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Climate Change and Rainfall Variability in Tamil Nadu – Trends, Seasonal Variability, Rainfall Anomalies (1990 – 2024)

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ABSTRACT:
Climate change is one of the critical environmental challenges in this twenty first century, profoundly altering the precipitation regimes, rising temperatures and erratic rainfalls. Tamil Nadu, predominantly an agrarian state with a unique dependence of both Southwest monsoon and the Northeast monsoon, is highly vulnerable to the changes in the rainfall patterns. Understanding these temporal behaviors and seasonal variability of rainfall is crucial for ensuring constant agriculture production and effective water resource management for the state. This study focuses on the trends and variability of seasonal and annual rainfall in the state of Tamil Nadu for the period of 35 years (1990-91 to 2024 -25), using the secondary data from the Directorate of Economics and Statistics, Government of Tamil Nadu. Descriptive statistics, Rainfall anomaly analysis, seasonal and decadal comparison analysis were conducted to evaluate the rainfall patterns across the Southwest monsoon, Northeast monsoon, Hot and Winter seasons respectively. This analysis revealed that there was a gradual increase in the annual rainfall, accompanied by a strong inter – annual variability in the rainfall pattern of the state. A modest increase in the southwest monsoon, an erratic yet intense Northeast monsoon, increased occurrence of off-season rainfall indicated the impact of climate change in the state. The finding identified that the changing rainfall regime has an effective impact on the agricultural activities, ground water recharge and water and disaster management. Thus, this study underscores the urgent need for adaptation and mitigation strategies on these sectors and also highlights the need for further more regional specific research in this area for better planning for the sustainable future.

Keywords: Climate change, Rainfall Patterns, Tamil Nadu, Southwest monsoon, Northeast Monsoon, Rainfall Variability, Climate adaptation.

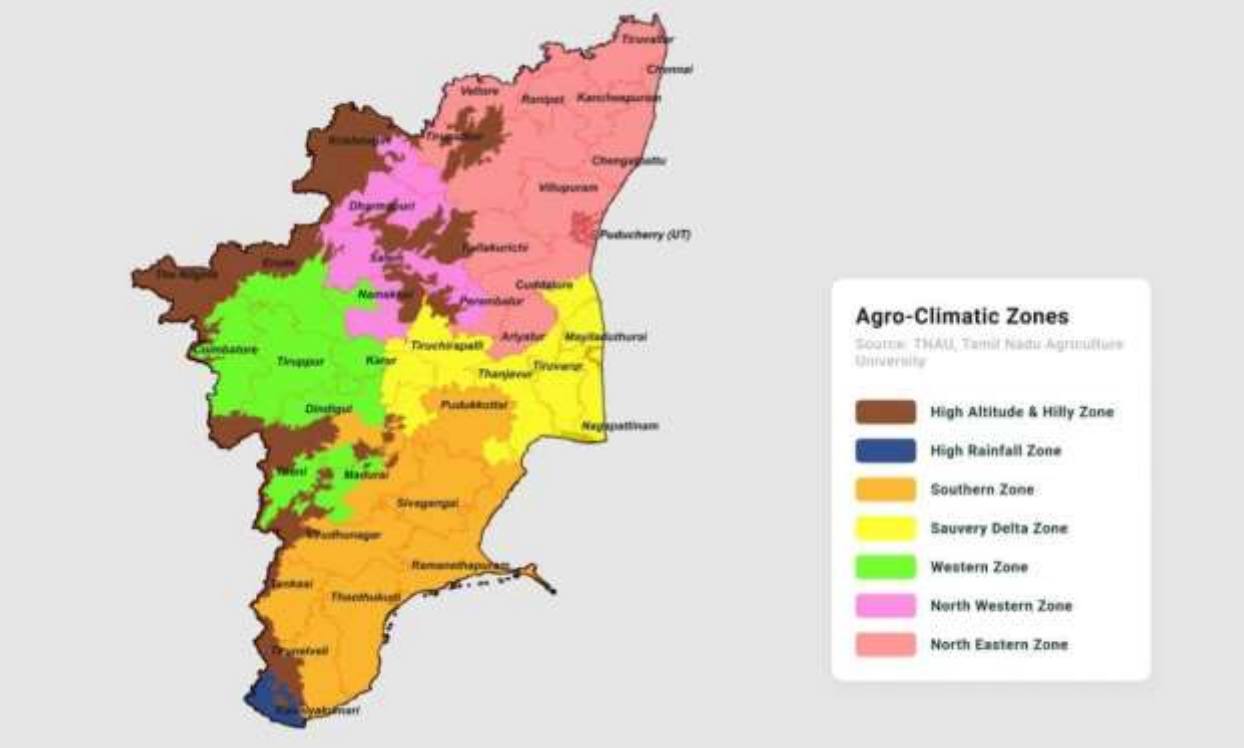
INTRODUCTION:

