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Drought Indicators to Assess Climate Risks in the Cuvelai Transboundary Basin

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Abstract: Hydrological droughts are characterized by their duration, severity, and magnitude. Among the most prominent factors, precipitation, transpiration, and runoff are essential in drought modelling. The study area is a transboundary basin shared by Angola and Namibia, named the Cuvelai Basin. In this study, the elaboration of two drought indices was established, namely, the Standardized Precipitation Index (SPI) which was calculated through the Programming Language Software Python and the Standardized Rainfall Evaporation Index (SPEI) which were calculated through the Global Drought Monitor website. This research aims to compute the drought indicators of the basin in study in order to assess the severe droughts during the 22 years for this specific area. From the analysis, the results indicate that both indices SPI and SPEI exceled on the provision of precise results when assessing the mitigation measures inside the transboundary Cuvelai Basin.

Key words: Cuvelai, cunene, drought, standardized precipitation index (SPI), standardized rainfall evaporation index (SPEI)

1. Introduction

Drought is a periodic atmospheric event associated with water scarcity in a geographic area for a time. This environmental event is therefore considered an integral part of climate change and a recurring event in different climates around the world [1]. Droughts adversely affect natural habitats, ecosystems, and many economic and social sectors. In this day and age, drought problems have become more frequent and therefore it affects many parts of the world due to increased water demand and climate change. Therefore, the phenomenon of drought has attracted the interest of a large number of researchers, and studying the characteristics of this phenomenon from different angles is a priority for researchers [2]. In addition, among the random and probable aspects, precipitation plays a crucial role in arid and semi-arid regions. In many parts of the world, drought is caused by a lack of rainfall, which when combined with an increase in temperature, drastically leads to a shortage of surface and its runoff, as well as groundwater resources. The drought index is an important part of the drought monitoring system, so researchers have developed numerous indicators to monitor drought conditions and study their quantitative impacts; Most of its indicators were developed for specific geographical regions and special purposes, so their implementation for rigorous and comprehensive analysis in other regions was established with considerable doubts due to the intrinsic complexity of drought phenomena and different climatic conditions. Drought forecasting can provide useful information to help with drought mitigation measures ongoing in the transboundary Cuvelai Basin. In present years severe and mild droughts frequently hit the southern area more leading

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to financial damages to its residents. To predict and investigate the possibility of hydrological drought in the south of Angola, the SPEI, and SPI indexes were applied on the Cuvelai drainage basin.

2. Material and Methods

2.1 Study Area

The Cuvelai Basin, also known as the Etosha Salt Basin, is a transboundary wetland shared by Angola and Namibia, consisting of a tropical and dry or semi-arid climate located in the province of Cunene between the latitude of -15°39'59.99" South and a longitude of 15°47'59.99" East.

Its geographical area is 159,620 km^2 split between Angola and Namibia, extending over 450 kilometres from north to south covering more than half of the Province of Cunene in Angola. Slivers of the Cuvelai Basin also lie within the Angolan provinces of Cuando Cubango and Huila.

The basin is drastically impacted by heavy rainfall, affecting the community dreadfully, resulting in the loss of fife and properties of many people; throughout plenty of years, the basin also experienced extreme levels of droughts. Due to the instability of the climate, in agricultural means, the Cuvelai community experiences tremendous loss which mostly leads to starvation.

Therefore, for such climatic events, (SPI) the Standardized precipitation index (an indicator that depends on the probability of precipitation for any time and is used to calculate different time scales) was implemented in this study [3] in an attempt to study various effects of scarcity of precipitation on groundwater, surface water reserves and resources, soil moisture, and waterway flow. SPI indicator is being used worldwide due to its simplicity as it uses the least amount of data during calculation, the independence of mean precipitation as well and the comparison of a wide range of climates. Its calculation begins by fitting a probability density function. Normally calculation is done by means of a two-parameter gamma, and at times a Log Pearson type III, to the total precipitation over periods of 3 months.

