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Climate Change and Rainfall Distribution in Tirupati District: An Urban & Rural Analysis Using Geospatial Technology

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ABSTRACT

The study focuses on the rainfall distribution in Tirupati district, Andhra Pradesh, with an emphasis on the implications of climate change on agricultural practices and water resource management. Focusing on 2000, 2010 and 2025. Secondary data from the Indian Meteorological Department, which provides high-resolution gridded rainfall datasets, are used to analyze rainfall patterns across all 36 mandals of the district. The methodology employs Geographic Information System techniques and standard statistical tools to evaluate rainfall variability and its implications for agriculture and water resource management.

The results indicate considerable temporal variability in rainfall patterns. In 2000, the district primarily experienced moderate rainfall (826-894 mm), supporting agricultural stability. By 2010, rainfall levels increased, resulting in both low (1200-1320 mm) and high (1460-1580 mm) categories, which suggests a shift toward more extreme weather conditions. Projections for 2025 indicate a slight decrease in moderate rainfall (1250-1410 mm) and an increase in high rainfall events (1420-1570 mm), raising concerns regarding flooding and water resource management. The analysis identifies distinct trends between urban and rural areas. Tirupati Urban exhibits increased rainfall variability, reflecting the influence of urbanization and climate change. In contrast, rural areas have experienced significant increases in both moderate and high rainfall categories, presenting challenges for agricultural practices and water resource management. The study highlights the need for modified adaptation strategies to address the specific challenges posed by changing rainfall patterns in both urban and rural contexts.

Keywords: Climate Change, Rainfall (mm), Urban, Rural, Environment & GIS

Tirupati district, established on April 4, 2022, is an administrative region in the Rayalaseema area of Andhra Pradesh, India. It covers 8,827 square kilometres and has its headquarters in Tirupati. The district is situated between 13°21'54" and 14°8'32" North latitudes and 79°5'42" and 80°4'10" Eastern longitudes. It is bordered by the Bay of Bengal to the east, Annamayya and Chittoor districts to the west, SPSR Nellore and Annamayya districts to the north, and Chittoor district and the state of Tamil Nadu to the south. Tirupati district comprises 5.05 percent of Andhra Pradesh's total area. As per the 2011 census, the population is 22.40 lakh. The average elevation of the mountainous region is approximately 2,500 feet above sea level. The Swarnamukhi River flows through the district from the north-northwest to the south-southeast (fig.1).

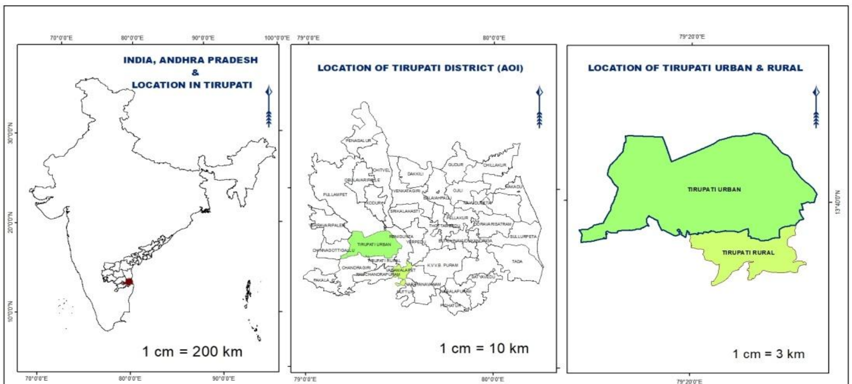

Fig:1

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INTRODUCTION

Climate change is increasingly recognized as a critical factor influencing global weather patterns, with significant implications for regions such as India. The Intergovernmental Panel on Climate Change (IPCC) has documented a marked increase in the frequency and intensity of extreme weather events, particularly altered rainfall patterns (IPCC, 2021). These changes pose a dual challenge for agriculture in drought-prone areas, as shifting rainfall patterns can lead to both floods and droughts, severely impacting crop yields and food security (Ghosh & Dutta, 2020).

