Evaluation of temporal drought variation and projection in a tropical river basin of Kerala
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ABSTRACT

Temperature is an indispensable parameter of climate that triggers evapotranspiration and has vital importance in aggravating drought severity. This paper analyses the existence and persistence of drought conditions which are said to prevail in a tropical river basin which was once perennial. Past observed data and future climate projections of precipitation and temperature were used for this purpose. The assessment and projection of this study employ the Standardized Precipitation Evapotranspiration Index (SPEI) compared with that of the Standardized Precipitation Index (SPI). The results indicate the existence of drought in the past and the drought conditions that may persist in the future according to RCP 4.5 and 8.5 scenarios. The past drought years identified in the study were compared with the drought declared years in the state and were found to be matching. The evaluation of the future scenarios unveils the occurrence of drought in the basin ranging from mild to extreme conditions. It has been noted that the number of moderate and severe drought months has increased based on SPEI compared to SPI, indicating the importance of temperature in drought studies. The study can be considered as a plausible scientific remark helpful in risk management and application decisions.

Key words | drought, gridded data, RCP, river basin, SPEI, SPI

INTRODUCTION

Drought is a slow natural phenomenon that is grievously hazardous and affects the majority of the globe (World Meteorological Organization (WMO) 2006). There are a number of definitions given to drought by various researchers (Mishra & Singh 2010). The most simple explanation given for drought is the shortage of water compared to its availability during normal conditions. Based on the amount of water loss, droughts are of different types, such as meteorological, hydrological, agricultural or soil moisture, socioeconomic, and ecological (Mishra & Singh 2010). Meteorological drought is caused by a deficit in precipitation. A decline in streamflow or groundwater flow results in hydrological drought and the wilting of crops with regard to the soil moisture drop causes agricultural drought. The inability to provide the essential water requirements of the population is defined as socioeconomic drought. Hydrological drought is complicated as it depends both on hydroclimatic variables and the catchment characteristics. There are several studies on the factors leading to hydrological drought (Potopova et al. 2019). The climate change aggravated by the increasing global temperature in recent decades is a matter of great concern; recent studies similarly emphasise the effect of precipitation and temperature. As drought is an event that depends on many different parameters, it is challenging to study and understand (Mishra & Singh 2010). Typically, the term drought focuses solely...
on arid and semi-arid regions; the humid tropical climates are essentially neglected.

Numerous drought indices such as PDSI, RDI, etc., have been developed to determine the duration, frequency, severity, and spatial dimensions of drought. Zargar et al. (2011) reviewed 74 drought indices out of the available 150 and stated that SPI, which is a meteorological drought index, can be deployed for longer timescales to reflect agricultural and hydrological droughts/impacts. Currently, this index has been widely adopted for research and operational modes. This index is also highly recommended by the WMO and several others (McKee et al. 1993; Bonaccorso et al. 2003) to quantify drought in a region. Considering the increase in global temperature, researchers (Vicente-Serrano et al. 2010) also incorporated the Standardized Precipitation Evapotranspiration Index (SPEI) which takes into account potential evapotranspiration apart from the precipitation data alone used in the analysis of SPI. SPEI combines multi-timescale aspects of the Standardized Precipitation Index (SPI) with information about evapotranspiration, making it more useful for climate change studies. The statistically-based index requires only climatological information without assumptions about the characteristics of the underlying system. Several studies compared meteorological indices at different climatic conditions resulting in isolated conclusions, and therefore none of the indices could be accepted globally for any climatic region. The combination of interactive characteristics such as rainfall, land use–land cover changes, humidity, temperature, biodiversity, anthropogenic influences etc. makes drought a regional phenomenon (Halwatura et al. 2015; Pathak & Dodamani 2019).

