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Tools for Drought Identification and Assessment: A Review

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ABSTRACT

Drought is a natural phenomenon in many arid, semi-arid, or wet regions. This showed that no region worldwide is excluded from the occurrence of drought. Extreme droughts were caused by global weather warming and climate change. Therefore, it is essential to review the studies conducted on drought to use the recommendations made by the researchers on drought. The drought was classified into meteorological, agricultural, hydrological, and economic-social. In addition, researchers described the severity of the drought by using various indices which required different input data. The indices used by various researchers were the Joint Deficit Index (JDI), Effective Drought Index (EDI), Streamflow Drought Index (SDI), Standard Precipitation Index (SPI), Standard Evapotranspiration Index (SPEI), and Palmer Index (PI). According to the researchers in hydrology and for the most accurate description of the drought, more than one indicator for drought should be used. Most reviewed studies recommended using the Standard Precipitation Index (SPI) as the best indicator to describe the drought.

Keywords: Drought, Types, Description, Indicators, SPI

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أدوات لتحديد و تقييم الجفاف: مراجعة

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الخلاصة

الجفاف ظاهرة طبيعية تحدث في العديد من المناطق حول العالم، سواء كانت جافة، أو شبه جافة، أو رطبة. وأظهر هذا أنه لا توجد منطقة في العالم مستثناة من حدوث الجفاف. وان حالات الجفاف الشديد ناجمة عن الاحتباس الحراري العالمي وتغير المناخ. لذلك لا بد من مراجعة الدراسات التي أجريت حول الجفاف للاستفادة من التوصيات التي قدمها الباحثون حول الجفاف. تم تصنيف الجفاف إلى أنواع جوية، زراعية، هيدرولوجية، واقتصادية اجتماعية. بالإضافة إلى ذلك، وصف الباحثون شدة الجفاف باستخدام مؤشرات مختلفة تتطلب بيانات مدخلات مختلفة. كانت المؤشرات التي استخدمها العديد من الباحثين هي مؤشر العجز المشترك (JDI)، ومؤشر الجفاف الفعال (EDI)، ومؤشر جفاف تدفق المياه (SDI)، ومؤشر الهطول القياسي (SPI)، ومؤشر التبخر القياسي (SPEI)، ومؤشر بالمر (PI). وبحسب الباحثين في مجال الهيدرولوجيا وللحصول على وصف أدق للجفاف يجب استخدام أكثر من مؤشر للجفاف. أوصت معظم الدراسات التي تمت مراجعتها باستخدام مؤشر الهطول القياسي (SPI) كأفضل مؤشر لوصف الجفاف.

الكلمات المفتاحية: الجفاف , أنواع , وصف, مؤشرات, مؤشر الهطول القياسي .

1. INTRODUCTION

Recently, it has been noticed that arid and semi-arid lands respond to climatic fluctuations very quickly. Global warming and climate change caused extreme events such as floods and droughts. Drought as a natural phenomenon may occur anywhere, and no region is excepted from the drought occurrence. **(Beran and Rodier, 1985)** stated that the chief characteristic of a drought is a decrease in water availability in a particular period and over a particular area. The consequences of drought on society and the economy are severe. Based on Benson and **(Benson and Clay, 1994)**, drought shocks have the most significant economy-wide impact in countries at the intermediate rather than early stages of development. The above two statements highlighted that the definition of drought is continuously updated by considering its impacts and complex interaction on the environment and society. For different periods, **(Guttman, 1998)** determined the Palmer drought severity index and the standard precipitation index and compared the results from the two indicators. In that study, the standard precipitation index performed better than the Palmer index because the former was easy to interpret and calculate. At the same time, the latter has a complex structure and is difficult to calculate.

(Keyantash and Dracup, 2002) described the drought as a deficit in precipitation, leading to a lack of water flow in streams that may extend for months or years. Three drought indices were generated and evaluated in Greece **(Loukas et al., 2003)** using information gathered from 28 locations over 40 years (1960-2000). Their study used the standardized precipitation index (SPI), rainfall abnormality index (RAI), and Z index. They initially determined the values of the indices for intervals of 3, 6, 12, and 24 months and then compared them. The findings showed that all three indices were equally effective at predicting the intensity and duration of the drought. A model was created by **(Hong et al., 2004)** to assess the risk of drought for two crops in Nebraska, the US: soy and maize. This study aims to present a straightforward definition of agricultural drought based on yield performance and suggest a new index to measure the severity of agricultural drought, taking into account all relevant factors as the final effects of the drought phenomenon in agriculture are on crops and fruits.

(Yazdani et al., 2006) examined the dryness of the Zayanderud watershed, Iran, and surrounding areas using more than one index, such as the percentage of the normal index, the precipitation index, and the standard precipitation index. Through these indicators, they identified the drought based on the calculated value. The probability of a drought persisting in the center sections of Sistan and Balouchestan province, Iran, is over 70%, while it is less than 50% in the eastern areas, according to findings from **(Raziei et al., 2007)** collected using SPI. Aside from that, this province's center region experiences drought for about 30% of the time each year. As a result, this province is more vulnerable compared to the other analyzed provinces in this article.

