

Remote Sensing as a tool for drought monitoring and assessment in Botswana

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Abstract: *There is large consensus among the scientific community that the global climate is changing and that climate change will accelerate the hydrological cycle with increased frequency of occurrence of flood and drought events. Botswana is characterized by an arid to semi-arid climate with low annual rainfall amounts in most parts of the country. Climate change is expected to exacerbate the impacts already being felt from a highly variable natural climate and most of the impacts will be imposed on communities whose livelihoods largely depend on rainfed agriculture. Droughts are a common and recurrent feature especially in most arid regions of the world. In order to safeguard livelihoods and food security against the adverse impacts of droughts, drought preparedness and early warning must be prioritized in policy making. Provision of timely information that informs the decision making process under the context of droughts requires monitoring tools that are able to capture both historical and real time events and at the same time being flexible and adaptive to different conditions. Most parts of southern Africa are characterized by paucity of observed station data which makes them limited in spatial and temporal coverage in such instances, satellite imagery can therefore be used as surrogate monitoring data. For a long time satellite-based remote sensing has been used to reliably monitor environmental activities. One advantage of remote sensing is that it provides continuous data with a large spatial coverage. This study explores the use of remote-sensed data in near real time monitoring of droughts in Botswana. Satellite-based drought indices are assessed and a comparison is made relative to the standardized precipitation index (SPI) which is derived from observed station data. Positive correlations (>0.5) exist between SPI and the remote sensed indices indicating that satellite based indices can be used to reliably inform drought risk management.*

Keywords: *drought monitoring, remote sensing, indices SPI, Botswana*

Introduction

Drought is a recurrent event that occurs as a result of prolonged periods of below average precipitation. Extended periods of drought have caused immense human suffering, social and economic losses as well as threatening environmental sustainability (Sharma et al., 2009). Natural climatic variability is the major driver of droughts particularly in the dry arid and semi-arid regions of the world. Climate is expected to worsen the negative impacts of drought (Mir et al. 2012) on livelihoods with significant negative social and economic effects. Compared to floods, droughts develop

slowly and can only be recognized once people and the environment start to feel their impact. Although it is difficult to avoid droughts, their impacts can be averted through an understanding of their nature and occurrence. Timely early warning systems and appropriate drought risk management strategies can only be achieved when the droughts are objectively defined and quantified (Smakhtin and Hughes, 2004). Compared to floods, droughts develop slowly and can only be recognized once their effects are evident on the people and the environment (Vicente-Serrano and Lopez-Moreno, 2005) therefore it is quite difficult to determine the onset and cessation of droughts.

Drought can be quantified from parameters such as rainfall, temperature, soil moisture and streamflow. In contrast to the use of raw data such as rainfall or temperature a number of drought indices can be derived which show the occurrence, magnitude, intensity and duration of a drought event (Zarger et al., 2011; Hayes, 2006). These climate-based indicators are, however, limited by lack of adequate spatial coverage since most of the data are obtained from station observations which are sparsely located most of the times thus compromising their reliability (Brown et al., 2002). The data sources for these indicators can be obtained from station observations or from satellite imagery. Station observed data have shortfalls of limited spatial and temporal coverages.

On the other hand remote sensing has the capability of providing data covering larger and ranging from local to regional scales as well as with finer temporal resolutions. The standardised precipitation index (SPI, McKee et. al, 1993) depends on rainfall as the single input variable; it assesses drought conditions based on the probability of long term precipitation. To assess the severity of wet and dry spells the index considers cumulative precipitation deficits at various spatio-temporal scales and quantifies precipitation anomalies as a single numeric value (Hou et al., 2007). On the other hand a vegetation index can also be calculated from satellite spectral signatures obtained from radiation absorption in the red and near infrared bands of the electromagnetic spectrum, these indicate the vegetation condition as well the dynamics of vegetation at different stages. Green vegetation has high absorption of radiation in the red band and high reflection in the infrared region and satellite remote sensors are able to quantify the fraction of radiation that is absorbed by the

photosynthetically active material. The normalized difference vegetation index (NDVI, Tucker, 1979) is the most commonly used form of remote sensed data (Rulinda et al., 2010). NDVI does not specifically give a reflection of the drought conditions but merely indicates vegetation health and density. Nonetheless, it can be transformed to other forms of drought monitoring indices such as the vegetation condition index (Kogan, 1997), the decile index and the aridity index anomaly. The vegetation condition index (VCI) indicates how close the NDVI for a particular period such as a month is close to the long term minimum NDVI.

Botswana (Fig 1) is a semi-arid country with very high dependence on rain-fed subsistence agriculture. Natural climatic variability together with erratic rainfall patterns have resulted in low total annual rainfall and consequently high uncertainty in water resources availability. Agricultural production is therefore susceptible to climatic variability and to the frequent occurrence of droughts. Continuous monitoring of droughts and provision of early warning systems is therefore crucial in safeguarding agricultural productivity. This study aims to use remote sensing to assess the droughts that have occurred in the past in Botswana. The standardized precipitation index (SPI) is employed to validate the remote-sensed droughts.



Fig 1: Location of Botswana

Materials and Methods

FEWSNet 10-daily rainfall estimates and daily potential evapotranspiration estimates as well as SPOT NDVI (pre-2014) and PROBA-V NDVI (post 2014) were used to generate the satellite-based indices for the period 2000-2016. The SADC-MESA drought monitoring software (DMS) was used to generate the indices. A comparative analysis of the indices against the standardized precipitation index (SPI) was also performed. Station rainfall data for the period 1980-2016 were obtained from the Department of Meteorological Services. The 6-monthly SPI was generated using the SPI package (Berguria et al., 2014) found in the R- software package (<http://www.R-project.org/>). Time series data of cumulative precipitation over the period of study are compiled after which the data are fitted

to a two-parameter gamma distribution. A cumulative probability density function for any given amount of precipitation is calculated from the fitted distribution and then it is transformed to a standard normal distribution with a zero mean and standard deviation of one to give the SPI value.

