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Spatio-Temporal Mechanisms of Rainfall in Kalaburagi District: An Analysis of Trends and Variability

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Abstract: The study used data from 11 taluks to analyse the changes and variability in annual and seasonal rainfall in the Kalaburagi district between 2016 and 2022. Sen Slope and Mann-Kendall analyses were used to evaluate trends, while the coefficient of variation was used to measure rainfall variability. The mean rainfall was calculated using simple mathematical formulas. The findings showed minimal seasonal and yearly variability, with the exception of the southwest monsoon season. The district as a whole as well as all 11 taluks consistently saw a rise in rainfall, according to annual Sen slope research. However, during the northeast monsoon season, negative trends were observed in Aland and Sedam Taluks. In the Mann-Kendall test, the district did not exhibit any general pattern; nevertheless, several taluks, such as Yadrami and Kamalapur, demonstrated remarkable trends in the southwest and northeast seasons, respectively. Due to geographical and climatic fluctuations, the district of Kalaburagi experienced an annual mean precipitation of 797 mm. Higher mean rainfall was recorded in Sedam, Kalagi, Chincholi, and Kamalapur, while lower mean rainfall was recorded in Jevaragi and Yadrami Taluks. In the water-scarce Kalaburagi district, this work is important for policymakers addressing climate change and water resource management.

Keywords: Rainfall variability; Water resource; Coefficient variation; Trend and pattern.

Introduction

The increasing global temperatures observed over the last century are expected to persist, leading to more frequent droughts and reduced rainfall (IPCC, 2013). Rainfall variability, which includes differences in precipitation over time and across different areas, is a key component of a region's climate. In meteorology and climatology, this concept is significant because it affects patterns of water availability and other climatic factors both spatially and temporally (De Luis et al., 2000). Rainfall variability is quantified by the standard deviation of the growth rate of rainfall, a metric often used in economic studies. Specifically, it is calculated as the five-year rolling standard deviation of the growth rate of rainfall over time. Rainfall variability affects rainfed agricultural production, leading to early ends, delays, and dry spells that hinder growth (Bahiru et al., 2020). There is a strong correlation between rainfall and conflicts worldwide; an increase in

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rainfall is often associated with a decrease in conflicts (Thierry Yerema Coulibaly et al., 2022). There is also a strong correlation between river discharge and rainfall variability, rainfall plays a vital role in amplifying water discharge and its related activity. Studies have confirmed an association between rainfall variability and nutrition. This relationship suggests that changes in rainfall patterns can significantly affect food availability and nutritional status (Isabel Mank et al., 2021). An increase in rainfall variability is associated with a rise in chronic undernutrition. Additionally, fluctuations in the water table are observed to correspond with variations in rainfall (Dey et al., 2020).

Understanding yearly and seasonal variations through the study of rainfall variability is crucial for agricultural planning and for alerting farmers to potential crop losses caused by unpredictable weather (Hailu Regassa Bedane, 2022). Monsoon rainfall variability remains highly unpredictable across different spatial and temporal scales, making it challenging to forecast accurately (Gouda et al., 2015). Knowing hydrological balance and regional climate variations requires a study of monsoon rainfall variability across various regions (Rajeevan et al., 2006). Due to geographical differences, understanding changes in rainfall in India is crucial for fields such as climatology, hydrology, industry, weather forecasting, and agriculture. Researchers have employed methods such as the Sen slope and Mann-Kendall tests to analyse rainfall variability globally, including in India. In the semi-arid Kalaburagi region, where the monsoon season spans from mid-June to October, our study focuses on examining rainfall changes from 2016 to 2022.

The climate of Kalaburagi is categorised into three distinct seasons: Summer (March to May), Southwest Monsoon (June to October), and Winter (November to February) (Belamkar et al., 2014). The district largely relies on the irregular and insufficient rainfall from the southwest monsoon, which is characterised by periodic deficits and dry spells. There is currently a lack of comprehensive research on the district's rainfall patterns. To address this gap, this study aims to analyze rainfall variability over the past seven years using the Mann-Kendall test, coefficient of variation test, and mean rainfall data to gain a better understanding of the rainfall patterns in this semi-arid region.

Study Area

Kalaburagi district is located in the northern part of Karnataka state, India, between the latitudes 12°54' and 13°53' North, and longitudes 75°04' and 76°21' East (Figure 1). It covers an area of 10,951 km², with elevations ranging from 300 to 750 meters above sea level. The district has a semi-arid climate, with the eastern part featuring dry and moist deciduous forests. Kalaburagi experiences the highest summer temperatures in Karnataka (March to May). Most rainfall occurs between June and September due to southwest monsoon winds, while October sees rain from northeast winds. From November to January, the district experiences cooler weather, with December being the coldest month of the year. Until 2019, Kalaburagi district was comprised of seven taluks: Afzalpur, Aland, Chincholi, Chittapur, Kalaburagi, Sedam, and Jevargi. In 2020, four new taluks were established: Kalagi, carved out of Chincholi; Yadrami, separated from Jevargi; and Kamalapur and Shahabad, derived from Kalaburagi taluk.

Data and Methodology

The study focusses on Kalaburagi district and its 11 taluks, analysing rainfall data from 2016 to 2022. The data encompasses annual and seasonal evaluations for pre-monsoon, southwest monsoon, and northeast monsoon periods, and was sourced from the Karnataka State Natural Disaster Monitoring Centre. To gain a comprehensive understanding of rainfall patterns and variability, statistical analyses were conducted, including calculations of mean, standard deviation, coefficient of variation, Mann-Kendall test, and Sen slope estimator, for both the district as a whole and each individual taluk.

Trend Detection Methods: The Mann-Kendall (MK) test, developed by Mann (1945) and Kendall (1948), is a non-parametric method used to identify trends in rainfall. This rank-based test has been extensively used to confirm the presence of autocorrelation in data sets (Duhan and Pandey, 2013). Instead of comparing the actual values, the MK test compares the relative magnitudes of the data. The true slope (magnitude) of the trend is estimated using Sen's slope (SS) estimator, introduced by Sen (1968). These tests are effective in identifying trends in time series data and are robust against extremes. Positive SS values indicate upward trends, while negative SS values indicate declining trends. The XLSTAT 2024 software has simplified the analysis process.

Variability Detection Methods : Techniques such as Standard Deviation (SD) and Coefficient of Variation are utilised to study rainfall variations. The average

