Assessment of Decadal Trends in Rainfall and Temperature and Their Agricultural Implications in Alluri Sitharama Raju District of Andhra Pradesh

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Received:- 14 December 2025/ Revised:- 22 December 2025/ Accepted:- 28 December 2025/ Published: 05-01-2026

***Abstract*—** *This study quantifies the decadal hydrometeorological variability (2016–2025) and its agronomic implications for the rainfed, high-altitude tribal agro-ecosystem of Chintapalle in the Eastern Ghats. Utilizing daily meteorological datasets—precipitation, maximum temperature (Tmax), and minimum temperature (Tmin)—sourced from the Agro-Meteorological Field Unit, we applied descriptive statistical models and decadal aggregation to assess temporal climatic shifts. Our temporal analysis indicates pronounced precipitation volatility driven by monsoonal anomalies. The decadal mean precipitation stabilized at approximately 1480 mm, yet exhibited severe inter-annual amplitude fluctuations of up to 570 mm. Thermally, the data confirms a distinct post-2018 warming trajectory. Specifically, Tmax recorded a significant positive anomaly of approximately 1.4°C. A concomitant escalation in Tmin indicates warming nocturnal regimes, thereby constricting the diurnal temperature range (DTR). These combined hydrometeorological perturbations fundamentally destabilize regional agricultural systems. Altered thermal and precipitation regimes directly impact critical sowing windows, disrupt soil moisture homeostasis, accelerate crop phenology, and shift pest-pathogen dynamics for key crops including rice, coffee, maize, and turmeric. To mitigate these systemic vulnerabilities, integrating climate-resilient agronomy—specifically, advanced hydro-conservation, robust crop diversification paradigms, and hyper-local meteorological agro-advisory frameworks—is imperative for sustaining the adaptive capacity of this ecologically fragile zone*.

Keywords*— *Hydrometeorological variability, Rainfed agro-ecosystem, Decadal climate analysis, Monsoonal precipitation variability, Diurnal temperature range (DTR), Climate change impacts on agriculture, Eastern Ghats agro-ecosystem, Climate-resilient agronomy.

I. INTRODUCTION

Rainfed agricultural ecosystems are acutely vulnerable to hydro-thermal volatility, where marginal climatic shifts drastically destabilize crop phenology and yield trajectories (FAO, 2016; IPCC, 2014). Nationally, the agricultural sector underpins the Indian economy, contributing approximately 18% to the Gross Value Added (GVA) and serving as a critical engine for foreign exchange (MoA&FW, 2025). This macroeconomic importance is strongly mirrored at the micro-level in Chintapalle, a high-altitude tribal agro-climatic zone in Andhra Pradesh's Alluri Sitharama Raju (ASR) district (17.6765°N, 82.3419°E; elevation 768 m AMSL). The region's rugged topography and heavy dependency on spatiotemporally erratic monsoons directly govern its agricultural viability.

The ASR district's agrarian economy is anchored by a specific blend of subsistence cereals and high-value commercial crops with immense export potential (DES-AP, 2024). Coffee dominates the landscape, covering approximately 100,000 ha with an annual production of 12,000 MT and a productivity of 120 kg/ha. Indian coffee exports are currently witnessing sharp decadal growth, surging to a record $1.8 billion in 2024–25, driven heavily by global demand for sustainable, shade-grown varieties characteristic of the Chintapalle agency area (Coffee Board, 2025). Additionally, commercial rhizomes like turmeric (8,000 ha; 32,000 MT) and ginger (4,000 ha; 12,000 MT) provide critical economic buffers, directly feeding into India's robust spice export basket which consistently commands over $4 billion annually (Spices Board, 2024). Staple cereals form the backbone of local food security, led by rice (45,000 ha; 90,000 MT), maize (6,962 ha; 24,367 MT), and climate-resilient finger millet (15,000 ha; 16,500 MT). Notably, Indian millet exports have seen aggressive global expansion recently, cementing the commercial viability of these traditional tribal crops.