Kumar and Singh (2019) demonstrate that these climatic changes are not uniform across India; some regions experience increased rainfall, while others endure prolonged dry spells, thereby exacerbating regional vulnerabilities. In Andhra Pradesh, rising temperatures and erratic rainfall have been shown to threaten agricultural productivity and the livelihoods of millions (Rao & Reddy, 2018). The broader consequences extend to water resources, public health, and economic stability, highlighting the urgent need for effective mitigation strategies in response to climate variability (Mishra & Singh, 2010).

Droughts, intensified by both climatic variability and anthropogenic factors, constitute a significant environmental challenge, particularly in Andhra Pradesh (Narasimhan & Raghavan, 2017). The increasing frequency and severity of droughts are associated with altered rainfall patterns driven by urbanization, which disrupt traditional weather systems and place additional strain on already limited water resources (Srinivasan & Sinha, 2021; Kumar & Sharma, 2022). Mishra and Singh (2010) further emphasize the profound socio-economic consequences of droughts, which affect millions and contribute to food insecurity, underscoring the necessity for both immediate relief measures and long-term resilience planning.

Objectives:

- To study the distribution of rainfall (in mm) across all 36 mandals of the study area for the years 2000, 2010 and 2025
- To analyze the distribution of rainfall variability specifically within the Tirupati Urban and Rural area for the years 2000, 2010 and 2025

METHODOLOGY

In this study, I used secondary data to gather information about the areas covered by different mandals and urban and rural districts in Tirupati. Have been collected from the Indian Meteorological Department, which has released a new high spatial resolution gridded rainfall dataset (0.25 x 0.25 degrees) in NetCDF format. Covering a long period from 1901 to 2024.

However, the website will also provide access to the data in 2025). For the data product provides daily gridded rainfall information with a very high spatial resolution. Rainfall amounts are measured in millimetres (mm). The primary analysis of rainfall patterns during 2000, 2010 and 2025 in urban and rural regions of Tirupati district. The analyzed rainfall data for each of the 36 mandals in the study area.

GIS techniques have been applied to map the analysed data.

Data collection

Data for the years 2000, 2010 and 2025 are available at the following site: https://www.imdpune.gov.in/cmpg/Griddata/Rainfall_25_NetCDF.html.

Software: All spatial analyses and map generation were conducted using ArcGIS 10.3 for geospatial processing.

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RESULT AND DISCUSSION

Distribution of Annual Rainfall in Tirupati District:

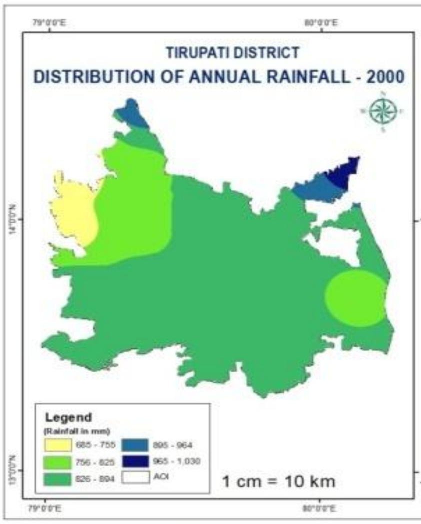
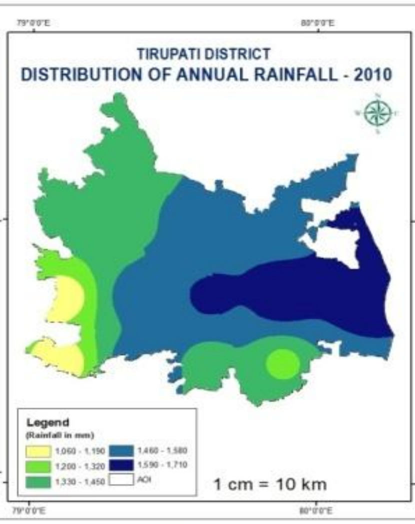


