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RESEARCH ARTICLE

Climate change linked spatio-temporal drought prediction over Tamil Nadu (India)

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Abstract

Climate change projections suggest an increased risk of extreme events, potentially accelerating the occurrence of droughts in the future. Drought is a recurring climatic phenomenon that significantly affects the social and economic development of agricultural countries. It can occur in many parts of the world, though its characteristics differ from one region to another. The study aims to analyze future drought events in Tamil Nadu to gain insights into their frequency and spatial extent. Dynamical downscaling of the global circulation model (CCSM4) was done by employing the regional climate model (RCM) RegCM4.4. The downscaled future rainfall data was used to calculate standardized precipitation index and drought characterization in the future period such as the near century (2010-2039), mid-century (2040–2069) and end of the century (2071-2099) under RCP 4.5 and RCP 8.5 scenario of CMIP5 project. The results of calculated SPI values showed that the drought frequency was higher in the Southwest Monsoon (20%) compared to the Northeast Monsoon in the future. Based on SPI, drought occurrence is expected to increase in the 4.5 scenario (50%) as compared to the 8.5 scenario, drought occurrence is projected to decrease due to an increase in rainfall projected in mid-century. This article paves the way for more accurate drought management strategies, contributing to improved resilience and sustainable development in drought-prone regions.

Keywords

climate change; drought; future; frequency; prediction

Introduction

Drought is one of the most dangerous natural disasters, occurring in almost all geographical areas and it is a complex phenomenon that is one of the least understood natural hazards because of the diverse causal factors or contributing elements that operate at various temporal and spatial scales (1). Drought had extensive impacts on regional and global scales in recent decades necessitating increased drought resilience (2). Increased CO_2 emissions from anthropogenic activities in recent decades triggered changes in the global climate (3). Significant variability in monsoon rainfall, temperature and climate would adversely affect agricultural production, water availability and socio-economic conditions. In addition, the growing population and declining availability of water are an additional challenge to future food and water security in India.

Weak Indian summer monsoon rainfall (ISMR) was reported for the changing climatic scenario (4). In recent decades, India has experienced frequent and severe drought (once every three years) (5). However, the severity and frequency of drought remain largely unexplored in India. Drought frequency of severe drought is projected to increase in India's warmer and wetter future climate. Drought is a perennial and recurring feature in many parts of India and has been a major natural cause of Indian famines in the past. Droughts in India are mainly due to failures of seasonal rainfall. The fluctuations in ISMR have a strong impact on the variability of aggregate *kharif* food grain production in India (6). Years with deficient monsoon rainfall are associated with low food grain production (7) but a need to increase the crop yield to meet the projected demand exists. Drought prediction is important for drought early warning and mitigating its effects. Drought prediction is a concept that relates to predicting the severity of a drought (8). Meteorologists and agriculturists have devised drought indices based on the climatology of particular locations.

Drought indices are calculated as a single numerical value to characterize drought viz., severity and extent of drought and the values of drought indices are used for evaluating the drought hazards and making decisions on declarations of drought-affected areas (9). A drought index calculated from known values of selected parameters enables the description of drought to be expressed quantitatively (10). Rainfall deviation from the long-term mean continues to be a widely adopted indicator for drought intensity assessment because of its simplicity. However, the application of this indicator is strongly limited by its inherent nature of dependence on the mean. The standardized precipitation index (SPI) expresses the actual rainfall as a standardized departure from the rainfall probability distribution function. As a result, this index has become important in recent years as a potential drought indicator permitting space and time comparisons (11) and assigned as a suitable tool for analysing drought for different hydrological purposes over different temporal and spatial variations (12).

The study could utilize climate models to project future drought patterns under various greenhouse gas emission scenarios, providing insights into the potential impacts of different climate change mitigation and adaptation strategies, tailored to the specific needs and vulnerabilities of Tamil Nadu.

Materials and Methods

Description of the study area

Tamil Nadu is situated in the southernmost part of the Indian Peninsula, spanning between 8°5' and 13°35' North latitude and 76°15' and 80°20' East longitude (Fig. 1).

Climate projections

Dynamical downscaling of the Global Circulation Model (CCSM4) was done by employing the Regional Climate Model (RCM) RegCM4.4. RegCM4.4 is a well-established and widely used RCM with a good balance of accuracy and computational efficiency. The downscaled future daily rainfall data was analyzed using various time series, including the near century (2010-2039), mid-century (2040-2069) and end of the century (2070-2099). The analysis was conducted under RCP 4.5 and RCP 8.5 scenarios. The climate model simulations utilized the representative concentration pathway (RCP) scenarios, specifically RCP 4.5 (medium stabilization) and RCP 8.5 (high emission) (13). These scenarios are designed to represent different levels of anthropogenic forcing on the climate system.

