PART TWO

DROUGHT INDICATORS FOR SOUTH AFRICA

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This article provides a guide for drought indicators for South Africa. The proposed indicators are in line with international best practice. Two of the leading countries in the world on drought management, the USA and Mexico, utilise similar indicators for drought monitoring and drought declaration. The USA expanded the number of indicators to more than 20 and is therefore in a position to better monitor the impacts of drought at all levels. Ten primary indicators are proposed. This should be expanded in future. The National Drought Task Team of South Africa accepted the proposed indicators as a good start and we expect the Department of Agriculture, Forestry and Fisheries (DAFF) and the National Disaster Management Centre (NDMC) to formalise the use of these indicators for all of South Africa.

Drought indicators

The finalisation of the drought indicators discussed in this report followed a process of consultative meetings between representatives from AgriSA, the Department of Water and Sanitation (DWS) and the Agricultural Research Council (ARC) under the chairmanship of DAFF. All parties involved in the development of the drought indicator document agreed that it was work in progress and the guidelines and indicators for drought declaration would be adjusted as we obtain more insight into especially the different thresholds. One of the major gaps identified are the thresholds for different types of drought and when a dry period becomes a drought, since these thresholds are not the same for all sectors due to the inherent differences in vulnerability and/or resiliency to drought.

Drought indicators proposed for South Africa are classified as primary and secondary indicators. The primary indicators are those indicators that are easy to monitor using meteorological data, satellite images and gauging stations, while the secondary indicators require actual field visits to the affected area. Not one single drought index fitted all needs to determine the different types of droughts. The idea with primary indicators is that continuous monitoring will take place and once certain thresholds are reached, drought classification can take place based on the thresholds and evaluation of secondary indicators are then activated. The secondary indicators serve to 'ground-truth' the impact of the dry period.

Drought indicators selected for South Africa

Table 1 summarises the thresholds for the indicators for different drought classifications.

One single indicator on its own is not sufficient to measure drought and a combination of indicators is required; for example, the six-month Standardised Precipitation Index (SPI) of -1,3 might indicate a D2 drought classified as a severe drought but the soil moisture content and the Normalised Difference Vegetation Index (NDVI) results remains within the D1 classification due to good rains prior to the six month period in which the SPI was measured. That will put the specific drought in a D1 category in spite of the low SPI values. In order to classify a dry period into a specific drought category, at least three of the indicator thresholds must concur. Composite indicators such as the (i) Combined Drought Indicator (CDI), (ii) Global Integrated Drought Monitoring and Prediction System (GIDMaPS), (iii) Multivariate Standardised Drought Index (MSDI) and (iv) United States Drought Monitor (USDM) should be implemented to monitor drought accurately. The National Drought Task Team (NDTT) specialist working group on drought indicators, however, proposed the indicators as shown in Table 1 as primary use for South Africa until the establishment of a drought monitor platform that should monitor drought in South Africa.

Dry periods and drought impact different sectors differently. Internationally it is accepted to declare the D3 and D4 droughts as disaster droughts, during which time government safety nets should be activated. An analysis by Jordaan et al. (2010) in the Northern Cape and by Jordaan and Sakulski (2014) in the Eastern Cape shows that SPI -1,2 is already disastrous for smallholder and communal farmers due to their high vulnerability and low resilience.

The primary indicators shown in Table 1 should be supplemented with secondary indicators, which are more an indication of the impact of the drought. Indicators are grouped as meteorological, remotely sensed and hydrological.

Meteorological indicators

A negative deviation from the normal (climatological mean) precipitation, required to maintain adequate soil moisture water content for normal plant growth, supply of reservoirs, streamflow and groundwater level, may result in drought. Precipitation is the main source of water for soil moisture, reservoirs, streamflow and groundwater; the lack thereof affects all these indicators. South Africa does not have significant snowfall and snow as an additional source of water for rivers and dams is not considered. The Palmer Drought Severity Index (PDSI), for example, is an indicator used in the USA in areas where snow is a source of water.

The effect of abnormally high temperatures increases evapotranspiration as well as stress in plants whilst further depleting surface water reserves through evaporation. High temperatures coupled with low relative humidity and desiccating or continental winds result in large water demands by vegetation. When the condition prevails over long periods it may lead to drought. The percentage of normal precipitation and SPI are recommended as meteorological indices for South Africa.

