Decoding Rainfall Diversity: A Long-Term GIS Assessment of the Chikkamagaluru Region

K.S. Sreekeshava*, C. Bhargavi and G. Gayathri

Department of Civil Engineering, Jyothy Institute of Technology, Affiliated to Visvesvaraya Technological University, Belagavi 590018, India

Abstract: This study analyses long-term rainfall variability across Chikkamagaluru, Mudigere and Belur taluks using a 47-year continuous dataset (1977–2024). Spatial interpolation (Ordinary Kriging, 1 km × 1 km resolution) and temporal trend diagnostics (Mann–Kendall, Sen's slope) were used to quantify seasonal patterns and windward–leeward gradients. Mean annual rainfall across the region is 1769 mm, with monsoon rainfall contributing 80–86% of yearly totals. Windward stations such as Kottigehara and Hosakere receive 3–4 times more rainfall (up to 4170 mm) than leeward stations such as Kalasapura (~680 mm). Trend analysis indicates weak but notable seasonal trends: monsoon rainfall shows non-significant decreasing tendencies at most leeward stations, while pre-monsoon rainfall shows slight increasing trends (Sen's slope +1.8 to +3.2 mm/year). Spatial rainfall maps and trends align strongly with Western Ghats orography and established monsoon climatology. These findings enhance hydro-climatic understanding and provide actionable insights for watershed planning, agriculture, and hazard mitigation.

Keywords: Rainfall variability, Kriging, Chikkamagaluru, Trend analysis, Mann–Kendall, Sen's slope, Western ghats, GIS.

1. INTRODUCTION

Rainfall is the principal driver of hydrology, ecology and agronomy in monsoon-dominated landscapes, and its spatial–temporal variability controls water availability, agricultural productivity, slope stability and ecosystem health across the Western Ghats foothills of India. In the Chikkamagaluru–Mudigere–Belur region (Malnad), Karnataka, India which forms the eastern flank of the Western Ghats, steep orography produces large rainfall gradients over short distances: windward ridges receive very high monsoon totals while adjacent leeward plains remain comparatively dry [1]. These sharp windward–leeward contrasts have direct consequences for groundwater recharge, soil erosion, landslide susceptibility, crop choice and local livelihoods, making detailed rainfall mapping a priority for environmental planning and hazard mitigation [2].

Recent advances in high-resolution gridded precipitation products and remote sensing have improved our ability to resolve orographic rainfall patterns at local scales, but station-based analyses remain essential for validation, historical baselines and ground-truthing of models [3, 4]. The India Meteorological Department's high-resolution gridded rainfall product (0.25° × 0.25°) and other merged gauge–satellite datasets provide valuable modern records for regional studies, while radar and satellite analyses increasingly reveal sub-kilometre variability in orographic precipitation that is important for local planning. These data developments underscore both the opportunity and the need to update regional rainfall assessments with contemporary, high-resolution information [5].

Several regional and catchment-scale studies have characterised long-term rainfall variability across southern India and the Western Ghats. Published analyses using non-parametric trend tests (Mann–Kendall) and Sen's slope estimators document spatially heterogeneous trends: some windward sectors show increases in high-intensity monsoon rainfall while other areas exhibit little change or even declines in seasons [6-9]. These heterogeneous signals reflect the complex interplay of large-scale monsoon dynamics, local orography and land-use change. However, many previous efforts either (a) focus on coarse national grids, (b) cover limited station networks, or (c) stop before the most recent decade — leaving a need for updated, taluk-scale maps and short-term trend assessments that are directly usable by planners and hydrologists.

Specifically for the Malnad/Chikkamagaluru region, spatial studies (isohyet mapping, station analyses) have established the dominant orographic control and the stark seasonal partitioning of rainfall (pre-monsoon, monsoon, post-monsoon, winter). Yet two important gaps remain for applied environmental management: (1) near-contemporary taluk-level summaries that explicitly quantify recent decadal changes, and (2) integrated products that combine station baselines with modern gridded/resampled surfaces to support updated isohyet maps, watershed planning and hazard zoning. The original station-based dataset for this study

*Address correspondence to this author at the Department of Civil Engineering, Jyothy Institute of Technology, Affiliated to Visvesvaraya Technological University, Belagavi 590018, India; E-mail: Sreekeshava.ks@jyothyit.ac.in,

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provides a robust historical baseline (1977–2024) that is ideal for this purpose.