In recent years, climate change is contributing deleterious impact on the environment around us, affecting the weather patterns, rainfall distribution and disruption in the food supply leading to frequent droughts, health risks, loss of species, poverty, displacement and much more. The occurrence of climate change even though is worldwide; the impact varies from across the regions depending on the geographical location, differing local climate patterns and unequal socio-economic capacities to adapt to the changes. Global warming, extreme weather patterns, melting glaciers, oceanic changes are all

indicators of climate change. Climate change is expected to impact agriculture productivity, farmer's income, labor productivity, industrial production, health, GDP growth, energy demand, conflict and migration (Melissa Dell, 2014,). This paper focuses the need for understanding the changes in these climate variables for appropriate planning and management of agriculture and other industrial activities. Most of the studies on climate change have focused on the changes in temperature of various locations but changes in rainfall is comparatively studied less. India being a developing country, where agriculture is still the backbone, supporting almost 40% of the workforce. its dependency on rainfall is colossal. The nation relies immensely on southwest monsoon to satisfy almost 80% of its annual precipitation. The Indian economy and the agricultural sector have witnessed a set back over the past decades. Hence the necessity to recognize, analyze and investigate the temporal changes of these meteorological variables is inevitable. This paper focuses on the rainfall variability in Tamil Nadu, the state which has a unique rainfall pattern compared to the country has a whole. The state has a geographical area of 130,058 km^2 with 4% of the total area of India, 7% of its population and with only 3% of the total water resources. The water scarcity of the state is still severe with poor water resources coupled with the current changes in the hydrologic cycle and increasing pollution (Natarajan, 2017). Hence it is essential to study the current climatic changes within the state, especially about the erratic annual rainfall variability to avoid serious socio-economic hazard of food and life security.

STUDY AREA AND SCOPE:

As mentioned above the area of the study is Tamil Nadu the southernmost state of India. The state is bordered by Andhra Pradesh in the north, Kerela and Karnataka in the west, surrounded by Bay of Bengal in the east and Indian Ocean in the south is mostly tropical in nature with warm to hot climatic conditions. The state experiences the average maximum temperature of 35℃ to 40℃ in the month of April to June. The state, unlike the other state depends heavily on the Northeast monsoon for its annual precipitation which falls during the month of October to December. The state of Tamil Nadu has 7 agro-climatic zones namely North eastern zone, North western zone, Western zone, Cauvery delta zone, Southern zone, High rainfall zone, Hilly and high-altitude zone respectively. The annual average rainfall of the state ranges between 945mm to 998mm, the range various significant within the region ranging from 857 mm in the southern zones to over 2100mm in hilly and high-altitude regions of the state (rainwaterharvesting.org). The coastal regions of the state are uncomfortably warm during summer season. Thus, the state has diverse pattern of climate depending on its rainfall pattern and soil fertility. To manage the water resources and for smooth function of economic activities regional level rainfall knowledge is inevitable. According to a recent research work, the per capita water resource is expected to drop by 416m^3 with a deficit of 1284 m^3 by the year 2050, (Natarajan, 2017) in this situation appropriate understanding of meteorological variables like rainfall variability across the state is crucial for the future sustainability. Thus, the study tries to capture the long-term trends, seasonal variability and rainfall anomalies in the state of Tamil Nadu.



Source: https://tnclimatetracker.tn.gov.in/

OBJECTIVES OF THE STUDY:

The aim of the study was to analyze and understand the rainfall pattern for the state of Tamil Nadu for the period 1990-2025 (35 years) and to investigate whether climate change has influenced the rainfall patterns in the recent years. The study also attempted to implement appropriate adaptation and mitigation strategies for the future survival**.** The following were the objectives of the study:

1. To examine the long-term rainfall pattern in Tamil Nadu for the period 1990-2024
2. To analyze the seasonal rainfall variability across the southwest and Northeast monsoon periods during the mentioned years.
3. To identify extreme wet and dry years through the rainfall anomalies
4. To understand the decadal rainfall pattern in Tamil Nadu from the year 1990 to 2025 for better clarity of the rainfall variability in Tamil Nadu over the years.

DATA AND METHODOLOGY:

The data used for the analysis of the study were obtained from the season and crop reports 2024 – 25, Department of Economics and Statistics, Government of Tamil Nadu, for the period 1990 – 2024. The obtained data was in time series format and to analyze the same initially a trend analyze was conducted and for further detailed understanding descriptive statistic methods, rainfall anomalies and decadal comparison were employed.

