सत्यमेव जयते

GOVERNMENT OF PUDUCHERRY

DEPARTMENT OF SCIENCE, TECHNOLOGY AND ENVIRONMENT

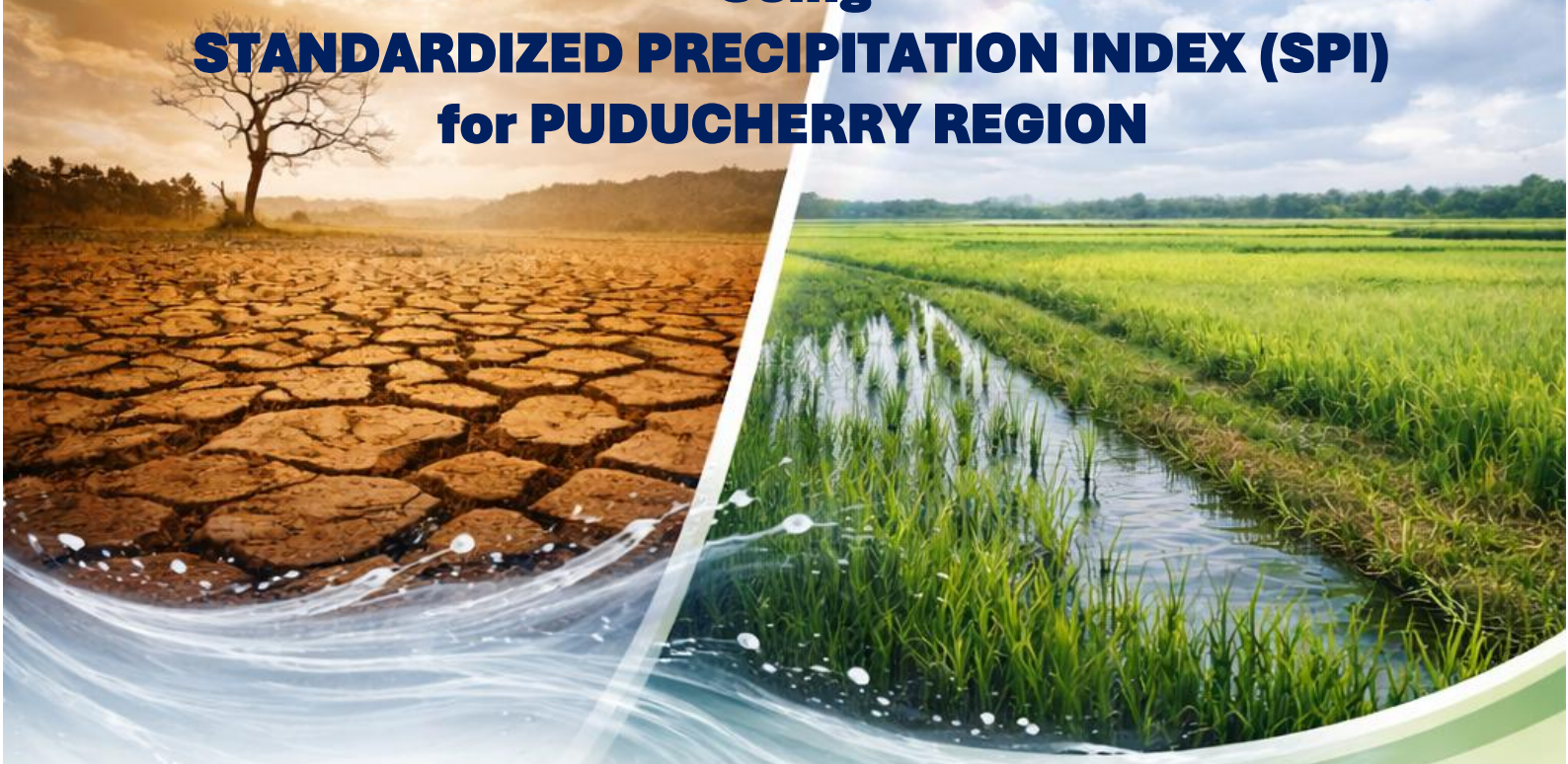
PUDUCHERRY CLIMATE CHANGE CELL

LONG – TERM RAINFALL VARIABILITY AND DROUGHT ASSESSMENT

Using

STANDARDIZED PRECIPITATION INDEX (SPI)

for PUDUCHERRY REGION



PCCC

March 2026

Abstract

This study presents a comprehensive assessment of long-term rainfall variability and drought characteristics in Puducherry using the Standardized Precipitation Index (SPI). Monthly rainfall data for the period 1996–2024 was analyzed at multiple timescales (SPI-3, SPI-6 and SPI-12) to understand short-term, seasonal and long-term variability. The analysis reveals significant fluctuations in rainfall patterns, with an increasing frequency of moderate to severe droughts in recent decades. The findings highlight growing climate variability and emphasize the need for adaptive water resource management and climate-resilient planning.