2.2 Standardized Precipitation Evapotranspiration Index (SPEI)

Penman-Monteith method (PM) was recommended as the standard method to calculate the reference crop evapotranspiration [4]:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma\left[\frac{890}{T+273}\right] + U_2\left(e_a + e_d\right)}{\Delta + \gamma\left(1 + 0,34U_2\right)} \tag{1}$$

The SPEI is established [5] and studied in various researches. Both the role of temperature, and the climate balance are involved in the calculation of the method studied in drought evaluation. The SPEI is dependent on the changes in difference between the potential evapotranspiration (P-PET), and the precipitation. The Palmer Drought Severity Index (PDSI) [6] had been presented concerning the changes in numerous source and demand variables of the hydrological cycle although it is not a standard index and did not consist of multi-scale characteristics. Studies of different calculation methods and comparison amongst each other; it is obvious that the Penman-Monteith method achieved more accurate results, for it is more based on atmospheric evaporation demand [7]. Thus, the calculation of SPEI in this study is based on the Penman-Monteith equation as described [4]. The method selected by the Meteorological Organization (WMO) as a standard method for the calculation of PET was the PM method as its accuracy was proven without requiring plenty of data. Based on climatic information by means of Eq. (1), it is then possible to calculate the monthly values of reference crop evapotranspiration. The difference between evapotranspiration (PET_{0i}), and Precipitation (P) calculated for the i_t, Fig. 1 shows both the geographical and spatial location.

$$D_i = P_I - PET_{OI}, \quad i = 1,\ 2, ..., \text{N} \tag{2}$$

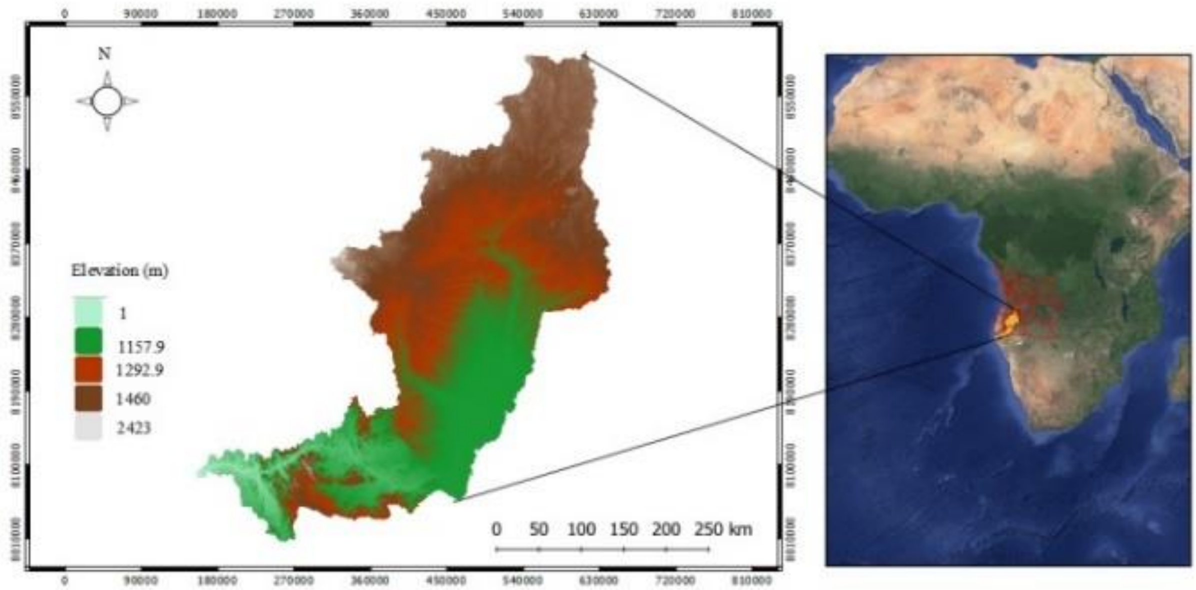

Fig. 1 The spatial location of the Cuvelai basin.