ANALYSIS AND INTERPRETATION:

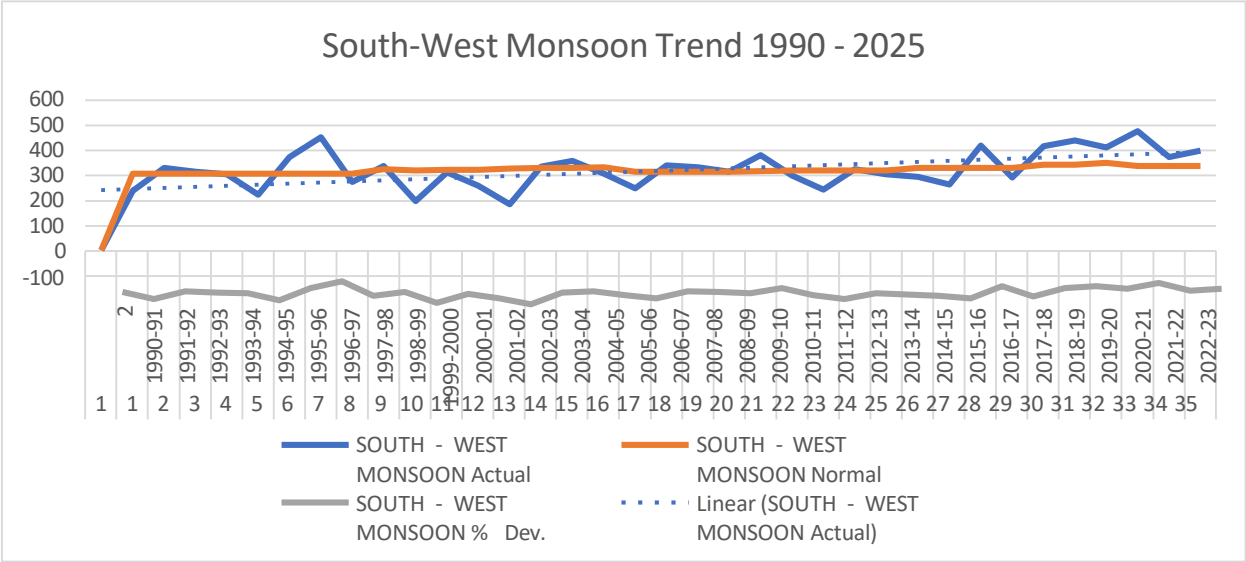
I. Trend Analyzes of the seasonal rainfall pattern in Tamil Nadu (1990 -91 to 2024 -25)

1. South-west Monsoon (June – September)

Southwest monsoon unlike the other states of India, contribute comparatively less due to the western

ghats acting as a natural rainfall barrier across the state. The dataset also reveals constant fluctuations in the rainfall pattern during this season over the given period.

