International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 12 Issue 6, June-2023, Impact Factor: 7.957

Assessment of drought using SPI and SPEI methods- A state-of-art review

Khyati Mistry[1], Grishma Salvi[2], Maulik Kakadiya[3]

[1,2,3] Assistant Professor, Civil Engineering Department, Chhotubhai Gopalbhai Patel Institute of Technology, Gujarat, India

ABSTRACT

Drought is a recurrent feature of a nature causing significant damage to the mankind and environment. Due to immense increase in global warming, intensity and frequency of drought has been rising continuously over past decades and became a global issue to research on. There are several indices available to assess the severity of drought, however standardized precipitation index and standardized precipitation evapotranspiration methods are widely used by researchers to determine various characteristics of drought over different geographical area. The present study provides comprehensive review of effectivity of SPI and SPEI methods in evaluating drought along with its benefits and drawbacks. Also, recent work done using these two methods are also mentioned. However, drought is depended on numerous factors that could impact on universal use of SPI and SPEI methods giving possibility of using other methods for drought assessment. Apart from this, a prediction model can also be generated to reduce after effects of drought.

Keywords: Drought Assessment, Drought Indices, Drought prediction, spatial changes, SPI, SPEI

INTRODUCTION

Drought is considered as one of the most disastrous as it inflicts untold numerous miseries on the human communities (Shewale & Kumar, 2005). Due to severity of drought, it attracted the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists and agricultural scientists globally (Swain, Mishra, & Pandey, 2021; Mishra & Singh, 2010). Droughts occur in virtually all climatic zones, such as high as well as low rainfall areas and are mostly related to the reduction in the amount of precipitation received over an extended period of time, such as a season or a year (Mishra & Singh, 2010). Temperatures; high winds; low relative humidity; timing and characteristics of rains, including distribution of rainy days during crop growing seasons, intensity and duration of rain, and onset and termination, play a significant role in the occurrence of droughts (Mishra & Singh, 2010; Wilhite, Svoboda, & Hayes, 2007). Since 2000, the number and duration of droughts has risen 29%. Droughts represent 15% of natural disasters but took the largest human toll, approximately 650,000 deaths from 1970-2019. From 1998 to 2017, droughts caused global economic losses of roughly USD 124 billion. In 2022, more than 2.3 billion people face water stress; almost 160 million children are exposed to severe and prolonged droughts (WMO, 2021).

The Indian meteorological department defines drought in any area when the rainfall deficiency in that area is ≥26% of its long term normal. It is further classified in to moderate and severe depending upon whether the deficiency is in between 26 to 50% and more than 50% respectively (IMO, 2020). Drought is basically divided into four categories Meteorological, Hydrological, Agricultural and economic (Wilhite, Svoboda, & Hayes, 2007). The characterization of drought can be done using variety of indices (Handbook of Drought Indicators and Indices, 2017; Nagarajan, 2009). Several drought indices have been derived in recent decades. Basically, a drought index is a prime variable for assessing the effect of a drought and defining different drought parameters, which include intensity, duration, severity and spatial extent (Mishra & Singh, 2010). Methods like Standardised Precipitation Index, Simplified rainfall Index (Swain, Mishra, & Pandey, 2021) Standardised precipitation Evapotranspiration Index (SPEI), Aridity Anomaly Index (AAI), Percent of Normal Precipitation, Weighted Anomaly Standardized Precipitation Index (WASP), Aridity Index (AI), Drought Reconnaissance Index (DRI), Drought Area Index (DAI), Palmer Drought Severity Index (PDSI), Rainfall Anomaly Index (RAI) and many others are available to assess the drought. In the present study, more emphasize is given on utilisation of SPI and SPEI methods for drought characteristics and the reason behind wide usage of it. Also, the possibility of using other indices and prediction model has been suggested by reviewing case studies of drought prone regions. This paper contains a brief introduction of drought as a natural disaster, followed by working methodology, significance of SPI and SPEI methods for worldwide acceptance, recent cases of drought assessment and a conclusion.