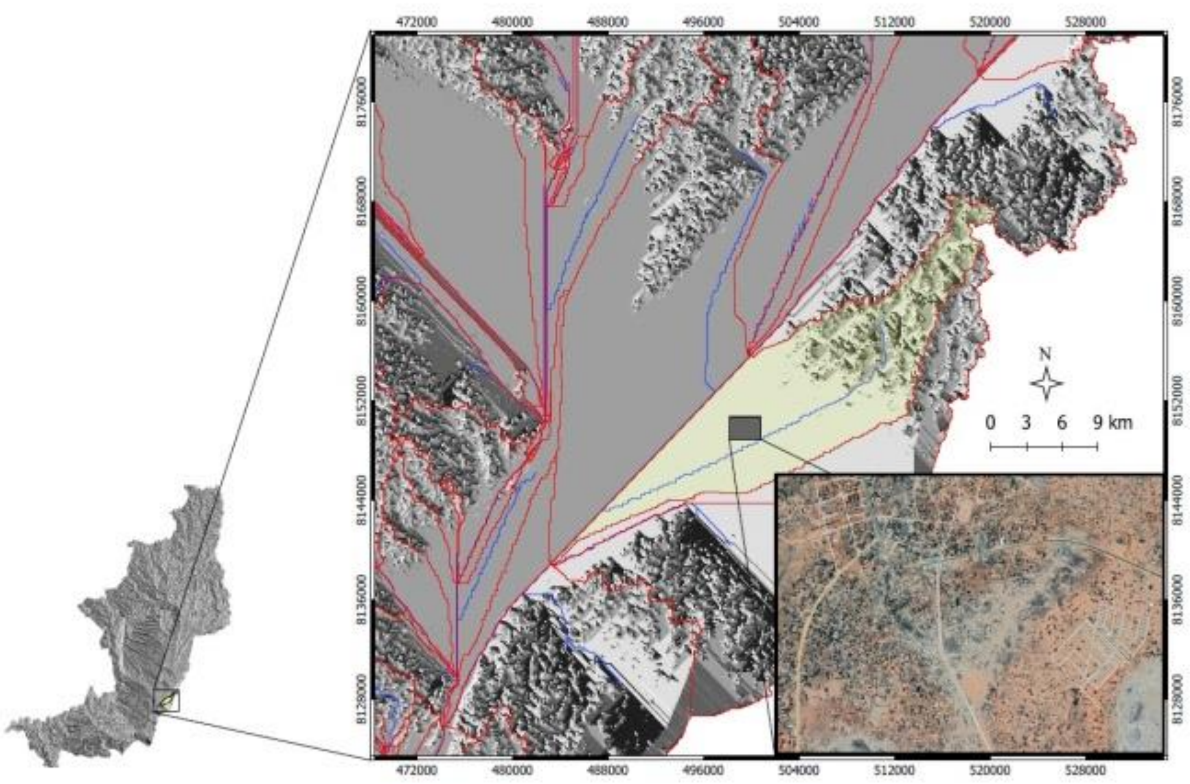

Fig. 2 Geographic location of a region in the Cuvelai subbasin.

3. Results and Discussion

In the management of water resources, it is extremely useful to predict runoff through the precipitation and evapotranspiration parameters.

In this study different scales for predicting SPI, a 3-month scale was selected and investigated as it had a higher correlation, and predicted by the introduced models. Table 1 presents statistical parameters of utilized drought indices in the transboundary Cuvelai River Basin and Figs. 3-6 show SPI precipitation indexes, and Figs. 7-9, show SPEI evapotranspiration indexes on a 3-month scale; A study of the SPI precipitation indices was carried out with results obtained in the Cuvelai Basin ranging from 3 to 12 months, the same monthly scale was used for SPEI index.

Figs. 3-6, the SPI precipitation indices have been inconsistent since 1998-2020, and as shown in Figs. 7-10, it can be depicted that the SPEI indexes have been inconsistent since 1998-2020; the rainfall did not lead to surface flow, which was perhaps caused by changes in the amount and type of precipitation, increase in evapotranspiration, and in temperature. Temperature increase leads to increased evaporation and dryness of the surface, resulting in an increase in the duration and intensity of drought. Also, it can be concluded that there was an occurrence of surface flow with a delay of a few months.

The use of the SPI to identify anomalously dry years also retrieved similar results (From Fig. 3 to Fig. 6). In the Cuvelai, the driest identified years were 1998, 2000, 2002, 2004, 2006, 2008, 2010, 2012, 2014, 2016, 2018, and 2020, which corroborates with previous studies in the region. These results agree with previous studies on the historical aspects of drought in Cuvelai.