There have been several studies (land use, land cover changes, morphometric analysis, decreasing trend of precipitation and increasing trends in temperature) conducted on the once perennial Bharathapuzha river basin in Kerala, India, which highlights the importance of drought studies in this basin (Raj & Azeez 2010; Magesh et al. 2013; Jagadeesh & Anupama 2014; Varughese et al. 2017). The increasing trends of averaged annual mean maximum temperature time series are significant over the Kerala region as per the Meteorological Monograph No. ESSO/IMD/EMRC/02/2013. Although several studies mention the condition of drought and water stress in the Bharathapuzha river basin, no drought study has been performed in this study area. A little more than two-thirds of the drainage area (4,400 km²) of the basin is within Kerala and the remaining area (1,786 km²) is in Tamil Nadu where the climate of the state ranges from dry sub-humid to semi-arid. On account of this warm and humid region that lies in the upstream of the basin, SPEI was incorporated in the study. This study tries to determine the effect of temperature regarding the drought conditions of the basin based on these trends. The changing climate pattern directs the researchers to focus on the regional hydrology and on the prediction of future scenarios, which will help to frame adequate mitigation measures and suitable action plans. Consequently, the past and the projected future climate change scenarios in the Bharathapuzha river basin have been analysed methodically to acquire an elementary quantitative profundity into the vulnerability of Bharathapuzha river basin based on the present and future climate changes. The study thus investigates the occurrence of the meteorological drought in the river basin with the standardized precipitation evapotranspiration index (SPEI) and compares it with the standardized precipitation index (SPI) for both the observed period as well as the projected future situations.

**METHODS**

**Study area**

Bharathapuzha, also known as Nila, is the largest basin (based on drainage area) and second-longest of the 44 rivers in the state of Kerala, India, located at 10°25’ to 11°15’ N and 75°50’ to 76°55’ E. Among the four medium-sized rivers in Kerala, Bharathapuzha is 209 km long with an area of 6,186 km² in which 4,400 km² falls within Kerala (hence referred to as a river basin in Kerala) and the rest in Tamil Nadu. Once a perennial river, it originates in the Anamalai hills of Tamil Nadu and debouches into the Arabian sea at Ponnani in Kerala. The average annual rainfall of the river basin is 2,060 mm. Seven reservoirs were constructed on this river by the Kerala Government and four of them were constructed by the Tamil Nadu Government. The river basin is also subjected to a distinctive physiographic feature. This region has three separate
physiographic zones; high land with an altitude greater than 76 m, the altitude in the midland that varies between 7.6 and 76 m and the lowland where the altitude is less than 7.6 m. The river serves as a lifeline to three administrative districts in Kerala and two districts in Tamil Nadu and also supports the agricultural production system of the Keralan state, specifically ‘the rice bowl of Kerala’ in Palakkad district. Thus, the river has a pivotal role in the societal, economic, and agricultural aspects of the state. The location map of the study area and the grid point locations chosen, along with the drainage map that represents the physical characteristics of the basin, are depicted in Figure 1.

Figure 1 | The study area location with its drainage map and the location of the selected grid points for precipitation and temperature during the period 1971–2100.
Data collection and pre-processing

The gridded datasets of temperature (1×1°) and precipitation (0.5×0.5°) between 1971 and 2005 (35 years), provided by the Indian Meteorological Department (IMD), are used in this study as these are the widely adopted and only available dataset for the study area during the time of the study. A map showing the grid point locations G1, G2, G3, G4 are presented in Figure 1. To project the SPI and SPEI indices for the future, the same variables for the same grid locations were extracted from freely downloadable simulated precipitation data of CORDEX (Coordinated downscaling regional experiment) (http://cccr.tropmet.res.in/home/ftp_data.jsp). The Representative Concentration Pathway (RCP) adopted in the analysis is for low and high emission scenarios (RCP 4.5 and RCP 8.5) for a period of 94 years (2006–2099). The Regional Climate Model (RCM) used is the Conformal-Cubic Atmospheric Model (CCAM) by the Commonwealth Scientific and Industrial Research Organization (CSIRO, Canberra, Australia) and the driving Global Climate Models (GCMs) used are ACCESS1.0. and CCSM4 (described in Appendix A). A linear scaling (LS) bias correction was also applied to the data before the drought index calculation. LS is a mean-based technique that is the most simple for computing the mean monthly correction factor which is applied to the RCM-simulated daily precipitation in a month (Lenderink et al. 2007; Teutschbein & Seibert 2012).

STANDARDIZED PRECIPITATION INDEX (SPI)

The Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) and it refined the concepts of other researchers (Bhalme & Mooley 1980; Soule 1990) and is considered one of the most popular and well-reviewed indices to detect drought severity. The SPI needs only the precipitation data as an input variable. In SPI, the long-term precipitation data set is first fitted to a distribution which is usually gamma distribution or Pearson type III distribution and it is then transformed to a normal distribution with its mean zero and standard deviation of one. As the SPI is normalized, the wet and dry period can be represented the same way, where the standard deviations higher than or less than the median precipitation explains the wet or dry condition. Further explanations of the computational procedures have been elaborately discussed in many other works (Almedeij 2014; Bong & Richard 2019).

