



# Detection of spatiotemporal patterns of rainfall trends, using non-parametric statistical techniques, in Karnataka state, India

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**Abstract** The unpredictability of the climate has drawn a lot of interest worldwide, especially that of the annual mean temperatures and rainfall. In this study, non-parametric tests such as the LOWESS curve method, Mann–Kendall (MK), SNHT test, Pettitt's test (PT), and Buishand range test (BRT) were used to evaluate long-term (2000–2020) rainfall data series to examine rainfall variability. The Dakshina Kannada district has the highest average rainfall is 3495.6 mm with a magnitude change% of about 26.2, while the Koppala district has the lowest average rainfall roughly about 530.4 mm, with a magnitude change % of about 11.49 mm in a year. The statistics from the fitted prediction line were utilized to determine the maximum coefficient determination ( $R^2=0.8808$ ) in the Uttara Kannada region. Because of the commencement of the present rising era, 2015 is the shift year in rainfall with the highest potential of being a change point in the state's Western Ghats region. It was also revealed that the majority of the districts exhibit positive trends before the change point and vice versa. The current research can be used

to plan for and minimize the agricultural and water resource challenges in the state of Karnataka. To link observable patterns to climate variability, the next inquiry must identify the source of these changes. Overall, the study's findings will help organize and improve drought, flood, and water resource management techniques in the state.

**Keywords** Non-parametric test · Rainfall · Climate change · LOWESS curve · Karnataka state

## Introduction

One of the most essential parts of the earth's system is the climate. Weather and climate are made up of a variety of factors, including temperature, precipitation, air pressure, and humidity. Generally, the climate is described as the typical weather (Saravanan, 2022; Yadav et al., 2014; Zhang & Lu, 2009). The major constituent of the hydrological cycle is precipitation; the accurate estimation of precipitation in time and space is crucial for agricultural activities. Traditionally, the measurements from point-based rain gauge observations are spatially interpolated to estimate areal rainfall. Increased global warming has a substantial impact on the pattern of climate change, which impacts interactions between the land surface and the atmosphere as well as environmental changes.

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For a long time, policymakers have been worried by the challenges of climate change (Cancelliere et al., 2007); notably in terms of precipitation and temperature, these changes have a significant impact on the frequency, intensity, and spatiotemporal distribution of rainfall patterns, leading to a variety of meteorological issues in the globe (Atilgan et al., 2017; Machiwal et al., 2019). Any region's food security, energy security, and agriculture are critically dependent on timely access to sufficient water supplies and a hospitable environment (Panda, 2019). The amount of water that can be used to satisfy various demands, including those for agricultural, industrial, domestic water supply, and hydroelectric power generation, depends significantly on the amount of rainfall that an area receives.

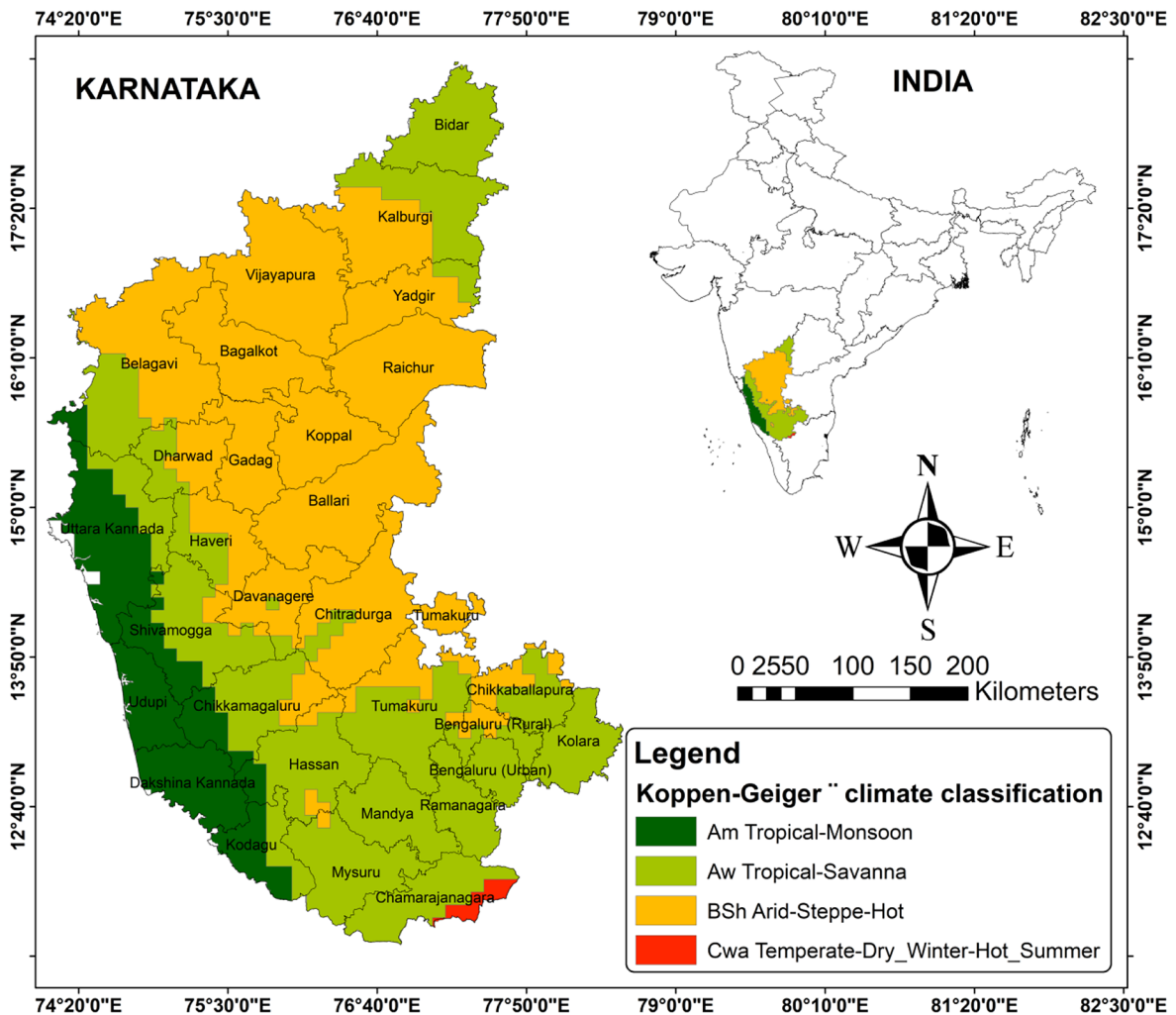
Given that, Indian farmers heavily depend on rainfall, and the lack of certainty and non-uniformity connected with its characteristics could have a serious impact on agricultural production (Seyhun & Akin-tug, 2013). Therefore, as well as other hydro-climatic variables like temperature, precipitation is a crucial variable. The lower the relative humidity, the drier the air, and the higher the evaporation rate (Prabhakar et al., 2019). Therefore, there is a need to research the altered precipitation patterns and their impact on water resources. The literature on the effects of global warming strongly suggests that the pattern of rainfall has significantly changed globally (Diaz et al., 1989; L. Zhang & Zhou, 2011). Numerous other researchers have also emphasized how future climate change will affect trends in rainfall; there will be severe differences in rainfall amount and spatiotemporal patterns of rainfall in the majority of India's regions. A study shows that examines rainfall characteristics features, variability, and precipitation trends (Ghosh, 2018). The research into climatic change for reliable water assets and variation in the dispersion of precipitation is essential. Above all, a comprehensive understanding of rainfall inspection in the modified ecology will lessen the likelihood of the greatest weather (Praveen et al., 2020a). The strength of the trend as well as its statistical significance is the two main components of long-term time series trend analysis. In general, non-parametric or parametric methods are used to determine the results of change detection studies for various hydrologic and climatic variables (Kumar et al., 2016). Karnataka is the seventh-largest peninsular state in India. Currently, only precipitation in 45 to

55% of the regions is utilized to grow crops. The state is located in the south agro-climatic region of India. It has tropical weather, a climate, winters, mild summers, and monsoons. Pre-monsoon started from January to May, Southwest is from June to September, and Northeast is from October to December, and these are the three seasons that make up the entire year (Harishnaika et al., 2022a, 2022b).

The first approach is referred to as a parametric approach, whereas the second approach (variation of trends in rainfall with the temporal variation) is referred to as a nonparametric approach MK and Sen's slope estimator. For the assessment of distributed data in the presence of uncertainty, as seen in hydro-meteorological time series, the use of a nonparametric methodology is more appropriate among these methods (Kalumba et al., 2013; Sabzevari et al., 2015). In this research long term rainfall data for Karnataka state available on an annual and monthly basis rainfall from the year 2000 to 2020. Sen's slope estimator and the MK test method were used to examine the rainfall trends. The standard normal homogeneity test (Salehi et al., 2020), the Pettitt's test, Buishand's test, and the Von Neumann test are used to analyze the change point in the long-term time data series of precipitation. The investigation of the annual rainfall variability and the LOWESS local regression method (Harishnaika et al., 2022a, 2022b), autocorrelations have also been looked at for the time series. This study aims to assess the spatiotemporal variability and trend of rainfall patterns in each district of Karnataka state.