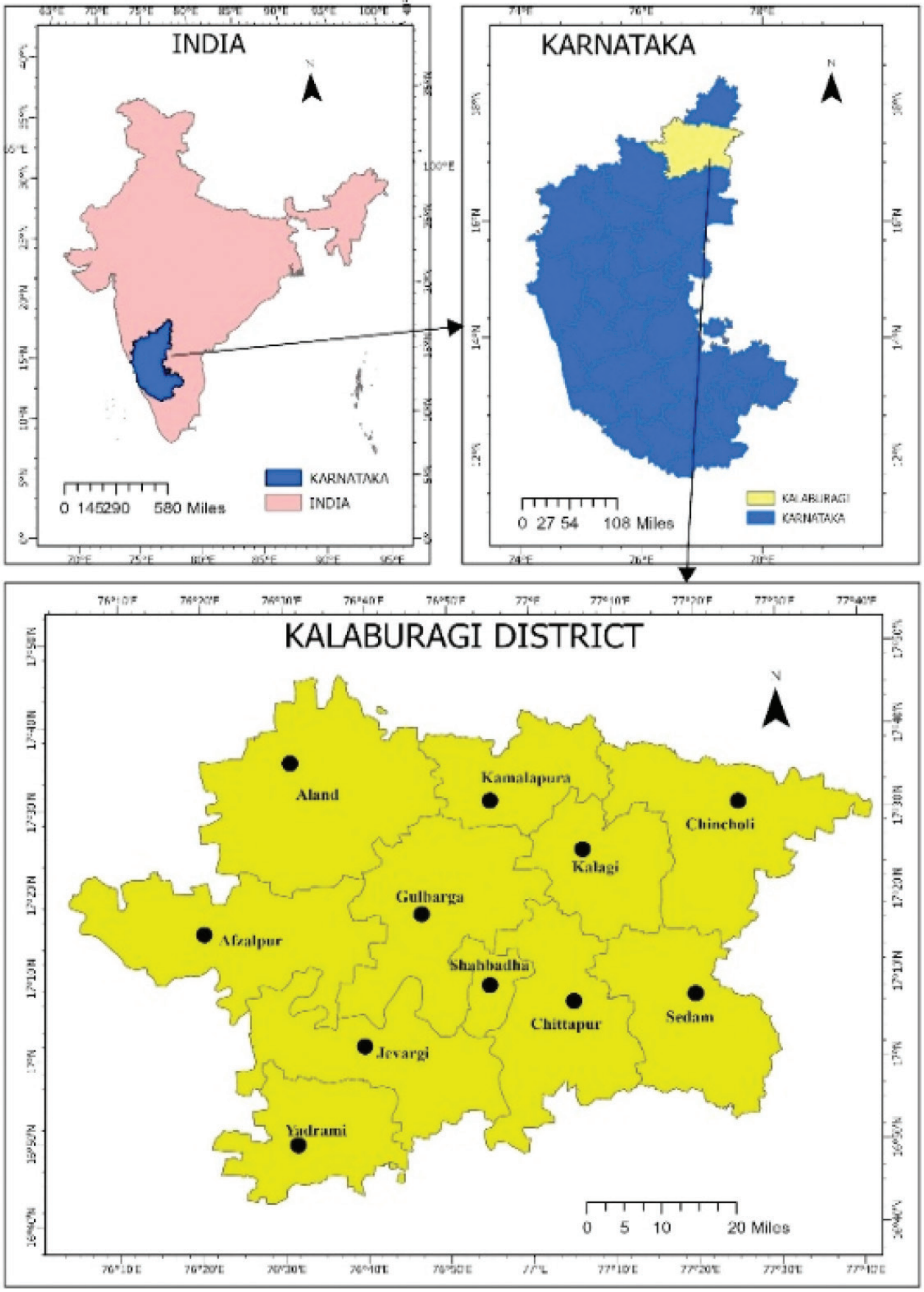

Figure 1: Study area map.

yearly rainfall is calculated from annual rainfall data collected over a period of 30–35 years. SD measures how much the data deviate from the mean, with a larger SD indicating greater dispersion and a smaller SD indicating that the data are clustering around the mean. A zero SD means that the data points are almost exactly aligned with the mean. These methods help assess the spread and consistency of rainfall patterns.

Formula for standard deviation is:

$$\sqrt{\frac{\sum(x_i - \mu^2)}{N}}$$

Analysing rainfall variability using the Coefficient of Variation (CV%) is relatively straightforward. CV helps determine the variability of rainfall in percentage terms, calculated as the standard deviation divided by the mean value of rainfall. It is used to identify variations in rainfall from year to year. This metric has been primarily applied to annual rainfall amounts, which tend to be fairly normally distributed, except under extremely dry conditions (Hastings, 1965; Schulze, 1965).

Formula for Coefficient variation is:

$$cv = \frac{\sigma}{\mu}$$

A CV of over 30% indicates high variability and significant fluctuations in rainfall. A CV between 20-30% denotes moderate fluctuations, while a CV of less than 20% indicates consistent rainfall from year to year. The annual and seasonal rainfall data for all taluks of Kalaburagi district over a period of 7 years were analysed. Both the arithmetic mean, standard deviation, and coefficient of variation were calculated, and the results are discussed.

Identification of Excess and Deficit Rainfall Years: In this study, simple observations and straightforward mathematical calculations are used to identify excess and deficit rainfall based on specific criteria. The classification is as follows, in line with the Karnataka State Natural Disaster Monitoring Centre's (KSNDMC) standards:

- Large Excess (LE): +60% and above
- Excess (E): +20% to +59%
- Normal (N): +19% to -19%
- Deficient (D): -20% to -59%
- Large Deficit (LD): -60% or below
- NR: No Rainfall (-100%)

Taluks are categorised accordingly as having excess, deficit and other classifications based on these criteria.

Result and Discussion

Over a seven-year period (2016–2022), the district received an average rainfall of 797 mm, with a standard deviation (SD) of 189.26 and a coefficient of variation (CV) of 23.74%. Jevaragi Taluk, with the highest CV of 30.84%, is particularly noteworthy due to its significant variations in rainfall. This variation partly results from the inclusion of Yadrami Taluk's data up until 2019. Jevaragi's average rainfall starting in 2020 is 880 mm, compared with Yadrami's average of 731 mm (Table 1).

Table 1: Taluk wise annual rainfall data

Sl. No	*Taluks*	*Mean Rainfall*	*SD*	*CV*
1	Kalaburagi (Dist.)	797	189.26	23.74
2	Afzalpur	698	160.38	22.97
3	Aland	838	169.65	20.24
4	Chincholi	860	195.36	22.71
5	Chittapur	838	211.08	25.18
6	Jevargi	682	210.38	30.84
7	Sedam	859	217.99	25.37
8	Kalaburagi(Tq)	818	214.62	26.23
9	Kalagi	1086	186.65	17.18
10	Kamalapur	1056	207.85	19.68
11	Shahbad	995	120.9	12.15
12	Yadrami	737	115.16	15.62

Shahabad exhibits the least variation in rainfall, with a CV of 12.15% and an average rainfall of 995 mm. Yadrami follows with an average of 737 mm and a CV of 15.62%. Aland, Chincholi, Afzalpur, Chittapur, Sedam, and Kalaburagi (Tq) show moderate rainfall variability, with CVs ranging from 20.24% to 26.23%. These variations are influenced by geographical factors: Jevaragi, located between semi-arid and dry deciduous forests, shows notable rainfall fluctuations. In contrast, Shahabad's consistent rainfall may be attributed to its specific geographic characteristics.

The diverse CV percentages across Kalaburagi district's taluks, shaped by local climate conditions, historical data, and geographical factors, reflect varied rainfall patterns. For instance, the presence of dry deciduous forests in Chincholi and Sedam taluks contributes to their moderate rainfall variability. Kalaburagi (Tq) and Chittapur taluks experience medium fluctuations due to their transitional zone climate. Aland and Afzalpur taluks, characterised by semi-arid landforms and vegetation, also show moderate variability influenced by these features.

Overall, Kalaburagi district demonstrates a CV of 23.74% over the past seven years (2016 to 2022), indicating a moderate level of rainfall fluctuation and variability.

Season Wise Rainfall Analysis

Pre-monsoon: Table 2 indicates that during the pre-monsoon season, Sedam taluk exhibits the highest variability in CV percentage at 120.35%, indicating extreme fluctuations and variability in rainfall. Alongside Sedam, taluks such as Aland, Chittapur, Shahabad, Kalaburagi (Tq), Chincholi, Jevaragi, and Kalagi also show high variability. In contrast, Yadrami has a low CV percentage of 5.7%, indicating very low variability in rainfall. Overall, Kalaburagi district has a CV of 38.88%, reflecting a high level of variability in rainfall during the pre-monsoon season over the last seven years (2016–2022) (Table 2).

Southwest-monsoon: Jevaragi taluk shows the highest CV percentage of 32.21% during the southwest monsoon season, indicating significant fluctuations and variability in rainfall. In contrast, Yadrami taluk has a very low CV of 0.71%, reflecting minimal variability in rainfall. Overall, Kalaburagi district experiences a moderate level of rainfall variability during the southwest monsoon season, with a CV of 25.84% (Table 2).

North west monsoon: Aland taluk exhibits the highest CV percentage of 55.02% during the northeast monsoon season, indicating extreme fluctuations and variability in rainfall. Conversely, Kamalapur taluk shows the lowest CV at 20.13%, reflecting less variability in rainfall. Overall, Kalaburagi district has a CV of 37.7% during the northeast monsoon season, suggesting a high level of rainfall variability (Table 2).

In 2016, Kalaburagi district received 839 mm of rainfall, which was 3% above the average for the area. Chincholi taluk recorded the highest rainfall at 1064 mm, a 15% increase, while Jevaragi taluk had the lowest at 601 mm, representing a -23% deviation. In 2017, the district received 734 mm of rainfall, a 10% deficit, but still considered typical. Aland taluk experienced the most rainfall at 854 mm, a 7% increase, whereas Jevaragi had the least at 620 mm, reflecting a -21% deviation. Chincholi also had a -21% deviation (Table 2).