However, these foundational crops exhibit strict bioclimatic thresholds. Coffee demands precise thermal baselines and pre-monsoon precipitation for optimal anthesis, while the cereals and rhizomes are highly susceptible to biphasic extremes of soil moisture deficit, waterlogging, and shifting nocturnal thermal regimes. Driven by increasing evidence of irregular monsoon onsets and warming trajectories (MoES, 2020), localized decadal analyses are critical. Consequently, this study quantifies the decadal meteorological variability (2016–2025) in Chintapalle to assess systemic implications for these primary cropping systems, aiming to safeguard both local livelihoods and their broader economic export contributions through targeted, weather-based agro-advisories.

II. MATERIALS AND METHODS

2.1 Study Area:

The present investigation was conducted in the high-altitude, tribal-dominated Alluri Sitharama Raju (ASR) district of Andhra Pradesh (17.6765°N, 82.3419°E; elevation 768 m AMSL). The geomorphology of the study area is characterized by undulating hilly terrain and dense forest cover, which restrict the development of extensive irrigation infrastructure and dictate a predominant reliance on rainfed agriculture. Climatologically, Chintapalle falls under a tropical monsoon regime. The regional hydrology is fundamentally driven by a bimodal precipitation pattern, with the primary moisture influx occurring during the Southwest Monsoon (June–September) and secondary contributions from the Northeast Monsoon (October–December).

The agro-ecological landscape features a topographically delineated cropping matrix:

- **Valley Ecosystems:** Dominated by lowland rice cultivation.
- **Upland and Hill Slopes:** Dedicated to shade-grown commercial coffee plantations.
- **Rainfed Tracts:** Utilized for cultivating staple coarse cereals (maize and finger millet/ragi) alongside high-value commercial rhizomes (turmeric and ginger).

Because these diverse cropping systems operate at strict bioclimatic thresholds, they are highly vulnerable to spatiotemporal anomalies in precipitation and diurnal temperature fluctuations. This inherent hydro-thermal sensitivity makes the Chintapalle region an ideal, representative locus for assessing the micro-level impacts of decadal climate variability.

2.2 Data Used:

The present study utilized secondary meteorological data for the period 2016–2025 obtained for Chintapalle area of Alluri Sitharama Raju district. The dataset comprised annual total rainfall (mm), monthly mean maximum temperature (°C), and monthly mean minimum temperature (°C). Monthly temperature records were aggregated to compute annual mean maximum and annual mean minimum temperatures for each year of the study period. Annual rainfall totals were derived from cumulative monthly rainfall data. The dataset represents continuous observations over a ten-year period and provides a consistent basis for assessing recent decadal climate variability in the district. The selected parameters—rainfall, maximum temperature, and minimum temperature—are critical agro-climatic indicators that directly influence crop growth, water availability, and overall agricultural productivity in predominantly rainfed systems.

2.3 Data Processing and Analysis:

The following analytical procedures were adopted:

2.3.1 Annual Mean Calculation:

Monthly maximum and minimum temperature values were summed and divided by twelve to obtain annual mean maximum and minimum temperatures. Annual rainfall totals were calculated by summing monthly rainfall values for each year.

2.3.2 Identification of Extremes:

The wettest and driest years were identified based on annual rainfall totals. Similarly, years with highest and lowest annual mean temperatures were determined.

2.3.3 Inter-Annual Variability Assessment:

Rainfall variability was assessed by examining the range between maximum and minimum annual rainfall values during the study period. Temperature variability was evaluated by comparing annual means across years to identify warming or cooling tendencies.

2.3.4 Trend Observation:

Decadal trends in maximum and minimum temperatures were assessed through comparative analysis of early-decade and late-decade averages to detect potential warming patterns. Statistical analyses were performed using appropriate software.