## Study area

Karnataka (191791 Km<sup>2</sup>) is located on flat land close to the intersection of the Eastern and Western Ghats ranges, as well as the Niligiri hill complex, and is approximately bounded by latitudes 11.5°N and 18.5° N and longitudes 74° E and 78.5° E. The Koppen-Geiger Climate classification system uses 30 types and 5 major classes to categorize the global climate pattern and The Karnataka state falls on 4 classes as shown in Fig. 1. The varied changes in monthly temperature and rainfall are significant aspects that establish the classification system (Ahmed et al., 2022). The majority of the area



**Fig. 1** Geographic location and Koppen-Geiger classification of climatic zones

is covered by Aw (Equatorial Winter Dry); however, BSh (Arid Steppe Hot) and Tropical monsoons (Am) can also be found (Naranjo et al., 2018). As a result, it is surrounded on three sides by mountains: east, south, and west. The majority of the state is a plateau, with nearly all of the lands at a higher elevation of 600 ft (300 to 600 m) above sea level and up to 900 m in the southern half. The coast, which spans around 225 Km from north to south, has an estimated range of 50 to 80 Km to the south. Both the Western and Eastern Ghats mountains have multiple 1500-m-high summits. Mullayanagiri, located in the Western Ghats, is the tallest peak situated at

a height of 1914 m (6317 ft). The annual mean rainfall of Karnataka is about 1248 mm, and the mean temperature is about 28°C. Karnataka state lies in the X and XII agro-climatic zone, which is Karnataka's southern plateau and hill, west coast plain, and Ghats regions. The site, which moderates the area's tropical climatic regions, is one of the finest descriptions of the world's monsoon periods. It also has a huge level of ecological endemism and diversity and is identified as one of the world's eight "hottest hotspots" of biological diversity, but sometimes the regions of Western Ghats have less rainfall in some years, which leads to cause forest fires in this region.

**Datasets and methodology**

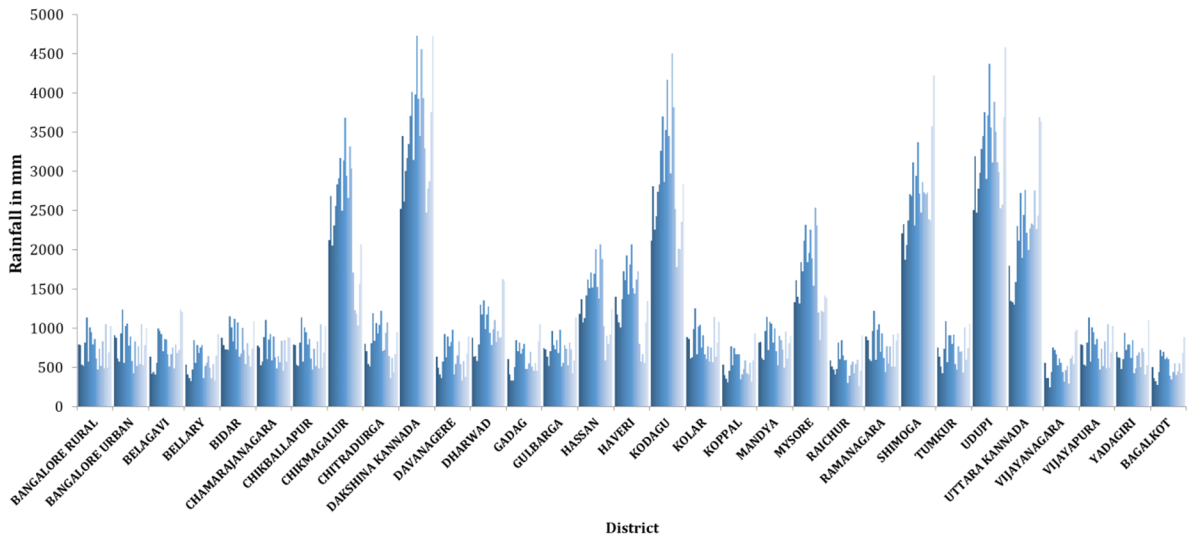
Climatic data

Table 1 shows the annual rainfall maximum, minimum, mean, and SD (standard deviation) for the selected meteorological stations. Each district of the state’s annual rainfall is shown in Fig. 2, which demonstrates over time. Based on the latitude and longitude of such a single location, the power global download widget provided users access to a (1/2 × 1/2 degree meteorological dataset for the entire world (Mu et al., 2013) Via its ESRP, the National Aeronautics and Space Administration (NASA) provides

data essential to the study of climate procedure (Earth Science research program). The basic different climatic average daily values retrieved from <https://power.larc.nasa.gov/data-access-viewer> are also provided with time series data (Reichle et al., 2017). The meteorological parameters used in this study from 2000 to 2020 are based on the same weather variables that were obtained from NASA POWER using the target sites’ closest grid point data of the MERRA-2 assimilation model. The Koppen-Geiger climate system considers the classification of the climate over the entire state (Ascencio-Vásquez et al., 2019). Using XLSTAT 2020, descriptive statistical computations were performed.

**Table 1** Rainfall statistics in districts of Karnataka

Stations	Long	Lat	Minimum	Maximum	Mean	Std. deviation
Bangalore rural	77.6	13.28	469.3	1133.8	746.3	209.3
Bangalore urban	77.65	12.97	421.9	1239.3	784.5	225.8
Belagavi	74.78	16.16	411.3	1239.3	736.8	236.9
Bellary	76.54	15.09	321.7	922.9	565.3	179.4
Bidar	77.51	17.91	506.3	1149.6	814.4	190.0
Chamarajanagara	77.28	12.05	453.5	1107.4	727.0	177.8
Chikballapur	77.72	13.43	469.3	1133.8	746.3	209.3
Chikmagalur	75.62	13.4	1033.6	3686.1	2412.5	747.1
Chitradurga	76.54	14.18	363.9	1223.4	797.8	241.5
Dakshina kannada	75.24	12.84	2469.0	4730.3	3495.6	685.4
Davanagere	75.99	14.33	327.0	980.9	633.6	201.4
Dharwad	75.24	15.37	580.1	1624.2	1018.5	292.3
Gadag	75.62	15.4	327.0	1049.4	610.0	189.9
Gulbarga	76.64	17.4	421.9	1133.8	719.2	173.0
Hassan	76.17	13.07	585.4	2061.9	1358.8	397.4
Haveri	75.43	14.66	553.7	2061.9	1327.4	436.5
Kodagu	75.8	12.33	1777.2	4503.5	2900.6	744.8
Kolar	78.2	13.17	564.3	1249.8	819.4	204.0
Koppal	76.17	15.62	305.9	928.1	530.4	166.2
Mandya	76.73	12.56	495.7	1144.3	814.9	182.6
Mysore	76.36	12.18	843.8	2531.3	1677.0	452.4
Raichur	76.64	15.92	263.7	907.0	549.7	164.0
Ramanagara	77.47	12.6	437.7	1218.2	771.2	209.4
Shimoga	75.15	14	1872.1	4218.8	2700.5	537.5
Tumkur	76.64	13.37	421.9	1091.6	727.0	201.4
Udupi	74.87	13.54	2468.0	4577.3	3281.1	588.8
Uttara kannada	74.68	14.79	1302.5	3691.4	2260.5	642.3
Vijayanagara	74.76	16.32	247.9	980.9	550.9	196.6
Vijayapura	77.8	13.29	469.3	1133.8	746.3	209.3
Yadagiri	77.14	16.76	406.1	1102.2	665.2	171.9
Bagalkot	75.62	16.13	274.2	885.9	520.1	155.8



**Fig. 2** Average annual rainfall variation from 2000 to 2020

**Methods**

Rainfall trend assessment using the MK test

The MK test typically works to correct patterns in hydro-meteorological investigations (Alashan, 2020; da Silva et al., 2015; Yanming et al., 2011). The World Meteorological Organization (WMO) frequently recommends this analysis due to its remarkable significance based on favorable or unfavorable signals; this study indicates major patterns (Khan et al., 2019). In this research, the alternative hypothesis (Ha) indicated an overtime series trend (either upward or downward), while the null hypothesis (H0) showed no trend in precipitation over time. To perform this test, it is necessary to assess the long-term data series’ long-term serial correlation as well as the influence of rainfall data’s trend, amplitude, size, and adaption.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(x_j - x_i) \tag{1}$$

These are the  $x_i$  and  $x_j$  numbers for the “ $i^{\text{th}}$ ” and “ $j^{\text{th}}$ ” idioms; the overall length of the information is  $n$ , and  $\text{sign}(x_j - x_i)$ , finally, considers the following values:

$$\text{sign}(x_j - x_i) = \begin{cases} +1, & \text{if } x_j - x_i > 1 \\ 0, & \text{if } x_j - x_i = 0 \\ -1, & \text{if } x_j - x_i < 1 \end{cases} \tag{2}$$

The variance is derived using

$$V(S) = \frac{1}{18} \left[ n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5) \right] \tag{3}$$

where  $n$  is indicated data length, the number of tied categories, and  $q$  is the value of times each of the  $p^{\text{th}}$  kinds in formula (3) which had a single value.

