Rainfall Variability and Monsoonal Extremes in Thanjavur District, Tamil Nadu, India: A Four-Decade Hydro-Climatic Assessment for Climate-Resilient Planning

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ABSTRACT

This study presents a comprehensive hydro-climatic assessment of Thanjavur District, Tamil Nadu, over 40 years (1984–2024) to evaluate rainfall variability and monsoonal extremes for climate-resilient water resource planning. Using high-resolution daily, monthly, and seasonal rainfall data from NASA POWER, IMD, and TNSDMA, statistical analyses including time-series decomposition, trend estimation, and graphical visualization were performed. Results reveal a distinct seasonal skew, with the Northeast Monsoon (October–December) contributing 52–55% of the annual rainfall, followed by the Southwest Monsoon (30–32%). November consistently emerged as the wettest month. The district exhibits significant inter-annual variability, with extreme wet years (1993, 2005, 2015) exceeding 1500 mm and drought years (2002, 2012, 2016) falling below 750 mm. These fluctuations have a critical impact on tank-fed irrigation systems, groundwater recharge, and crop productivity. The study highlights the increasing frequency of high-intensity rainfall events and prolonged dry spells, reflecting the regional influence of climate change. Recommendations include enhanced rainwater harvesting, tank rehabilitation, dynamic reservoir operations, and adoption of climate-resilient agricultural practices. This long-term rainfall analysis provides a scientific basis for adaptive water resource management, drought mitigation, and sustainable agricultural planning in the Cauvery Delta region.

INTRODUCTION

Climate change remains a critical concern, affecting rainfall distribution, hydrological cycles, and agricultural sustainability in India [IPCC, 2021; Mall et al., 2006]. In the deltaic plains of Tamil Nadu, the Thanjavur district stands out due to its historical and agricultural significance, often referred to as the "Rice Bowl of Tamil Nadu." Its agricultural productivity is highly sensitive to climatic variability, particularly

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fluctuations in rainfall [NRAA, 2012]. Rainfall variability directly affects not only crop yields and irrigation scheduling but also surface and subsurface water resources [Rao *et al.,* 2019].

Thanjavur receives rainfall from both the Southwest Monsoon (June–September) and the Northeast Monsoon (October–December), with the latter contributing significantly to its annual precipitation [IMD, 2022]. This seasonal dependency makes the region vulnerable to even minor anomalies in monsoon patterns, resulting in frequent episodes of drought or waterlogging [KaviKumar, 2010]. Understanding and managing these seasonal variations is crucial for maintaining agricultural productivity and ensuring water security in the district.

The present study investigates the long-term hydrological behavior of Thanjavur district using detailed daily, monthly, and seasonal rainfall data. High-resolution datasets are analyzed using statistical hydrology tools, including time series decomposition, autocorrelation, and trend estimation techniques. The analysis reveals significant variations in rainfall intensity and distribution across different time scales, which are crucial for understanding the region's hydroclimatic regime [Sasikala & Premavathi, 2022].

Daily rainfall analysis captures high-frequency variations that are essential for short-term flood forecasting and storm water planning. At the same time, monthly and seasonal aggregations reveal long-term trends necessary for drought assessment and aquifer recharge planning [MoEFCC, 2021]. Graphical tools, such as bar graphs and seasonal distribution plots, are employed to visualize rainfall patterns and identify critical wet and dry periods. The Northeast Monsoon, particularly the months of October and November, emerges as the dominant rainfall period [TNSDMA, 2023].

This study also explores how rainfall variability affects water availability, crop planning, and groundwater recharge potential. The insights gained support the development of climate-resilient water resource strategies, including rainwater harvesting, irrigation scheduling, and infrastructure planning [FAO, 2017; Singh et al., 2018]. Ultimately, this hydrological analysis provides a foundational dataset for researchers, planners, and policymakers working toward sustainable water management and climate adaptation in Thanjavur [TERI, 2019].

