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# Future Projections of Rainfall for Tamil Nadu from Coupled Model Intercomparison Project- 6 (CMIP6)

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Precipitation is a crucial input for agriculture and living things in the world, which changes drastically under a warmer climate due to climate change. Hence, the study was carried out to project the changes in annual and seasonal precipitation based on the France Centre National de Recherches Météorologiques (CNRM-CM6) model. In the present study, Coupled Model Intercomparison Project phase six (CMIP6) datasets were used for two SSP scenarios: SSP2-4.5 and SSP5-8.5 and three-time slices for the future *viz*., near (2021–2050), mid (2051–2080) and end-century (2081–2099) and base period (1991–2020) dataset obtained from the India Meteorological Department (IMD) was used to compare with the future climate over Tamil Nadu. The result revealed that the highest positive mean deviations in annual (81%), SWM (21%), NEM (79%) and summer (163%) were observed in the projected precipitation under the SSP5-8.5 scenario during the Near, mid, near and mid-century respectively. For winter, SSP2-4.5 showed the highest mean deviation of 122% in the near century. According to the three future time scale simulations for the twenty-first

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century, annual rainfall is predicted to increase by 81% in the near future and 19% in the mid-century, while it is expected to decline by 1.5% at the end of the century under SSP5-8.5. In the SSP2-4.5 scenario, rainfall would increase by 1% in the near future, decrease by 30% in the end century and decrease by 30.5% in the mid-century. From the result, it is concluded that there would be an increase in heavy precipitation occurrences at the near, mid and end of the 21st century under both the SSP5-8.5 and SSP2-4.5 scenarios. These findings might be helpful in framing future agricultural water management regulations to deal with threats from heavy precipitation and researchers to study precipitation changes at the global level.

*Keywords: CMIP6; precipitation; future changes; ssp scenarios.*

## 1. INTRODUCTION

The most challenging and significant concerns of the 21st century are related to the changing climate and its socioeconomic effects. Scientists are constantly working to increase their understanding of these issues [1]. Climate change is projected to impact the amount and spatiotemporal patterns of hydroclimatic variables such as precipitation, etc. Such changes may have profound effects on ecology, human communities, and current and projected water resources. GCMs are commonly used in climate change and variability research to simulate historical and predicted precipitation and other climate variables. [2,3].

Multiple studies have been conducted to investigate climate change-induced irregular precipitation and rising temperatures in various parts of the world [4]. It is widely assumed that the frequency, severity, and hazards of disasters, notably droughts and floods, have risen [5]. All monsoon regions have already experienced a significant rise in more severe, high-impact weather and hydro-climatic events over the past century, and this trend is expected to increase [6]. They are also predicted to increase in the future under various emission scenarios by global climate models (GCMs), which are the major tool used to generate climate forecasts and predict future climate. GCM performance reviews are essential for building confidence in future climate forecasts [7].

The Coupled Model Intercomparison Project (CMIP) organized by the World Climate Research Programme (WCRP), recently distributed under its sixth phase (CMIP6), offers a unique opportunity to conduct comprehensive analyses of climate variability and change at both global and regional scales, based on an ensemble of climate models [8]. Recent version of the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6). Based on the outcomes of Phase 6 of the Climate Model Intercomparison Project, the source code repository includes downscaled historical and future projections for the period 1950–2100. Currently, about 35 global climate models may be used to get eight variables from five CMIP6 experiments (historical, SSP126, SSP245, SSP370, and SSP585). The NEX-GDDP-CMIP6 record will help in assessing trends in projected changes in climate at a variety of spatial and temporal scales [9]. Between these indications, the simulation results of tropical climates were enhanced by models like the France Centre National de Recherches Météorologiques (CNRM-CM6) model. This study examines the projected changes in precipitation across the Tamil Nadu region.

## 2. METHODOLOGY

### 2.1 Study Area

Tamil Nadu state is located in the southern part of India and has a total geographical area of approximately 130,058 sq. km. It lies from 15.125˚ N to 75.625˚ W latitude and 7.875˚S to 80.375˚ E longitude (Fig. 1). It is surrounded by Kerala, Karnataka, Andhra Pradesh and the union territory of Puducherry. The state experiences numerous modulations of tropical climatic conditions in its 38 districts.

### 2.2 Datasets Used

IMD gridded precipitation data at the spatial resolution of 0.25°×0.25° from 1991 to 2020 was used as reference data to compare it with future data [10]. NASA Earth Exchange Global Daily Downscaled projections (NEX-GDDP-CMIP6) renders statistically downscaled historical and future estimates for 1950-2100 based on CMIP6 Phase 6 output. The downscaled products have a 1/4-degree horizontal resolution and were created using a daily variant of the monthly bias correction/spatial disaggregation (BCSD)