For the one-tailed derivation of  $S$ , Eq. (4) offers the standard estimate ( $Z$ ) for the Mann–Kendall test.

$$Z_{mk} = \begin{cases} \frac{s-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{s+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{4}$$

Although  $Z_{MK}$  includes 0 values, in an Mk test, the sign of  $Z_{MK}$  desired both positive and negative values of statistics return the declining and increasing trend independently. The Mann-Kendall test was used to analyze the variation in yearly and monthly rainfall patterns statistically significant at 5%.

Homogeneity and non-homogeneity test

Rainfall data is only considered “homogenous” when the observed rainfall data are caused by climatic differences and not by non-climatic (Ahmad et al., 2021; Saravanan, 2022) factors. The rainfall series data at internal to decadal time scales are frequently very difficult to obtain without introducing artificial changes that lead to data inhomogeneity. Inspecting for potential in-homogeneity in any hydrogeological time series is a prerequisite to trend analysis because the inhomogeneity in the information expands the original hydrologic rainfall data (Jenifer & Jha, 2021). However, aside from a few prior studies, the homogeneity test results have generally been disregarded.

To examine the homogeneity in the annual rainfall, four homogeneity statistical methods namely (1) standard normal homogeneity test (SNHT), (2) Buishand range test (BRT), (3) Von Neumann test (VNT), and (4) Pettitt’s test (PT) has been used in this study. These homogeneity tests all operate under the same fundamental presumptions; a different homogeneity test can be performed to determine whether two variables have the same distribution. Following the null hypothesis, the rainfall data values are independent, evenly dispersed, and homogeneous (Mallenahalli, 2020; Praveen et al., 2020a). Whereas the alternative hypothesis claims that the average value abruptly changes at an unknown time (the precipitation data is inhomogeneous). The null hypothesis (H0) is approved in each homogeneity test if the evaluated *p*-value is higher than the value at the 5% level of statistical significance; otherwise, it is rejected. As a result, each rain gauge station’s homogeneity of rainfall was evaluated using the aforementioned homogeneity method, and the rain gauge stations were then divided into two groups, likely nonhomogeneous and homogenous. While the latter indicates that the annual precipitation series is turned down in all 4 or any 3 of the statistically applied tests, the districts in the former group must meet the criteria for having to accept the null hypothesis in 4 homogeneity tests. The 5% significance level was used for all four tests, in a brief presentation of the theoretical context and test statistics for these homogeneity tests.

Pettitt’s test

This analysis is frequently used to identify variations in climate rainfall data (Zhang & Lu, 2009). According to Pettitt’s, if  $x_1, x_2, x_3, x_4, \dots, x_n$  is and perceives data with a variation point at *t*, the project is  $x_1, x_2, x_3, \dots, x_t, F_1(x)$  and has a function distribution, which is distinct by the  $F_2(x)$  function distribution, 2nd part  $(xt + 1), (xt + 2), (xt + 3), (xt + 4) \dots (Xn)$ . The statistics Pettitt  $U_t$  is written as follows:

$$U_t = \sum_{i=1}^t \sum_{j=t+1}^n \text{sign}(x_i - x_j) \tag{5}$$

$$\text{sign}(x_i - x_j) = \begin{cases} 1 & \text{if } (x_i - x_j) > 1 \\ 0 & \text{if } (x_i - x_j) = 0 \\ -1 & \text{if } (x_i - x_j) < 1 \end{cases} \tag{6}$$

The sampling size (*n*), *K* statistic, and associated confidence level (*p*) are written as follows:

$$K = \text{Max}|U_t| \tag{7}$$

$$\rho = \exp\left(\frac{-K}{n^2 + n^3}\right) \tag{8}$$

The null hypothesis is rejected because the number is smaller than the particular level of confidence. For a change point, the estimated probability (*p*) was written as:

$$p = 1 - \rho \tag{9}$$

For this test, which is used to examine rainfall trends, the *K*-statistics are analyzed using a standard approach at a specific confidence level. Then, it noted the change point and the assessment of *K* at a 5% confidence level (Pal & Al-Tabbaa, 2011; Panda, 2019).

SNHT test

To compare the average rainfall of the first *n* observations with the rainfall average of the remaining (*n-k*) observations, the statistic (*Tk*) is used, where *n* is the data time.

$$Tk = kZ_1^2 + (n - k) \tag{10}$$

$Z_1$  and  $Z_2$  are evaluated as:

$$Z_1 = \frac{1}{k} \sum_{i=1}^k \frac{(x_i - \bar{x})}{\sigma_x} \tag{11}$$

$$Z_2 = \frac{1}{n - k} \sum_{i=k+1}^n \frac{(x_i - \bar{x})}{\sigma_x} \tag{12}$$

Yearly,  $k$  can be considered a turning break and a point in the rainfall series of  $Tk$  reach out maximum statistics.

*Buishand’s test*

The BT is a simplified total of the continuous divergence from the total mean of the  $k^{\text{th}}$  observation of a series dataset, where “ $x_1, x_2, x_3, x_4 \dots x_k \dots x_n$ ” with average ( $\bar{x}$ ) is listed as follows:

$$S_k = \sum_{i=1}^k (x_i - \bar{x}) \tag{13}$$

At any shift point, data must be homogenous because, in random data, the deviation from the average distribution is to both parts of the average of the data. The following equation is used to calculate the shift-adjusted range of significance ( $r$ ):

$$r = \frac{\text{Max}(S_k) - \text{Min}(S_k)}{\bar{x}} \tag{14}$$

Then, compare statistical data for  $R/\sqrt{n}$  to interpretive values.

*Von Neumann test*

The ratio of the mean square consecutive (year to year) difference to the variance is known as the von Neumann ratio  $N$ . The test is the most popular test for determining whether a time series is homogeneous or not. The alternative is that the time series is not randomly distributed, and the null hypothesis is that the data are independent, identically distributed random values. It can be defined as follows and is closely connected to the first-order serial correlation coefficient.

$$N = \frac{\sum_{t=1}^{n-1} (x_t - x_{t+1})^2}{\sum_{t=1}^n (x_t - \bar{x})^2} \tag{15}$$

When the sample is homogeneous,  $N=2$ . The value of  $N$  tends to be lower than this expected

number if the sample contains a break.  $N$  values could exceed 2 if the sample contains rapid mean changes.

Relative magnitude change calculation in % of precipitation trend

The percentage change is calculated using the linear trend. This is similar to  $\beta$  median (average) rainfall slope multiplied by the overall length of the data series and divided by the matching average values; it is expressed as a % magnitude change of rainfall (Mondal et al., 2018, Harishnaika et al., 2022a, 2022b)

$$\text{Magnitude Change in (\%)\text{rainfall}} = \left( \frac{\text{Total period} \times \beta}{\text{Average Rainfall}} \times 100 \right) \tag{16}$$

Long-term persistence of annual precipitation

To identify the long-term persistence of precipitation trends, the LOWESS curve was fitted to the yearly precipitation data series (Gajbhiye et al., 2016; Praveen et al., 2020b). Throughout the study period, the differences between the observed and projected precipitation were determined to be statistically significant at the 5% level (2000–2020). The arithmetic mean is not robust (significant) to local variations as such, to reduce the local variation, the LOWESS regression curve was used for the seasonal rainfall. By employing this statistical technique, a group of researchers produced results that were adequate when compared to the arithmetic mean.

