Shri. Suresh Lamani, 2026, 14:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Spatio-Temporal Assessment of Rainfall Variability in Gadag District, Karnataka

Research Scholar Shri. Suresh Lamani[1], Assistant Professor Dr.M.B. Chalawadi[2]
[1,2]Department of Studies and Research in Geography, Rani Channamma University, Belagavi
[1]Programme coordinator, MGRDPR University, Gadag

Abstract- Rainfall is the key hydro-meteorological determinant governing agricultural sustainability in the semi-arid regions of North Interior Karnataka. This paper presents a rigorous statistical appraisal of rainfall characteristics in Gadag district over a 35-year epoch (1991–2025) across seven taluks Gadag, Mundargi, Shirhatti, Ron, Nargund, Lakshmeshwar, and Gajendragad. The long-term mean annual rainfall of the district is established at 542.53 mm with a standard deviation of 103.77 mm and a Coefficient of Variation (CV) of 19.13%, representing moderate inter-annual variability. Seasonal partitioning demonstrates the dominance of the South-West (SW) monsoon, contributing 66.8% (362.48 mm) to the annual budget, followed by the North-East (NE) monsoon at 16.7% (90.40 mm). Spatial analysis indicates that Shirhatti receives the highest annual mean (586.74 mm), while Nargund is the most arid taluk (501.69 mm). According to the India Meteorological Department (IMD) drought indices, the 35-year period witnessed 6 excess years, 7 deficit years, and 22 normal years. These findings offer critical baselines for predictive water budgeting, drought preparedness, and regional cropping patterns.

Keywords— Remote Sensing and GIS Spatio-temporal analysis, Gadag district, South-West Monsoon, Coefficient of Variation, Rainfall departure, Drought assessment.

I. INTRODUCTION

Gadag district is situated in the drought-prone, semi-arid region of North Interior Karnataka on the Deccan Plateau, India. Owing to its location in the rain-shadow region of the Western Ghats, the district receives low and highly variable rainfall, resulting in frequent water scarcity and a strong dependence on monsoon rainfall for agriculture and groundwater recharge (CGWB 2022; IMD 2023). Agriculture in the district is predominantly rain-fed, making it highly vulnerable to fluctuations in seasonal rainfall.

Rainfall is one of the most important climatic variables controlling agricultural productivity, groundwater recharge, streamflow, and water resource availability in semi-arid regions (WMO 2018; FAO 2021). The southwest monsoon (June–September) contributes the major share of annual rainfall in Karnataka, while variations in its onset, intensity, and distribution directly influence crop production and drought occurrence (IMD 2023; Krishnan et al. 2020).

Recent studies indicate that climate change has increased the frequency and intensity of hydro-meteorological extremes, including droughts, extreme rainfall events, and irregular monsoon behaviour across the Indian subcontinent (IPCC 2023; Krishnan et al. 2020). Changes in land-use patterns and anthropogenic activities have further altered local hydrological processes, increasing the uncertainty of rainfall distribution in semi-arid regions (IPCC 2023; WMO 2021).

Long-term analysis of rainfall variability provides valuable information for understanding regional climate behaviour and supports effective planning for agriculture, groundwater management, and drought mitigation (Rajeevan et al. 2006; WMO 2018). Statistical indicators such as the arithmetic mean, standard deviation, coefficient of variation, and rainfall departure are widely used to quantify rainfall variability and identify climatic anomalies (Hare 2003; WMO 2018).

Several studies have investigated rainfall variability and climate trends across different parts of India and

Karnataka using long-term meteorological observations (Gadgil and Gadgil 2006; Krishnan et al. 2020; IMD 2023). However, detailed spatio-temporal assessment of rainfall characteristics at the taluk level for Gadag district remains limited despite its importance for regional water resource planning and drought management.

Therefore, the present study analyses a continuous 35-year rainfall dataset (1991–2025) to evaluate the spatio-temporal variability of rainfall across the seven taluks of Gadag district. The study examines annual and seasonal rainfall characteristics, spatial variability, and rainfall departure based on the India Meteorological Department classification. The findings provide a scientific basis for sustainable water resource management, drought preparedness, groundwater conservation, and climate-resilient agricultural planning in the semi-arid region of North Interior Karnataka.

