# An Assessment on Frequency of Drought Episodes using Standardised Precipitation Index in Vaigai River Basin, South India

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***Abstract***

*Drought is a reoccurring creeping phenomenon of the global climate. The drought events of the past two decades have highlighted India's continued vulnerability to this natural hazard. Thorough knowledge of the drought characteristics using indices will lead us to enhanced water resource management plans and build future drought resilience. This study employs the Standardised Precipitation Index (SPI) to a series of rainfall data (1981-2013) from twenty stations across the Vaigai river basin. The SPI drought analysis is performed for both long and short terms. Key droughts within the period are analyzed to develop understanding between the rainfall characteristics that exist during and terminate drought events. There is a higher frequency of occurrence of mild droughts than the moderate and severe droughts.*

*However, the occurrence of severe droughts increases distinctly with the increase of time scales. The results of the analysis will highlight the spatial variation in the occurrence of different drought types concerning the different time-scales. The study emphasizes the importance of SPI in understanding the climate change impacts across the river basin. The results help in planning the best management strategies for society to adapt and mitigate the impacts of drought and climate change induced extremes.*

**Keywords:** Drought indices SPI, climate change, Best management, Resilience.

## Introduction

Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought in India has resulted in over ten million deaths during the 18th, 19th and 20th centuries. Climate change is one of the significant challenges of this period that adds considerable stress to our humankind and environment. With the effect of climate change, increasing temperatures, increased greenhouse gas (GHG) emissions are projected to intensify droughts in the twenty-first century.[9] Indian agriculture is heavily dependent monsoonal system which is slowly abating with the changing climate. A favorable monsoon year is essential in securing water for irrigating Indian crops. In some parts of India, the failure of the monsoons results in water shortages, resulting in below-average crop yields and massive drought scenarios. Climate change is a significant component contributing to drought impacts for the entire agricultural sector in various facets. Agriculture is the most vulnerable sector to climate change, it is also a major cause directly accounting for about 14 percent of greenhouse gas emissions. Recent researches highlight that technological solutions such as seasonal forecasting and early warning systems are insufficient to address the underlying social drivers of vulnerabilities to climate change.[3]

Drought is generally characterized by three main aspects: intensity, duration and spatial coverage. The intensity of a drought is the degree of precipitation and soil moisture; it may include consideration of the severity of the associated impacts. The duration of a drought is the period from which the index values are less than zero to the day it reverts to a positive value (>0). A typical drought lasts for a few months to a year and a severe drought persists for several years. India, being a monsoon dependent, always experiences rainfall variability resulting in variability in water levels in natural and artificial storage structures.

Water resources are strongly influenced and are also highly sensitive to periods of prolonged drought conditions in a continent with limited water storage infrastructure. Natural water reservoirs such as lakes experience a marked interannual water level fluctuation related to rainfall interannual variability.[19,28] The study intends to analyse the rainfall variability and measuring the drought with an index-based approach using drought indices.

Drought indices are commonly used to monitor and quantify different types of drought (meteorological, agricultural and hydrological drought). Numerous drought indices have been developed for quantification of drought. Some of which include Palmer Drought Severity Index (PDSI)[20], the Reconnaissance Drought Index (RDI)[26], the Standardized Precipitation Index (SPI)[16,17], the Standardized Precipitation Evapotranspiration Index (SPEI)[30], the Surface Water Supply Index (SWSI)[22], the Streamflow Drought Index (SDI)[18], the Rainfall Anomaly Index (RAI)[27] and the Standardized Runoff Index (SRI).[23]

The SPI is the most widely used drought index which is capable of analysing the meteorological drought which is a temporary low in precipitation that could reduce the water resources availability impacting the environment, economy and human life.[4,24] SPI is considered as the robust and effective drought index, less complex and capable of comparing multiple time scales and regions.[8,29,31]

Studies on drought indices suggested that SPI is statistically consistent over the other indices and can identify both short term and long term droughts effectively. Apart from this; its inherent probabilistic nature makes it a perfect pick for drought risk assessment. These advantages have made SPI a comprehensive widespread tool in drought related studies across the world.[6,7,11,14,25]

Drought already being a natural hazard has its own complications. The recent attenuation of climate change has made the situation even worse. Nearly 800 millions of the global population are currently considered as vulnerable to the effects of climate change.