(Loukas et al., 2008) assessed how climate change has affected the severity of the drought throughout a large region of Tesla in Greece. They evaluated using information gathered over 30 years from 50 locations. They concluded that drought had occurred at different periods and varying degrees in all areas of this region using the SPI.

An index called the Palmer drought index (PDI) and also called the Palmer drought severity index (PDSI) is a regional drought index commonly used for monitoring drought events and studying areal extent and severity of drought episodes **(Mishra and Singh, 2010)**. Based on SPEI data **(Yang et al., 2016)** looked at spatiotemporal drought fluctuation patterns in the Haihe River Basin (HRB) between 1962 and 2010. The results showed that drought occurrence and severity have increased during the study period on both an annual and seasonal scale. All drought-affected areas exhibit a temporal pattern of increasing variability **(Liu et al., 2018)** used the drought indices to assess agricultural drought in northern China. The drought indices used in the assessment were the standard Precipitation Index (SPI), Standard Evapotranspiration Index (SPEI), and Palmer Drought Severity Index (PDSI).

In Ethiopia, specifically at Upper Blue Nile, **(Bayissa et al., 2018)** used six indices to describe historical drought and compare the results. The indices used were SPI, SPEI, Evapotranspiration Drought Index (ETDI), Soil Moisture Drought Index (SMDI), Total Drought Index (TDI), and the Standard Runoff Index (SRI). The assessment obtained from all these indicators enabled them to determine the beginning of the drought. The above indices were described respectively using the following equations **(Mckee et al., 1993),** the indices SPI:

$$\mathrm{SPI} = \pm\left(\mathrm{t} - \frac{\mathrm{c_0} + \mathrm{c_1 t} + \mathrm{c_2 t^2}}{1 + \mathrm{d_1 t} + \mathrm{d_2 t^2} + \mathrm{d_3 t^3}}\right) \quad \text{for } 0 < H(\mathrm{x}) \leq 1.0 \qquad (1)$$

and the indices SPEI:

$$\mathrm{SPEI} = \mathrm{w} - \frac{\mathrm{c_0} + \mathrm{c_1 w} + \mathrm{c_2 w^2}}{1 + \mathrm{d_1 w} + \mathrm{d_2 w^2} + \mathrm{d_3 w^3}} \qquad (2)$$

where according to **(Mckee et al., 1993)**, the values of c_0, c_1, c_2, d_1, d_2 and d_3 are 2.521, 0.803, 0.010, 1.432, 0.189, and 0.001, respectively.

- The indices ETDI

$$ETDI_j = 0.5ETDI_{j-1} + \frac{WSA_j}{100} \quad (3)$$

where

WSA is the monthly water stress anomaly

j is month number $(1,2,\cdots\cdots,12)$

- The indices SMDI

$$SMDI_j = 0.5\,SMDI_{j-1} + \frac{SD_j}{100} \quad (4)$$

where SD is the soil water deficit

The SRI had the same SPI equations but was given a **(Tian et al., 2018)** presented the results of using a few drought indicators, including Palmer's Drought Severity Index (PDSI), Palmer's Z-index, precipitation percentiles, Standardized Precipitation Index (SPI), and Standardized Precipitation Evapotranspiration Index (SPEI) and Z-index to assess agricultural drought in the central south of China. They found that using SPEI and Z-index was beneficial for monitoring agricultural drought. For spatial, temporal, and directional analysis of drought occurrence in the upper Tana River, Kenya, Wambua and his colleagues applied the standard and effective precipitation indexes **(Wambua et al., 2018)**. They found that both indicators confirmed the negative effects and risks of the drought at the upper Tana River. **(Polong et al., 2019)** used SPEI at timescales of 6 and 12 months and monthly rainfall and temperature data gathered between 1960 and 2013 to investigate the spatial and temporal variability of dryness and wetness conditions and their extent, intensity, and severity in the Tana River Basin in Kenya. According to the index, dryness episodes predominated in the 1960s through the 1980s, whereas wetness incidents predominated from 1990 to 2000. The SPEI was chosen as the best index since it can consider future climate change effects in the area.

(Asaad and Abed, 2020) conducted a study using three groups of monitoring data for the Tigris River in the Baghdad Governorate to characterize the low flow in the River Tigris decline. Based on the drought class, they recommend using inflatable dams as an effective solution. It is challenging to pinpoint the primary reason for a drought. It is well-recognized that droughts happen when there is no precipitation or below-average precipitation. Human activities, including land usage, mining, deforestation, and poor management of water resources, can readily increase both the frequency and severity of droughts **(Abara and Budiastuti, 2020; Ayugi et al., 2020)**.

