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**RESEARCH PAPER**

# Annual and seasonal rainfall variability analysis at micro-level administrative units within Vijayapura district under hot semi arid eco-sub region of the Deccan Plateau of India

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**Abstract:** This study analyzes annual and seasonal rainfall variability in Vijayapura district, Karnataka, using 2013-2023 data from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC). Results show that the district received a decadal mean annual rainfall of 511.43 mm, with high inter-annual variability (Coefficient of Variation (CV) 31.24%) and frequent dry spells. The south-west monsoon contributes nearly 70 per cent of the annual rainfall, while the north-east monsoon (16.7%) and pre-monsoon (14%) were highly erratic and winter rains were negligible. *Hobli* (Cluster of villages)-level assessment highlights sharp spatial contrasts *viz*., Nidagundi faces extreme aridity (< 400 mm, CV > 50%), while areas like Indi, Vijayapura and Ballolli exhibited relatively stable rainfall and rainy days. Across the district, 65-75% of rainy days occur during the south-west monsoon, underscoring its dominance in sustaining agriculture. However, the uneven distribution and high variability in other seasons intensify the risks of drought, crop failure and groundwater dependence. In general, findings emphasize that rainfall variability, rather than mean rainfall, is the key determinant of agricultural reliability. The study advocates adaptive strategies such as rainwater harvesting, *in-situ* moisture conservation, watershed development, supplemental irrigation, crop diversification and contingency crop planning to strengthen resilience and ensure sustainable agriculture in the semi-arid tropics.

**Key words:** Drought, *Hobli* level analysis, Rainfall, Rainy days, Spatial variability

## Introduction

Rainfall is one of the most critical climatic factors influencing agricultural production, human livelihoods, water resource management and ecosystem functioning (Kumar and Gautam, 2014). It plays a central role in terrestrial cycles by sustaining soil moisture, groundwater recharge and river flows, thereby regulating both ecological balance and socio-economic stability in rain-dependent regions (Rockström *et al*., 2010). Variations in the onset, intensity and spatial distribution of monsoon rains directly affect crop selection, sowing dates and input management at the farm level (Singh *et al.,* 2018). Seasonal and inter-annual variability in rainfall, especially at micro-level administrative units such as *hoblis*, greatly impacts farmers' decisions.

Agro-ecologically, Vijayapura district falls within the hot semi-arid eco-sub region of the Deccan Plateau, while agro-climatically it is classified under the Northern Dry Zone (Zone-3) of Karnataka. This classification reflects the district's characteristic low and erratic rainfall, high evapotranspiration and frequent drought occurrence (Anon., 2020). Entire district is principally a plain region with no major tract under mountains. The major rivers of the district are *Krishna*, *Bhima* and *Doni*. Nearly, 77 per cent of the population lives in rural areas, most of them depending on agriculture for their livelihood.

Agriculture in Vijayapura district is highly dependent on rainfall due to the predominance of cultivated dryland and the negligible forest cover (< 1%). Out of the total geographical area of 10.53 lakh ha, nearly 84 per cent (8.90 lakh ha) is under cultivation, making farming the backbone of the district's economy. With a gross cropped area of 9.68 lakh ha and a modest cropping intensity of 109 per cent, most of the land is used for single cropping and only a small portion (0.77 lakh ha) supports double cropping (Anon., 2023). The present irrigated area is 3.64 lakh ha of which 1.08 lakh ha is canal irrigated from Upper Krishna Project of Almatti reservoir. The remaining 2.58 lakh ha is irrigated through open and tube wells (Anon., 2023).

In this context, rainfall plays a critical role in sustaining agricultural productivity. Since irrigation facilities are limited, timely and adequate rainfall directly influences sowing, crop growth and yields. Variability or deficit in rainfall can lead to severe stress on crops, reducing farm incomes and affecting the rural economy (Thornton *et al.,* 2014). So, present study analyzes seasonal variability of rainfall trends across the *hobli's* of Vijayapura district. These findings highlight the importance of localized rainfall analysis and emphasize the need for climate-resilient agricultural practices, efficient water resource management and policy interventions to mitigate the adverse effects of rainfall variability in Vijayapura district.