II. STUDY AREA

Gadag District is situated in the north-central part of the state of Karnataka, India, and forms an important component of the semi-arid Deccan Plateau. The district was carved out of the erstwhile Dharwad District on 24 August 1997. It extends between 15°02′ to 15°52′ North latitude and 75°18′ to 76°12′ East longitude, covering a geographical area of approximately 4,656 km². The district is bounded by Koppal District to the east, Haveri District to the south, Dharwad District to the west, and Bagalkot District to the north.

Administratively, Gadag District comprises seven taluks: Gadag, Mundargi, Ron, Shirahatti, Nargund, Gajendragad, and Laxmeshwar. According to the 2011 Census of India, the district has a population of approximately 1.07 million, with a population density of around 229 persons per km².

The climate of Gadag District is classified as hot semi-arid (BSh) according to the Köppen climate classification. The district lies in the rain-shadow region of the Western Ghats, receiving an average annual rainfall of approximately 600–700 mm, mainly during the southwest monsoon season (June–September). The annual temperature ranges from about 16°C in winter to over 42°C during summer, with high evapotranspiration rates contributing to frequent water scarcity.

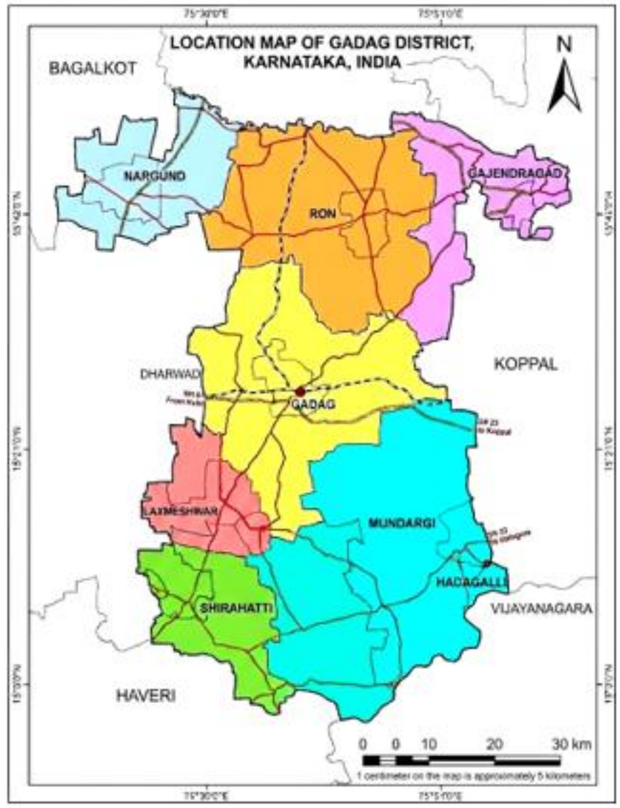

Figure 1: Location Map of the study Area

Topographically, the district consists of gently undulating plains with elevations ranging from approximately 550 to 700 m above mean sea level

III. METHODOLOGY

1. Data Acquisition

The present study investigates the spatial and temporal variability of rainfall in Gadag District, Karnataka, using long-term rainfall observations and geospatial techniques. Daily rainfall data for the period 1991–2025 were collected from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC) and the India Meteorological Department (IMD). The daily records were aggregated into monthly, seasonal (Southwest Monsoon, Northeast Monsoon, Winter, and Summer), and annual rainfall datasets using Microsoft Excel and Python.

Data quality assessment was performed to identify missing values, outliers, and inconsistencies. Missing observations were filled using standard statistical interpolation methods wherever appropriate. Descriptive statistical measures, including mean, standard deviation, coefficient of variation (CV), rainfall anomaly,were computed to quantify rainfall variability. The database tracks continuous precipitation indicators over a 35-year window. The calendar year is segmented into four standardized meteorological seasons:

Pre-Monsoon: March to May

- South-West (SW) Monsoon: June to September
- North-East (NE) Monsoon: October to December
- Winter: January to February

2. Statistical Formulation

The mathematical constructs employed to resolve central tendency, absolute dispersion, relative dispersion, and atmospheric fluctuations are given as follows:

Arithmetic Mean (μ): Measures the baseline long-term climatological normal.

$$\boldsymbol{\mu = (1 / N) * \Sigma\,(from\ i = 1\ to\ N)\ of\ P\_i}$$

Standard Deviation (σ): Represents absolute dispersion around the historical baseline.