1. Introduction

Rainfall is the primary source of freshwater in Puducherry, influencing agriculture, groundwater recharge and urban water supply. Due to its coastal location, Puducherry is highly dependent on the **Northeast Monsoon (October–December)**, which contributes a major share of annual rainfall.

However, recent years have shown increasing irregularity in rainfall patterns, including delayed monsoons, prolonged dry spells and extreme rainfall events. Such variability affects:

- Agricultural productivity
- Water availability
- Climate resilience

To systematically assess these variations, the **Standardized Precipitation Index (SPI)** is widely used. SPI helps in identifying drought intensity, duration and frequency in a standardized manner, making it suitable for long-term climate analysis.

2. Study Area

Puducherry is a coastal Union Territory located along the South eastern coast of India. The region experiences a **tropical climate** with high humidity and seasonal rainfall.

Key characteristics:

- Dominant rainfall: **Northeast Monsoon**
- Moderate contribution: Southwest Monsoon

- High interannual variability
- Vulnerability to:
    - Droughts
    - Floods
    - Cyclonic rainfall events

This climatic sensitivity makes Puducherry an ideal case for SPI-based drought assessment.

3. Data and Methodology

3.1 Data Collection and Preparation

The present study utilizes monthly rainfall data for the Puducherry region covering the period from 1996 to 2024. The data was compiled into a continuous time series to ensure consistency in analysis. Prior to analysis, the dataset was subjected to quality checks to identify missing values, inconsistencies or anomalies.

Where necessary, minor gaps in the data were addressed to maintain continuity. The rainfall data, originally available in daily format was aggregated into monthly totals, as SPI analysis is typically performed using monthly precipitation data. The prepared dataset thus represents a reliable and consistent basis for long-term climate analysis.

3.2 SPI Computation Method

The SPI was computed using a **statistical normalization approach**, involving the following steps:

Step 1: Rainfall Aggregation

Rainfall was aggregated over different time periods:

- **SPI-3** → 3-month rainfall (short-term)
- **SPI-6** → 6-month rainfall (seasonal)
- **SPI-12** → 12-month rainfall (long-term)

$$R_t^{(k)} = \sum_{i=0}^{k-1} P_{t-i}$$

Step 2: Fitting Gamma Distribution

Rainfall data was fitted to a **Gamma probability distribution**, which is suitable because:

- Rainfall values are non-negative
- Data is positively skewed

Step 3: Probability Calculation

The cumulative probability of rainfall occurrence was calculated and adjusted for zero rainfall values.

Step 4: Transformation to SPI

The probability values were converted into a **standard normal distribution (Z-score)**:

$$SPI = \Phi^{-1}(H(x))$$

Where:

- Mean = 0
- Standard deviation = 1

3.3 SPI Classification

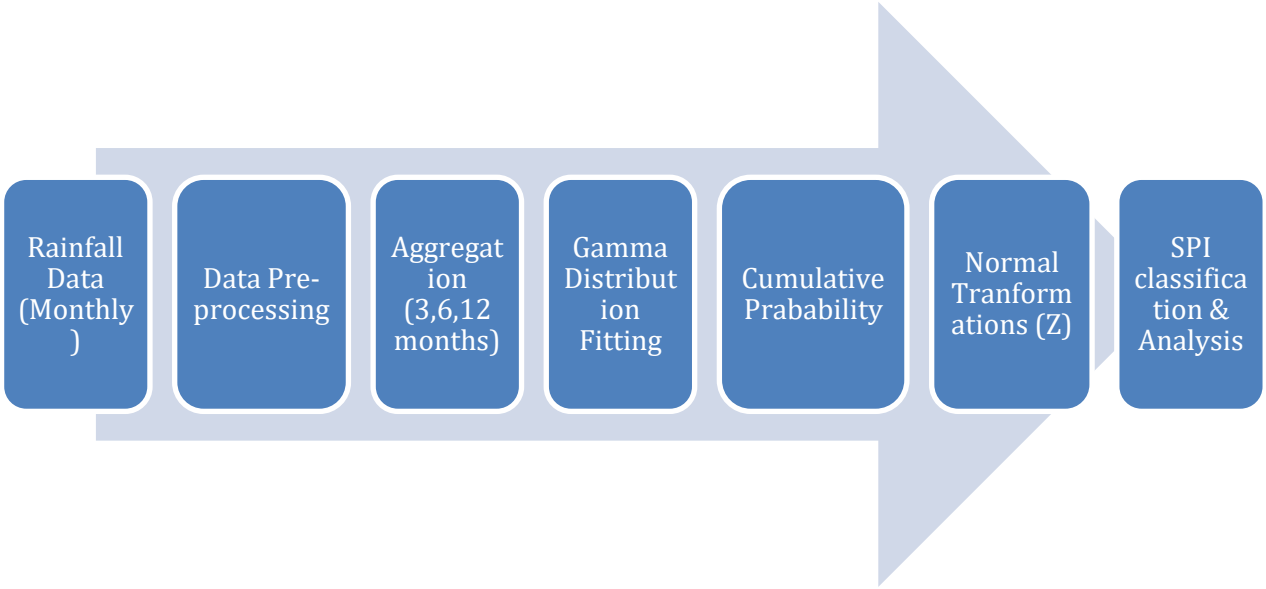
SPI Value	Category
≥ 2.0	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
≤ -2.0	Extremely Dry