MATERIALS AND METHODS

Study Area

Thanjavur District is located in the eastern part of Tamil Nadu, India, within the fertile Cauvery Delta region. It lies approximately between 10°15′N and 11°25′N latitude and 78°45′E to 79°45′E longitude, bordered by Ariyalur, Thiruvarur, Trichy, and Nagapattinam districts. The district spans a geographical area of about 3,396 square kilometers. Its topography is predominantly flat with low elevation, making it ideal for intensive agriculture but also prone to both flooding and drought conditions.

Thanjavur falls under the Cauvery Delta Agro-Climatic Zone, characterized by a tropical climate with distinct wet and dry seasons. It receives rainfall from both major Indian monsoon systems:

- Southwest Monsoon (SWM): June to September

- Northeast Monsoon (NEM): October to December

The Northeast Monsoon accounts for the majority of the annual rainfall, with November typically being the wettest month. Rainfall during the summer and winter months is minimal. Given the district's agricultural prominence, any variation in monsoon behavior can directly impact irrigation, cropping cycles, and groundwater recharge, emphasizing the need for detailed hydrological studies [TNAU, 2020; IMD, 2022].

Data Collection

Rainfall data used in this study were obtained from the NASA Langley Research Center's POWER Data Access Viewer (DAV), which provides long-term, satellite-based meteorological datasets suitable for hydrological and climate studies. This source was selected due to its:

- Long temporal coverage (1984–2024)

- High spatial and temporal resolution

- Global validation and reliability

The 40-year data span allows for the evaluation of both short-term rainfall fluctuations and long-term climatic trends with statistical robustness. Additional secondary data were gathered from reputable sources, including the Indian Meteorological Department (IMD), Tamil Nadu State Disaster Management Authority (TNSDMA), and peer-reviewed hydrological studies

related to rainfall and monsoon behavior in the Cauvery Delta region.

All datasets were carefully reviewed for continuity and reliability. Discontinuous or anomalous records were excluded to ensure analytical integrity. The rainfall data, recorded in millimeters (mm), were compiled and organized into annual, seasonal, and monthly datasets using structured spreadsheets to facilitate systematic analysis.

Data Categorisation

For an accurate and multi-temporal hydrological assessment, rainfall data for Thanjavur district were categorized into monthly, seasonal, and annual segments in accordance with IMD classification standards. These classifications were graphically represented using pie charts (for seasonal distribution) and bar graphs (for monthly averages), spanning the 40 years from 1984 to 2024.

Monthly Rainfall:

Monthly rainfall was analyzed to capture intra-annual variability. The bar graph representation shows minimal rainfall from January to April, a gradual increase beginning in May, and a distinct peak from October to December, with November typically recording the highest rainfall. These insights are crucial for determining sowing periods, irrigation scheduling, and planning for rainwater harvesting.

Seasonal Rainfall:

Rainfall was grouped into the following standard seasons:

- Winter: January–February
- Summer: March–May
- Southwest Monsoon (SWM): June–September
- Northeast Monsoon (NEM): October–December

Pie chart analysis clearly shows that the Northeast Monsoon contributes the majority share of rainfall, followed by the Southwest Monsoon. Rainfall during the winter and summer months remains minimal. This seasonal breakdown is crucial for designing water storage systems, planning reservoir operations, and managing flood risks.

Annual Rainfall:

Annual rainfall totals were calculated by summing monthly values for each year from 1984 to 2024. While this study emphasizes seasonal and monthly rainfall patterns, annual totals provide insight into inter-annual variability, highlighting extreme wet years or drought conditions. These annual trends are essential for strategic water resource planning, crop insurance formulation, and climate adaptation policies.