Fig:2



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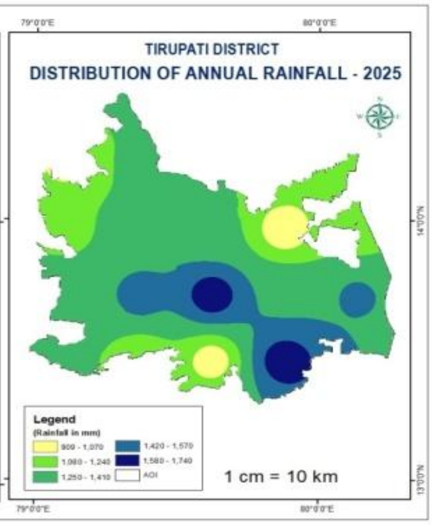

Fig:4

The main interpretation of the map data is to examine the rainfall patterns for the years 2000, 2010 and 2025 in the Urban & Rural areas of Tirupati district.

Rainfall Distribution of Tirupati District in 2000:

Rainfall in Tirupati District demonstrates considerable spatial variation, which has a direct impact on agricultural activities.

- Very Low Rainfall (685 mm to 755 mm): Pullampeta and portions of Pengalur receive the lowest rainfall, presenting significant challenges for agricultural production.
- Low Rainfall (756 mm to 825 mm): Several mandals, including Pengalur, Chitvel, and Pullampeta, fall within this category, indicating widespread insufficient precipitation.
- Moderate Rainfall (826 mm to 894 mm): Mandals such as Pengalur, Kodur, and Tirupati receive rainfall levels that generally support favorable crop growth.
- High Rainfall (895 mm to 964 mm): A smaller number of mandals, including Pengallur and Vakadu, receive higher rainfall, which may enhance agricultural productivity but also increases the risk of flooding and soil erosion.
- Very High Rainfall (965 mm to 1030 mm): Chilakur is the only mandal in this category, experiencing the highest rainfall, which has significant implications for regional water management and agriculture.

In summary, the rainfall patterns observed in 2000 highlight the need for effective agricultural strategies and water management to address the uneven distribution of precipitation.

Rainfall Distribution of Tirupati District in 2010:

In 2010, annual rainfall in Tirupati District was classified into five categories based on specific millimeter (mm) ranges:

- Very Low (1060 mm - 1190 mm): Mandals such as Chinagottigalu, Pakala, Chandragiri (in part) and Yerravaripalem experienced significant water scarcity, which adversely affected agricultural productivity.
- Low (1200 mm - 1320 mm): This range includes mandals such as Chinagottigalu, Pakala (in part), Chandragiri, Yerravaripalem, Satyavedu, Nagalapuram and Varadaiahpalem (in part). Although water availability increased slightly, water scarcity remained a concern.

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- Moderate (1330 mm - 1450 mm): A broader range of mandals, including Chandragiri, Nagalapuram, Varadaiahpalem, Puttur, Narayanavanam, Venkatagiri (in part), Chillakur, Tirupati Urban, Dakali, Balaiahpalle and KVVB Puram, fall within this category. Increased rainfall in these areas supported improved agricultural conditions.
- High (1460 mm - 1580 mm): Mandals such as Varadaiahpalem, Tada, Yerpedu, Srikalahasti, Renigunta, Tirupati Urban and Rural, Ramachandrapuram, Puttur, Narayanavanam (in part), Ojili, Dakali, Chillakur, Nayudupeta, Pellakur, Venkatagiri, Vakadu (in part), Thottambedu, KVVB Puram and Doravarisatram received substantial rainfall, which supported robust agricultural practices.
- Very High (1590 mm - 1710 mm): Mandals including Varadaiahpalem, Tada, Yerpedu, Srikalahasti, Renigunta, Pellakur, Chandragiri, B.N. Kandriga, Sullurpet, Vakadu, Doravaristram and Thottambedu experienced abundant rainfall, which enhanced water resources but also increased the risk of flooding.