Table 1 Statistical characteristics of the utilized data.

Period	Step and Source	Skewness	Coeficiente variation	Standard deviation	Maximum	Minimum	Mean
1998-2022	TRMM 3B42	6.040	2.869	4.709	83.10	0	1.641

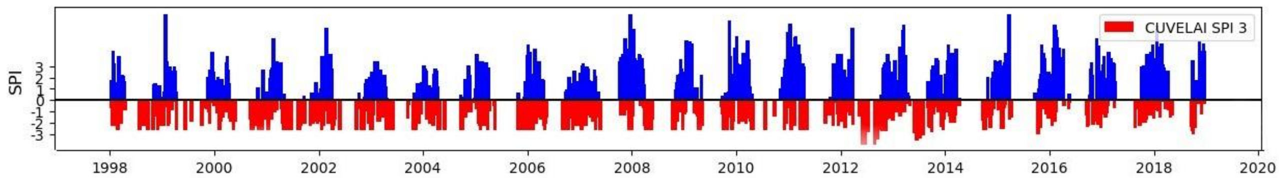

Fig. 3 SPI Index- 3 months.

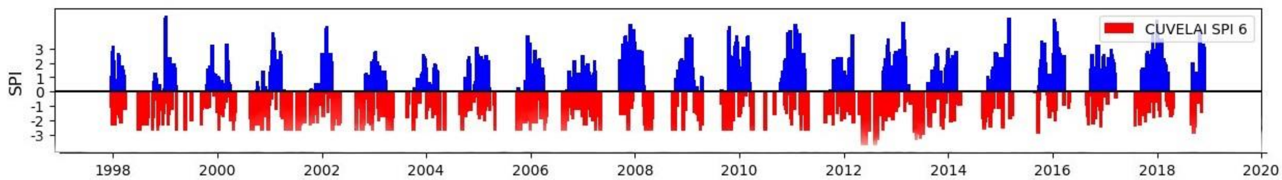

Fig. 4 SPI Index- 6 months.

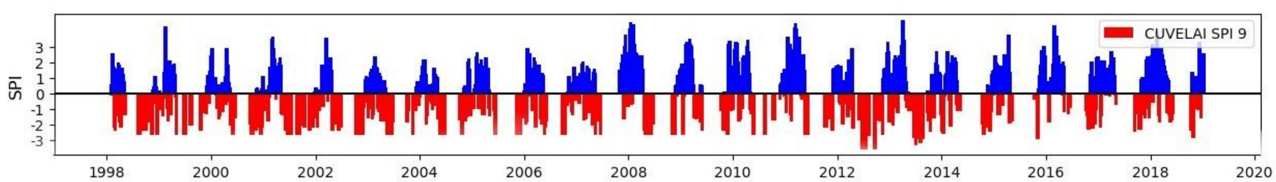

Fig. 5 SPI Index- 9 months.

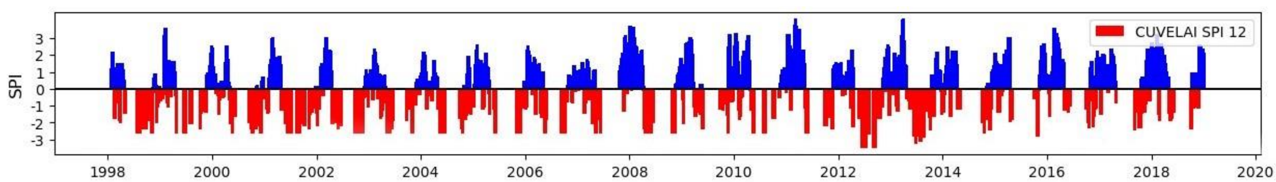

Fig. 6 SPI Index- 12 months.