RESULTS AND DISCUSSION

Annual Rainfall Analysis

The annual rainfall pattern in Thanjavur district over the 40 years from 1984 to 2024 exhibits considerable inter-annual variability, indicating a region influenced by both monsoonal dynamics and climate variability. The mean annual rainfall across this period is estimated to range between 950 mm and 1300 mm, with clear fluctuations between high and low rainfall years rather than a smooth trend.

- The wettest years—notably 1993, 2005, and 2015—received well above 1500 mm of rainfall, primarily attributed to vigorous Northeast Monsoon activity, often triggered by cyclonic storms and enhanced Bay of Bengal depressions.

- In contrast, years like 2002, 2012, and 2016 were markedly dry, with rainfall totals falling below 750 mm, leading to reduced surface water storage and agricultural distress.

This annual rainfall variation reflects Thanjavur's sensitivity to monsoon variability and the need for flexible water resource management. Years such as 2004 and 2018 exhibited moderate rainfall, underscoring the unpredictable nature of seasonal rainfall. The absence of a clear increasing or decreasing trend in annual totals implies an overall stability in mean values but with rising extremes—a typical signal of regional climate irregularities. Adaptive cropping systems and inter-seasonal water storage mechanisms are crucial for managing this hydro-climatic inconsistency.

Monthly Rainfall Analysis

The monthly rainfall analysis of Thanjavur district between 1984 and 2024 shows a highly seasonal pattern, strongly dependent on the Northeast Monsoon. Rainfall is minimal from January to March, with monthly values averaging below 25 mm, indicating a dry winter and early summer phase.

- A moderate rise is seen in April and May due to pre-monsoon convection, with rainfall reaching 50–60 mm on average.

Annual Rainfall Analysis for Thanjavur District
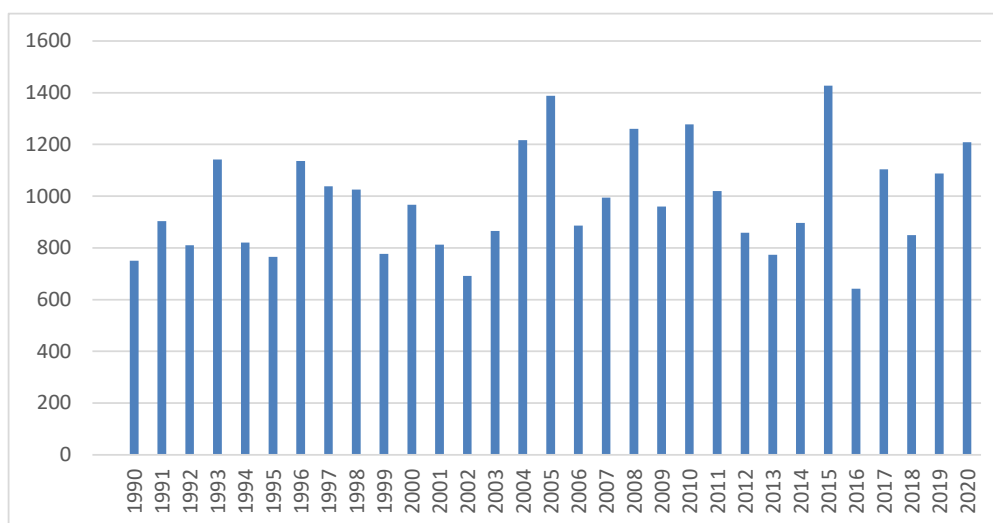
Monthly Rainfall Analysis for Thanjavur District
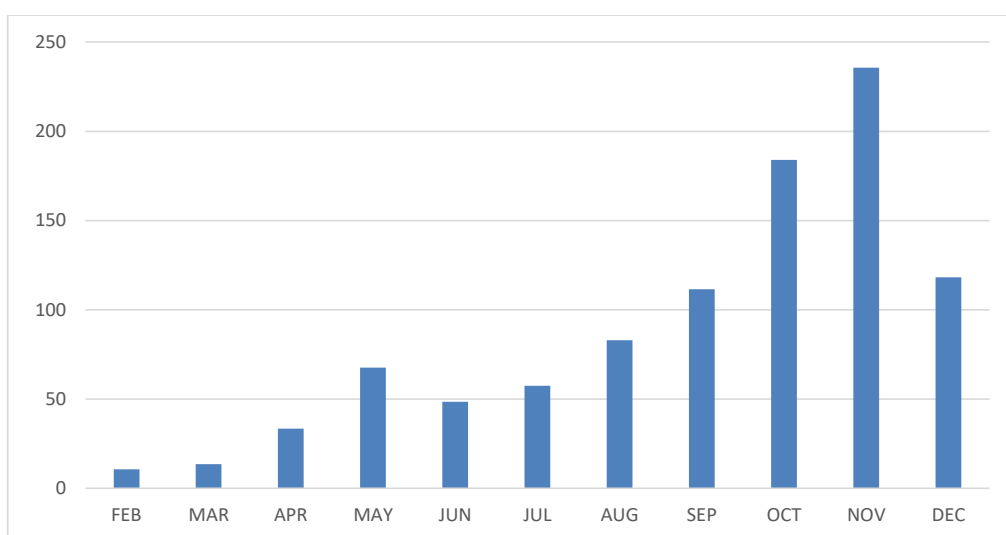
- The Southwest Monsoon (SWM), from June to September, contributes steadily, with rainfall increasing from about 60 mm in June to nearly 130 mm by September. This early-season rainfall supports initial sowing and soil preparation for major crops.

