
- *temp – flag for the temperature indicator*
- *veldcondition – flag for veld condition indicator*
- *animalcondition – flag for animal condition indicator*
- *damstreamlevels – flag for dams stream levels indicator*
- groundwaterlevels – flag for groundwater levels indicator
- plantingconditions – flag for planting conditions indicator
- cropconditions – flag for crop conditions indicator
- yieldpotential – flag for yield potential indicator

4.5.2.2 Monthly Report

TABLE 4.5.3: MONTHLY REPORT

COLUMN_NAME	DATA_TYPE	NUMERIC_PRECISION	IS_NULLABLE
userid	int	10	NO
reportid	int	10	NO

timestamp	varchar	NULL	NO
highertemperature	int	10	NO
lessrainfall	int	10	NO
lessclouds	int	10	NO
whirlwinds	int	10	NO
plantswilted	int	10	NO
grazingcapacityloss	int	10	NO
productionloss	int	10	NO
reservefeedandfodder	int	10	NO
feedandfodderpurchased	int	10	NO
animalconditionloss	int	10	NO
kraalfeeding	int	10	NO
lesswoolyield	int	10	NO
lessweightofprogenyatweaning	int	10	NO
forcedsalesofanimals	int	10	NO
increasedmotalityofyounganimals	int	10	NO
increasedmotalityofolderanimals	int	10	NO
lessprogeny	int	10	NO
lowergroundwaterlevels	int	10	NO
dams	int	10	NO
lowerstreamflow	int	10	NO
lesswateravailable	int	10	NO
dryness	int	10	NO
moredust	int	10	NO
higherstressthannormal	int	10	NO
cancelfamilyholidays	int	10	NO
labourretrenchments	int	10	NO
struggletopayschoolfees	int	10	NO
stressinfamilyrelations	int	10	NO
withdrawfromsocialevents	int	10	NO
withdrawleadershippositions	int	10	NO
familyseparation	int	10	NO
considersuicide	int	10	NO
migratefarmadditinalincome	int	10	NO
stopcapitalexpenditure	int	10	NO
usesavingstobuyanimalfeed	int	10	NO
condisderdebtconsolidation	int	10	NO
salesofliquidassets	int	10	NO
salesoffixednonfarmassets	int	10	NO
localbusinesssuffering	int	10	NO

behindwithinstallment	int	10	NO
stopbuyingnewvehicles	int	10	NO
seekalternativeincome	int	10	NO

Database table name: monthreport

Column meta data:

- *userid – unique identifying user id*
- *reported – unique report id*
- *timestamp – date for the reporting period*
- *highertemperature – flag for higher temperature indicator*
- *lessrainfall – flag for less rainfall indicator*
- *lessclouds – flag for less clouds indicator*
- *whirlwinds – flag for whirlwinds indicator*
- *plantswilted – flag for plants wilted indicator*
- *grazingcapacityloss – flag for grazing capacity loss indicator*
- *productionloss – flag for production loss indicator*
- *reservefeedandfodder – flag reserve feed and fodder indicator*
- *feedandfodderpurchased – flag for feed and fodder purchased indicator*
- *animalconditionloss – flag for animal condition loss indicator*
- *kraalfeeding – flag for kraal feeding indicator*
- *lesswoolyield – flag for less wool yield indicator*
- *lessweightofprogenyatweaning – flag for less weight of progeny at weaning indicator*
- *forcedsalesofanimals – flag for forced sales of animals indicator*
- *increasedmotalityofyounganimals – flag for increased mortalities for young animals indicator*
- *increasedmotalityofolderanimals – flag for increased mortalities of folder animals indicator*
- *lessprogeny – flag for less progeny indicator*
- *lowergroundwaterlevels – flag for lower ground water levels indicator*
- *dams – flag for dams indicator*
- *lowerstreamflow – flag for lower stream flow indicator*

- *lesswateravailable – flag for less water available indicator*
- *dryness – flag for dryness indicator*
- *moredust – flag for more dust indicator*
- *higherstressthannormal – flag for higher stress than normal indicator*
- *cancelfamilyholidays – flag for cancel family holidays indicator*
- *labourretrenchments – flag for labor retrenchments indicator*
- *struggletopayschoolfees – flag for struggle to pay school fees indicator*
- *stressinfamilyrelations – flag for stress in family relations indicator*
- *withdrawfromsocialevents – flag for withdraw from social events indicator*
- *withdrawleadershippositions – flag for withdraw leadership positions indicator*
- *familyseparation – flag for family separation indicator*
- *considersuicide – flag for consider suicide indicator*
- *migratefarmadditinalincome – flag for migrate farm additional income indicator*
- *stopcapitalexpenditure – flag for stop capital expenditure indicator*
- *usesavingstobuyanimalfeed – flag for use savings to stop buying animal feed indicator*
- *condisderdebtconsolidation – flag for consider debt consolidation indicator*
- *salesofliquidassets – flag for sales of liquid assets indicator*
- *salesoffixednonfarmassets – flag for sales of fixed non-farm assets indicator*
- *localbusinesssuffering – flag for local business suffering indicator*
- *behindwithinstallment – flag for behind with installment indicator*
- *stopbuyingnewvehicles – flag for stop buying new vehicles indicator*
- *seekalternativeincome – flag for seek alternative income indicator*

4.5.3 User Interaction

4.5.3.1 User registration

This is the first page in the website below

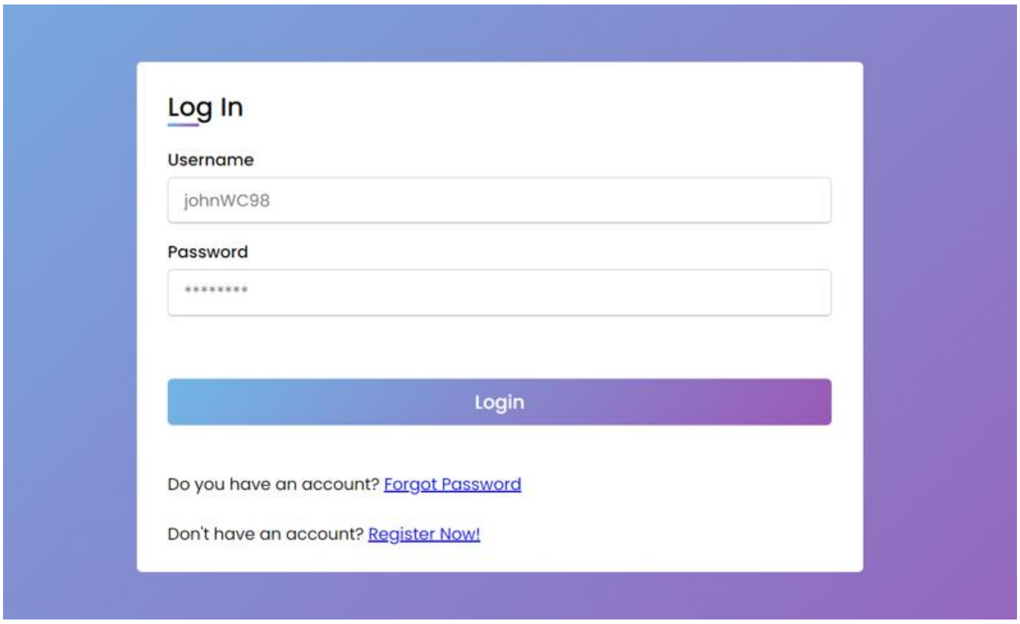


FIGURE 4.5.1: LOG-IN PAGE

User must click Register Now to sign up to perform reporting

User must complete the details below

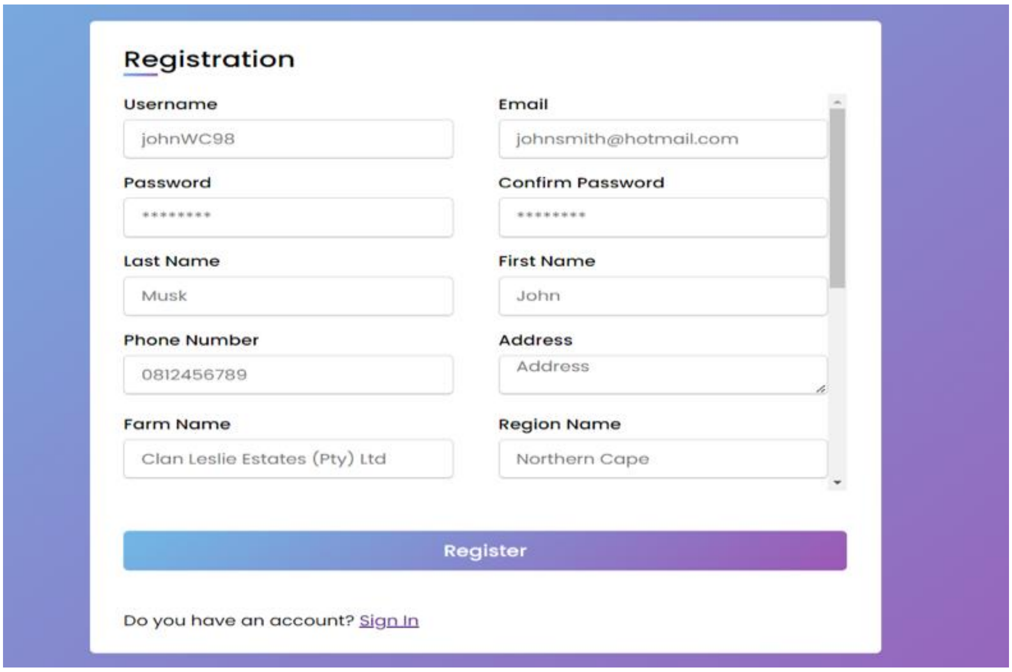


FIGURE 4.5.2: REGISTRATION PAGE

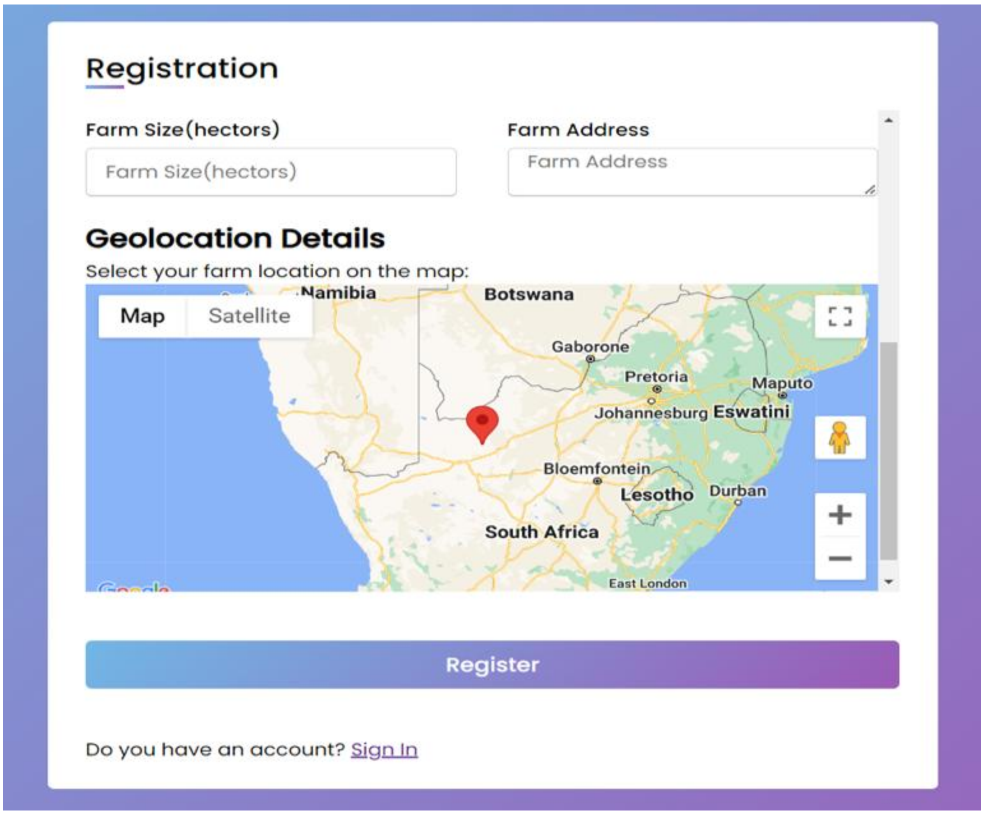


FIGURE 4.5.3: GPS DETAILS

User will be navigated to page as indicated in Figure 4.5.4.

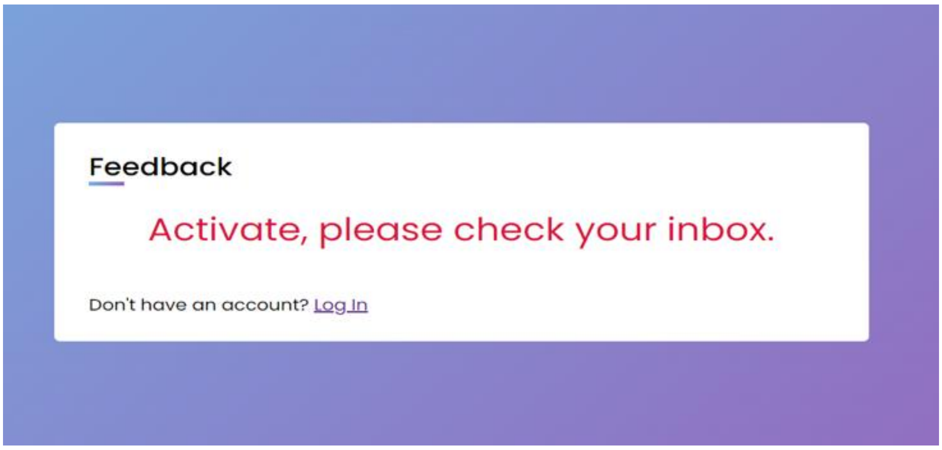


FIGURE 4.5.4: ACTIVATION PAGE

The user must check their email for an activation link. After clicking the link the will be redirected to this page. The user must click the button to activate the account.

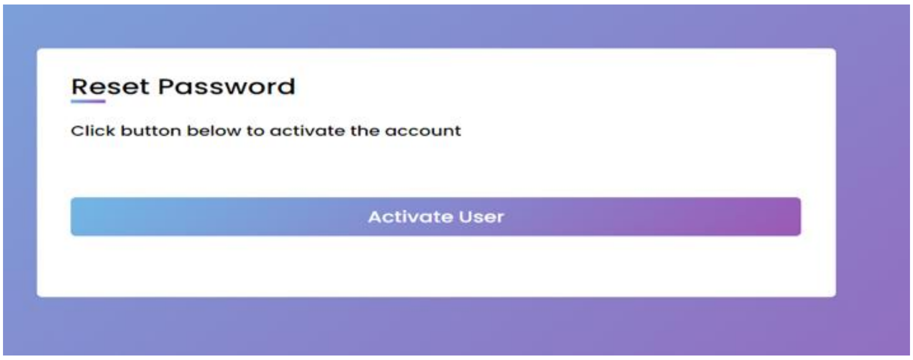


FIGURE 4.5.5: PASSWORD RESET PAGE

The user can now continue to login on the start page.

4.5.3.2 User login

User can login using their details on the home page below

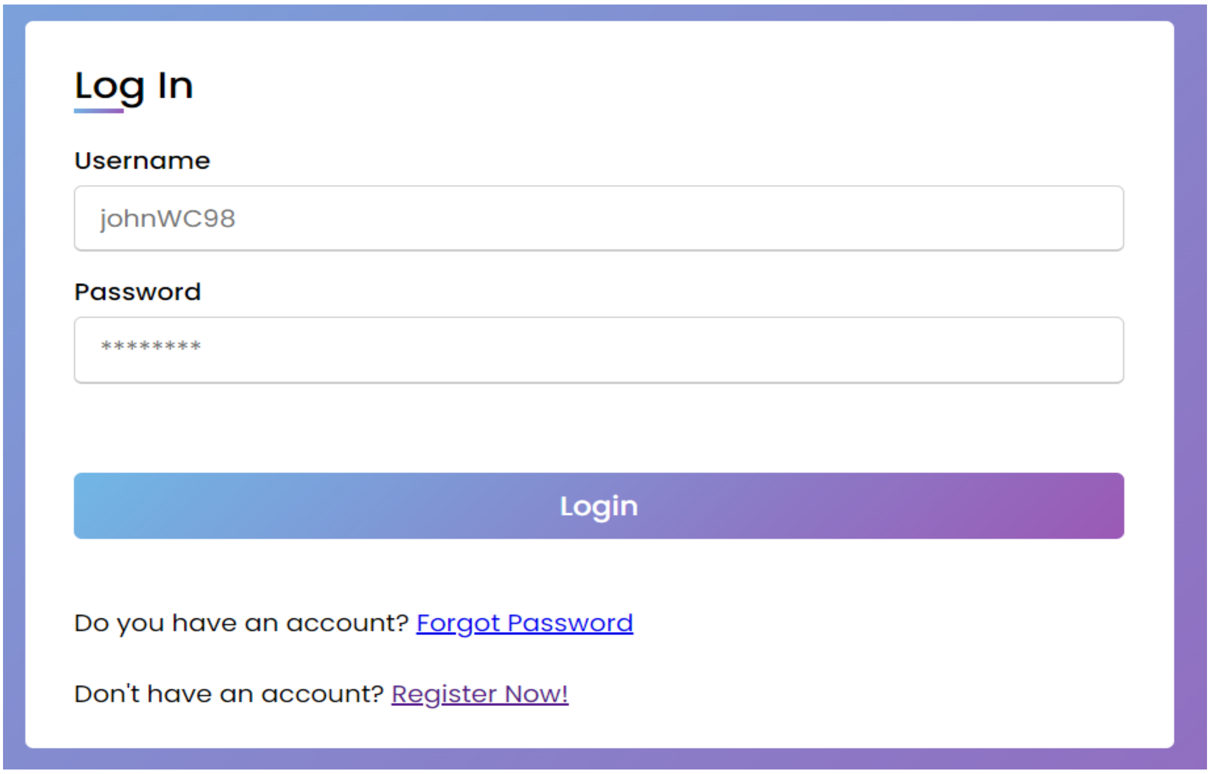


FIGURE 4.5.6: LOG-IN PAGE

After the user login they will be redirected to the home page below

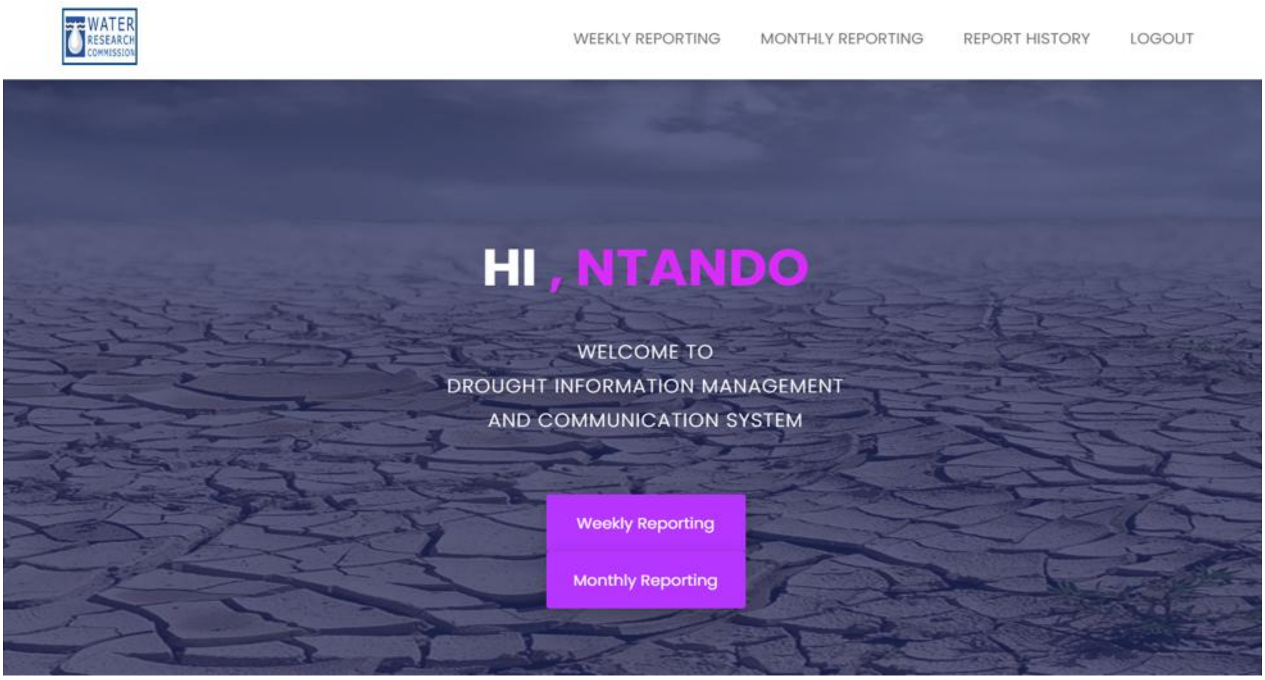


FIGURE 4.5.7: HOME PAGE

4.5.3.3 Weekly Reporting

User can access the weekly reporting by clicking the highlighted buttons on the home page