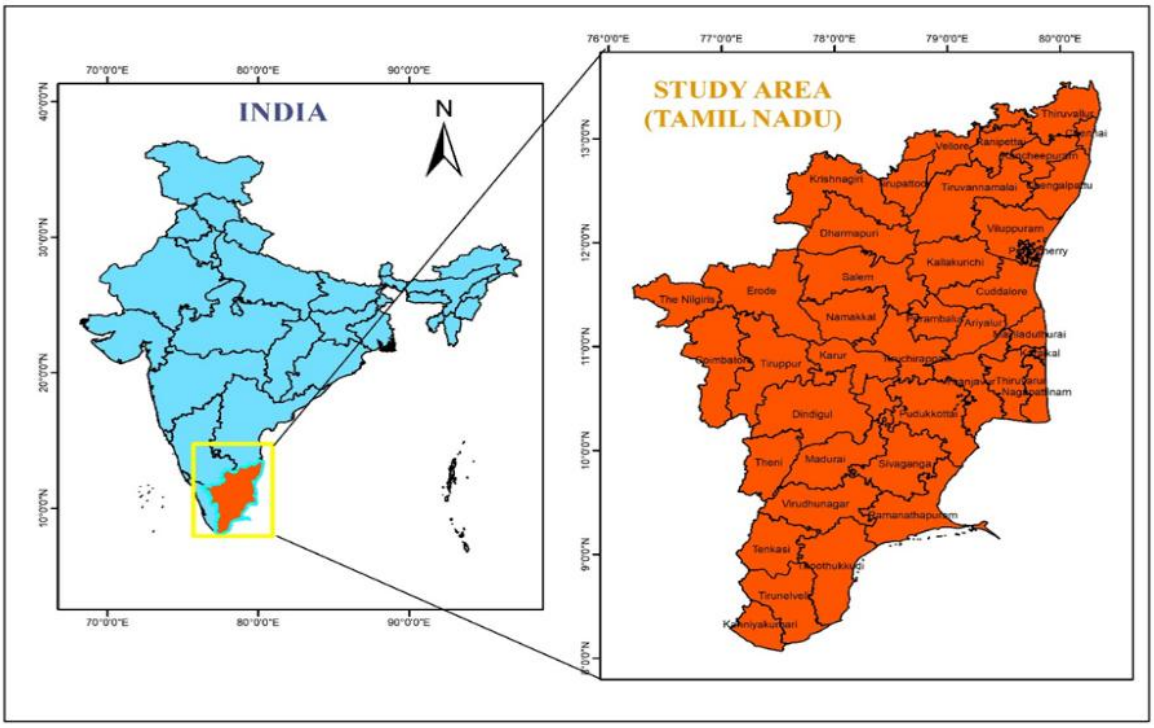


**Fig. 1. Study locations over Tamil Nadu**

approach. It is valuable for monitoring trends in anticipated climate change at various regional and temporal scales, as well as for driving impacts and adaptation models that may require higher spatial and/or temporal resolution than other climate data products [11].

The National Centre for Meteorological Research and the European Centre for Research and Advanced Training in Scientific Calculus (CNRM-CERFACS) has developed the European climate model CNRM-CM6-1-HR [12]. To facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation, the Shared Socioeconomic Pathways (SSP) 4.5 $W/m^2$ and 8.5 $W/m^2$ (SSP2-4.5 and SSP5-8.5) emission scenarios were used for this model [13]. The SSP2 scenario proposes a course in which economic, social, and scientific tendencies do not diverge much from past trends [14].

This study examines projected changes in annual and seasonal mean precipitation for two shared socioeconomic pathways (SSP): SSP2-4.5 and SSP5-8.5, along with distinct time scales, *viz*., near future (2021-2050), mid-century (2051-2080) and end-of-century (2081-2099) comparing with the historical baseline period (1991-2020) of the IMD dataset. The mean deviation (%) is applied for CNRM-CM6 model data to determine how the precipitation percentage of the projected amount grows and decreases from the observed value.

$$Mean\ deviation\ \% = \frac{X-\bar{x}}{\bar{x}} * 100$$

Where,

x = projected mean value,
$\bar{x}$ = baseline mean value.

## 3. RESULTS AND DISCUSSION

### 3.1 Projected Precipitation

The mean values of the predicted precipitation are shown in Table 1 since the variances were calculated based on the mean deviation % value that was determined from the projections using zonal statistics.

### 3.2 Projected Changes in Annual Precipitation

Annual rainfall distribution during baseline (1991 to 2020), near (2021 to 2050), mid (2051 to 2080), and end century (2080 to 2099) for two scenarios (SSP)– SSP2-4.5 and SSP5-8.5 are depicted in Fig. 2.

**Table 1. Predicted precipitation**

| | | ANNUAL | SWM | NEM | SUMMER | WINTER |
|---|---|---|---|---|---|---|
| BASE | | 978.72 mm | 371.17 mm | 510.62 mm | 69.74 mm | 27.19 mm |
| SSP245 | NEAR | 995.03 mm | 367.27 mm | 459.62 mm | 107.55 mm | 60.59 mm |
| | MID | 676.32 mm | 294.33 mm | 842.69 mm | 131.69 mm | 48.46 mm |
| | END | 1273.60 mm | 396.34 mm | 201.84 mm | 30.34 mm | 4.23 mm |
| SSP585 | NEAR | 1779.73 mm | 367.27 mm | 917.66 mm | 87.44 mm | 18.72 mm |
| | MID | 1167.16 mm | 451.48 mm | 517.80 mm | 183.59 mm | 14.30 mm |
| | END | 970.16 mm | 354.69 mm | 530.42 mm | 82.96 mm | 2.10 mm |

The SSP5-8.5 scenario is shown to have a greater rainfall amount than the other scenarios (SSP2-4.5) and baseline period. Towards the near and mid-century, rainfall is expected to increase by 81% and 19%, respectively from the baseline (978.71mm), while it is anticipated to decline by 0.5% towards the end of the century under SSP5-8.5. In the SSP2-4.5 scenario, rainfall would increase by 1% in the near and 30% in the end future and decrease by 31% in the mid-century.