A daily SPEI dataset was created by **(Wang et al., 2021)** using data collected over 58 years, from 1961 to 2018, at 427 meteorological stations spread out across the Chinese mainland. In addition, it was noted that the daily SPEI dataset might be used to explore droughts on various timesteps, including meteorological, agricultural, and hydrological ones. The study revealed that the SPEI value with a three-month (roughly 90 days) timestep illustrated no significant trends toward intensification in frequency, severity, and duration of drought incidents. Both academics and scientists have recently expressed serious concern about the use of drought indices, and a greater emphasis has been placed on understanding the phenomena of drought and delving further into its characteristics **(Nkunzimana et al., 2021; Myronidis and Theofanous, 2021; Stefanidis and Alexandridis, 2021; Ndayiragije and Liu, 2022)**. By creating new or improved techniques and choosing

indicators, much work has been put into creating statistical drought prediction models that are accurate and dependable.
After reviewing the literature, no studies focused on various tools used to quantify drought in various regions worldwide. In addition, a recommendation for the most accurate drought identification numerical tool is required. The present study demonstrates the types of drought, describes the drought using various drought identification indices, assesses the application of various drought identification methods, and recommends the most accurate indices for drought identification.

2. DROUGHT CLASSIFICATION AND CHARACTERISTICS

After defining drought and finding out the causes of drought occurrence, most of the researchers highlighted the linkage between precipitation and drought. Accordingly, **(Wilhite and Glantz,1985)** classified drought into three categories, as shown in **Fig. 1**.

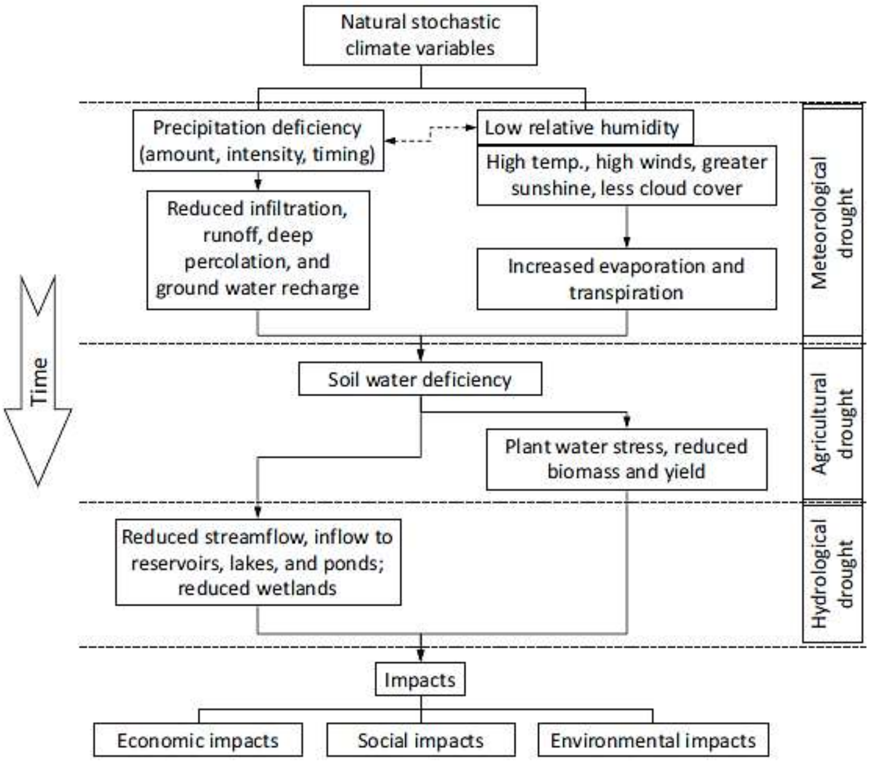

Figure 1 Types of drought based on drought classification **(Wilhite and Glantz,1985)**

Besides the drought types, other drought characteristics such as severity, length, magnitude, frequency, and duration are important in identifying and analyzing the drought. Depending on a region's location, drought duration can range from a week to several years. The drought magnitude is the cumulative water deficit in precipitation, soil moisture, or runoff during a drought period that falls below a certain threshold. The drought intensity is the ratio of drought magnitude to its duration. Drought frequency (return period) is the average amount of time between drought events with a severity equal to or higher than a threshold, known as drought frequency or return period **(Wilhite and Glantz,1985; NDMC, 2006; Haroon et al., 2016)**.

2.1 Metrological Drought

This type of drought is specified to meteorology and results from decreased precipitation and the duration of this deficiency. (**Shiru et al., 2019)** evaluated the changes in the intensity and frequency of the meteorological drought during the agricultural seasons in Nigeria using the SPEI as an index. In addition, data on temperatures confirmed that the drought was greatly affected by the temperature increase due to global warming. The Joint Deficit Index (JDI) was used in northwestern Iran by **(Mirabbasi et al., 2013)** to determine and assess drought prediction since it offers important information about water resources. The JDI indicator only depends on monthly rainfall data. For Iran's Western Azerbaijan, **(Nosrati and Zareiee, 2011)** analyzed drought using SPI as an indicator and considering the intensity, duration, and frequency of droughts since the results showed that the drought gets worse as the yield period and scope grow.