2. METHODOLOGY OF REVIEW

A literature review is a systematic method for identifying, evaluating and interpreting the work produced by researchers, scholars and practitioners (Fink, 2005). The present study follows a systematic steps mentioned below.

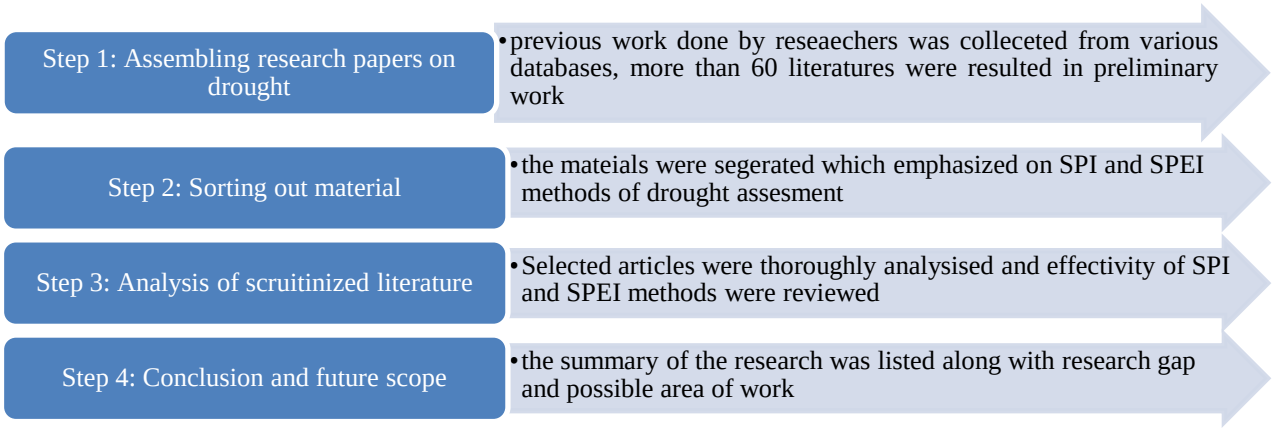

Figure 1: Methodology outline for drought assessment

SIGNIFICANCE OF STANDARDIZED PRECIPITATION METHOD (SPI)

Standardized precipitation is defined as the difference of precipitation from the mean for a specified time period divided by the standard deviation where the mean and standard deviation are determined from past records (McKee, Doesken , & Kleist, 1993). The standardized precipitation index (SPI) is bases on probability that represents the degree to which the accumulative precipitation of a specific period departs from the average state (Du, Fang, Xu, & Shi, 2012). The SPI rely on two assumptions: 1) the variability of precipitations much higher than that of other variables, such as temperature and potential evapotranspiration (PET), and2) the other variables are stationary (i.e., they have no temporal trend) (SERGIO M. VICENTE-SERRANO, 2010).The SPI is space-independent and has a sound performance when representing precipitation anomaly (Du, Fang, Xu, & Shi, 2012). Because of the reason that this index is standardized, it can be used to assess the drought impact in many regions and countries, such as China (Liu, Yang, Yang, & Wang, 2021), Malaysia (Isia, et al., 2023), Bangladesh (Kamruzzaman, et al., 2022), Iran (Lotfirad, Hasan Esmaeii-Gisavandani, & Adib, 2022), United States (Wu, Svoboda, Hayes, Wilhite, & Wen, 2006), Italy (Vergni & Todisco, 2011).Also, the SPI may be computed for any time scale whether short, intermediate, or long by simply estimating the probability distribution function for the selected time scale over any location (Almedeij, 2014). Apart from this, SPI indices involves following benefits (McKee, Doesken , & Kleist, 1993).