In 2018, Kalaburagi district faced a significant deficit with 495 mm of rainfall, a 39% shortfall. Jevaragi received the least amount at 374 mm, with a -52% deviation, while Chincholi recorded the most at 584 mm, with a -37% deviation. In 2019, the district saw 650 mm of rainfall, which was 20% below the average annual precipitation of 812 mm, classifying it as deficient (Table 2).

In 2020, Kalaburagi district experienced 1068 mm of rainfall, 39% above the average, categorising it as excess. Kamalapur taluk had the highest rainfall at 1295 mm, accounting for 70% of the district's total, while Yadrami taluk recorded the least with 859 mm or 25% of the district's total. Chincholi taluk had the highest rainfall at 762 mm, with an -18% deviation, while

Table 2: Taluk and season wise rainfall data

		Pre-Monsoon			*Southwest*			*Northeast*		
Sl. No	*Taluks*	*Mean*	*SD*	*CV*	*Mean*	*SD*	*CV*	*Mean*	*SD*	*CV*
1	Kalaburagi(Dist)	69	26.89	38.88	615	158.93	25.84	111	41.85	37.7
2	Afzalpur	64	20.85	32.57	516	134.33	26.03	110	56.68	51.52
3	Aland	75	35	46.66	649	153.52	23.65	114	62.73	55.02
4	Chincholi	70	25.52	36.45	675	174.41	25.83	114	46.56	40.84
5	Chittapur	76	31.9	41.97	640	172.16	26.9	120	51.64	43.03
6	Jevargi	75	31.12	41.49	630	134.21	21.3	112	49.76	44.42
7	Sedam	64	28.56	44.62	519	167.18	32.21	99	53.46	54
8	Kalaburagi(Tq)	73	87.86	120.35	681	146.43	21.5	105	57.62	54.87
9	Kalagi	91	48.24	53.01	727	191.71	26.37	179	36.04	20.13
10	Kamalapur	96	22.73	23.67	661	66.62	10.07	169	34.02	20.13
11	Shahbad	91	48.28	5.7	640	98.17	15.31	155	33.51	28.52
12	Yadrami	54	3.08	53.05	510	3.67	0.71	109	31.09	21.61

Jevaragi taluk had the lowest rainfall at 539 mm, with a -31% deviation. Aland taluk contributed the highest percentage of the total rainfall at 10% (Table 3).

In 2021, Kalaburagi district experienced an unusual climatic pattern with 943 mm of rainfall, marking a 22% increase above the long-term average, indicating significantly above-average precipitation. Among the taluks in the district, Yadrami recorded the lowest rainfall at 630 mm, representing an 8% deficit from its norm, while Kalagi taluk received the highest rainfall at 1,263 mm, accounting for an impressive 65% of the district's total precipitation (Table 3).

The following year, 2022, the district received 847 mm of rainfall, which was 10% above the average, a figure that aligns with what is generally considered normal precipitation. Yadrami again had the lowest rainfall, though slightly improved at 723 mm, with a modest 5% deviation from the norm. On the other hand, Kamalapur taluk recorded the highest rainfall at 915 mm, which contributed to 20% of the district's total rainfall (Table 3).

Over the recent years, Kalaburagi district's rainfall pattern has varied notably. The district experienced excess rainfall in both 2020 and 2021, while the years 2018 and 2019 were marked by insufficient precipitation. The rainfall levels in 2016, 2017, and 2022 were relatively normal, reflecting the district's average climatic conditions (Figure 2).

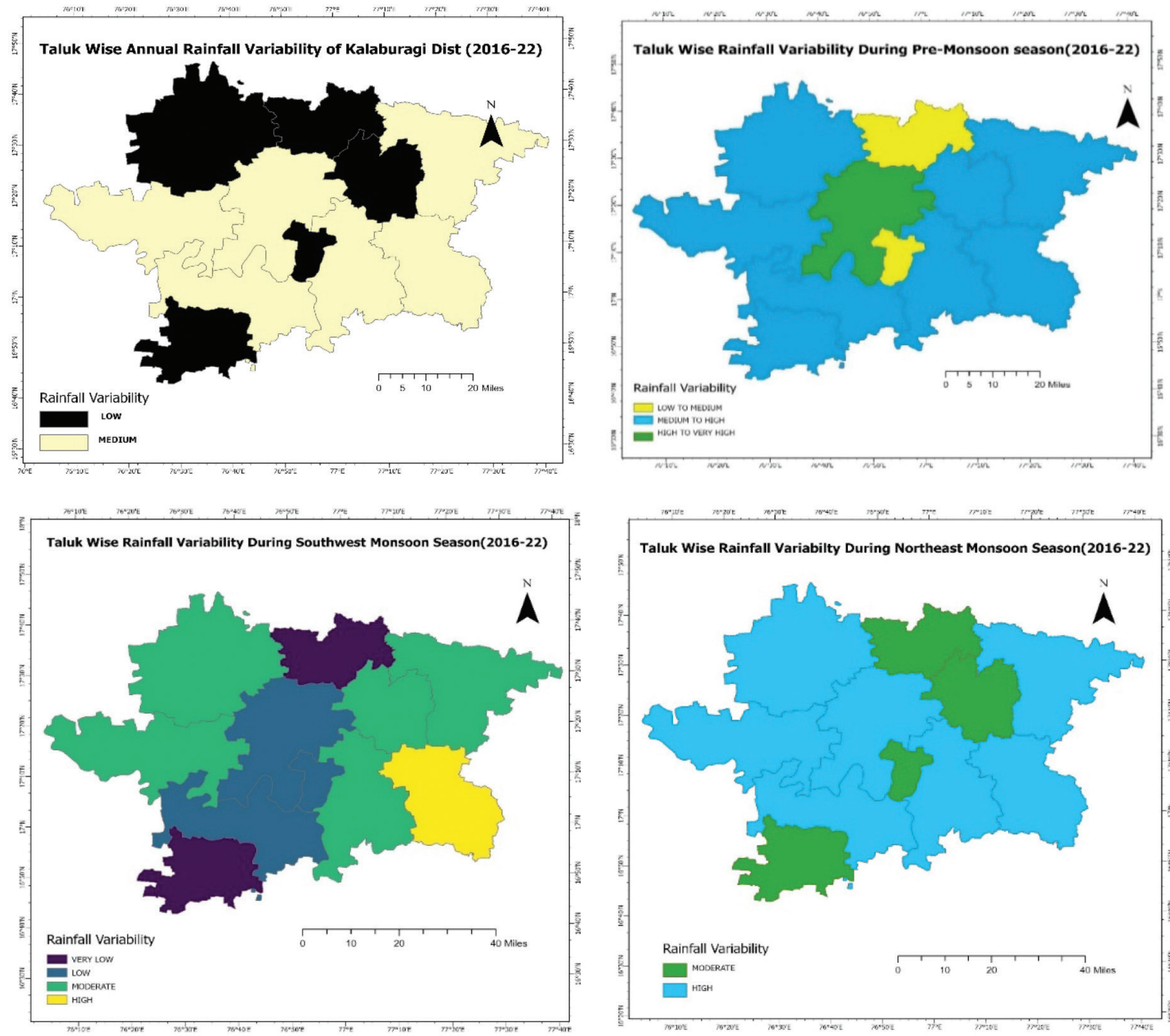

Figure 2: Taluk wise annual & season wise rainfall variability maps of Kalaburagi District from 2016-2022.