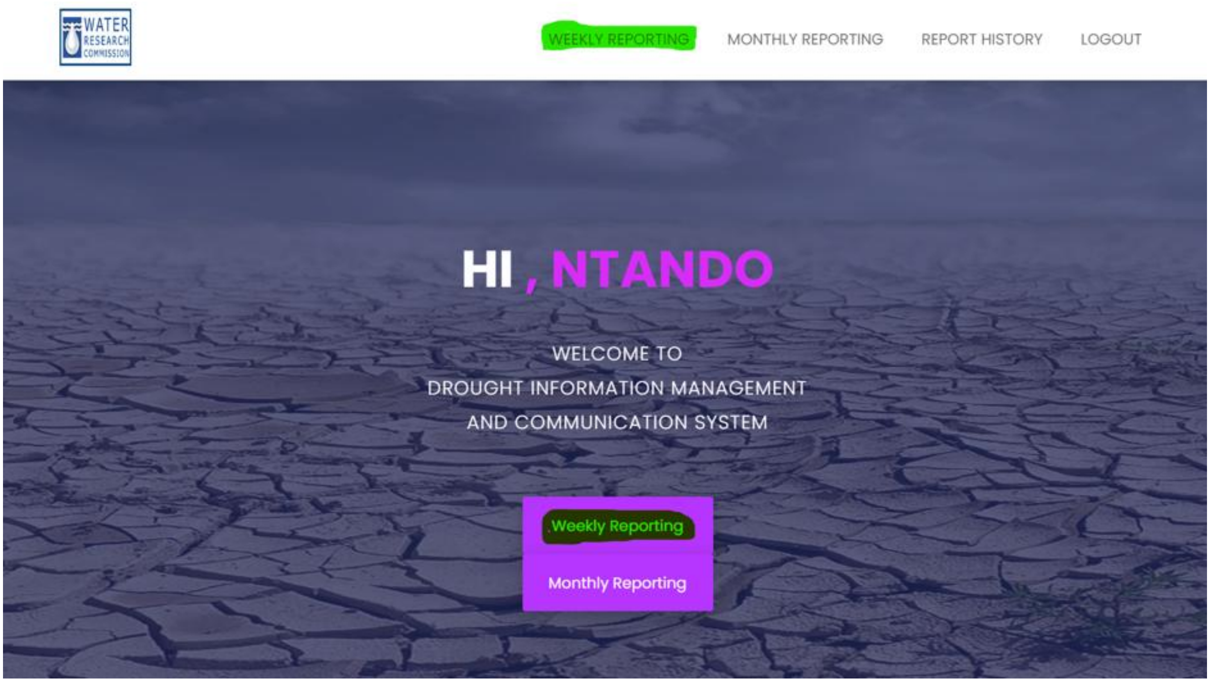


FIGURE 4.5.8: WEEKLY REPORTING HOME PAGE

After clicking the button the user will be presented with the page below where they must choose a week to perform reporting on as shown then start the survey

FIGURE 4.5.9: WEEKLY REPORTING WEEK SELECTION PAGE

The survey will have a number of options to select from every question as shown below

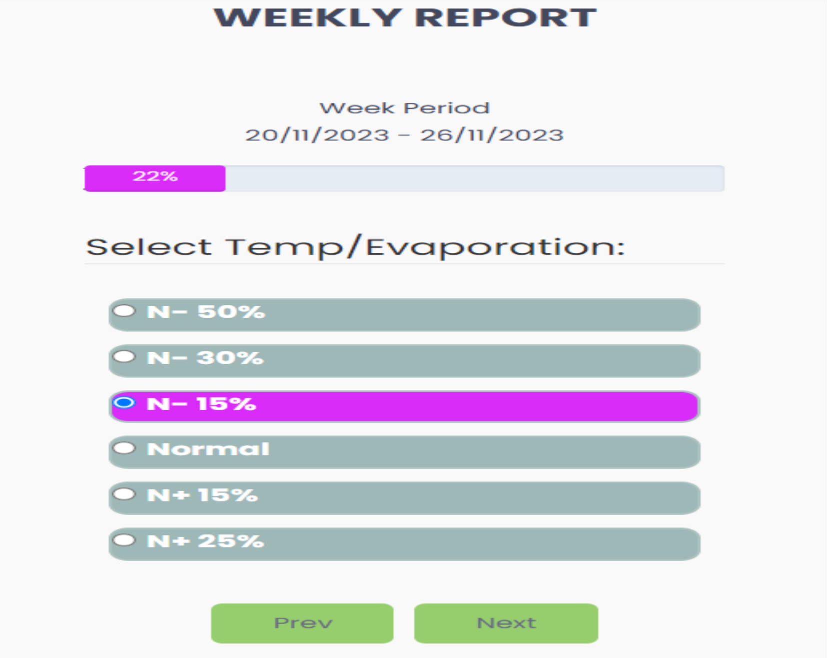


FIGURE 4.5.10: WEEKLY REPORT INDICATOR SELECTION PAGE

The user can finally submit the report when they reach the last question as shown below

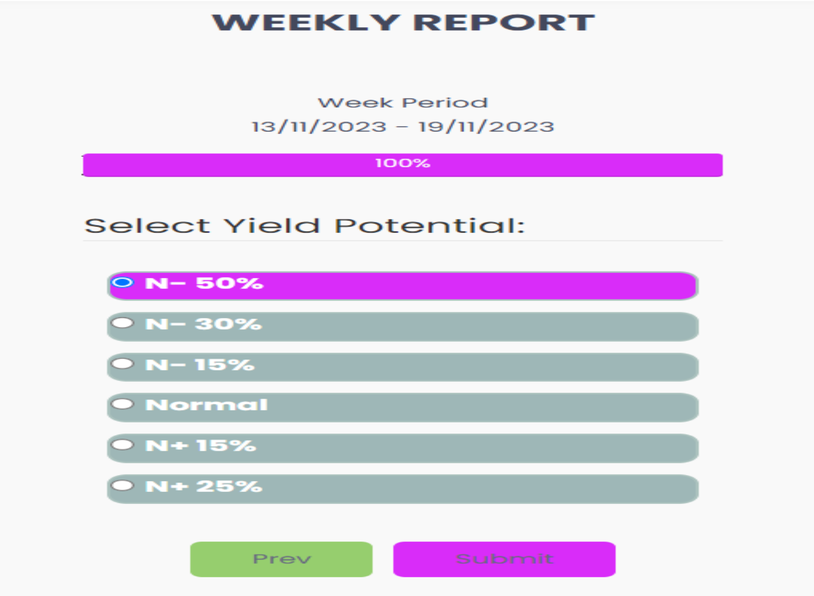


FIGURE 4.5.11: WEEKLY REPORT SUBMISSION PAGE

4.5.3.4 Monthly Reporting

User can access the weekly reporting by clicking the highlighted buttons on the home page

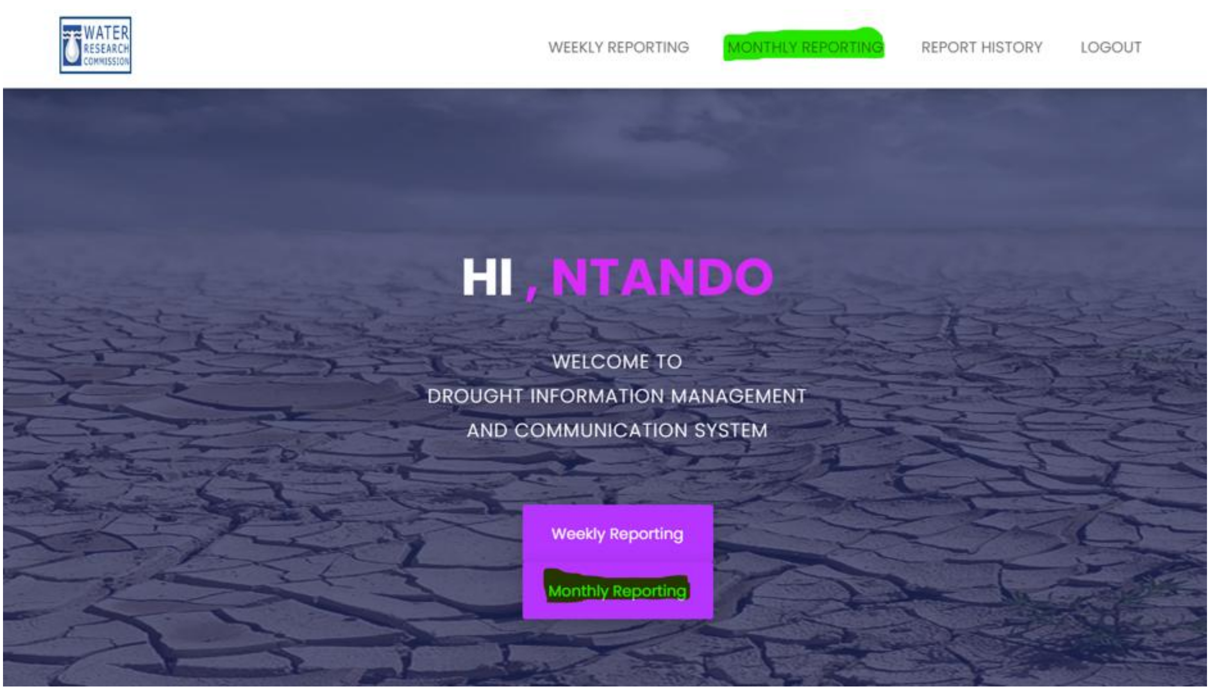


FIGURE 4.5.12: MONTHLY REPORT HOME PAGE

After clicking the button the user will be presented with the page below where they must choose a week to perform reporting on as shown then start the survey

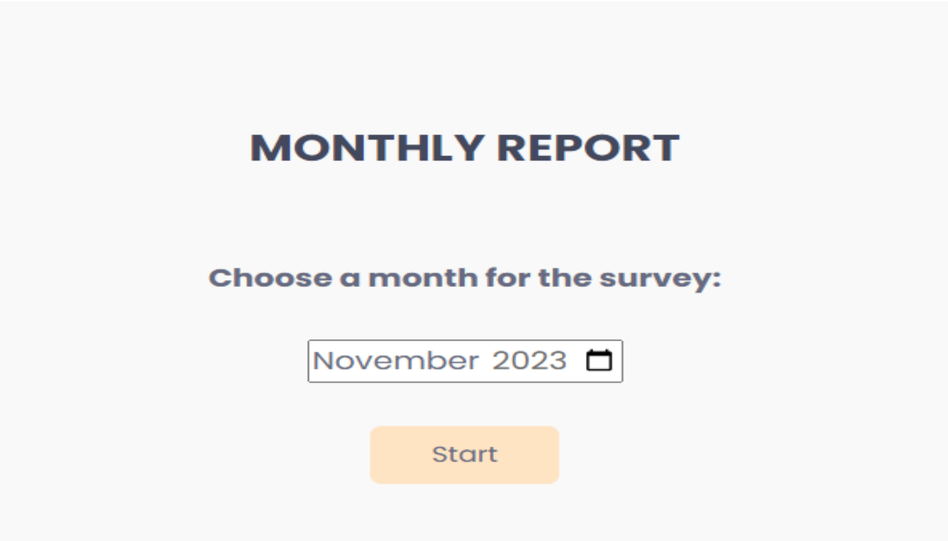


FIGURE 4.5.13: MONTHLY REPORT START PAGE

The survey will have a number of options to select from every question as shown below

FIGURE 4.5.14: MONTHLY REPORT DROUGHT INDICATORS - ANIMALS

The user can finally submit the report when they reach the last question as shown below

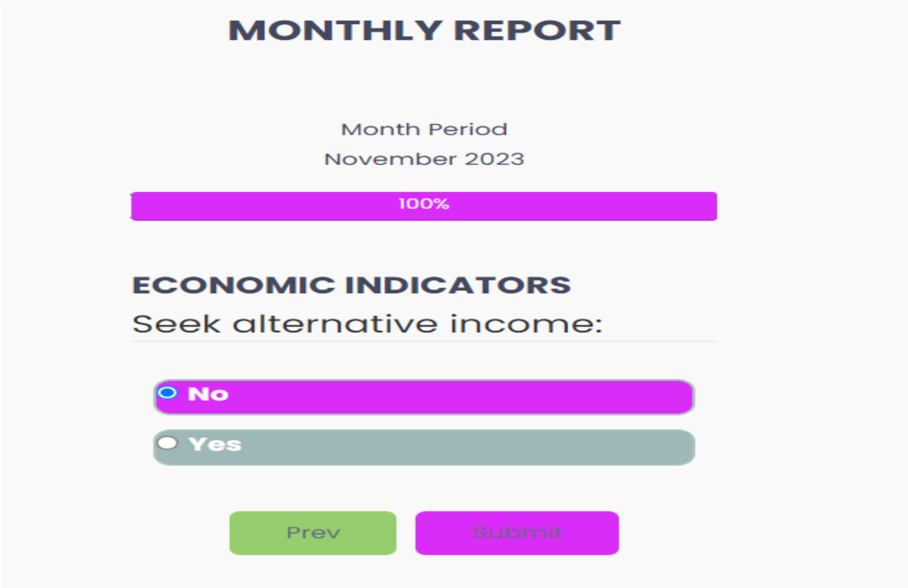


FIGURE 4.5.15: MONTHLY REPORT DROUGHT INDICATORS – ECONOMIC

<u>Monthly reporting templates</u>

Below are the monthly reporting templates to be completed by farmers. All information is compared with the long term history of the same corresponding month.

Meteorology

TABLE 4.5.4: PRECIPITATION INDICATORS REPORTING

Drought Category	D0 Seasonal Dry period	D1 1 in 3 yr	D2 1 in 7 Yr	D3 1 in 12 yr	D4; 1in 30-50yr
Deviation from the mean	<10%	11%-20%	21%-40%	41%-75%	>76%
Higher Temperature					
Less Rainfall					
Less Cloud cover					
More Whirlwinds					

Vegetation

TABLE 4.5.5: VEGETATION INDICATORS REPORTING

Drought Category	D0 Seasonal Dry period	D1 1 in 3 yr	D2 1 in 7 Yr	D3 1 in 12 yr	D4; 1in 30-50yr
Deviation from the mean	<10%	11%-20%	21%-40%	41%-75%	>76%
Plants wilted					
Grazing capacity loss					
Production loss					
Reserve feed and fodder used					
More feed and fodder purchased as a result of drought					

Animals

TABLE 4.5.6: ANIMALS INDICATORS REPORTING

Drought Category	D0	D1	D2	D3	D4;	

	Seasonal Dry period	1 in 3 yr	1 in 7 Yr	1 in 12 yr	1in 30-50yr	Not applicable
Deviation from the mean	<10%	11%-20%	21%-40%	41%-75%	>76%	
Animal condition loss						
More kraal feeding as a result of drought						
Less wool yield						
Less weight of progeny at weaning						
Forced sales of animal numbers (% of total flock)						
Increased mortalities of young animals as a result of drought						
Increased mortalities of older animals as a result of drought						
Less progeny						

Water

TABLE 4.5.7: WATER INDICATORS REPORTING

Drought Category	D0 Seasonal Dry period	D1 1 in 3 yr	D2 1 in 7 Yr	D3 1 in 12 yr	D4; 1in 30-50yr	Not applicable Don’t know
Deviation from the mean	<10%	11%-20%	21%-40%	41%-75%	>76%	
Lower groundwater levels ie boreholes						
Lower dam levels						
Lower stream flow						
Less water available for animals						

Soil

TABLE 4.5.8: SOIL INDICATOR REPORTING

Drought Category	D0 Seasonal Dry period	D1 1 in 3 yr	D2 1 in 7 Yr	D3 1 in 12 yr	D4; 1in 30-50yr
Deviation from the mean	<10%	11%-20%	21%-40%	41%-75%	>76%
Soil dryness					
More dust					

Social Impact as a result of drought

FIGURE 4.5.9: SOCIAL IMPACT INDICATOR REPORTING

Social impact as a result of drought	No	Yes
Higher stress than normal		
Cancellation of family holiday		
Labour retrenchments		
Struggle to pay school fees for children		
Stress in family relations		
Withdraw from social events		
Withdraw from leadership positions		
Family separation		
Consider suicide		
Migrate from farm for additional income		

Financial Impact

FIGURE 4.5.10: FINANCIAL IMPACT INDICATOR REPORTING

Financial impact as a result of drought	No	Yes
Stop capital expenditure		
Use savings to buy animal feed		
Consider debt consolidation		
Sales of liquid assets		
Sales of fixed non-farm assets		
Businesses at local town suffering		
Getting behind with instalments		
Farmers stop buying new vehicles		
Seek alternative income		

4.5.4 Administrative Account

4.5.4.1 User Enabling and Disabling

To log in to the application as an administrator you need administrative credentials which will be provided. After logging in as an administrator the start page you will be presented with the home page as shown below.

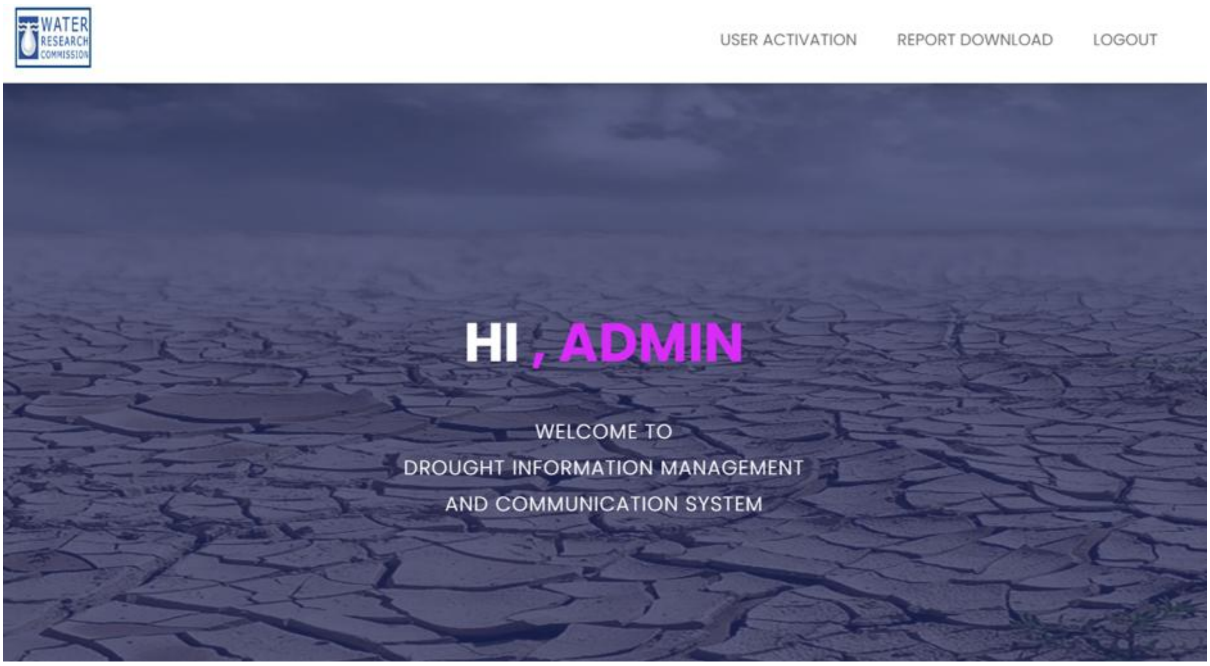


FIGURE 4.5.16: ADMIN HOME PAGE

As shown the admin user only has access to User Activation page and Report Download page. Thus, to enable or disable a user you must click on user activation navigation link. And you will be presented with the screen below.

USER ACTIVATION

USER ID	USERNAME	EMAIL	ACTIVE	
0	admin	zamacraig@gmail.com	☑	DISABLE
52	zama	zamacraig@gmail.com	☐	ENABLE
53	ntando	erica8th@gmail.com	☑	DISABLE

FIGURE 4.5.17: USER ACTIVATION

To activate a user, you must click enable next to that specific user and to disable the user you can click disable next to that user.

4.5.4.2 Downloading Report Data

The report data can only be downloaded to an excel sheet using the administrative account.

You must click Report Download from the homepage when logged in as the admin. You will be presented with a page below.

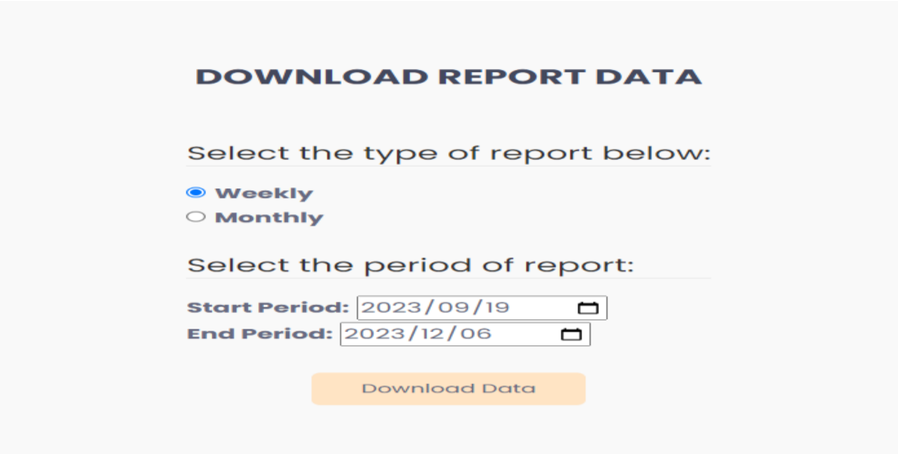


FIGURE 4.5.18: DOWNLOAD REPORT PAGE

To initiate the data download process, you will first need to indicate your preferred report type, with the weekly report preselected as the default option. Following this selection, you will be prompted to specify the desired reporting timeframe, encompassing both the commencement and conclusion dates of the reporting period. Once these date fields have been populated, simply click the "Download Data" button.

Subsequently, an Excel file will be promptly downloaded through your web browser. This Excel file serves as a repository of the report data, providing valuable information that can be harnessed for comprehensive analysis and assessment.

4.5.5 ARC Website login

When users register on the reporting website, they will automatically be registered on the ARC website that will be used for communicating the analysis. Users can log into the ARC website by opening this address on any browser https://www.drought.agric.za.

When the user opens the link, they will be presented with this start page where they can click on the login to access the login table as highlighted below.