Benefits of SPI method:

1. The SPI has a special relationship with probability.
2. The precipitation used in SPI can be used to calculate the precipitation deficit for the current period.
3. The SPI indices can be used to determine the present percent of average precipitation over the past i months.
4. Because the SPI is regularly distributed, it may be used to track both dry and rainy periods.
5. Snowpack, reservoir, streamflow, soil moisture, and ground water are other water variables that can be estimated using SPI.
6. The SPI is normalized so that wetter and drier climates will be represented similarly.
7. It is easy to use as it requires only precipitation data to monitor a drought results in to best method where hydrological data are scarce.

Drawbacks of SPI method:

1. It requires high quality data set of at least 30 years to monitor the drought (McKee, Doesken , & Kleist, 1993).
2. It gives the results of severe and extreme droughts using same frequency which are unable to identify most drought prone area of the region.
3. It does not give accurate results in the area of low precipitation on shorter time scales.
4. It does not consider water balance based on evapotranspiration.
5. Spatial distribution features cannot be identified using this.

SIGNIFICANCE OF STANDARDISED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI) METHOD

The standardized precipitation evapotranspiration index (SPEI) was first proposed by Vicente-Serrano et al. (2010a) as an improved drought index that is especially suited for studies of the effect of global warming on drought severity (Beguer´ıa, 2014).The standardized precipitation evapotranspiration index (SPEI) is similar to SPI, SPEI considers surface evapotranspiration due to the background of global warming, and replaces precipitation in SPI with the difference between monthly precipitation and potential evapotranspiration (Liu, Yang, Yang, & Wang, 2021). SPEI has a higher utilization rate than other indices, and its main advantage is the ability to detect the effect of changes in evapotranspiration and temperature concerning global warming (M. Nejadrekabi, 2022). It can be calculated for time steps of as little as 1 month up to 48 months or more (WMO, 2017). The multi-scalar nature of the SPEI enables identification of different drought types and drought impacts on diverse systems (Vicente-Serrano et al., 2012a, 2012b, 2013a, and 2013b). The SPEI method use "climatic water balance", the difference between precipitation and reference evapotranspiration (P – ET0), instead of precipitation (P) as the input. The climatic water balance compares the available water (P) with the atmospheric evaporative demand (ET0), and therefore provides a more reliable measure of drought severity than only considering precipitation. The climatic water balance is calculated at various time scales (i.e. over one month, two months, three months, etc.), and the resulting values are fit to a log-logistic probability distribution to transform the original values to standardized units that are comparable in space and time and at different SPEI time scales (Beguer´ıa, 2014). Due to its effectiveness it is widely used across many countries like Iran (Lotfirad, Hasan Esmaeii-Gisavandani, & Adib, 2022), India (Raja, 2022), China (Wang, 2019), Malaysia (Isia, et al., 2023), Pakistan (Jamro, 2019), Bangladesh (Kamruzzaman, et al., 2022).

Benefits of SPEI method:

1. This method considers temperature and evapotranspiration data in addition to the precipitation data gives accurate picture of drought severity.
2. It is an ideal index to use when climate change has severely impacted a region.
3. Only climatological information of a region is required.
4. It includes surface evaporation changes which is more connected to drought cause due to global temperature rise.
5. It can reflect dry and wet conditions more accurately in complex regions.

Drawbacks of SPEI method:

1. Accurate and continuous temperature data are required.
2. Long base period of 30 to 50 years are required to assess severity of drought.