The mean annual rainfall departure (%) from the baseline data is shown in Fig. 3. Results indicated that SSP5-8.5 showed a deviation of 784 mm, 490 mm, and - 303 mm *i.e., (–) indicates a decline in the predicted precipitation) at the near, mid, and end when compared to SSP2-4.5. Based on the findings of [15], it is predicted that precipitation will increase annually across China by the end of the twenty-first century, with larger increases under the SSP5-8.5 scenario than under the SSP2-4.5 scenario. Similar results were observed by [16], who found a higher mean daily precipitation deviation in scenario SSP5-8.5 (22%) than in scenario SSP2-4.5 (20%) when compared to the base period.

## 3.3 Projected Changes in Seasonal Precipitation

### 3.3.1 Southwest Monsoon (SWM) rainfall

The Southwest monsoon (SWM) rainfall distribution over Tamil Nadu in baseline, near, mid, and end century are presented in Fig. 4. In the SSP2-4.5 scenario, precipitation is likely to decline about 1% in the near and 20% in mid future whereas the quantity may increase about 6% in the end century. In the SSP5-8.5, the rainfall is projected to increase by 21% in the mid-century whereas about 1% in the near and 4% decrease in the end future concerning the base precipitation value (371.17 mm).

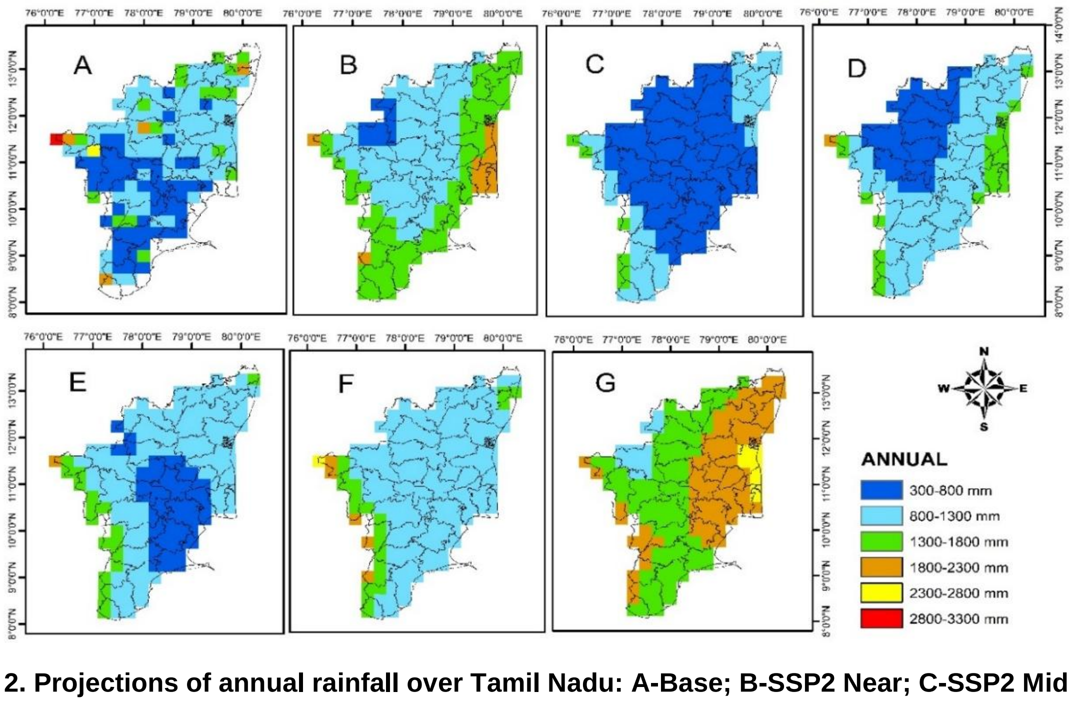


**Fig. 2. Projections of annual rainfall over Tamil Nadu: A-Base; B-SSP2 Near; C-SSP2 Mid; D-SSP2 End; E-SSP5 Near; F-SSP5 Mid; G-SSP5 End**