**Result and discussion**

Annual precipitation and their magnitude change in %

The preliminary evaluation of yearly rainfall data for each station from 2000 to 2020 includes maximum, minimum, mean, and SD (standard deviation) in Table 1. In the Western Ghats, regions fall more than the average rainfall from a year. The Western Ghats mountain chain contains significant geomorphic features as well as distinctive biophysical and ecological methods. The high mountainous forest ecosystems at the site have an impact on

the Indian monsoon meteorological conditions. The district Chikmagalur falls in this region, and the rainfall is about 2412.5 mm with a standard deviation (SD) of 747.07 mm, followed by Kodagu (rainfall=2900.6 mm and SD=744.81 mm), Dakshina Kannada (3495.6 mm, and 685.38 mm), Shimoga (2700.5 mm and 537.53 mm), and Mysore (1677.0 mm and 452.36 mm). The northern part of Karnataka suffers the drought condition most of the year because of the climatic condition this area has less than average rainfall; district like Bellary Fall in the arid steppe hot region is having rainfall of about 565.3 mm and 179.43 mm (SD), and Chitradurga, Kolar, and Raichur districts suffer less rainfall in this study period. Dakshina Kannada received the most annual rainfall, approximately 3495.58 mm, while Bagalkot received the least, approximately 155.7 mm. Based on the yearly standard deviation, it appears that stations with more annual precipitation have more unpredictability; however, this variability is not constant and changes from year to year, but there is less variability in places with lower precipitation. The yearly mean precipitation graph and statistics show how variable the rainfall is (Fig. 2 and Table 1). The average yearly rainfall varies significantly from year to year in the Western Ghats regions. More than a 20% variation in rainfall magnitude, such as in the north of Karnataka's Vijayapura and Uttara Kannada districts, which are, respectively, about 69.72% and 50.24% with Sen's slope of 13.18 mm and 75.059 mm. The Mk test only revealed a monotonic trend; the slope was interpreted when the trend was significant. The central part of area Haveri has a negative linear trend in rainfall that is around  $-30.412$  with a slope value of  $-20.566$ . These results demonstrate that each state's stations vary according to their areas' climatic conditions. The remaining stations are listed in Table 2. Figure 3 shows the number of dry and rainy years as well as the variation in the spatial pattern of average rainfall deviation across the entire state.

#### Nonparametric regression to prediction analysis of rainfall

To reduce the local fluctuations, LOWESS curves were used ( Ahmad et al., 2015). Over the study period, utilizing statistical regression curves on yearly precipitation throughout the research period,

the rainfall outcome was statistically significant at a level of 5%. The non-parametric regression method for yearly precipitation reveals a distinct outline from thirty-one regions (Fig. 4), indicating a declining trend for the districts over the 20-year study period. The results of the LOWESS curve show that yearly rainfall began to increase in 2004 but then began to gradual decline from the years 2005 to 2015 it showed in Fig. 4.

The LOWESS curve had the lowest point from 2000 to 2005, and then it increased the most until 2020. On the whole, the annual precipitation data reveal an increasing and reducing variation in precipitation across the districts. Annual precipitation for Udupi districts (Fig. 4) shows a consistent rise from 2000 to 2020, with a mean value of 3281.08 mm. Its highest value was observed in 2010, which will be above the initial to last decade with the value of 4366.41 mm, while the lowest value was observed in 2003. In Vijayanagara, the decreasing value was recognized in 2004 with the smallest amount of 247.85 mm, and it achieved a low value in 2015; after that, an expanding trend was noticed up to 2020 with the least amount of 980.86 mm. The trend in the rainfall at station Chikmagalur was slightly increasing. In Vijayanagara, the decreasing value has been recognized in 2004 with the least amount of 247.85 mm, and it reached a low value in the year 2015; after that, an increasing rainfall trend was indicated up to 2020 with 980.86 mm. The annual variation of the LOWESS curve is shown in Fig. 4. Time series of rainfall for each decade of the study the general trend remained consistent for some decades, and the time series shows little variation. The series of articles at rainfall was predicted by the yearly LOWESS test (line), which revealed significant results in every district. The standards of coefficient measurements reveal a connection, between the rainfall data, and both expected and actual rainfall.

#### Performance of traditional trend tests

The MK approach was mentioned in the interest of finding trends in annual precipitation (Table 3). A mix of positive and negative precipitation patterns is observed at various stations, corresponding to the yearly inspection. For the annual series, positive trends (increased) with significant levels were identified in Shimoga and Uttara Kannada districts (Table 3). According to



**Table 2** Average rainfall and their Sen’s slope and magnitude change

Districts	Sen’s slope	Mean rainfall	Length	Magnitude change
Bangalore rural	−2.912	746.3	21.0	−8.194
Bangalore urban	−5.273	784.5	21.0	−14.117
Belagavi	16.666	736.8	21.0	47.503
Bellary	4.306	565.3	21.0	15.996
Bidar	−6.686	814.4	21.0	−17.242
Chamarajanagara	−0.504	727.0	21.0	−1.455
Chikballapur	−2.912	746.3	21.0	−8.194
Chikmagalur	−34.937	2412.5	21.0	−30.412
Chitradurga	−6.859	797.8	21.0	−18.055
Dakshina kannada	44.562	3495.6	21.0	26.771
Davanagere	1.922	633.6	21.0	6.370
Dharwad	19.025	1018.5	21.0	39.225
Gadag	7.910	610.0	21.0	27.233
Gulbarga	−0.842	719.2	21.0	−2.458
Hassan	−12.393	1358.8	21.0	−19.153
Haveri	−20.566	1327.4	21.0	−32.536
Kodagu	7.063	2900.6	21.0	5.113
Kolar	−3.233	819.4	21.0	−8.287
Koppal	2.903	530.4	21.0	11.493
Mandya	−6.236	814.9	21.0	−16.072
Mysore	−8.262	1677.0	21.0	−10.346
Raichur	−2.783	549.7	21.0	−10.634
Ramanagara	−5.867	771.2	21.0	−15.976
Shimoga	43.286	2700.5	21.0	33.660
Tumkur	5.083	727.0	21.0	14.684
Udupi	33.355	3281.1	21.0	21.348
Uttara kannada	75.059	2260.5	21.0	69.728
Vijayanagara	13.182	550.9	21.0	50.245
Vijayapura	−2.912	746.3	21.0	−8.194
Yadagiri	−0.706	665.2	21.0	−2.229
Bagalkot	6.338	520.1	21.0	25.592

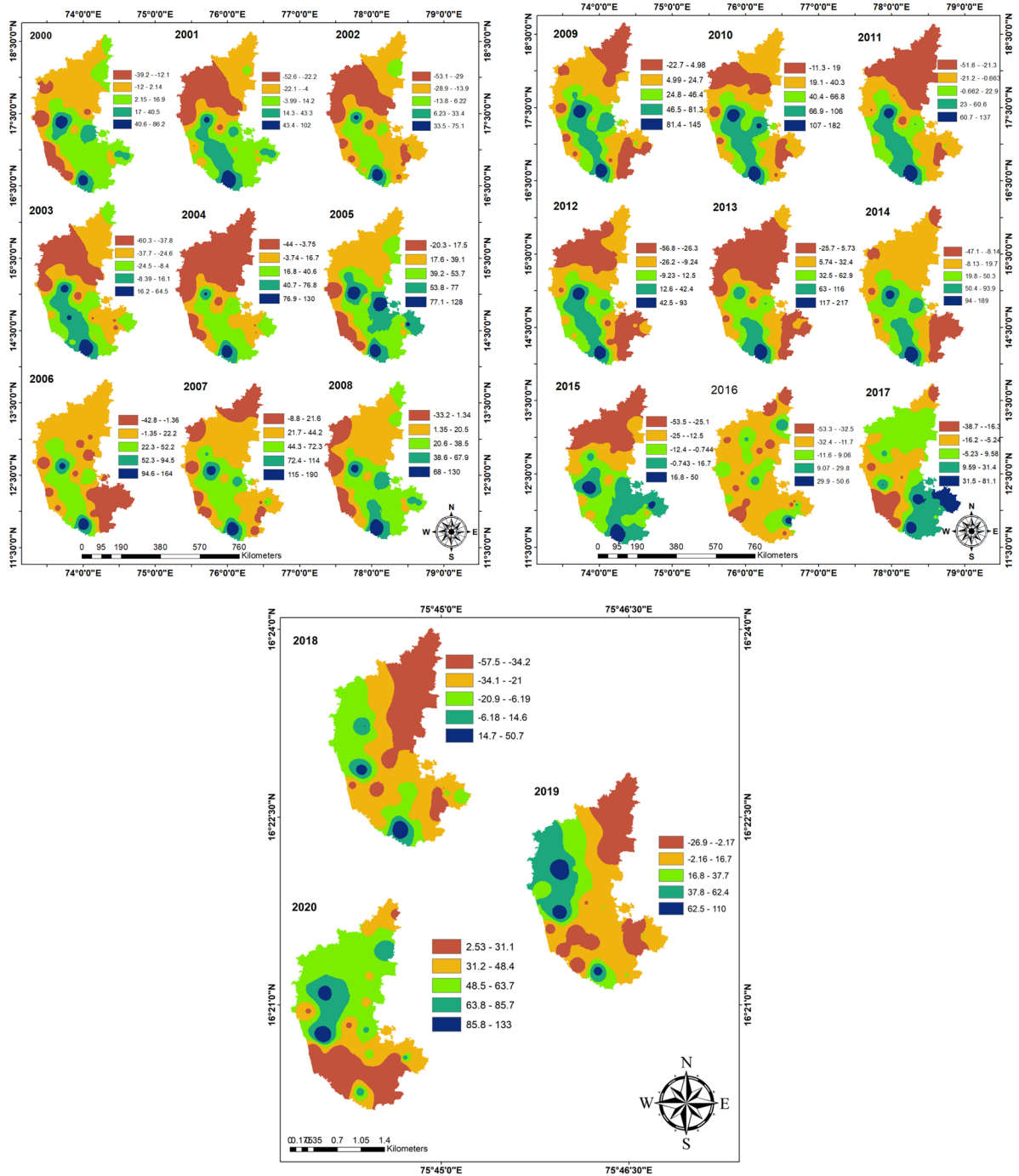
Table 3, only Uttara Kannada and Shimoga have significant positive trends, with *p*-values of 0.009 and 0.001, respectively. When the alpha value is greater than the *p*-value, it is considered to as a significant positive trend. The annual rainfall is highly declining, whereas it is −32.536% at Chitradurga −18.05%. Table 2 indicates the magnitude change and Sen’s slope values of average rainfall.