- The Northeast Monsoon (NEM) period—October to December—dominates the annual cycle. October (~180 mm) and November (~240 mm) are the wettest months, with November consistently recording the highest rainfall across multiple years. December (~130 mm) also provides significant contributions as the season transitions.

This distribution clearly establishes the dominance of the Northeast Monsoon in Thanjavur's hydrological regime, reinforcing its importance for tank irrigation, paddy cultivation, and groundwater recharge. The reliance on late-year rainfall underscores the district's need for adequate water storage and flood risk mitigation during this period.

Seasonal Rainfall Analysis

The seasonal distribution of rainfall in Thanjavur further confirms the pivotal role of the Northeast Monsoon (NEM) in shaping the district's annual water balance and agricultural output. Based on the seasonal classification:

- Northeast Monsoon (Oct–Dec): Contributes approximately 52–55% of the total annual rainfall, making it the most crucial season for

agriculture, reservoir filling, and recharge of traditional tank systems. Any deviation from this season's norm leads to water stress or increased flood vulnerability.

- Southwest Monsoon (Jun–Sep): Accounts for about 30–32% of the annual rainfall. While less intense than the NEM, it is vital for initial field preparation, short-duration crops, and maintaining moisture balance.

- Summer Season (Mar–May): Adds around 9–10% of the annual rainfall, mostly from sporadic pre-monsoon showers. These rains provide marginal soil moisture, which supports early-season cultivation in some areas.

- Winter Season (Jan–Feb): Makes up only 3–4% of the total rainfall and has a negligible impact on cropping or water resource conditions.

This skewed seasonal rainfall pattern has significant implications for water resource planning. The dependence on the NEM requires robust rainwater harvesting systems and efficient canal management, while the moderate contributions from the SWM should be stored and distributed to supplement irrigation. In the context of shifting climate behavior, understanding these seasonal components is crucial for designing sustainable agriculture, mitigating flood damage, and enhancing drought preparedness in the Thanjavur district.