A one-month SPI value compares the percentage of normal precipitation for the month. It is also stated that the one-month representation is more accurate for monthly data for a given location. The correlation of crop stress and soil moisture for the growing season is also obtained here. The higher timescales combine the precipitation totals of the previous year belonging to the same period and include all the recorded years considered in the study. Thus a three-month SPI is a good indicator that reflects the seasonal precipitation and shows the short- and medium-term moisture conditions correspondingly. The termination of a three-month drought period could be justified only by comparing it with a long-term event. The medium-term trends in precipitation, which display the precipitation over distinct seasons, and the association with streamflow and reservoir levels is obtained from a six-month timescale of the SPI. The nine-month SPI denotes the pattern of the rainfall over a medium-timescale and also shows that an SPI value of less than −1.5 usually has a significant impact on agriculture. The cumulative result of 12 consecutive months of each of these years provides the long-term precipitation pattern to provide 12-month SPI, reflecting streamflow and reservoir levels. It can also be considered as an annual estimation of water conditions.

STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI)

Vicente-Serrano et al. (2010) developed the multi-scalar Standardized Precipitation Evapotranspiration Index (SPEI) with regard to empirical studies on temperature-induced drought stress. The computation of the index is based upon the climatic water balance equation where the potential surplus or deficit of water, its accumulation with regard to the different time periods, and log-logistic probability distribution adjustment is carried out as it fits well to all timescales. The water balance equation calculates the difference (D) between precipitation (P) and potential evapotranspiration (PET).
being that evaporation which would have occurred under the presence of sufficient amounts of water in the source.

\[ D = P - PET \]

The calculated \( D \) values aggregated at different timescales are as below:

\[ D_k^n = \sum_{i=0}^{k-1} P_{n-i} - PET_{n-i}, \ n \geq k \]

Here, \( n \) is the calculation number, \( k \) (months) represents the timescale of aggregation.

The most popular methods to calculate potential evapotranspiration are the radiation-based Penman-Monteith (PM) equation and temperature-based Hargreaves equation and Thornthwaite equation. The Penman-Monteith equation considers the effects of precipitation and temperature along with the wind speed, relative humidity, sun hours, or cloud cover and elevation. The Hargreaves equation requires monthly precipitation totals, maximum and minimum monthly mean daily temperature, and monthly mean temperature. Monthly precipitation totals and monthly mean temperatures are the only inputs to the Thornthwaite equation. The Thornthwaite equation is used in this study based on the availability of the data. The detailed explanation of SPEI calculation is mentioned in Vicente-Serrano et al. (2010).

The Pearson correlation coefficient computation is a widely used technique in drought studies to compare different indices calculated (Vicente-Serrano et al. 2010; Ali et al. 2017) and such a computation is also implemented in this study along with Refined Index of Agreement and Theil’s U Index of Inequality to find the proximity between the two indices SPI and SPEI.

### RESULTS AND DISCUSSION

The computation of the SPI can be performed for different time periods. A one- to 24-month timescale is most commonly followed in the relevant literature. The aim of this study is to understand the short- and long-term drought events. Therefore, a multiscale drought analysis was performed in the study. The negative and positive values of the SPI results indicate the dry and wet conditions of the region. The higher the magnitude of the index, the more severe is the wet or dry condition. The ideal period for calculating SPI is 50–60 years although the computation demands at least 20–30 years of monthly precipitation data. Hence the available monthly precipitation data during the years 1971–2005 (55 years) were used to calculate the historical SPI values for the basin and CORDEX data from the GCMs ACCESS 1.0 and CCSM4 was used in the computation of future scenarios.

The computation of SPI and SPEI was performed with the help of an SPI calculator from the National Drought Mitigation Centre and an SPEI calculator respectively. The computational procedure for SPEI is very similar to that of the SPI. Therefore, the drought classification category followed by the SPEI is the same as that of the SPI, proposed by McKee et al. (1993) and depicted in Table 1.