## Material and methods

### Study area

Vijayapura district located in North Western part of Karnataka state (Fig 1). It lies between 15° 50' - 17° 28' North latitude and 74° 59' - 76° 28'East longitudes at an average altitude of 593 m mean sea level. The district coversa geographical area of 10.53 lakh ha, accounting for 5.33 per cent

Table 1. Descriptive analysis of rainfall variability in Vijayapura district (2013-2023)

| Categories | Mean | S.D. | CV (%) | Max(mm) | Min.(mm) | % of total |
|---|---|---|---|---|---|---|
| Annual | 511.43 | 159.75 | 31.24 | 744.90 | 265.20 | 100 |
| South West Monsoon | 354.70 | 124.48 | 35.09 | 546.63 | 135.97 | 69.35 |
| North East Monsoon | 85.25 | 51.45 | 60.34 | 178.51 | 18.12 | 16.67 |
| Pre-Monsoon | 71.48 | 33.13 | 46.36 | 117.66 | 10.93 | 13.98 |
| Winter | 1.20 | 1.57 | 130.86 | 4.50 | 0.00 | 0.23 |

of state's geographical area. The district is divided into thirteen Taluks and 20 *Hobli's*. The 20 *Hobli's* namely, Talikoti, Kolhar, Chadachan, Babaleshwar, Devar Hipparagi, Alamel, Vijayapura, Sindagi, Basavana Bagewadi, Ballolli, Nagathana, Huvin Hipparagi, Managuli, Tikota, Nalatvada, Indi, Dhavalagi, Muddebihal, Mamadapura and Nidagundi.The district represents five types of soils namely, shallow black soil (2,62,596 ha), medium black soil (4,01,737 ha), deep black soils (2,34,113 ha), red loam soils (48,061) and red sandy soils (20,230 ha) (Anon., 2016).

**Data collection and analysis**

The required data for this study was collected from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Bengaluru, Government of Karnataka for the period from 2013 to 2023. KSNDMC utilizes 211 telemetric raingauages located across various gram panchayats of Vijayapura district. The mean value from all grid point data was taken to calculate daily rainfall of Vijayapura district. The daily rainfall data for the year was classified as annual rainfall. Then the annual rainfall was further divided into four seasons; January to February month rainfall as winter season rainfall, March to May month rainfall as pre-monsoon season rainfall, June to September rainfall as south-west monsoon season rainfall and October to December month rainfall as north-east monsoon season. Annual and seasonal rainfall data were analyzed statistically and the statistical parameters like mean, maximum, minimum, standard deviation and coefficient of variation(CV) were studied for Vijayapura district.

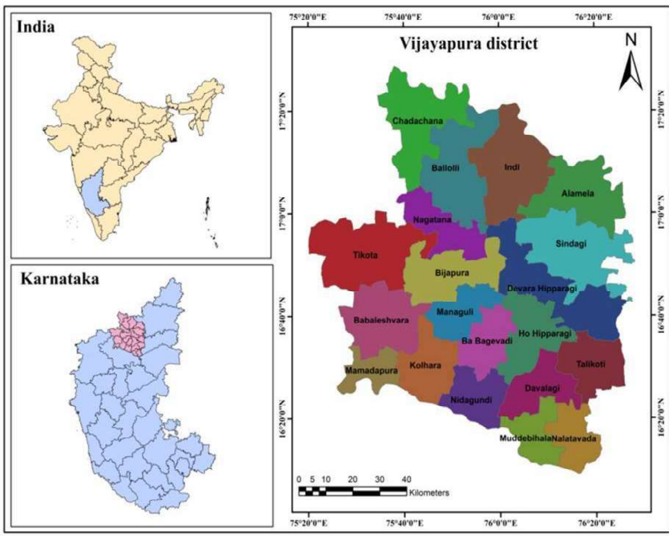


Fig 1. Study area map of Vijayapura district depicting different *hobli* boundaries

**Results and discussion**

**Annual and seasonal distribution of rainfall and its variability**

Variability in both seasonal and annual rainfall has a direct adverse impact on crop yields. Table 1 presents the descriptive statistics of Vijayapura district's annual and seasonal rainfall over the past eleven years. The annual rainfall is categorized into four distinct seasons: winter, pre-monsoon, south-west monsoon (SW monsoon), and north-east monsoon (NE monsoon). The table provides values for minimum and maximum rainfall, mean, standard deviation, CV and the seasonal contribution to the annual total.