III. RESULTS

3.1 Rainfall Variability

The analysis of annual rainfall during the period 2016–2025 revealed substantial inter-annual variability in Chintapalle area of Alluri Sitharama Raju district. The decadal mean annual rainfall was approximately 1480 mm, indicating generally adequate rainfall conditions for rainfed agriculture. However, considerable fluctuations were observed across individual years. High rainfall years may contribute to soil erosion and nutrient leaching, while deficit years intensify soil moisture stress (FAO, 2016). The highest annual rainfall was recorded in 2020 (1749 mm), while the lowest rainfall was observed in 2022 (1180 mm) as per Figure 1. The total variation between the wettest and driest year was approximately 570 mm, reflecting high rainfall variability within the decade. Studies indicate that rainfall variability rather than total annual rainfall often determines crop yield stability in monsoon-dependent regions (MoES, 2020). Although no consistent linear increasing or decreasing trend was evident, the alternating occurrence of excess and deficit years suggests unstable monsoonal behavior. Such variability increases the risk of both waterlogging during high rainfall years and moisture stress during deficit years, particularly in rainfed cropping systems (Gadgil & Gadgil, 2006; IPCC, 2021).

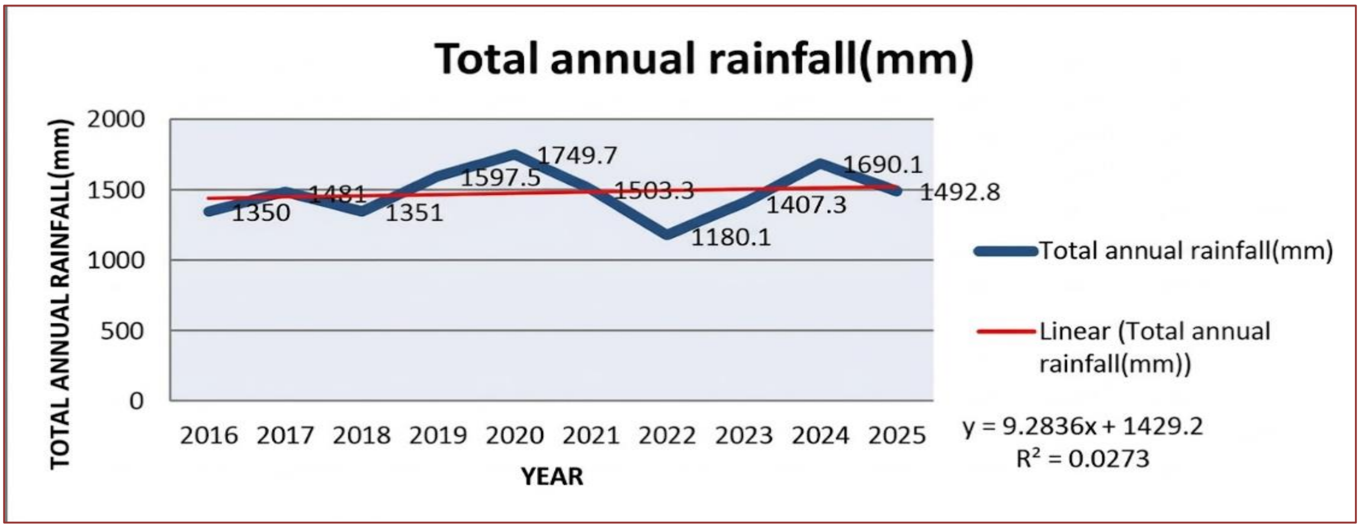

FIGURE 1: Annual rainfall variability in Chintapalle, ASR district (2016-2025). The decadal mean (1480 mm) is shown as a horizontal line. Note the wettest year (2020: 1749 mm) and driest year (2022: 1180 mm).