Given the socioeconomic dependence on reliable monsoon rains in the study area, decision-makers require high-resolution isohyet maps that reflect long-term means and recent changes, taluk-scale seasonal breakdowns (pre-monsoon, monsoon, post-monsoon, winter) to inform cropping calendars and water-storage planning and short-term trend indicators (*e.g.*, Mann–Kendall, Sen's slope) that flag areas of potential intensification or drying for targeted field verification.

Earlier studies have established strong monsoonal control over Peninsular India's rainfall and documented spatially heterogenous trends across the western ghats. However the gaps remain in high resolution taluk scale spatial mapping, updated trend diagnostic extending beyond 2010 and integrated GIS-based rainfall surfaces validated with dense station networks.

To meet these needs, the present study (a) uses the station network and baseline summary from the original dataset (1977–2024) as a continuous historical reference, (b) augments that reference to deliver near-contemporary 1977–2024 composites for mapping and short-term trend diagnostics and (c) applies GIS interpolation and non-parametric trend testing to produce actionable products (isohyets, seasonal rasters and trend summaries). This combined station and gridded approach follows best practice in recent Western Ghats rainfall research and responds directly to the policy-relevant gap in up-to-date, taluk-scale rainfall products.

The objectives of the study hence includes producing taluk-scale, seasonally resolved isohyet maps for Chikkamagaluru, Mudigere and Belur based on a continuous dataset (1977–2024),quantifying spatial patterns and windward–leeward gradients and identify high-risk zones for erosion and recharge, applying short-term trend diagnostics (Mann–Kendall and Sen's slope) on the recent decade to identify areas showing indications of intensification or decline in rainfall and provide maps and summary statistics suitable for planners, hydrologists and researchers working on watershed management, crop scheduling and slope stabilization.

2. MATERIALS AND METHODS

2.1. Data Source and Dataset Continuity

All rainfall data used in this study originate from a single, continuous, authoritative meteorological source to ensure homogeneity. The core dataset includes 47 years of observed annual and seasonal rainfall (1977–2024) for all stations in Chikkamagaluru, Mudigere, and Belur taluks, extracted from the institutional rainfall obtained from the institutional meteorological archives and IMD/KSNDMC validated station data sets from 1977-2013 and 2014-2024 respectively.

The final dataset used in this study spans 47 years (1977–2024) and includes annual rainfall for 40+ stations, seasonal rainfall (for the three primary taluks) Winter (Jan–Feb), Pre-monsoon (Mar–May), Monsoon (Jun–Sep) and Post-monsoon (Oct–Dec). All stations were checked for internal consistency, missing data(<5% for most stations), homogeneity across double mass curves and cross-comparison with neighbouring stations. Missing values(<2%) were estimated using Ordinary Kriging and Normal Ratio Method where appropriate.

2.2. Study Area and Station Network

The study covers Chikkamagaluru, Mudigere, and Belur taluks in the Western Ghats transition zone. The region features steep orographic gradients that strongly modulate rainfall.

The station network comprises of high-rainfall windward stations (*e.g.*, Kottigehara, Hosakere, Sringeri), mid-elevation interior stations (*e.g.*, Aldur, Kadur) and low-rainfall leeward stations (*e.g.*, Kalasapura, Arsikere). This spatial diversity enabled accurate interpolation and mapping of rainfall gradients. Table **1** and Figures **1**,**2** and **3** present the geographical and satellite imagery of the study area. Table **2** presents the details of the stations considered in this study.