2.2 Agricultural Drought

When agricultural drought occurs, it results in a decrease in production. This results from the soil moisture deficit, which decreases the plant's productivity. **(Kamruzzaman et al., 2019)** performed a study on Bangladesh to evaluate the characteristics of agricultural drought using an index called the Effective Drought Index (EDI). The findings of their study were similar to those obtained by **(Rafiuddin et al., 2011),** who carried out a study on the same area using the SPI index. Both studies revealed that the northern, southeastern, and central regions are the most affected by agricultural drought, as shown in **Fig. 2**.
(**Qiang et al., 2020)** describe the drought in Inner Mongolia using annual SPEI. The SPEI-12 in December can be used to characterize the annual droughts. **Fig. 3** shows the relationship between drought and plant growth **(Hao et al., 2016)**.

2.3 Hydrological Drought

A hydrological drought occurs when a region's precipitation. The main impacts of the hydrological drought are lowering river and groundwater levels. When there is a long shortage of precipitation, the effect of a hydrological drought starts after the end of the meteorological drought. (**Jahangir and Yarahmadi, 2020)** conducted a study to detect Hydrological drought in Lorestan Province, Iran, using the Streamflow Drought Index (SDI) and knowing the drought trend for different periods. Their results were consistent with the discharge values for the period under study. **Fig. 4** shows the spatial analysis of the drought in the studied area.
The standard precipitation index and the streamflow index for various periods were employed by (**Boudad et al., 2018)** to study the two most significant types of drought in northern Morocco: meteorological and hydrological droughts. The findings revealed a link between these two parameters; mainly, such results are helpful to the Department of Water Resources taking necessary actions for the 12-month scale **(Smakhtin and Hughes, 2004; Shukla and Wood, 2008)**.

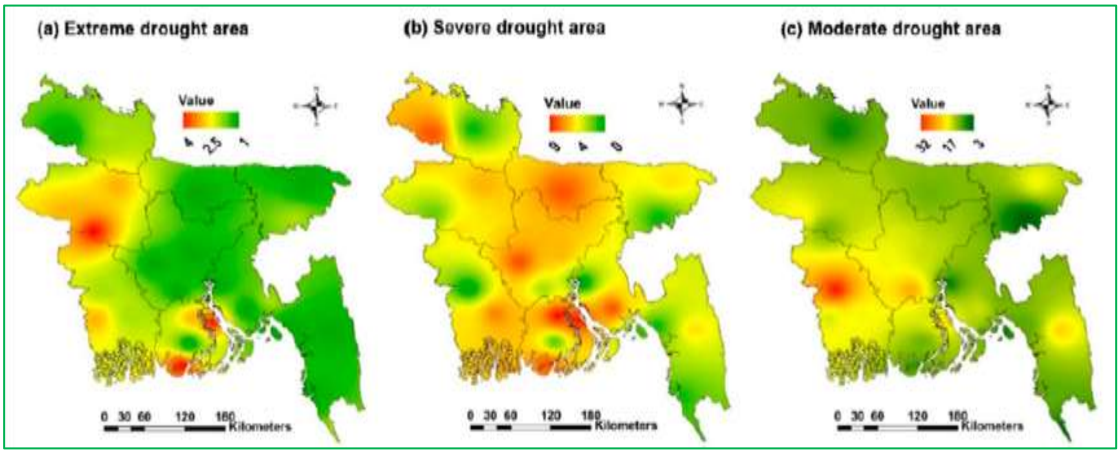

Figure 2. Spatial distribution of droughts during 1981–2015 in Bangladesh **(Kamruzzaman et al., 2019)**

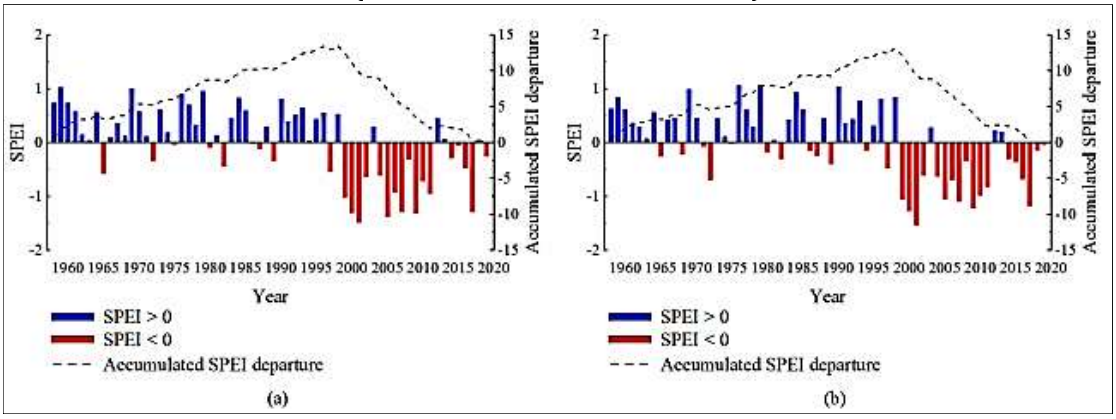

Figure 3. Changes in annual drought index and its effect on plant growth in Mongolia, China: a) changes of annual standardised precipitation evapotranspiration index (SPEI) values and b) plant growth period SPEI values over the years **(Qiang et al., 2020)**