However, the impacts that climatic extremes have on humans and ecosystems (including those altered by humans) depend also on several other non-climatic factors.[2] Some adaptation strategies are followed by stakeholders, while few other types of adaptation are planned and implemented by governments on behalf of the communities, not often anticipating a change but predominantly in response to experienced climatic events and extremes.[1,15]

Understanding the complexities, this study puts an effort to analyze the drought episodes based on rainfall analysis using SPI indices. Any positive or negative changes in rainfall indices were analyzed to observe the spatiotemporal extent of droughts. The meteorological drought has been evaluated using SPI indices for short term (3-6 months) and long term (9-12 months). The frequency of drought episodes at different time scales is mapped to obtain GIS-based critical area maps for a better understanding of the impacts.

## Material and Methods

**Study area description:** The river Vaigai originates from the Varshanadu hills with the major tributaries Vaigai, Suriliar, Theniar, Varattar and Varaghanadi. The Vaigai basin is geographically located between the co-ordinates $90^0$ 33'-$10^0$27' N and $77^0$10'E- $9^0$10' E. The total area stretching from the Western Ghats in the West to Rameswaram in the East (Bay of Bengal), Kottaikara Aru basin on the North and Uttarakosai Mangai Aru basin on the South covers an area of 7031 $km^2$. The index map of the Vaigai basin is presented in fig. 1. It is the primary water resource for five drought-prone districts of Tamil Nadu namely Theni, Madurai, Ramanathapuram, Dindugal and Sivagangai.