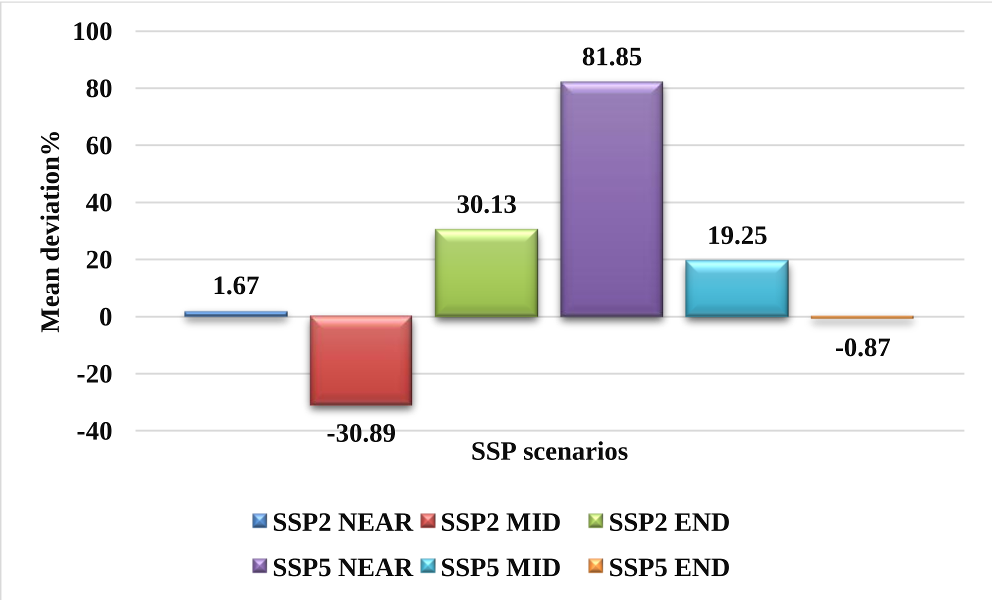


**Fig. 3. Percentage of mean deviation in annual precipitation in Tamil Nadu**

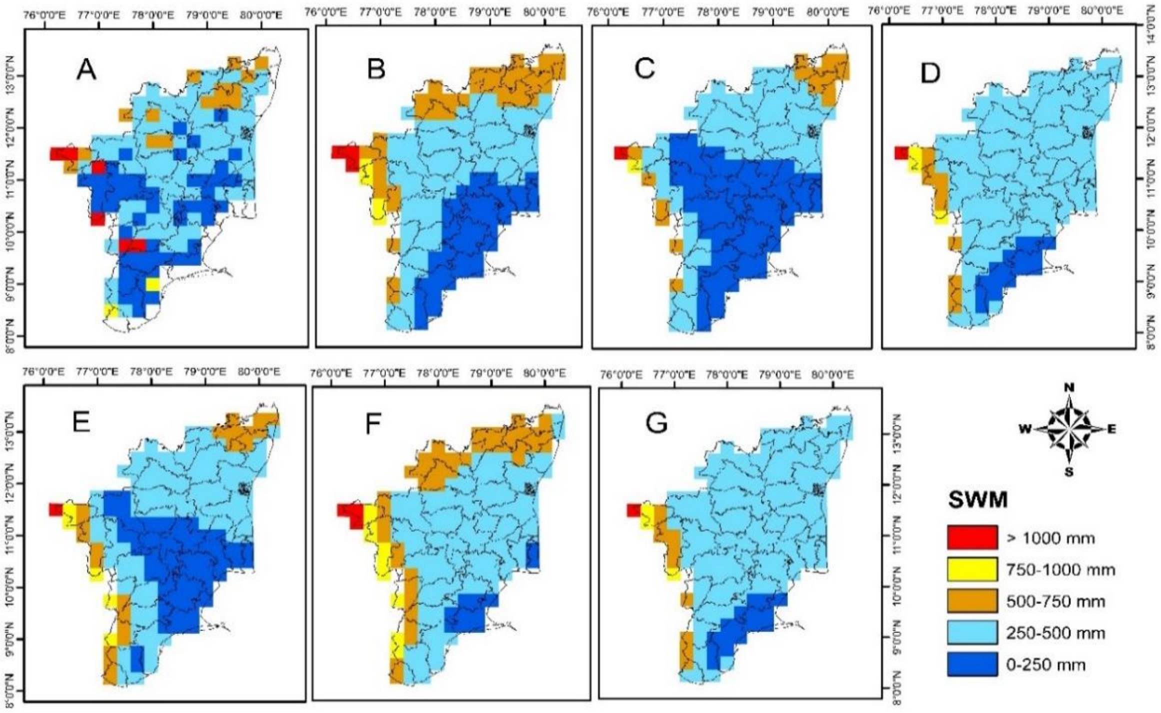


**Fig. 4. Projections of SWM rainfall over Tamil Nadu: A-Base; B-SSP2 Near; C-SSP2 Mid; D-SSP2 End; E-SSP5 Near; F-SSP5 Mid; G-SSP5 End**

Fig. 5 shows that rainfall is expected to increase after the near future under SSP5-8.5 and steadily decrease after the near future under SSP2-4.5. The SSP5-8.5 scenario showed around 157 mm departure in the mid, -42 mm* departure in the end century and no deviations in the near century, respectively, when compared to the SSP2-4.5 scenario. A similar result was also obtained by [17] who stated that the SWMR has increased significantly over the 21$^{st}$ century under the SSP5-8.5 scenario compared to the SSP2-4.5 scenario.