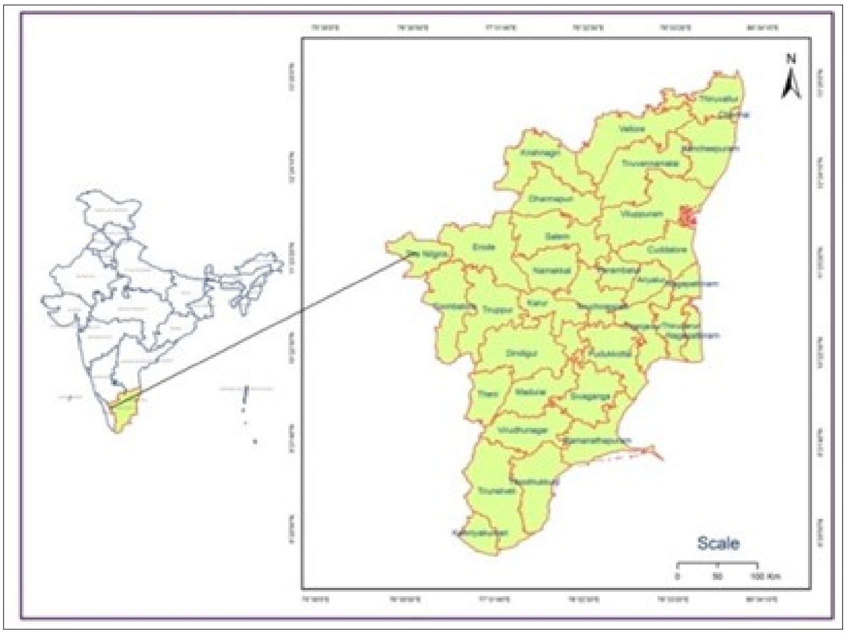

Fig. 1. Location of study area.

National Command Language (NCL)

After the simulation completion of the WRF model, National Command Language (NCL) version 6.3.1 was used to extract the rainfall data required for this study. A separate shell script was written for arranging the data into columns and to respective number of days in text format for further analysis.

Standardized precipitation index (SPI)

SPI was developed in Colorado to quantify the scarcity of precipitation over multiple time scales highlighting the impact of drought on the availability of the various water resources (14). The calculation of the SPI is based on the long-term record of precipitation. Data for SPI use are recommended for at least 30 consecutive years. Using the SPI, the study showed the relationship between drought frequency, drought duration and drought time scale.

$$SPI = \frac{X - \bar{X}}{\sigma} \qquad \text{Eqn. 1}$$

where,

X = mean precipitation for the i^{th} station

$\bar{X}$= precipitation for the i^{th} station and k^{th} observation

σ = standardized deviation for the i^{th} station

SPI on a seasonal and annual basis was calculated at the district level for future. In the interpretation of SPI, the positive values indicate greater values than the median precipitation while negative values indicate lesser values than the median precipitation. The classification of SPI values as shown in Table 1 describes drought intensities.

Table 1. Classification of SPI values

SPI range	Drought intensity class
>2	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
0.5 to 0.99	Mild wet
0.5 to -0.5	Near normal
-0.5 to 0.99	Mild drought
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severe dry
-2 and less	Extremely dry

Results

Projected changes in drought frequency

Drought frequency varies significantly across Tamil Nadu due to a complex interplay of geographic and climatic factors (15). Rainfall patterns, particularly the erratic Northeast Monsoon, are a primary driver, with regions dependent on it experiencing more frequent droughts (16). The Western Ghats' rain shadow effect exacerbates drought in leeward districts (17). Topography, soil type and land use also play crucial roles in influencing water availability and retention (18).

SPI-based annual drought frequency projection revealed that the drought frequency is expected to have slight changes toward the increasing side (up to 3 years) in the near century for the RCP 4.5 scenario (Fig. 2). In contrast, the decline in drought frequency is projected up to 6 counts in the mid-century. The increase in drought frequency of 6 to 7 counts is projected for most regions by the end of the century. It is seen from the results that a few changes would happen in the drought occurrence in all the time scales under the RCP 8.5 scenario. In the future, the drought occurrence is projected to decrease in most places in Tamil Nadu. This might be due to the projected increase in the monsoon rainfall due to enhanced hydrological activity as a result of the expected increase in temperature. These results are in line with the findings of (19, 20). Seasonal SPI indicates that the changes in drought frequency patterns during SWM and NEM are expected to be almost similar to the changes in annual drought frequency in the future climatic conditions of the RCP 4.5 scenario (Fig. 3 & 4). The projected change in SWM and NEM drought frequency follows the same pattern of annual drought frequency in all the time scales except near century during SWM and mid-century of NEM with the RCP 8.5 scenario.