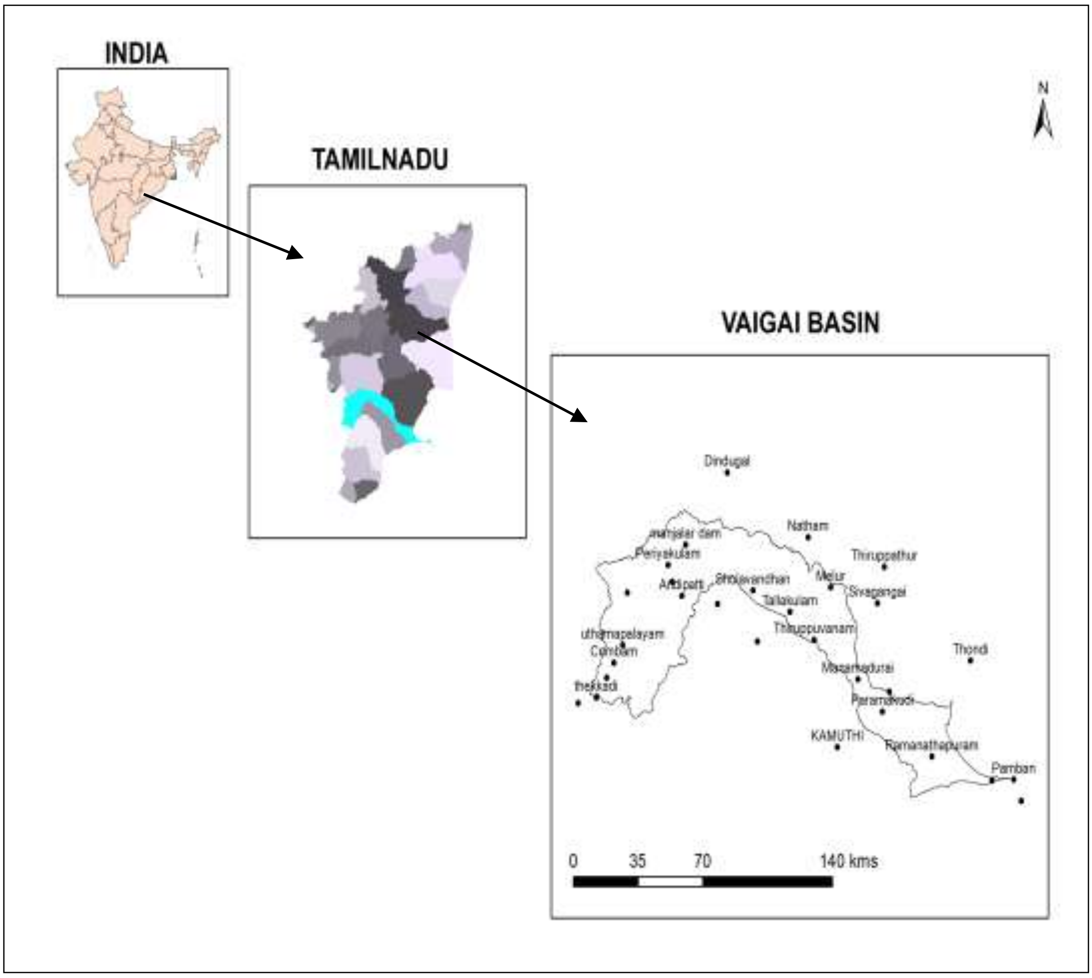


**Figure 1: Index map of the study area**

Periyar and Vaigai reservoirs are the two major surface water reservoirs of the basin. The Vaigai basin consists of 26 raingauge stations out of which 20 stations have long term hydrometeorological records maintained by PWD, Tamil Nadu and IMD, Chennai. The records about the surface water potential and groundwater potential in different zones of the Vaigai basin give complexity in distribution and availability both concerning time and space. Irrigation requirement is a major water demand of the basin and the main crop grown in the area is paddy within different seasons.

**Data collection and method:** A data set of 20 stations in the Vaigai basin with daily rainfall data collected from the Institute of Water Studies for the period 1981-2013 (33years) was employed in this study for drought analysis. Drought indices are calculated and analysed at different time scales. The short term drought analysis is performed using a three-month and six-month time period whereas the nine-month and twelve-month scale are used in long term drought analysis. Spatial mapping of the frequency of drought indices is carried out through ArcGIS 10.1 software.

**Drought Indices and Mapping – SPI:** The primary analysis is through drought indices and the SPI method is used in the calculation. Standardized precipitation index (SPI) is the most straightforward drought index based on precipitation data developed in 1993 by Macke et al[16] who measured precipitation deficit for multiple time scales allowing it to be useful for both short-term agricultural and long-term hydrological applications. Technically, the SPI index is the number of standard deviations by which the observed variance deviates from the long-term mean (NCAR Climate data guide). SPI predicts a drought event when the SPI is continuously negative and reaches an intensity of -1.0 or less and the event ends when the SPI becomes positive. Each drought event has a beginning and an end, it has an intensity and the sum of all the months within a drought is called its magnitude.

$$SPI = (X – X_m)/ \sigma \qquad (1)$$

where X is precipitation for the station, Xm is mean precipitation and σ is a standardized deviation. DrinC is a stand-alone PC software that operates on Windows platforms. The software facilitates the procedure of the calculation of drought indices which might be complicated especially in the case of the assessment of the spatial distribution of indices.

Daily rainfall data for each station was converted into monthly data and a dataset with a standard format (year, month, precipitation,) in MS Excel suitable for DrinC indices calculator as an input file, then SPI for 3, 6, 9, 12, months was calculated.

The results of 3 and 6 months SPI were used in short term drought indices having its impacts on agriculture and plant life and the results of 9 and 12 months SPI were used as long term drought indices which affect the water resources of the region.[5,10] Obtained SPI values were then further classified according to the table 1. Based on the classification a frequency analysis is attempted in this study to understand the frequency of drought occurrence in the Vaigai basin.[12,21] Furthermore, based on the type of drought, critical area maps were generated using ArcGIS.10.1 Software.