Seasonal Rainfall Analysis for Thanjavur District

WINTER SUMMER RAINY MONSOON
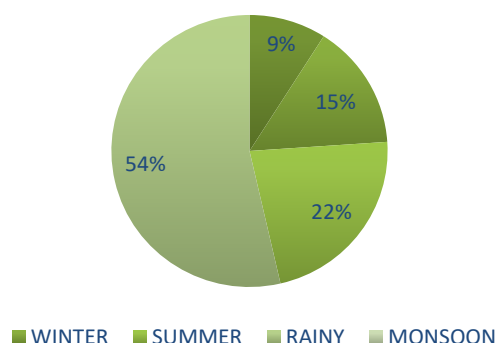
DISCUSSION

Watershed Management Implications

The seasonal and inter-annual rainfall variability in

Thanjavur poses significant challenges for sustainable water resource management. With the majority of precipitation occurring during the Southwest Monsoon (June–September) and the Northeast Monsoon (October–December), the district experiences both rainfall surpluses and deficits depending on the year. The annual rainfall ranges from less than 800 mm in drought-prone years to over 1600 mm in years with intense monsoonal activity. This fluctuation impacts water availability, irrigation reliability, and agricultural productivity. Therefore, a flexible watershed management strategy that aligns with these dual monsoon cycles is necessary. Focus must be placed on seasonal water conservation, tank rehabilitation, and optimizing monsoonal inflows through decentralized, community-led approaches. Developing such systems is key to reducing climate-related vulnerability and ensuring long-term water sustainability.

Rainwater Harvesting and Monsoonal Storage

Rainwater harvesting is a crucial intervention in Thanjavur, where rainfall is seasonally concentrated, especially during the Northeast Monsoon. High-intensity rains in October and November generate significant surface runoff, which can be effectively captured through check dams, percolation ponds, recharge wells, and traditional tank systems. These structures not only increase groundwater recharge but also help prevent runoff loss and soil erosion. In the Cauvery Delta region, where irrigation tanks are standard, desilting and interlinking of tanks can significantly improve water storage and prolong availability during dry spells. Strengthening tank-based irrigation and harvesting infrastructure will improve both water security and crop reliability in high-risk blocks such as Orathanadu and Pattukkottai. Efficient harvesting practices provide resilience against erratic rainfall and help balance water supply across the agricultural seasons.

Flexible and Dynamic Reservoir Operations

Reservoir operations in Thanjavur require increased flexibility to handle fluctuating rainfall patterns and short-duration storm events. Many tanks and reservoirs fail to capture the full benefit of sudden monsoonal downpours due to rigid operating rules and a lack of real-time response. A dynamic system based on rainfall forecasting and hydrological monitoring is essential. This includes capturing water during excess

rainfall periods and controlling releases to prevent overtopping or downstream flooding. During drought years, stored water must be allocated to critical needs, such as drinking water and protective irrigation. Surplus rainfall years should be used to recharge shallow aquifers and fill interconnected tanks. Dynamic operations enhance the district's capacity to adapt to rainfall anomalies and improve overall water management efficiency.

Catchment Afforestation and Soil Conservation

Though Thanjavur is mainly flat and deltaic, catchment areas surrounding tanks and canals suffer from soil erosion and declining infiltration due to vegetation degradation. Afforestation efforts in these micro-catchments can reduce runoff velocity, stabilize embankments, and improve percolation. Soil conservation methods, such as bund strengthening, mulching, and vegetative barriers, can further enhance water retention. Agroforestry using native species like Pongamia, Neem, and Gliricidia along bunds and farm peripheries can increase organic matter, support biodiversity, and reduce irrigation needs. Improving catchment health directly contributes to enhancing tank life, maintaining soil moisture, and promoting sustainable agriculture. These interventions are significant for tail-end areas dependent on tank-fed irrigation.

Drought-Resilient Agricultural Practices

Over 60% of Thanjavur's rainfall occurs between October and December, making agriculture vulnerable to delays or failures in the Northeast Monsoon. Introducing drought-tolerant crops such as short-duration paddy, pulses, millets, and oilseeds can help reduce dependence on irrigation. Micro-irrigation systems, such as drip and sprinkler methods, offer improved water-use efficiency, particularly for horticultural crops. Government schemes such as PMKSY and TNIAMP can be leveraged to expand these technologies. Integrated farming practices and climate-based advisories also help farmers align sowing and irrigation with the actual behavior of the monsoon. Encouraging climate-resilient practices enhances adaptive capacity and ensures agricultural productivity under variable rainfall conditions.