Table 1: List of case studies used SPI and SPEI Indices for drought assessment

Sr. No.	Case studies	Cited By	Year	Method used
1	Sarawak, Malaysia	(Isia, et al., 2023)	2023	SPI and SPEI method
2	Tamilnadu, India	(Natarajan, et al., 2023)	2023	Standardized Precipitation Index (SPI), China Z Index (CZI), Modified China Z Index (MCZI), Deciles Index (DI), Rainfall Anomaly Index (RAI), and Z-Score Index (ZSI)
3	Uttarpradesh, India	(H. BISHT, 2023)	2023	SPI and SPEI method
4	Punjab, Pakistan	(Ghouri & Rasheed, 2022)	2022	SPI and SPEI with Mann-Kendall Trend Test
5	Iran	(Lotfirad, Hasan Esmaeii-Gisavandani, & Adib, 2022)	2022	SPI, SPEI, and random forest model
6	Bangladesh	(Kamruzzaman, et al., 2022)	2022	SPI and SPEI method
7	Khuzestan Province, Iran	(Nejadrekabi, Eslamian, & Zareian , 2022)	2022	SPEI and NDVI method
8	Sichuan Province, China	(Liu, Yang, Yang, & Wang, 2021)	2021	SPI and SPEI method

9	Nagpur, India	(Bera, Kumar Shit, Sengupta, & Saha, 2021)	2021	SPI and SPEI method
10	South Iran	(Zarei, 2019)	2019	SPI method

RECENT CASES OF DROUGHT ASSESSMENT USING SPI AND SPEI METHODS OVER DIFFERENT REGIONS

The table listed below shows certain recent work done on drought monitoring using SPI and SPEI methods in different countries of the world along with description of case studies of Malaysia and India.

1) Case study of drought assessment in Malaysia: In recent work in Malaysia, the strong El Niño caused six droughts in Sarawak in the years 1982–1983, 1986–1988, 1991–1992, 1997–1998, 2009–2010, and 2014–2016 as per the report of World Meteorological Organization (WMO). Temporal assessment of drought was performed using SPI and the SPEI indices at 3-, 6-, 9-, and 12-month timescales for the period from 1980 to 2020. Taking precipitation and evapotranspiration data into account, the SPEI was able to identify more severe-to-extreme drought in the study area over longer time periods and moderate droughts over shorter time periods than the standard drought index (Isia, et al., 2023). Figure 2 depicts the numbers of sever and extreme droughts over different time scales using SPI and SPEI indices