**Table 1**
**SPI Drought Classes**

| S. N. | Criteria of SPI values | Type of drought |
|---|---|---|
| 1. | 0.00 to -0.99 | Mild drought |
| 2 | -1.0 to - 1.49 | Moderate drought |
| 3. | -1.5 to -1.99 | Severe drought |
| 4. | -2 and less | Extreme drought |
| 5. | More than 0 | Above normal drought |

## Results and Discussion

**SPI Analysis:** To calculate SPI, the long term historical rainfall record is fitted to a probability distribution (generally the gamma distribution), which is again transformed into a normal distribution.[10] In the present study, critical area maps were created from SPI analysis of 3, 6, 9, 12 months. The frequency of occurrence of mild, moderate and severe drought was calculated and mapped using ArcGIS. The taluks with a higher percentage of drought occurrence in a given period of 33 years (1981-2013) are considered as critical regions. These results of SPI are categorized as short term and long term analysis to have a comparative analysis.

**Short Term SPI Analysis (3 Month and 6 Month):** The results of 3 months and 6 months SPI are considered for short term drought analysis as it gives an estimation of drought impacts for a short time scale. The drought frequencies for mild, moderate and severe types of drought were obtained from the SPI indices and stations are interpolated from higher drought frequencies highlighted with red colour for lower frequencies and highlighted with green colour in the maps.

The SPI values for three months and six months are useful in providing short and medium-term moisture conditions for agriculture. They also provide an estimation of seasonal precipitation, which signifies any deviation in precipitation totals. A six-month SPI is effective in showing the seasonal precipitation information, streamflow and reservoir levels. Short term SPI shows that there is a higher frequency of mild droughts than moderate or severe droughts in the majority of the taluks in the study area for both 3 and 6 months SPI.

A perceptible change in the frequency percentages is observed with the increase in time-scale, it decreases for mild droughts and increases for severe droughts along with the increase in the time scale. It can be understood from the table 2.

The results of the frequency of occurrence of drought for short term (3 and 6 months) SPI are mapped and presented in fig. 2. A higher percentage of mild drought is seen in 3 month than in 6 month SPI. The middle reach of the basin is seen affected by the results of 3 month SPI whereas the head and the tail are affected by the inference of 6 month SPI. The important taluks affected are Mana Madurai, Mandapam, Melur, Tiruppathur and Thirupuvanam from the East and Vaigai dam and Uthamapalayam affected in the West. Natham and Vaigai dam are the two taluks that are affected by both mild and moderate droughts.

The frequency of occurrence of mild and severe drought in 6-month SPI is higher in the head reach taluks like Bodinaickanur, Gudalur and Thekkadi. By identifying the critical stations, the short term measures can be suggested for those areas to fulfill the agricultural requirements attaining optimum soil moisture and reducing agricultural drought vulnerabilities. It is good to take proper measures early in response to mild drought which may turn into severe droughts on longer time scales. It is essential to know the dynamics of drought and adopt strategies according to the site-specific impacts.

**Table 2**
**Results for short term drought analysis**

| Types of droughts | Range of SPI values | 3-month SPI Frequency percentage | 6-month SPI Frequency percentage | Critical Taluks in 3 months SPI | Critical Taluks in 6 months SPI |
|---|---|---|---|---|---|
| Mild drought | 0.00 to -0.99 | 38.91- 49.96 | 38.44 -49.99 | Mana Madurai, Mandapam, Melur, Tiruppathur, Thirupuvanam, Utamapalayam Vaigai dam. | Natham, Sivagangai |
| Moderate drought | -1.0 to - 1.49 | 15.27 –24.95 | 16.16 -24.86 | Natham, Bodinaickanur. | Vaigai dam |
| Severe drought | -1.5 to -1.99 | 12.75-16.66 | 12.22-16.65 | Manjalar dam, Periyakulam. | Bodinaickanur, Gudalur, Thekkadi |