Decentralised and Community-Led Water Supply Systems

In Thanjavur, spatial variation in rainfall across blocks, such as Budalur and Peravurani, limits the efficiency of centralized water distribution systems. Decentralized systems, including tank rehabilitation, localized recharge structures, and roof water harvesting units, provide reliable alternatives. Community participation in water resource governance, through Water User Associations (WUAs) and Panchayat-level committees, can improve the sustainability of these systems. Micro-watershed-based planning ensures equitable distribution and site-specific solutions. Empowering local communities fosters ownership, reduces dependency on external agencies, and improves long-term operation and maintenance of water infrastructure. These decentralized approaches are especially beneficial in addressing the diverse water needs across agro-climatic sub-zones within the district.

Adaptive Water Management in a Variable Climate

Rainfall in Thanjavur varies not only in volume but also in onset and distribution, demanding an adaptive and climate-responsive approach to water management. Incorporating seasonal climate forecasts, groundwater monitoring, and hydrological modeling into planning processes is essential. Recharge structures should be strategically located to capture peak monsoonal flows, especially during Northeast Monsoon events. Water allocation decisions should be informed by post-monsoon assessments of groundwater and storage levels. Coordination among agriculture, water resources, and rural development departments is crucial for implementing integrated plans. Building local institutional capacity and using digital tools for agro-climatic advisories can further enhance the district's ability to respond to water-related challenges posed by climate variability.

Climate Change Inference

Increase in Extreme Rainfall and Drought Incidents

Thanjavur district has witnessed an observable rise in the frequency of both extreme rainfall events and prolonged dry spells over the past few decades. Years such as 2005, 2015, and 2021 recorded unusually high rainfall within short durations, resulting in local flooding and waterlogging in agricultural fields. In contrast, years such as 2002, 2012, and 2016 experienced rainfall deficits, resulting in agricultural stress and groundwater depletion. These hydrological extremes are increasingly being linked to regional climate disruptions, including changes in Bay of Bengal

sea surface temperatures and altered monsoonal wind patterns. The intensification of the Northeast Monsoon in certain years and its near-failure in others reflects the growing climate volatility in the delta region. These extremes affect crop cycles, tank storage reliability, and rural water access. It is critical to invest in real-time monitoring systems, disaster preparedness plans, and predictive analytics to minimize the impact of such events.

Shifts in Monsoon Timing and Distribution

Shifts in the onset and withdrawal patterns of the monsoons are increasingly evident in Thanjavur. The Northeast Monsoon, which typically begins in October, has been delayed in several years, shortening the window available for cultivating key Rabi crops. Similarly, instances of unseasonal rainfall during March and April have impacted summer land preparation, resulting in operational disruptions and reduced crop productivity. These irregularities result in mismatched sowing periods, inadequate moisture availability, and post-harvest losses. Rainfed farmers, particularly those cultivating pulses and oilseeds, are most vulnerable to these shifts. To manage these changes, adaptive agricultural practices are required, including adjusting planting schedules, choosing early-maturing crop varieties, and expanding supplemental irrigation infrastructure. Enhanced forecasting of monsoon onset at the block level would greatly benefit agricultural planning and input management across the district.

Broader Climatic Consistency

The evolving climate trends in Thanjavur district are consistent with global and national projections highlighted in reports such as the IPCC Sixth Assessment Report and India's State Action Plans on Climate Change. The region fits the broader trend of increasing climatic extremes—"wet-get-wetter and dry-get-drier." With the district lying in a deltaic transitional zone, even slight deviations in monsoonal behavior can cause cascading impacts on agriculture, irrigation, and drinking water systems. A greater concentration of rainfall over fewer days has already been observed, which increases the risk of flash floods. Meanwhile, prolonged dry periods between rainfall events strain storage and groundwater recharge. These indicators underscore the pressing need for localized climate vulnerability assessments and responsive water management policies that are tailored to both the spatial and temporal dimensions of climate change.