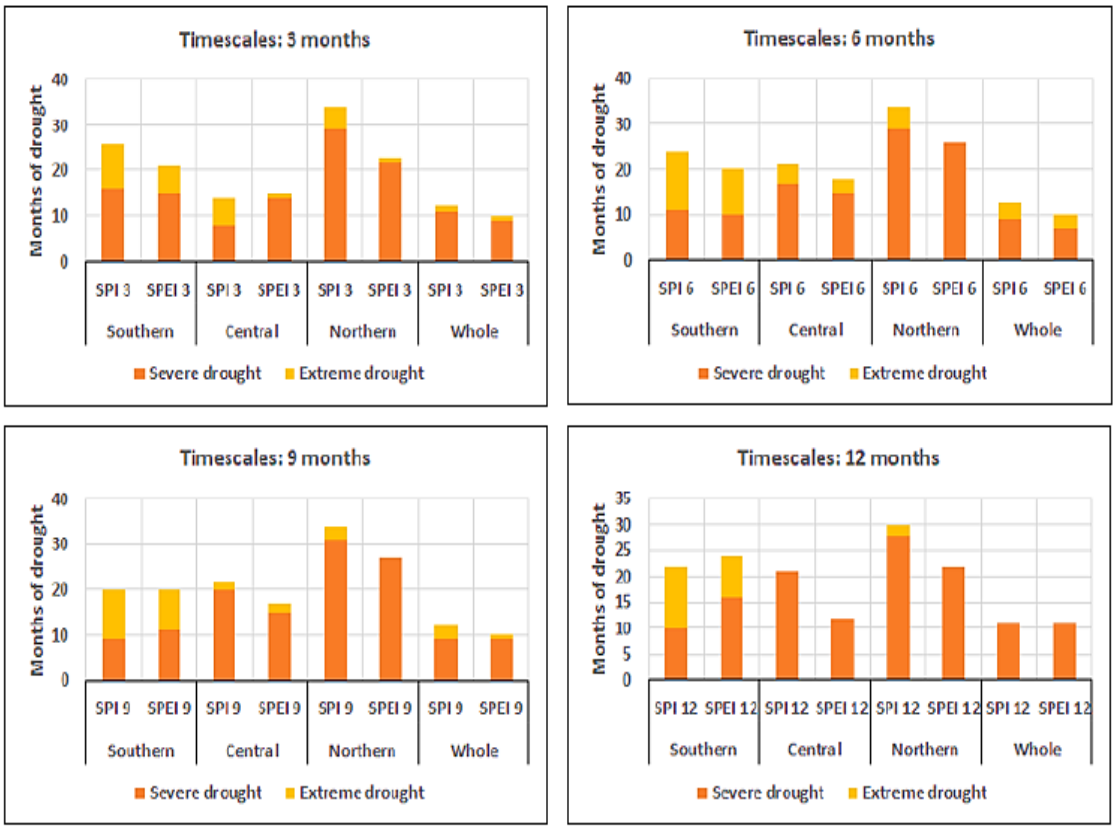

Figure 2: The months of drought in Sarawak (1980–2020) on different timescales of the SPI and SPEI(Isia, et al., 2023)**.**

2) Case study of drought assessment in India: In the recent study of Bundelkhand region, Uttarpradesh, India trend analysis and drought assessment had been done using 48 years of data (1969-2016) of rainfall and temperature. Trend analysis was performed using Mann-Kendall test and drought was assessed using SPI and SPEI indices on various time scales (1, 3 months). The region is most drought prone area of central India. The shorter time scales of SPI and SPEI values are capable of providing an accurate description of the early warning of meteorological drought as well as agricultural drought considering the soil moisture and crop yield deficit. However, the negative trend of SPI and SPEI indicates increasing trend of meteorological drought that could turn out in a soil moisture deficit and crop yield failure situation (H. BISHT, 2023).