2.3. Seasonal Classification

Rainfall values were grouped into four climatological seasons commonly used in Indian monsoon

Table 1: Geographical Characteristics of the Study Area

Taluks	Mudigere	Chikkamagalur	Belur
Coordinates	13°08´N & 75°38´E	13°19´N & 75°46´E	13°17´N & 75°87´E
Altitude	915m	1037m	963m
Population	128,134	1,137,961	184,458

Table 2: Complete Station Metadata used in the Study

Sl. No	Station Name	Latitude (N)	Longitude (E)	Elevation (m)
1	Kottigehara	13.1335	75.5664	1010
2	Hosakere (Mudigere)	13.1368	75.6441	980
3	Mudigere	13.1337	75.6408	970
4	Hanbal	13.1271	75.6302	965
5	Gonibeedu	13.1783	75.7339	960
6	Madenahalli (Mudigere)	13.1530	75.7005	945
7	Arehalli	13.1761	75.6520	940
8	Balur	13.1185	75.5129	1040
9	Banakal	13.1359	75.5204	1035
10	Aldur	13.3500	75.6500	995
11	Sringeri	13.4195	75.2520	680
12	Jayapura	13.4063	75.3371	720
13	Chikkamagaluru	13.3223	75.7740	1090
14	Kadur	13.5540	76.0123	780
15	Lingadahalli	13.4856	75.8704	850
16	Sakrepatna	13.3362	75.8723	910
17	Mallanduru	13.2912	75.7392	995
18	Marle	13.2702	75.7099	980
19	Hiremagalur	13.3345	75.8126	1005
20	Kanathi	13.2571	75.8001	970
21	Malleshwara Betta (Foothill gauge)	13.2400	75.7800	1150
22	Belur	13.1620	75.8629	970
23	Halebeedu	13.2158	75.9922	915
24	Halagaere (Hagare)	13.1655	75.9270	910
25	Channakeshava Puram	13.1700	75.8560	925
26	Bikkodu	13.2394	75.9427	900
27	Javagal	13.2439	76.0308	895
28	Haluvalli	13.1625	75.8095	960
29	Arekere	13.2054	75.8874	900
30	Mallapura	13.1805	75.8403	940
31	Dasarahalli (Belur)	13.3105	76.0245	860
32	Halekote	13.2502	75.9318	920
33	Maravanji	13.2142	75.9054	905
34	Khandya	13.4453	75.6535	900
35	Aldhara	13.2900	75.6100	1020
36	Thogari Beedhi	13.1050	75.5320	1025
37	Makonahalli	13.2980	75.5700	985
38	Kelakuli	13.2050	75.7200	1020
39	Balehonnur	13.3581	75.4763	670
40	Basarikatte	13.4011	75.5497	720

climatology. The classification of seasons, months and their climatic influence is mentioned in Table **3**. For 1977–2024, seasonal rainfall was taken directly from the station/taluk dataset.

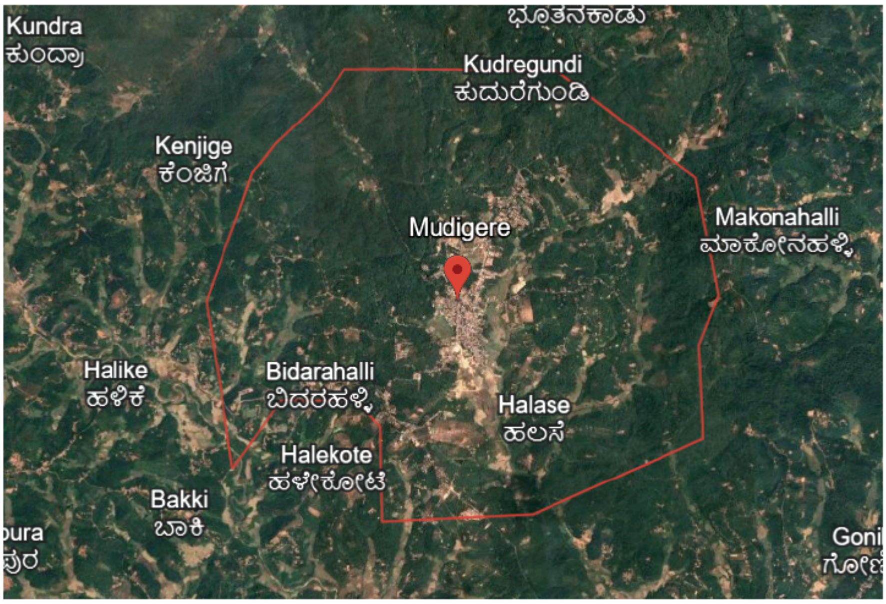

Figure 1: Mudigere Taluk.