As the Bharathapuzha river basin is barely a trickle during the summer months, the study emphasizes the inter-seasonal timescale obtained from a three-month time period and also the interannual timescale from the 12-month values of SPI and SPEI. A 12-month timescale was considered for the drought assessment in order to measure the drought concern regarding the hydrology of the basin. The \( 1 \times 1^\circ \) resolution temperature data obtained from IMD for the period of 1971–2005 and the extracted CORDEX data were subjected to linear interpolation and bias correction to obtain a finer resolution of \( 0.5 \times 0.5^\circ \). As the SPEI is calculated based upon both precipitation and potential evapotranspiration (PET), it can capture the main impacts of temperatures on water demand.

### Table 1 | Drought classification based on the SPI and SPEI (source: McKee et al. 1993)

<table>
<thead>
<tr>
<th>Drought category</th>
<th>SPI, SPEI values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-drought</td>
<td>Index value &gt;0</td>
</tr>
<tr>
<td>Mild drought</td>
<td>(-1.0 &gt; ) Index value &gt; 0</td>
</tr>
<tr>
<td>Moderate drought</td>
<td>(-1.5 &gt; ) Index value &gt; (-1.0)</td>
</tr>
<tr>
<td>Severe drought</td>
<td>(-2.0 &gt; ) Index value &gt; (-1.5)</td>
</tr>
<tr>
<td>Extreme drought</td>
<td>Index value &gt; (-2.0)</td>
</tr>
</tbody>
</table>
Figure 2 | Annual variation of SPI and SPEI in the basin during 1971–2005 for the location: (a) Grid 1, (b) Grid 2, (c) Grid 3, (d) Grid 4.
Temporal variation of the SPI and SPEI for observed IMD data

The temporal variation of SPI and SPEI at a timescale of three and 12 months denotes the seasonal and annual variation of water deficit caused by drought (Wang et al. 2014). Figure 2 is the SPI/SPEI series for December that depicts the annual variation and Figure 3 shows the seasonal variation with respect to the three-month timescale for all the grid locations of the basin.

Figure 3 | Seasonal variation of SPI and SPEI in the basin during 1971-2005 for the location: (a) Grid 1, (b) Grid 2, (c) Grid 3, (d) Grid 4.
study area for the observed IMD data during the years 1971–2005. The analysis of 12-month or annual estimation of water conditions for the period 1971–2005, obtained from IMD, reveals the occurrence of drought conditions in the river basin ranging from moderate to extreme. The notable drought months were found to be during the years 1973–1974, 1990–1991 and 1997, which were considered as

![Figure 4](https://example.com/fig4.png)

**Figure 4** | Annual variation of SPI and SPEI in the future (2006–2099) using GCM ACCESS for scenario 4.5 in the location: (a) Grid 1, (b) Grid 2, (c) Grid 3, (d) Grid 4.
Figure 5 | Annual variation of SPI and SPEI in the future (2006–2099) using GCM ACCESS for scenario 8.5 in the location: (a) Grid 1, (b) Grid 2, (c) Grid 3, (d) Grid 4.
moderate drought years. The years 1983 and 1986–1987 were considered as moderate to severe drought years and the years 1976–1977, 2000, 2002 and 2005 were found to be severe to extreme drought years in the grid 1 location which falls under the Kerala region. The grid 2 location of the Tamil Nadu region shows a moderate drought during

Figure 6  | Annual variation of SPI and SPEI in the future (2006–2099) using GCM CCSM4 for scenario 4.5 in the location: (a) Grid 1, (b) Grid 2, (c) Grid 3, (d) Grid 4.
1989–1990 and 2001–2003 were found to be moderate drought years and 1987–1988 and 2003–2004 were considered to be severe drought years in the grid 4 location. Most of the drought years were found to be overlapping with the drought declared years as per the Kerala State Disaster Management Plan of 2016 (https://sdma.kerala.gov.in) and Nathan (2000) where the severe drought years declared were 1983, 1985, 1986, 1987 and 1989. It was observed from the seasonal analysis that all the drought years in the annual or 12-month water condition repeat as far as the moderate to severe drought conditions and several other moderate drought years are concerned.

**Temporal variation in the SPI and SPEI for projected CORDEX data**

The timely variation of SPI and SPEI at a timescale of 12 months for all the grid locations of the study area for the CORDEX data (GCMs ACCESS and CCSM4 under RCP 4.5 and RCP 8.5) during the years 2006–2100 are shown in Figures 4–7.