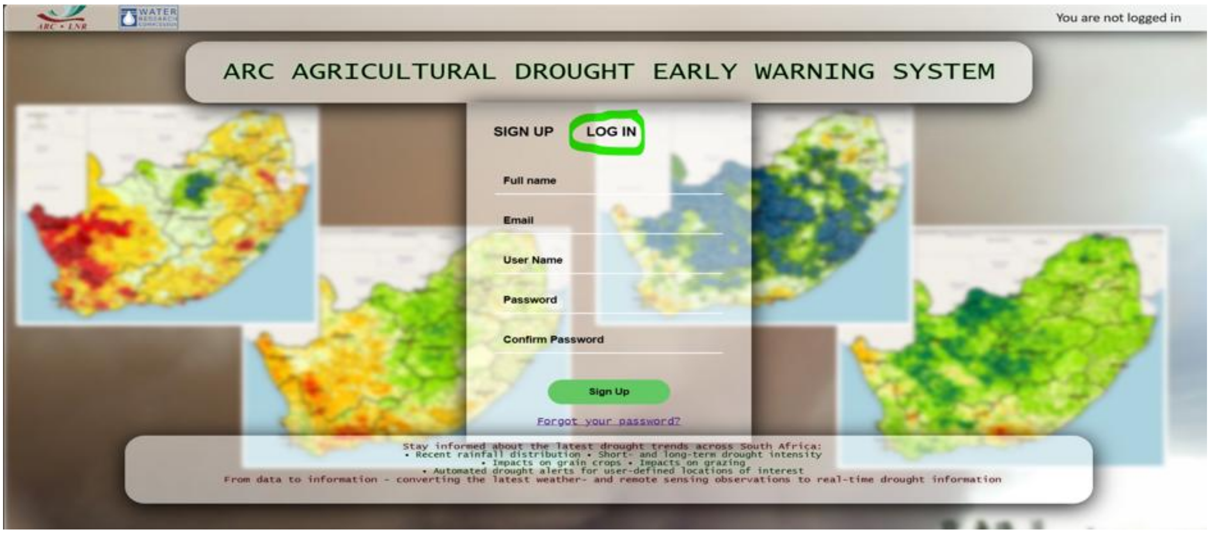


FIGURE 4.5.19: ARC WEBSITE LOGIN PAGE

After the user clicks login, they will be presented with this login page below

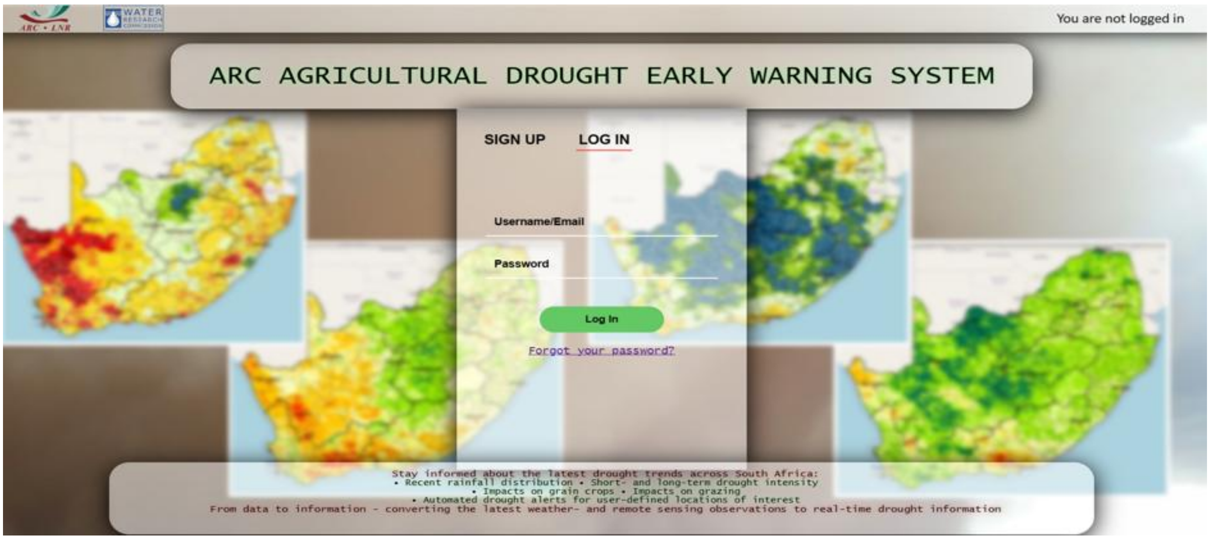


FIGURE 4.5.20: ARC LOGIN PAGE 2

The user can use the same credentials the used to register on the Reporting Website and click login and they will be presented with the home page below where insights on drought will be communicated to them.

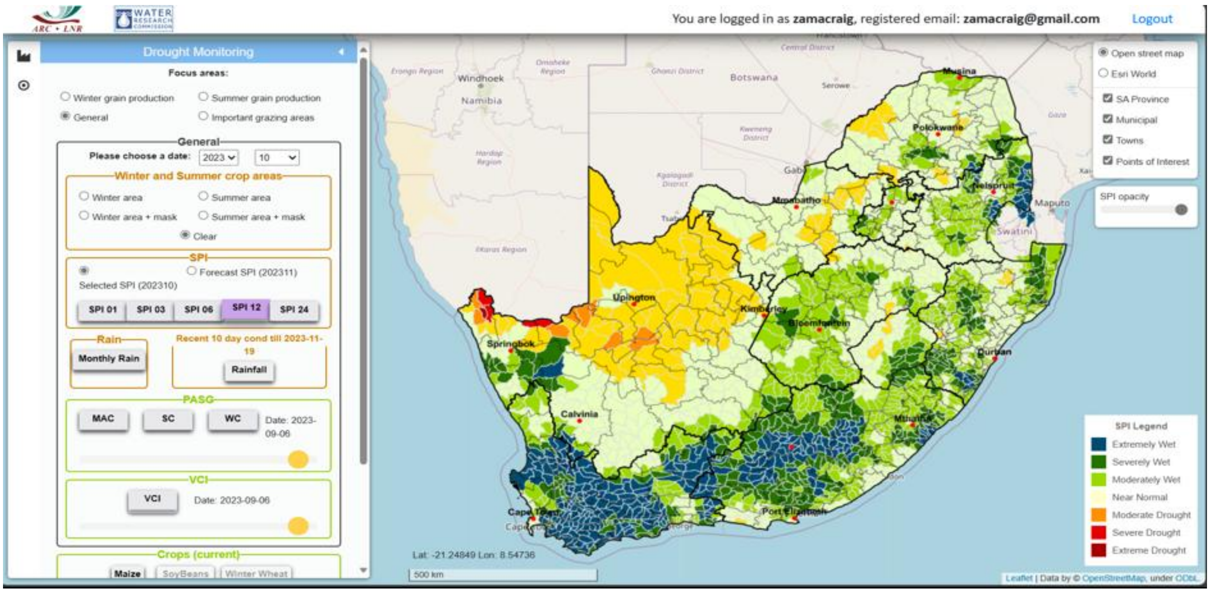


FIGURE 4.5.21: ARC DROUGHT REPORTING PAGE

4.5.6 Conclusion

The ARC website was created by the ARC and it has been online for a while now. After gathering enough data from the users, ARC will be able to start developing the report on their website to inform the users about the outcomes of the analysis.

4.6 Conclusion

The development of the DICMS supported with farm-level drought information represents a significant step forward in enhancing drought early warning and monitoring capabilities. This comprehensive web-based system, geared towards gathering and consolidating crucial data on drought indicators, holds the promise of providing reliable, timely, and actionable drought forecasts and assessments. By evaluating the severity of drought conditions and understanding their impacts, the DICMS empowers decision-makers with valuable insights.

Furthermore, the implementation of the DICMS has a pivotal role in drought classification within quaternary catchment areas, establishing the necessary thresholds for contingency plans. This report has delved into the fundamental aspects of data collection, emphasising the user-friendly nature of the platform tailored for farmers. The application's accessibility via mobile devices ensures broad usability, accommodating farmers from diverse backgrounds.

As we move forward with the DICMS, it is poised to become an invaluable resource for drought monitoring and analysis. The data collected through this system will not only inform decision-makers but also contribute to our understanding of drought conditions, enabling more effective response strategies. This report has outlined the journey of developing this essential tool, underscoring the importance of its user-centric design, cross-platform accessibility, and its role in advancing drought monitoring practices. The involvement and the support of the ARC is a key element in the sustainability of the system.

With this system in place, managed from an already proven platform at the ARC, farmers should be better equipped to address the challenges posed by drought and work towards more resilient agricultural practices and water resource management.

Chapter 5: Drought Contingency Plans for the Livestock Sector

5.1 Introduction

Drought has significant impacts on the agricultural sector in South Africa; this includes both environmental and socio-economic impacts, such as loss of employment, smaller crop yields, environmental degradation (such as depletion of groundwater resources and increased soil erosion) and increased food insecurity (Baudoin, et al., 2017). Smallholder farmers are particularly vulnerable to drought, as they lack the coping capacity of their commercial counterparts; however, drought also poses a substantial risk for commercial farmers, who are primarily responsible for food security throughout the country (Meza, et al., 2021). Furthermore, smallholder farmers in the Northern Cape are particularly vulnerable to drought as they lack land ownership, and the communal land which they utilise is often subject to overgrazing and application of inappropriate stocking rates, leading to land degradation (Jordaan, et al., 2015).

Further exacerbating smallholder farmers' vulnerability to drought is their lack of access to proper agricultural infrastructure and lack of social and financial resources (Ruwanza, et al., 2022); smallholder farmers often cannot handle a drought event without external support, such as financial packages from the government (Muthelo, et al., 2019). All these factors limit the resilience and adaptive capacity of smallholder farmers. According to Keshavarz, et al. (2013), other socio-economic impacts associated with drought include loss of income, conflict over remaining natural resources (such as water and grazing lands), forced migration and declining mental health, amongst others. It is thus evident that many of these drought impacts cannot be measured by way of meteorological data and/or through remote sensing technology, thus requiring drought monitoring on a local, farm-based level.

A contingency plan states what changes in management are necessary when conditions no longer conform to their normal ranges (Haigh, et al., 2021). Contingency plans provide a means to address disaster that may occur somewhere in the future and increase the coping capacity of those that are at risk (Lembara, et al., 2011). According to Mabaso and Manyena (2013), contingency planning contains six aspects: contingency planning is continuous (and must thus be evaluated regularly); it is based on policy which promotes adequate response; it encourages early response measures; the validation of contingency plans through preparedness planning; the efficient use of resources; and it must be a plan which is conceived through a participatory approach, which involves all relevant stakeholders, with clear delegation of responsibilities and promoting of proper coordination. Successful drought contingency plans need to meet several criteria, such as being based on a proper risk assessment, the inclusion of drought contingency plans in disaster risk management policy and legislation, effective public awareness campaigns, implementation of water conservation methods and the creation of emergency measures (Durley, et al., 2003).

The Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) is an international agreement which was adopted in 2015 during the third United Nations (UN) World Conference on Disaster Risk Reduction; the overarching goal of this framework is for countries to further enhance their DRR capacity and to improve their resilience towards disasters (United Nations Office for Disaster Risk Reduction, 2015). According to the Disaster Management Act (No. 57 of 2002), the National Disaster Management Centre (NDMC) is responsible for assessing risk and engaging in disaster risk reduction (DRR), which includes the development as well as the integration of methodologies related to plans and programmes which aid in DRR (The Presidency, 2003). Furthermore, according to Key Performance Area (KPA) four of the National Disaster Management Framework (NDMF) of 2005 (South African Government, 2005), the NDMC is responsible for disaster response and recovery, in which contingency plans play a crucial role.

Thus, to properly mitigate the various impacts of drought on the livestock farming sector in the Northern Cape, enhance resilience and engage in efficient DRR, contingency plans for the agricultural sector in the livestock farming industry need to be developed.

5.2 Problem statement

Drought poses a significant risk to farmers in the Northern Cape, and current drought management strategies are still very reactive, which leads to responses that suffer from poor coordination and which are ultimately ineffective (Sivakumar, et al., 2014); there is a need to engage in proactive behaviour regarding drought management and decrease losses associated with this hazard. According to Agri SA (2019), in 2019 more than 15 000 farms in the Northern Cape had been subject to prolonged drought, with over 20 million hectares of land having been severely impacted, as well as over 600 000 units of livestock; overall, over 27 million hectares of land and over a million livestock were adversely impacted.

The impacts of drought in the Northern Cape are further exacerbated by the high climatic variability of the province and its high levels of evaporation (Mukheibir & Sparks, 2005). Drought aid and relief by the government also often occurs too late (or not at all) or is ineffective and inadequate (Ruwanza, et al., 2022). The 2015/2016 drought led to the deaths of almost 650 000 livestock throughout the SADC region, due to lack of water and food (Nhamo, et al., 2019). There is therefore a need to develop appropriate response mechanisms to quantitatively determined drought categories to mitigate the various environmental and socio-economic impacts of drought and to reduce farmers' vulnerability and enhance their resilience.

5.3 Research objective

The main objective of this study was to develop contingency plans for livestock farmers in the Northern Cape, based on various drought categories (D0-D4), as determined by Jordaan (2022). These objectives seek to enhance drought mitigation and preparedness and, thus, move away from a reactive approach to proactive drought response and management.

5.4 Description of the study area

The Northern Cape is the largest province in South Africa. It borders the Free State and Eastern Cape provinces to the east, the North-West province the northeast, and the Western Cape province to the south. It is also bordered by the Atlantic Ocean in the west. In addition, it shares international borders with Namibia and Botswana. The image below illustrates the Northern Cape province's position within South Africa.

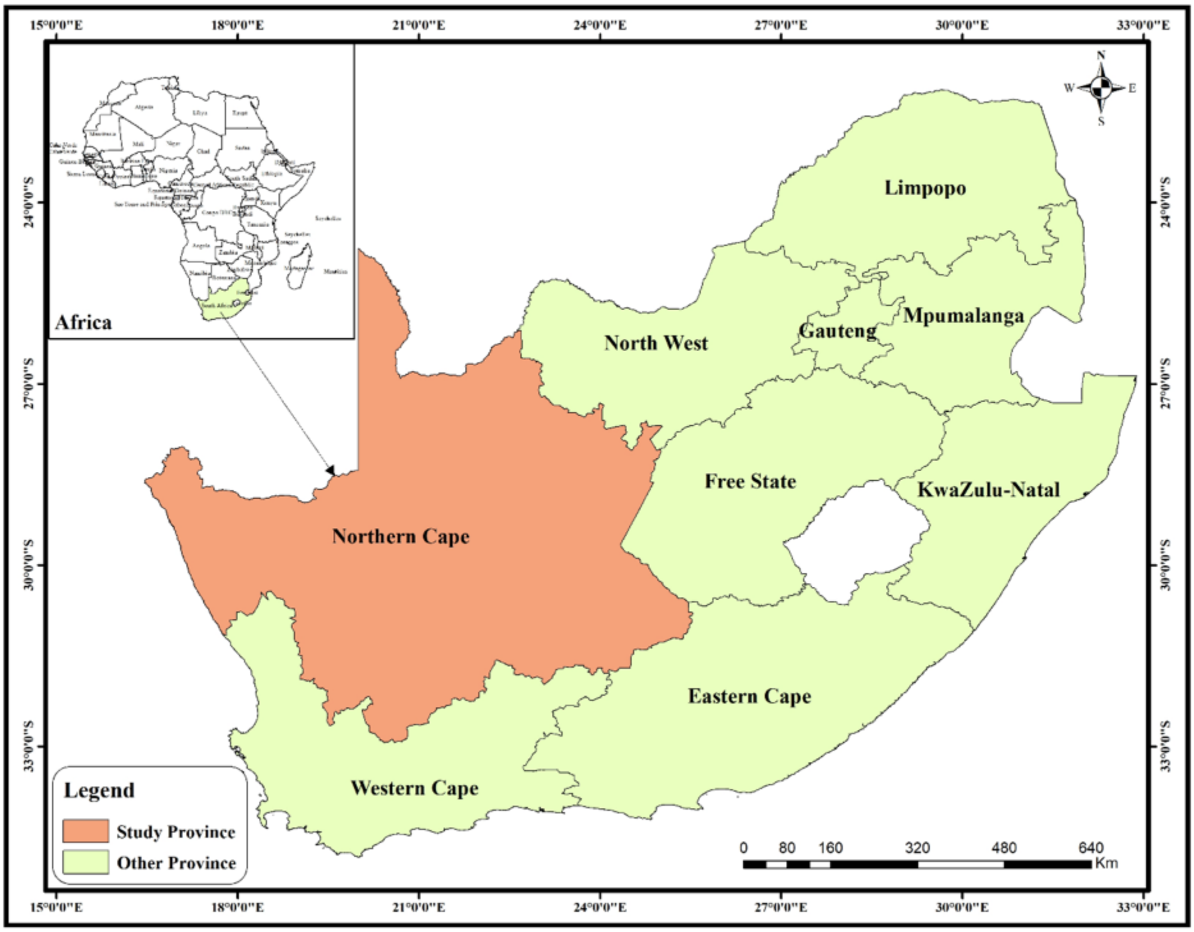


FIGURE 5.4.1: NORTHERN CAPE PROVINCE
Source: Mshelia (2023)

The Northern Cape is the province in South Africa with the largest surface area, covering approximately 36 274 000 hectares, or close to 30% of the country's land area (FAO, n.d.).

The largest city in the province is Kimberley, known for its diamond mining activities in the 19th and 20th centuries; it is also the provincial capital. The Northern Cape consists of 26 local municipalities and five district municipalities. The following images illustrate the district municipal boundaries and the local municipal boundaries in the province.

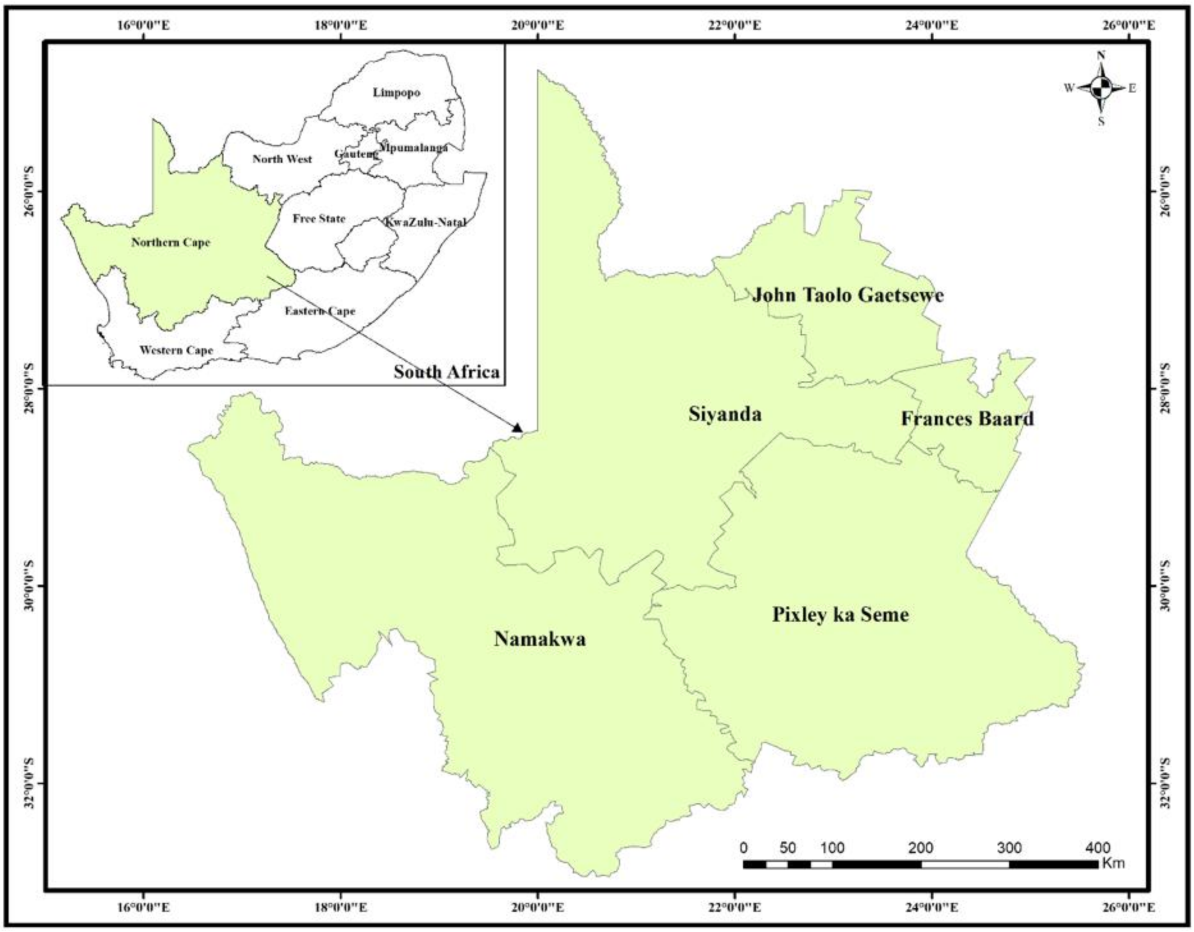


FIGURE 5.4.2: DISTRICT MUNICIPALITIES OF THE NORTHERN CAPE
Source: Mshelia (2023)

The Namakwa District Municipality is the largest in the Northern Cape and covers over a third of the province's land area; the district is one of the driest in the entire country, and faces significant issues regarding water availability, as well as having saline soils (Cooperative Governance and Traditional Affairs, 2020b). The ZF Mgcawu (previously known as Siyanda) District Municipality is the third largest in the Northern Cape, and covers a land area of approximately 102 000 km^2; it contains a significant portion of the Kalahari Desert and is known for its semi-arid climate with low average rainfall and high summer temperatures (Cooperative Governance and Traditional Affairs, 2020c). Pixley ka Seme District

Municipality is the second largest in the Northern Cape and covers approximately 103 410 km^2; the district has large climatic variability with rainfall ranging from approximately 130 mm to 300 mm and temperatures also range from -10°C in winter to over 40°C in summer (Pixley ka Seme District Municipality, 2014). The Frances Baard District Municipality is the smallest in the province (covering only approximately 3% of the land area) and is located in the northeast of the province; it is home to the Vaalharts irrigation scheme, which is the largest of its sort in South Africa (Cooperative Governance and Traditional Affairs, 2020a). It is also the district which receives the highest rainfall on average annually in the province at approximately 450 mm (Harmse, et al., 2019). John Taolo Gaetsewe District Municipality is the second smallest in the province, only covering approximately 6% of the land area (John Taolo Gaetsewe District Municipality, 2020). The district is also subject to wide rainfall variations, ranging from 500 mm in the southeast to 200 mm in the northwest, which is often received in a few heavy rainfall events at the end of the rainy season in summer (John Taolo Gaetsewe District Municipality, 2022).