Chart 1.1

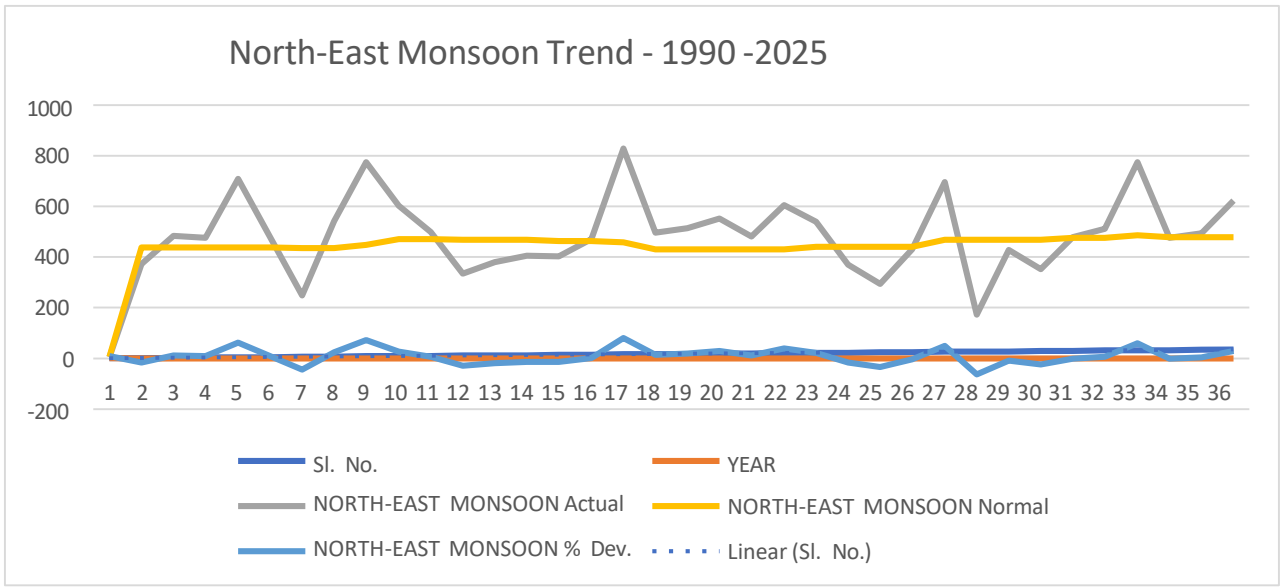


The observed pattern shows an average annual rainfall of 326.6 mm during the mentioned study period, with a minimum rainfall of 185.4 mm and a maximum rainfall of 478.2 mm. The estimated trend shows **a moderately increasing pattern in the southwest monsoon**, with the early years (1990 – 1995) experiencing a below – normal rainfall and the recent years recording a above normal hike. The period between 2000 – 2020 shows minimum fluctuations from the normal trend gradually after 2020 the state has experienced rainfall above their respective normal. This shows that the state has experienced relatively wetter southwest monsoon than a decade before.

2. North-east Monsoon (October – December):

North-east monsoon is the principal rainy season of Tamil Nadu providing almost half of the state's annual rainfall.

Chart 1.2



The above observed pattern shows an average rainfall of 494.8 mm over the mentioned years, with the

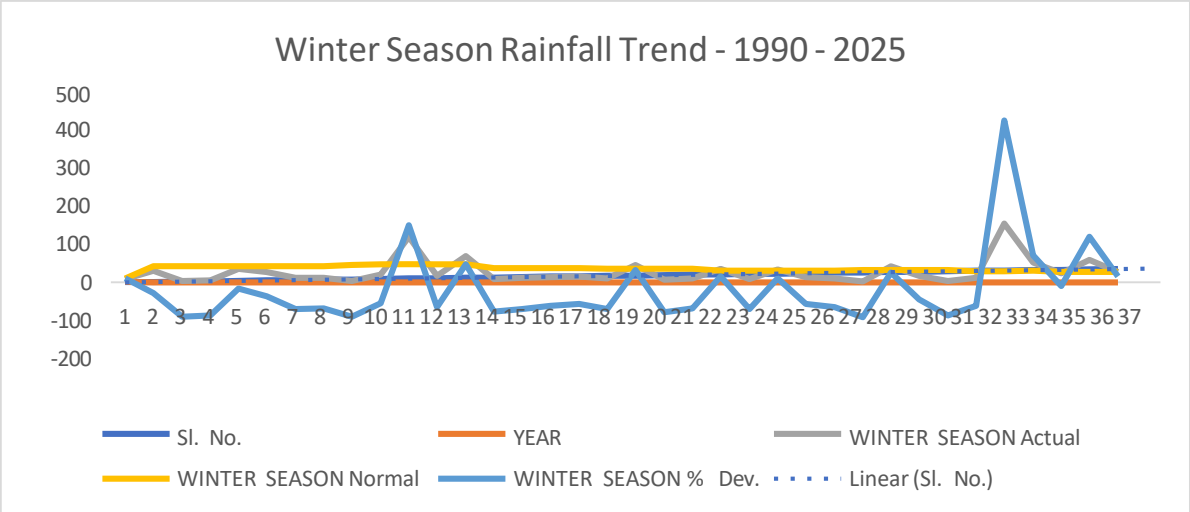
minimum rainfall of 174.0mm and the maximum of 828.8 mm. This estimated trend shows almost stable, only with slight increase in the rainfall over these years. The extreme high rainfall was recorded during the years 1993-94, 2005-06, 2015 -16 and 2023 -2025. The Northeast monsoon in the long term shows relatively stable compared to southwest monsoon but has experienced more deviation from the normal. The monsoon in the recent years have become increasingly erratic with high risk of both floods and droughts. This monsoon rainfall is very important to the state as the irrigation supplies for agriculture relies totally on this for the cultivation of rice in the state.

3. Winter Season (January – February)

Winter rainfall contributes to only meager amount of Tamil Nadu's Rainfall. The below given pattern depicts an average rainfall of about 28.2 mm for the mentioned years, with the minimum of 2.9 mm rainfall and a maximum of 154.6 mm in the mentioned period.

Most of the years have experienced fewer rainfall expect for the recent years from 2023 – 2025, the recoded rainfall patterns were significantly high. This winter rainfall pattern remains highly irregular reflecting the impacts of climate change. Such increase in the off-season rainfall events largely tend to damage the crops, reduce grain quality and also delay post-harvest operation.