Inspection of homogeneous and heterogeneous in average historical data rainfall

The examination of the consistency of rainfall data trends and the homogeneity test enables the detection

of homogeneity in data. Pettitt’s test is a non-parametric experiment that not requires any acceptance of the distribution of precipitation data. Tables 4, 5, 6, and 7 show the results of enumerating change points detection in yearly precipitation using a test such as Pettitt’s, SNHT, Buishand, and von Neumann’s tests for data analysis to determine the homogeneous series (H0) and heterogeneous series (Ha) of rainfall.

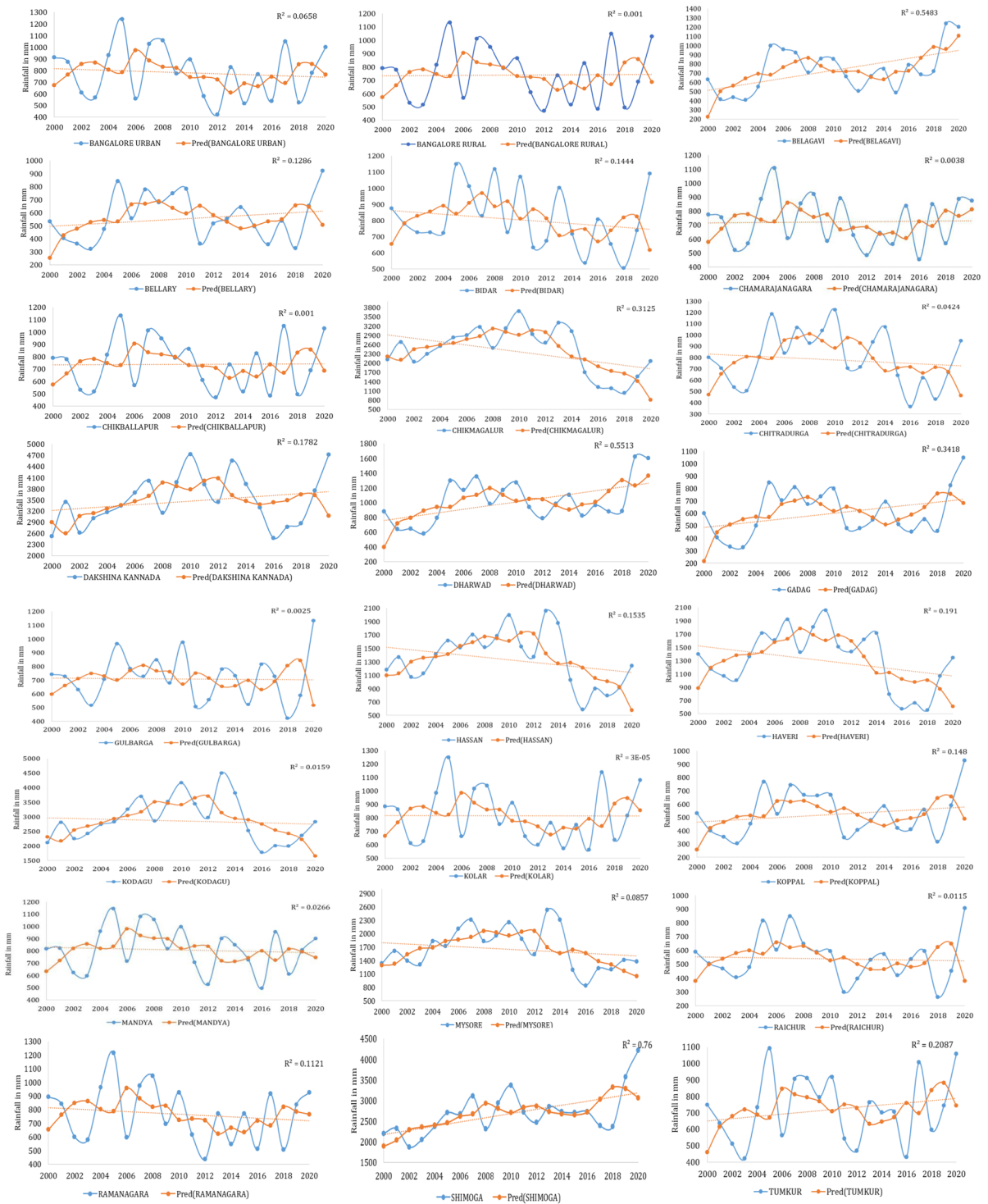
Tables 4, 5, 6 and 7 show the findings of the four homogeneity tests conducted on the precipitation of 31 rain gauge sites (districts) located throughout the study area. It can be seen that the rain gauge at Chikmagalur (*p*=0.008) station is rejected in all four non-parametric tests and thus falls into the



**Fig. 3** Average annual rainfall deviations from 2000 to 2020

non-homogeneous category, whereas Hassan ( $p=0.014$ ), Mysore ( $p=0.027$ ), Haveri ( $p=0.022$ ), Shimoga ( $p=0.039$ ), and Uttara Kannada ( $p=0.012$ )

reject the null hypothesis in four tests and thus fall into the majorly heterogeneous series category, there more breakpoint in the time series.



**Fig. 4** Non-parametric (LOWESS) regression lines for annual rainfall (prediction and actual rainfall)



**Fig. 4** (continued)

The Chikmagalur station’s break-in precipitation data series showed 2015, followed by Hassan, Mysore, Haveri, Shimoga, and Uttara Kannada districts in 2015 and 2016, respectively. Figures 5, 6, and 7 show a line depicting the mean (average rainfall) before ( $M_1$ ) and then after ( $M_2$ ) the break in the rainfall trend for these five sites. These homogeneity test results were validated through ground truth investigations.

To determine reasonable explanations for the heterogeneities discovered by the statistical tests, the station’s historical records were searched. One of the stations in the state’s north, Vijayanagara, is found to be nonhomogeneous by the SNHT test; this region

suggests acceptance of the null hypothesis by all other methods and is thus separated into homogeneous rainfall series. Because none of the three homogeneity tests reject the null hypothesis, the other districts are highly homogeneous.

The homogeneous nature of the 25 districts indicates that any overall trend in the rainfall series is truly due to climate extremes. Because well-accepted statistical methods for trying to adjust daily and weekly data are not available, the inhomogeneity recognized in the time series of precipitation gathered from 6 stations was not corrected. According to the Bureau of Meteorology Department, that data be examined to ensure the effects

**Table 3** Outcome of MK test, at significance level (5%) in annual rainfall

Mann–Kendall trend tests					
Districts	Kendall’s tau	S	Var(S)	p-value	Alpha
Bangalore rural	−0.048	−10	1094.667	0.786	0.05
Bangalore urban	−0.143	−30	1096.667	0.381	0.05
Belagavi	0.257	54	1096.667	0.110	0.05
Bellary	0.081	17	1095.667	0.629	0.05
Bidar	−0.216	−45	1093.000	0.183	0.05
Chamarajanagara	−0.019	−4	1094.667	0.928	0.05
Chikballapur	−0.048	−10	1094.667	0.786	0.05
Chikmagalur	−0.152	−32	1096.667	0.349	0.05
Chitradurga	−0.072	−15	1095.667	0.672	0.05
Dakshina kannada	0.196	41	1095.667	0.227	0.05
Davanagere	0.053	11	1095.667	0.763	0.05
Dharwad	0.245	51	1093.667	0.131	0.05
Gadag	0.148	31	1095.667	0.365	0.05
Gulbarga	−0.034	−7	1093.000	0.856	0.05
Hassan	−0.086	−18	1096.667	0.608	0.05
Haveri	−0.153	−32	1094.667	0.349	0.05
Kodagu	0.043	9	1095.667	0.809	0.05
Kolar	−0.062	−13	1095.667	0.717	0.05
Koppal	0.081	17	1095.667	0.629	0.05
Mandya	−0.105	−22	1094.667	0.526	0.05
Mysore	−0.081	−17	1095.667	0.629	0.05
Raichur	−0.067	−14	1094.667	0.694	0.05
Ramanagara	−0.144	−30	1094.667	0.381	0.05
<b>Shimoga</b>	<b>0.421</b>	<b>88</b>	<b>1094.667</b>	<b>0.009</b>	<b>0.05</b>
Tumkur	0.095	20	1096.667	0.566	0.05
Udupi	0.234	49	1095.667	0.147	0.05
<b>Uttara kannada</b>	<b>0.552</b>	<b>116</b>	<b>1096.667</b>	<b>0.001</b>	<b>0.05</b>
Vijayanagara	0.205	43	1095.667	0.204	0.05
Vijayapura	−0.048	−10	1094.667	0.786	0.05
Yadagiri	−0.024	−5	1095.667	0.904	0.05
Bagalkot	0.158	33	1095.667	0.334	0.05