Overall, the spatial distribution of rainfall in 2010 had significant implications for both agricultural productivity and water resource management in Tirupati District.

Rainfall Distribution of Tirupati District in 2025:

In 2025, annual rainfall in Tirupati District is categorized into five distinct groups:

- Very Low (909 mm - 1070 mm): Narayanavanam, Puttur (in part), Ojili, Nayudupeta, and Pullampeta receive minimal rainfall, which may negatively affect agricultural activities.
- Low (1080 mm - 1240 mm): This group includes Narayanavanam, Puttur, Vadamalapeta, Tirupati Urban and Rural, Srikalahasti, Vakadu, Kodur, Obulavaripalle, Pengalur, Pullampeta, Yerravaripalem, Balaiahpalle, Ramachandrapuram, and Chandragiri. These areas experience a moderately favourable climate for agriculture, although water scarcity may continue.
- Moderate (1250 mm - 1410 mm): Tada, Sullurpet, B.N. Kandriga, Vadamalapeta, Tirupati urban and rural, Srikalahasti, Vakadu, Kosur, Obulavaripalle, Chitvel, Pengallur, Yerravaripalem, Balaiahpalle, Ramachandrapuram, Chandragiri, Pakala, and Chinagottigalu fall within this range, which supports the cultivation of diverse crops and increases agricultural productivity.
- High (1420 mm - 1570 mm): Satyavedu, Nagalapuram, Varadaiahpalem, Tada, Sullurpet, Tirupati Urban, Chinnagottigallu, and Srikalahasti receive higher rainfall, which may increase crop yields but also raises the risk of soil erosion and water logging.
- Very High (1580 mm - 1740 mm): Satyavedu, Nagalapuram and Varadaiahpalem receive the highest rainfall, which has a substantial impact on local environmental and agricultural conditions.

In conclusion, spatial variability in rainfall across Tirupati District remains a critical factor influencing agricultural potential, water resource management, and environmental planning.

Distribution of Annual Rainfall in Tirupati Urban: 2000, 2010 & 2025

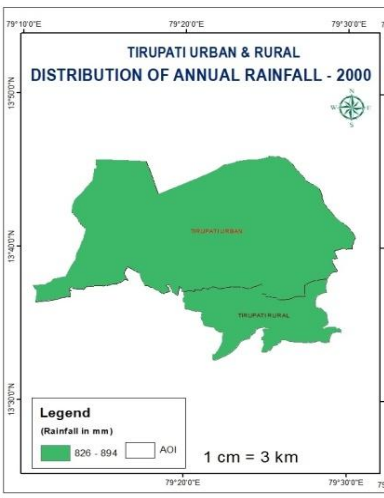
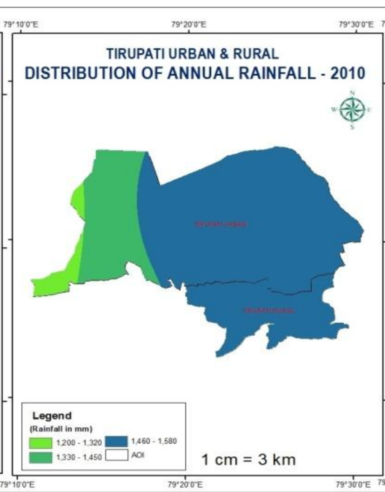


Fig:5



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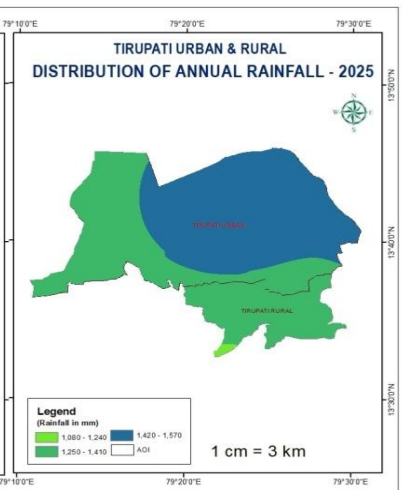

Fig:7

A review of rainfall distribution maps for the Tirupati urban area in 2000, 2010, and 2025 shows that precipitation patterns have changed significantly.