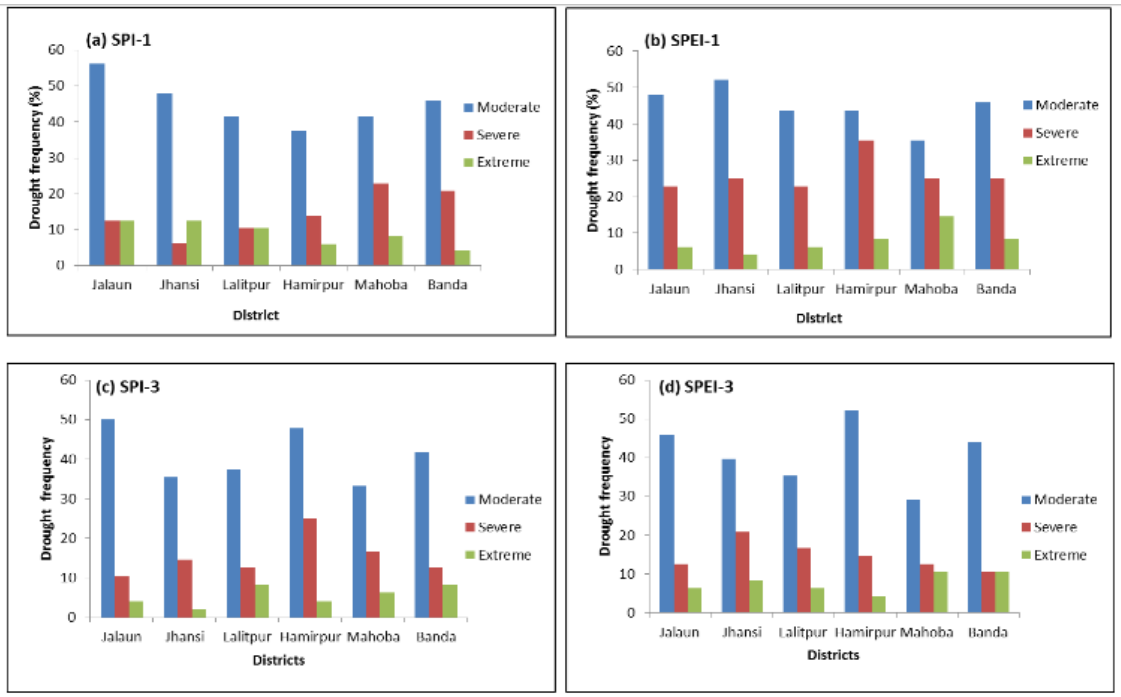

Figure 3: **Frequency (%) of moderate, severe and extreme drought events in monsoon months (June-September) based on (a) SPI-1, (b) SPEI-1, (c) SPI-3 and (d) SPEI-3 during the period 1969-2016** (H. BISHT, 2023)

CONCLUSION

The present study provides overview of two most used drought indices SPI and SPEI methods along with its significance, merits and demerits. However, there are so many factors affecting drought such as, global warming, climate change, excessive water demands, deforestation, soil degradation, and geographic positioning which could be driving factors for selecting appropriate method for drought evaluation. Lack a detailed analysis of drought quantification of specific drought-prone regions considering temporal and spatial analyses (soil, land use land cover, slope map, Normalized Difference Vegetation Index (NDVI), and groundwater level map), impacts of droughts, and mitigation strategies. There are many indices are available for calculation of drought index, but more frequently SPI and SPEI methods are used. Other methods can also be used and comparative analysis can be done. For assessment of drought some research work has been carried out, but no significant work done for prediction model in drone prone regions of the world.

ACKNOWLEDGMENT

The authors gratefully acknowledge the guidance and support provided by the Head of department Dr. Manoj J. Gundalia.

REFERENCES

[1]. Almedeij, J. (2014). Drought Analysis for Kuwait Using Standardized Precipitation Index. *Hindawi Publishing Corporation*, 10.
[2]. Beguer´ıa, S. (2014). Standardized precipitation evapotranspiration index (SPEI)revisited: parameter fitting, evapotranspiration models, tools,datasets and drought monitoring. *INTERNATIONAL JOURNAL OF CLIMATOLOGY*.
[3]. Bera, B., Kumar Shit, P., Sengupta, N., & Saha, S. (2021). Trends and variability of drought in the extended part of Chhota Nagpur plateau (Singbhum Protocontinent), India applying SPI and SPEI indices. *Springer*.
[4]. Du, J., Fang, J., Xu, W., & Shi, P. (2012). Analysis of dry/wet conditions using the standardizedprecipitation index and its potential usefulness for drought/floodmonitoring in Hunan Province, China. *Springer*.
[5]. Fink, A. (2005). *Conducting research literature reviews : from the Internet to paper.* Sage Publications.
[6]. Ghouri, A. Y., & Rasheed, F. (2022). Drought in Punjab, Pakistan using SPI and SPEI with Mann Kendall test. *Discovery*.
[7]. H. BISHT, S. L. (2023). Drought assessment and trend analysis using SPI and SPEI during southwest monsoon season over Bundelkhand region of Uttar Pradesh, India. *MAUSAM*, 10.