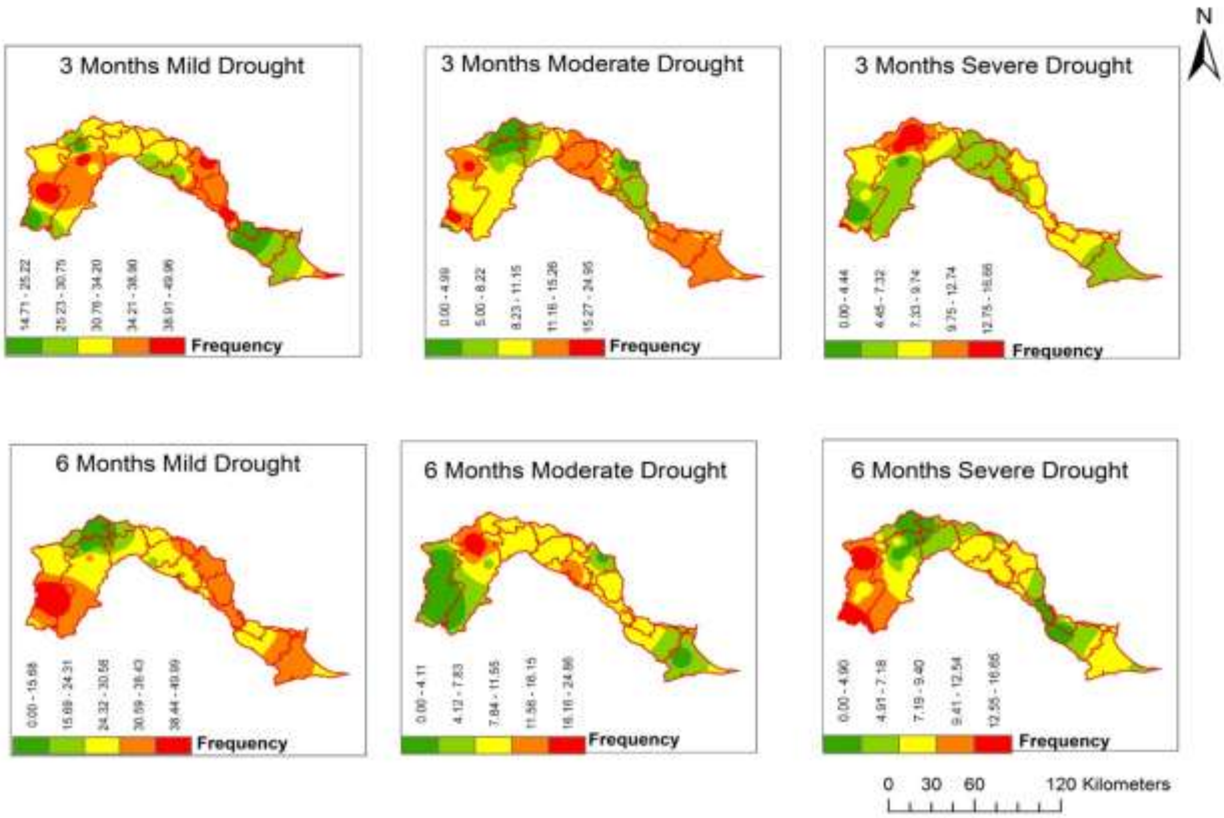


**Figure 2: Short-term (3, 6 months) SPI analysis, for mild, moderate and severe drought**

**Long Term SPI Analysis (9- Month and 12- Month):** Results obtained from 9 and 12 months SPI are considered for long term analysis illustrating the drought frequencies for mild, moderate and severe types of droughts for all the taluks of the study area, highlighting the critical regions from a red colour to the regions with no drought as green colour. The SPI values are analyzed for their frequency of occurrence of mild, moderate and severe drought. The frequencies are interpolated and mapped to identify the regions of immediate concern.