Rainfall distribution in Vijayapura district shows considerable variability across the year, with each season contributing differently to the overall total. The district received an average annual rainfall of 511.43 mm during the last decade (2013-2023), with five of those ten years recording below-average rainfall. This indicates that the district generally experiences moderate annual rainfall. However, the standard deviation of 159.75 mm against the mean reflects substantial year-to-year variation, suggesting that certain years were significantly wetter or drier than the average. The maximum annual rainfall of 744.90 mm was recorded in 2020, while the minimum of 265.20 mm occurred in 2017. This variability has direct implications for agriculture in the district. The recurrence of below-average rainfall in half of the observed years points to a high frequency of dry spells, increasing the likelihood of drought and water stress (Gadgil, 1995; Patil *et al.,* 2014). The wide gap between maximum and minimum annual rainfall values reflects the uncertainty farmers face, particularly in predominantly rainfed areas with limited irrigation infrastructure (Rao *et al.,* 2013).

Vijayapura district receives the majority of its rainfall during the SW monsoon season (June–September), with a decadal mean of 354.70 mm, contributing 69.35 per cent to the annual total rainfall. However, in five out of the eleven observed years, rainfall during this season fell below the mean. The standard deviation of 124.48 mm indicates considerable interannual variability, though slightly lower than that observed for the annual total rainfall (159.75 mm). During the NE monsoon season (October-December); the district recorded an average of 85.25 mm rainfall, contributing 16.67 per cent to the annual total, but again half of the years were below the mean value. The dominance of the SW monsoon provides the strong seasonal concentration of rainfall, which effectively enhances the crop-growing period, while the limited contributions from the winter and NE monsoon seasons provide little supplementary moisture

Table 2. Annual and seasonal distribution of rainfall and their variability at *Hobli* level

| *Hobli* name | Annual (mm) | CV (%) | SW Monsoon (mm) | CV (%) | NE Monsoon (mm) | CV (%) | Pre Monsoon (mm) | CV (%) | Winter (mm) | CV (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Talikote | 594.88 | 39.99 | 415.50 | 47.11 | 95.44 | 52.85 | 83.56 | 76.93 | 0.38 | 233.67 |
| Kolhara | 547.38 | 34.11 | 360.31 | 39.86 | 111.69 | 83.59 | 74.94 | 95.87 | 0.44 | 282.84 |
| Chadachana | 546.56 | 42.35 | 383.25 | 47.85 | 115.75 | 56.62 | 47.44 | 85.03 | 0.13 | 282.84 |
| Babaleshvara | 545.63 | 39.20 | 354.63 | 52.31 | 115.88 | 92.22 | 74.88 | 96.22 | 0.25 | 282.84 |
| Devarahipparagi | 533.95 | 36.99 | 397.93 | 39.85 | 79.67 | 64.56 | 55.63 | 67.46 | 0.72 | 198.23 |
| Alamel | 533.68 | 30.94 | 404.47 | 35.19 | 79.50 | 59.13 | 49.59 | 61.98 | 0.13 | 107.34 |
| Vijayapura | 530.65 | 26.28 | 362.20 | 29.08 | 85.73 | 71.33 | 80.83 | 45.29 | 1.89 | 146.61 |
| Sindagi | 530.22 | 34.79 | 386.30 | 41.77 | 74.99 | 62.83 | 67.67 | 41.52 | 1.27 | 136.89 |
| Basavanbagevadi | 522.00 | 30.51 | 360.07 | 34.06 | 92.21 | 58.33 | 68.00 | 60.86 | 1.72 | 231.60 |
| Ballolli | 520.83 | 29.69 | 365.99 | 31.17 | 89.45 | 60.38 | 62.68 | 58.83 | 2.71 | 169.42 |
| Nagathana | 511.24 | 30.78 | 352.97 | 34.33 | 81.40 | 65.18 | 74.34 | 41.34 | 2.52 | 196.90 |
| Huvinhipparagi | 509.32 | 32.29 | 350.18 | 37.73 | 85.06 | 56.22 | 72.81 | 42.63 | 1.27 | 193.28 |
| Managuli | 504.61 | 31.37 | 343.91 | 36.76 | 98.21 | 67.59 | 61.52 | 77.60 | 0.98 | 212.23 |
| Tikota | 500.21 | 35.45 | 337.98 | 37.73 | 86.01 | 66.85 | 72.94 | 60.30 | 3.27 | 205.52 |
| Nalatvada | 497.79 | 44.87 | 342.33 | 47.33 | 85.12 | 59.57 | 69.49 | 55.03 | 0.85 | 226.13 |
| Indi | 493.91 | 28.41 | 351.31 | 34.31 | 75.83 | 61.21 | 64.25 | 54.99 | 2.52 | 197.87 |
| Dhavalagi | 492.48 | 36.21 | 343.35 | 42.00 | 69.51 | 55.31 | 77.99 | 40.88 | 1.64 | 184.20 |
| Muddebihala | 476.93 | 40.54 | 320.79 | 47.38 | 80.52 | 64.16 | 74.18 | 50.35 | 1.43 | 206.01 |
| Mamadapura | 446.75 | 39.81 | 303.38 | 38.07 | 91.50 | 99.03 | 50.94 | 90.53 | 0.94 | 190.04 |
| Nidagundi | 347.94 | 55.85 | 239.88 | 59.99 | 82.75 | 80.42 | 25.31 | 138.88 | 0.00 | 0.00 |