Figure 2: Belur Taluk.

2.4. GIS, Interpolation and Spatial Resolution

Spatial rainfall surfaces for annual and seasonal rainfall were generated using ArcGIS 10.x and SURFER-8, integrating both geostatistical and deterministic interpolation techniques [12] to evaluate spatial variability [13] across Chikkamagaluru, Mudigere and Belur Taluks. The workflow consisted of spatial data preparation, interpolation model testing, surface generation and map refinement.

2.4.1. Spatial Data Preparation

All rainfall station locations were decoded using theor latitude and longitude coordinates(WGS 84) and imported as point features into ArcGIS. The processing steps included verification of station coordinates and removal of spatial duplicates, quality check for outliers and anomalous values, conversion of rainfall attributes into annual and seasonal datasets, creation of a boundary mask for the study area using district and

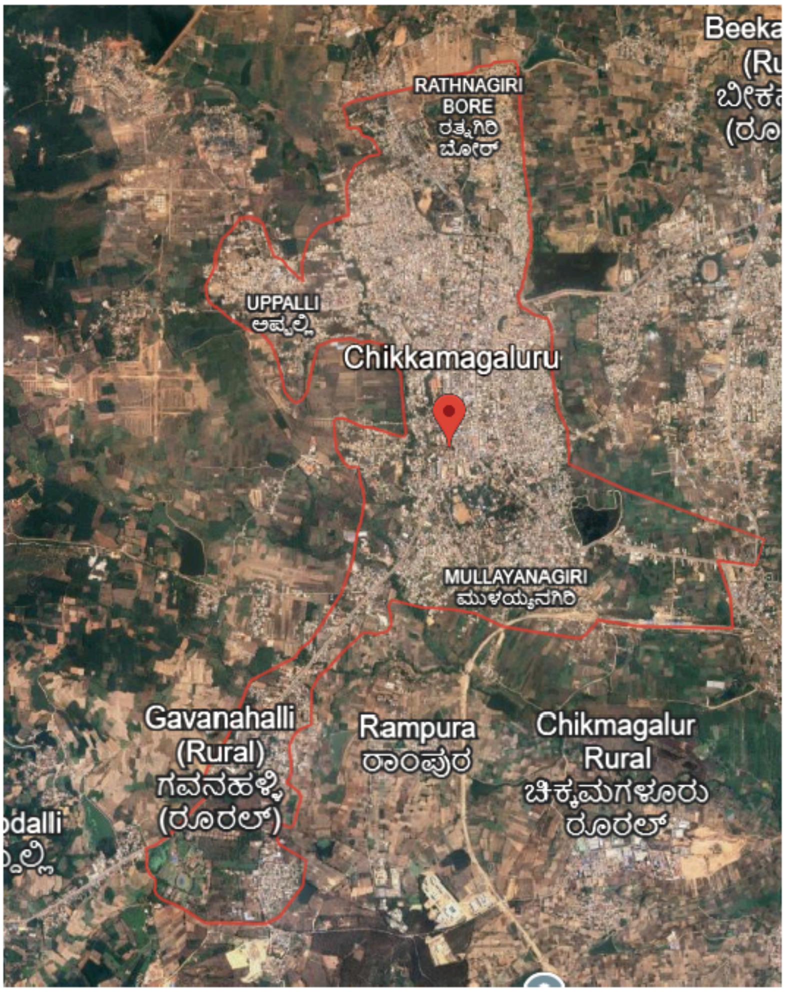

Figure 3: Chikkamagaluru Taluk.

Table 3: Classification of Climatic Influence in Various Seasons in Indian Climatology

Season	Months	Climatic Influence	References
Winter	Jan–Feb	Weak NE monsoon residual rainfall	[10,11]
Pre-monsoon	Mar–May	Convective thunderstorms, heat-low formation	

taluk shapefiles, reprojection of all layers to WGS 84 for spatial consistency.

2.4.2. Interpolation Method Selection

Three interpolation methods were tested including Inverse Distance weighting(IDW), Spline and Ordinary Kriging.