Results and Discussion

Selected indicators for assessing drought conditions in Botswana for the period of October 2015 to March 2016 relative to the long term conditions are presented in Fig 2. Clearly rainfall is a major driver to the availability or nonavailability of water as such the plant-based remote sensing indicators of water. The results confirm that although NDVI is a good indicator of vegetation health it is not necessarily a drought index. NDVI simply shows the vegetation health status with respect to a certain period (whether dry or wet). Therefore it is possible to show a positive condition (green) of vegetation NDVI even during drought conditions for example if there was improvement from extreme to moderate conditions. The VCI and the rainfall deciles appear to be in sync with the cumulative rainfall and can be reliable drought indices. Both indices show that below normal conditions were experienced in most parts of the country during the period of study, with extreme drought conditions in the southern parts of the country whereas areas in the north experienced relatively wet conditions. Areas of high drought potential (red) were observed more in the south for both VCI and the decile indices. More than 30% of the country was under severe to extreme drought conditions. 22% of Botswana had a VCI less than 36, indicating unusually poor conditions in some parts of Botswana while about 3% of the country had a VCI value > 64, indicating fairly good conditions. Significant correlations (Table 1) were observed between the anomalies of VCI and SPI for the period under observation. This may be attributed to the fact that precipitation is the major driver for both indices and as such vegetation health is sensitive to precipitation especially after prolonged periods of antecedent dry conditions. This observation is also supported by the high correlations obtained for the districts in the south which happen to be areas of less rainfall and therefore more prone to droughts than the northern areas. Generally in all cases the correlations are strong ($R^2 > 0.5$) because most of the vegetation growth is rainfed while conditions in the country remain semi-arid in nature.

Table 1: Correlation VCI - SPI

District	R^2 (VCI-SPI)
Ngamiland	0.498
Central District	0.613
North East	0.574
Ghanzi	0.627
Kweneng	0.69
Kgatleng	0.715
Southern	0.648
South East	0.687
Kgalagadi	0.755

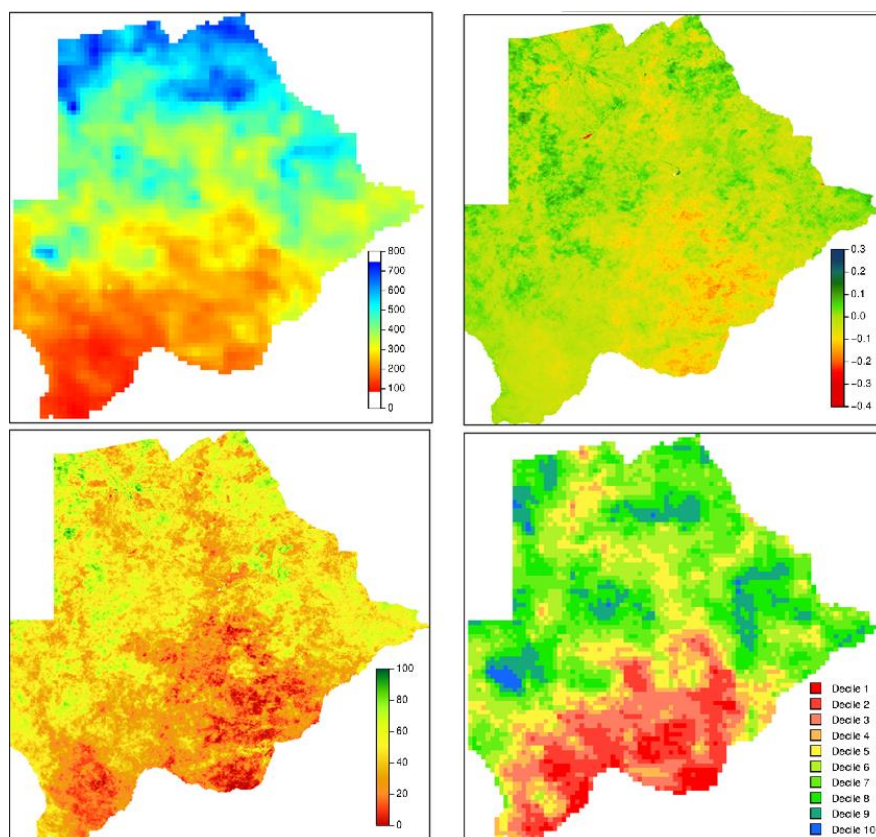


Fig 2: Figure 2: Drought indicator maps for Botswana, October 2015-March 2016. a) cumulative rainfall b) NDVI c) VCI d) rainfall decile

Conclusion

An attempt was made to assess drought conditions in Botswana using remote sensed indices as a proxy to indices derived from station data. Generally it can be concluded that the southern parts of the country are more drought prone than areas in the north. Positive correlations were obtained between the vegetation condition index and the SPI indicating that remote sensed indices can be adequately used to monitor droughts in arid and semi-arid areas. Based on the VCI a and the rainfall deciles large part of the country was under a high drought risk for the 2015-16 agricultural season. Remote sensed indices derive their strength in that they can be produced at various spatial scales ranging from local to regional and can be used for assessment in areas where there is sparse station data. Both the indices based on station observed data and on remote sensing can be used to complement each other in order to produce more certain drought assessment results which can better inform the drought risk management process.

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