Characterization of drought over Botswana using multivariate statistics

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Abstract

Droughts produce a complex set of negative social, environmental, and economic, impacts across the world. The Standardized Evapotranspiration Index (SPEI) was able to detect the spatial variation of drought events at a high areal extent. SPEI was also used to determine the three drought characteristics namely duration, severity and intensity. A set of seven clusters/ regions with similar drought characteristics were obtained from the SPEI data over Botswana. The univariate marginal distribution for drought duration, severity and intensity were identified by employing the Akaike Information Criterion (AIC) method. The drought duration was best distributed with the Generalized Extreme Value distribution while the drought severity and intensity were both best distributed with Weibull distribution. Nine copula distributions, namely; Normal, Student's t, Gumbel-Hougaard, Rotated Gumbel, Clayton, Rotated Clayton, Joe-Clayton, Frank, and Plackett copula distributions were applied to construct the three dimensional joint distributions. The most appropriate copula functions were determined also based on AIC method. The Normal copula distribution had the lowest values of AIC when compared to other copula families across all the regions in the study area. The joint probabilities in the OR cases indicated that drought events with high intensities had a low probability of occurrence while lower intensities had a high chance of occurrence within 5 to 10 years. Drought events with short duration had high probabilities of occurrence and vice versa and the severity of the drought was similar. The trivariate joint return periods increase as values of duration, severity, and intensity increase. Generally the short return period is mainly distributed in the northern region. Such knowledge on the identification of drought return periods may be useful in risk assessment of water management activities under severe and extreme drought situations.

Introduction

Semi-arid countries are well known for frequent and severe drought. Botswana is not exceptional. Therefore, Botswana as a semi-arid country with a relatively low and variable rainfall, has experienced frequent drought in the past over the entire country. Hence drought made strong impacts on the livelihood and economic development of the country for a long period since 1983.

The agricultural sector has been playing a dominant role on the economy of the country (highest contribution to the country's Gross Domestic Product (GDP)). The sector is very dependent on rainfall with very few percent of the total arable land being irrigated. But recently the agricultural contribution to the GDP has dropped to about 2.6 % which is linked to rainfall shortage and extreme temperatures. (Batisani, 2012).

Aims/Objectives

The study aims to analyse drought characteristics over Botswana using Standardized Precipitation Evapotranspiration Index (SPEI) at a timescale of 12 months over Botswana, with the following specific objectives:

- To evaluate the performance of the SPEI's ability to characterize the drought events (spatial and temporal variability).
- To identify drought prone areas over the country.
- To determine the recurrence time of drought with different duration, severity and intensity from historical data of 118 years (1901-2018) in the frame work of multivariate drought characterization using copula.

Methodologies

Fig.1 shows the sequence in which the different methodologies are applied for drought analysis.