- The Namakwa District Municipality contains the following local municipalities: Karoo Hoogland, Hantam, Khai Ma, Kamiesberg, Nama Khoi and Richtersveld.
- The ZF Mgcawu District Municipality contains the following local municipalities: Dawid Kruiper (previously comprised of Mier and //Kara Hais Local Municipalities), Kai! Garib, !Kheis, Kgatlelopele and Tsantsabane.
- John Taolo Gaetsewe District Municipality contains the following local municipalities: Gamagara, Joe Morolong and Ga-Segonyana.
- Frances Baard District Municipality contains the following local municipalities: Sol Plaatje, Dikgatlong, Phokwane and Magareng.
- Pixley ka Seme District Municipality consists of Siyancuma, Umsobomvu, Siyathemba, Ubuntu, Emthanjeni, Renosterberg, Kareeberg and Thembelihle.

The location of these local municipalities within the district municipalities can be seen in Figure 5.4.3.

FIGURE 5.4.3: LOCAL MUNICIPALITIES OF THE NORTHERN CAPE
Source: Mshelia (2023)

5.4.1 Geography of the Northern Cape

In the following section, the geography of the Northern Cape will be discussed, including its climate, water resources as well as soil type.

5.4.2 Climate

The vast majority of the Northern Cape has either an arid or semi-arid climate, with rainfall ranging from 20 mm on the coastal region in the west of the province, to over 500 mm in the eastern regions of the province close to the Free State; furthermore, the province is also subject to a wide range in temperatures, with minimum temperatures as low as -10°C in winter and maximum temperatures exceeding 40°C (Jordaan, et al., 2013). Most of the province receives its rainfall during the summer months, with only the region adjacent to the Atlantic Ocean receiving its rainfall during winter. The following Figure (Figure 5.4.4) illustrates the differences in average yearly rainfall throughout the Northern Cape.

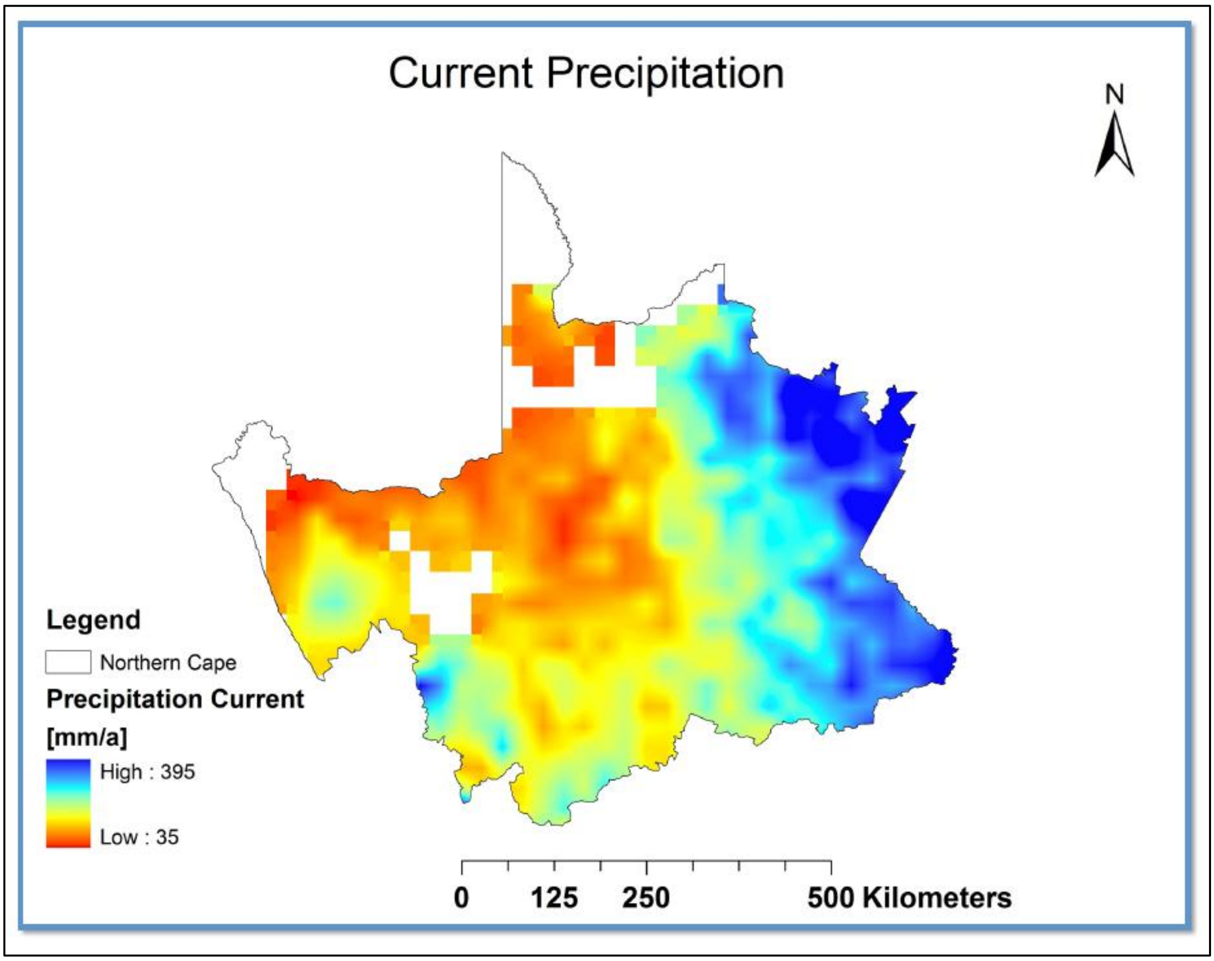


FIGURE 5.4.4: DIFFERENCE IN AVERAGE YEARLY RAINFALL IN THE NORTHERN CAPE
Source: Dennis (2009)

5.4.3 Water resources in the Northern Cape

Water is a critical element of any agricultural activity, and thus access to water resources may significantly enhance drought resilience (Jordaan, et al., 2017a). The two largest rivers in the country, the Orange and Vaal rivers, both flow through the Northern Cape and provide the largest perennial source of surface water in the province; however, a significant proportion of the province is reliant on groundwater to meet their needs (approximately 40% of all Northern Cape households) (South African Government, 2020). Furthermore, due to the arid nature of the Northern Cape, groundwater is a critical resource for livestock farmers in the province, as they provide virtually all the drinking water needed by livestock (Matlou, et al., 2021). The following image (Figure 5.4.5) indicates the approximate depth of the groundwater found throughout the Northern Cape.

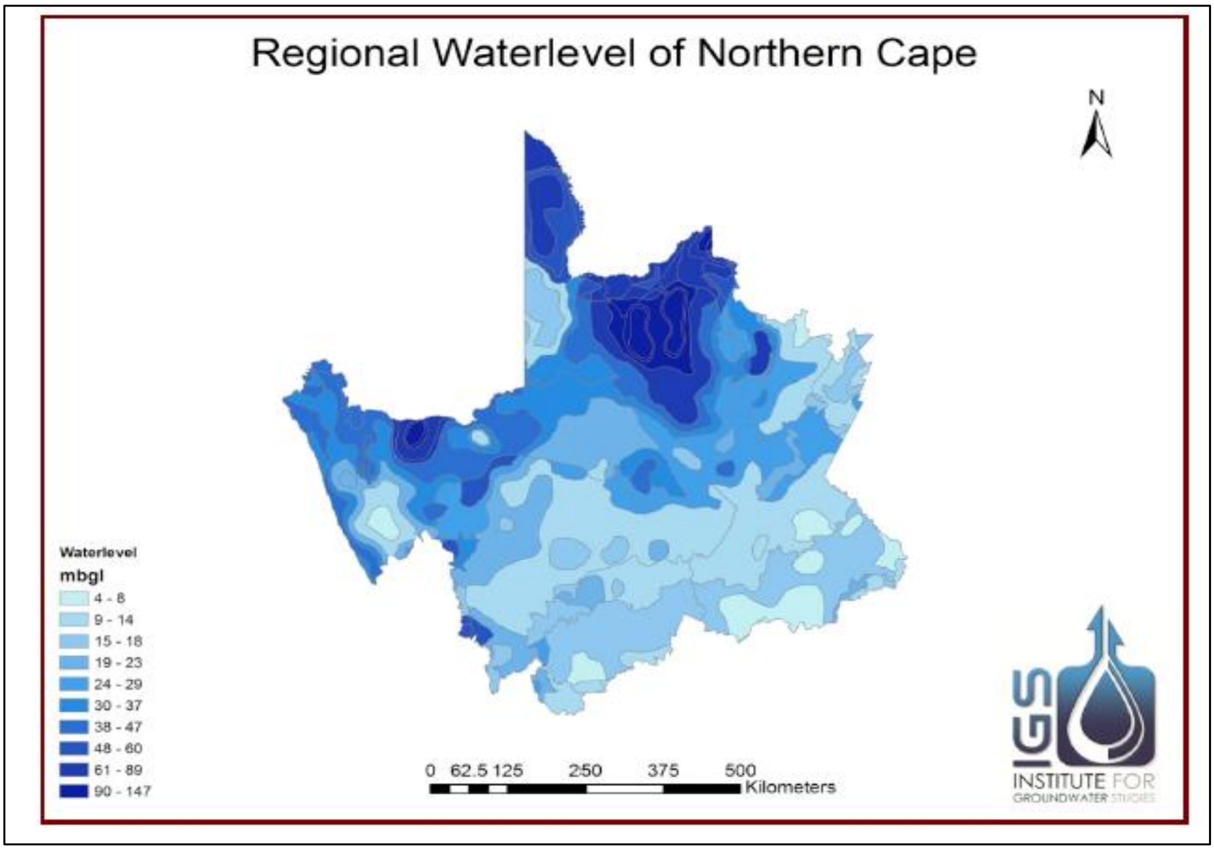


FIGURE 5.4.5: GROUNDWATER DEPTH IN THE NORTHERN CAPE
Source: Dennis (2011)

The Northern Cape also has many catchment areas; a catchment area is an area in which water (both surface and sub-surface) is drained to a certain point, with the unit of measurement in South Africa being the quaternary catchment (Department of Water and Sanitation, n.d.). The following image (Figure 5.4.6) indicates the quaternary catchment areas in the Northern Cape.

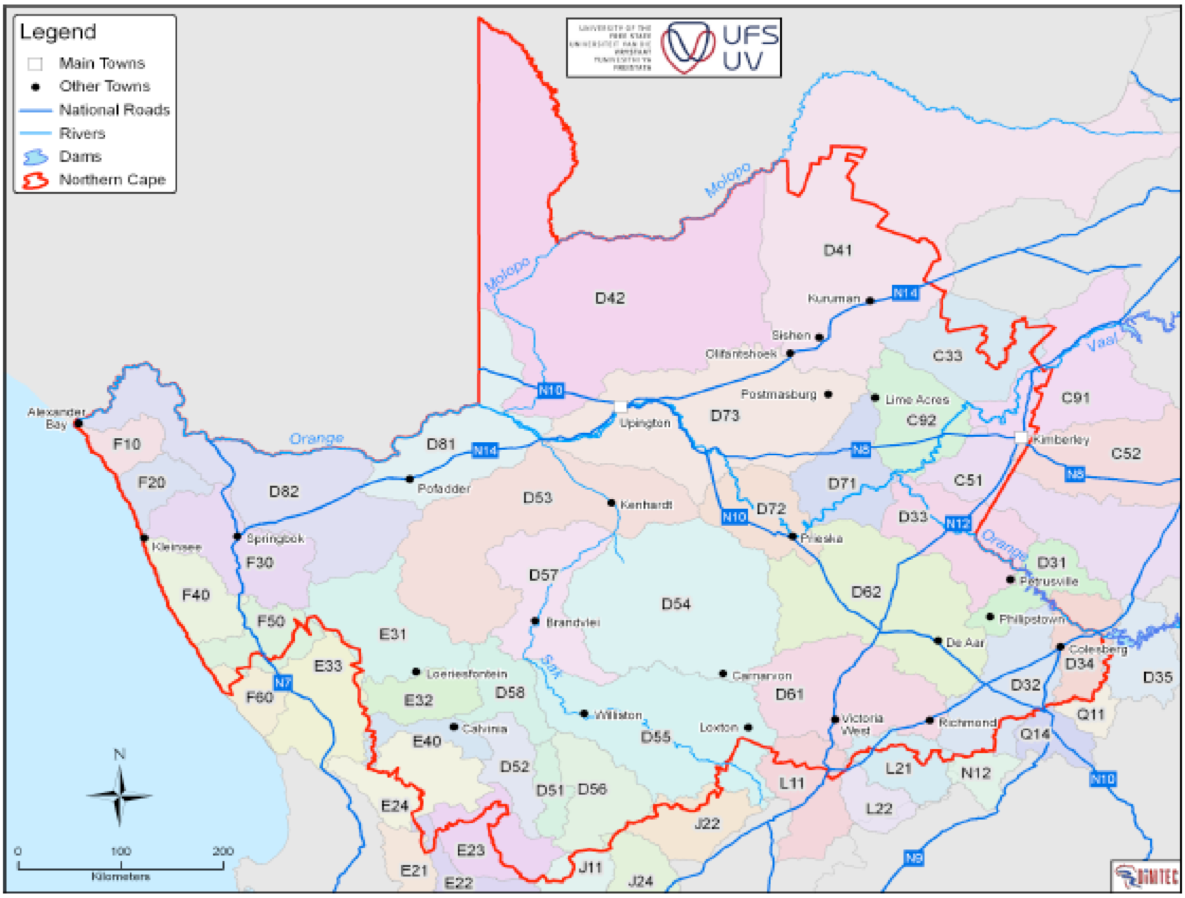


FIGURE 5.4.6: QUATERNARY CATCHMENTS IN THE NORTHERN CAPE
Source: Jordaan et al. (2015)

Grazing capacity can be defined as the approximate number of animals which a farm can handle on a sustainable basis, while stocking rate refers to the amount of land which is available for a single animal to graze on during the year; the grazing capacity of a farm is determined by its stocking rate (Galt, et al., 2000). As most farmers in the semi-arid and arid areas of Southern Africa (including the Northern Cape) depend on the natural vegetation as the primary source of feed for their livestock, it is critical that the grazing capacity is adhered to ensure that sustainable agricultural production can occur (Espach, et al., 2006). Studies conducted in the United States indicated that conservative stocking rates (a stocking rate which utilises approximately 35% of the available forage) helps the grazing lands maintain a much higher quality (Holechek, et al., 1999). The following image (Figure 5.4.7) indicates the grazing capacity (in ha/LSU) for the Northern Cape.

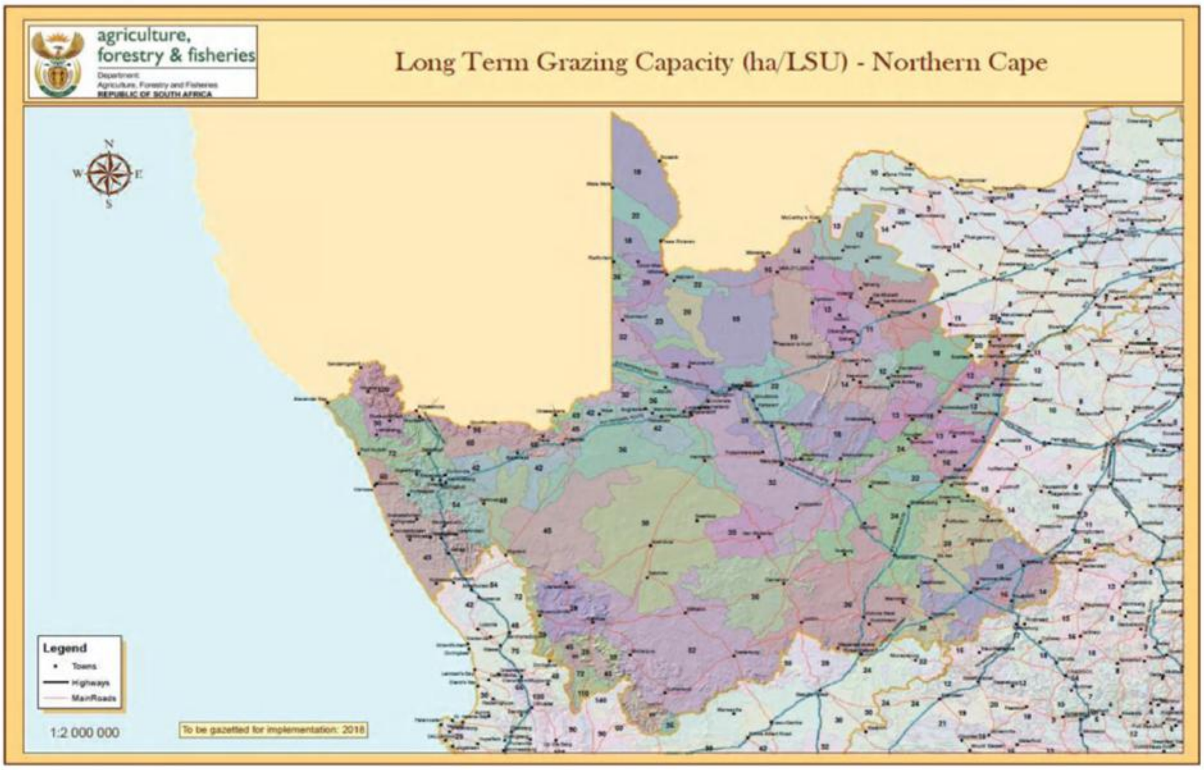


FIGURE 5.4.7. GRAZING CAPACITY FOR EACH NORTHERN CAPE DISTRICT
Source: DAFF (2018)

The following information indicates the average grazing capacities of the districts where the farms are located and in which research data was gathered:

- Xhariep District Municipality (Free State): 5 ha/LSU
- Thabo Mofutsanyana District Municipality (Free State): 4 ha/LSU
- Namakwa District Municipality: 39 ha/LSU
- Pixley ka Seme District Municipality: 32 ha/LSU, 18 ha/LSU, 24 ha/LSU
- John Taolo Gaetsewe District Municipality: 15 ha/LSU
- Frances Baard District Municipality: 9 ha/LSU, 12 ha/LSU

5.4.4 Conclusion

The Northern Cape is situated in the western part of South Africa and is the largest province in the country. The province has an arid to semi-arid climate with large variances in rainfall and temperature; generally, the average annual rainfall increases from the west to the east. A large proportion of the province's inhabitants are dependent on groundwater to meet their water needs; this is especially true for livestock farmers. Livestock farming is the dominant form of agriculture practiced in the Northern Cape, especially farming enterprises involving sheep and cattle.

5.5 Research methodology

5.5.1 Introduction

According to Bhattacharyya (2006), research can be defined as a purposeful investigation which aims to solve a specific problem or answer a specific question; these objectives are then realised using a systemic approach. In the following chapter, the methodology used to conduct the research will be thoroughly discussed; this includes the research design and data collection tools, population and sampling methods, and data reliability and validity.

5.5.2 Research design and data collection tools

Research design can be described as the process of obtaining answers to a specific research question or problem in a manner which is economical, timeous, objective, accurate and with minimum errors as well as variance (Jongbo, 2014). Research design also aids the researcher by providing a binding structure to the research and indicates how the different components in the research process work in conjunction to ultimately answer the research question or problem (Asenahabi, 2019). This study followed an exploratory research type, more specifically an experience survey, which involves gathering data from specific individuals who are familiar with the research question and have experience in dealing with the problems related to it (Kothari, 2004).

This study followed a qualitative research approach, to gain a better understanding behind farmers' experience with drought events and the reasoning behind their drought management practices. The use of semi-structured interviews was deemed the most appropriate data collection tool, as this allowed for the necessary data regarding drought management practices to be obtained, but also allowed for a sufficient degree of freedom for livestock farmers to provide any additional information not explicitly asked for in the interview and for them to highlight any specific areas of expertise or interest that they may have (Horton, et al., 2004).

5.5.3 Population and sampling

A population can be defined as the entirety of a certain group from which information must be obtained to conduct a study (Banerjee & Chaudhury, 2010). However, when conducting research, it is often not feasible to obtain the necessary information from the entire population and thus a sample is utilised; a sample can be defined as a certain representative part of the population which is to be studied (Majid, 2018). A representative sample is useful as it results in lower research expenses, reduces the time necessary to conduct the research and can be conducted by fewer people (Acharya, et al., 2013). There are two types of sampling which are utilised in research: probability sampling and non-probability sampling (Etikan & Bala, 2017). Both will be briefly discussed as follows.

5.5.3.1 Probability sampling

Probability sampling is the process of selecting a sample and that each person in the population has an equal chance of being included in the study sample (Barreiro & Albandoz, 2001).

5.5.3.2 Non-probability sampling

Non-probability sampling involves the selection of a sample not based on any form of probability; non-probability sampling is often more time-efficient and more cost-effective compared to probability sampling (Rahman, 2023). However, this means that using non-probability sampling also inevitably leads to some selection bias; statistical inference can also not be applied (Vehovar, et al., 2016). The researcher does not necessarily have to select a representative sample, with the researcher selecting the sample to best suit the needs of the study (Etikan & Bala, 2017).

This study utilised both purposive and snowball sampling. The study leader first provided names of farmers known to him and who are located throughout the Northern Cape, which were contacted to ask if they wished to participate in the study. These farmers were then also asked if they knew of any additional farmers in the Northern Cape who would potentially want to participate in the study. Both of these techniques were useful in identifying study participants.

5.5.3.3 Sample size

The sample size for this study was determined by the concept of saturation; saturation is achieved when the data provided by the growing sample as the study progresses stops producing new information or themes and thus becomes ‘saturated’ (Marshall, 1996). According to Morse (2015), due to the relatively small sample sizes typically utilised in qualitative research, the sample must be both appropriate (the participants should be experts in the relevant research topic) and adequate (for the process to be replicable). Furthermore, Marshall (1996) states that a sample size which allows for the research objective to be achieved is adequate. The knowledge and data which the researcher possesses also influences the sample size (Mthuli, et al., 2022); if the sample size utilised can adequately meet the research objectives, it is sufficient. The sample size utilised in this study was 14 farmers, known for good drought management principles; this sample size was sufficient to achieve saturation and to achieve the research objective.