The percentage of drought frequency for moderate (RCP 4.5) and high (RCP 8.5) emission scenarios for the Southwest Monsoon (SWM) and Northeast Monsoon (NEM) at the near, mid and end of the century is presented in Table 2. It was found that the drought frequency is projected to be higher in the SWM (20%) compared to the NEM in the future.

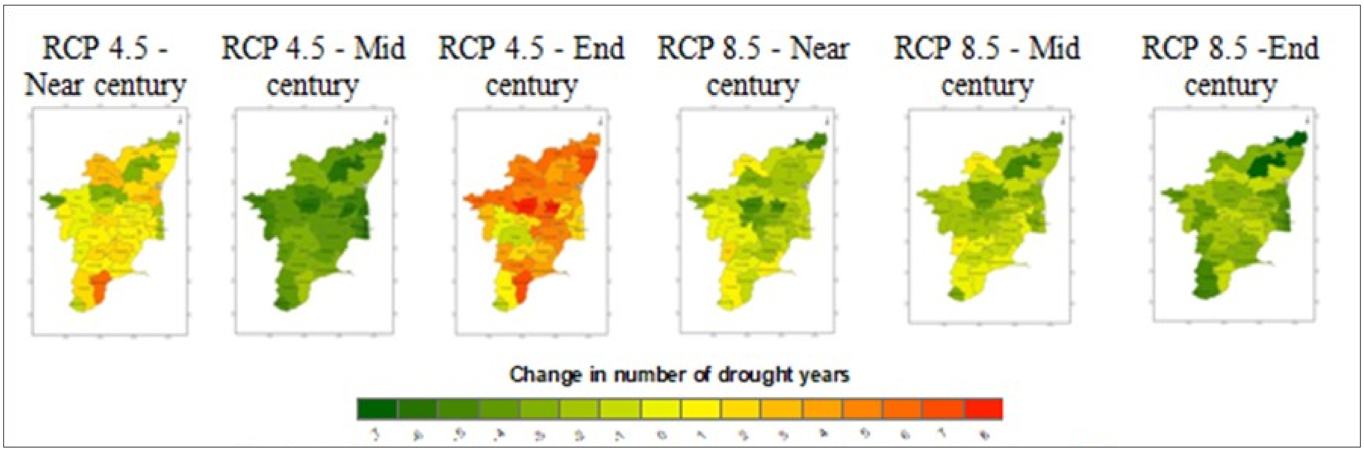

Fig. 2. Projected changes in annual drought frequency in future based on SPI.

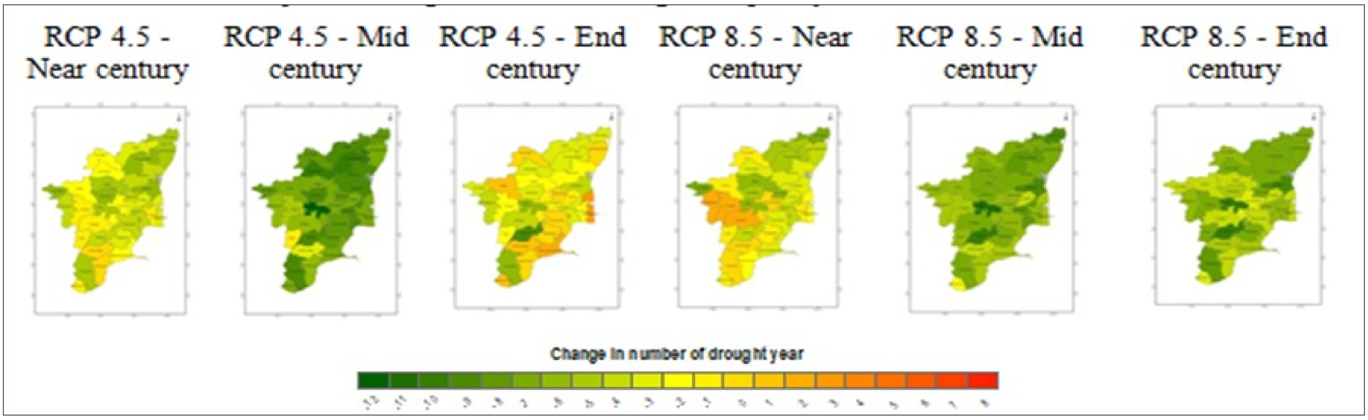

Fig. 3. Projected changes in SWM drought frequency in future based on SPI.