3.2 Maximum Temperature Trend:

The annual mean maximum temperature exhibited a gradual increasing tendency over the study period. As per Figure 2, the mean maximum temperature was 28.8°C in 2016, which increased to 30.2°C in 2024, representing an approximate rise of 1.4°C during the decade (IPCC, 2014). Higher maximum temperatures were particularly noticeable after 2018, indicating a warming phase in recent years. Elevated daytime temperatures can accelerate crop phenological stages, increase evapotranspiration demand, and intensify heat stress during critical growth periods such as flowering and grain filling (Lobell et al., 2011). The rise in maximum temperature, though moderate, is significant in the context of hill and tribal agricultural systems that are traditionally adapted to relatively stable climatic conditions.

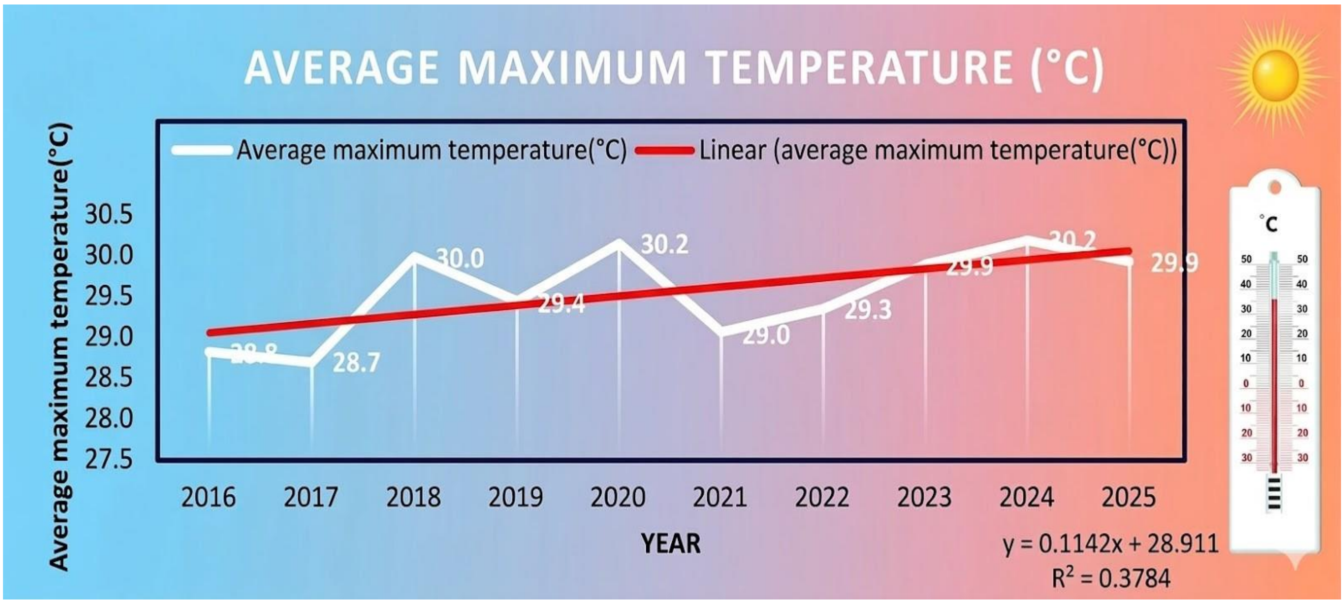

FIGURE 2: Annual mean maximum temperature (Tmax) trend in Chintapalle, ASR district (2016-2025). Temperature increased from 28.8°C (2016) to 30.2°C (2024), a rise of approximately 1.4°C.

3.3 Minimum Temperature Trend:

The annual mean minimum temperature showed notable fluctuations during the decade. As per Figure 3, the minimum temperature in 2016 was 17.1°C, whereas a pronounced cold anomaly was observed in 2018 (12.0°C). This sharp decline represents a significant deviation from the decadal norm. Following 2018, a consistent rise in minimum temperature was observed, reaching 18.5°C in 2024, which represents the highest value during the study period. This indicates a clear pattern of night-time warming in recent years (Peng et al., 2004). Increasing minimum temperatures are particularly important as they influence crop respiration rates, pest survival, and disease proliferation (FAO, 2016). Night-time warming is widely recognized as a signature of regional climate change (IPCC, 2021) and may have long-term implications for perennial crops such as coffee and spice crops grown in upland areas.