Precipitation expressed as percentage of the long term mean

Total precipitation for any period is expressed as a percentage of the long term average. Below the threshold of 75 percent 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. Important, however, for especially crop farmers is the timing of the deviation. A low percentage of normal precipitation combined with high temperatures during the growing season of specific crops might have disastrous results. On the other hand, a low percentage of normal precipitation outside the growing season might not be as damaging.

Standardised Precipitation Index (SPI)

The SPI quantifies precipitation deficits at variable time scales and provides an indication of drought intensity and duration (severity), 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 makes it an attractive tool for delineation of drought conditions. The SPI has been used to track the evolution of drought at time scales ranging from 1 to 24 months or longer. Depending on the relevant period, the index can be used to identify both agricultural and hydrological droughts.

Important, however, is the time scale of measurement and during which season it is applied. 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 negatively on livestock farmers.

The SPI and Standardised Precipitation Evapotranspiration Index (SPEI) are, globally, the preferred index to be used for drought risk assessment (WMO, 2009), henceforth the use of the SPI and SPEI as the preferred indicators for drought classification. In order to understand the meaning of SPI and SPEI, one should also review some other definitions and concepts related to these indices (McKee et al., 1993; Western Regional Climate Centre, 2011). Tom McKee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in 1993 to give a better representation of wetness and dryness to quantify a precipitation deficit for different time scales and for different locations. It was designed to be an indicator of dry and wet periods that recognises the importance of time scales in the analysis of water availability and water use (McKee et al., 1993; 1995; Keyantash and 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 has already been shown in several studies (Keyantash and Dracup, 2002; Paulo et al., 2003; Paulo and Perreira, 2005; 2007; 2008, Moreira et al., 2008). The SPI has the following desirable traits (McKee et al., 1993):

- SPI is uniquely related to probability.
- The SPI is normally distributed and is therefore useful to monitor dry and wet periods.
- Because of the normal distribution of SPI, the drier and wetter climate regimes are represented in a similar way.
- The precipitation data used in SPI can be used to calculate percent of mean precipitation for a specific time period.
- The precipitation data used in SPI can be used to calculate the precipitation deficit for a specific period.

Remotely-sensed agricultural drought indicators

Earth Observation (EO) data can be employed to provide information on the abundance and condition of vegetation. The data are remotely sensed and unlike several other climate products, which are interpolated from point values, they are comprised of contiguous pixels representing conditions on the ground. Various bands in the visible through near infrared and short wave infrared are sensitive to, amongst others, various characteristics of vegetation.

Normalised Difference Vegetation Index (NDVI)

The Normalised Difference Vegetation Index (NDVI) expresses vegetation health in terms of the amount of reflectance/radiation in the red and near-infrared bands. The index is used to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation or not. The NDVI is often directly related to other ground parameters such as percentage of ground cover, photosynthetic activity of the plant, surface water, leaf area index and the amount of biomass. Several derivatives of this index, based on cumulative and historical data, may provide information on the duration and intensity of drought, while the contiguous nature of the data is an excellent indicator of the spatial extent of such a drought.

The Vegetation Condition Index (VCI)

The VCI compares the current NDVI to the range of values observed in the same period in previous years. The VCI is expressed as a percentage and gives an idea where the observed value is situated between the extreme

Cat	Description		Freq.	Meteorological	
				% of Normal Preciptn.	SPI
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 30 days	-0,5 to -0,7
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 30 days	-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 180 days	-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 180 days	-1,6 to -1,9
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 to larger economy	1:50yr	< 65% for 360 days	-2 or less

Table 1: Drought classification and index thresholds

values (minimum and maximum) in the previous years. Lower and higher values indicate poor and good vegetation state conditions, respectively.

One of the challenges for the use of VCI is the fact that the satellite data do not distinguish between man-made droughts as a result of overgrazing and actual drought. Therefore, one should consider different indicators in combination with each other.

The Percentage of Average Seasonal Greenness (PASG)

The PASG provides an indication of the cumulative vegetation activity over a specified period ie a growing season, relative to the long term average for the period. The index expresses the current cumulative vegetation activity determined by the cumulative NDVI as a percentage of the long term average cumulative NDVI value for the specified period. Over a shorter time span, such as a three-month to six-month period, the PASG provides an overview of conditions relating to possible drought stress during a growing period and is therefore relevant for the monitoring of agricultural drought. At a 24-month time scale, the index may be more applicable as an indicator for hydrological drought.