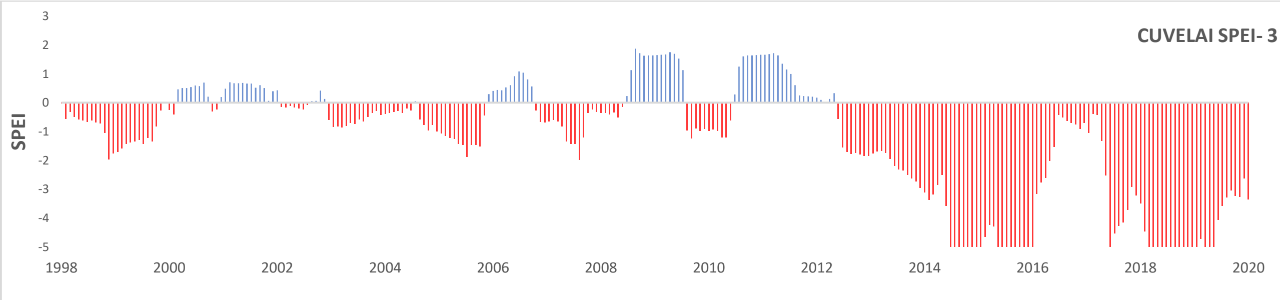

Fig. 7 SPEI Index- 3 months.

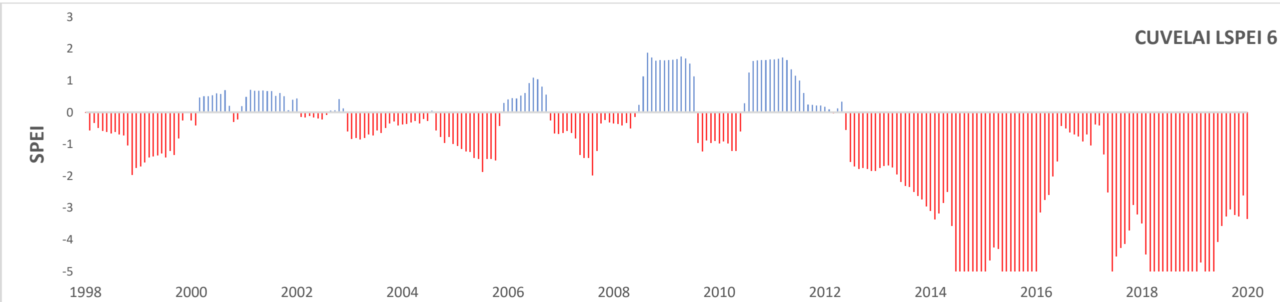

Fig. 8 SPEI Index- 6 months.

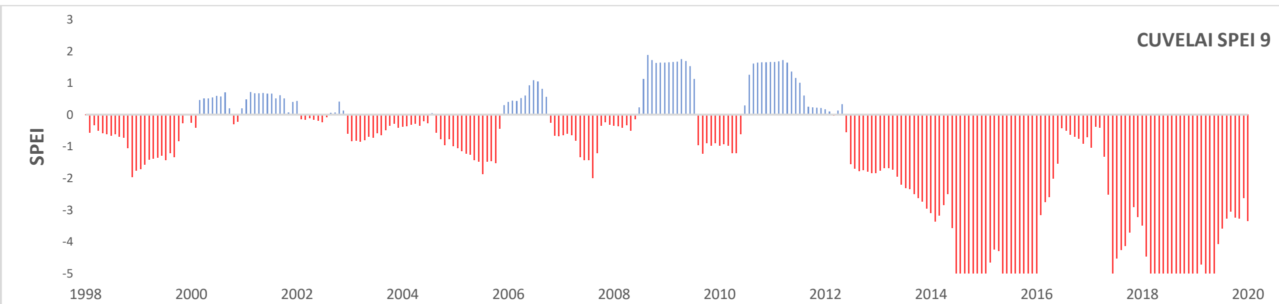

Fig. 9 SPEI Index- 9 months.