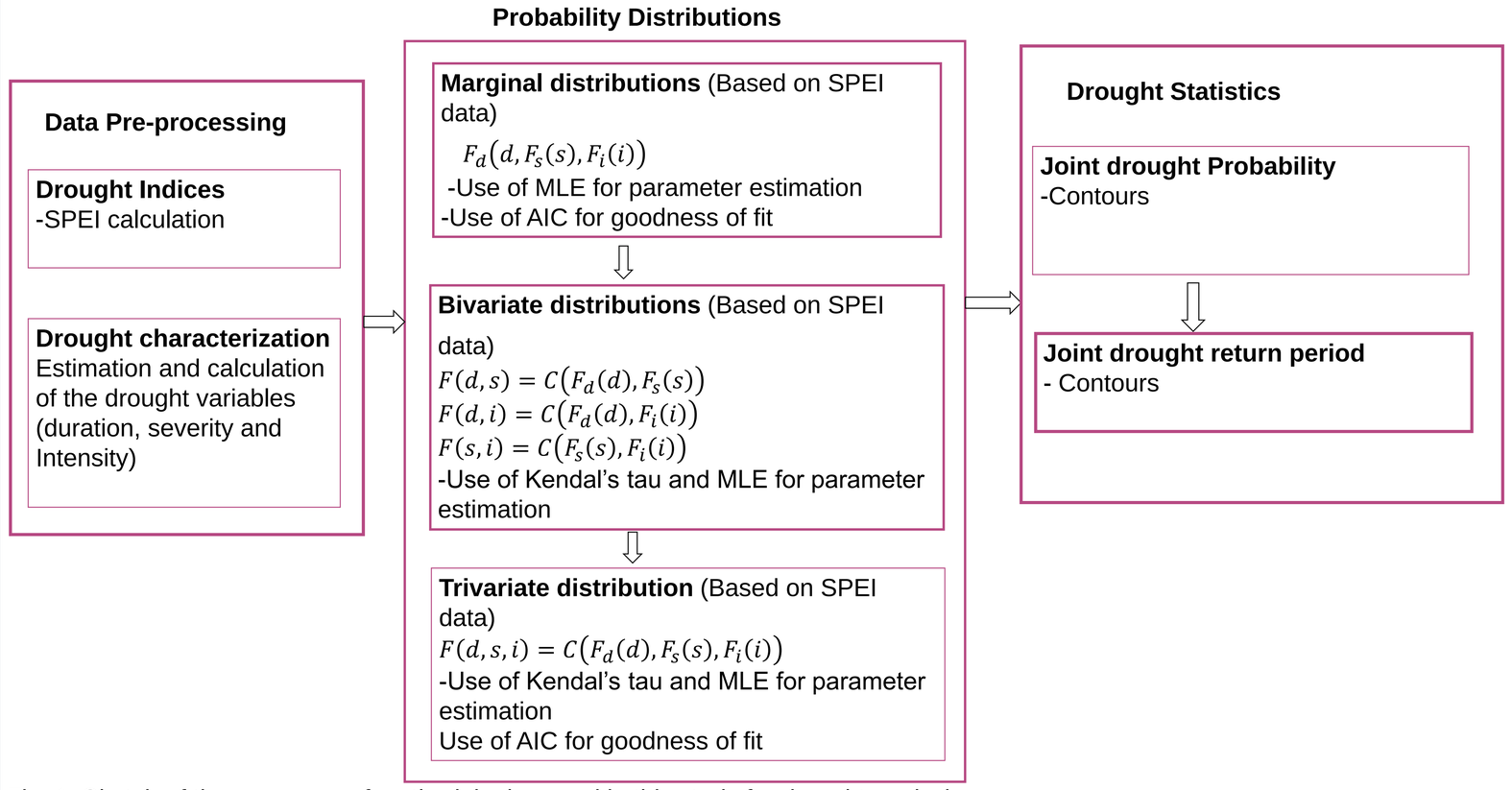
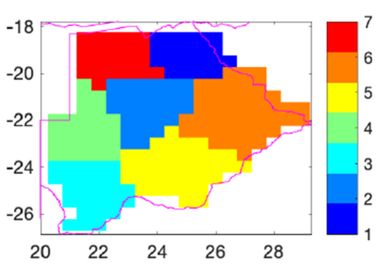


Fig. 1: Sketch of the sequence of methodologies used in this study for drought analysis.

Results and Discussion

Fig. 2 shows the results of clustering based on time series of the 12-month time scale SPEI. The drought sub regions in Botswana can be largely classified as; the north eastern region (cluster 1), central region (cluster 2), south-south-western (cluster 3), western region (cluster 4), south-eastern region (cluster 5), eastern region (cluster 6) and north-western region (cluster 7).



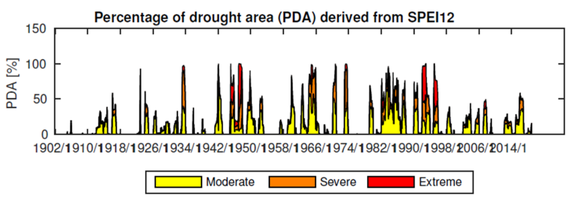


Fig.4.: The percentage of the drought occurrence over Botswana for SPEI-12 during the period 1901-2018

Fig. 2: Homogeneous drought zones in Botswana based on K-means clustering

Figs. 3 shows the mean monthly average SPEI over Botswana.
SPEI was able to identify high areal extent of severe drought over the western half of Botswana.
It was observed that SPEI is more consistent with the climatology of rainfall and temperature over Botswana (low rainfall and high temperatures).

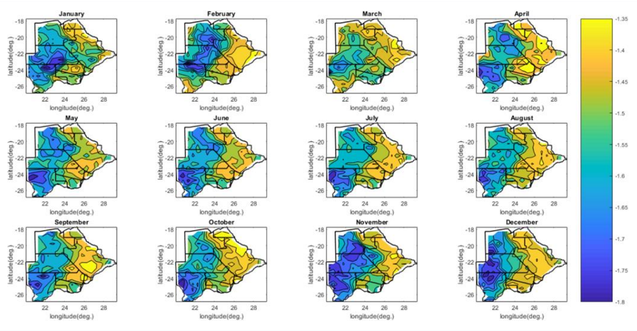


Fig. 4 shows that moderate drought is most prevalent, followed by severe drought while extreme drought are less frequent.