Implications for Climate-Adaptive Planning

In light of increasing hydro-climatic uncertainty, Thanjavur district must incorporate climate resilience into its developmental planning framework. Early warning systems for flood and drought forecasting, based on satellite data and agro-meteorological modeling, should be made accessible at the village level. Infrastructure design must accommodate dual objectives of flood control and drought mitigation. Promotion of climate-resilient agriculture through conservation tillage, crop rotation, and water-efficient cropping patterns should be supported through targeted extension programs and financial incentives. Monitoring systems must be strengthened to track changes in rainfall intensity, distribution, and groundwater levels. Additionally, planning institutions must integrate climate data into land use zoning, water budgeting, and tank cascade management. Effective adaptation depends not only on technology and data, but also on governance capacity and the translation of climate science into district-level action plans that empower local communities.

Socio-Economic and Agricultural Impacts
Agricultural Productivity and Yield Losses

Agriculture in Thanjavur is heavily reliant on monsoonal rainfall, particularly the Northeast Monsoon, making it vulnerable to variations in rainfall. In years such as 2012 and 2016, delayed or insufficient monsoon led to significant yield losses in paddy, pulses, and groundnut, with estimated reductions exceeding 35 to 40 percent. On the other hand, years with excessive rainfall, such as 2015 and 2021, resulted in waterlogging and an increased incidence of pests and diseases, especially in low-lying paddy fields. Irregular rainfall distribution within the cropping season disrupts planting and harvesting cycles, resulting in reduced crop stand quality and productivity. In tank-fed command areas, insufficient rainfall often fails second-season crops. Farmers face reduced returns, which discourages investment in quality inputs and increases the likelihood of shifting to low-risk subsistence crops or leaving fields fallow. Strengthening climate-resilient farming systems is essential not only for agricultural stability but also for preserving rural livelihoods.

Labour Migration and Income Shocks

Erratic rainfall patterns and uncertain crop incomes have driven seasonal and long-

term labour migration from rural areas in Thanjavur. Post-harvest periods following failed monsoons see an increase in migration to urban centres, such as Chennai and Trichy. Landless agricultural laborers and marginal farmers migrate in search of alternative employment, leading to labour shortages during peak agricultural periods such as transplanting and harvest. This disrupts farm operations and increases dependency on mechanised labor. Migration also impacts household income stability, children's education, and access to healthcare. During the COVID-19 lockdown in 2020, many return migrants faced challenges reintegrating into the rural economy. Enhancing rural employment opportunities through programs such as MGNREGA and providing skill-based training in agri-allied sectors can reduce migration stress and improve socio-economic resilience.

Groundwater Stress and Drinking Water Crises

Intensive use of groundwater for irrigation in Thanjavur, particularly in borewell-fed command areas, has led to alarming declines in groundwater levels. Following years of deficient rainfall, blocks such as Orathanadu, Thiruvaiyaru, and Papanasam have reported falling water tables and reduced borewell yields. The problem is compounded by low recharge due to decreased runoff and sedimentation in tank systems. Drinking water sources in rural areas become unreliable during dry months, forcing dependence on tanker supply or shared sources. Women and children are disproportionately affected, often spending hours fetching water during the summer. Groundwater stress also increases the cost of agriculture, as farmers invest in deeper borewells and pumps. Promoting managed aquifer recharge, regulating borewell drilling, and restoring tank-fed recharge zones are critical to improving long-term water security.

