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Climate Change

Assessment of long term Spatio-temporal variability and Standardized Anomaly Index of rainfall of Northeastern region, Karnataka, India

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ABSTRACT

In this study, assessed the spatial-temporal variability of rainfall over the Kalaburgi District of Karnataka, India for the period 1981–2018, using gridded data with 0.5-degree resolution obtained from the National Aeronautics and Space Administration prediction of worldwide energy resource (NASA POWER) project. Trend detection and quantification in the rainfall and index evaluated using the non-parametric Mann–Kendall (MK) test and Sen's slope estimator. Also, an investigation carried out to know the dry and wet years using Standardized Anomaly Index (SAI). The overall rainfall data and Sen's estimate showed the decreasing trend in series for the last 38 years. SAI results show shows that 1981, 1995, 1998 and 2005 are incredibly wet years of widespread flooding in the region and 1985, 1999, 2003 and 2016 were found as extreme drought years for 1981 to 2018. In the overall, the spatial distribution analysis results observed the better distribution of rainfall in Aland, Chincholi, Sedam and part of Chittapur with a range from 800 to 900 mm and sparse distribution in the range of 600 to 700 mm over the Afzalpur, Jewargi, and part of Kalaburgi and Chittapur.

Keywords: Spatial Analysis, Mann–Kendall (MK) test, Sen's slope, Standardized Anomaly Index

1. INTRODUCTION

Climate change is a change in annual, seasonal variation of weather conditions, or in the time variation of weather within the context of longer-term average conditions (IPCC, 2007). In India, Several Governmental and Non-Governmental organizations have initiated numerous researches on climate change and its impact on agriculture and water resources. Globally, it estimated that the occurrence of precipitation has increased by about 10 to 15 % (IPCC, 2014). In the Indian subcontinent, the precipitation trend has been random, i.e. both decreasing and increasing trend was reported. However, total precipitation occurred over the country has increased (Darshana and Pandey, 2013). Since the Karnataka is an agricultural-based state of India, precipitation and temperature play a vital role in the fulfillment of water requirement in terms of agricultural as well as domestic purposes.

Furthermore, changes in precipitation pattern and rise in temperature lead to a massive impact on the agriculture sector in terms of cropping pattern, reduction in production and yield. (Bae *et al.* 2008) conducted a study on the spatial and temporal variations of precipitation and runoff for 139 basins in South Korea, for a period of 34 years (1968–2001). The results indicated that the long-term trends in annual precipitation increased in northern regions of the study area during the study period. (Pal and Tabbaa, 2009) examined the trends in seasonal precipitation extremes over Kerala state from 1954-2003. They observed winter and autumn season significantly increasing trends in extreme rainfall and spring extreme seasonal rainfall showed decreasing trends. (Atef and Mohammad, 2013) studied the spatial and temporal variability of the mean annual rain in Jordan recorded in 28 years from 1980-2007. They collected and analysed monthly and annual rainfall data from twenty-five meteorological stations. The non-parametric Mann-Kendall test used to determine a positive or negative trend in data with their statistical significance and Sen's method used to determine the magnitude of the trends. Therefore, they concluded that there is a decreasing trend of rainfall in the area in these 28 years. (Zhang *et al.*, 2013) analysed the spatial and temporal patterns of precipitation in the north-east and north-west China. They indicated that various complex influencing factors are responsible for changes in precipitation in China and the availability of water closely associated with precipitation changes. (Khadeeja, 2015) assessed the spatial and temporal variability of rainfall at the Anand district of Gujarat state and found the highest variability in June and the lowest in August. They observed very high spatial and temporal variability in rainfall in the district during monsoon months. (Panthi *et al.,* 2015) conducted a study on the spatial and temporal variability of rainfall in the Gandaki River Basin (GRB) of Nepal Himalaya. From this study they revealed the pre-monsoon, post-monsoon rainfalls are decreasing significantly in most of the zones, but monsoon rainfall is increasing throughout the basin. In the hill region, the annual rainfall is increasing, but the rainy days do not show any trend. Similarly, numerous studies conducted by various scientists viz. (Martinez *et al.*, 2012), (Saeidabadi *et al.*, 2016), (Cristiano *et al.*, 2017), (Kambale *et al.*, 2017), (Mohan and Ram, 2018) and (Huang *et al.*, 2018).