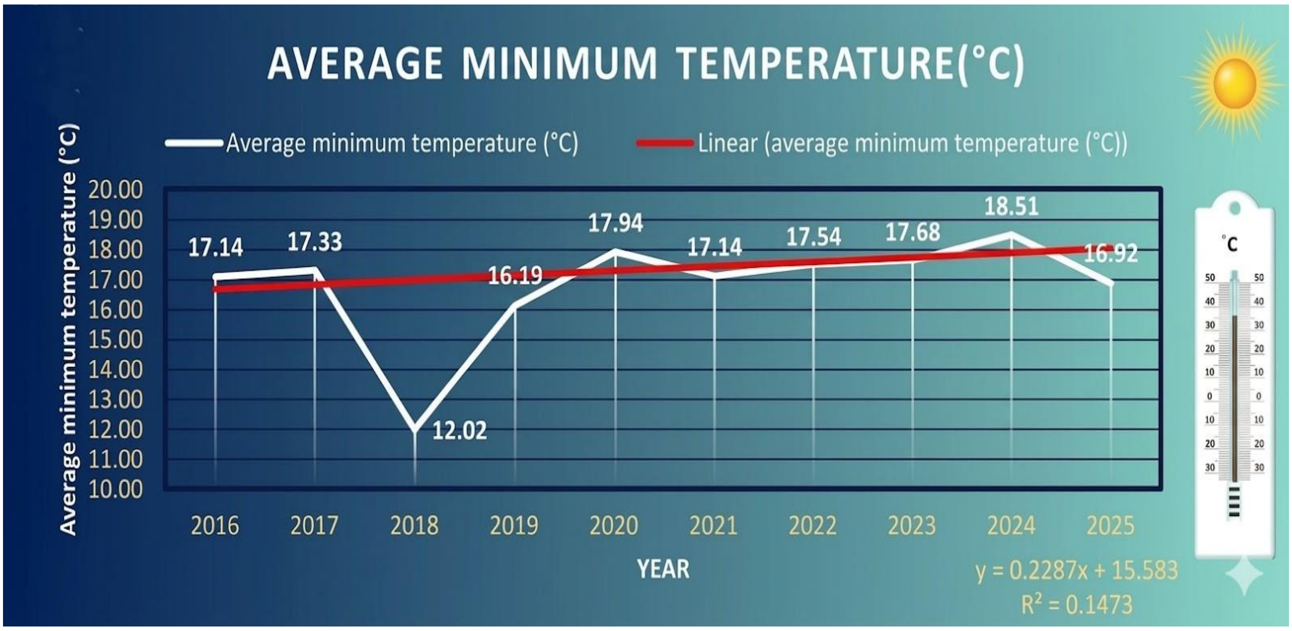

FIGURE 3: Annual mean minimum temperature (Tmin) trend in Chintapalle, ASR district (2016-2025). Note the cold anomaly in 2018 (12.0°C) and subsequent warming to 18.5°C in 2024.

3.4 Diurnal Temperature Range (DTR):

The Diurnal Temperature Range (DTR), calculated as the difference between annual mean maximum and minimum temperatures, provides insight into thermal variability and stress conditions. Changes in diurnal temperature range are considered important indicators of climate variability (Braganza et al., 2004). The year 2018 recorded an unusually high DTR (~18°C), primarily due to the sharp decline in minimum temperature. Such elevated DTR indicates strong thermal contrast between day and night temperatures, which can impose physiological stress on crops, particularly during sensitive growth stages. In contrast, during most other years of the decade, the DTR remained within the range of 12–13°C, indicating relatively stable thermal conditions. However, the gradual rise in minimum temperature after 2018 has contributed to a slight narrowing of DTR in recent years, consistent with warming trends observed in many tropical regions (IPCC, 2021). Overall, the combined analysis of rainfall variability, increasing maximum temperature, rising minimum temperature, and fluctuations in DTR suggests increasing climatic instability in the district.