Table 3: Taluk wise mean and actual rainfall data

			2016		2017		2018		2019		2020			2021		2022	
	Taluk	*Mean Average (mm)*	*Actual (mm)*	*Deficit%*	*Actual (mm)*	*Deficit%*	*Actual (mm)*	*Deficit%*	*Actual (mm)*	*Deficit%*	*Mean Average 2020-22 (mm)*	*Actual (mm)*	*Deficient%*	*Actual (mm)*	*Deficient%*	*Actual (mm)*	*Deficient%*
1	KALABURAGI (Dist)	512	839	3	734	-10	495	-39	653	-20	770	1068	39	943	22	847	10
2	AFZALPUR	693	652	-6	644	-7	448	-35	617	-11	692	943	36	825	19	762	10
3	ALAND	798	856	7	854	7	536	-33	716	-10	763	1039	36	994	30	874	15
4	CHINCHOLI	925	1064	15	728	-21	584	-37	762	-18	913	1085	19	920	1	879	-4
5	CHITTAPUR	798	913	14	747	-6	526	-34	640	-20	771	1088	41	1066	38	887	15
6	JEVARGI	782	601	-23	620	-21	374	-52	539	-31	805	1001	24	819	2	821	2
7	SEDAM	871	972	12	803	-8	547	-37	644	-26	791	1228	55	913	15	911	15
8	KALABURAGI	821	861	5	752	-8	478	-48	662	-19	794	1105	39	1036	31	837	5
9	KALAGI	766									766	1104	44	1263	65	891	16
10	KAMALAPUR	762									762	1295	70	959	26	915	20
11	SHAHBAD	864									864	1102	45	1020	34	864	14
12	YADRAMI	723									723	859	25	630	-8	723	5

This fluctuation in rainfall can be partly explained by the influence of global climatic phenomena, particularly El Niño and La Niña. The El Niño phenomenon, characterised by the warming of sea surface temperatures in the central and eastern tropical Pacific Ocean, can severely disrupt monsoon patterns in India. During El Niño years, the Indian subcontinent often experiences weakened monsoon winds and reduced rainfall. The deficient rainfall in Kalaburagi district during 2018 and 2019 aligns with these broader El Niño-induced disruptions in the Indian monsoon system (Figure 15).

Conversely, the nationwide lockdowns imposed in 2020 and 2021 due to the COVID-19 pandemic resulted in a significant reduction in pollution, which inadvertently created favourable conditions for increased rainfall. This factor, combined with the La Niña phenomenon, which often brings higher-than-average rainfall to certain regions of India, contributed to the excessive rainfall experienced in Kalaburagi district during those years (Figure 15).

Looking at specific taluks, Sedam had the highest rainfall in the district between 2016 and 2019, followed closely by Chincholi. From 2020 to 2022, Kalagi and Kamalapur taluks emerged as the regions with the most substantial rainfall. The primary reason for this elevated precipitation is their semi-forested status, characterised by loosely dense forests and hilly terrain, which significantly influence local rainfall patterns (Figure 4). Extensive forests can increase the quantity and frequency of rainfall, with forested areas potentially receiving up to 25% more precipitation than adjacent non-forested regions (Figure 5).

In contrast, Jevaragi taluk recorded the lowest rainfall from 2016 to 2019, and Yadrami taluk had the lowest from 2020 to 2022. These taluks are primarily semi-arid, with predominantly plain landscapes and sparse, desert-like vegetation. Such environmental conditions contribute to their inability to attract clouds and precipitation. The susceptibility of arid and semi-arid regions to variations in local climate, particularly in terms of precipitation, underscores the challenges these taluks face in maintaining consistent rainfall levels (Figure 3).

For Kalaburagi district, the Sen slope analysis from 2016 to 2022 reveals a positive trend in rainfall, with a slope value of 0.006 indicating an overall increase in precipitation during this period. This positive trend is consistent across all 11 taluks within the district, suggesting a general pattern of rising rainfall (Figure 6).

Among the taluks, Kamalapur exhibits the smallest increase, with a Sen slope of 0.005, while Yadrami shows the highest rate of increase at 0.011. These variations indicate that while there is a steady rise in precipitation district-wide, the rate of this increase differs significantly between taluks (Figure 7).

The differing trends in rainfall across the taluks can be attributed to a combination of local climatic conditions and geographic features. Factors such as topography, vegetation cover, and regional weather patterns can influence the amount and distribution of rainfall. For example, taluks with more complex terrain or greater forest cover, such as Kamalapur and Yadrami, may experience different rates of precipitation increase compared with those with more uniform landscapes.

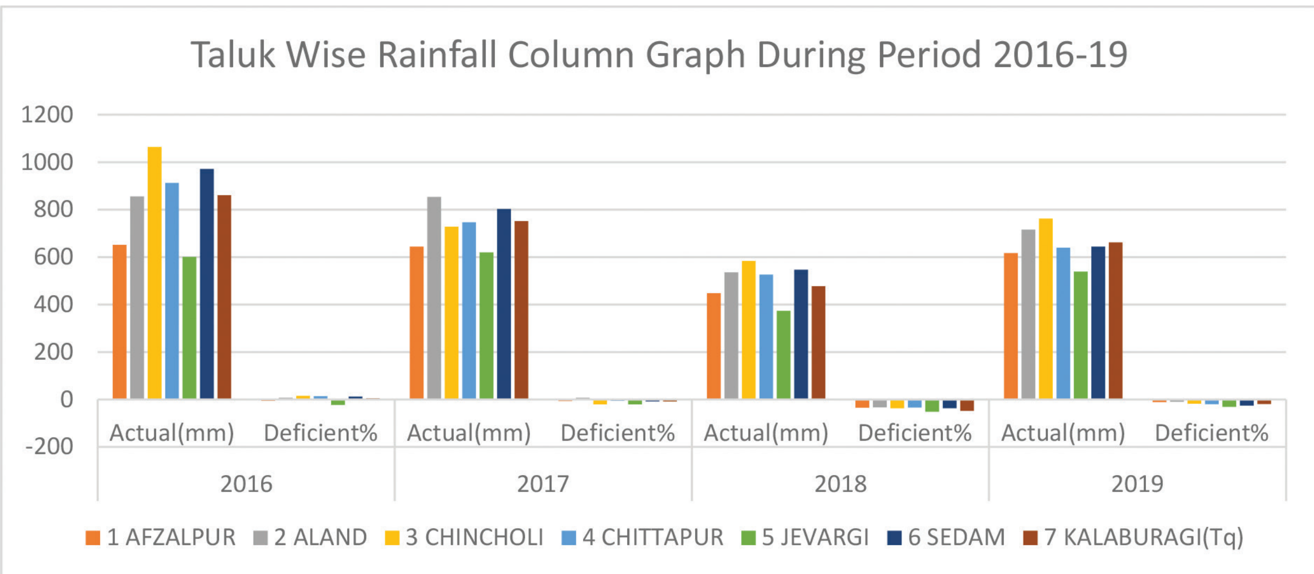

Figure 3: Talukwise rainfall from 2016 to 2019.

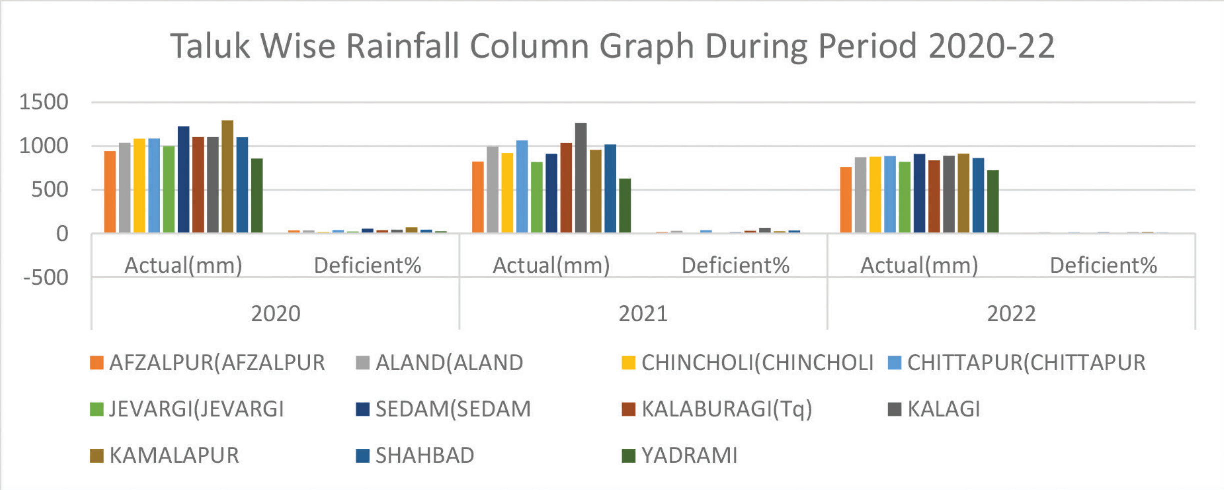

Figure 4: Taluk wise rainfall column graph during period 2020-22.