In 2000, the recorded rainfall was exclusively categorized as Moderate, with totals ranging from 826 to 894 mm. Notably, there were no instances of very low, low, or very high rainfall, which may indicate either a lack of data or the absence of these extremes during that year.

By 2010, the rainfall distribution exhibited a marked shift. The Low rainfall category emerged, defined by a range of 1200 to 1320 mm, indicating an increase in overall precipitation. Additionally, the Moderate category expanded to encompass 1330 to 1450 mm, further underscoring the rise in rainfall levels. These changes could be attributed to various factors, including alterations in climatic conditions or the impacts of urban development.

In 2025, the rainfall patterns continued to evolve. The Moderate category adjusted to a range of 1250 to 1410 mm, reflecting a slight decrease from 2010 but still higher than the levels recorded in 2000. Importantly, a new High rainfall category was introduced, with an expected range of 1420 to 1570 mm, suggesting an increase in extreme rainfall events. Overall, the data illustrate a consistent trend of changing rainfall patterns in the Tirupati urban area over the years, highlighting growing variability in precipitation.

Distribution of Annual Rainfall in Tirupati Rural:

The comparative analysis of annual rainfall distribution in Tirupati Rural for the years 2000, 2010 and 2025 reveals notable changes in rainfall patterns across different categories.

In 2000, moderate rainfall, defined as precipitation between 826 and 894 mm, was present, indicating a stable rainfall environment. However,

By 2010, the moderate rainfall category was absent, which could suggest either a lack of data or a significant shift in rainfall patterns.

In 2025, the moderate rainfall range increased dramatically to 1250-1410 mm, signifying a substantial rise in overall rainfall levels.

The analysis also highlights trends in the high rainfall category. In 2010, high rainfall was recorded between 1460 and 1580 mm, showing an increase compared to previous years. Yet, by 2025, this range adjusted slightly to 1420-1570 mm, indicating a decrease in high rainfall levels. These fluctuations may be linked to changing weather patterns or the broader impacts of climate change.

The data presented in the maps demonstrate a significant trend in rainfall patterns in Tirupati rural during the observed years. There were no recorded instances of very low or low rainfall, indicating that precipitation consistently surpassed these thresholds. This persistent absence of low-rainfall categories underscores the region's tendency toward higher precipitation levels. Additionally, the analysis reveals notable fluctuations in rainfall dynamics, especially within the moderate and high rainfall categories, which showed considerable variation over time. Collectively, these findings indicate a relatively stable climate characterized by substantial rainfall, suggesting a shift in the region's hydrological patterns.

CONCLUSION

The analysis of annual rainfall distribution in Tirupati district for 2000, 2010 and 2025 reveals significant variability in precipitation patterns, with important implications for agriculture and water resource management.

In 2000, rainfall levels were primarily categorized as moderate, with no instances of very low or very high rainfall. By 2010, there was a notable increase in rainfall, with the emergence of low and high categories, indicating a shift in climatic conditions. The moderate category also expanded, suggesting improved water availability for agricultural practices.

Looking ahead to 2025, projections indicate a slight decrease in moderate rainfall levels compared to 2010, while the introduction of a high rainfall category suggests an increase in extreme weather events. This trend highlights growing concerns regarding rainfall variability and intensity, necessitating effective water management and urban planning strategies.

In Tirupati urban and rainfall patterns have evolved from a stable moderate range in 2000 to increased variability by 2010 and projected changes in 2025, reflecting the impact of urban development and climate change. In contrast, Tirupati Rural has shown significant increases in both moderate and high rainfall categories, indicating potential challenges and opportunities for local agriculture and ecosystems.

The findings underscore the need for tailored strategies to address the unique challenges posed by changing rainfall patterns in both urban and rural areas of the Tirupati District.

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