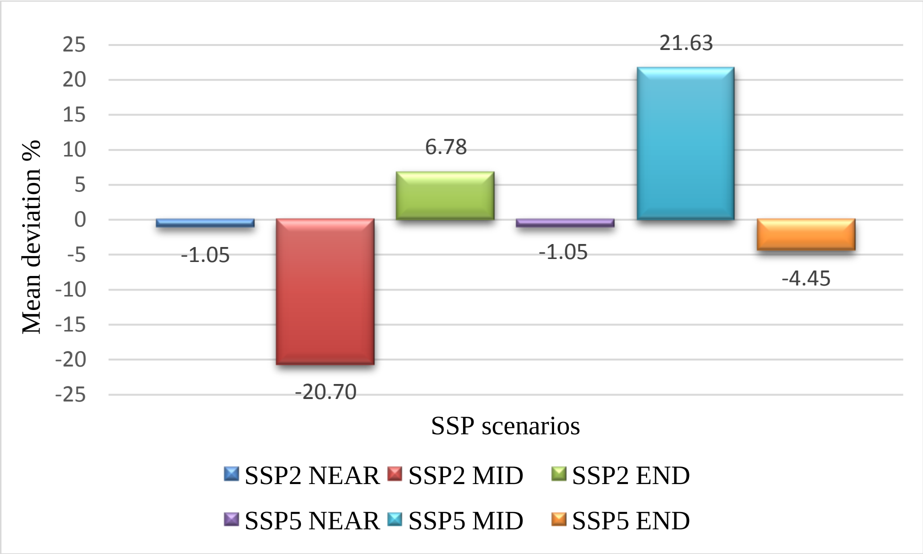


**Fig. 5. SWM precipitation percentage of Mean deviation in Tamil Nadu region**

### 3.4 Northeast Monsoon (NEM) Rainfall

Northeast monsoon (NEM) rainfall distribution during baseline (1991 to 2020), near (2021 to 2050), mid (2051 to 2080), and end century (2080 to 2099) for two scenarios (SSP) – SSP2-4.5 and SSP5-8.5 are given in Fig 6. The SSP2-4.5 showed a mean precipitation increase of 65% in the mid-century, a decrease of 9% in the near future, and 60% decrease at the end of the century compared to baseline rainfall (510.61mm). However, precipitation was estimated to rise sharply in the near, mid, and end futures by 79%, 1%, and 3.5%, respectively, with the SSP5-8.5 scenario.

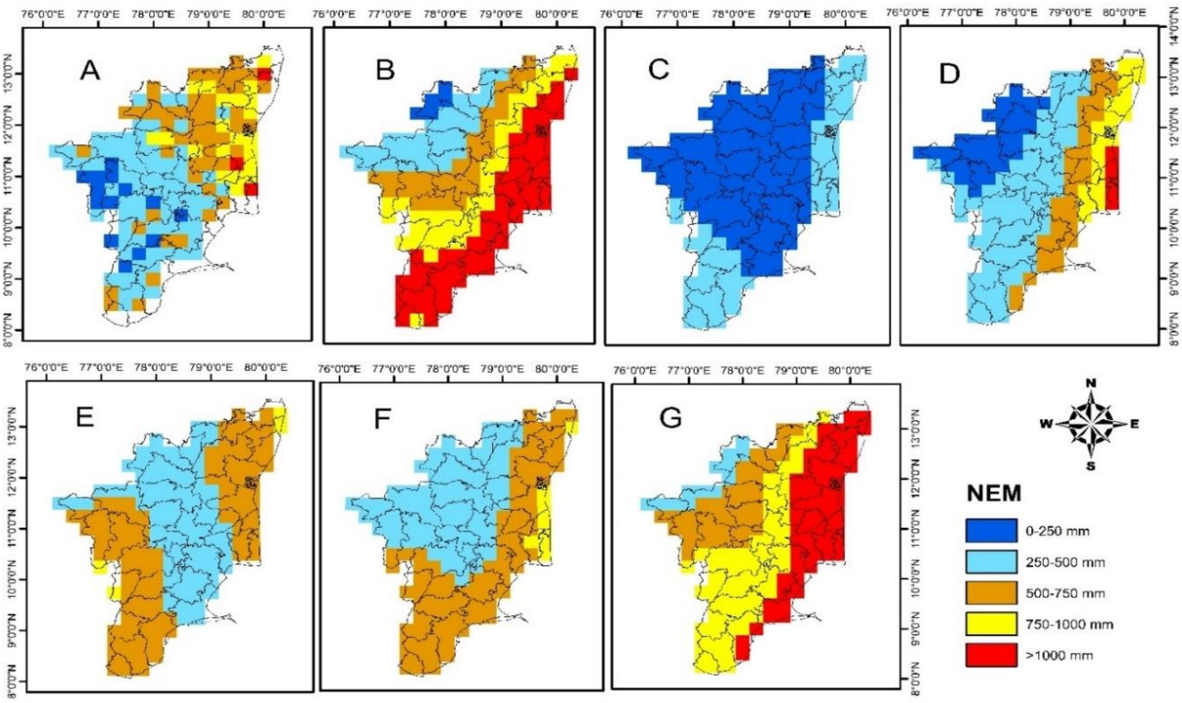


**Fig. 6. Projections of NEM rainfall over Tamil Nadu: A-Base; B-SSP2 Near; C-SSP2 Mid; D-SSP2 End; E-SSP5 Near; F-SSP5 Mid; G-SSP5 End**

Fig. 7 illustrates that the deviation of 458 mm, -325 mm*, and 328 mm from the SSP5-8.5 to the SSP2-4.5 scenario and the increases in precipitation amount are predicted for all future time scales under the SSP5-8.5 scenario. [18] also noticed a similar result in the SSP8.5 scenario and mentioned that precipitation was increasing as a result of a stronger subtropical westerly jet and its southerly movement over southern India.