[8]. Isia, I., Hadibarata, T., Jusoh, M. N., Kumar Bhattacharjya, R., Fifinatasha Shahedan, N., Bouaissi, A., & Syafrudin, M. (2023). Drought Analysis Based on Standardized Precipitation Evapotranspiration Index and Standardized Precipitation Index in Sarawak, Malaysia. *MDPI Sustainability*.
[9]. Jamro, S. (2019). Spatio-Temporal Variability of Drought in Pakistan Using Standardized Precipitation Evapotranspiration Index. *Applied science*.
[10]. Kamruzzaman, M., Almazroui, M., Salam, M. A., Anarul Haque Mondol, M., Mizanur Rahman, M., Deb, L., . . . Md. Towfiqul Islam , A. (2022). Spatiotemporal drought analysis in Bangladesh using the standardized precipitation index (SPI) and standardizedprecipitation evapotranspiration Index (SPEI). *Scientific reports*.
[11]. Liu, C., Yang, C., Yang, Q., & Wang, J. (2021). Spatiotemporal drought analysis by the standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI) in Sichuan Province, China. *Scientific reports*.
[12]. Lotfirad, M., Hasan Esmaeii-Gisavandani, & Adib, A. (2022). Drought monitoring and prediction using SPI, SPEI, and random forest model in various climates of Iran. *Journal of water and climate change*.
[13]. M. Nejadrekabi, e. a. (2022). Spatial statistics techniques for SPEI and NDVI drought indices: a case study of Khuzestan Province. *International Journal of Environmental Science and Technology*.
[14]. McKee, T. B., Doesken , N. J., & Kleist, J. (1993). THE RELATIONSHIP OF DROUGHT FREQUENCY AND DURATION TO TIME SCALES. *Eighth Conference on Applied Climatology*, (p. 6). Anaheim, California.
[15]. Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, 15.
[16]. Nagarajan, R. (2009). *Drought Assessment.* Springer.
[17]. Natarajan, N., Vasudevan, M., Raja, S., Mohanpradaap, K., Sneha, G., & Shanu, S. (2023). An assessment methodology for drought severity and vulnerability using precipitation-based indices for the arid, semi-arid and humid districts of Tamil Nadu, India. *Water supply springer*.
[18]. Nejadrekabi, M., Eslamian, S., & Zareian , M. J. (2022). Spatial statistics techniques for SPEI and NDVI drought indices: a case study of Khuzestan Province. *Springer*.
[19]. Ojha, S. S., Singh, V., & Thendiyath , R. (2021). Comparison of Meteorological Drought using SPI and SPEI. *Civil Engineering Journal*.
[20]. Raja, A. (2022). Drought Analysis Using the Standardized Precipitation Evapotranspiration Index (SPEI) at Different Time Scales in an Arid Region. *Engineering Technology and Applied Science Research*.
[21]. SERGIO M. VICENTE-SERRANO, e. a. (2010). A Multiscalar Drought Index Sensitive to Global Warming: The StandardizedPrecipitation Evapotranspiration Index. *Journal of climate*.
[22]. Shewale, M. P., & Kumar, S. (2005). *CLIMATOLOGICAL FEATURES OF DROUGHT INCIDENCES IN INDIA.* NATIONAL CLIMATE CENTRE PUNE.
[23]. Swain, S., Mishra, S. K., & Pandey, A. (2021). A detailed assessment of meteorological drought characteristics using simplified rainfall index over Narmada River Basin, India. *Environmental Earth Sciences springer*.
[24]. Vergni, L., & Todisco, F. (2011). Spatio-temporal variability of precipitation, temperature and agricultural drought indices in Central Italy. *Agricultural and Forest Meteorology*.
[25]. Wang, X. (2019). Temporal and spatial evolution trends of drought in northern Shaanxi of China: 1960–2100. *Theoretical and Applied Climatology*.
[26]. Wilhite, D. A., Svoboda, M., & Hayes, M. J. (2007). Understanding the Complex Impacts of Drought: A Key to Enhancing Drought Mitigation and Preparedness. *Springer*.
[27]. WMO. (2017). *Handbook of Drought Indicators and Indices.*
[28]. WMO. (2021). *State of the global climate.*
[29]. Wu, H., Svoboda, M. D., Hayes, M. J., Wilhite, D. A., & Wen, F. (2006). Appropriate application of the standardized precipitation index in arid locations and dry seasons. *International Journal of climatology*.
[30]. Zarei, A. R. (2019). Analysis of changes trend in spatial and temporal pattern of drought over south of Iran using standardized precipitation index (SPI). *Springer nature* .