$$\boldsymbol{\sigma = \sqrt{[\,(1 / (N - 1)) * \Sigma\,(from\ i = 1\ to\ N)\ of\ (P\_i - \mu)^2\,]}}$$

Coefficient of Variation (CV): The relative index used to categorize precipitation stability. A higher CV signifies lower stability and higher vulnerability.

$$\boldsymbol{CV\,(\%) = (\sigma / \mu) * 100}$$

Percentage Departure (D): Used to gauge anomalous deviations from the long-term normal.

$$\boldsymbol{D\,(\%) = [\,(P\_actual - P\_normal) / P\_normal\,] * 100}$$

3. Meteorological Classification

Using the guidelines laid down by the India Meteorological Department (IMD), individual annual performances are categorized using the following thresholds:

- Excess Year: D ≥ +20%
- Normal Year: -19.9% ≤ D ≤ +19.9%
- Deficit Year (Drought): D ≤ -20%

IV. RESULT AND DISCUSSION

1. Macro District-Wide Rainfall Summary

The consolidated statistical response of Gadag district over the 35-year observation span shows a long-term annual mean of 542.53 mm. The total structural variation matches the expected patterns of the semi-arid zone (CV = 19.13%).

Table 1: Seasonal Rainfall Breakdown for Gadag District (1991–2025)

Season	Historical Mean (μ, mm)	Standard Deviation (σ, mm)	Coefficient of Variation	Relative Contribution (%)
Pre-Monsoon	70.63	15.17	21.48%	13.0%
SW Monsoon	362.48	70.67	19.50%	66.8%
NE Monsoon	90.40	17.32	19.16%	16.7%
Winter	19.02	7.15	37.59%	3.5%
Total Annual	542.53	103.77	19.13%	100.0%

2. Taluk-Wise Spatial Heterogeneity

Spatial analysis shows distinct changes across the micro-administrative blocks of the district.

Table 2: Taluk-Specific Annual and Seasonal Statistical Matrix (mm)

Taluk	Annual Mean	Annual SD	Annual CV (%)	Pre-Monsoon Mean	SW-Monsoon Mean	NE-Monsoon Mean	Winter Mean
Shirhatti	586.74	125.56	21.40%	80.73	393.08	98.33	14.60
Gadag	560.27	112.34	20.05%	72.97	379.33	90.32	17.66

Lakshmeshwar	551.62	110.84	20.09%	72.20	366.89	92.11	20.44
Gajendragad	537.76	107.01	19.90%	69.48	357.56	93.47	17.25
Mundargi	530.12	115.81	21.85%	68.25	350.24	86.34	25.29
Ron	529.51	107.70	20.34%	69.08	352.20	88.96	19.26
Nargund	501.69	100.73	20.08%	61.71	338.07	83.24	18.66

The High-Rainfall Zone: Located in the southern/south-western margins, Shirhatti (586.74 mm) and Gadag (560.27 mm) benefit from convective elements near the transitional zones.

The Low-Rainfall Zone: The northern core plains, represented by Nargund (501.69 mm) and Ron (529.51 mm), show pronounced rain-shadow aridity. Nargund exhibits the lowest overall moisture levels across all seasons.

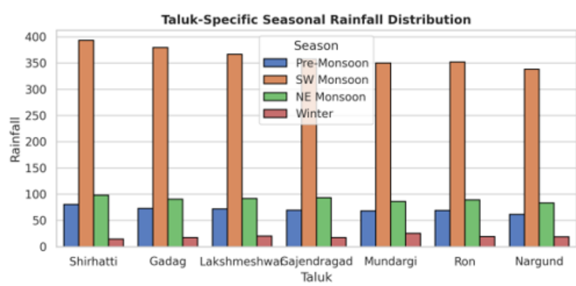

Figure 2: Grouped Seasonal Rainfall Distributions across Taluk Administrative Blocks