### 3.5 Summer and Winter Rainfall

Fig 8 and 9 elucidate the distribution of summer and winter rainfall at the baseline, near, mid, and end of the century in Tamil Nadu. The summer rainfall is predicted to increase by 54% and 88% in the near and mid-century, respectively, under the SSP2-4.5 scenario, and a 56% drop in rainfall at the end of the century. In the SSP5-8.5 scenario, it is expected to increase by

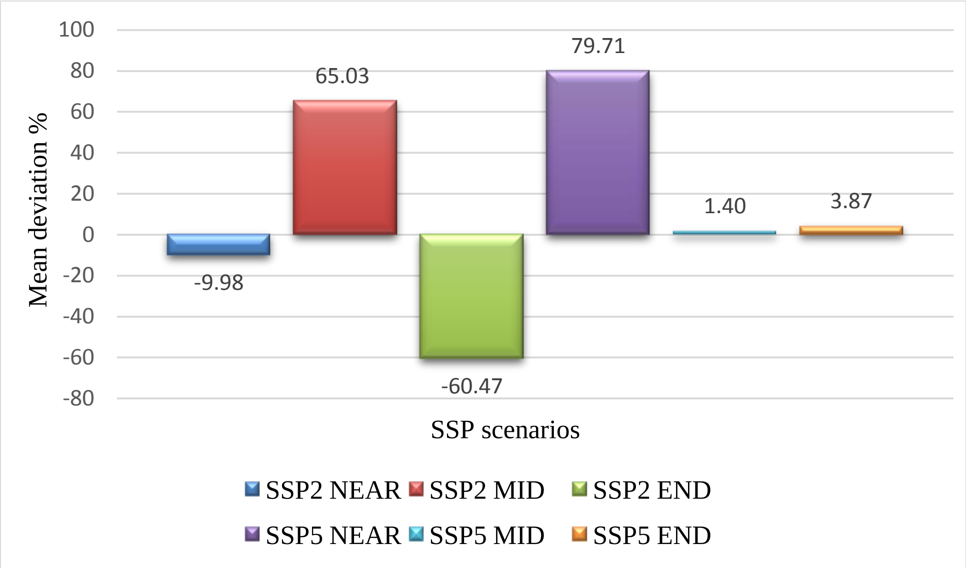


**Fig. 7. NEM precipitation percentage of mean deviation in Tamil Nadu region**

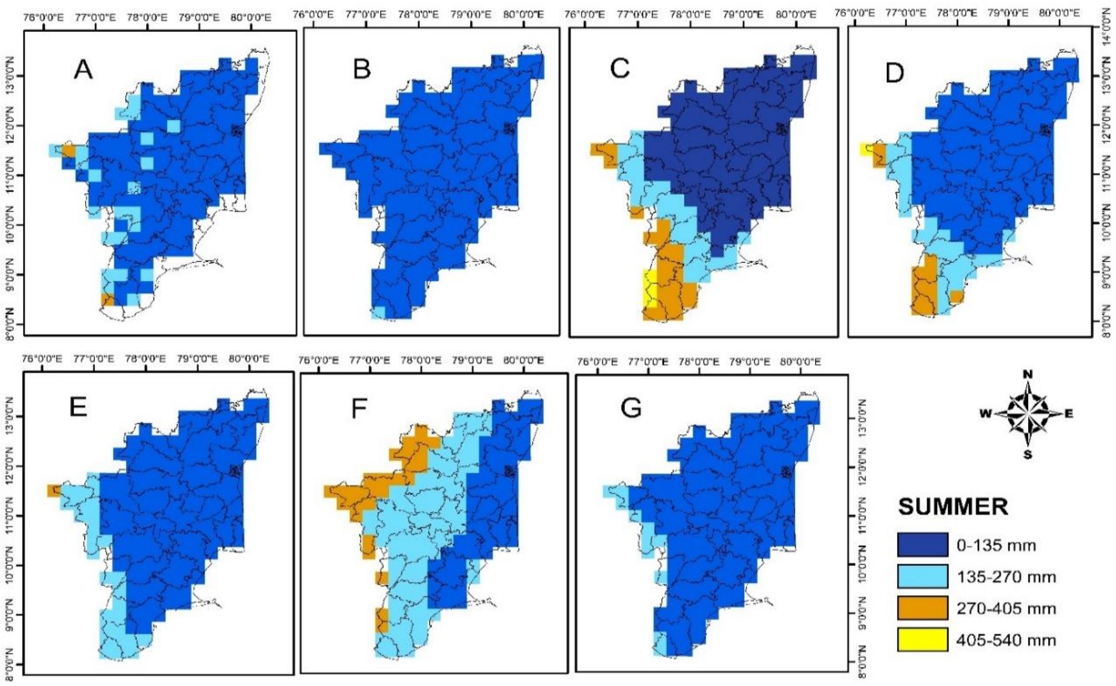


**Fig. 8. Projections of Summer rainfall over Tamil Nadu: A-Base; B-SSP2 Near; C-SSP2 Mid; D-SSP2 End; E-SSP5 Near; F-SSP5 Mid; G-SSP5 End**