3. RESULTS AND DISCUSSION

3.1. Annual Rainfall Characteristics (1977–2024)

Analysis of the 47-year continuous observational dataset shows substantial spatial variability in annual rainfall across the study region. Annual rainfall exhibits a pronounced west–east declining gradient, which is characteristic of the Western Ghats foothill climate. Figure **4** presents the 40 rain Guage stations in and around the study area.

As depicted in the Figure **5**, the long term mean annual rainfall of the study area is 1769.48mm. The spatial distribution of rainfall is strongly influenced by the unique topography of the western ghats, the presence if numerous hill ranges and extensive Balur green forest located in the southern part of Mudigere taluk. The region experiences significant rainfall due to these orographic and ecological factors [14]. The highest annual rainfall was recorded in Kottigehara(4170.84mm) while the lowesr occurs at Kalasapura(677.68mm). The southern part of study area consistently received the greatest amount of rainfall, particularly at stations such as Kottigehara(4170.84mm), Hosakere(4089.68mm),

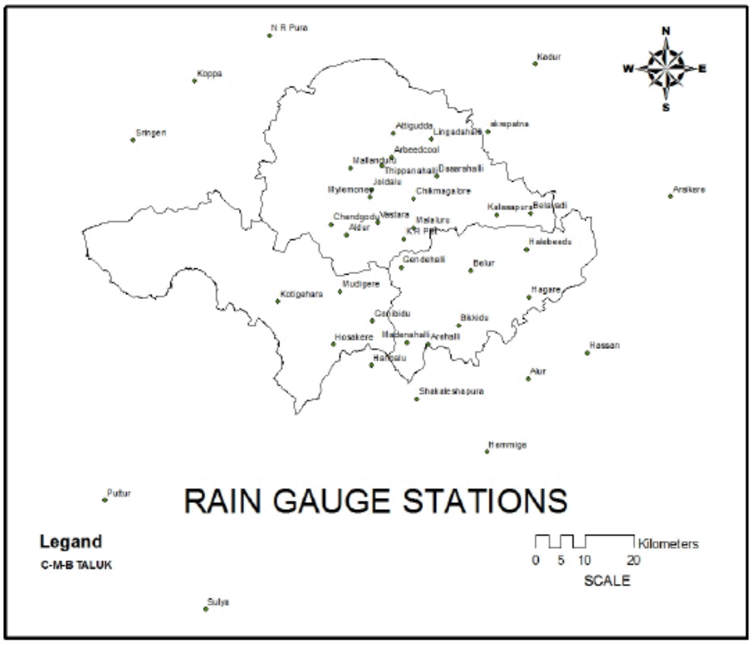

Figure 4: Rain gauge stations.

Hanbalu (2599.90mm), Mudigere(2366.40mm), Gonibeedu(2271.97mm) and Madenahalli(1959.27mm). These locations lie within the windward slopes of the Western Ghats in the Malnad region and receive substantial monsoon rainfall due to orographic uplift.

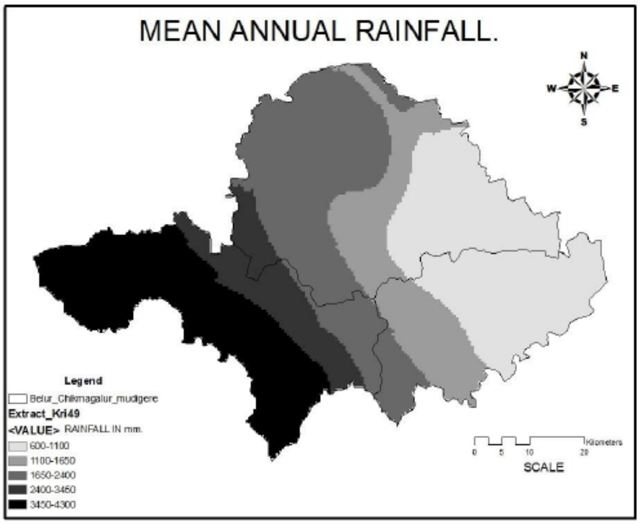

Figure 5: Mean Annual Rainfall.

Rainfall gradually decreases towards the north, east and northeast uplands forming a distinct rain-shadow zone. Stations such as Kalasapura(677.68mm) and Dasarahalli(765.30mm) represent the driest parts of the district during the period.