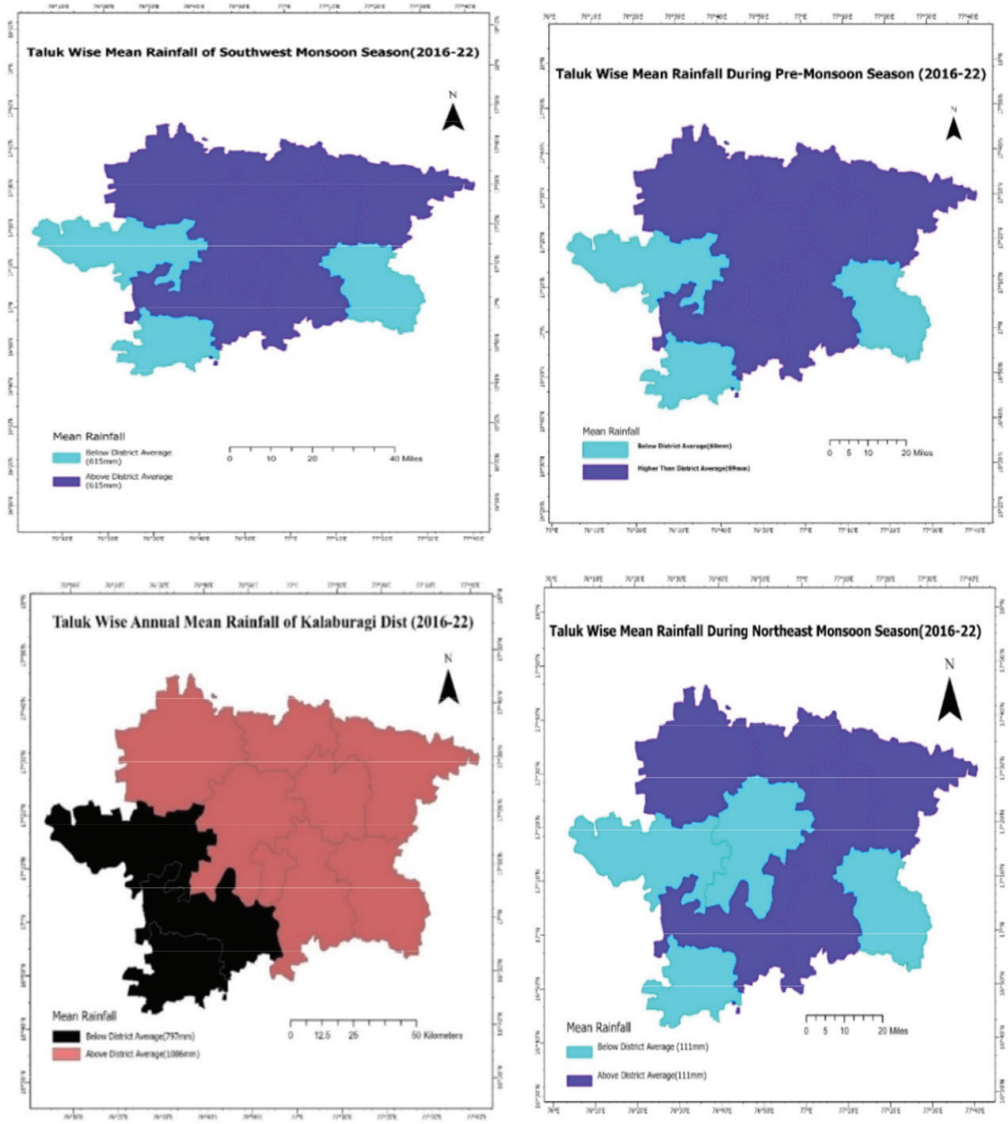

Figure 5: Taluk wise annual and season wise maps of mean rainfall of Kalaburagi district from 2016-2022.

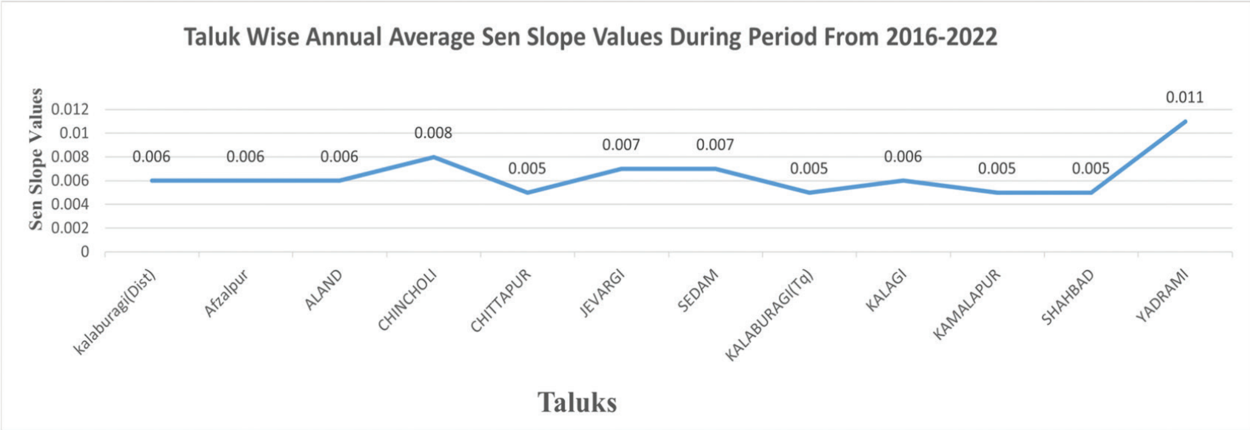

Figure 6: Taluk wise annual Sen slope during period from 2016-22.

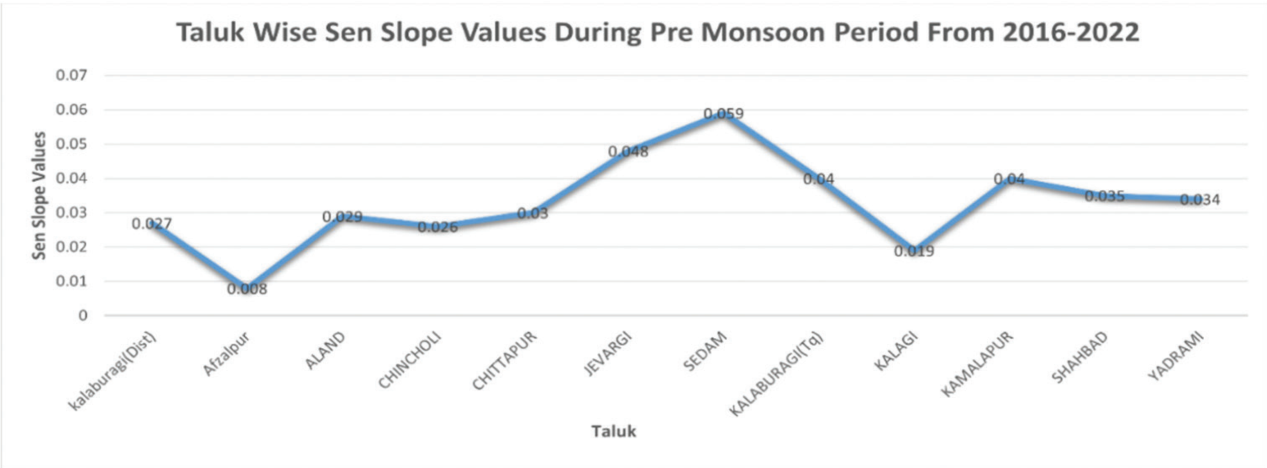

Figure 7: Taluk wise pre monsoon Sen slope during from 2016-22.

In summary, the observed positive Sen slopes across Kalaburagi district highlight a general upward trend in rainfall from 2016 to 2022. However, the variation in the rate of increase among taluks suggests that local geographic and climatic factors play a significant role in shaping the rainfall patterns within the district.

During the **pre-monsoon** period, all taluks within Kalaburagi district exhibit a positive Sen slope curve, albeit with variations among them. This collective trend suggests a moderate increase, with Kalaburagi district as a whole showing a Sen slope of 0.027 percentage points. This indicates a discernible upward trajectory in the pre-monsoon conditions, albeit at a moderate pace.

During the **southwest monsoon** period, Positive Sen slopes in the majority of taluks indicated an upward trend. In contrast to Aland's moderate trend (Sen slope of 0.005), Chittapur recorded a rapid increase (Sen slope of 0.03), indicating different rates of change in southwest monsoon rainfall (Figure 8).