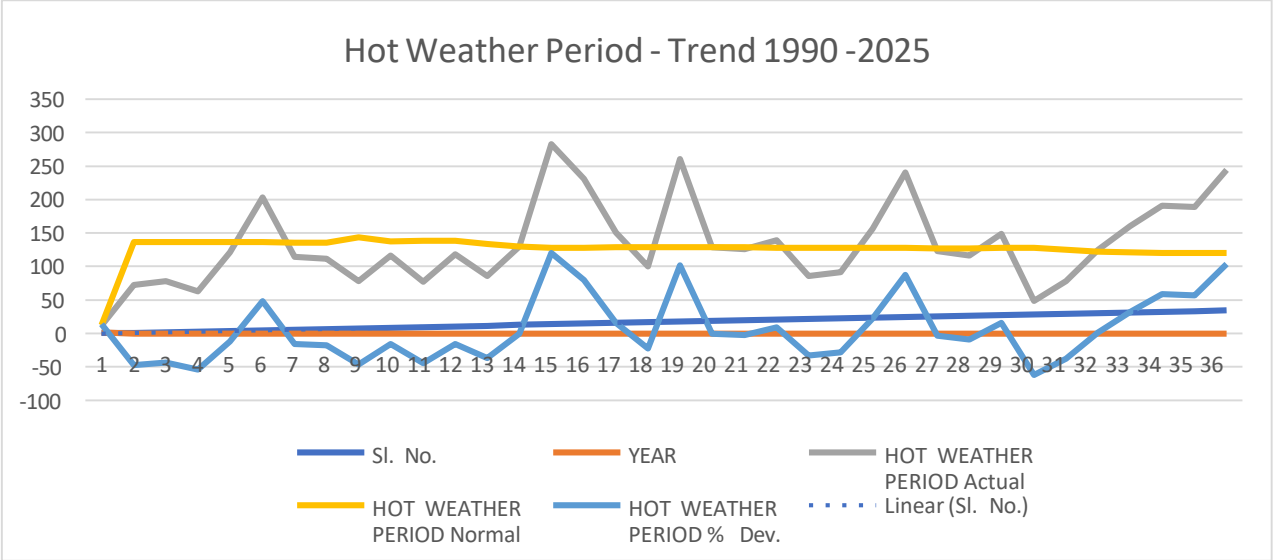
Chart 1.3



4. Hot Weather Period (March – May):

The rainfall during the hot weather season is generally due to convective thunder storms or pre monsoon rainfall. The analysis identified that the average hot weather rainfall was estimated to be 137.2mm, with the minimum rainfall of 49.3mm and the maximum rainfall recorded as 283.4mm. which depicts that there is noticeable increase in the hot weather rainfall over the recent years.