Bold letter showed significant positive trend

of homogeneities and that time data series with homogeneity issues be eliminated from the study (Chattopadhyay & Edwards, 2016). As a result, rather than correcting the inhomogeneity in the series data, these districts were excluded from further assessment in this study. The LOWESS curve analysis was applied to 31 rain gauge stations with homogeneous time series of precipitation. The results of the von Neumann’s (*N*) value analysis for Bellary show 1.293 with the highest estimation, and the *p*-value for Bellary is 0.045, followed by Koppala (*N*=1.221 and *p*-value=0.031), Belagavi

(*N*=0.774 and *p*-value=0.001), the district of Dakshina Kannada (*N*=1.004 and *p*-value=0.007), Haveri (*N*=0.654 and *p*-value=0.000), Shimoga (*N*=0.781 and *p*-value=0.001), and the district of Uttara Kannada (*N*=0.578); many districts fall into the heterogeneous sequence in the von Neumann test; a few of these districts have been discussed here; all of the districts and the quality and loyalty have been shown in the table. The district with the lowest value estimated is Chikmagalur, and the values are shown as *N*=0.527 and *p*-value=0.0001.

**Table 4** Probable shift years by Buishand's test

Districts	$Q$	$t$	$p$ -value	Alpha
Bangalore rural	2.692	2010	0.745	0.05
Bangalore urban	3.772	2010	0.360	0.05
Belagavi	5.327	2004	0.074	0.05
Bellary	4.154	2004	0.254	0.05
Bidar	4.216	2010	0.253	0.05
Chamarajanagara	2.753	2010	0.743	0.05
Chikballapur	2.692	2010	0.745	0.05
<b>Chikmagalur</b>	<b>7.811</b>	<b>2014</b>	<b>0.000</b>	<b>0.05</b>
Chitradurga	4.693	2014	0.151	0.05
Dakshina kannada	4.306	2005	0.229	0.05
Davanagere	3.534	2004	0.428	0.05
Dharwad	5.466	2004	0.062	0.05
Gadag	4.761	2004	0.139	0.05
Gulbarga	2.456	2019	0.832	0.05
<b>Hassan</b>	<b>6.908</b>	<b>2014</b>	<b>0.005</b>	<b>0.05</b>
<b>Haveri</b>	<b>6.948</b>	<b>2014</b>	<b>0.005</b>	<b>0.05</b>
Kodagu	5.378	2014	0.065	0.05
Kolar	3.015	2010	0.625	0.05
Koppal	3.733	2004	0.374	0.05
Mandya	3.737	2010	0.367	0.05
<b>Mysore</b>	<b>6.343</b>	<b>2014</b>	<b>0.016</b>	<b>0.05</b>
Raichur	3.209	2010	0.548	0.05
Ramanagara	4.242	2010	0.239	0.05
Shimoga	5.123	2006	0.079	0.05
Tumkur	2.989	2003	0.628	0.05
Udupi	4.333	2005	0.220	0.05
<b>Uttara kannada</b>	<b>6.475</b>	<b>2006</b>	<b>0.008</b>	<b>0.05</b>
Vijayanagara	5.130	2015	0.092	0.05
Vijayapura	2.692	2010	0.745	0.05
Yadagiri	2.605	2019	0.786	0.05
Bagalkot	4.582	2004	0.172	0.05

Bold letter indicate shift years heterogeneous (Ha) series

**Table 5** Probable shift years by Von Neumann's test

Districts	$N$	$p$ -value	Alpha
Bangalore rural	2.282	0.741	0.05
Bangalore urban	2.187	0.663	0.05
<b>Belagavi</b>	<b>0.774</b>	<b>0.001</b>	<b>0.05</b>
<b>Bellary</b>	<b>1.293</b>	<b>0.045</b>	<b>0.05</b>
Bidar	1.815	0.335	0.05
Chamarajanagara	2.230	0.699	0.05
Chikballapur	2.282	0.741	0.05
<b>Chikmagalur</b>	<b>0.527</b>	<b>&lt;0.0001</b>	<b>0.05</b>
<b>Chitradurga</b>	<b>1.151</b>	<b>0.018</b>	<b>0.05</b>
<b>Dakshina kannada</b>	<b>1.004</b>	<b>0.007</b>	<b>0.05</b>
Davanagere	1.424	0.086	0.05
<b>Dharwad</b>	<b>0.843</b>	<b>0.003</b>	<b>0.05</b>
<b>Gadag</b>	<b>0.866</b>	<b>0.003</b>	<b>0.05</b>
Gulbarga	1.875	0.381	0.05
<b>Hassan</b>	<b>0.747</b>	<b>0.000</b>	<b>0.05</b>
<b>Haveri</b>	<b>0.654</b>	<b>0.000</b>	<b>0.05</b>
<b>Kodagu</b>	<b>0.815</b>	<b>0.001</b>	<b>0.05</b>
Kolar	2.058	0.545	0.05
<b>Koppal</b>	<b>1.221</b>	<b>0.031</b>	<b>0.05</b>
Mandya	1.972	0.467	0.05
<b>Mysore</b>	<b>0.923</b>	<b>0.003</b>	<b>0.05</b>
Raichur	1.465	0.100	0.05
Ramanagara	2.106	0.595	0.05
<b>Shimoga</b>	<b>0.781</b>	<b>0.001</b>	<b>0.05</b>
Tumkur	1.995	0.488	0.05
Udupi	1.036	0.009	0.05
<b>Uttara kannada</b>	<b>0.578</b>	<b>&lt;0.0001</b>	<b>0.05</b>
<b>Vijayanagara</b>	<b>0.793</b>	<b>0.001</b>	<b>0.05</b>
Vijayapura	2.282	0.741	0.05
Yadagiri	1.746	0.276	0.05
<b>Bagalkot</b>	<b>0.767</b>	<b>0.001</b>	<b>0.05</b>

Bold letter indicate shift years heterogeneous (Ha) series

### The effects of rising and falling rainfall trends

The above findings are critical for nature and economic management and planning. The previous research on groundwater potential evaluation in the research indicates that groundwater accessibility is in the poor stage in more and over 50% of the state, which is primarily prevalent in the tropical savanna and arid steppe hot regions in the state. In this study period, there is a consequent variation in the rainfall; suppose the rainfall trend decreases continuously in future days, it may exacerbate water

scarcity, going to lead to drought in the north and southeast parts of the state. It may also have negative consequences for water supply, agriculture, and energy production. Furthermore, the reduced rainfall trend has the potential to affect water quality and outcome in drinkable water scarcity. As a result, the decreasing trend may have serious consequences for the sustainable development of surface water supplies and groundwater recharge. As a result, water management through the construction of appropriate water harvesting is critical in this region. Timely adoption of efficient systemic

**Table 6** Probable shift years by SNHT test

Districts	T0	<i>t</i>	<i>p</i> -value	Alpha
Bangalore rural	1.907	2019	0.807	0.05
Bangalore urban	2.586	2010	0.643	0.05
<b>Belagavi</b>	<b>9.226</b>	<b>2018</b>	<b>0.014</b>	<b>0.05</b>
Bellary	4.315	2004	0.233	0.05
Bidar	3.232	2010	0.483	0.05
Chamarajanagara	1.652	2018	0.872	0.05
Chikballapur	1.907	2019	0.807	0.05
<b>Chikmagalur</b>	<b>13.557</b>	<b>2014</b>	<b>&lt; 0.0001</b>	<b>0.05</b>
Chitradurga	4.894	2014	0.171	0.05
Dakshina kannada	4.159	2004	0.260	0.05
Davanagere	3.122	2004	0.464	0.05
<b>Dharwad</b>	<b>9.161</b>	<b>2018</b>	<b>0.013</b>	<b>0.05</b>
Gadag	6.622	2018	0.061	0.05
Gulbarga	6.030	2019	0.157	0.05
<b>Hassan</b>	<b>10.605</b>	<b>2014</b>	<b>0.001</b>	<b>0.05</b>
<b>Haveri</b>	<b>10.728</b>	<b>2014</b>	<b>0.001</b>	<b>0.05</b>
Kodagu	5.378	2014	0.065	0.05
Kolar	1.728	2019	0.841	0.05
Koppal	6.011	2019	0.138	0.05
Mandya	2.539	2010	0.691	0.05
<b>Mysore</b>	<b>8.941</b>	<b>2014</b>	<b>0.006</b>	<b>0.05</b>
Raichur	4.987	2019	0.164	0.05
Ramanagara	3.272	2010	0.457	0.05
<b>Shimoga</b>	<b>10.953</b>	<b>2018</b>	<b>0.006</b>	<b>0.05</b>
Tumkur	2.869	2019	0.565	0.05
Udupi	5.089	2019	0.149	0.05
<b>Uttara kannada</b>	<b>10.569</b>	<b>2018</b>	<b>0.005</b>	<b>0.05</b>
<b>Vijayanagara</b>	<b>9.936</b>	<b>2018</b>	<b>0.010</b>	<b>0.05</b>
Vijayapura	1.907	2019	0.807	0.05
Yadagiri	6.786	2019	0.102	0.05
Bagalkot	6.304	2018	0.082	0.05