3.4 Analytical Approach

The SPI values computed at different timescales were analyzed using a time series approach to understand temporal variations in rainfall patterns. The analysis focused on identifying periods of drought and wetness, as well as examining trends in rainfall variability over the study period.

Particular attention was given to detecting recurring drought events and assessing whether the frequency and intensity of such events have changed over time. The use of multiple timescales allowed for a comprehensive understanding of rainfall variability ranging from short-term meteorological fluctuations to long-term hydrological trends.

Figure 1: Methodological framework for SPI computation

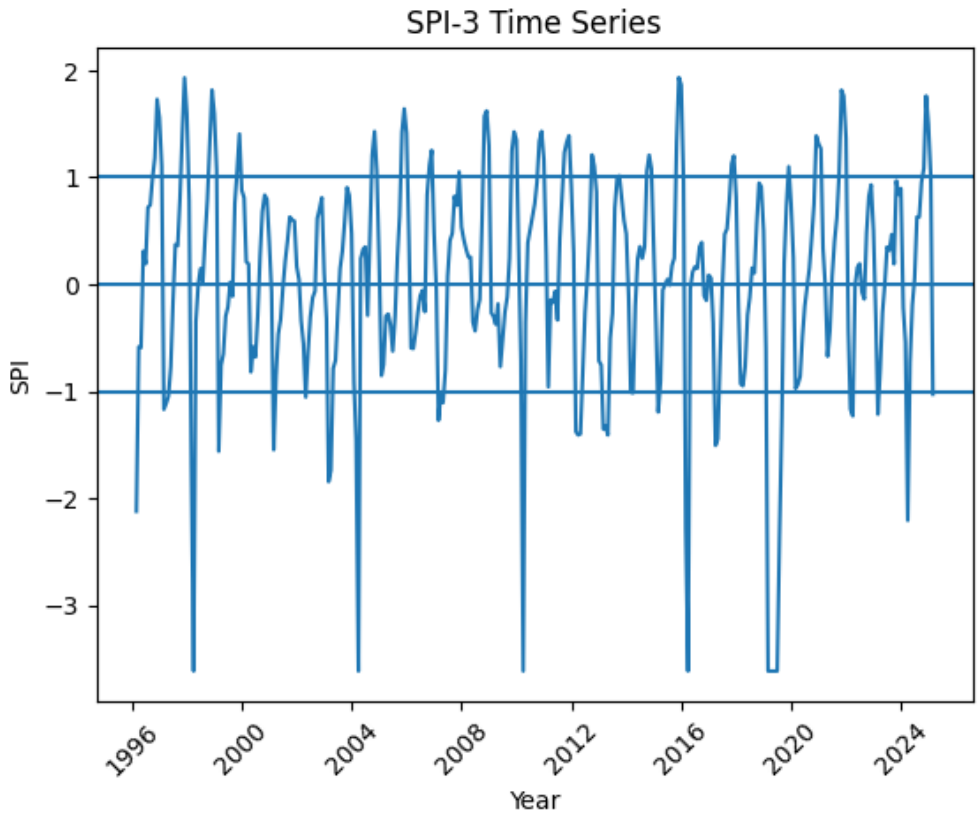


4. Results and Discussion

The Standardized Precipitation Index (SPI) analysis was carried out at three different timescales, namely SPI-3, SPI-6 and SPI-12, to assess short-term, seasonal and long-term rainfall variability in the Puducherry region. The results reveal significant temporal variability in rainfall patterns, indicating the occurrence of both drought and wet conditions over the study period.