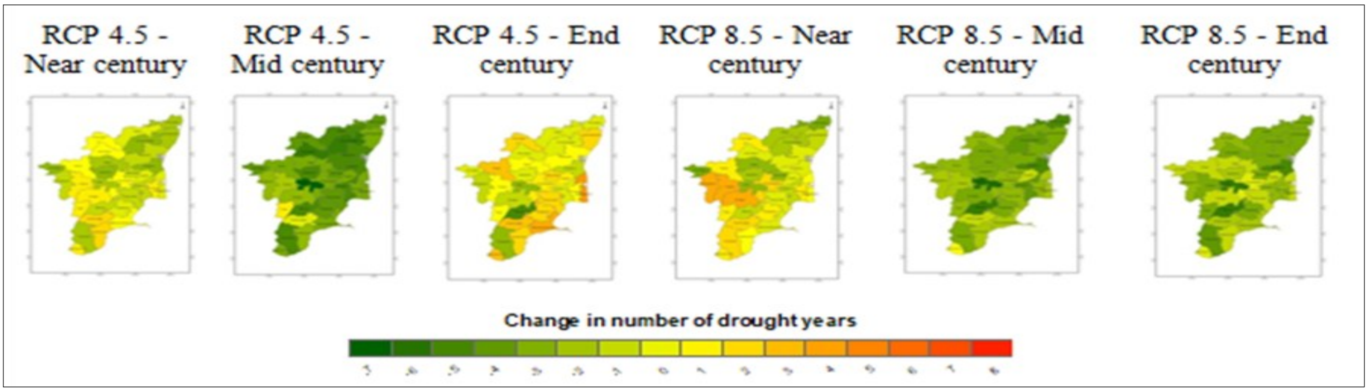

Fig. 4. Projected changes in NEM drought frequency in future based on SPI.

Table 2. Percentage of the number of drought years in future

No of drought years (%)	RCP 4.5						RCP 8.5					
	Near		Mid		End		Near		Mid		End	
	SWM	NEM	SWM	NEM	SWM	NEM	SWM	NEM	SWM	NEM	SWM	NEM
No drought		**45**	**35**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**6**	**26**
1	0	32	32	0	0	0	0	6	29	0	13	26
2	0	13	23	19	0	0	0	32	35	0	23	45
3	0	10	6	10	6	0	13	32	26	6	29	3
4	29	0	0	35	6	3	3	16	6	16	19	0
5	23	0	0	23	10	10	26	13	3	23	6	0
6	29	0	3	6	16	6	23	0	0	23	3	0
7	13	0	0	3	29	16	13	0	0	16	0	0
8	6	0	0	3	13	13	10	0	0	6	0	0
9	0	0	0	0	13	19	6	0	0	3	0	0
10	0	0	0	0	3	19	6	0	0	3	0	0
11	0	0	0	0	3	10	0	0	0	3	0	0
12	0	0	0	0	0	3	0	0	0	0	0	0

SPI index-based drought occurrence reveals that there would be more drought in the RCP 4.5 scenario (50%) compared to the RCP 8.5 scenario. These results align with previous research showing increased drought frequency under the RCP 4.5 scenario, suggesting more water scarcity compared to RCP 8.5 (19, 21). Related studies observed higher drought frequency under the moderate emission scenario RCP 4.5 compared to the high emission scenario RCP 8.5 (22). This can be attributed to complex regional rainfall shifts, where RCP 4.5 may lead to more pronounced drying in crucial agricultural areas (23). Although evapotranspiration is higher under RCP 8.5, increased precipitation in some regions might offset this effect (24). Changes in atmospheric circulation patterns could favor drought-prone conditions in specific locations under RCP 4.5. Additionally, drier initial soil moisture conditions under RCP 4.5 could contribute to more frequent droughts (25). During the mid-century (2041-2070), change in severe drought frequency based on SPI is projected to decrease over the majority of the regions in Tamil Nadu under the RCP 4.5 and RCP 8.5 due to high rainfall projected in mid-century (26).

Conclusion

Drought prediction in Tamil Nadu has become important as climate change brings unpredictable weather conditions. In future, the frequency of drought will be higher in the Southwest monsoon compared to the Northeast monsoon. Based on SPI, drought occurrence is expected to increase in the 4.5 scenario as compared to the 8.5 scenario and both under RCP 4.5 and RCP 8.5, drought occurrence is projected to decrease due to an increase in rainfall projected in mid-century. This suggests that the future climate conditions, as predicted by these scenarios, may reduce drought events in Tamil Nadu. A decrease in drought occurrence projected in the future may be due to the rainfall patterns predicted by climatic models.

This research provides essential insights that strengthen early warning systems, facilitate proactive mitigation strategies and sustainable water management, prompting adaptation strategies like emission reduction, increased water storage and drought-resistant practices. These insights equip policymakers to make informed decisions, implement effective drought mitigation measures and build a more resilient towards the drought risks.

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Authors' contributions

VG and MV conceptualized the study. MV and KB carried out the methodology. SE and SA were responsible for the software. VG and MV carried out the investigation. VG and CD handled data curation. MV and TB prepared the original draft. MV, KB, AS and TB were involved in the writing-review and editing. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors declare that there is no conflict of interest.

Ethical issues: None

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