(Ambite *et al.,* 2022). This uneven rainfall distribution places substantial stress on agricultural planning and water resource management, often leading to reduced yields, crop failure and increased reliance on ground water for irrigation (Mall *et al.,* 2006; Kiran Kumar and Patil, 2019).

During pre-monsoon season, Vijayapura district received 71.48 mm rainfall (13.98%) with a deviation of 33.13 mm. The higher amount of rainfall received during the pre-monsoon season necessitates appropriate harvesting through effective land management and *in-situ* moisture conservation practices- including techniques such as ridges and furrows and tied ridging, which helps in recharging the soil profile and facilitate early or timely sowing of *kharif* crops like pigeonpea, a major crop in Vijayapura district (Biradar *et al.,* 2020; Rahil *et al.,* 2023).

The CV is used to assess the degree of variability in the rainfall data (Bharath *et al*. 2023; Kumar *et al*. 2023). Table 1 shows the CV values for different rainfall variables across various seasons. The annual rainfall has a CV of 31.24 per cent, indicating high variability. The SW monsoon season also shows higher variability with a CV of 35.09 per cent. In contrast, the NE monsoon and pre-monsoon season exhibit very high variability, reflected by 60.34 and 46.36 per cent CV, respectively. Similarly, winter season rainfall displays significant variability, with 130.86 per cent CV, but its contribution to total annual rainfall is negligible (< 1%). Overall, the analysis demonstrates the variability of seasonal rainfall. Seasonwise per cent contribution to the total annual rainfall in the district is presented in Fig 2. SW monsoon (June - September) rainfall accounts for 69 per cent, NW monsoon (October - December) rainfall accounts for 16 per cent, while pre-monsoon (March - May) rainfall accounts for 14 per cent and winter (January - February) rainfall accounts < 1 per cent (0.23 %) of the total annual rainfall.

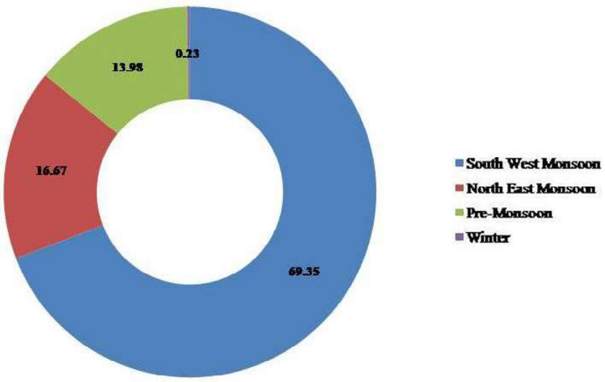


Fig 2. Seasonwise percent distribution of annual rainfall of Vijayapura district

Low variability in the annual and SW monsoon rainfall is obvious for the district because of the fact that maximum amount of annual rainfall is contributed by SW monsoon. Lower variability provides better reliability and stability, but the higher variability in NE monsoon and pre-monsoon season calls for effective rain water harvesting and advanced water management strategies and infrastructure development for assured crop yield.