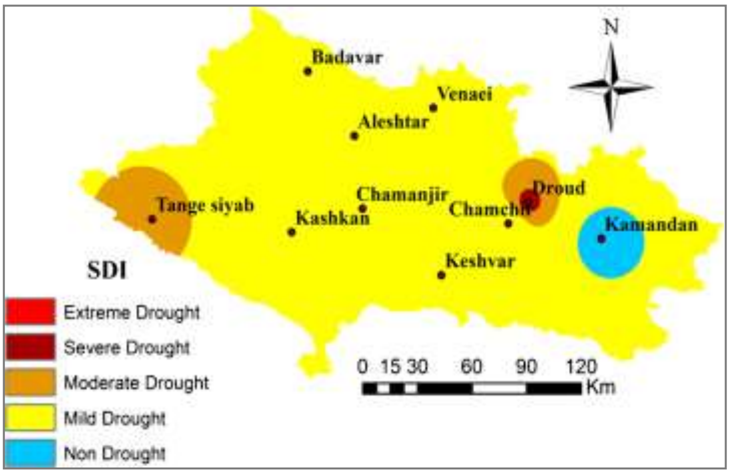

Figure 4. Spatial distribution of the drought in the Lorestan region **(Jahangir and Yarahmadi, 2020)**

2.4 Socioeconomic Drought

Socioeconomic drought tends to happen due to increased demand for natural products such as fish, grain, and hydropower. However, these products depend on the availability of water. In addition, the availability of water depends on climatic fluctuations. For example, the Uruguayan drought that occurred in 1988–1989 reduced the flow of water and reduced hydroelectric power production.

3. DROUGHT INDICES

A symbol or a number that indicates the occurrence of a drought is referred to as a drought indicator. Scientists developed these indicators because they are important and useful for various purposes, but they did so while considering the available data for the area under study. (**Friedman, 1957)** prepared a list of the most important necessities for any specified index. For this purpose, steps outlined the requirements that any drought index must satisfy, as shown in **Fig. 5.**

The following are the operational benefits of employing an index for drought characterization:

- Real-time monitoring and drought detection **(Niemeyer, 2008)**
- announcing the start or conclusion of a drought **(Tsakiris et al., 2007)**
- enabling drought managers to announce levels and initiate responses;
- drought assessment
- Depicting the idea of drought in a particular area, enabling the communication of drought conditions among multiple interested entities, and connecting with quantitative drought impacts over variable scales of geography and time.

The researchers have strived to create various drought indicators, each of which has advantages over the others regarding data and the drought it can identify. A list of some of the most popular drought indicators is presented in **Table 1.**