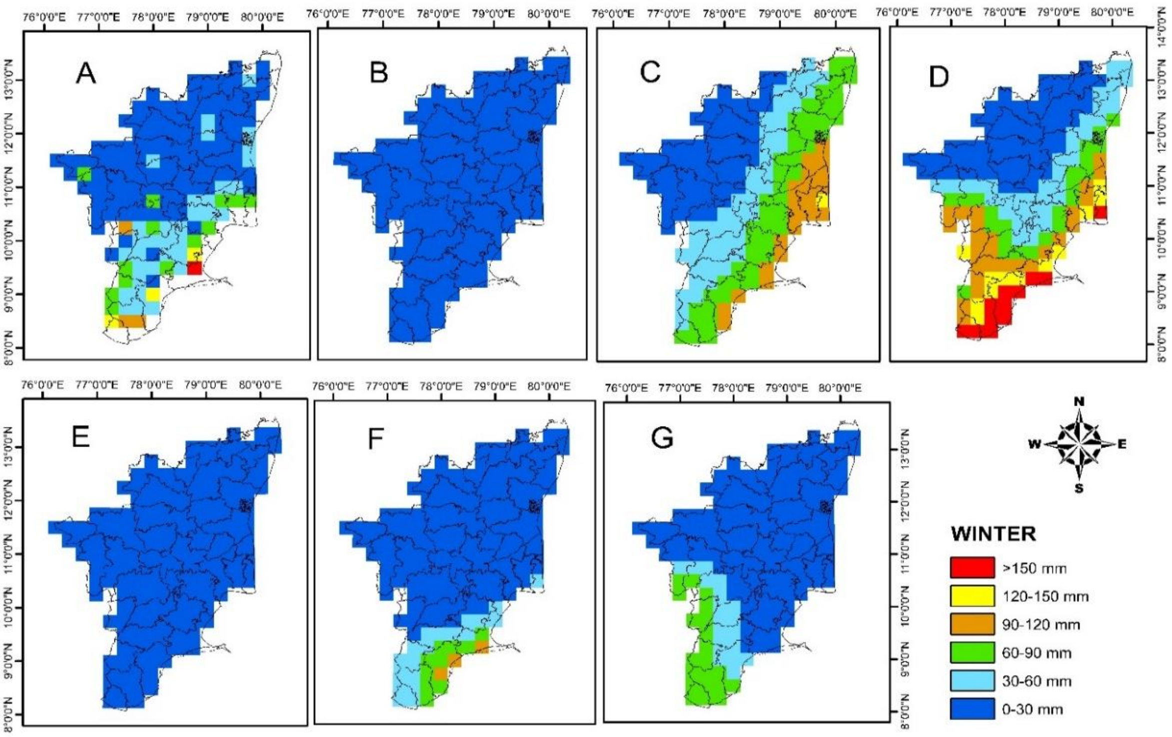


**Fig. 9. Projections of Winter rainfall over Tamil Nadu: A-Base; B-SSP2 Near; C-SSP2 Mid; D-SSP2 End; E-SSP5 Near; F-SSP5 Mid; G-SSP5 End**

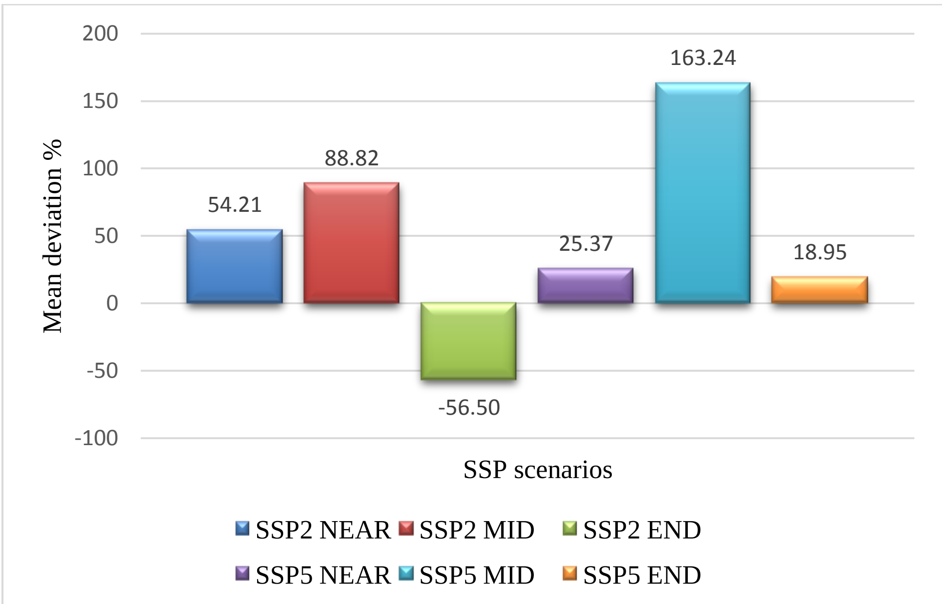


**Fig. 10. Summer precipitation percentage of Mean deviation in Tamil Nadu region**

25%, 163%, and 18% in the near, mid, and end of the century, respectively, when compared to the baseline rainfall (69.74 mm).