3.2. Temporal Analysis

Based on rainfall zone classification, identifying the same amount of rainfall at different places in different seasons. Isohyets were plotted for mean seasonal rainfalls and the annual rainfall is classified as Pre-monsoon (March-May), Monsoon (June-September), Post-Monsoon(October-November) and Winter(December-February).

3.2.1. Pre-Monsoon

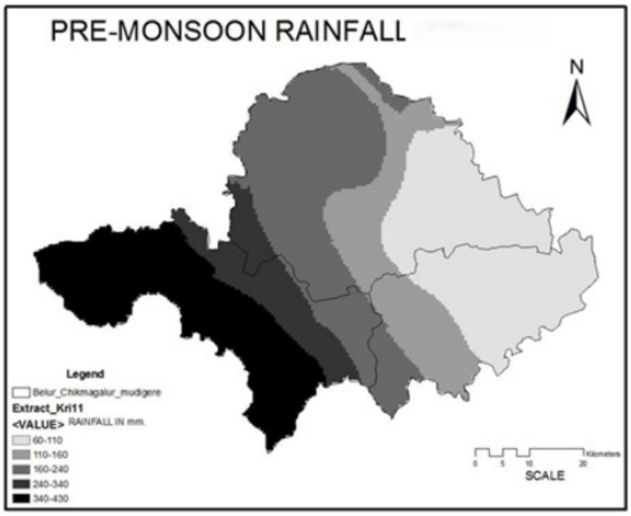

Figure 6: Pre Monsoon rainfall.

The analysis of seasonal rainfall (March–May) as indicated in Figure **6** shows a significant spatial variation across the region. The western and hilly adjoining areas such as Kotigehara and Hosakere receive substantially higher rainfall, indicating strong local influences such as orographic effects. In contrast, interior locations like Belvadi, Dasarahalli, and Halaebeedu experience much lower precipitation, suggesting reduced moisture penetration into inland regions. The considerable difference between the highest (417 mm) and lowest (74.2 mm) values highlights pronounced variability in pre-monsoon rainfall patterns. The seasonal mean of 176.94 mm reflects a moderate rainfall regime, with only a few stations contributing disproportionately to the seasonal totals. This spatial contrast emphasizes the need to consider topography and local climatic factors when assessing rainfall distribution in the study area [15].

3.2.2. Monsoon

As indicated in Figure **7**,significant variations in rainfall are observed during this season, which accounts for more than 80% of the annual precipitation. The average rainfall across the study area is 1327.11 mm. The highest seasonal rainfall is recorded at Kotigehara (3128.13 mm), Hosakere (3067.36 mm), Gonibeedu (1703.97 mm), and Madenahalli (1469.45 mm). In contrast, the lowest rainfall is observed at Belavadi (561.11 mm), Hagarae (678 mm), Belur (753 mm), Halaebeedu (572 mm), and Chikkamagaluru (920 mm). For computing the seasonal mean, precipitation data from June to September is taken into account.

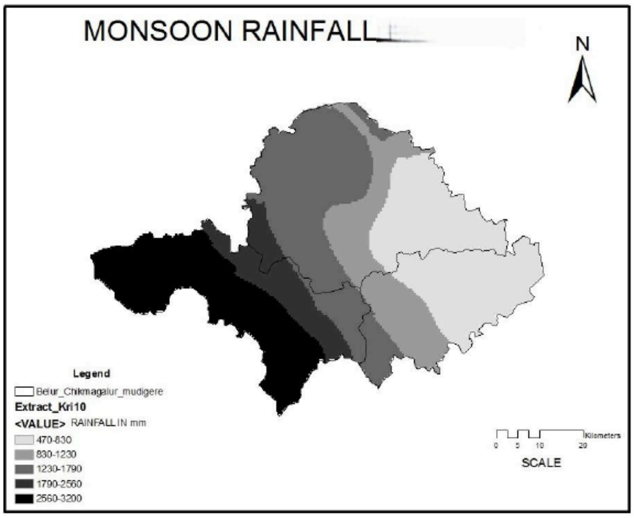

Figure 7: Monsoon Rainfall.