5.5.4 Data analysis

Data analysis in terms of qualitative research involves the processing of the data (such as transcripts, audio, notes or videos) in a systematic manner and ordering it, thus transforming large amounts of collected raw data into useful information, and subsequently gaining a better understanding of the data and being able to draw logical conclusions from it (Wong, 2008). When analysing qualitative data, one of two approaches can be used: the inductive approach (which involves data analysis with little or no predetermined theory or framework present) and the deductive approach (which involves the use of a predetermined framework to aid in data analysis) (Burnard, et al., 2008). When analysing qualitative data, various steps are followed: first, the raw data is converted to a more useful format, then the data is cleaned (redundant or repetitive information is eliminated), and finally, the data is coded (typically according to categories and themes) (Male, 2016).

The data collected for this study was in the form of audio recordings from semi-structured interviews with livestock farmers. The raw data, in the form of the audio recordings, was listened to, and information from each relevant section of the questionnaire was written down in the form of notes and summarised. This was done with each farmer interview. The data was then coded in the form of five categories (biographic information, grazing management, livestock management, financial management and social management) and then this coded data was integrated with the relevant drought categories to create the drought contingency plans.

5.5.5 Data validity and reliability

The reliability and validity of the research findings from this study were determined by assessing whether the research tool (semi-structured interview questionnaire) provides the necessary information to reach the research objective. Each of the cases from the sample were also compared to each other to check for similarities and differences in each of the responses and, thus, to ensure that all perspectives are accounted for. The research findings were also examined by the study leader to ensure their validity. Research findings were also compared to the information contained in the literature review to further ensure data validity.

5.6 Research process

Potential participants were identified through purposive and snowball sampling. Respondents were selected based on their reputation as conservation farmers with excellent drought management principles. Interviews were then held with participants in person; a total of 14 participants were interviewed, at various locations in the Northern Cape. The interviews were conducted in Afrikaans. This number of participants proved to be satisfactory for saturation to be achieved. Audio recordings of the interviews were made and then analysed after the interviews were concluded; the data was then coded according to each relevant management section. The most significant challenge during the research process was that participants struggled to grasp the concept of the drought categories; they had difficulty distinguishing between categories and consequently struggled to define their drought management practices and adaptation measures according to the various categories.

5.6.1 Conclusion

This study utilised a qualitative research approach to better understand farmers' experience with drought and why they apply certain drought management practices. The type of research which was used was exploratory. There are typically three data collection tools used in qualitative research; in-depth interviews, focus group discussions and participant observation (Mack, et al., 2005). This study utilised semi-structured interviews to allow for the necessary data to be obtained, but also allow for an adequate degree of freedom. A total of 14 livestock farmers/drought experts were interviewed; according to the principle of saturation, this number proved to be sufficient for the study. The validity and reliability of the data were ensured by checking whether the research tool provides the necessary information to reach the research objective, consulting with the study leader and comparing the research findings with the literature review.

5.7 Contingency plans for drought management

5.7.1 Introduction

According to the United Nations International Strategy for Disaster Reduction (UNISDR) (2009, p.7), contingency planning can be defined as:

> *A management process that analyses specific potential events or emerging situations that might threaten society or the environment and establishes arrangements in advance to enable timely, effective, and appropriate responses to such events and situations.*

Drought contingency planning is of utmost importance to mitigate the various environmental, social, and economic impacts of drought, and to make those who are vulnerable to drought more resilient (Mabaso & Manyena, 2013). According to the U.S. Department of the Interior, Bureau of Reclamation (2016), the process of contingency planning must be formulated in such a way to answer three questions. The first question is how the drought will be identified in its infancy stages. The second question is what impacts the drought will have (social and economic), and the third question is what preventative measures can be taken to mitigate the impacts of future drought events.

According to Jordaan (2020), drought contingency planning is done after conducting a drought risk assessment, and is divided into four separate phases:

i. The first phase is the demarcation of the specific sector (or area); this study looks at contingency for the livestock sector and will thus contain the relevant plans to mitigate the negative impacts of drought on this sector.
ii. The second phase is the categorisation of the drought as either meteorological, agricultural, hydrological, or socio-economic through the conduction of a drought risk analysis. Vulnerability to the drought can be defined as the vulnerability of the previously identified sector to the drought, while the coping capacity can be defined as the capacity possessed by the specified sector to handle the drought.
iii. The third phase is where the drought assessment is done; this involves the conducting of cost-benefit analyses, determining what the acceptable level of risk is, the refinement of existing measures of risk reduction, and the determination of potential scenarios that may occur. The conducting of drought risk assessment and drought analysis is extremely important to promote effective risk reduction, with their main goal being the understanding of the problem faced by the specific sector.
iv. The fourth and final stage is to develop a drought management plan, which is derived from the results obtained in the risk assessment and risk analysis procedures. Drought preparedness, the reduction of drought risk, sound agricultural management practices, use of drought early warning systems, the monitoring of drought, and the inclusion of contingency plans for effective response must all be present in the drought management plan.

Figure 5.7.1 illustrates the relationship between contingency planning and the various categories of drought.

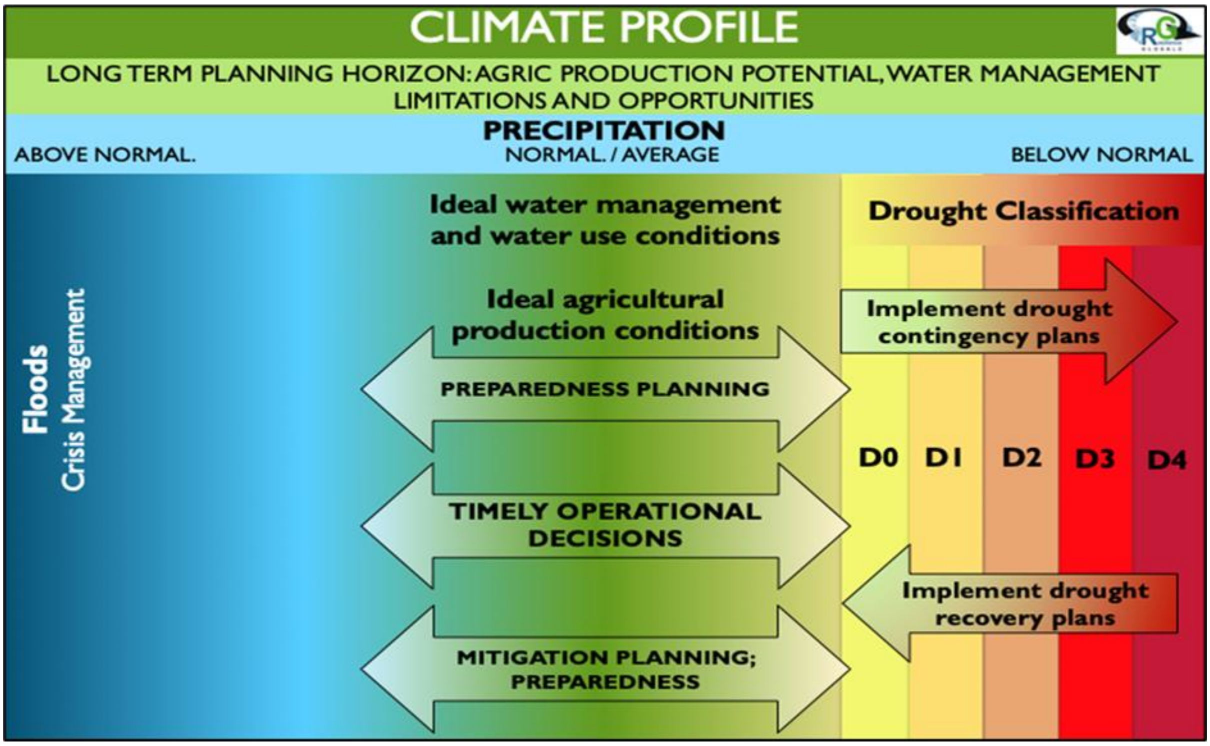


FIGURE 5.7.1: RELATIONSHIP BETWEEN DIFFERENT DROUGHT CATEGORIES AND CONTINGENCY PLANS
Source: Jordaan (2020)

5.7.2 Drought management plans

There are two approaches which are commonly utilised when dealing with drought (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014):

i. The first approach is the reactive or crisis management approach, which focuses only restoring an area which was affected by drought to its previous state through responsive actions by the government and other private donors (such as fodder and water provision); thus, this form of drought management only addresses the ‘symptoms’ of drought and does not involve those affected by implementing any form of drought risk reduction.

ii. The second approach involves engaging in drought preparedness by engaging in proactive behaviour to reduce drought risk; this approach will reduce vulnerability by raising awareness about drought, providing drought early warnings, and providing communities with the means to adapt and thus mitigate the adverse impacts of drought, increasing their resilience.

The risk reduction approach to drought management is important to reduce the impacts of drought through the use of DEWS, implementing drought preparedness measures to enhance the capacity to cope with drought and to engage in a more effective emergency drought response; ultimately these measures will aid in promoting sustainable development (Sivakumar, 2011). According to Nicholson et al. (2011), Australia implemented a National Drought Policy with the aim of proactively managing drought risk in the agricultural sector; the aim of this policy was to: 1) encourage farmers in Australia to adapt to changing climatic conditions and consequently reduce reliance on external support; 2) engage in conservation agriculture during periods of drought to protect the environmental and agricultural resources, and 3) enhance the recovery efforts of the agricultural sector after a drought event.

Another critical element of drought risk management is coordination; effective drought mitigation and response requires a multisectoral approach involving all relevant stakeholders, such as the government, NGOs, private sector entities, academic and scientific institutions, and local communities (Motha, 2011). The UNDP (2011) identified four elements which are required to engage in effective coordination for drought risk management:

i. A stakeholder analysis must be conducted. This is to ensure that all relevant stakeholders are aware that they will participate in drought risk management activities.
ii. The responsibilities and roles of each stakeholder must be clearly stated. In addition to this identification of roles and responsibilities, clear channels of communication are critical as well as to adopt measures of accountability.
iii. It is important that the drought risk management stakeholders are given the appropriate resources to effectively engage in their agreed upon tasks.

iv. It is important to establish milestones and benchmarks for the stakeholders, which can be done using a road map. This will aid in measuring the performance and success of the interventions.

To engage in effective drought risk reduction, it is important for a national drought policy to arise which shifts the focus from the existing 'crisis management' approach to one which promotes a proactive approach to drought management; however, this is often a complex process which requires effective coordination and the political will of the government to implement (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014).

A study conducted by Makaya et al. (2020) in Limpopo identified enablers and barriers at community level, as well as enablers and barriers at district level regarding drought management:

i. Enablers at community level include the structures of community leadership, extension services, presence of farming communities and groups who engage in water monitoring.
ii. Barriers at community level include the overall lack of knowledge regarding proactive drought management practices, relatively low number of skilled individuals in communities, and lack of access to necessary financial resources.
iii. Enablers at district level include the presence of committees overseeing disaster management, the availability of information related to drought management and the presence of institutions overseeing water management.
iv. Barriers at district level include slow pace of decision-making due to departmental meeting schedules, poor financial situation and a lack of communication and quality information.

5.7.3 Risk reduction and response measures to be included in the drought management plan

In the following section, the various drought preparedness and response measures with regard to grazing land management, livestock management, financial management and social management will be discussed.

5.7.3.1 Sustainable land management

Sustainable land management (SLM) can be defined as a management approach (which considers both prevalent socio-economic and environmental conditions) which aims to protect, conserve and promote the sustainable use of natural resources such as water, soil and biodiversity; it also aims to restore those natural resources which have undergone degradation and restore the services provided by ecosystems (FAO, 2023a). Furthermore, according to the UNCCD (2017), SLM preserves ecosystem services through the incorporation of socio-economic and environmental needs in a holistic manner, ultimately contributing to the achievement of the Sustainable Development Goals (SDGs).

Drought is a major contributing factor in land degradation, and often has severe impacts on the health of grazing lands and crop lands (see Chapter 4 on Environmental Vulnerability) (Graw, et al., 2017). Thus, to properly mitigate the impacts of drought and to effectively engage in drought risk reduction, it is critical for farmers to adopt SLM practices. For livestock farmers in the Northern Cape, this will involve implementing effective grazing management strategies (Sanz, et al., 2017).

Grazing land management

In the following section, grazing land drought preparedness and response measures will be discussed.

Preparing for drought

Grazing land management is of great importance in SLM as it greatly influences the ecosystem services provided by the grassland ecosystem, such as soil erosion control (Li, et al., 2021).

The selection of an appropriate stocking rate (and thus ensuring that the carrying capacity of the grassland is not exceeded) is an extremely important aspect of grazing management (Smart, et al., 2010). Sanz et al. (2017) identified various grazing management practices that promote SLM and help farmers prepare for drought:

i. Selecting an appropriate stocking rate per ha.
ii. Implementing rotational grazing, to ensure that grazing lands have adequate time to recover.
iii. Resting of grazing lands for a select period to ensure that vegetation properly recovers.
iv. Closing of a region to grazing to rehabilitate degraded grazing lands.
v. Use of shrubs to rehabilitate grazing lands.
vi. Restoration of degraded pastures.
vii. Irrigation of pastures and fields early to ensure adequate soil moisture during dry periods.

Snyman and Van der Westhuizen (2016) also identified various strategies regarding the management of grazing land during drought conditions:

i. The grazing land vegetation must be given the opportunity to properly spread seed.
ii. Ensuring that the stocking rate is appropriate for the carrying capacity of the farm.
iii. Systems of grazing should allow for a degree of flexibility regarding drought; they must be sufficient for periods of drought and make provision for grazing land recovery after wildfire events. It is thus important to have fodder reserves to keep the core breeding livestock alive.
iv. Ensure an appropriate number of grazing camps are available.
v. Do not let overgrazing occur, as this will severely inhibit the vegetation’s ability to recover in a timely manner.
vi. Ensure adequate vegetation cover to prevent excessive soil moisture evaporation and soil erosion.

According to Du Pisani (2019), grazing lands which are sustainably managed and in good condition possess four advantages compared to land in poor condition. The first advantage is that the soil has a larger water storage capacity. The second advantage is that plants which are present in high quality grazing lands utilise water more efficiently (they produce more material with the same amount of water). The third advantage is that the plants which are present in high quality grazing lands possess better nutritional value than those plants in degraded lands. The fourth advantage is that high quality grazing lands are more profitable, as they provide superior margins of profit per hectare of land.

Responding to drought

Howery (2016) also identified various practices which can help mitigate impacts during a drought event:

i. Continuously monitor the health of the grazing lands.
ii. Ensure that enough water is available to livestock at appropriate locations where there is adequate forage as well.
iii. Utilise reserve fodder which has been stockpiled during normal periods to feed animals.

Kachergis et al. (2014) also identified the following grazing management practices which can help farmers cope in response to a drought event:

i. Purchasing of additional fodder
ii. Leasing of additional land
iii. Feeding of livestock in lots
iv. Move livestock to areas with better grazing land.

Du Pisani (2017) also states that it is preferable to establish dryland lucerne and purchase maize to prepare for drought, rather than establishing dryland winter pastures; the establishment of irrigated pastures (if possible) also enhances drought preparedness. The drilling of additional boreholes to provide water for pastures and animals, adoption of more efficient irrigation technologies and engaging in soil and water conservation practices (such as terracing and pitting) are also response measures often implemented by farmers to cope with drought (O'Farrell, et al., 2009).

5.7.3.2 Livestock management

The effective management of livestock during a drought period is a critical coping mechanism for farmers, to ensure that productivity is maintained to the best extent possible during the period of drought (Ndlovu, 2019). Jordaan (2011) identified the following livestock management measures which Northern Cape farmers implemented during periods of drought:

i. Farmers purchase additional supplementary feeds, such as licks and concentrates.
ii. Purchasing of additional primary feeding sources.
iii. Reducing livestock numbers through the selling of animals to compensate for reduced forage production in grazing lands; typically, old, and poor-quality animals are sold first.
iv. Sale of core-breeding livestock in case of severe drought.

During a drought, it is also recommended to get rid of animals with no productive value, such as horses, milk cows, and donkeys to reduce pressure on fodder supplies (Du Pisani, 2015). It is recommended that farmers employ conservative stocking rates in response to forage availability, and not rely too heavily on providing them with purchased feed, as this will make farmers more hesitant to sell their animals (due to lower livestock prices during drought and the monetary investment made in purchasing the extra feed); ultimately, this leads to further degradation of the grazing lands and could financially ruin the farmer (Holechek, 1996). Three types of additional feed are especially suitable during periods of drought (Du Pisani, 2015):

i. *Sisal*. Sisal can be used in addition to lucerne to feed livestock; the sisal can be used to replace up to 45% of an animal's lucerne needs and will lead to substantial savings in additional feed purchases. The sisal can either be fed directly to livestock after harvesting or it can be dried (maximum drying period of 3-4 days).
ii. *Spineless prickly pear (cactus pear)*. Prickly pear can either be fed on directly by livestock, harvested, carved and dried, or ground into flour. It is recommended that the prickly pear be dried and be fed to livestock in combination with lucerne and a lick supplement.

iii. *Oldman Saltbush*. The most effective way to utilise the oldman saltbush is to let the livestock graze on it directly. Oldman saltbush is also effective when used in combination with sisal and cactus pear, as well as lucerne.

Howery (2016) also stated various livestock management practices which can help mitigate the impacts during a drought event:

i. Ensure that livestock is distributed evenly throughout your farm; this can be aided by placing licks, supplementary feed, and watering points at specific locations.
ii. Predetermine the amount of money available which can be spent on the purchase of additional sources of feed and supplements.
iii. Sell animals before they lose substantial amounts of weight.
iv. Sell the least productive livestock first, to protect the core breeding animals.
v. Engage in early weaning of animals, to reduce feeding requirements.

It is also helpful to provide creep feed to aid in the early weaning of lambs and thus reducing feeding requirements and reducing the stress on ewes (Du Pisani, 2017). Furthermore, when feeding animals, it is recommended to move the animals to smaller camps and feed them there to reduce animal energy expenditure from walking and reduce land degradation (Du Pisani, 2019).

De Waal (2016) identified various measures which can be implemented during drought period to prevent the death of livestock:

i. Ensure that cashflow is maintained.
ii. Make sure that livestock have easy access to drinking water.
iii. Ensure that animals in poor condition do not lie down before being fed.
iv. Do not waste supplementary feed by scattering it on the ground; use feeding troughs.
v. Employ strategic feeding; feed animals only enough to ensure adequate production levels are maintained.
vi. Group animals together according to productivity and age and assess whether female animals are pregnant, for they must receive priority.
vii. Seek professional advice regarding parasite control from a veterinarian.

5.7.3.3 Financial management

Sound financial management during a drought is critical for farmers to ensure that their enterprises are not financially ruined and can continue operating during periods of drought. Jordaan (2011) identified the following financial coping strategies during periods of drought:

i. Farmers sell assets not relevant to agricultural production.
ii. Farmers sell agricultural assets which are deemed a surplus.
iii. Many farmers take out loans from financial institutions and/or cooperatives, to purchase production related necessities.
iv. Farmers must sometimes utilise their own personal savings for production related expenses.
v. Farmers may try and reschedule instalment payments on current loans.
vi. Temporarily suspending farm infrastructure maintenance.

Additionally, Du Pisani (2015) identified the following financial management measures which can be implemented to cope with drought:

i. Farmers must make an appointment with their accountant and engage in cashflow planning, as well as create a budget for their personal finances.
ii. Carefully assess expenditure on the five largest expenses, which are usually labour, fuel, repair and maintenance costs, electricity, and insurance; reduce labour force (if necessary), suspend non-essential maintenance and repair programs, and consult with financial advisor to cease the insurance of non-essential assets.
iii. Farmers must consult with their bank manager and negotiate to ease any financial pressure and improve cashflow, such as extending loan instalment periods and consolidating any existing short- and medium-term loans into a single long-term instalment.
iv. Get rid of any assets which serve no purpose on the farm.

Another potential financial coping mechanism during drought is to request government support, either through the supply of feed or through repairing faulty water infrastructure (Ngaka, 2012). However, Jordaan et al. (2015) state that while government support may be of some help to farmers, this method of relief is inadequate and always arrives too late. Another significant method often utilised by farmers to reduce the financial impact of drought is to diversify their forms of income by earning money from non-agricultural activities (O'Farrell, et al., 2009). Du Pisani (2019) also stated that it is extremely important for farmers to timeously change financial management practices in response to a drought and farmers must consider their reduced levels of income when budgeting; they must also save the money obtained from forced livestock sales and not use it for personal expenses.

5.7.3.4 Social management

Drought often leads to farmers having to implement various social measures to cope with the impacts of drought. Jordaan (2011) identified various social coping measures implemented by commercial farmers during periods of drought in the Northern Cape such as lowering of personal living standards (which included measures such as reduced vacation expenditure and ceasing to purchase any new vehicles). The selling of personal assets, such as vacation or additional houses, for cash reserves is also a mechanism which help build resilience to drought (Du Pisani, 2015). Forming part of social networks related to drought is also an important coping strategy, as belonging to agricultural associations and institutions may enhance drought resilience through more effective coordination of drought programmes (Muyambo, et al., 2017). Access to other social capitals, such as family and friend connections, social support services and government assistance are also potentially helpful coping mechanisms (Jordaan, 2022). Access to these social networks means that there are more resources available to combat the impacts of drought and makes it easier for members to help each other (Bahta & Myeki, 2021).

5.7.4 Conclusion

Drought contingency planning can be defined as those plans and measures which are developed to enhance drought preparedness and help build drought resilience (Wilhite, 1996). Furthermore, Jordaan (2020) states that contingency planning is the key factor which structures the effective response to drought events through the implementation of pre-determined measures. Drought continency planning is a critical aspect of drought risk reduction, as it evaluates drought holistically by building upon drought risk assessment which considers the drought hazard, vulnerability, and resilience (Mabaso & Manyena, 2013).

A drought contingency plan must be able to answer three questions: how the drought will be detected while still in its early stages; what the potential impacts of this drought are, and what mitigation and response measures can be implemented to reduce vulnerability to drought (U.S. Department of the Interior, Bureau of Reclamation, 2016). Contingency planning must adhere to certain principles and must contain the appropriate information. Coordination between all relevant stakeholders is of critical importance when developing contingency plans, with each stakeholder’s roles and responsibilities clearly defined (Lembara, et al., 2011).