4.1 SPI-3 (Short-Term Variability)

The SPI-3 analysis reflects short-term fluctuations in rainfall and is useful for identifying meteorological drought conditions. The results indicate frequent oscillations between wet and dry conditions throughout the study period. Several instances of negative SPI values below -1 and -2 were observed, indicating moderate to extreme drought conditions. These short-term droughts appear to occur intermittently and are often followed by rapid transitions to wet conditions.

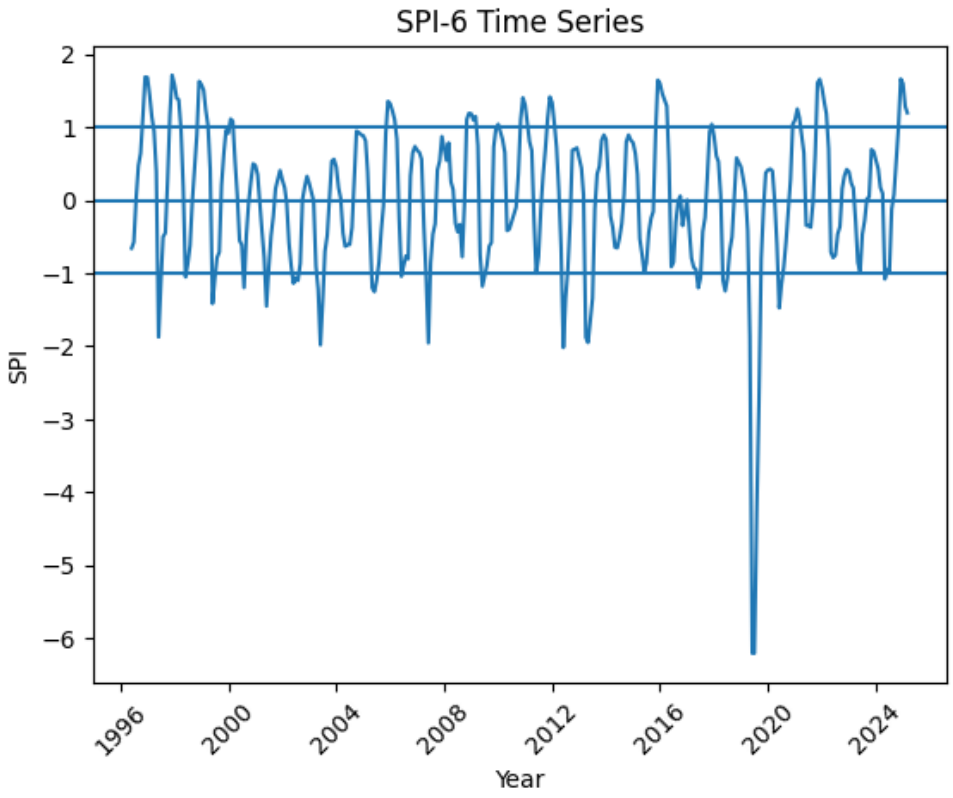


This pattern suggests that rainfall in Puducherry has become increasingly erratic at shorter timescales, with sudden deficits and surpluses occurring within short durations. Such variability has direct implications for soil moisture availability and can adversely affect agricultural activities, particularly during critical crop growth stages.

4.2 SPI-6 (Seasonal Variability)

The SPI-6 analysis represents seasonal rainfall variability and provides insights into monsoon performance. The results show distinct periods of sustained drought, particularly during the years 2016 to 2020, where SPI values remained consistently negative. In addition, a few instances of extreme negative SPI values were observed, indicating severe seasonal drought conditions.

The analysis also reveals that seasonal rainfall variability has increased in the recent decade, with noticeable fluctuations between wet and dry conditions. This suggests that the monsoon system, especially the Northeast Monsoon, has become less reliable in terms of both onset and intensity.