Soil Moisture Index

Drought occurs when the balance between rainfall, evapotranspiration and discharge leaves less available water in the soil storages than necessary for plant growth and for support of animals. The key role of available soil moisture in the root zone is providing food for people and animals. This feature places accurate monitoring and effective responses as central issues in food security. In this regard, drought can be considered as a combination of moisture deficit and land use due to this idealised cause-effect relationship, which assumes that a shortage of rainfall (the cause) leads to a soil moisture deficit that results in a reduction of vegetation production (the effect). This relationship gives an opportunity to provide an early warning system for drought by monitoring soil moisture. Remote sensing of soil moisture is a new development with good potential for drought monitoring.

Hydrological indicators

Hydrological indicators are important for the irrigation sector and these are an indication of the amount of water available for irrigation. Livestock farmers also depend mostly on groundwater and potable water for livestock drinking water and are, as such, also threatened by hydrological drought. Streamflow and dam level indicators are not finalised as yet and there is still a knowledge gap in South Africa in this regard. Obviously, critical river levels will differ according to watershed characteristics as well as the time of the year. Low streamflow levels just before the rainy season might not be critical if compared to after the rainy season; the same applies for dam levels and groundwater levels. The measurement for streamflow, dam levels and groundwater levels should be translated to an index, which represents the percentage of normal long term flow during a specific time of the season. One possible method is the use of the same calculations used for SPI or the Z score. The Z score is calculated as follows:

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

where X = streamflow value (observed or simulated)
$\hat{X}$ = mean streamflow for the same period of measurement (observed)
σ = Standard deviation

Reservoirs/dams

Generally, a reservoir is a storage system created by a wall across a river and its purpose is for harvesting water during the rainy season when streamflow rates are more than the required water supply abstraction rates. Therefore, during dry and/or drought periods water supply is sustained by appropriate releases from the reservoir. The reservoir storage level is therefore a function of the season's runoff amounts, meaning that during drought little water is harvested and the reservoir level will be low. Based on previous records, the Department

Remote sensing				Hydrological			
NDVI	**PASG**	**1-month VCI**	**St Veg Health Index**	**CPC Soil Moisture %**	**Dam levels zone Z score**	**Str. Flow Z score**	**Groundwater level % Z score**
	3month PASG < 90%	< 90%	36 - 45	21-30	In the moderately low zone	21-30	60- 100
	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
	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
	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
	12/24-month PASG < 80%	< 60%	1-5	0-2	Dams dry Z<-2	0-2 Z<-2	0- 15 Z<-2

of Water and Sanitation (DWS) has prepared graphs that indicate zones/ranges of water levels in the different reservoir during the year.

Water levels falling in and below the 'Low' zone/range would signal drought conditions (www.dws.gov.za/hydrology/State of Dams/WMA/Indicators- for dams across the country). These tools (graphs) for dams across the country are available on the DWS's website. It is important to mention here that the characteristics of the storage zones are different for different dams depending on the hydrology and general water supply and water use pattern of the system. Also important is the time of measurement. An empty dam at the end of the rainy season might be an indication of extreme drought while the same dam level at the beginning of the rainy season might reflect a normal dry period.

Streamflow levels

Streamflow levels are a direct or indirect function of precipitation in the catchment area of a specific river. Some of the precipitation water (runoff) also enters the ground and is released into the stream after weeks, months or even years. In certain areas, water directly from streams is used in various agricultural activities such as irrigation and water for livestock. Depending on the size of the catchment, drought stress can cause serious impacts on streamflow. As for reservoirs, indicators should be prepared to indicate zones/ranges of water levels in the river over the year but only for sites that are not under the influence of releases from upstream reservoirs. However, because most critical streamflow sites are influenced by artificial reservoir releases and/or other human activities, such graphs are not readily available for streamflow but can be easily generated by a professional hydrologist/engineer where necessary. This is currently a gap in the drought monitoring system and should be calculated to quaternary catchment level.

Groundwater

- Drought is exacerbated by lack of precipitation and excess evapotranspiration. 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 the ocean)
- 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 and only in later stages of a drought will groundwater storage and hence availability diminish as a result of a continued drought. Hence, groundwater can be used as a drought mitigation strategy but only to a certain degree because the available groundwater may not represent the present day recharge. It should be noted that during drought, it is often boreholes that fail and not the aquifers.

After a drought event, groundwater may be in short 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 a drought and in the end of a drought.

Summary

The adoption of quantitative drought indicators should go a long way in taking the guessing out of disaster drought declaration. The indicators discussed in this article are the primary indicators and should be used in combination with secondary indicators to ground truth the actual impact of a dry period. Secondary indicators include actual grazing condition, actual soil moisture content, crop conditions, animal condition, drinking water supply and others. These are discussed in a follow up article.