There are two approaches which are commonly utilised when dealing with drought: the crisis management approach (which is almost exclusively reactive), and the drought risk reduction approach (which encourages proactive drought management (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014). The crisis management has been the approach most commonly used up until now, but it often provides inadequate relief, suffers from poor coordination, is untimely, and does not encourage affected communities to change their behaviour towards drought; thus, there is a need for communities and governments to engage in proactive drought management and enhance drought preparedness (Wilhite, 2019). Wilhite et al. (2005) developed a ten-step process for drought planning, which aims to enhance drought preparedness; it looks at drought holistically and includes conducting drought risk assessments, stakeholder coordination and raising awareness about drought. However, most nations in the SADC do not engage in proactive drought planning, mainly due to lack of capacity (SADC, IUCN, UNCCD, 2022). SLM is a critical factor in drought risk reduction, as it aims to provide humanity with ecosystem services to meet their environmental, economic, and social needs while simultaneously maintaining ecosystem productivity and health, ultimately promoting sustainable development (Sanz, et al., 2017). Effective grazing and livestock management are critical for farmers when preparing for and responding to drought, to ensure that production is maintained to the best degree possible. Farmers can also adopt various financial and social coping mechanisms to reduce their vulnerability to drought and keep their farming enterprise running. Farmers must thus implement long-term adjustment strategies (to enhance drought preparedness) and short-term coping strategies (plans which are implemented during the onset of a drought event).

Please see Deliverable 2 for a discussion on the indicators and scoring template which were used as a base for the development of the interview questionnaire and consequently the contingency plans.

5.8 Data analysis and discussion of results

5.8.1 Introduction

In the following chapter, the data which was obtained in the study will be analysed and the results will be displayed. In the first section, the biographic information of the participants will be provided, as prompted by the interview questionnaire. This will be followed by an analysis and discussion of the results obtained with regard to grazing land management. An analysis and discussion on the livestock management results will then follow. That will then be followed by analyses and discussions regarding the financial management and social management results. The chapter will then be concluded with a brief summary of the content.

5.8.2 Biographic information

Leading farmers who implement best drought management practices from four district municipalities in the Northern Cape were interviewed; two farmers were located in Frances Baard Municipality, four farmers were located in Namakwa District Municipality, five farmers were located in Pixley ka Seme District Municipality, and one was located in John Taolo Gaetsewe District Municipality. The two remaining farmers were located in the Free State (one in Xhariep District Municipality and the other in Thabo Mofutsanyana District Municipality), but also applied similar drought management practices; these two individuals also have substantial experience with drought in the Northern Cape as they have been extensively involved in the livestock farming sector in the province in the past in a professional capacity. The average age of the participants who were interviewed was 58 years old. The average amount of farming experience of the participants was 32 years. The following table (Table 5.5.1) illustrates the main form of farming undertaken by the participants:

TABLE 5.5.1: MAIN FORMS OF FARMING UNDERTAKEN BY PARTICIPANTS

Main form of farming	Number of farmers
Mixed farming (Crops and livestock)	1
Cattle, sheep, goats and game	1
Cattle and sheep	1
Cattle	2
Mutton sheep	4
Wool sheep	1
Mutton and wool sheep	3
Goats	0
Game	1

The average size of the participants' farms was approximately 24 082 ha. The average carrying capacity of the participants' farms, according to the long-term grazing capacity guidelines (DAFF, 2018), was 22.5 ha/LSU. The average number of large stock units (cattle) per farm on which they are farmed with is approximately 740, while the average number of small stock units (goats and sheep) per farm on which they are farmed with is approximately 2 972. Only two participants have game animals on their farms; thus, the average number per farm is approximately 2 575 units.

Only two participants have established additional branches of farming in addition to livestock farming, which is the production of cash crops. The following table (Table 5.5.2) indicates the highest qualifications obtained by the participants.

TABLE 5.5.2: HIGHEST QUALIFICATION OF RESEARCH PARTICIPANTS

Highest qualification	Number of farmers who have obtained it
Doctoral degree	1
Honours degree	2
Bachelor's degree	8
Diploma	1
Matric	1
Grade 11	1

Participants also indicated previous severe drought events; there were substantial differences between the responses, indicating the participants' potentially subjective experiences regarding drought. The following table (Table 5.5.3) indicates time periods in which severe droughts occurred, according to the participants.

TABLE 5.5.3; TIME PERIODS OF PREVIOUS SEVERE DROUGHT EVENTS WHICH PARTICIPANTS EXPERIENCED

Time period	Number of farmers who indicated severe drought events during this time period
1980-1990	5
1991-2000	7
2001-2010	3
2011-2019	11
2020-present	1

5.8.3 Grazing land management

In the following section, the results obtained regarding grazing land drought preparedness and response measures will be discussed.

5.8.3.1 Drought preparedness

In the following sections, the various grazing land management practices that farmers implement to enhance their drought preparedness will be discussed.

Resting of grazing land

The majority of the farmers indicated that they rest their grazing land for dedicated periods of time; the responses ranged from 2-12 months of rest for selected areas of their grazing land. One farmer, who farms with game, does not intentionally rest their field due to the specific grazing system they utilise; however, the large farm areas mean that areas of the grazing land are rested unintentionally. One farmer does not rest their grazing land at all.

Use of land conservation methods

The vast majority of farmers also apply land conservation methods to improve the quality of their grazing lands. The methods that are applied by participants include the elimination of trenches to help decrease erosion associated with run-off, the rehabilitation of bare patches of grazing land, the elimination of invasive plant species to improve the plant composition of their grazing land, and the building of erosion terraces.

Type of grazing system which is utilised

The majority of participants utilise a multi-camp rotational grazing system, which allows for land to be rested for a specific period of time. One farmer, who farms with game, utilises a natural grazing system with no camps, and another farmer practices continuous grazing with a low stocking rate; this is done to minimise land degradation during drought periods. One farmer also divides his grazing land according to the grazing type present on the land; it is then grazed at different times of the year. One farmer applies a high-density grazing system in which a flock is allowed to graze once in a camp during summer and once during the winter; the camps are then completely rested for approximately six months. The aim of high-density grazing is to enhance the quality of the grazing land by improving the plant composition found on the land (Franke & Kotzé, 2022). However, farmers who have experienced severe or exceptional droughts, state that when the drought is severe enough, grazing systems often have to be abandoned and the animals moved to any part of land where there is still some form of feed remaining.

Presence of additional pastures and feed bank

Six farmers indicated that they have additional pastures which they cultivate, these pastures mainly being dryland, with only two participants having access to irrigated pastures. Contained in these pastures are eragrostis grass, blue buffalo grass, smuts finger grass, and lucerne. The farmers use these pastures to contribute to a feed bank on their farm, which can be used during adverse times, such as drought. Most farmers stated that their grazing land is their feed bank, and thus it must be properly managed and conserved. Some farmers also only purchase additional feed as necessary, or to purchase feed during good times and store it as this is cheaper than producing it yourself. The majority of farmers who do not have additional pastures state that the lack of a sustainable water source is the main hurdle to the establishment of these pastures, as rainfall is often unreliable.

Other specific grazing land management practices

Some farmers stated that, if possible, the establishment of additional pastures can be helpful to enhance your drought preparedness. There was also consensus among farmers that it is critical that the animals have access to permanent, clean water supplies at appropriate locations throughout the farm. Some farmers also indicated that they utilise rainfall records and long-term climate forecasts to help them with grazing management planning. In case of wildfires, the grazing lands should also be rested for at least one growing season; some farmers also stated the importance of continuously trying to improve the quality of your grazing lands. The majority of farmers also stated that you should follow your grazing system to the utmost extent possible, and that you should only deviate from it during exceptional cases of drought. Some farmers also emphasised the importance of early planning for the following year; some also stated that you should not aggressively increase your livestock numbers during good times, but rather keep them the same to protect and conserve your grazing lands.

5.8.3.2 Drought response

Farmers had difficulty understanding the various drought categories and stated that it is difficult to distinguish one from the other. However, the vast majority of farmers stated that D0 and D1 droughts are normal for them, and that they do not deviate from their usual practices regarding grazing land management during these drought events.

Leasing of land during drought

Some farmers stated that it is helpful to lease land during a drought, especially in a different geographic area where the grazing lands are in a better condition. However, some also stated that they manage their farm in such a way that it is not necessary for them to lease land during drought. Farmers who did lease land due to drought stated that they did so during D3 and D4 drought events.

5.8.4 Livestock management

In the following section, the various livestock management practices that farmers implement to enhance their drought preparedness, as well as their drought response measures will be discussed.

5.8.4.1 Drought preparedness

In this section, the various livestock management practices that farmers implement to enhance their drought preparedness will be discussed.

Stocking rate

The majority of farmers utilise a conservative stocking rate well below the prescribed guidelines, to be prepared for drought. One farmer stated that they do not decrease their stocking rate during drought, as they have access to additional land that can be utilised during drought. Another farmer stated that they can be more aggressive with their stocking rate, as their grazing systems and grazing land composition allows for this. Another farmer stated that they utilise a slightly more aggressive stocking rate during good times, but then adopt a more conservative stocking rate as drought becomes apparent. However, there was a consensus among the farmers, that it is vital to not overstock and exceed the carrying capacity of the farm, even during good years, to conserve the land and build feed reserves.

Selection of breeding livestock

Farmers also stated the importance of breeding with drought hardy animals. The animals must be adapted to conditions on the farm and be able to produce optimally in these conditions. The majority of farmers breed their own rams, as these animals are adapted to conditions on the farm, and farmers want to minimise external influences. A few farmers also engage in the crossbreeding of animals to obtain the desirable characteristics of each breed. Farmers also stated that the animals must be able to withstand adverse conditions, such as drought, with minimal external support and input costs.

5.8.4.2 Drought response

In this section, the drought response measures which farmers implement regarding livestock will be discussed.

Reduction of livestock numbers

A universal theme among farmers is that is it vital to timeously reduce livestock during drought. As stated earlier, farmers see D0 and D1 droughts as part of their normal condition, and do not typically reduce animals during these stages of drought. For D2 drought, livestock numbers are reduced by approximately 10-20%, for D3 drought approximately 30-50%, and with a D4 drought, only the core breeding herd/flock remains to continue some form of production. The first animals which are typically sold are old animals, unproductive animals, and animals which are weak and/or in poor condition (such as having broken or worn-out teeth). Farmers also stated the importance of constantly monitoring their grazing lands to ensure that the feed available on the land reflects livestock numbers. One farmer, who farms with game, stated that it is recommended to first sell the majority of the female animals and keep male animals, as the male animals are worth more for hunting and breeding purposes. One farmer also stated that one should first see if one can lease additional land before reducing livestock, to ensure minimum disruptions to one's farming enterprise.

Early weaning of livestock

Since farmers see D0 and D1 drought as part of their normal conditions, they do not engage in early weaning during these stages of drought. From D2-D4 droughts, the vast majority of farmers wean their animals early, with the weaning age ranging between 2.5-6 months. One farmer, who farms with game, does not wean the animals, as these animals operate in a natural system. One farmer does not wean their lambs early, even during drought, and they are kept with their mothers as long as possible.

Movement of animals to smaller camps/pens during drought

As D0 and D1 droughts are seen as normal conditions by the farmers, animals are only moved to smaller camps or pens from D2-D4 droughts. All farmers only bring animals to pens when these animals are to be rounded-off and sold to conserve their grazing land and minimise additional feeding costs. However, some farmers who have experienced D3 and D4 droughts have also penned their core breeding animals during these droughts and provided them with additional feed to keep some form of production going.

Selling of core breeding animals

Only four farmers had to sell a portion of their breeding livestock during drought; one farmer had to sell during a D3 drought but stated that it was totally preventable (as he had significantly overstocked). The remaining three farmers (who had very conservative stocking rates) had to sell core breeding livestock during a D4 drought. The remaining farmers never had to sell any core breeding livestock during a drought.

Additional livestock feeding requirements during drought

For D0 and D1 drought, which farmers see as part of normal conditions, the animals only receive additional production lick, which utilises the roughage on the land. For D2 and D3 drought, animals still receive production lick to utilise the roughage on the land, but also receive energy feed, mostly in the form of maize. All farmers who have experienced a D4 drought stated that during this time they had to rely on roughage from external sources, such as donations or purchasing it, as there was very little roughage left on the land; these roughage sources were mostly lucerne and oats. Some farmers also stated the usefulness of using supplements such as LS 33, which is sprayed onto roughage sources to make it more palatable for the animals.

Full-scale additional feeding of livestock

During a D3 drought, one farmer engaged in the full-scale feeding of their livestock, while three others engaged in full-scale feeding of their livestock during a D4 drought. The remaining farmers never had the need to engage in full-scale additional feeding of their livestock.

Division of livestock into similar age and productivity groups when feeding them during drought

The majority of farmers group their livestock into similar age and productivity groups; however, this is a standard practice that they implement, irrespective of drought. Only one farmer does not implement this, as they farm with game in a natural system and thus the animals arrange themselves into groups.

Frequency of supplementary feed provision

During D0 and D1 droughts, which are part of normal conditions for these farmers, no supplementary feed is given to livestock. One farmer stated that from D2-D4 droughts, daily feeding of livestock is necessary. Other farmers who have experienced D4 droughts stated that the daily feeding of livestock is necessary, as at this stage all of the animals are in pens. The remaining farmers who provide extra feed during droughts do so either twice per week, or three times per week.

Additional livestock management adaptation measures

Numerous farmers stated the importance of consulting with livestock experts when making decisions or developing management practices. Some also stated that the lack of quality agricultural extension services is of concern, as this service can potentially be of great help to farmers. Farmers also stressed the importance of animal health, such as checking them for internal and external parasites, and giving them their necessary dosages and engaging in frequent health check-ups. Another universal theme is not to overstock, even during good times; however, farmers stated that one must try and keep as many animals as reasonably possible on the farm for production purposes, as they are one’s main source of income. Farmers also stated that is important to frequently scan female animals and sell those who are unproductive, as well as animals that are weak.

5.8.5 Financial management

In the following section, drought preparedness and response measures of farmers with regard to financial management will be discussed.

5.8.5.1 Drought preparedness

In this section, the financial preparedness measures which farmers implement with regard to drought will be discussed

Presence of emergency drought fund

Only three farmers stated that they have an emergency drought fund, which is used for drought or any other disaster events; the remaining farmers do not possess an emergency drought fund. The remaining farmers utilise their profits to expand their farming enterprises, and thus there is no money to deposit into an emergency drought fund.

Management of debt burden in preparation for drought

There was consensus among the farmers that it is important to keep one's debt burden under control, to be prepared for a drought situation. They stated that one should make debt responsibly and only for expansion of one's farming enterprise; One must also only undertake this during good years. They stated that one must always be in a position to pay one's instalments.

Meetings with accountant to engage in cashflow planning and budgeting

The majority of farmers do their cashflow planning and budgeting themselves. The remaining farmers indicated that they see their accountants on a regular basis; it ranges from twice per month to once per year.

Additional forms of income not related to agriculture

Seven farmers stated that they have a form of income not related to agriculture. These incomes include dividends on long-term investments, taxidermy and hunting businesses, leasing of properties that they own, and pension. Some farmers who did not have an alternative form of income stated their desire to obtain one, to diversify their sources of income and reduce financial risk.

5.8.5.2 Drought response

In this section, the financial response measures which farmers implement with regard to drought will be discussed.

Selling of agricultural or non-agricultural assets during drought

Only one farmer had to sell agricultural equipment and vehicles during a D3 drought. None of the remaining farmers have had to sell any agricultural or non-agricultural assets during a drought.

Taking out loans from an institution during drought

Only one farmer had to take out a loan during a D3 drought to keep their farming enterprise running. The remaining farmers have only had to utilise the overdraft facility at their bank to keep their farming enterprises running

Relief of financial pressure during a drought

The majority of farmers asked their banks to increase their overdraft limit during D3 and D4 droughts. One farmer extended their loan instalment period and engaged in debt consolidation during a D3 drought, while another farmer had to extend a loan instalment period on existing land debt and to restructure debt payments, also during a D3 drought.

Postponement of maintenance and repair procedures during drought

Farmers stated that only absolutely essential maintenance and repair procedures must be undertaken during D3 and D4 droughts; all available time and resources must be allocated to the animals during these droughts. Major repair and maintenance procedures should be postponed for better times. These essential procedures include the repairing of broken fences and broken/leaking water infrastructure.

Retrenchment of labourers during drought

Only one farmer has had to retrench labourers during a D3 drought. None of the remaining farmers have had to retrench labourers during drought; many stated that their labourers are even more important during drought, due to the increased volume of work on the farm during this time, mainly the feeding of animals.

Adjustment of short-term insurance during drought

Five farmers had to adjust their short-term insurance during drought. Two had to cancel their short-term insurance during a D3 drought, while three had to cut significantly on their insurance costs. This involved cancelling insurance on farm vehicles and covering personal vehicles with only third-party insurance, and underinsuring their houses and household content. It was not necessary for the rest of the farmers to adjust their short-term insurance.

Use of money from forced livestock sales

None of the farmers keep the money from forced livestock sales to exclusively purchase new livestock. All the money they receive from their livestock sales goes into a single account which is utilised for all farming expenses.

Drought aid from government

The only farmers who received any substantial aid from the government were farmers who were already farming in the 1980s and 1990s. These farmers received aid from the government in the form of subsidies which were tied to the livestock reduction scheme; four farmers benefitted from this. One farmer stated that he received aid from the government in the form of a debt relief programme in 1982 and received aid from the government regarding debt consolidation and write-off in 1992; this aid was received during D3 drought events.

Additional financial adaptation measures

The majority of farmers stated that it is very important to be conservative with money, during both good times and drought. During drought, do not purchase new vehicles and restrict expenses to the greatest extent possible. Farmers also stated that one should only make debt during good years for the purpose of expanding one's farming enterprise, which includes the purchase/leasing of additional land or the purchasing of animals. Some farmers also emphasised the importance of saving money where possible, such as using a motorcycle to conduct farm operations instead of a bakkie where possible, to reduce fuel consumption.

5.8.6 Social management

In the following section, the social response measures which farmers implement to combat drought will be discussed.

5.8.6.1 Cutting of personal expenses during drought

Since D0 and D1 droughts are seen by farmers as part of their normal conditions, farmers do not alter their personal expenses during these stages. Farmers indicated that from a D3 drought, they cancel their vacation plans and stay on the farm to monitor farming operations. Some farmers also indicated that they reduce their standard of living, and eliminate non-essential household expenses, such as DSTV. They also do not purchase any vehicles for personal use. Many farmers stated, however, even if you cancel your vacation, it is important for your mental health to still at least go away for a weekend.

5.8.6.2 Social network access during drought

Farmers stated that from D3 drought onward, social networks are important support mechanisms. Many farmers stated that their local farmer's associations are important to voice the concerns and needs of the farmers that they represent. Many also stated that the local farming community also provides support to one another, either financially or emotionally, creating a tight-knit community. Some farmers also stated the importance of their religious communities with regard to emotional support during drought, as well as their family and friends. Farmers who have experienced D4 drought, stated that their access to social networks enabled them to receive substantial drought aid in the form of money and feed.

5.8.6.3 Cancellation of contributions to important expenses

No farmer in this study has had to cancel contributions to important expenses which includes medical aid, their children's education expenses, or life insurance policies.

5.8.6.4 Additional social management adaptation measures

Some farmers stressed the importance of preserving one's mental health during drought by still taking a weekend off to go and see friends/family or for relaxation. One farmer also stated the importance of supporting one's workers as much as possible during a drought, as they are also adversely impacted by it.

5.8.7 Conclusion

Farmers had difficulty understanding the different drought categories, and how they are distinguished from each other. Some farmers also had not experienced certain stages of drought, and therefore had difficulty relating their drought management practices to these drought stages, but still attempted to answer to the best of their ability. Farmers stated that they see D0 and D1 stages of drought as part of their normal conditions and it is thus included when they are developing their standard management practices, and that drought management practices are only altered from D2-D4 droughts. The most important theme to emerge from grazing land management was to improve the quality of one's grazing land to the greatest extent possible and to conserve it, as it is one's main source of feed. Thus, it is of utmost importance that overstocking does not occur. The most important theme from livestock management is to timeously reduce livestock on the farm, to ensure the condition of one's grazing land reflects the number of livestock. The selling of weak or unproductive animals during drought is also important. The most important theme from financial management is to be conservative with one's money during all times, and when making debt, to do so responsibly. The most important theme to emerge from a social management perspective is to eliminate all non-essential personal expenses and to remain on the farm during drought to ensure farm operations are conducted optimally. It is also important to utilise social networks to support you during drought.

5.9 Contingency Plans for Different Drought Categories and Conclusion

In the subsequent section, we'll outline the contingency plans developed for each type of drought category.

5.9.1 D0 and D1 drought

The contingency plans for D0 and D1 drought will be presented in the next section.

5.9.1.1 Grazing land management

i. If possible, establish additional pastures (only if you have access to a perennial surface water source).
ii. Deposit into a feed bank by allocating a certain amount of money to additional feed purchases; continuously build the feed bank by depositing purchased feed into it.
iii. Ensure that grazing land quality is maintained with adequate vegetation cover, to avoid excessive soil moisture evaporation.
iv. Continuously try to eliminate invasive plant species which disturb grazing land composition.
v. Maintain a conservative stocking rate to protect grazing land and allow for adequate feed reserves to be maintained on the field.
vi. Utilise a multi-camp rotational grazing system to allow land to achieve adequate rest.
vii. If in a financial position to do so, lease additional land to potentially move animals there, to reduce pressure on existing grazing land.
viii. Continuously monitor condition of grazing land, to ensure animal number reflects feed availability on the land.
ix. Ensure that water points are located at appropriate locations throughout each grazing camp, for optimal utilisation of feed throughout the camp; also ensure that water supply infrastructure is operational.

5.9.1.2 Livestock management

i. Maintain a conservative stocking rate, preferably even below prescribed departmental guidelines.
ii. Not necessary at this stage to sell any animals; however, it is recommended that unproductive and weak animals are identified and sold to reduce burden on grazing land and improve flock/herd composition; scan ewes after breeding season.
iii. Not necessary to engage in early weaning of animals; however, it can still be done if the farmer feels that it is required.
iv. Give additional production lick for animals to utilise available roughage on the land.
v. Ensure that flock/herd composition is of such a nature which allows for a substantial number of animals to be sold off without influencing production to a significant extent, thus protecting core breeding animals.
vi. Only move animals which are to be rounded off and sold to feeding pens.