However, to the best of our information, there has been no other inclusive study of rainfall changes, either spatial or temporal changes, in the northeastern region of Karnataka. The region has not adequately investigated in earlier studies. Thus, a detailed analysis of the statistical characteristics of temporal and spatial variations in rainfall across the northeastern region could augment the understanding of the statistical characteristics of rainfall, improve water resource management reduce climate-induced food risks, and appropriate risk management strategies. Because of this, the present study was undertaken in the Kalaburgi district of Karnataka state to analyze the long term spatial and temporal variability of rainfall.

2. MATERIAL AND METHODS

Description of Study Area

The area selected for the study comes under the northeastern dry zone of the agro-climatic condition of Karnataka state, India (Fig. 1). The entire district located on Deccan plateau and altitude range from 300 to 750 m above Mean Sea Level (MSL). Most of the area covered with black soil and to some extent, red soil as well. The area lies between 17˚12′ and 17˚46′ N latitude and 76º 04′ and 77˚54′ E longitude.

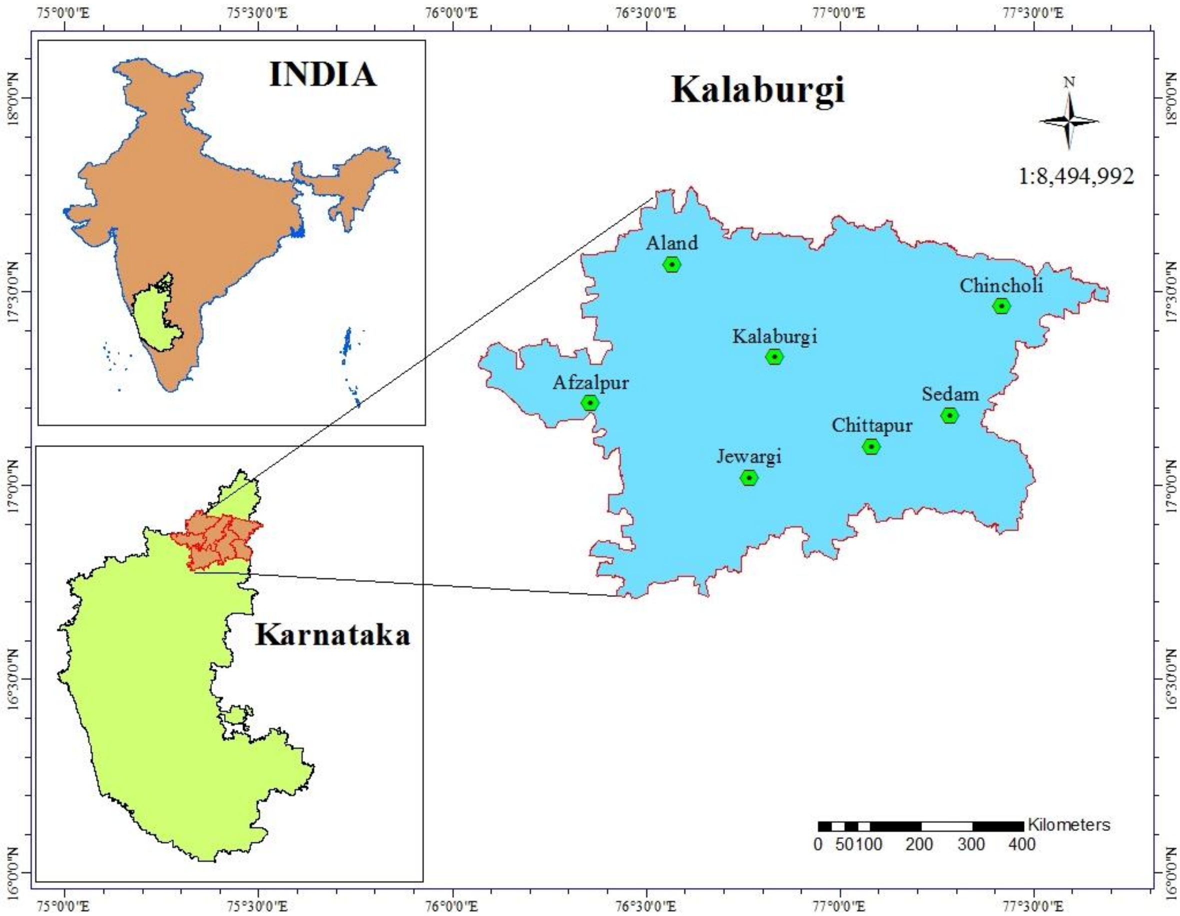


Figure 1 Location of the study area

Climate

The climate of the district is mostly dry with, temperature ranging from a minimum of 8 ºC to a maximum of 45 ºC and annual rainfall is about 750 mm. May is the hottest with an average maximum temperature of 40 °C and December is the coolest with an average minimum temperature of 15.9 °C.

Weather data collection

The long-term rainfall (mm) data from 1981 to 2018 collected in the gridded form with 0.5-degree resolution of data freely available worldwide obtained from the National Aeronautics and Space Administration prediction of worldwide energy resource (NASA POWER) project. Historical rainfall data collected for 7 weather stations *viz*. Aland, Afzalpur, Chincholi, Chittapur, Kalaburgi, Sedam and Jewargi, for the periods of 1981-2018.

Statistical analysis