IV. DISCUSSION

4.1 Hydrometeorological Volatility:

The 2016–2025 assessment of the Alluri Sitharama Raju (ASR) district reveals severe inter-annual precipitation amplitude fluctuations (exhibiting variances of up to ~570 mm against a ~1480 mm decadal mean). In a predominantly rainfed, undulating topographical system, these biphasic extremes dictate regional agronomic outcomes (Raji Reddy et al., 2007). Hyper-precipitation events trigger topsoil erosion, nutrient leaching, and transient hypoxia (waterlogging) in valley-bottom rice systems. Conversely, deficient years induce acute soil moisture deficits, compromising the yield stability of upland coarse cereals like maize and millets.

4.2 The 2018 Thermal Anomaly:

The 2018 dataset exhibits a distinct cold anomaly, defined by an acute depression in minimum temperature (Tmin) and an unusually expanded Diurnal Temperature Range (DTR). Such abrupt thermal shocks disrupt sensitive crop phenology. For instance, suppressed nocturnal temperatures delay anthesis and disrupt berry setting in shade-grown coffee (IPCC, 2014), while simultaneously arresting the early vegetative vigor of staple cereals like rice and maize.

4.3 Post-2018 Warming Trajectory and Physiological Stress:

Following 2018, a persistent warming trend emerged, characterized by escalations in both maximum temperature (Tmax, approximately +1.4°C) and Tmin. Elevated Tmax intensifies atmospheric evapotranspirative demand, exacerbating moisture stress in rainfed soils. Concurrently, rising Tmin accelerates nocturnal respiration, depleting non-structural carbohydrates and lowering net biomass accumulation. This thermal shift triggers specific physiological penalties across the cropping matrix:

- **Rice:** Elevated thermal regimes during anthesis and grain-filling stages induce spikelet sterility and diminish final grain weight (Peng et al., 2004).
- **Maize & Ragi:** Heat stress during critical reproductive windows severely truncates grain-filling duration, reducing ultimate yield potential (Lobell et al., 2011).
- **Rhizomes (Turmeric/Ginger):** The synergistic stress of erratic soil moisture and elevated ground temperatures directly compromises rhizome bulking and biochemical quality.

V. CONCLUSION

The decadal analysis (2016–2025) of rainfall and temperature in the Chintapalle region of the High Altitude and Tribal (HAT) Zone of Alluri Sitharama Raju District indicates increasing climatic variability characterized by irregular rainfall distribution and a gradual rise in temperature. The occurrence of alternating excess and deficit rainfall years reflects growing uncertainty in monsoon behavior, while increasing day and night temperatures may influence crop phenology, water demand, and productivity in predominantly rainfed farming systems. Strengthening climate resilience in this vulnerable tribal region requires targeted interventions, including:

1. Expansion of rainwater harvesting structures such as farm ponds, check dams, and contour trenches through convergence of PMKSY (Pradhan Mantri Krishi Sinchayee Yojana), watershed programmes, and RAMG-type rural asset development schemes.

2. Strengthening weather-based agro-advisories under GKMS (Gramin Krishi Mausam Sewa).
3. Promotion of climate-resilient millets and traditional crops under NFSM-Millets (National Food Security Mission-Millets) and tribal livelihood programmes.
4. Enhanced involvement of agricultural universities through location-specific climate-resilient agriculture and livelihood security in the HAT zone of Alluri Sitharama Raju district.

ACKNOWLEDGMENT

The authors express their sincere gratitude to the India Meteorological Department (IMD), Pune, for providing the necessary meteorological data and technical support used in this research. The weather data supplied by IMD played an important role in analyzing climatic variability and its implications in the present study

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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