Fig. 3: Historical monthly mean of 12-month SPEI for the period of 1901-2018 over Botswana

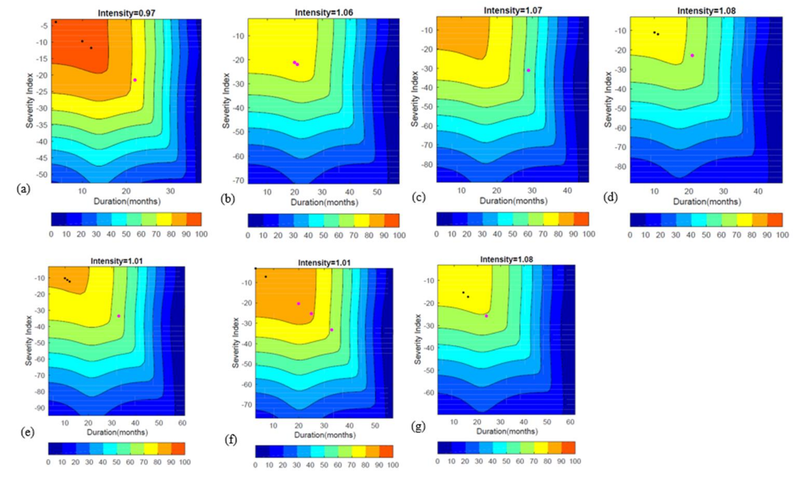


Figure 5.shows the contours of joint probability of drought duration and severity given at a certain intensity for the seven clusters under the condition; $P^{\cup}{}_{DSI}(Dd \geq d \; or \; Ds \geq s \; or \; Di \geq i)$.

- Drought events with high intensities had a low probability of occurrence while lower intensities had a high chance of occurrence within 5 to 10 years and the severity of the drought was similar.
- Drought events with short duration had high probabilities of occurrence and vice versa.

Fig. 5: The joint probabilities of drought events of any duration, severity or intensity of interest based on SPEI-12 for cluster 1 (a) to cluster 7 (g)

Fig.6 shows a comparison for the joint bivariate and trivariate drought return periods ($T_{Or}(DSI)$) for cluster 1.

- The bivariate return periods has the shortest return periods compared to the trivariate return periods.
- Drought events with longer duration were observed to have longer drought return periods.
- Drought events with higher intensity and severity were observed to have short drought return periods.
- Return period is dependent on the location within the study area, variable type and the combination of variables.
- These results be useful in risk assessment of water management activities under severe and extreme drought situations.

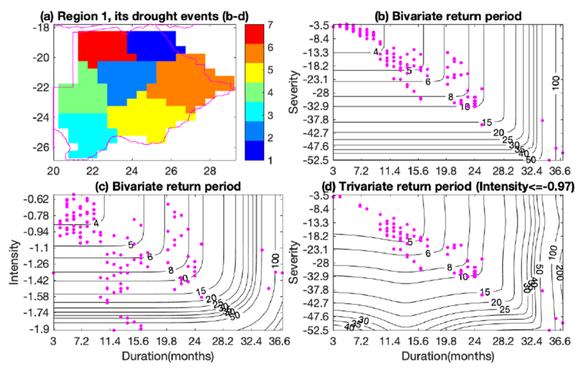


Fig.6: Joint bivariate and trivariate return periods of drought duration, severity, and severity in cluster 1 during 1901–2018

Conclusion

- The western and southern parts are mostly affected by the severe drought conditions while the central and eastern parts are dominated by moderate droughts.
- SPEI proves to be more robust in characterizing droughts in semiarid areas
- Copulas can be a useful tool in providing probability information of droughts, that can be used in long-term planning for development of effective strategies in the country.
- Normal copula performed better in modeling joint dependence structure of drought duration while Clayton copula distribution was recognised as the best fitting copula model for the drought severity and intensity across all the clusters.
- Information on the drought conditional probabilities and return period can be useful in evaluating the water-supply capability and the needed supplementary water resources during severe droughts for a specific water-supply system.

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