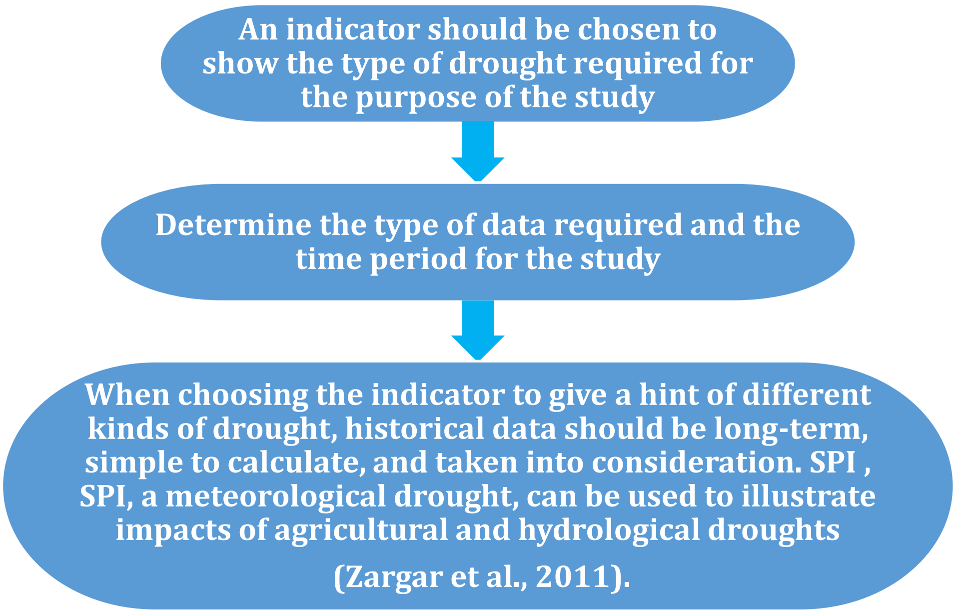

Figure 5. Flowchart for choosing the best index

Table1. Comments on the usage of the most popular drought indicators

Drought indicators	Source and inputs	purpose	Comments
Standardized Precipitation Index (SPI)	**(McKee et al., 1993)** Precipitation	Numerous applications are possible because of SPI's versatility in timescales at which it can be calculated.	The most significant strength of this indicator is its reliance on rain data that may be available. It is one of the powerful indicators that can be used to monitor different types of droughts. The SPI-3 is used to monitor meteorological drought for three months or less. The SPI-9 is used to monitor the effects of agricultural drought for nine months. The SPI-6 and SPI-12 are used for six months to monitor hydrological drought, where drought begins at -1 and ends when its value becomes zero.
Palmer Drought Severity Index(PDSI)	**(Palmer, 1965)** Precipitation, temperature, and the soil's local accessible	It was first developed to detect agricultural drought and then created to monitor drought instances.	The most key aspect of this indicator is that it provides a clear visualization of the long-term drought, unlike other indicators that do not provide a clear visualization for periods shorter than a year. The indicator is complicated, data is hard to come by, and it cannot be compared across regions like SPI. According to the maps of operational agencies like NOAA, the index values range between -4 to +4, and occasionally, it extends beyond that range because positive values imply wetness and liquid over drought.
Standardized Precipitation-Evapo Transpiration	**(Vicente-Serrano, et al., 2010)** precipitation and temperature	This type approximates the standard precipitation index because it records all types of drought.	This indicator is similar to the SPI indicator. Still, it includes temperatures in addition to precipitation since it provides a comprehensive image of drought for various periods and requires monthly data with an extended series for a long time, which can be challenging to obtain.
Stream flow Drought Index (SDI)	**(Nalbantis and Tsakiris, 2008)**	It employs a unique gauge to monitor the hydrological dryness.	An indicator with good dry results practically identical to SPI values has the drawback that the results change without flow, producing less-than-ideal results. Its values, representing dry and wet circumstances, range from -1 to +1.
Effective Drought Index (EDI)	**(Byun and Kim, 2010)** Daily precipitation	It is used to monitor both agricultural and meteorological droughts.	The indicator's use of daily precipitation data makes it one of a kind and allows for the determination of the start and end of the drought period. It is also one of the most effective indicators for determining meteorological and agricultural drought. Still, the data itself presents a problem because it is possible for updates to be made to all data daily.

4. APPLICATION OF DROUGHT INDICES: PERFORMANCE ASSESSMENT

Several studies compared various drought indicators utilized worldwide and determined the effectiveness of each indicator **(Askarimarnan et al., 2021)**. **(Tirivarombo et al., 2018)** conducted a study on northern Zamia to detect drought in the Kafu River basin. Two indicators were used: the standard evapotranspiration index (SPEI) and the standard precipitation index (SPI), as the first depends on both precipitation and temperature and the second on precipitation only. The correlation coefficient between these two indicators for different time scales (1, 3, 6, and 12) months was determined and shown in **Fig. 6.**

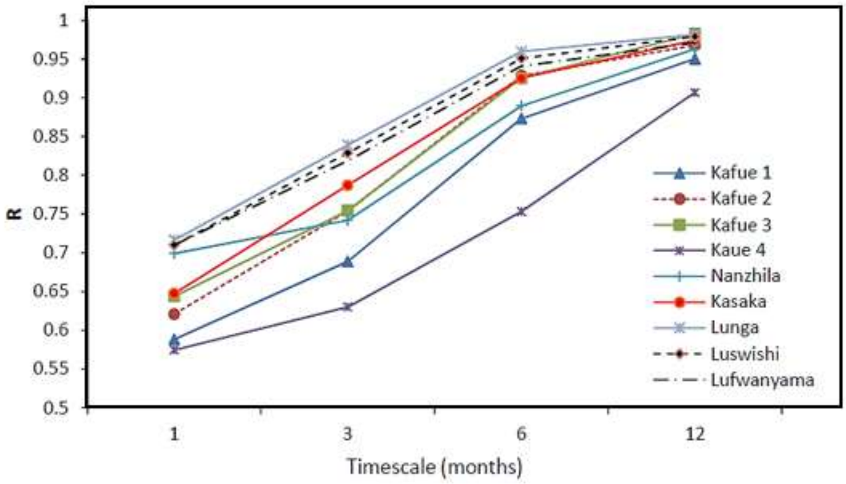

Figure 6. Correlation coefficient between SPI and SPEI at different time scales **(Tirivarombo et al., 2018).**