Fig. 10. shows a deviation of -20 mm*, 51 mm, and 52 mm in the predicted rainfall for the near, mid, and end of the century, respectively, under the SSP5-8.5 to the SSP2-4.5 scenario. According to [19], rainfall during the Asian summer monsoon would rise under warming scenarios with the CMIP6 model.

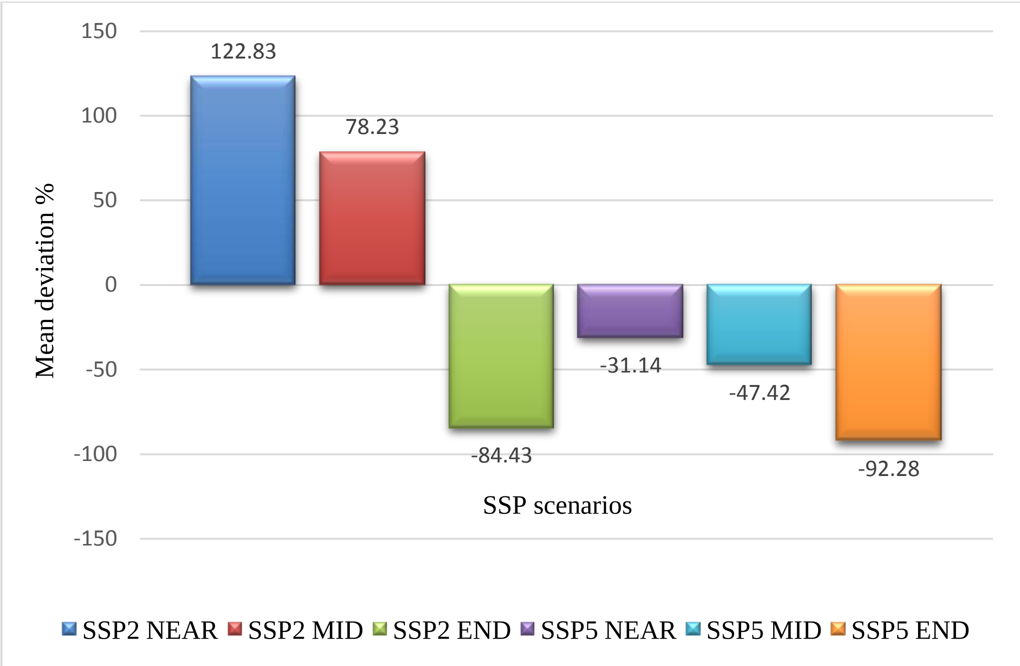


**Fig. 11. Percentage of Mean deviation in winter precipitation across the Tamil Nadu region**

In SSP2-4.5 precipitation would rise by 122% in the near future and 78% in the mid-term during the winter season, while dropping by 84% is expected at the end of the century. In the SSP5-8.5, rainfall is expected to decline by 31%, 47%, and 92% in the near, mid, and end futures, respectively, compared to the baseline condition (27.18 mm). Fig. 11 depicts that summer mean precipitation is rising compared to winter mean precipitation in all the future scenarios and a deviation of 42 mm, 34 mm, and 2 mm at the near, mid, and end of the century, respectively, is found in SSP2-4.5 from SSP5-8.5. The result was corroborated by [20] that the winter season over the Eastern part of Nepal experienced less precipitation in the historical period as well as the SSP585 scenario.

## 4. CONCLUSION

From the study, it is observed that the annual mean rainfall would increase in each of the potential future scenarios. The climate model projection indicates a 30% higher rainfall at the end under the SSP2-4.5 scenario and an 81% larger positive rainfall departure from baseline in the near future under the SSP5-8.5 scenario. The projection of seasonal precipitation for the SSP5-8.5 scenario demonstrates an increasing deviation of 21% in SWM during the mid-century, 79% in NEM towards the near-century, and 163% in summer at the mid-century. SSP2-4.5 shows an increasing deviation of about 6% for SWM in the end-century, 65% for NEM in the mid-century, 88% for summer in the mid-century, and 122% for winter in the near-century when compared with the base condition. Both the SSP5-8.5 and SSP2-4.5 scenarios predict an increase in heavy precipitation occurrences in the near, mid, and end of the 21st century. The results clearly emphases the need for strong research on improved water-saving techniques and agricultural adaptation strategies for handling high precipitation risks. Policymakers might use the projected precipitation to inform their decisions on how much water to allocate to agriculture to sustain agricultural production and ensure food security.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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