5.9.1.3 Financial management

i. If possible, regularly try and deposit a portion of profits into an emergency drought fund, which can be used for drought related expenses.
ii. Ensure that debt burden is under control, and that you are still able to pay existing instalments.
iii. Sell any assets that do not serve any purpose on the farm.
iv. When budgeting, do so based on a conservative income level, and if necessary, consult with an accountant to help you with cashflow planning for a possible reduced income.
v. Try to obtain a form of income not related to agriculture, such as purchasing property to lease out, or making long-term investments; this will help reduce the economic impact of drought during the more severe stages.

5.9.1.4 Social management

i. Try to reduce non-essential personal expenses, such as expensive vacations and new vehicle purchases.

ii. Ensure that social networks are intact, both professional and personal.

5.9.2 D2 drought

The contingency plans for D2 droughts will be presented in the next section.

5.9.2.1 Grazing land management

i. Reduce stocking rate to help preserve grazing land quality and to help sustain feed reserves in the land for a longer period of time.
ii. Stick to multi-camp rotational grazing system; however, reduce the number of animals in each camp to give the vegetation a better chance at recovery.
iii. If you have the financial means, purchase extra feed such as lucerne, oats and maize residues and deposit it into a feed bank so that it can be used when necessary.
iv. If you have access to additional land in another area, move a portion of your flock/herd to this area, to reduce the grazing burden on the land.
v. Continuously monitor grazing land condition and make sure that animal numbers reflect feed availability on the land; overgrazing must not occur.
vi. Ensure that all water infrastructure on the farm is in good condition and operational, to ensure that animals have access to good quality water.

5.9.2.2 Livestock management

i. Reduce animal numbers; sell approximately 10-20% of animals, depending on the condition of your grazing land.
ii. Scan ewes/cows for pregnancy; sell animals which are not pregnant, as well as old/weaker animals.
iii. Start to wean lambs/calves early to reduce burden on mothers; animals can be weaned from three months.
iv. Only move animals which are to be rounded-off and sold to feeding pens.
v. Provide animals with production lick to effectively utilise roughage on the land, but also provide them with additional maize for energy. Provide this additional feed 2-3 times per week, depending on the condition of the animals.

5.9.2.3 Financial management

i. If possible, deposit a portion of profits into an emergency drought fund, which can be used for drought related expenses such as feed.
ii. Arrange with bank for increase in overdraft facility limit, in case it is needed.
iii. When budgeting and planning cashflow, do so using a reduced income level; enlist the help of an accountant if necessary.
iv. Sell any redundant assets or equipment.
v. If you have existing debt payments and are struggling to pay instalments, go see bank manager to increase loan instalment period, or to consolidate debt.
vi. Conduct maintenance and repair programmes to the greatest possible extent; however, if financial position comes under pressure, conduct only essential procedures.

5.9.2.4 Social management

i. Cut back further on personal expenses; reduce number of vacations taken during the year.
ii. Ensure that social networks are intact; ask for help from local farmer's association if you have any concerns or needs that need to be voiced regarding the drought.
iii. Go and see family and/or friends for emotional support if necessary.

5.9.3 D3 drought

The contingency plans for D3 droughts will be presented in the next section.

5.9.3.1 Grazing land management

i. Further reduce stocking rate to protect and conserve the remaining grazing land. At this stage, stocking rate should be extremely conservative, preferably half of the prescribed guidelines.
ii. If you have the means, purchase additional feed that can be deposited into a feed bank to be used as necessary.

iii. Ensure that overgrazing does not occur; reduce the size of the flock/herd in each camp to allow the vegetation the best chance at recovery when it is resting.
iv. If you have access to additional land in another area, move a significant number of your animals there to reduce the grazing burden on the land.
v. Continuously monitor the condition of the grazing land; ensure animal numbers reflect feed availability on the land, to minimise land degradation.
vi. Ensure that all water infrastructure is in good condition and operational, and that animals have easy access to clean water supplies at appropriate locations in each camp.
vii. Try to maintain grazing system; however, if roughage in the camp is virtually depleted, move animals to camps where there are still adequate amounts of roughage.

5.9.3.2 Livestock management

i. Further reduce animal numbers; sell approximately 30-50% of animals, depending on the condition of your grazing lands.
ii. Sell all unproductive/weak/poor-quality animals that do not contribute to meaningful production on the farm.
iii. Wean lambs/calves early; they can be weaned from three months. Lambs can be supported in the weaning process with creep feed.
iv. Only core-breeding animals should be placed in feeding pens for production purposes; the remaining animals must be placed in feeding pens only to be rounded-off and sold.
v. Provide animals with additional production lick to utilise any roughage still available on the land and provide them with additional maize for energy; coat roughage with LS 33 to make it more palatable for the animals. Provide this supplementary feed three times per week.
vi. Ensure animal health; check for internal and external parasites, check the condition of their teeth, and give them their necessary dosages.

5.9.3.3 Financial management

i. If available, use extra funds to purchase additional feed such as lucerne, oats or maize residues for animals.

ii. If necessary, see an accountant to help with your budgeting and cashflow planning on a reduced income.
iii. If necessary, utilise overdraft facility from bank for farming related expenses, and increase it if necessary.
iv. If you have existing debt and are struggling to pay instalments, go and see the bank manager to arrange an increase in the debt instalment period or to engage in debt consolidation.
v. If you do have a non-agriculture related form of income, use that income to cover personal expenses and thus reduce the financial burden on the farming enterprise.
vi. Sell all non-essential farming equipment, and do not purchase any new vehicles.
vii. Only conduct essential maintenance and repair procedures, such as broken fences and faulty/leaking water infrastructure; major maintenance and repair procedures can be conducted once the drought is over.
viii. Reduce short-term insurance costs by insuring only absolutely essential items.

5.9.3.4 Social management

i. Cut down on all personal and household expenses; cancel vacation plans to save money and stay on farm to ensure farm operations are conducted smoothly.
ii. Ensure that social networks are intact; ask local farmer's association for professional support and visit family and friends on the weekend or on important days for mental health purposes and attend religious events if you are part of a religious community.
iii. If necessary, reach out to farmers in different areas, NPOs and other private donors for aid with regard to farming needs, such as feed.

5.9.4 D4 drought

The contingency plans for D4 drought will be presented in the next section.

5.9.4.1 Grazing land management

i. Drastically reduce stocking rate to conserve what little vegetation is left on the land, approximately one third of recommended guidelines.

ii. If following a multi-camp grazing system, drastically reduce number of animals in each camp; if camps start to become excessively barren, open all farm gates and let animals graze anywhere where there is still some form of roughage available.
iii. If in possession of one, utilise all feed present in the feed bank.
iv. Ensure that all water infrastructure is functional and ensure that animals do not have to travel excessive distances to water points; drill additional boreholes if water supplies become an issue.
v. If you access land in another area, move the majority of animals to this area to protect grazing land and help keep production cycle going.
vi. Continuously monitor the condition of your grazing land; if land degradation becomes excessive and vegetation is virtually depleted, move animals to pens.

5.9.4.2 Livestock management

i. Drastically reduce livestock numbers; by this stage, only core breeding animals must remain on the farm and receive priority to keep some degree of production going.
ii. Sell all unproductive, weak and old animals, to ensure that only productive and hardy animals remain on the farm.
iii. Utilise any form of available roughage still on the land by spraying the roughage with LS 33 to make it more palatable.
iv. When all roughage on the land has been depleted, move animals to pens.
v. Provide animals with necessary roughage and production lick while they are in pens; at this stage, daily feeding will be necessary.
vi. Only provide extra feed to animals which are to be rounded-off and sold.
vii. Wean lambs/calves early, preferably from two months, and support them with creep feed up until weaning, and then sell lambs which will not be utilised for production purposes.
viii. Frequently do health check-ups on core-breeding animals, to ensure that the production cycle continues to the greatest extent possible.

5.9.4.3 Financial management

i. Use any available funds to purchase additional feed.
ii. If necessary, go see an accountant to help with cashflow and budgeting on drastically lower income level.
iii. Go and see bank manager to increase overdraft facility limit and utilise it for farming purposes only.
iv. Do not purchase any new vehicles and equipment, and sell all redundant assets.
v. If absolutely necessary, take out a loan from an institution to keep farm operational; however, go and see bank manager beforehand to discuss instalment amount and period.
vi. If you have existing debt, go and see bank manager to increase loan instalment periods and engage in debt consolidation.
vii. Suspend all non-essential maintenance and repair procedures.
viii. Reduce short-term insurance costs; underinsure your house and household content, cancel farm vehicle insurance, and put personal vehicles on third-party insurance.
ix. Use a motorcycle to conduct farm operations where possible instead of a bakkie, to save on fuel expenses.

5.9.4.4 Social management

i. Eliminate all non-essential personal expenses, such as streaming and television subscriptions; cancel all vacation plans and stay on farm to monitor farm operations.
ii. Visit family and friends on weekends or important days for mental health purposes.
iii. If necessary, use social network to obtain financial and emotional support, and reach out to NPOs and private entities for support in the form of money or feed.
iv. Ask local farmer's association for support, such as raising awareness of the drought in the region.

5.10 Conclusion

The research objective was to develop contingency plans for various categories of drought, D0-D4, for the livestock farming sector in the Northern Cape. In South Africa, the Northern Cape is particularly at risk of drought, due to semi-arid to arid climate and large climatic variability (Jordaan, et al., 2013). Livestock farming is the most significant form of agriculture in the Northern Cape province, and since agriculture forms a vital part of the South African economy (International Trade Administration, U.S. Department of Commerce, 2021), it is important for livestock farmers in the Northern Cape to engage in risk reduction with regard to drought by promoting drought preparedness and proactive drought response measures, thus mitigating the various impacts of drought and enhancing drought resilience.

The participating farmers in the study indicated that they take drought into account when developing their agricultural management practices, as it is so prevalent in the Northern Cape. However, farmers struggled to grasp the concept of the various drought categories. However, farmers do apply proactive drought management and response measures to mitigate the impacts of drought to keep their farming enterprises as productive as possible during drought events.

5.11 Recommendations for future studies

This study attempted to develop indicator-based contingency plans for various categories of drought for the livestock farming sector in the Northern Cape by obtaining best drought management practices and adaptation measures implemented by leading farmers. Since farmers struggled to understand and differentiate between various drought categories, it is recommended that, for any future research involving drought categories, participants be given prior training to better understand the indicator-based drought classification system, and how the various drought categories are distinguished from each other. Due to the fact that drought not only impacts the agricultural sector, it is also recommended for future studies to develop drought contingency plans for the business and municipal sectors, as well as other agricultural systems.

References

Acharya, A., Prakash, A., Saxena, P. & Nigam, A., 2013. Sampling: Why and How of it?. *Indian Journal of Medical Specialties,* 4(2), pp. 330-333.

Agri SA, 2019. *Agriculture Drought Report 2019/2020,* Pretoria: Agri SA Research.

Asenahabi, B., 2019. Basics of Research Design: A Guide to selecting appropriate research design. *International Journal of Contemporary Applied Researches,* 6(5), pp. 76-89.

Bahta, Y. & Myeki, V., 2021. Adaptation, coping strategies and resilience of agricultural drought in South Africa: implication for the sustainability of livestock sector. *Heliyon,* 7(11), p. e08280.

Banerjee, A. & Chaudhury, S., 2010. Statistics without tears: Populations and samples. *Industrial Psychiatry Journal,* 19(1), pp. 60-65.

Barreiro, P. & Albandoz, J., 2001. Population and sample. Sampling techniques. *Management Mathematics for European Schools,* 1(1), pp. 1-18.

Baudoin, M., Vogel, C., Nortje, K. & Naik, M., 2017. Living with drought in South Africa: lessons learnt from the recent El Niño. *International Journal of Disaster Risk Reduction,* Volume 23, pp. 128-137.

Bhattacharyya, D., 2006. *Research Methodology.* 2nd ed. New Delhi: Excel Books.

Burnard, P. et al., 2008. Analysing and presenting qualitative data. *British Dental Journal,* 204(8), pp. 429-432.

Cooperative Governance and Traditional Affairs, 2020a. *Frances Baard District - Northern Cape.* [Online]
Available at: https://www.cogta.gov.za/ddm/wp-content/uploads/2020/07/District_Profile_FRANCES_BAARD.pdf
[Accessed 11 November 2023].

Cooperative Governance and Traditional Affairs, 2020b. *Namakwa District - Northern Cape.* [Online]

Available at: https://www.cogta.gov.za/ddm/wp-content/uploads/2020/11/Namakwa-District-September-2020.pdf
[Accessed 11 November 2023].

Cooperative Governance and Traditional Affairs, 2020c. *ZF Mgcawu District - Northern Cape.* [Online]
Available at: https://www.cogta.gov.za/ddm/wp-content/uploads/2020/07/ZF-MGCAWU-PROFILE-24062020.pdf
[Accessed 11 November 2023].

DAFF, 2018. *Conservation of Agricultural Resources Act: Long-term grazing capacity map for South Africa 2017,* Pretoria: DAFF (Department of Agriculture, Forestry and Fisheries).

De Waal, H., 2016. *Livestock can survive a drought, learn how.* [Online] Available at: https://www.farmersweekly.co.za/agri-technology/farming-for-tomorrow/livestock-can-survive-a-drought/
[Accessed 24 November 2023].

Dennis, I., 2009. *Northern Cape Agricultural Risk Assessment: Groundwater,* Bloemfontein: Institute for Groundwater Studies, University of the Free State.

Department of Water and Sanitation, n.d. *Groundwater Dictionary.* [Online] Available at: https://www.dws.gov.za/Groundwater/Groundwater_Dictionary/index.html?introduction_catchment.htm
[Accessed 10 July 2023].

Du Pisani, L., 2015. *Bestuursmaatreëls wanneer midde in 'n rampdroogte.* [Online] Available at: https://www.nwga.co.za/file/5a041c711d851/bestuurmaatreels.pdf
[Accessed 7 August 2023].

Du Pisani, L., 2017. *LESSE GELEER UIT DIE AFGELOPE DROOGTE - ZUURANYS STUDIEGROEP.* [Online]
Available at: https://www.nwga.co.za/blog-articles/dr-louis-du-pisani/climate-and-drought/lesse-geleer-uit-die-afgelope-droogte-zuuranys-studiegroepnbsp/58
[Accessed 9 August 2023].

Du Pisani, L., 2019. *Smart Drought Management for Livestock Farmers.* 1st ed. Krugersdorp: Kefaja Knowledge Works.

Durley, J., de Loë, R. & Kreutzwiser, R., 2003. Drought Contingency Planning and Implementation at the Local Level in Ontario. *Canadian Water Resources Journal,* 28(1), pp. 21-52.

Espach, C., Lubbe, L. & Ganzin, N., 2006. Determining grazing capacity in Namibia: Approaches and methodologies. *Agricola,* Volume 16, pp. 28-39.

Etikan, I. & Bala, K., 2017. Sampling and sampling methods. *Biometrics & Biostatistics International Journal,* 5(6), pp. 215-217.

FAO, 2023a. *Land & Water.* [Online] Available at: https://www.fao.org/land-water/land/sustainable-land-management/slm-practices/en/
[Accessed 2 August 2023].

FAO, n.d. *Chapter 2: Climate and agro-ecological zones.* [Online] Available at: https://www.fao.org/3/y5998e/y5998e06.htm#TopOfPage
[Accessed 7 July 2023].

Franke, A. & Kotzé, E., 2022. High-density grazing in southern Africa: Inspiration by nature leads to conservation?. *Outlook on Agriculture,* 51(1), pp. 67-74.

Galt, D. et al., 2000. Grazing Capacity and Stocking Rate. *Rangelands Archives,* 22(6), pp. 7-11.

Graw, V. et al., 2017. Drought Dynamics and Vegetation Productivity in Different Land Management Systems of Eastern Cape, South Africa—A Remote Sensing Perspective. *Sustainability,* 9(10), p. 1728.

Haigh, T. et al., 2021. Ranchers' Use of Drought Contingency Plans in Protective Action Decision Making. *Rangeland Ecology & Management,* Volume 74, pp. 50-62.

Harmse, C., Swanepoel, A. & Gerber, H., 2019. *Rainfall trends in the Northern Cape Province,* Upington: Department of Agriculture, Land Reform and Rural Development.

Hayes, M., Svoboda, M., Wall, N. & Widhalm, M., 2011. The Lincoln declaration on drought indices: Universal Meteorological drought index recommended. *Bulletin of the American Meteorological Society,* 92(4), pp. 485-488.

Holechek, J., 1996. Drought in New Mexico: prospects and management. *Rangelands,* 18(6), pp. 225-227.

Holechek, J., Gomes, H., Molinar, F. & Galt, D., 1999. Grazing Studies: What We've Learned. *Rangelands,* 21(2), pp. 12-16.

Horton, J., Macve, R. & Struyven, G., 2004. Qualitative Research: Experiences in Using Semi-Structured Interviews. In: C. Humphrey & B. Lee, eds. *The Real Life Guide to Accounting Research: A Behind-the-Scenes View of Using Qualitative Research Methods.* s.l.:Elsevier, pp. 339-350.

Howery, L., 2016. *Rangeland Management Before, During and After Drought,* Tuscon: College of Agriculture, University of Arizona.

International Trade Administration, U.S. Department of Commerce, 2021. *South Africa - Country Commercial Guide.* [Online]
Available at: https://www.trade.gov/country-commercial-guides/south-africa-agricultural-sector
[Accessed 2 March 2023].

John Taolo Gaetsewe District Municipality, 2020. *Integrated Development Plan 2012-2017: Section B.* [Online]
Available at: https://taologaetsewe.gov.za/wp-content/uploads/2020/07/IDP-Review-2016-Part-B-Situation-Analysis-final.pdf
[Accessed 11 November 2023].

John Taolo Gaetsewe District Municipality, 2022. *Integrated Development Plan.* [Online]
Available at: https://taologaetsewe.gov.za/wp-content/uploads/2022/09/Final-JTGDM-IDP-2021-2022.pdf
[Accessed 11 November 2023].

Jongbo, O., 2014. The Role of Research Design in a Purpose Driven Enquiry. *Review of Public Administration and Management,* 3(6), pp. 87-94.

Jordaan, A., 2011. *Drought Risk Reduction in the Northern Cape,* Bloemfontein: University of the Free State.

Jordaan, A., 2020. *Guidelines to Contingency Plans,* Pretoria: National Disaster Management Centre.

Jordaan, A., 2022. *Research Report Internal Publication: Deliverable Two: Analysis of farm-level drought indicators,* Pretoria: WRC.

Jordaan, A., Sakulski, D. & Jordaan, A., 2013. Interdisciplinary drought risk assessment for agriculture: The case of communal farmers in the Northern Cape Province, South Africa. *South African Journal of Agricultural Extension,* Volume 41, pp. 44-58.

Jordaan, A., Sakulski, D. & Jordaan, A., 2015. *Northern Cape Province: Drought Risk Assessment,* Kimberley: Department of Agriculture and Rural Development.

Jordaan, A. et al., 2017a. *Vulnerability, Adaptation to and Coping with Drought: The Case of Commercial and Subsistence Rain Fed Farming in the Eastern Cape Volume I,* Pretoria: WRC.

Kachergis, E. et al., 2014. Increasing flexibility in rangeland management during drought. *Ecosphere,* 5(6), pp. 1-14.

Keshavarz, M., Karami, E. & Vanclay, F., 2013. The social experience of drought in rural Iran. *Land Use Policy,* 30(1), pp. 120-129.

Kothari, C., 2004. *Research Methodology.* 2nd ed. New Delhi: New Age International.

Lembara, S. et al., 2011. *Drought Contingency Planning with Pastoral Communities. A Community Managed Disaster Risk Reduction Planning toolkit for Humanitarian Workers in the Horn of Africa,* s.l.: IIRR Publishing.

Li, X. et al., 2021. Strengthening grazing pressure management to improve grassland ecosystem services. *Global Ecology and Conservation,* Volume 31, p. e01782.

Mabaso, E. & Manyena, S., 2013. Contingency planning in southern Africa: Events rather than processes?. *Jàmbá: Journal of Disaster Risk Studies,* 5(1), pp. 1-8.

Mack, N. et al., 2005. *Qualitative Research Methods: A Data Collector's Field Guide,* Research Triangle Park: Family Health International.

Majid, U., 2018. Research Fundamentals: Study Design, Population, and Sample Size. *Undergraduate Research in Natural and Clinical Science and Technology (URNCST) Journal,* 2(1), pp. 1-7.

Makaya, E. et al., 2020. Water governance challenges in rural South Africa: exploring institutional coordination in drought management. *Water Policy,* 22(4), pp. 519-540.

Male, T., 2016. Analysing Qualitative Data. In: I. Palaiologou, D. Needham & T. Male, eds. *Doing Research in Education: Theory and Practice.* London: SAGE, pp. 177-191.

Marshall, M., 1996. Sampling for qualitative research. *Family Practice,* 13(6), pp. 522-526.

Matlou, R., Bahta, Y., Owusu-Sekyere, E. & Jordaan, H., 2021. Impact of Agricultural Drought Resilience on theWelfare of Smallholder Livestock Farming Households in the Northern Cape Province of South Africa. *Land,* Volume 10, p. 562.

Meza, I. et al., 2021. Drought risk for agricultural systems in South Africa: Drivers, spatial patterns, and implications for drought risk management. *Science of The Total Environment,* Volume 799, p. 149505.

Morse, J., 2015. Data Were Saturated . . .. *Qualitative Health Research,* 25(5), pp. 587-588.

Motha, R., 2011. Elements of National Drought Policy in USA. In: M. Sivakumar, R. Motha, D. Wilhite & J. Qu, eds. *Towards a Compendium on National Drought Policy. Proceedings of an Expert Meeting.* Geneva: World Meteorological Organization, pp. 46-56.

Mshelia, Z., 2023. *Northern Cape District Municipalities,* Bloemfontein: DIMTEC Laboratory, University of the Free State.

Mshelia, Z., 2023. *Northern Cape Local Municipalities,* Bloemfontein: DIMTEC Laboratory, University of the Free State.

Mshelia, Z., 2023. *Northern Cape Province,* Bloemfontein: DIMTEC Laboratory, University of the Free State.