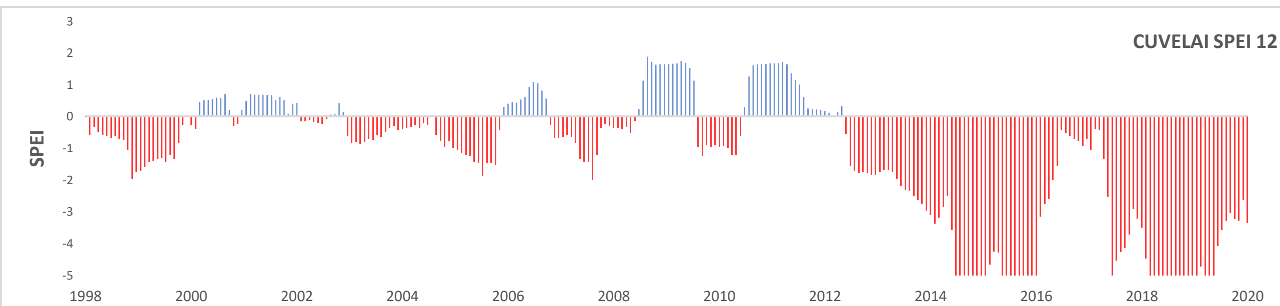

Fig. 10 SPEI Index- 12 months.

4. Drought Characterization

There are different methods to assess meteorological drought, usually considering alterations and variations in climatological aspects in relation to normal behavior. At the first moment, the main indices and techniques used were based on the fact that meteorological drought is established with the occurrence and persistence of negative anomalous rainfall amounts [8]. Among the indices used to classify drought in the Cuvelai River

Basin the classification for dry conditions, SPI is presented in Table 2.

As per the SPI results attained, the droughts in Cuvelai read as -2.00 a -2.99 and are characterized as moderate droughts.

Finally, the SPEI represents the Standardized Precipitation Index of the drought series and its values can be classified according to the degree of intensity of the drought as shown in Table 3. As per the SPEI results attained, the droughts in Cuvelai read as -2,00 or less and are characterized as extremely dry.

The historical drought years detailed drought severity, duration, intensity, onset, and termination of the events were indicated in Tables 4 to 5. According to the outputs obtained from the SPI Alert level in Table 4, readings show that the Hydrological Drought Category are extreme throughout the years, whereas the Weather Drought Category is moderate, the Intervention Level is A.1, and remains constant.

According to the outputs obtained from the SPEI Alert level in Table 5, readings show that the Hydrological Drought Category has been extreme throughout the years, whereas the Weather Drought Category is extremely dry, the Intervention Level is A.2 and remains constant.

Table 2 Classification table for dry conditions SPI (Font: Palmer 1965).

0.99 to -0.99	approximately normal
-1.00 to -1.99	Slightly dry
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
≥ -4.00	Extreme drought

Table 3 Classification table for dry conditions SPEI (Adapted from Loukas and Vasiliades 2010).

2.00 or more	Extremely wet
1.00 to 1.99	Severely wet
0.00 to 1.00	Normal (wet)
-1.00 a 0.00	Normal (dry)
-1.99 a -1.00	Severely dry
-2.00 or less	Extremely dry

Table 4 SPI drought alert level.

Years	Hydrological Drought Category	Weather Drought Category	Alert Level	Intervention Level
1998 à 2003	extreme drought	Moderate drought	Pre-Alert	A.1
2004 à 2009	extreme drought	Moderate drought	Pre-Alert	A.1
2010 à 2015	extreme drought	Moderate drought	Pre-Alert	A.1
2016 à 2020	extreme drought	Moderate drought	Pre-Alert	A.1

Table 5 SPEI drought alert level.

Years	Hydrological Drought Category	Weather Drought Category	Alert Level	Intervention Level
1998 à 2003	extreme drought	Extremely dry	Pre-Alert	A.2
2004 à 2009	extreme drought	Extremely dry	Pre-Alert	A.2
2010 à 2015	extreme drought	Extremely dry	Pre-Alert	A.2
2016 à 2020	extreme drought	Extremely dry	Pre-Alert	A.2

5. Conclusion

The effects of drought on different Angolan communities are unpleasant, as it occurs in several climates, and thus, to account for the cruciality of studying drought as well as the critical role that its indices have in forecasting this phenomenon, the prediction of drought through the SPI and SPEI indexes was carried throughout this study.

From the classification tables for SPI and SPEI dry conditions for both indexes, it was noted that the drought levels are moderate drought and extremely drought ranging from -2.00 to -2.99 and -2.00 or less, it can be concluded that precise precipitation results were acquired from the prediction of SPI, and precise evapotranspiration results were acquired from the prediction of the SPEI meteorological indexes, and thus, drastic measures are to be taken to diminish or abolish drought on the Cuvelai Basin.

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