Long term SPI describes the long-time effects on the hydrology of the study area. The long term drought impacts the streamflow, reservoir storage and groundwater level, thus it is eventually related to hydrological droughts. Higher percentages of occurrence of mild droughts were observed than the moderate and severe droughts covering most of the taluks in the study basin. Long term severe droughts are mostly found in the middle reach of the basin and the taluks are listed table 3 comparing different drought types and their frequency percentages for 9 and12 months SPI.

The long term SPI (9- and 12-month SPI) shows higher frequencies for mild and severe droughts. The frequency percentages of occurrence of drought have been noticed increasing in long term analysis as shown in fig. 3. It is understood that there is a higher probability of hydrological drought and depletion of groundwater, streamflow in the critical areas of the Vaigai basin. Hence, there is a prior need to adopt adaptation strategies to challenge desertification due to climate change. The immediate concern should be on the adoption of water conservation and management practices in the critical areas.

## Conclusion

In this study, the daily observed precipitation records are converted to monthly datasets to analyze the drought episodes in the South Indian River basin during the period 1981–2013 using SPI based on multiple time-scales (3, 6, 9, 12 months). A frequency analysis was applied to the SPI values at different timescales. As a result, the frequency of occurrence of each drought type based on severity classes considering the dry episodes of all four timescales 3,6,9,12-month has been evaluated. In particular, the regions of the frequent occurrence of any type of drought are identified as critical regions.