Institutional and Policy Gaps

Despite the availability of various government schemes in agriculture, irrigation, and rural livelihoods, Thanjavur faces implementation challenges due to institutional fragmentation. Many schemes operate in silos, with limited integration at the panchayat level. Delays in disbursing input subsidies and insurance payouts reduce the effectiveness of safety nets, such as PMFBY. Inadequate coordination between departments and poor access to extension services limit farmers' ability to adopt adaptive practices. The lack of localized climate advisories and district-level convergence platforms hampers proactive planning.

Establishing a district climate resilience cell that links various departments and coordinates interventions based on real-time climate data can significantly enhance planning and response capabilities.

Recommendations for Socio-Economic Resilience

Enhancing resilience in Thanjavur's rural economy requires targeted interventions across sectors. First, weather-indexed insurance should be expanded to cover all major crops and include faster claim settlement mechanisms. Second, diversified livelihoods such as dairy farming, agro-processing units, aquaculture, and eco-based enterprises can be promoted through SHGs and FPOs. Third, providing farmers with timely weather and market advisories via SMS and mobile apps can improve decision-making. Fourth, financial literacy and risk management training can enable smallholders to better budget and plan for the long term. Finally, inclusive participatory planning, social audits, and community engagement can ensure that climate-resilient infrastructure and schemes reach the most vulnerable populations. These integrated efforts can build long-term adaptive capacity in the district.

CONCLUSION

This study examines the monsoonal behaviour and rainfall variability in Thanjavur District over a 40-year period from 1984 to 2024, with a particular focus on the influence of the Northeast Monsoon. The results clearly show a seasonal skew, with October and November contributing the highest share of annual precipitation. Thanjavur's heavy reliance on the Northeast Monsoon for both agricultural and water resource needs increases its exposure to climate-related risks, especially when the monsoon is delayed or performs below average.

Hydro-climatic extremes, such as high-intensity rainfall in years like 2005 and 2021, and droughts in years like 2012 and 2016, continue to challenge the stability of water availability, groundwater recharge, and crop productivity in Thanjavur. These disruptions affect sowing periods, reservoir operations, and the performance of traditional tank-fed irrigation systems that are essential to the Cauvery Delta. To address these challenges, this study recommends integrated adaptation approaches including rainwater harvesting, tank restoration, flexible water distribution mechanisms, and the adoption of climate-resilient

agricultural practices tailored to Thanjavur's specific agro-climatic context.

The findings highlight the importance of integrating real-time meteorological data, climate-smart agro-advisories, and participatory water governance structures into district-level planning in Thanjavur. These measures can help local communities prepare for rainfall variability and increase resilience against both flood and drought conditions.

In summary, this study emphasizes the crucial role of rainfall trend analysis in informing water management, agricultural planning, and climate adaptation strategies in Thanjavur District. The use of long-term historical rainfall data provides a scientific foundation for developing drought mitigation plans, sustainable cropping systems, and localized water budgeting. By linking climatic data with grassroots-level action, Thanjavur can strengthen its adaptive capacity and respond more effectively to the challenges posed by climate change.

DATA AVAILABILITY

The data supporting the findings of this study were obtained from publicly accessible sources, including the Indian Meteorological Department (IMD), NASA POWER database, and Tamil Nadu State Disaster Management Authority (TNSDMA). Processed datasets and graphical rainfall summaries generated during the study are available from the corresponding author upon reasonable request.

DISCLAIMER

The views and conclusions presented in this paper are solely those of the authors and do not reflect any official position of institutions or agencies. While care has been taken to ensure the accuracy of the information, the authors bear full responsibility for the content.

DETAILS OF AI USAGE

AI tools, such as ChatGPT, were utilized during the manuscript preparation process to assist with editing, refining structure, and enhancing language clarity. All interpretations, analyses, and graphical representations were independently performed and verified by the authors.

COMPETING INTERESTS

The authors declare that they have no known financial or personal conflicts of interest that could have influenced the content, interpretation, or conclusions of this study.

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