Chart 1.4

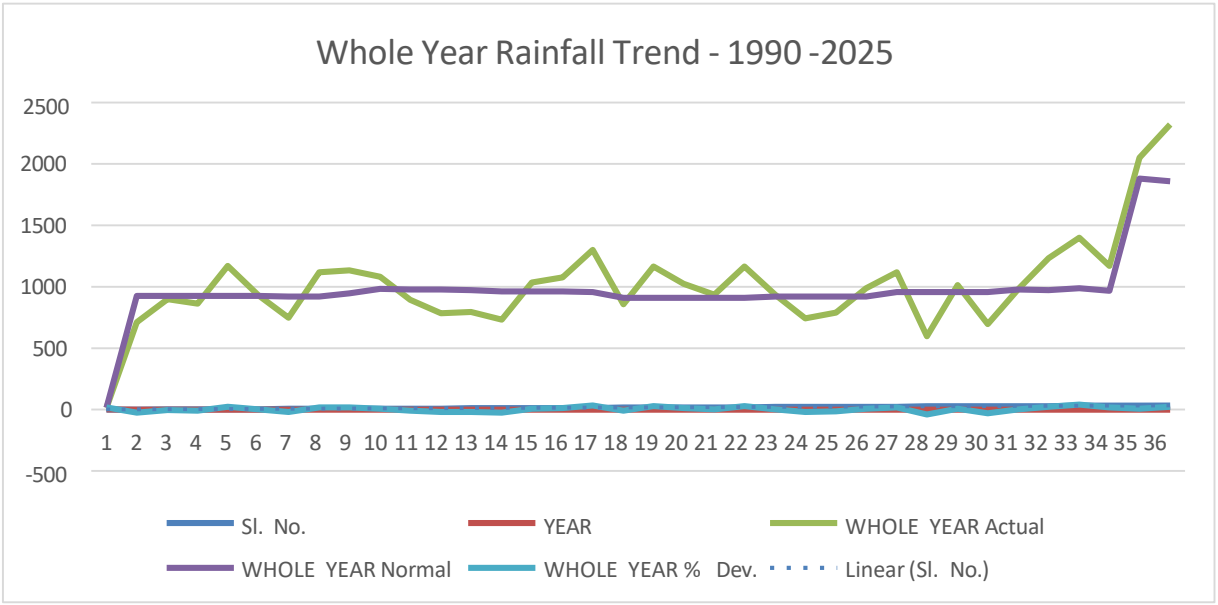


The above graph depicts that during the early years the rainfall was close to normal with some sudden spikes in a few years, but in the recent years (2018 – 2025) the hot weather rainfall has recorded gradual hike. These irregularities of extreme rainfall in this period can be connected to climate change issues like warmer atmospheric conditions due to rising temperature. Even though it seems to be beneficial in reducing the heat and helps in preparing the land with groundwater recharge, its unpredictability reduces the reliability of crop planning.

5. Whole Year Rainfall:

The combined analysis for the whole year, during the mentioned time period identified that the annual average rainfall for the study period is 1042.9mm, with a minimum of 598.1mm and a maximum of 2323.9mm. The whole year rainfall observation showed a constant increase with minimum fluctuations. The recent years after 2020 – 2025 have experienced a sudden hike in rainfall than the usual years marking it as the wettest years so far.

Chart 1.5



The increase in the whole year rainfall does not imply that the water availability of the state have seen an

improvement because of its ununiformed distribution of the rainfall over the years. These events reflect the widely doubted manifestations of climate change like more intense rainfall events, greater seasonal variability longer dry spells and also increasing frequency of floods occurring in the same climatic regime.

2. SEASONAL RAINFALL VARIABILITY ACROSS THE SOUTHWEST AND NORTHEAST MONSOON PERIODS DURING THE MENTIONED YEARS.

To analyze the seasonal variability between the southwest monsoon and the northeast monsoon for the above mentioned 35 years (1990 – 2025), the co-efficient of Variation formula was employed.

CV = (Standard deviation /Mean) *100

The mean and standard deviation of the southwest monsoon and northeast monsoon over the 35 years were calculated separately and then cautiously substituted in the above-mentioned formula and estimated as 21.89 % for south west monsoon and 29.50 % for the Northeast monsoon respectively. These estimations indicate the fact that the southwest monsoon exhibits moderate inter annual variability (21.89%), whereas the northeast monsoon exhibit substantially higher annual variability (29.50%) compared to the southwest monsoon. This provides a clear implication that the northeast monsoon is less predictable and hence more susceptible to climatic fluctuations than the southwest monsoon.

3. IDENTIFICATION OF EXTREME WET AND DRY YEARS THROUGH THE RAINFALL ANOMALIES:

Furthermore, to analyze the extreme wet and dry years experienced during this time period during the recent years, rainfall anomalies were calculated for the time period between 2010 -11 to 2024 -25 by using the formulas given below:

Rainfall Anomaly = Average rainfall – long term mean

Rainfall Anomaly % = [(Average rainfall – Mean) / Mean] *100 Table: 1

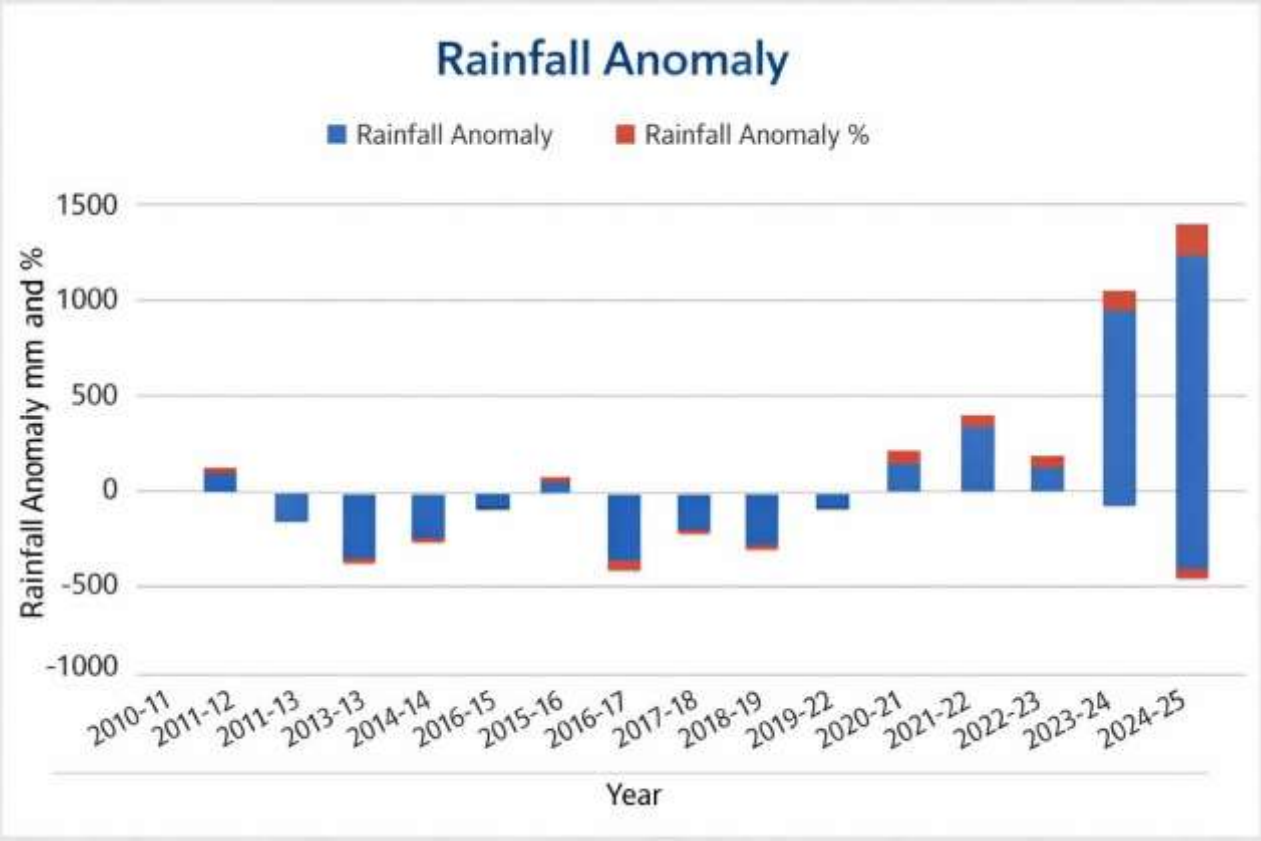
Year	Rainfall Anomaly (mm)	Rainfall Anomaly %	Interpretations
2010-11	122.2	11.712	Above Average rainfall
2011-12	-105.8	-10.148	Slightly dry year
2012-13	-299.8	-28.750	Extremely dry year
2013-14	-252.3	-24.195	Extremely dry year
2014-15	-55.0	-5.2781	Dry year
2015-16	75.1	7.1960	Average rainfall
2016-17	-444.8	-42.652	Exceptionally dry year
2017-18	-25.7	-2.4688	Slightly dry year
2018-19	-344.0	-32.988	Exceptionally dry year
2019-20	-57.1	-5.4795	Dry year
2020-21	189.9	18.2033	Above Average rainfall
2021-22	358.2	34.3402	Wet year
2022-23	127.7	12.2394	Above Average rainfall
2023-24	1011.6	96.9895	Extremely wet year
2024-25	1281.0	122.8202	Exceptionally wet year

The rainfall anomaly analysis conducted for the latest 15 years indicates that the state of Tamil Nadu have experienced inter – annual variability over the years. During the early years we can clearly see that the rainfall is predominantly low, when compared to the long term annual average rainfall notably during the years 2011(-10.14%), 2012 (-28.75%), 2013 (-24.19%), 2014 (-5.27%).

This scenario was even worse during the mid years like 2017 (-2.46%), 2018 (-32.98%) and 2019 (-5.47%). The year 2016 -17 recorded the highest negative anomaly among the selected years for the study, indicating the driest year amongst all the years in the study period.

In contrast to the above observation 2020-21 onwards the state has received abundant rainfall, values indicating 18.20% in the year 2020 -21 to a maximum of 122.82% in the year 2024 -25. This rainfall anomaly observations clearly portrays that the rainfall trends in the state of Tamil Nadu have increased in the recent years when compared to the initial years (2010 -2018). Yet the distribution of the rainfall was not the same across all the districts of Tamil Nadu leading to the occurrence of constant floods in some parts of the state, where as the other parts of the state experience water scarcity to extreme drought. Thus, there is an immediate need for agriculture planning, water resource management and climate adaptation strategies for a sustainable future.

Chart 1.6



4. DECADAL RAINFALL PATTERN IN TAMIL NADU:

After cautiously calculating the yearly rainfall anomalies and understanding the inter annual variability of rainfall, decadal analysis was done to get more clarity on the prevalence of the impact of climate change on the rainfall patterns in the state. To estimate the decadal Co-efficient of variation, the mean rainfall, maximum mean and minimum mean and standard deviation for the respective decades were calculated and their respective co-efficient of variation was estimated.