Bold letter indicate shift years heterogeneous (Ha) series

**Table 7** Probable shift years by Pettitt’s test

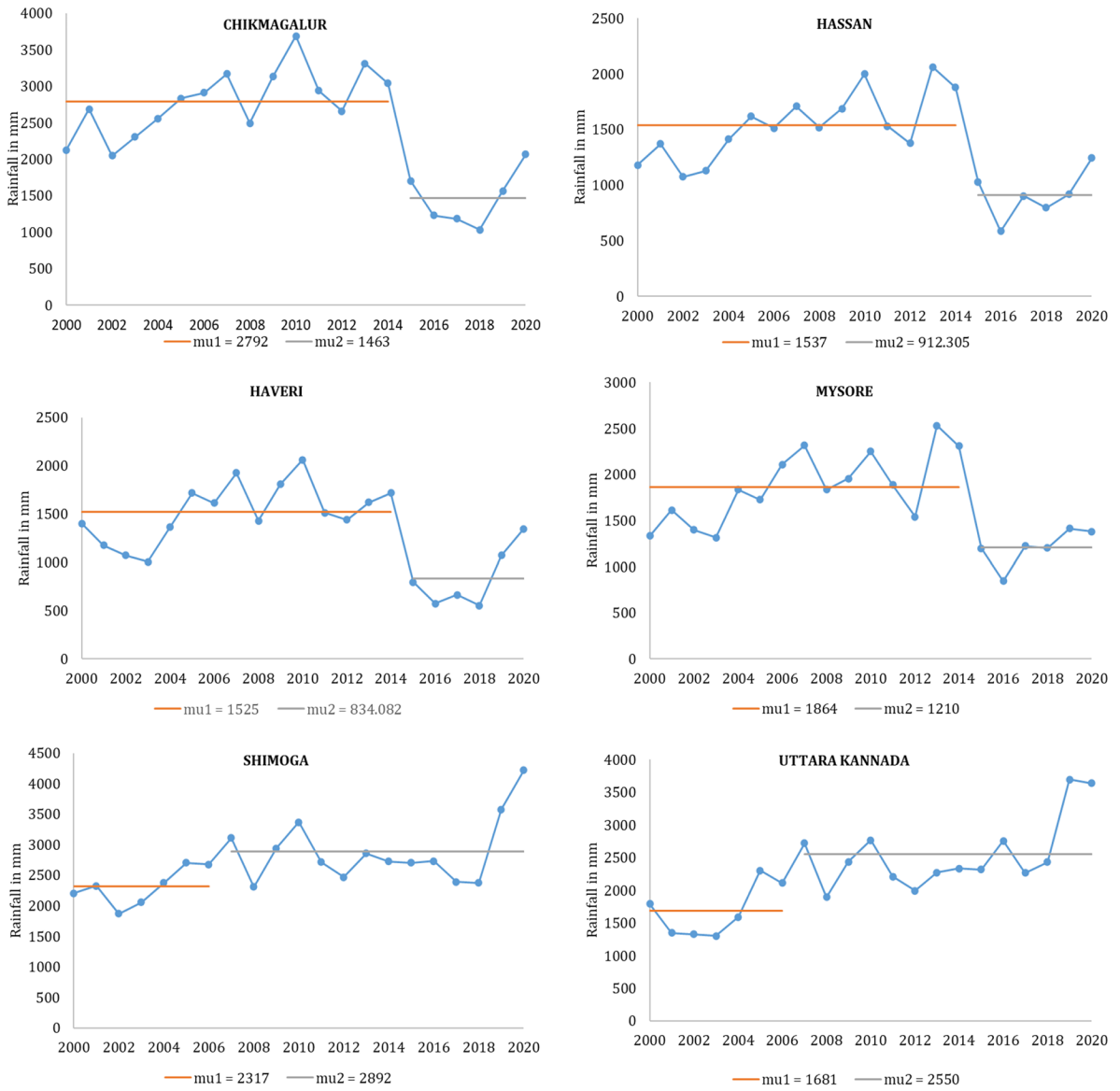
Districts	<i>k</i>	<i>t</i>	<i>p</i> -value	Alpha
Bangalore rural	37.000	2010	0.802	0.05
Bangalore urban	50.000	2010	0.511	0.05
Belagavi	72.000	2004	0.062	0.05
Bellary	53.000	2004	0.427	0.05
Bidar	60.000	2010	0.214	0.05
Chamarajanagara	36.000	2010	0.735	0.05
Chikballapur	37.000	2010	0.804	0.05
<b>Chikmagalur</b>	<b>88.000</b>	<b>2014</b>	<b>0.008</b>	<b>0.05</b>
Chitradurga	58.000	2014	0.282	0.05
Dakshina kannada	51.000	2005	0.496	0.05
Davanagere	44.000	2004	0.795	0.05
Dharwad	73.000	2004	0.054	0.05
Gadag	58.000	2004	0.276	0.05
Gulbarga	30.000	2010	0.396	0.05
<b>Hassan</b>	<b>84.000</b>	<b>2014</b>	<b>0.014</b>	<b>0.05</b>
<b>Haveri</b>	<b>81.000</b>	<b>2014</b>	<b>0.022</b>	<b>0.05</b>
Kodagu	69.000	2014	0.095	0.05
Kolar	39.000	2010	0.917	0.05
Koppal	48.000	2004	0.608	0.05
Mandya	44.000	2010	0.795	0.05
<b>Mysore</b>	<b>80.000</b>	<b>2014</b>	<b>0.027</b>	<b>0.05</b>
Raichur	47.000	2010	0.662	0.05
Ramanagara	55.000	2010	0.361	0.05
Shimoga	76.000	2006	0.039	0.05
Tumkur	36.000	2003	0.761	0.05
Udupi	58.000	2004	0.282	0.05
<b>Uttara kannada</b>	<b>84.000</b>	<b>2006</b>	<b>0.012</b>	<b>0.05</b>
Vijayanagara	55.000	2015	0.363	0.05
Vijayapura	37.000	2010	0.804	0.05
Yadagiri	38.000	2010	0.865	0.05
Bagalkot	57.000	2004	0.301	0.05

Bold letter indicate shift years heterogeneous (Ha) series

change and efficient managing water resources targets is required. In contrast hand, the inclining trend in rainfall in the state’s southwest can lead to extreme rainfall events. So the research lacks proper drainage structure, and such extreme precipitation events are probable to have negative consequences including sewage overflows and increased runoff, which can result in inland flooding and heavy soil degradation. As a result, impactful soil and water conservation measures, as well as efficient water management, must be implemented in this region.

**Conclusions**

The current study focuses on precipitation trends in Karnataka’s 31 districts during the last two decades as a result of climate change. The pattern of precipitation trends is depicted using scientific methodology, together with a geographical explanation, interpretive figures, and statistical tables. Every station’s Mann–Kendall and Sen’s slope estimator trend shows both a downward and an upward trend. The output’s coefficient values show a strong correlation between the expected and observed values. Data at