The June–September season shows very high rainfall variability across the study area, contributing to more than 80% of the total annual precipitation. This pattern is consistent with the characteristics of the Indian Summer Monsoon (ISM), which is known to deliver the major share of annual rainfall to peninsular India. Literature widely notes that topography plays a dominant role in shaping regional rainfall gradients during the monsoon months[16].

Stations such as Kotigehara and Hosakere, which record extremely high rainfall (exceeding 3000 mm), are located in the Western Ghats foothills, where orographic lifting enhances precipitation significantly. This aligns with studies showing that locations on the windward side of the Western Ghats often receive three to four times more rainfall than inland areas due to the forced uplift of moisture-laden monsoon winds.

In contrast, lower rainfall recorded at stations like Belavadi, Hagarae, Belur, and Halaebeedu reflects their interior and leeward positions, where monsoon clouds lose a substantial portion of moisture before moving further east. This "rain-shadow–type effect," documented in monsoon climatology research, explains the sharp decline in rainfall away from the Ghats [17].

The regional average rainfall of 1327.11 mm falls within the range typical for transitional zones between coastal heavy-rainfall belts and drier inland areas, as reported in previous climatological assessments of Karnataka. The substantial spatial variability observed in this study is therefore consistent with established monsoon behaviour, local geomorphology, and well-documented rainfall patterns of the Western Ghats region [18, 19].

3.2.3. Post-Monsoon

With reference to Figure **8**, the October–November season shows comparatively low precipitation across the study area, with an average rainfall of 212.33 mm. This aligns with established climatological observations that rainfall during this period is primarily influenced by the Northeast Monsoon (NEM) and retreating monsoon circulation, which deliver significantly less moisture to interior Karnataka than the dominant Southwest Monsoon (June–September).

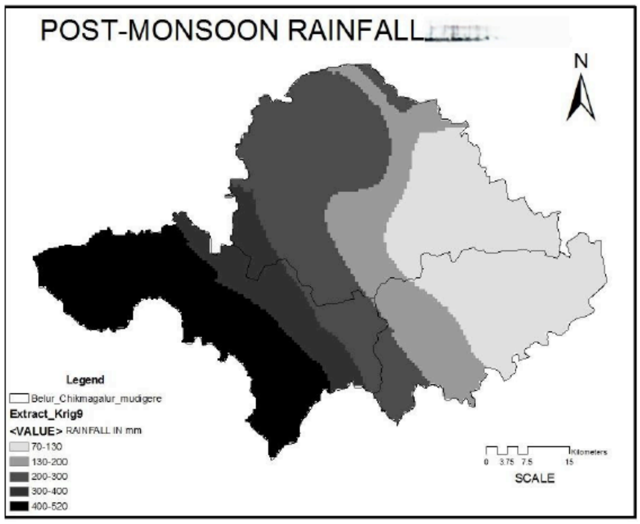

Figure 8: Post-Monsoon Rainfall.

Stations such as Kotigehara and Hosakere continue to record relatively higher rainfall (around 500 mm) because they lie close to the Western Ghats, where residual moisture and orographic uplift still influence post-monsoon showers. Literature consistently notes that even during the retreating monsoon, regions along the windward slopes of the Ghats receive more rainfall due to localized convection and orographic effects [18].

Conversely, the lower rainfall recorded at Kalasapura, Belavadi, Halebeedu, Hagarae, and Belur reflects the typical behaviour of interior and leeward regions, which receive limited NEM influence. Studies on Karnataka's rainfall climatology indicate that these inland areas depend mainly on isolated post-monsoon depressions and easterly waves, which are less frequent and weaker in this region compared to coastal and southeastern parts of the state [16, 17].

3.2.4. Winter

During the winter season, the region receives very minimal rainfall and is the driest period of the year. As indicated in Figure **9**, the highest winter precipitation is recorded in areas adjacent to the Western Ghats, including Kotigehara (125.1 mm), Hosakere (122.69 mm), Mudigere (70.9 mm), and Hanbalu (77.99 mm). In contrast, the lowest rainfall is observed at Halaebeedu (22.8 mm), Hagare (27.12 mm), Belur (30.08 mm), Dasarahalli (22.2 mm), Belavadi (22.4 mm), and Lingadahalli (25.79 mm).