During the **northeast monsoon**, The taluks of Afzalpur, Jevaragi, Chittapur, Kamalapur, and Yadrami had positive Sen slopes, which indicated an increase in rainfall. The district of Kalaburagi showed an overall positive Sen slope of 0.016 (Figure 9).

Overall Kalaburagi district *p*-value of 0.348, it means that there is not enough evidence to reject the null hypothesis at a typical significance level of 0.05. Therefore, we would interpret this result as indicating that there is no statistically significant trend in the rainfall data for Kalaburagi District from 2016-2022.

P-values for Kalaburagi Taluks range from 0.091 to 0.348, suggesting little variations in rainfall between 2016 and 2022 (Figure 13). Patterns before the monsoon are not significant (*p*-values: 0.091-0.573) (Figure 12). A small amount more evidence is presented by Aland and Sedam to disprove the null hypothesis. Overall (Figure 14), no trend is obvious with the possible

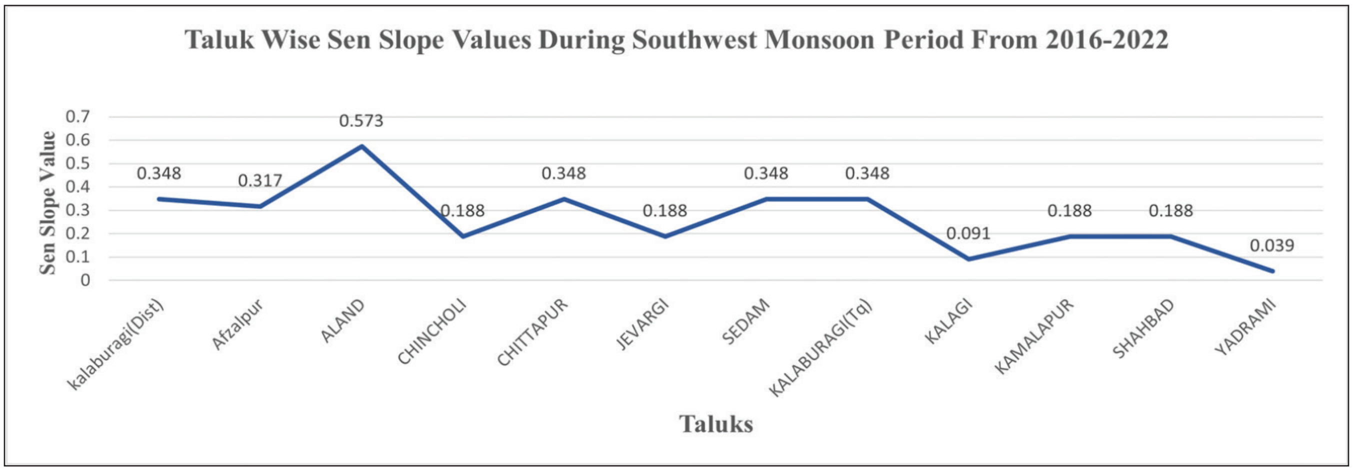

Figure 8: Taluk wise SouthWest Season Sen Slope Values During 2016-22.

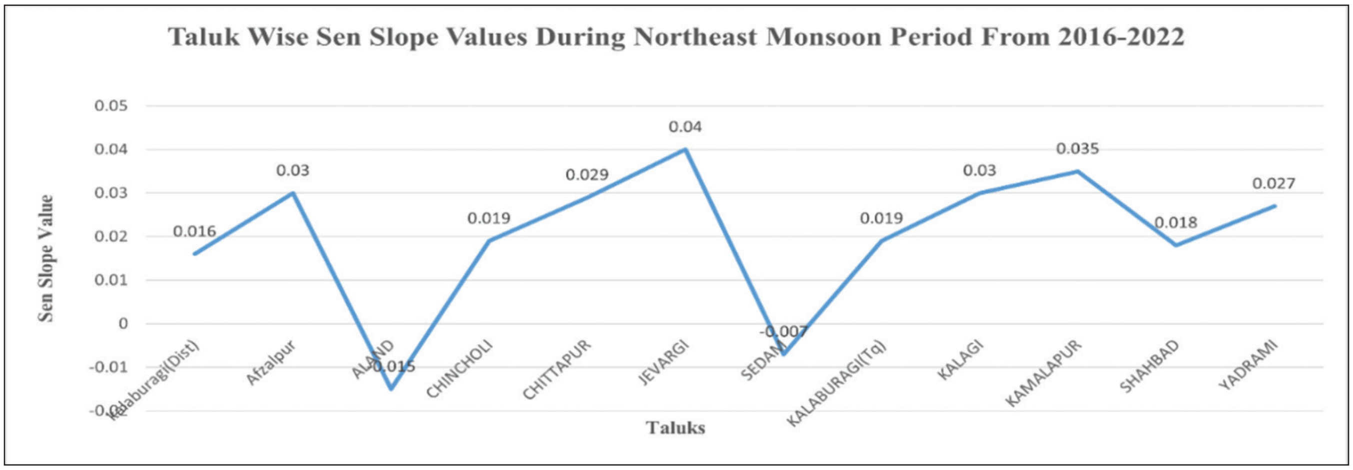

Figure 9: Taluk wise Northeast Season Sen Slope Values 2016-22.

exception of Kalagi. There is no pre-monsoon trend in Shahabad or most of the taluks.

In Kalaburagi District (2016–2022), Yadrami shows a noteworthy declining tendency (*p*-value: 0.039) during the **southwest monsoon**. Kalagi's decline is less evident (*p*-value: 0.091) (Figure 10). Afzalpur, Chittapur, Sedam, and Kalaburagi (Tq) are among the other taluks where no trends are visible (*p*-value: 0.348). Additionally, there is not a noticeable pattern in Aland, Chincholi, Jevargi, Kamalapur, or Shahbad (*p*-value: 0.188-0.573) (Figure 11).

The northeast monsoon rainfall in Kalaburagi District (p-values ranging from 0.091 to 0.851) shows little variation from 2016 to 2022. With the exception of Kamalapur, Chittapur, and Kalagi, the majority of taluks display not a clear pattern, giving thin proof of possible patterns. In general, during this period, there are no major trends in the northeast monsoon rainfall in most of the district's taluks.

Implications for Water Resource Management in Kalaburagi:

The results of this study reveal significant trends in water availability and usage patterns in Kalaburagi, which have direct implications for the region's water resource management strategies. The observed fluctuations in water levels, coupled with the increasing demand from both agricultural and urban sectors, highlight the urgent need for a more sustainable and adaptive management approach.

1. Seasonal Variability and Water Supply Planning: The data indicates marked seasonal variations in water availability, with substantial reductions during the dry months. This seasonal fluctuation suggests that Kalaburagi's current water storage and distribution systems may not be sufficient to meet peak demand periods. To mitigate this, it is crucial to develop and implement strategies such as enhanced water storage infrastructure, the promotion of rainwater