**Fig. 5** Pettitt test (PT) non-homogeneous series

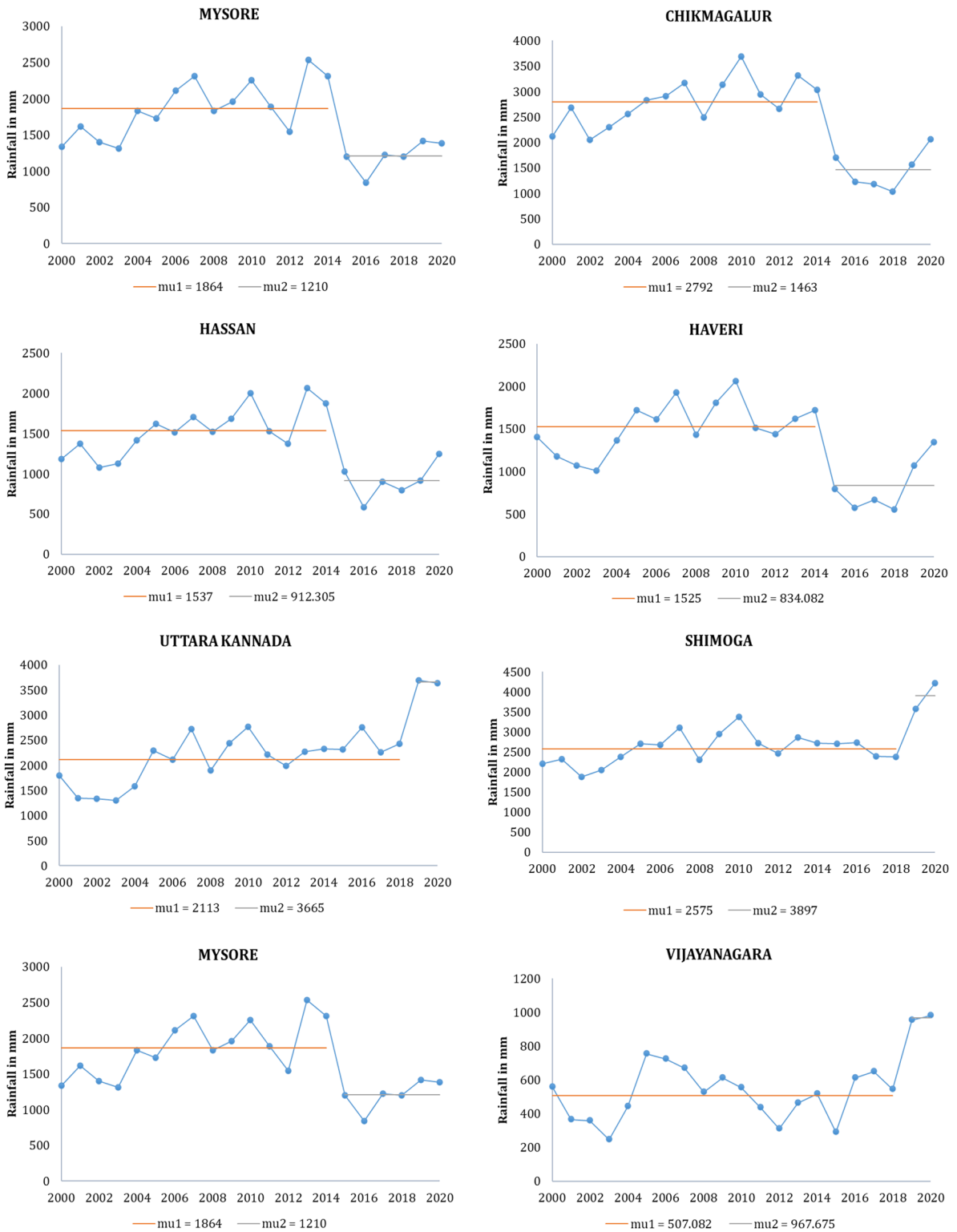
5% statistical significance levels or 95% confidence levels, the precipitation trend was analyzed, and annual rainfall series in each district of Karnataka were found to have a true slope (magnitude) of rising and dropping, as determined by parametric and non-parametric testing.

1. The Dakshina Kannada district has the highest average rainfall, which is 3495.6 mm, with a magnitude change of roughly 26%, while the

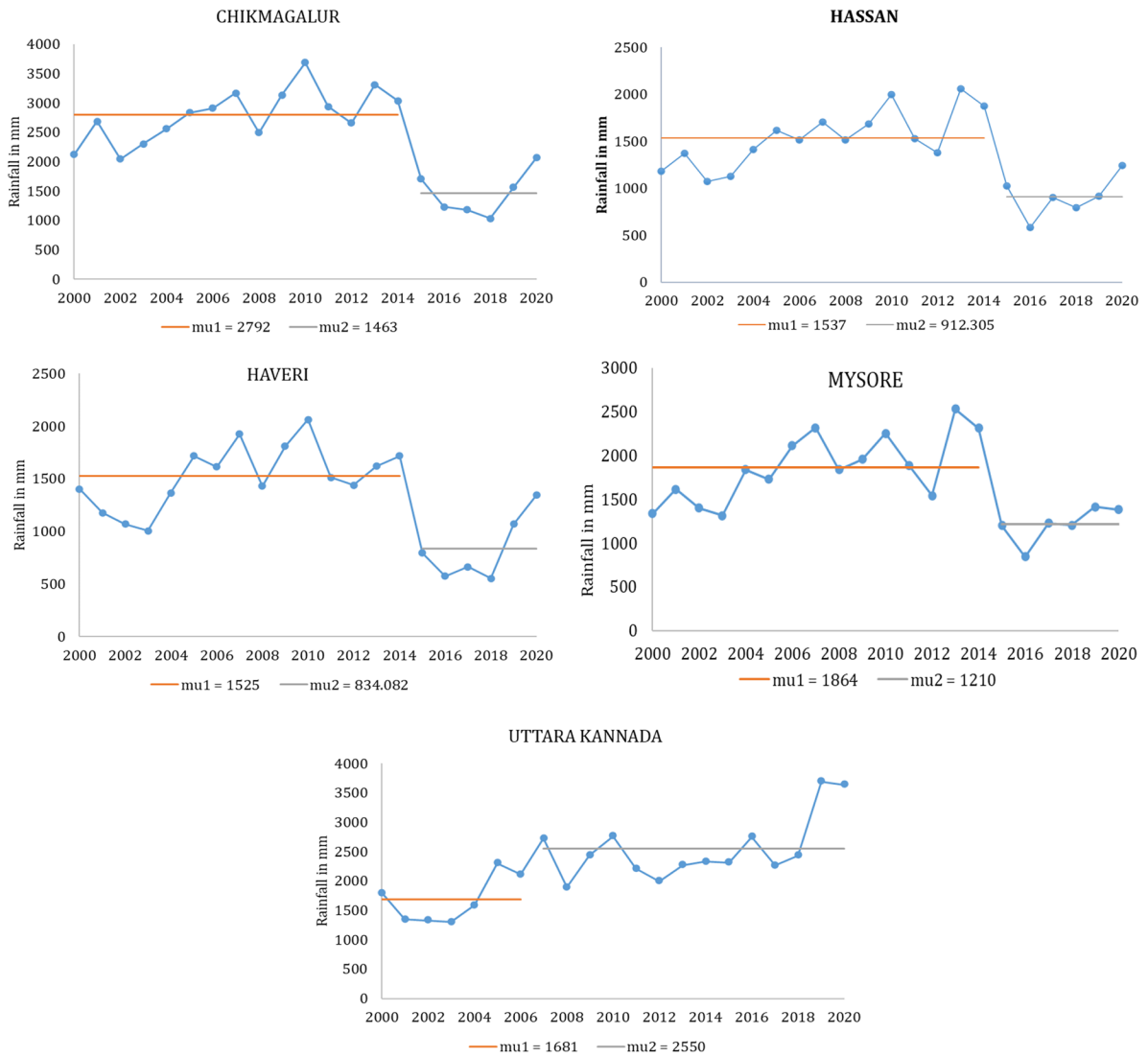
Koppala district has the lowest average rainfall about 530.4 mm, with a magnitude change of 11%, because of the commencement of the current rising era, 2015 has the greatest chance of being a break point in rainfall time series.

2. The trend of rainfall has been reported to be decreasing beyond this year. Annual precipitation is increasing at a 5% level, with two districts, Shimoga and Uttara Kannada, showing a posi-





**Fig. 6** Standard normal homogeneity test (SNHT) non-homogeneous series



**Fig. 7** Buishand range test (BRT) non-homogeneous series

tive significant trend in the Mk test with  $p$ -value 0.009 and 0.001, respectively.

3. The fitted prediction line statistics were utilized to establish the mean coefficient of determination ( $R^2=0.8808$ ) that was highest in the Uttara Kanna region for yearly rainfall patterns using non-parametric regression (LOWESS curve). The changing temperature of the planet, as well as the reallocation of precipitation circulation during monsoon seasons, may have an impact on long-term rainfall fluctuations.

4. The generated spatial maps can assist water resource planners and local stakeholders in understanding the risks and vulnerabilities related to climate change in the region.

Drought and flood in agriculture cropping systems are produced by spatial-temporal variability and various precipitation trends. The next investigation must determine the source of these changes to link observed patterns to climatic variability. Overall, the findings of the study will help organize and influence

drought, flood management, and water resource control approaches in the state.

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**Author contribution** 1. Harishnaika N. — Conceptualization, formal analysis, investigation, software handling, and writing the original draft.

2. Shilpa N. — Data interpretation, figure and table preparation, software handling, writing the original draft, formal analysis, conceptualization.

3. S.A. Ahmed — Investigation; writing, review; validation; and editing.

**Data availability** The data that support the findings of this study are available on request from the corresponding author.

**Declarations**

**Conflict of interest** The authors declare no competing interests.

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