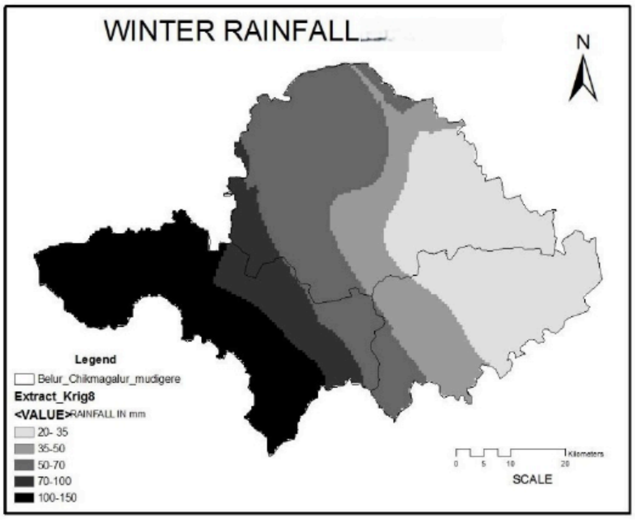

Figure 9: Winter Rainfall.

The winter season shows extremely low rainfall across the study area, which is consistent with established climatological patterns for interior Karnataka. According to literature on Indian climatology, the months of December to February are dominated by dry northeasterly continental winds, resulting in very limited moisture availability [8, 19]. As a result, this season typically contributes the least to annual rainfall totals across most of southern India.

The relatively higher rainfall at stations such as Kotigehara and Hosakere can be attributed to their proximity to the Western Ghats, where occasional post-monsoon residual moisture and weak westerly disturbances may still trigger light showers. Studies indicate that locations closer to the Ghats often show slightly elevated winter precipitation due to localized convection and orographic effects, even though overall rainfall remains very low [4, 6, 18, 19].

Conversely, inland areas such as Halaebeedu, Hagare, Belur, and Belavadi record extremely low values—often less than 30 mm—reflecting their position in the rain-shadow interior. Literature consistently describes winter rainfall in the southern peninsula as sparse, irregular, and largely influenced by isolated easterly waves or rare cyclonic remnants, which seldom penetrate far inland.

Thus, the spatial distribution observed—marginally higher rainfall near the Ghats and very low totals across interior regions—is fully in agreement with documented winter climatology of Karnataka and the broader dry continental circulation that characterizes this season.

CONCLUSION

The primary objective of this study was to examine the rainfall trends and variability across the Chikkamagaluru, Mudigere, and Belur taluks. Using GIS-based analysis, the study successfully identified distinct spatial patterns in precipitation. The findings reveal that areas located on the windward side of the Western Ghats—such as Kotigehara, Mudigere, Hosakere, Hanbalu, Gonibeedu, Madenahalli, and Arehalli—receive significantly higher rainfall, particularly during the monsoon season. This monsoonal rainfall provides stable and sustained precipitation across the region, supporting agricultural activities.

Chikkamagaluru, often referred to as the gateway to the Western Ghats, along with Mudigere, is extensively influenced by the Sahyadri mountain range and dense evergreen forests, resulting in much higher rainfall compared to Belur taluk. Mudigere lies within a very high rainfall zone and includes the Balur State Forest within its boundaries. The Malenadu hills, known for their rich forest cover, contribute to the region's humid climate and substantial precipitation.

Overall, the study confirms that the windward highlands of the Western Ghats receive considerably more rainfall than the adjacent lowland areas, primarily due to the orographic lifting of moisture-laden monsoon winds.

CONFLICT OF INTEREST STATEMENT

The Authors declare that there are no relevant financial or non-financial competing interests to report.

AUTHORS' CONTRIBUTION

Conceptualisation: K S Sreekeshava, Visualisation : G Gayathri, Data Analysis: K S Sreekeshava and C

Bhargavi, Writing: K S Sreekeshava, C Bhargavi and G Gayathri, Reviewing and Editing: K S Sreekeshava, C Bhargavi and G Gayathri

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ETHICAL STATEMENTS

The study protocol complies with the relevant ethical guidelines and is approved by the relevant institutional Ethics Committee.

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