The future scenarios RCP 4.5 and RCP 8.5 of ACCESS 1.0 and CCSM4 are projected to understand the variation of the SPI and SPEI in each of the locations and the way it propagates with respect to time. The observations pronounce the occurrence and recurrence of the drought events in the future where the notable events range from moderate to extreme conditions in addition to the mild conditions. The years 2011, 2016, 2019–2020, 2049–2050, 2065, 2068–2069, 2075–2078 and 2093–2094 in grid 1 are identified as moderate drought years; 2011, 2019, 2023–2024, 2043–2045, 2056 and 2065 and 2076–2078 in grid 3 location. Also, a moderate drought in the years 2038–2039 and severe drought in the years 2043–2044 are noticed in grid 4. In addition to the above information, the years 2076–2078 in the Tamil Nadu region of the basin and the years 2093–2094 in the Kerala region of the basin are found to experience moderate drought events. The episodes of severe to extreme conditions observed in the basin at all the locations are from the years 2026–2028 and 2033–2034.

**Identification of drought events**

Figures 8 and 9, based on SPEI, show the number of drought months that have occurred in the basin, during the years 1971–2005, using IMD data and the number of drought months for the future years (2006–2100) using the CORDEX data. The bar chart represents the mild to extreme condition of drought at each of the grid locations in the past and for the future under the projected scenarios. Table 2 provides a numerical comparison of the number of drought months which occurred under each timescale for different severity conditions of the SPI and SPEI.
Figure 9 | Projected number of drought months at the four grid points during the years 2006–2100 for: (a) Grid 1, (b) Grid 2, (c) Grid 3, (d) Grid 4.
Figures 8 and 9, along with Table 2, explain that the occurrence of drought events observed in the river basin between 1971 and 2005 is in the range of 16.90–39.29% for mild SPI events, 6.67–12.86% for moderate SPI events, 0–3.81% for severe conditions, and 1.67–9.05% for extreme and severe conditions for the 12-month SPI in the river basin. The values are 22.14–34.76%, 4.76–13.81%, 0–2.67% for mild, moderate, severe and extreme drought conditions for 12-month SPEI. These values for the future are 29.43–41.31%, 7.09–14.80%, 0.09–2.84% under mild, moderate, severe and extreme conditions respectively, comparing both the ACCESS 1.0 and CCSM4. Table 2 also shows that the number of drought events under moderate and severe conditions has increased based on SPEI compared to SPI. The number of drought months under moderate and severe conditions has increased after considering temperature along with precipitation. However, a greater number of extreme events are spotted under SPI than SPEI. According to the analysis, the decrease in precipitation is the sole cause of extreme events, whereas the influence of temperature is more in causing moderate and severe drought events.

Figure 10(a) is an illustration of changing patterns of drought in the study area. It is evident from the figure that the eastern and western part of the basin consistently remains dry during the summer and monsoon period respectively. It is noteworthy that a similar variation of drought pattern is obtained under SPI and SPEI. Figure 10(b) explains that the SPEI captures a slightly higher number of drought events than SPI of the same duration.

The results of the future projections are subjected to a non-parametric trend test using the Mann–Kendall (MK) test and are shown in Figure 11. The MK test is a statistical test to check for the presence of monotonic trends (upward or downward) in a time series data. The non-parametric MK test, which uses a distribution-free test, takes precedence over the parametric linear regression analysis. A P-value of <0.05 indicates that there is a (monotonic) trend and if Kendall’s Tau (τ) is positive, an increasing trend, and if τ is negative, a decreasing trend. When the P value is >0.05, it shows that there is no monotonic trend or the given series is away from the monotonic trend. From the analysis, it was found that in most
the trend is positive. This explains that the drought conditions will reduce in the future. The other cases where a decreasing trend is observed fall under SPEI analysis, reflecting the influence of temperature in drought.

Proximity analysis between SPI and SPEI

The proximity between SPI and SPEI was analysed with the elementary correlation analysis by computing the Pearson product-moment correlation coefficient, Refined Index of Agreement and Theil’s U index of inequality. The outcome of the analysis is the degree to which temperature influences the intensity of drought. Thus, the association between the indices was evaluated based upon the correlation coefficient, the level of significance and \( P \)-value.