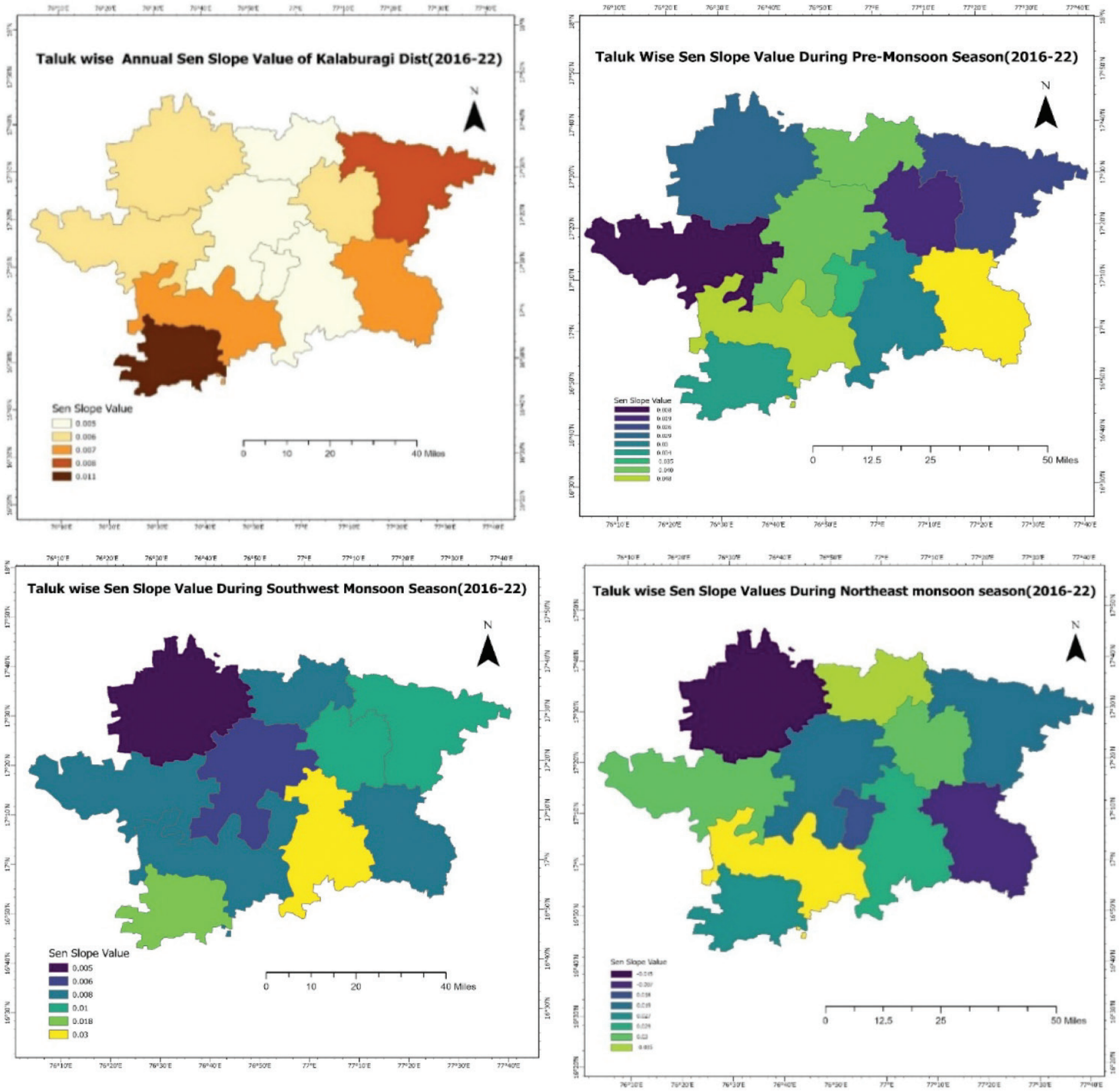

Figure 10: Annual and Season wise Sen Slope Maps of Kalaburagi district from 2016-22.

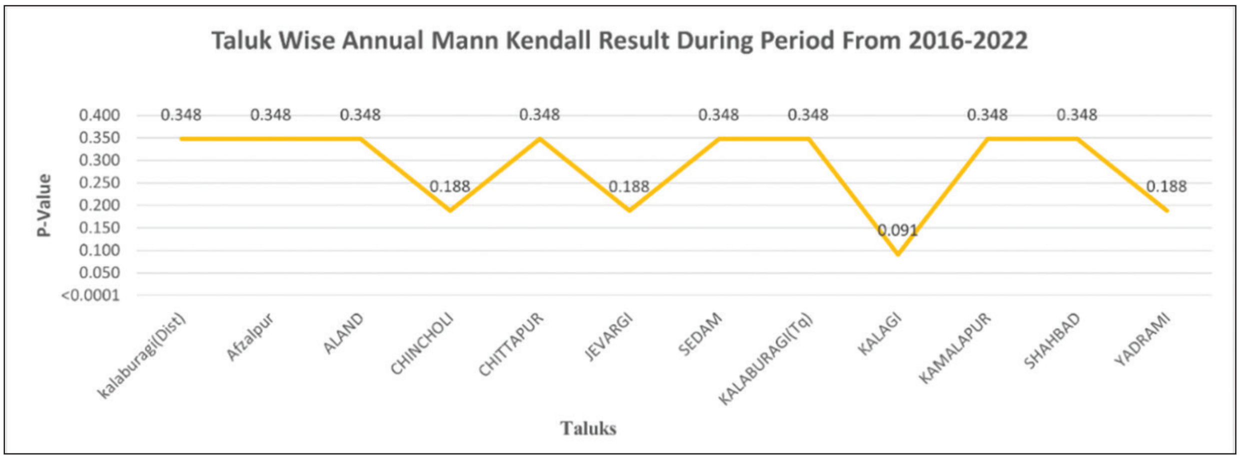

Figure 11: Taluk wise annual Mann Kendall result during from 2016-22.

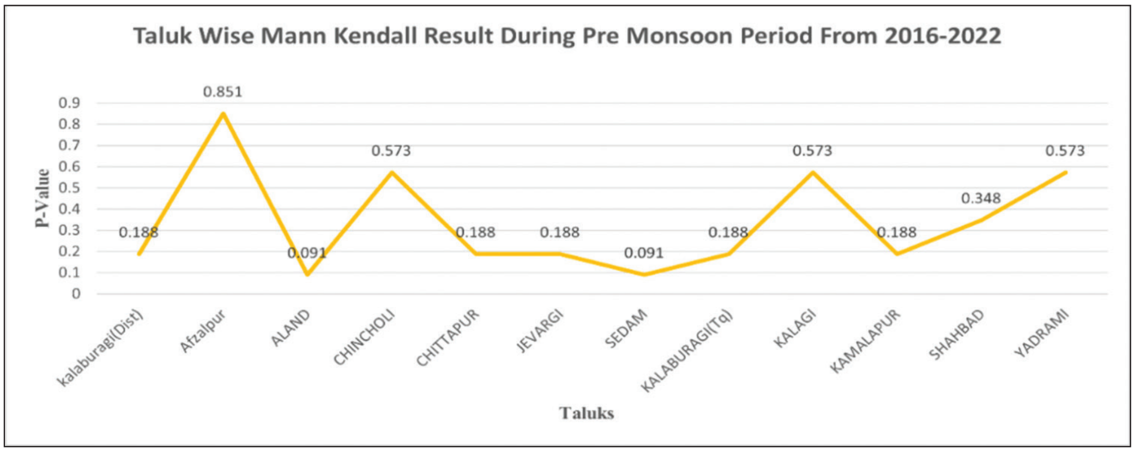

Figure 12: Taluk wise Mann Kendall result during pre monsoon from 2016-22.

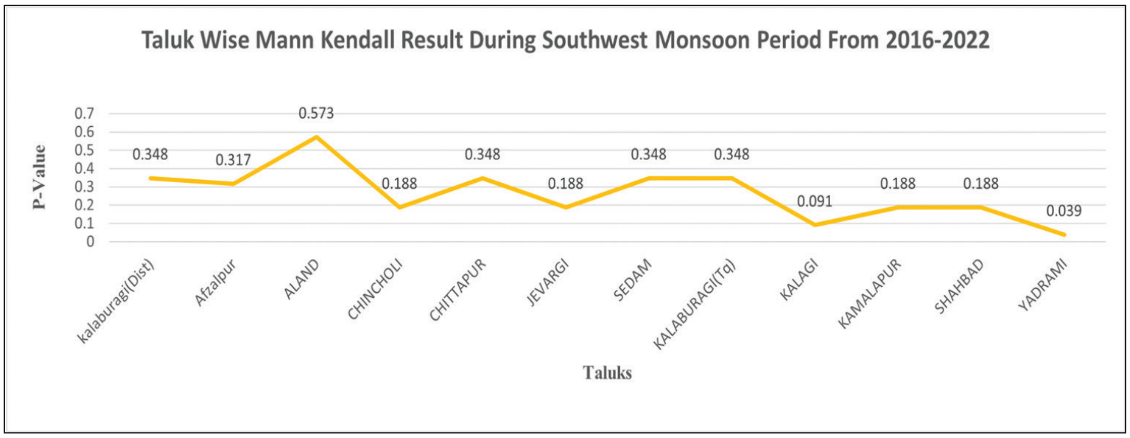

Figure 13: Taluk wise Mann Kendall result during Southwest monsoon from 2016-22.