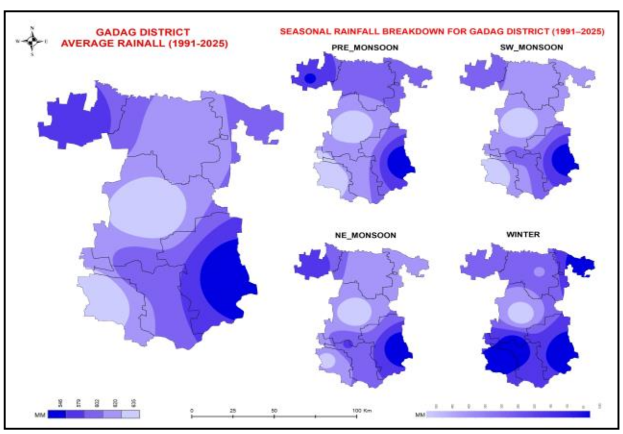

Figure 3: Seasonal and Annual Rainfall Breakdown Map for Gadag District (1991–2025)

3. Historical Trend and Annual Departure Analysis

Evaluating annual performance against the district long-term normal (542.5 mm) highlights a highly variable history of climate anomalies.

Table 3: Year-wise Total Rainfall, Percentage Departure, and As per IMD Classifications

Year	Actual Rainfall (mm)	Normal Baseline (mm)	Percentage Departure (D, %)	IMD Classification
1991	577.26	542.5	+6.41%	Normal
1992	476.97	542.5	-12.08%	Normal
1993	567.14	542.5	+4.54%	Normal
1994	550.71	542.5	+1.51%	Normal
1995	521.09	542.5	-3.95%	Normal
1996	619.40	542.5	+14.18%	Normal
1997	580.14	542.5	+6.94%	Normal
1998	662.93	542.5	+22.20%	Excess
1999	523.79	542.5	-3.45%	Normal
2000	513.00	542.5	-5.44%	Normal
2001	494.64	542.5	-8.82%	Normal
2002	488.09	542.5	-10.03%	Normal
2003	425.29	542.5	-21.61%	Deficit
2004	547.69	542.5	+0.96%	Normal
2005	360.57	542.5	-33.54%	Deficit
2006	535.44	542.5	-1.30%	Normal
2007	500.71	542.5	-7.70%	Normal
2008	393.34	542.5	-27.49%	Deficit
2009	427.36	542.5	-21.22%	Deficit
2010	503.87	542.5	-7.12%	Normal
2011	559.90	542.5	+3.21%	Normal
2012	731.00	542.5	+34.75%	Excess
2013	330.34	542.5	-39.11%	Deficit
2014	691.57	542.5	+27.48%	Excess
2015	567.74	542.5	+4.65%	Normal
2016	503.49	542.5	-7.19%	Normal
2017	411.57	542.5	-24.13%	Deficit
2018	615.73	542.5	+13.50%	Normal
2019	725.54	542.5	+33.74%	Excess
2020	616.73	542.5	+13.68%	Normal
2021	518.86	542.5	-4.36%	Normal
2022	434.46	542.5	-19.92%	Normal
2023	730.31	542.5	+34.62%	Excess
2024	563.81	542.5	+3.93%	Normal
2025	718.07	542.5	+32.36%	Excess

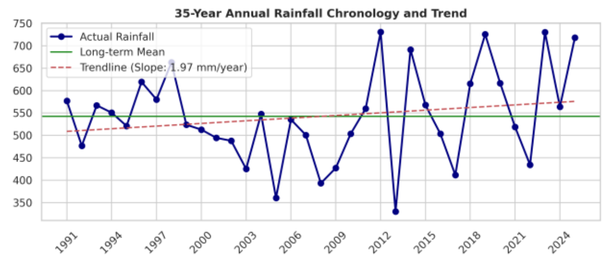

Figure 4: 35-Year Continuous Annual Rainfall Chronology and Linear Slope Trendline

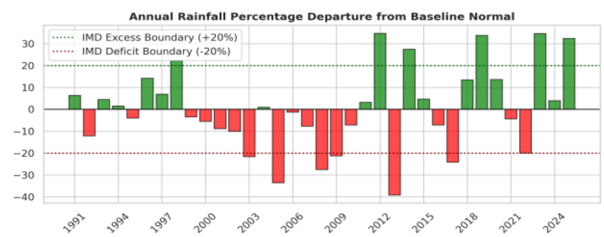

Figure 5: Historical Anomaly Evaluation Mapping via IMD Percentage Departures

4. Drought Recurrence and Frequency Response

During this 35-year study window, the distribution of agricultural and meteorological classifications is defined as:

- Excess Climatic Years (6 cases): 1998, 2012, 2014, 2019, 2023, 2025. These correspond to strong regional monsoonal conditions, occasionally causing severe flooding along seasonal streams such as the Bennihalla.
- Deficit Drought Years (7 cases): 2003, 2005, 2008, 2009, 2013, 2017. The most acute event occurred in 2013 (D = -39.11%), triggering widespread crop failures and requiring government relief operations.
- Normal Climatic Years (22 cases): Representing 62.8% of the temporal observations, confirming that while the baseline remains semi-arid, deviations tend to fall within manageable boundaries during roughly two out of three seasons.