**Annual and seasonal distribution of rainfall and their variability at *hobli* level**

The mean annual rainfall for 20 *Hobli's* of Vijayapura is furnished in Fig 3. The analysis of annual rainfall distribution across the *Hobli's* indicates distinct patterns of variability with significant implications for agricultural sustainability and water resource management. Nidagundi is the only *Hobli* that falls under low rainfall zone (< 400 mm) category and it exhibits high variability (CV> 30%), making it highly susceptible to recurrent droughts and unreliable crop production (Table 2). In the moderately low rainfall zone (400-500 mm), Indi demonstrates

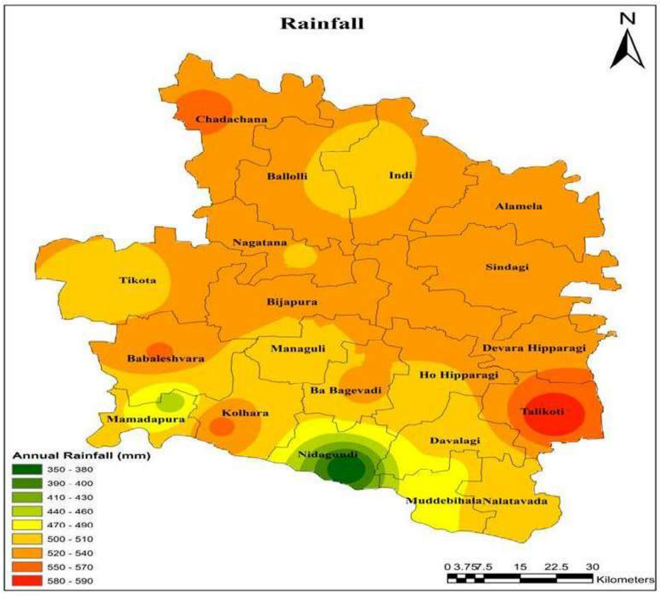


Fig 3. Mean annual rainfall (mm) at *Hobli's* across Vijayapura district (2013-2023)

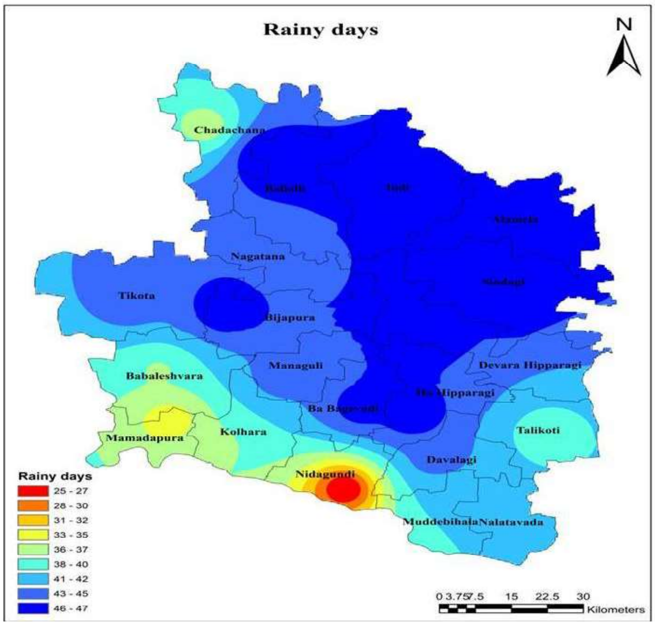


Fig 4. Mean annual rainy days (No.) at *hobli's* across Vijayapura district (2013-2023)

medium variability (CV of 20-30%), suggesting relatively stable rainfall, whereas Nalatvada, Dhavalagi, Muddebihal and Mamadapura experience high variability, thereby increasing rainfall uncertainty despite comparable mean precipitation levels. In the moderate rainfall zone (> 500 mm), Vijayapura and Ballolli are characterized by medium variability, which makes them relatively dependable for rainfed agriculture. However, most other *Hobli's* in this category- including Talikote, Kolhar, Chadachan, Babaleshwar, Devar Hipparagi, Alamel, Sindagi, Basavan Bagewadi, Nagathana, Huvin Hipparagi and Tikota- exhibit high variability, suggesting that although these areas receive higher annual rainfall, the inconsistency of precipitation undermines their agricultural reliability.