Results showed that the SPI was marginally superior to SPEI in drought prediction. In contrast, both indicators were promising tools for drought identification. To evaluate drought in the northern part of Burundi, **(Ndayiragije et al., 2022)** evaluated the drought by using both indicators SPI and SPEI.
The results showed that both indicators gave a clear picture of the drought onset and severity. However, the SPI gave a clearer picture of the severity. Based on the reviewed literature, this study recommended using more than one indicator for drought identification in an area**. (Ceglar et al., 2008)** used two indicators for the identification of the drought in Slovenia. The standard precipitation and Palmer indexes were used since they are important and relatively simple in drought identification. However, results showed that the standard precipitation index is better than the Palmer index in the drought characterization, considering the occurrence period. This was confirmed (**Guttman, 1998)** when the results of applying the standard precipitation index in the United States were more satisfactory than those obtained from applying the Palmer index.
A study was done **(Stagge et al., 2014)** to see if SPEI differed significantly from SPI. They concluded that SPEI includes PET in the calculation instead of SPI. SPEI is therefore highly recommended for quantifying drought. The Streamflow Drought Index (SDI) and the SPI were used by **(Gumus et al., 2017)** to analyze hydrological and meteorological droughts in Turkey's Seyhan and Ceyhan River Basins. Their research revealed that using SPI and SDI, along with their categorizations, is a reliable methodology when analyzing hydrological and meteorological droughts. **(Haied et al., 2017)** employed Decile, SPI, and RDI to evaluate and monitor meteorological drought in the Wadi Djelfa-Hadija sub-basin in the southern section of the Saharian Atlas. The findings showed that compared to SPI and Deciles, the RDI index showed a greater frequency of months with drought. **(Wambua et al., 2018)** used two drought indicators that depend on rainfall data to assess and detect drought in Kenya,

specifically the upper Tana River watershed. The indicators used for this purpose were the effective drought index (EDI) and the standard precipitation index (SPI). The values of the SPI and EDI for the Nyeri station (one of the study stations) were effectively illustrated in **Fig. 7**.

Where the results of drought detection in different time scales were demonstrated, both indicators presented effective outcomes for identifying the drought. By comparing the SPI and SPEI indexes, **(Haile et al., 2020)** evaluated the potential for drought in the nations of Eastern Africa. SPEI was used to forecast the upcoming droughts since it can consider temperature impacts. The results showed that the "dryness becoming more drier, wetness becoming more wetter" paradigm is maintained despite drought changes throughout Eastern Africa. **(Taji and Seskar , 2021)** to identify and analyze drought events, a study was carried out to evaluate the meteorological drought in the Beed district of the Marathwada area of India using SPI at different timescales (1, 3, 6, 9, and 12 months). SPI1 should be used to measure precipitation deficiencies over a smaller period. In contrast, SPI3 and SPI6 can be used to assess seasonal dryness according to the findings showed that SPI fluctuated on a shorter timescale and caused numerous droughts of short length.

(Liu et al., 2021) computed the SPI and SPEI values based on data collected from 44 meteorological stations dispersed throughout the Province of Sichuan to evaluate and explore the variations in drought features. The findings showed that these two indicators could faithfully capture the shifting characteristics of drought in different Sichuan geomorphological environments.