V. POLICY RECOMMENDATIONS AND WATER RESOURCE MANAGEMENT

Given the high inter-annual variability and localized drought frequencies observed in the data, the following interventions are recommended

- Integrated Watershed Strategy: The steep gradients of the Kappatagudda range across Shirhatti and Gadag require structural barriers like check dams and contour bunding to maximize retention of SW monsoonal surges.
- Crop Restructuring: In arid blocks like Nargund and Ron, traditional water-intensive farming should give way to drought-hardy crops (millet, sorghum, pulses) that align with the baseline 500 mm crop-water requirement.
- Managed Aquifer Recharge (MAR): High-volume run-off during the 6 identified 'Excess' years should be redirected into deep borewells to artificially recharge the fractured peninsular crystalline aquifer systems.

VI. CONCLUSION

This systematic 35-year analysis provides a clear picture of the moisture dynamics in Gadag district. The long-term normal of 542.53 mm highlights its semi-arid status, while a CV of 19.13% reveals moderate, yet impactful, inter-annual variability. The highly skewed seasonal structure where two-thirds of the annual budget falls within a single four-month monsoon window emphasizes the importance of water storage infrastructure. The taluk-level analysis successfully delineates regional differences, contrasting the moisture advantages of Shirhatti against the aridity of Nargund. These quantitative baselines provide municipal water authorities and agricultural planners with the data needed to advance climate-resilience frameworks across the district.

REFERENCES

1. Kumar, U., Singh, S., Bisht, J. K., & Kant, L. (2021). Use of meteorological data for identification of agricultural drought in semi-arid and hilly regions. Journal of Earth System Science, 130(3), 121–133. https://doi.org/10.1007/s12040-021-01622-1
2. Reddy, S., Keerthy, G. S., Challa, N. G., Naidu, G. K., & Reddy, S. (2024). Assessment of climate change in different regions of Karnataka state. MAUSAM, 75(2), 333–348. https://doi.org/10.54302/mausam.v75i2.5873

3. Sanjeevaiah, S. H., Rudrappa, K. S., Lakshminarasappa, M. T., Huggi, L., & Hanumanthaiah, M. M. (2021). Understanding the temporal variability of rainfall for estimating agro-climatic onset of cropping season over Karnataka, India. Agronomy, 11(6), 1135. https://doi.org/10.3390/agronomy11061135
4. Sawant, S., & Kukkemane, S. (2024). Evaluating agricultural drought severity in Karnataka, India through integrated remote sensing indices. Ecocycles, 10(2), 128–143. https://doi.org/10.19040/ecocycles.v10i2.477
5. Sreekesh, S., Kaur, N., & Sreerama Naik, S. R. (2019). Agricultural drought and soil moisture analysis using satellite image based indices in North Interior Karnataka basins. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-3/W6, 507–514. https://doi.org/10.5194/isprs-archives-xlii-3-w6-507-2019
6. India Meteorological Department (IMD). Historical District-wise Rainfall Statistics Reports.
7. Central Ground Water Board (CGWB). Hydrogeological Framework and Water Quality Management Options in Gadag Craton.
8. Geological Society of India. Agrarian Vulnerability to Hydro-Climatic Variables in Crystalline Terrains of North Karnataka.
9. Journal of Farm Sciences (2023). Historical and Projected Rainfall Analysis for North Interior Karnataka Districts. 12(3), 241-249.
10. India Meteorological Department (IMD). (2024). Historical District-wise Rainfall Statistics Reports for North Interior Karnataka. Ministry of Earth Sciences, Government of India. International Journal of Scientific Research in Computer Science Engineering and Information Technology, vol. 5, no. 2, pp. 345–350, 2020.