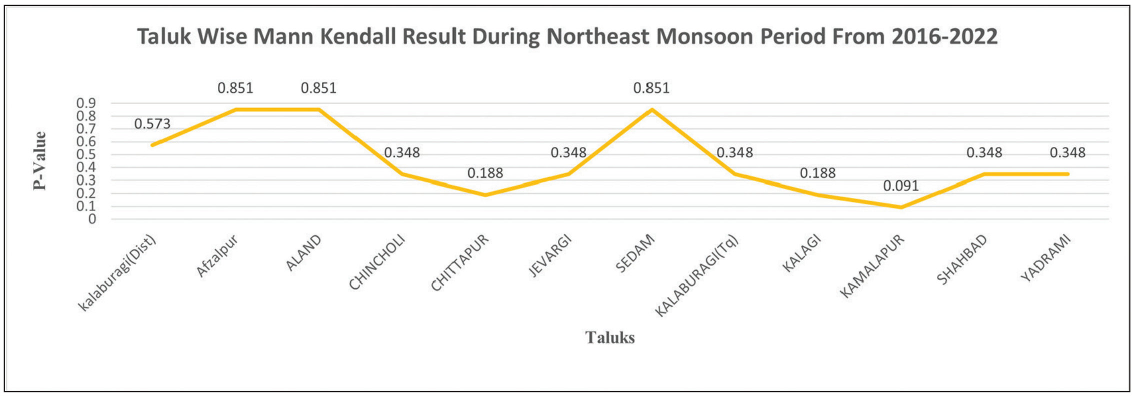

Figure 14: Taluk wise Mann Kendall result during Northeast monsoon from 2016-22.

harvesting, and the adoption of advanced water conservation techniques to ensure a reliable water supply throughout the year.

2. Groundwater Depletion and Recharge Strategies: The study also highlights a concerning trend of groundwater depletion, driven by over-extraction for agricultural purposes. To address this, it is imperative to implement groundwater recharge initiatives, such as the construction of check dams and the promotion of sustainable agricultural practices that reduce water consumption. Additionally, regulating groundwater extraction through stricter policies and encouraging the use of alternative water sources could help in reversing the depletion trend.

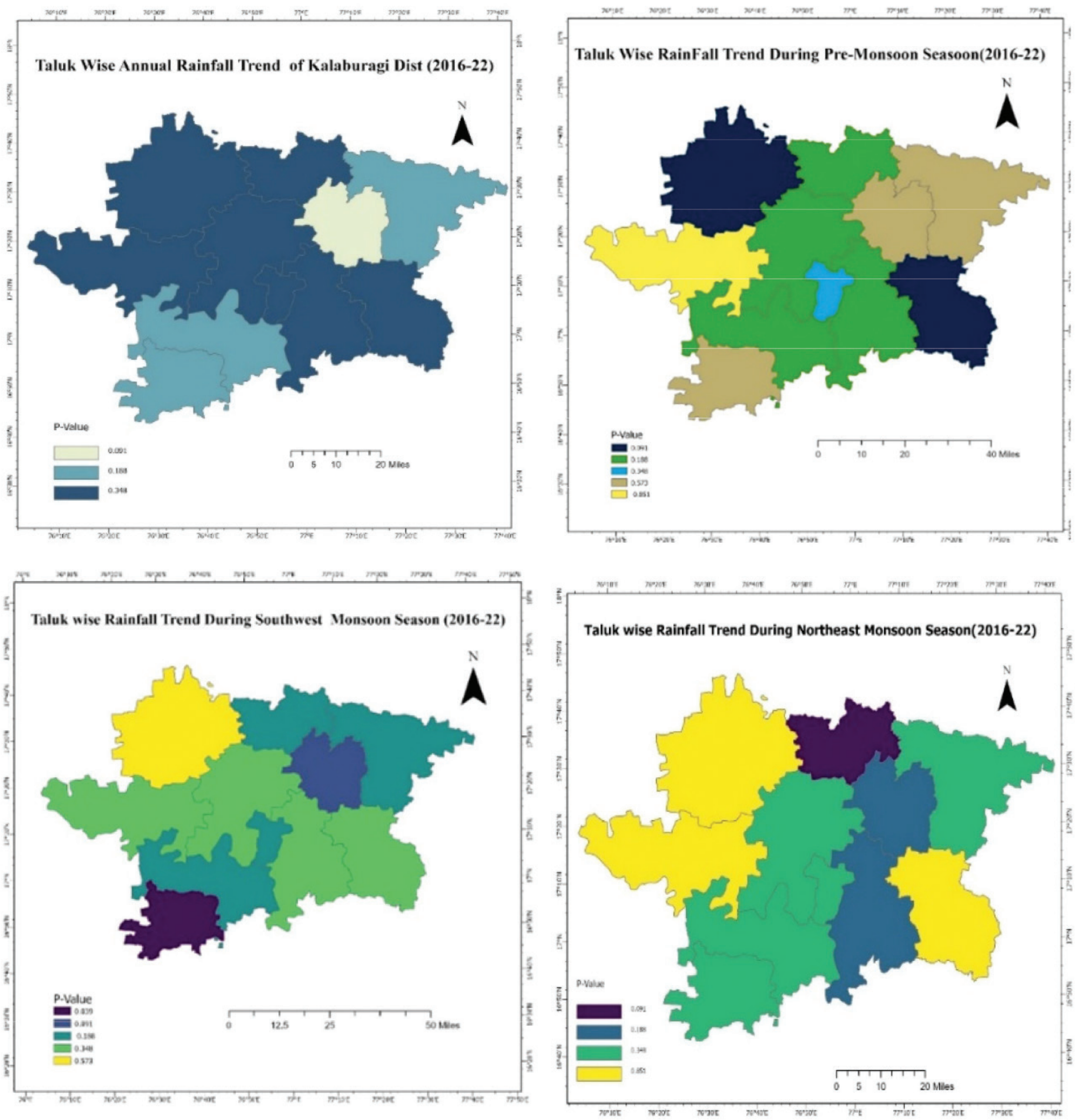

Figure 15: Taluk wise annual and season wise map of rainfall trends of Kalaburagi District from 2016-2022.

3. Urbanisation and Water Demand Management: The rapid urbanisation in Kalaburagi is contributing to increased water demand, putting additional pressure on already stressed water resources. The findings suggest that urban planning in Kalaburagi must incorporate integrated water resource management (IWRM) principles to balance the needs of urban development with sustainable water use. This could involve promoting the use of water-efficient technologies in households and industries, enhancing wastewater treatment and reuse, and encouraging community-based water management practices.
4. Climate Change Adaptation: The observed trends in rainfall patterns and temperature changes indicate that Kalaburagi's water resources are increasingly vulnerable to the impacts of climate change. As such, there is a need for adaptive water management strategies that can respond to the uncertainties associated with climate variability. This might include diversifying water sources, improving the resilience of water infrastructure, and developing early warning systems for droughts and floods.
5. Policy and Governance Implications: The research underscores the importance of robust water governance frameworks that can support sustainable

water management in Kalaburagi. Policymakers should consider revising existing water management policies to incorporate the findings of this study, with a focus on promoting equitable water distribution, enhancing stakeholder participation, and fostering collaboration between government agencies, local communities, and non-governmental organisations.

Conclusion

To summarise, from 2016 to 2019, Sedam Taluk experienced the highest annual mean rainfall, followed by Chincholi, while Jevaragi Taluk had the lowest. From 2020 to 2022, Yadrami Taluk recorded the lowest annual mean rainfall, whereas Kamalapur and Kalagi Taluk received the most. On average, Kalaburagi District receives 797 mm of rainfall annually. Jevaragi Taluk has the highest variability in annual rainfall, while Shahabad Taluk has the lowest.

Rainfall in Kalaburagi District exhibits slight variation annually, with greater fluctuations occurring during the pre-monsoon and northeast monsoon seasons. The pre-monsoon season shows the most variation in Sedam Taluk, while the southwest monsoon season is the most variable in Jevaragi Taluk, and the northeast monsoon season is the most variable in Aland Taluk. Yadrami Taluk shows less variability during the pre-monsoon and southwest monsoon seasons, whereas Kamalapur Taluk exhibits the least variability during the northeast monsoon.

Overall, the Sen slope analysis for Kalaburagi District and its 11 taluks indicates a general increase in rainfall, with the exception of negative Sen slopes in Aland and Sedam Taluks during the northeast monsoon. The Mann–Kendall test reveals no significant annual trend in rainfall for most taluks and the district as a whole from 2016 to 2022, except for noticeable trends in Yadrami and Kamalapur Taluks during the southwest and northeast monsoon seasons, respectively.

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