The analysis of seasonal rainfall distribution across different *Hobli's* of Vijayapura district furnished in Table 3. It indicates that the South-West monsoon is the dominant rainfall season, contributing between 240 mm at Nidagundi and 416 mm at Talikote. The CV during this period ranges from 29 per cent in Vijayapura to nearly 60 per cent at Nidagundi, which implies that while some *Hobli's* receive relatively stable rainfall, others experience highly erratic distribution. The NE monsoon contributes comparatively less, ranging from 70 mm to 116 mm across the *Hobli's* and is marked by high variability, with CV values exceeding 50 per cent in all cases. This makes the NE monsoon unreliable as a dependable water source for agriculture, although it provides some supplementary moisture. Pre-monsoon rainfall, varying between 25 mm in Nidagundi and 84 mm in Talikote, is equally uncertain, as reflected by its very high CV, which often exceeds 100 per cent in certain *Hobli's*. While pre-monsoon showers play a role in facilitating land preparation and sowing, their unpredictability limits their agricultural significance. Winter rainfall is negligible across the district, with the most *Hobli's* receiving less than 3 mm and some receiving none at all, and the extremely high variability associated with this season makes it agriculturally non-significant. Overall, the findings highlight that Vijayapura district is heavily dependent on the SW monsoon, which contributes about 70-75 per cent of the total rainfall, while the NE monsoon adds 15-20 per cent in an erratic manner and the pre-monsoon and winter seasons contribute only marginally.

The analysis of *Hobli*-level rainfall distribution in Vijayapura district reveals that the high degree of rainfall variability across all seasons, particularly outside the South-West monsoon, is a more critical determinant of agricultural stability than mean annual rainfall. While a few *Hobli's* such as Indi, Vijayapura and Ballolli exhibit relatively stable rainfall conditions, the majority remain vulnerable to erratic precipitation, underscoring the region's susceptibility to drought. This necessitates the adoption of region-specific drought management practices, supplemental irrigation strategies and contingency crop

Table 3. Annual rainfall variability at *Hobli* level

| Annual rainfall of *Hobli's* | Variability | |
|---|---|---|
| | Medium (C.V.: 20 - 30%) | High (C.V.: >30%) |
| < 400 mm | - | Nidagundi |
| 400 - 500 mm | Indi | Nalatvada, Dhavalagi, Muddebihal, Mamadapura |
| > 500 mm | Vijayapura and Ballolli | Talikote, Kolhar, Chadachana, Babaleshwar, Devarahipparagi, Alamel, Sindagi, Basavanbagewadi, Nagathana, Huvinhipparagi and Tikota |

Table 4. Annual and seasonal distribution of rainy days at *hobli* level

| Hobli name | Annual (Mm) | SW monsoon (mm) | NE monsoon (mm) | Pre-monsoon (mm) | Winter (mm) |
|---|---|---|---|---|---|
| Talikote | 38 | 26 | 6 | 7 | 0 |
| Kolhara | 37 | 26 | 7 | 5 | 0 |
| Chadachana | 36 | 25 | 7 | 4 | 0 |
| Babaleshvara | 37 | 24 | 8 | 7 | 0 |
| Devarahipparagi | 47 | 33 | 8 | 8 | 0 |
| Alamel | 47 | 35 | 7 | 5 | 0 |
| Vijayapura | 47 | 30 | 8 | 8 | 0 |
| Sindagi | 46 | 32 | 7 | 7 | 0 |
| Basavanbagevadi | 46 | 30 | 7 | 8 | 0 |
| Ballolli | 47 | 33 | 7 | 6 | 0 |
| Nagathana | 43 | 29 | 7 | 7 | 0 |
| Huvinhipparagi | 47 | 30 | 8 | 8 | 0 |
| Managuli | 43 | 29 | 8 | 7 | 0 |
| Tikota | 43 | 28 | 8 | 7 | 0 |
| Nalatvada | 40 | 27 | 7 | 6 | 0 |
| Indi | 45 | 32 | 6 | 6 | 0 |
| Dhavalagi | 44 | 29 | 7 | 8 | 0 |
| Muddebihala | 40 | 26 | 6 | 7 | 0 |
| Mamadapura | 33 | 23 | 6 | 4 | 0 |
| Nidagundi | 25 | 18 | 5 | 2 | 0 |

planning to enhance resilience in the semi-arid tropics. Previous studies support these findings such as Rao *et al*. (2011) highlighting that rainfall variability influences the onset and duration of the cropping season in the Deccan Plateau. Again, Gadgil and Gadgil (2006) emphasizing that fluctuations in rainfall patterns are more strongly linked to drought occurrences in peninsular India than the mean annual rainfall. Gajbhiye *et al*. (2015) and Singh *et al*. (2018) further corroborates that high inter-annual variability intensifies the vulnerability of rainfed agriculture, thereby necessitating adaptive strategies such as watershed management, crop diversification and improved irrigation practices.