The values of the co-efficient of variation states that decadal rainfall between 1990 – 1999 is 16.99% with an average rainfall of 956.4 mm. This shows that there was a stable rainfall condition with minimum fluctuations.

Decadal Comparison: Table: 2

Decade	No. of Years	Mean Rainfall (mm)	Minimum (mm)	Maximum (mm)	Standard Deviation (mm)	Coefficient of Variation (%)
1990–1999	10	956.4	714.6	1171.9	162.46	16.99
2000–2009	10	971.45	731	1304.1	183.6	18.9
2010–2019	10	904.18	598.1	1165.1	187.38	20.72
2020–2024	5	1636.58	1170.6	2323.9	520.26	31.79

The average rainfall for the decade 2000 – 2009 was 971.45 mm with the co-efficient of Variation 18.9% shows that the variance is higher compared to the previous decade. This depicts that the fluctuations were high.

For the decade 2010 – 2019, the average rainfall was 904.18 mm which was lesser than the previous decades and also the co-efficient of variation is 20.72% which was again higher than the previous decades. This shows that rainfall was also lesser and at the same time more volatile during this period making it a dry decade.

The final period was calculated for the years 2020 – 2024, with an average rainfall of 1636.58 mm but the co-efficient of variation was 31.79%, revealing that the rainfall variability was exceptionally high with the average rainfall also being higher. Thus, in the recent years there is a consistent increase in the occurrence of extreme rainfall events and climate change has a considerable role to play.

FINDINGS OF THE STUDY:

The findings from the trend analysis of the rainfall pattern in Tamil Nadu during the period of 1990-2025, aligns with the IPCC regional assessment report. The results shows that the Southwest Monsoon is moderately increasing and the Northeast Monsoon is consistent yet erratic. The off-season rainfall both winter and summer is increasing, clearly showing an upward trend in the annual rainfall but not uniformly distributed across all regions.

The long-term annual rainfall average has been identified as 1042.95mm, the inter annual variability seems to be so high with difference ranging from 598.10mm to 2323.90 mm. The co-efficient of variation for the long-term annual rainfall was estimated as 32.97%, which also seems to be extremely variable.

The analysis on rainfall anomaly conducted for the latest 15 years also showed alternative periods of surplus and deficit rainfall. The periods between 2010 -2019 recorded below average rainfall, with the year 2016 -17 recording the highest negative (-42.65%) rainfall anomaly. The recent years from 2020 – 2024 portrays a distinct shift from below average to exceptionally high rainfall anomalies (18.20% to 122.82%) indicating the occurrence of extreme wet years.

The decadal comparison also shows the gradual increase in the value of coefficient of variation from 16.99% to 31.79%. Thus, the analysis identified that the growing rainfall variability is consistent with

the escalating threat of climate change.

SUGGESTIONS FOR FUTURE SURVIVAL:

The major learnings of the study call for the utmost requirement for appropriate adaptation and mitigation strategies for the challenges in the upcoming years. First and foremost, requirement is the **strengthening of water resource management** for the state like expanding the water harvesting, rising the ground water recharge structures, expanding and maintaining existing reservoirs to survive both dry and extreme wet years. The next focus should be on **sustainable agriculture practices**, like shifting to drought resilient crops, changing the sowing calendars and relying on climate resilient technology for mitigating the impact of the rainfall variability due to climate change.

Improving the flood management infrastructure is also very crucial both in the coastal regions and also in the heavily populated urban regions. **Strengthening climate monitoring and warning systems technologies** helps saving human lives and also improving agricultural decision making. Further the incorporation of climate variability in the state level planning of agriculture, irrigation and disaster management is the essence for the survival in the future.

CONCLUSION:

The study examined the annual rainfall variability in Tamil Nadu for the period 1990-91 to 2024–2025 using descriptive statistics techniques, rainfall anomalies and decadal comparison. The results demonstrates that although the states receive an annual average rainfall of about 1043 mm, the rainfall distribution is increasingly irregular over the years and the results highlights the role of climate change to these erratic shifts. The largest values of the coefficient of variation (32.97%), the highly altering deficit and surplus rainfall events, the shift in the increasing rainfall patterns from the year 2020 – 2024, indicating the occurrence of extreme wet years signals the alarming signs of the impact of climate change. These fluctuations pose a significant effect on the agriculture productivity, water resource and disaster management. This study establishes a foundation for state's resilience and future survival during the never-ending climatic uncertainties.

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