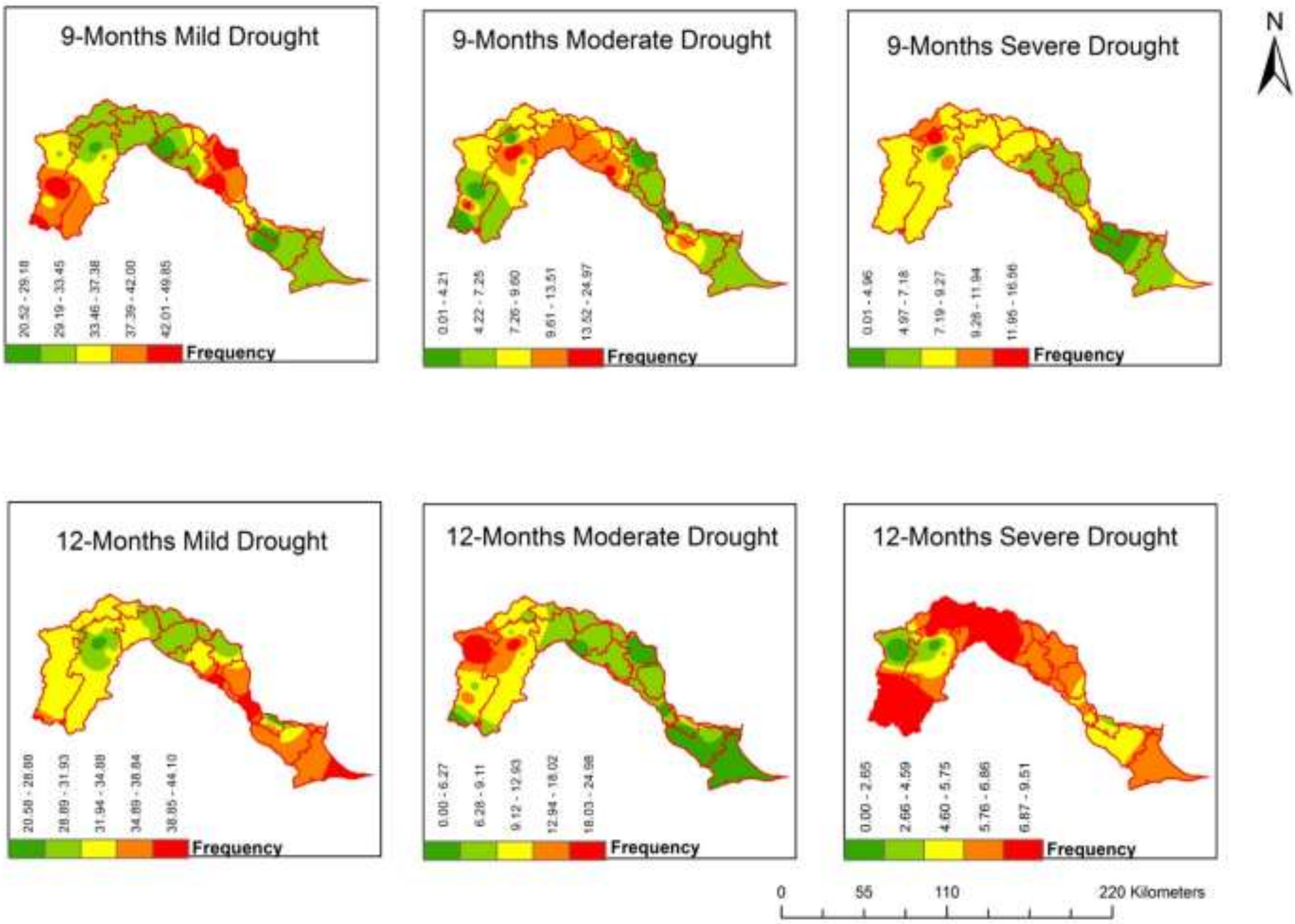


**Figure 3: Long-term (9, 12 months) SPI analysis, for mild, moderate and severe droughts**

**Table 3**
**Results for Long term drought analysis**

| Types of droughts | Range of SPI values | 9-month SPI Frequency percentage | 12-month SPI Frequency percentage | Critical Taluks in 9 months SPI | Critical Taluks in 12 months SPI |
|---|---|---|---|---|---|
| Mild drought | 0.00 to -0.99 | 42.01-49.85 | 38.85 -44.10 | Melur, Sivagangai, Thiruppuvanam, Uthamapalayam. | Mana Madurai, Mandapam, Thekkadi, Thiruppuvanam |
| Moderate drought | -1.0 to -1.49 | 13.52 – 24.97 | 18.03 -24.98 | Cumbam, Vaigai dam | Vaigai dam |
| Severe drought | -1.5 to -1.99 | 11.95-16.56 | 6.87-9.51 | Periyakulam | Dindigal, Cumbam,Gudalur, Manjalar, Pamban, Periyakulam, Sholavandhan, Thekkadi, Thondi, Usilampatti, Uthamapalayam |

It is found that almost all parts of the basin are frequently affected by mild droughts during both short and long timescales. Regarding the 3 and 6 month SPI, the middle and the tail part of the basin are most affected. Although there are few regions of concern in the head part, the classification of SPI is due to a decline in precipitation. The frequency analysis of 9-month SPI indicates a frequent effect on the head and the middle part of the basin whereas the values of 12-month SPI indicate an overall impact on all three parts of the basin. This frequency analysis of the SPI drought index reveals that droughts in the Vaigai basin vary spatially and temporally from mild to severe throughout the basin. The frequency of occurrence of mild drought along the basin is common at any time scale whereas the frequency of severe drought increases with an increase in time scale.

The results of drought analysis substantiate that the river basin is at a risk due to drought hazard; the inclusion of the effect of climate change could worsen the threat. These impacts cannot be avoided but can be assessed with different indices and managed with appropriate adaptation strategies to reduce the risk.

Short term drought analysis depicts the loss of soil moisture and agricultural drought, which has to be treated with short term measures like planned irrigation system and crop rotation in the most critical regions. Long term drought analysis illustrates the impacts on surface water resources like changes in streamflow, dried-up lakes and tanks etc.

The adaptation and mitigation measures can be planned only with a comprehensive knowledge on drought, climate change and policy interventions and should be categorized as long term measures and short term measures. This study on drought indices is useful in monitoring drought in the basin and further studies are recommended to provide timely warnings to the farmers regarding the drought and erratic rainfall and soil moisture level. Current policy strategies should be reframed to address the adaptation and mitigation of climate change that includes economic instruments and legal frameworks.

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