Mthuli, S., Ruffin, F. & Singh, N., 2022. ‘Define, Explain, Justify, Apply’ (DEJA): An analytic tool for guiding qualitative research sample size. *International Journal of Social Research Methodology,* 25(6), pp. 809-821.

Mukheibir, P. & Sparks, D., 2005. *Climate variability, climate change and water resource strategies for small municipalities ,* Pretoria: WRC.

Muthelo, D., Owusu-Sekyere, E. & Ogundeji, A., 2019. Smallholder Farmers’ Adaptation to Drought: Identifying Effective Adaptive Strategies and Measures. *Water,* 11(10), p. 2069.

Muyambo, F., Jordaan, A. & Bahta, Y., 2017. Assessing social vulnerability to drought in South Africa: Policy implication for drought risk reduction. *Jàmbá: Journal of Disaster Risk Studies,* 9(1), pp. 1-7.

Ndlovu, T., 2019. Coping with drought: Reflection of communal cattle farmers in Umzingwane district in Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies,* 11(1), pp. 1-9.

Ngaka, M., 2012. Drought preparedness, impact and response: A case of the Eastern Cape and Free State provinces of South Africa. *Jàmbá: Journal of Disaster Risk Studies,* 4(1), pp. 1-10.

Nhamo, L., Mabhaudhi, T. & Modi, A., 2019. Preparedness or repeated short-term relief aid? Building drought resilience through early warning in southern Africa. *Water SA,* 45(1), pp. 75-85.

Nicholson, M., Bruce, S., Walcott, J. & Gray, J., 2011. Elements of a National Drought Policy: The Australian Context. In: M. Sivakumar, R. Motha, D. Wilhite & J. Qu, eds. *Towards a Compendium on National Drought Policy: Proceedings of an Expert Meeting.* Geneva: World Meteorological Organization, pp. 33-45.

O'Farrell, P., Anderson, P. M. S. & Dean, W., 2009. Human response and adaptation to drought in the arid zone: lessons from southern Africa. *South African Journal of Science,* 105(1), pp. 34-39.

Pixley ka Seme District Municipality, 2014. *Pixley ka Seme District Spatial Development Framework/Land Development Plan.* [Online] Available at: https://cer.org.za/wp-content/uploads/2021/03/Dr-Pixley-isaka-seme-Local-Municipality-SDF-2014.pdf
[Accessed 11 November 2023].

Rahman, M., 2023. Sample Size Determination for Survey Research and Non-Probability Sampling Techniques: A Review and Set of Recommendations. *Journal of Entrepreneurship, Business and Economics,* 11(1), pp. 42-62.

Redmond, K., 2002. The depiction of drought: A commentary. *Bulletin of the American Meteorological Society,* 83(3), pp. 1143-1147.

Ruwanza, S., Thondhlana, G. & Falayi, M., 2022. Research Progress and Conceptual Insights on Drought Impacts and Responses among Smallholder Farmers in South Africa: A Review. *Land,* 11(2), p. 159.

SADC, IUCN, UNCCD, 2022. *SADC Drought Risk Management and Mitigation Strategy 2022-2032. Volume 3: Strategy Elements and the Implementation Arrangements,* Gaborone: s.n.

Sanz, M. et al., 2017. *Sustainable Land Management contribution to successful land-based climate adaptation and mitigation. A Report of the Science-Policy Interface,* Bonn: United Nations Convention to Combat Desertification (UNCCD).

Sivakumar, M., 2011. Current Droughts: Context and Need for National Drought Policies. In: M. Sivakumar, R. Motha, D. Wilhite & J. Qu, eds. *Towards a Compendium on National Drought Policy. Proceedings of an Expert Meeting on the Preparation of a Compendium on National Drought Policy.* Geneva: World Meteorological Organization, pp. 2-22.

Sivakumar, M. et al., 2014. High Level Meeting on National Drought Policy: Summary and Major Outcomes. *Weather and climate Extremes,* Volume 3, pp. 126-132.

Smart, A. et al., 2010. Effects of Grazing Pressure on Efficiency of Grazing on North American Great Plains Rangelands. *Rangeland Ecology & Management,* 63(4), pp. 397-406.

Snyman, H. & van der Westhuizen, M., 2016. Guidelines for veld management after drought and the importance of resting. In: *Veld & Livestock Management: Disaster Drought Information.* Bloemfontein: Free State Agriculture and University of the Free State, pp. 7-11.

South African Government, 2005. *Disaster Managment Act Policy framework for disaster risk management in South Africa.* [Online] Available at: https://www.gov.za/sites/default/files/gcis_document/201409/275340.pdf [Accessed 2 March 2023].

South African Government, 2020. *Water and Sanitation on status of Water in Northern Cape.* [Online]
Available at: https://www.gov.za/speeches/status-water-nc-22-may-2020-0000 [Accessed 7 July 2023].

The Presidency, 2003. *No.57 of 2002: Disaster Management Act, 2002. No 24252,* Cape Town: Government Gazette.

U.S. Department of the Interior, Bureau of Reclamation, 2016. *Drought Response Program Framework: WaterSMART Program,* Denver: U.S. Department of the Interior.

UNCCD, 2017. *Sustainable Land Management for Climate and People,* Bonn: United Nations Convention to Combat Desertification (UNCCD).

UNDP, 2011. *Mainstreaming Drought Risk Management,* Nairobi: United Nations Development Programme (UNDP).

UNDRR, 2017a. *Vulnerability.* [Online]
Available at: https://www.preventionweb.net/understanding-disaster-risk/component-risk/vulnerability
[Accessed 11 July 2023].

UNISDR, 2009. *Drought Risk Reduction Framework and Practices: Contributing to the Implementation of the Hyogo Framework for Action,* Geneva: United Nations secretariat of the International Strategy for Disaster Reduction (UNISDR).

United Nations International Strategy for Disaster Reduction, 2009. *2009 UNISDR Terminology on Disaster Risk Reduction,* Geneva: United Nations International Strategy for Disaster Reduction (UNISDR).

United Nations Office for Disaster Risk Reduction, 2015. *Sendai Framework for Disaster Risk Reduction 2015-2030.* [Online] Available at: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf [Accessed 2 March 2023].

Vehovar, V., Toepoel, V. & Steinmetz, S., 2016. Non-probability Sampling. In: C. Wolf, D. Joye, T. Smith & Y. Fu, eds. *The SAGE Handbook of Survey Methodology.* s.l.:SAGE Publications Ltd, pp. 327-343.

Wilhite, D., 1996. A Methodology for Drought Preparedness. *Natural Hazards,* Volume 13, pp. 229-252.

Wilhite, D., 2000. Drought as a Natural Hazard: Concepts and Definitions. In: D. Wilhite, ed. *Drought: A Global Assessment.* London: Routledge, pp. 3-18.

Wilhite, D., 2019. Integrated drought management: moving from managing disasters to managing risk in the Mediterranean region. *Euro-Mediterranean Journal for Environmental Integration,* 4(42), pp. 1-5.

Wilhite, D. & Glantz, M., 1985. Understanding the Drought Phenomenon: The Role of Definitions. *Water International,* 10(3), pp. 111-120.

Wong, L., 2008. Data Analysis in Qualitative Research: A Brief Guide to Using Nvivo. *Malaysian Family Physician : the Official Journal of the Academy of Family Physicians of Malaysia,* 3(1), pp. 14-20.

World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014. National Drought Management Policy Guidelines: A Template for Action. In: D. Wilhite, ed. *Integrated Drought Management Programme (IDMP) Tools and Guidelines Series 1.* Geneva and Stockholm: WMO and GWP, pp. 3-9.

APPENDIX A: INTERVIEW QUESTIONNAIRE

Farmer questionnaire

Section 1: Biographic information

1. In which district municipality is your main farm located?
2. What is your age?
3. How many years of farming experience do you have?
4. What is your main form of farming? (cattle, wool sheep, mutton sheep, goats, game)
5. What is the size of your farm in hectares?
6. What is the carrying capacity of your farm in ha/LSU?
7. How many livestock units do you have on your farm?
8. Do you have any additional branches of farming that you engage in, such as crop production?
9. What is your highest qualification?
10. Have you experienced any previous severe drought events during your time as a farmer?

Section 2: Grazing land management

Drought preparedness

1. Do you rest your grazing lands for certain periods to prepare for drought?
2. Do you use grazing land conservation methods (such as soil erosion control)?
3. Do you use a multiple grazing camp strategy to conserve your grazing lands?
4. Do you have additional pastures which animals can graze on during drought? Are they irrigated?
5. Do you possess a feed bank which you actively make deposits into? If so, what type of feed do you deposit into this bank?
6. Do you have any other specific grazing land management practices which you apply to prepare for a drought?

Drought response

1. Have you ever had to lease additional land during drought? If so, during which phase of drought (D0-D4) did this occur?
2. Are there any additional adaptation measures which you implement during a drought regarding grazing land management? If so, what drought category (D0-D4) is it applicable to?

Section 2: Livestock management

Drought preparedness

1. Do you employ a conservative stocking rate on your farm, in case of drought?
2. Do you know what the prescribed carrying capacity of your farm is? If so, do your livestock numbers reflect this carrying capacity?
3. When selecting breeding livestock, is drought hardiness one of the most important characteristics?

Drought response

1. How do you reduce your livestock numbers during each category of drought (D0-D4), in terms of percentage reduction as well as which animals are sold during each category?
2. Do you wean your lambs/calves early during drought? At which category of drought (D0-D4) does this become necessary?
3. Do you remove your animals from the land (such as to place them in pens) or do you place them in smaller camps during droughts (to protect the land and reduce animal energy expenditure)? During which stage of drought (D0-D4) does this become necessary and how does it differ for each stage?
4. Have you ever had to sell your core breeding animals? If so, during which stage of drought (D0-D4) did this occur?

5. How do the animals' additional feeding requirements differ for each category of drought (D0-D4)? Do they receive different types of feed during each category?
6. During which stage of drought (D0-D4) do the animals receive full scale additional feeding? Which sources of feed do they receive?
7. Do you divide the animals into similar age and productivity groups when feeding them? If so, during which category of drought (D0-D4) do you apply this measure?
8. How often do you provide supplementary feed to your animals during each stage of drought? (For example: every day, once a week, etc.)
9. Do you have any additional adaption measures regarding livestock management which you apply during a drought? If so, what drought category (D0-D4) is it applicable to?

Section 4: Financial management

Drought preparedness

1. Do you have an emergency drought fund which you actively make deposits into, to be used when drought occurs?
2. Do you ensure that your debt burden is manageable during all times, to ensure that it remains under control even during periods of drought?
3. Do you regularly have meetings with your accountant to engage in cashflow planning and help you with budgeting?
4. Do you have any additional form of income not related to agriculture, which can help reduce the impact of drought?

Drought response

1. Have you ever had to sell non-agricultural assets (for example: vacation homes or personal vehicles) during a drought? If so, during which category of drought (D0-D4) did this occur?
2. Have you ever had to sell agricultural assets during a drought? If so, during which category of drought (D0-D4) did this occur?

3. Have you ever had to take out additional loans from institutions (such as banks or cooperatives) during a drought period for farming purposes? If so, during which category of drought (D0-D4) did this occur?
4. Have you had to consult with your bank manager to relieve financial pressure during a drought, such as increasing loan instalment periods or consolidating existing short- and medium-term loans into a single long-term loan? If so, during which category of drought (D0-D4) did this become necessary?
5. Has it ever been necessary for you to restructure your debt payments, such as temporarily ceasing the payment of capital instalments and only paying the interest on the loans? If so, at which category of drought (D0-D4) did this occur?
6. Do you postpone farm repair and maintenance procedures during a drought? During which category of drought (D0-D4) does this become necessary?
7. Have you ever had to retrench labourers during a drought? During which category of drought (D0-D4) did this become necessary?
8. Do you adjust your short-term insurance during a drought? If so, during which category of drought (D0-D4) does this become necessary?
9. Do you keep the money from forced livestock sales exclusively to rebuild your flock/herd after the drought has ended?
10. Have you ever applied and received any drought aid from the government? If so, during which category of drought (D0-D4) did you do this?
11. Do you have any additional adaptation measures regarding financial management that you apply during a drought? If so, what drought category (D0-D4) is it applicable to?

Section 5: Social management

Drought response

1. Do you cut down on personal expenses during a drought, such as vacation expenditure, recreational activities, vehicle purchases, etc.? During which category of drought (D0-D4) does this become necessary?

2. Do you have access to social networks, such as friends, family, organisations, etc., who can help you during a drought? If so, during which category of drought (D0-D4) do you start to make use of these networks?
3. Have you ever had to cancel contributions to important things such as medical aid, children's education, life insurance policies, etc.? During which category of drought (D0-D4) did you have to do this?
4. Do you have any additional adaptation measures regarding social management that you apply during a drought? If so, what drought category (D0-D4) is it applicable to?

APPENDIX B: INTERVIEW QUESTIONNAIRE (AFRIKAANS)

Boere Vraelys

Afdeling 1: Biografiese inligting

1. In watter distriksmunisipaliteit is u plaas geleë?
2. Wat is u ouderdom?
3. Hoeveel jaar se boerdery ervaring het u?
4. Wat is u hoofboerdery vertakking? (Bees, wolskaap, vleisskaap, boerbok, wild)
5. Wat is die grootte van u plaas in hektaar?
6. Wat is die drakrag van u plaas in ha/GVE?
7. Hoeveel vee het u op u plaas?
8. Het u enige addisionele boerdery vertakkings, soos gewas produksie?
9. Wat is u hoogtste kwalifikasie?
10. Het u al enige vorige besonderse droogtes ervaar gedurende u tyd as 'n boer?

Afdeling 2: Veldbestuur

Droogte voorbereiding

1. Rus u u se veld vir 'n sekere tydperk om voor te berei vir 'n droogte?
2. Gebruik u enige veldbewaring tegnieke, soos om byvoorbeeld gronderosie te voorkom?
3. Gebruik u 'n multikamp weidingstrategie om u veld te bewaar?
4. Het u enige addisionele aangeplante weidings waarvan u vee kan gebruik maak tydens 'n droogte? Word hierdie weidings besproei?
5. Besit u 'n voerbank waarin u gereeld deponeer? Indien so, watter tipes voer deponeer u in hierdie voerbank?

6. Het u enige ander spesifieke veldbestuur praktyke wat u toepas om voor te berei vir ‘n droogte?

Droogte reaksie

1. Moes u al ooit ekstra land huur tydens ‘n droogte? Indien so, tydens watter droogtekategorie (D0-D4) moes u dit doen?
2. Het u enige addisionele aanpassings maatreëls rakende veldbestuur of voer wat u toepas tydens ‘n droogte? Indien so, tot watter kategorie droogte (D0-D4) het dit betrekking?

Afdeling 3: Veebestuur

Droogtevoorbereiding

1. Het u ‘n konserwatiewe drakrag op u plaas, in geval van ‘n droogte?
2. Weet u wat is die voorgeskrewe drakrag van u plaas? Indien so, is u veegetalle aangepas by hierdie voorgeskrewe drakrag?
3. Wanneer u nuwe genetika kies, is droogte gehardheid een van die belangrikste eienskappe?

Droogte reaksie

1. Hoe maak u u veegetalle minder tydens elke kategorie van droogte D0-D4, in terme van persentasie vermindering asook watter diere tydens elke kategorie verkoop word?
2. Speen u u lammers en/of kalwers vroeg tydens ‘n droogte? Tydens watter kategorie van droogte (D0-D4) word dit nodig?
3. Haal u u vee af van die veld af (soos om hulle in krale se sit) of sit u u vee in kleiner kampe tydens droogte? Tydens watter kategorie droogte (D0-D4) word dit nodig en hoe verskil elke kategorie?
4. Moes u al ooit kernteeldiere verkoop? Indien so tydens watter kategorie droogte (D0-D4)?
5. Hoe verskil die diere se addisionele voerbehoeftes tydens elke kategorie droogte (D0-D4)? Kry hulle verskillende tipes voer tydens elke kategorie?

6. Tydens watter kategorie droogte (D0-D4) kry die diere volskaalse addisionele voer? Watter tipes voer word dan vir hulle gegee?
7. Plaas u u vee in soortgelyke ouderdoms en/of produktiwiteits groepe wanneer hulle gevoer word? Indien so, tydens watter kategorie droogte (D0-D4) pas u hierdie maatreël toe?
8. Hoe gereeld word addisionele voer vir diere gegee tydens elke kategorie droogte (D0-D4)? (Byvoorbeeld: daagliks, weekliks, ens.)
9. Het u enige addisionele aanpassings maatreëls rakende veebestuur wat u toepas tydens ‘n droogte? Indien so, tot watter kategorie droogte (D0-D4) het dit betrekking?

Afdeling 4: Finansiële bestuur

Droogtevoorbereiding

1. Het u ‘n nooddroogtefonds waarin u aktief deponeer, waarvan u dan gebruik kan maak tydens ‘n droogte?
2. Maak u seker dat u skuldlas altyd onder beheer is, om voorbereid te wees vir ‘n droogte wanneer ‘n mens moontlik nog skuld moet aangaan?
3. Het u gereeld vergaderings met u rekenmeester om u kontantvloei te beplan en/of om u met u begroting the help?
4. Het u enige addisionele bronne van inkomste wat nie verwant is aan u boerdery nie, wat moontlik vir u kan help om die impakte van droogtes te verminder?

Droogte reaksie

1. Moes u al ooit nie-landbou verwante bates (soos vakansie huise of persoonlike voertuie) verkoop gedurende ‘n droogte? Indien so, gedurende watter kategorie droogte (D0-D4) moes u dit doen?
2. Moes u al ooit landbou verwante bates verkoop gedurende ‘n droogte? Indien so, gedurende watter kategorie droogte (D0-D4) moes u dit doen?

3. Moes u al ooit addisionele lenings by instellings uitneem (soos banke of kooperasies) gedurende ‘n droogte om u boerdery aan die gang te hou? Indien so, tydens watter kategorie droogte (D0-D4) moes u dit doen?
4. Moes u al ooit u bankbestuurder gaan sien om finansiële druk te verlig, soos om lening paaiemente periodes te verleng, of om bestaande korttermyn en mediumtermyn lenings te konsolideer in ‘n enkele langtermyn lening? Indien so, tydens watter kategorie droogte (D0-D4) het dit nodig geword?
5. Was dit al ooit nodig dat u u skuldbetalings moes hekstruktureer, soos om byvoorbeeld tydelik op te hou kapitaal paaiemente betaal en net die rente op die lenings te betaal? Indien so, tydens watter kategorie droogte (D0-D4) het dit nodig geword?
6. Staak u u onderhoud en herstelprogramme op die plaas gedurende ‘n droogte? Indien so, tydens watter kategorie droogte (D0-D4) word dit nodig?
7. Moes u al ooit werkers afdank tydens ‘n droogte om geld te spaar? Indien so, tydens watter kategorie droogte (D0-D4) het dit nodig geword?
8. Pas u u korttermynversekering aan tydens ‘n droogte? Indien so, tydens watter kategorie droogte (D0-D4) word dit nodig?
9. Hou u die geld wat u kry van veeverkope tydens ‘n droogteperiode uitsluitlik om u kudde te herbou na die droogte?
10. Het u ooit al vir droogtehulp by die regering aansoek gedoen en dit gekry? Indien so, tydens watter kategorie droogte (D0-D4) het u dit gedoen?
11. Het u enige addisionele aanpassings maatreëls rakende finansiële bestuur wat u toepas tydens ‘n droogte? Indien so, tot watter kategorie droogte (D0-D4) het dit betrekking?

Afdeling 5: Sosiale bestuur

Droogte reaksie

1. Sny u u persoonlike uitgawes tydens ‘n droogte, soos byvoorbeeld vakansieuitgawes, ontspanningsaktiwiteite, ens.? Indien so, tydens watter kategorie droogte (D0-D4) word dit nodig?

2. Het u toegang tot sosiale netwerke (soos vriende, familie, verenigings, ens.) wat vir u steun kan bied tydens ‘n droogte? Indien so, tydens watter kategorie droogte (D0-D4) maak u gebruik van hierdie netwerke?
3. Moes u al ooit belangrike uitgawes, soos kinders se skoolgeld, mediese fonds betalings of lewensversekering polisse, staak tydens ‘n droogte? Indien so, tydens watter kategorie droogte (D0-D4) moes u dit doen?
4. Het u enige addisionele aanpassings maatreëls rakende veebestuur wat u toepas tydens ‘n droogte? Indien so, tot watter kategorie droogte (D0-D4) het dit betrekking?

6 Conclusion

In conclusion, this research has meticulously developed systems and strategies pivotal for drought management and resilience for extensive livestock farmers.

Key outcomes from this project include the development of a robust indicator framework for drought monitoring focused on the extensive livestock sector, a computerised web-based reporting and data capturing system that enhances real-time monitoring, and well-defined contingency plans for various drought categories. These innovations are crucial for timely and effective drought response strategies, replacing outdated methods and significantly improving the proactive management capabilities of livestock farmers.

However, the project also highlights several challenges. These include the practical difficulties in implementing farm-level reporting systems, as seen with the limited success of previous initiatives. Discussions with Northern Cape farmers to implement the system was also unsuccessful due to negative experiences of farmers from government drought relief initiatives. Despite these hurdles, there is strong government and departmental support for continuing and expanding these efforts, recognizing their importance in safeguarding the agricultural sector and broader provincial economy.

Moreover, the the specialized reporting mechanisms suggest a shift towards more integrated and coordinated drought management strategies that align with both provincial and national goals. This holistic approach is seen as essential for enhancing the resilience of the agricultural sector and the wider community to the recurrent challenges posed by drought.

Future directions suggested by this research include enhancing understanding and operationalisation of drought categories through targeted training for stakeholders, expanding the contingency planning to other sectors, and improving the integration and accessibility of drought-related data across various platforms for a comprehensive and unified response mechanism.

Ultimately, the successful implementation and continual refinement of the strategies and systems developed by this project are expected to form a cornerstone of South Africa's approach to drought risk reduction, serving as a model for similar initiatives both nationally and internationally. This aligns with global best practices and leverages innovative technology and local knowledge to forge a resilient agricultural sector capable of withstanding the challenges and uncertainties of climate variability.