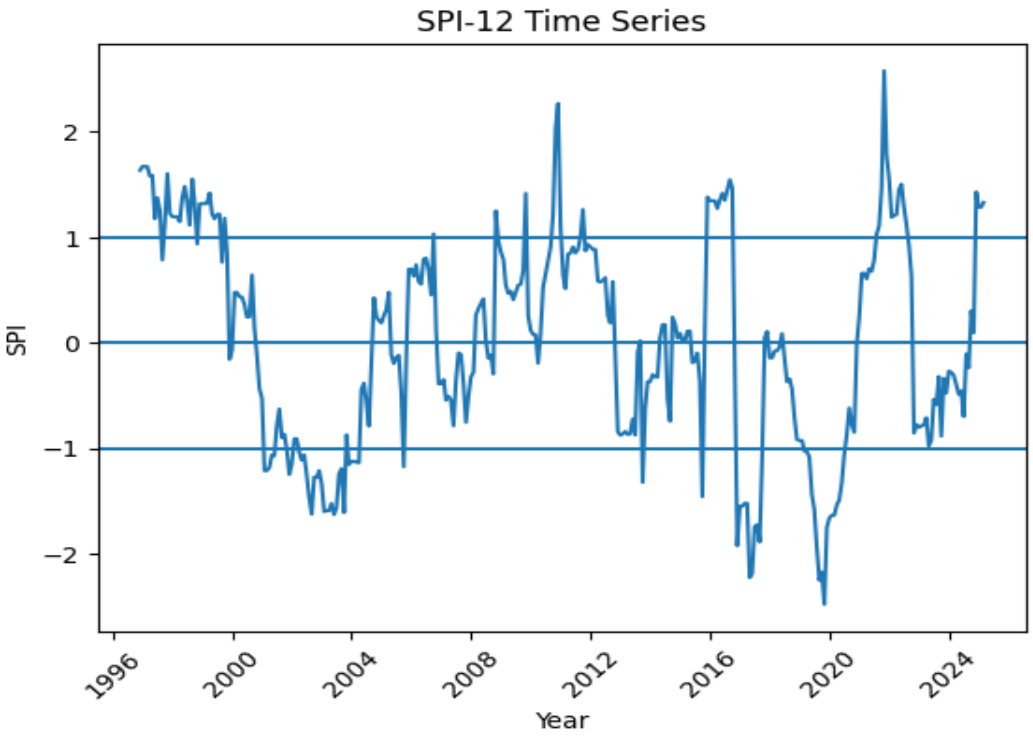


Such seasonal variability can significantly impact water storage systems, including reservoirs and groundwater recharge and may lead to reduced agricultural productivity due to inconsistent water availability.

4.3 SPI-12 (Long-Term Variability)

The SPI-12 analysis captures long-term hydrological trends and provides an understanding of prolonged wet and dry periods. The results indicate the presence of multi-year drought cycles interspersed with periods of above-normal rainfall. Notably, recent years exhibit higher variability, with both extreme dry and wet conditions occurring more frequently compared to earlier periods.

The increasing occurrence of prolonged negative SPI values suggests a rising trend in long-term water stress conditions. This has important implications for groundwater levels, surface water availability and overall water resource sustainability in the region.



4.4 Drought Characteristics

The SPI analysis indicates that Puducherry has experienced multiple drought events of varying intensity during the study period. Moderate droughts (SPI between -1 and -1.5) were observed more frequently, while severe (SPI between -1.5 and -2) and extreme droughts (SPI less than -2) occurred less frequently but had significant impacts. The recurrence of drought events in recent years suggests an increasing trend in drought frequency and intensity. This pattern highlights the growing vulnerability of the region to climatic stress.

4.5 Climate Variability Trend

The overall analysis of SPI across different timescales indicates a clear increase in rainfall variability over time. The post-2010 period, in particular, shows a higher frequency of extreme events, both in terms of droughts and excessive rainfall.

This increasing variability may be attributed to broader climate change influences, including shifts in monsoon patterns and increased occurrence of extreme weather events. The findings suggest that Puducherry is experiencing a transition towards a more variable and unpredictable climate regime.

5. Key Findings

The SPI-based assessment reveals that rainfall variability in Puducherry has increased significantly over the study period. The frequency of moderate and severe drought events has risen, particularly in the recent decade. Seasonal rainfall patterns have become less consistent, affecting monsoon reliability. Additionally, both extreme wet and dry conditions are occurring more frequently, indicating increased climate instability. These trends suggest that the region is becoming more vulnerable to water stress and climate-related risks.

6. Conclusion

The present study demonstrates that the Puducherry region is experiencing significant changes in rainfall patterns, characterized by increased variability and recurrent drought conditions. The SPI analysis across multiple timescales confirms that both short-term and long-term water stress conditions are becoming more prominent.

The increasing frequency of extreme events highlights the need for improved climate adaptation strategies and efficient water resource management. Without appropriate interventions, the region may face increased challenges related to water scarcity, agricultural productivity and climate resilience.

7. References

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