**Annual and seasonal distribution of rainy days at hobli level**

The effectiveness of rainfall and the water use efficiency are significantly influenced not only by the amount of rain but also by the number of rainy days.The mean annual rainy days were furnished in Fig 4 and seasonal rainy days in Table 4.The spatial distribution of annual rainy days across the *Hobli's* exhibits marked variability, revealing both drought-prone areas and relatively rainfall-reliable zones. Nidagundi (25 days) and Mamadapura (33 days) are particularly vulnerable, with very low annual rainfall events concentrated mainly in the SW monsoon, signaling extreme aridity and a heightened risk of crop failure. In contrast, Talikote, Kolhara, Chadachan, Babaleshwar, Nalatvada and Muddebihal- falling into the moderate category (36-40 days) demonstrate limited rainfall occurrence, suggesting high dependence on the SW monsoon and vulnerability to dry spells. Nagathana, Managuli, Tikota and Dhavalagi occupy an intermediate position (41-44 days), indicating slightly better water availability but still constrained by seasonality. Meanwhile, *Hobli's* such as Devara Hipparagi, Alamel, Vijayapura, Sindagi, BasavanBagevadi, Ballolli, Huvin Hipparagi and Indi, which recorded 45-47 rainy days, represent areas of relatively stable rainfall occurrence (Table 5). This greater number of rainy days, especially during the SW monsoon, underscores their relative suitability for rainfed agriculture.

Table 5. Classification of total rainy days

| Categories | Rainy days | *Hobli's* |
|---|---|---|
| Low | < 35 | Nidagund(25),Mamadapura(33) |
| Moderate | 36 - 40 | Talikote(38), Kolhara (37), Chadachana (36), Babaleshwar(37), Nalatvada(40), Muddebihal (40) |
| Intermediate | 41 – 44 | Nagathana (43), Managuli (43), Tikota (43), Dhavalagi (44) |
| High | ≥45 | DevaraHipparagi (47), Alamel (47), Vijayapura (47), Sindagi (46), Basavan Bagevadi(46), Ballolli (47), Huvin Hipparagi (47), Indi (45) |

Notably, across all categories, rainfall exhibits strong seasonality wherein,65-75 per cent of the rainy days fall within the SW monsoon, with marginal contributions from the NE monsoon and pre-monsoon periods and virtually no rainfall in winter. These results are consistent with the rainfall pattern of Gadag district in North Karnataka, where the SW monsoon alone contributes more than 60 per cent of the annual rainfall, while pre-monsoon and NE monsoon seasons provide highly variable and limited inputs (Dhage *et al.,* 2025). Broader assessments across Karnataka have revealed that rainfall and rainy days show significant spatio-temporal variability, with localized *hobli*-scale analysis being crucial for agricultural planning (Prasad, 2022; Sridhara and Gopakkali, 2021).

**Conclusion**

Rainfall analysis in Vijayapura district shows high annual and seasonal variability, with an average of 511.43 mm but wide fluctuations (265.20-744.90 mm), making agriculture highly vulnerable to droughts and crop failures. Nearly, 70 per cent of rainfall occurs during the south-west monsoon, while the erratic nature of pre-monsoon and north-east monsoon rains adds further uncertainty. *Hobli*-level assessment reveals sharp spatial contrasts- areas like Nidagundi face extreme aridity, whereas Indi, Vijayapura and Ballolli are relatively more stable- yet most *hobli's* experience inconsistent rainfall and rainy days, challenging sustainable farming. Mean annual rainfall alone cannot capture agricultural reliability; instead, rainfall variability is the critical factor. Adaptive strategies such as rainwater harvesting, *in-situ* moisture conservation, watershed development, supplemental irrigation, crop diversification, and contingency planning are essential to build resilience and ensure sustainable agriculture in the semi-arid tropics.

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