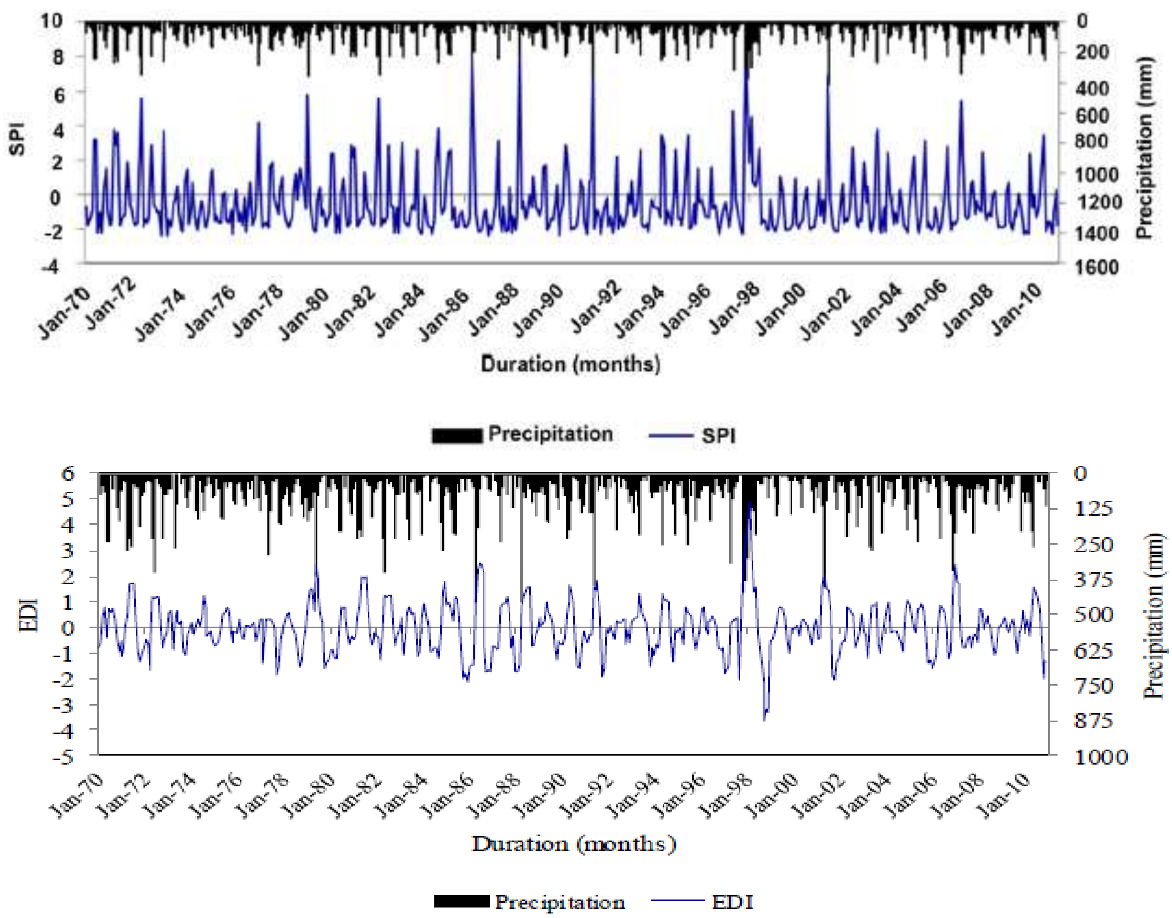

Figure 7. Time series for a) SPI and b) EDI with precipitation **(Wambua et al., 2018)**

In Iran, research was conducted to monitor hydrological and meteorological drought **(Salimi et al., 2021).** Drought was monitored at three different basins regarding climate (dry, semi-arid, wet). It was monitored using three indicators: the standard precipitation index, the standard evaporation-transpiration index, and the standard flow index. Each indicator's efficiency was tested using the Pearson correlation matrix, shown in **Fig. 8**.

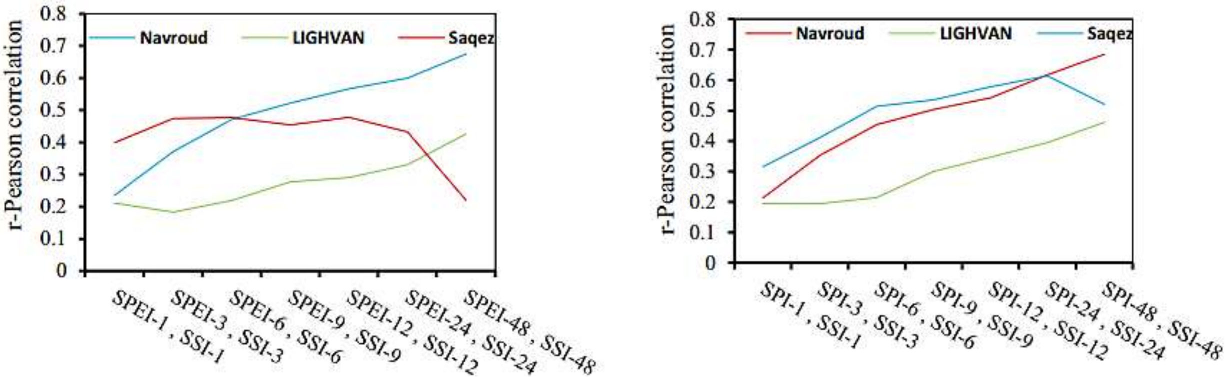

Figure 8. Pearson correlation coefficient for different drought indicators **(Salimi et al., 2021)**

5. CONCLUSIONS

This study conducted a comprehensive literature review on drought identification and categorization. The droughts are categorized as metrological, agricultural, hydrological, and socioeconomic. These types relate to the data type used in the drought categorization. The drought is quantified using various indices, and these are the Joint Deficit Index (JDI), Effective Drought Index (EDI), Streamflow Drought Index (SDI), standard precipitation index (SPI), standard evapotranspiration index (SPEI), and Palmer Index (PI).

The results of the drought index can be utilized for measuring the intensity of drought and forecasting the drought. This is very useful in the planning and management of water resources. Also, forecasting the drought is essential, and it helps to take the preventive measures that can alleviate the drought effects on the public, including using early warning and taking appropriate actions before the drought reaches a dangerous level. Most researchers recommended using more than one indicator in drought studies since determining indicators is a significant step in dealing with drought as a natural phenomenon. Most researchers recommended using more than one indicator in drought studies since determining indicators is a significant step in dealing with drought as a natural phenomenon, and using more than one index can help confirm the type of drought in the studied region.

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