Figure 12 illustrates the outcome of the comparative analysis between the SPI and SPEI using Pearson correlation, Refined Index of Agreement and Theil’s U Index of Inequality. Under the Pearson correlation, the indices were significantly correlated at all timescales with a correlation coefficient ranging from 0.74 to 0.99. In all the proximity analysis performed, relatively weak correlation values at one- and three-month timescales were observed indicating that at shorter timescales the fluctuations in the climatic variables are more, thereby causing much variation. The cause of this variability may be that not enough precipitation has reached the earth’s surface to compensate the amount of moisture loss that would have occurred due to evapotranspiration at a seasonal scale. The indices were highly correlated at longer timescales, and the reason for this may be that the effect of temperature was negligible in the SPEI computation. SPI and SPEI from all the stations were in general highly correlated, indicating that either of the indices is good for drought depiction based on the current climatic conditions. However, the observed increasing trend in temperature and the decreasing trend in
precipitation of the region indicate that the SPEI may depict severe and long duration droughts better than SPI. Therefore, it is advisable to use SPEI instead of SPI for drought depiction, considering the projected increases in the temperature during the 21st century.

CONCLUSIONS

The occurrence and persistence of the drought in the Bharathapuzha river basin of Kerala was analysed in the study and it was found that the river basin was subjected to multiple drought conditions in the past and future scenarios. SPEI is an unavoidable tool used to measure the availability of water, which incorporates the effect of temperature along with precipitation to detect anomalies in the climate water balance. The anomalies in the precipitation are measured in the most widely used SPI. The major findings and conclusions of this study are as below.

- Drought analysis in the river basin shows that in the near future (2006–2040), the SPI detects slightly severe drought events compared to SPEI.
- Beyond 2040, although SPI and SPEI show a similar pattern of drought severity, the severity of drought events detected by SPEI is slightly more than SPI.
- The results obtained in the study could be well validated with the findings that the river basin is subject to a decreasing trend in precipitation and increasing trend in temperature in the future (Raj & Azeez 2010; Magesh et al. 2013; Jagadeesh & Anupama 2014; Varughese et al. 2017).
- In all the scenarios and models studied, the basin is also found to be severely drought-prone during 2026–2040.
- Both SPI and SPEI capture the variability of droughts at different timescales but with different effects. SPEI identified more droughts than SPI in the Bharathapuzha river basin. Compared to SPI, SPEI records drought with increased duration and severity.

Figure 11  |  Trend analysis summary for SPI and SPEI under RCP 4.5 and RCP 8.5 scenarios in all grid locations during the years 2006–2100 for: (a) CCSM4; (b) ACCESS.
The comparative study of SPI with SPEI under existing climatic conditions reveals that both the indices are proficient enough in capturing the multi-temporal drought characteristics in Bharathapuzha river basin as the spatial variation shows a similar pattern.

Although a similar pattern of spatio-temporal drought behaviour for SPI and SPEI is obtained for the basin, in certain cases the severity and the number of moderate and severe drought events under SPEI tends to be higher as it incorporates the additional temperature variable and in turn the potential evapotranspiration. The effect of higher temperature that rules over the amount of precipitation received leads to a higher number of drought events.

The analysis also exhibits that SPI is found to be the sole cause of extreme drought events in the basin.

It is found that by incorporating temperature in the computation, the drought events so far unnoticed under SPI have become evident under SPEI. The events where SPI and SPEI are close to each other describe that those drought events are pronounced by the impact of the decrease in precipitation of the region and lesser variability in the temperature.
• As observed in several other studies, it has to be noted that the longer the timescale, the shorter the frequency and vice versa.
• Further multiple proximity analysis indicates that higher correlation exists among the higher timescales. This is because the fluctuating effects of the precipitation and temperature at longer timescales are less and therefore the performance of either SPI or SPEI can be considered as an authentic result for the hydrological study.

It is important to note that the SPEI calculation was based upon the Thornthwaite method due to insufficiency in the data. The data used in this study, along with more meteorological variables, can be determined using the Penman method, which will also help determine the condition of drought in the region. More studies on the comparative analysis of the indices will also help to draw concrete conclusions in this matter.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at https://dx.doi.org/10.2166/wcc.2020.240.

REFERENCES


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