Statistical analysis of long-term rainfall data executed in MS office Excel spreadsheet package. The analysis was carried out by using Mann- Kendall Test, Sen's slope estimator and Standardized Anomaly Index (SAI) of rainfall to know the Spatio-temporal variability and the wetness and dryness in the study area.

Trend Analysis

Trend analysis of rainfall data carried out to assess the long-term variability and trend slope by Mann-Kendall test and Sen's slope estimator.

Mann- Kendall Test

Mann Kendall test (non -parametric test) is one of the commonly used tools for examining climatic and hydrologic time series data. Non-parametric methods focus on the location of the probability distribution of the sampled population, rather than specific parameters of the population. The outcome of the test not determined by the overall magnitude of the data points, but it also depends on the ranking of individual data points. The Mann- Kendall test is often used to identify a trend in a series. The test is of non-parametric trend test is proposed by (Mann, 1945), further studied by (Kendall, 1975) and improved by (Hirsch *et al*., 1982). The Mann-Kendall statistic (S) measures the trend in the data. Positive values indicate an increase in constituent concentration over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall statistics (*i.e*., large magnitudes indicate a strong trend). Data for performing the Mann-Kendall analysis should be in a time-sequential order.

$$S= \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{Sgn}(X_j-X_k) \qquad (1)$$

Where,
X_j and X_k = sequential data values for the time series data of length n.

The sum of the Sgn function and the mean-variance Var(S), under the null hypothesis (H_o) of no trend and independence of the series terms, are given in equations (3) and (4) respectively.

$$\mathrm{Sgn}(X_j - X_k) = \begin{cases} 1 \text{ if } Xj > Xk \\ 0 \text{ if } Xj = Xk \\ -1 \text{ if } Xj < Xk \end{cases} \qquad (2)$$

$$\mathrm{Var}(S) = \frac{N(N-1)(2N+5) - \sum_{i=1}^{m} U_i(i)(i-1)(2i+5)}{18} \qquad (3)$$

Where,

N = Length of the data set,
m = Number of tied groups
U_i= Size of the M^{th} group
i = Integer

The standard normal test statistic Z_S (Equation (4) indicates a trend in the data series with a positive or negative value indicating increasing or decreasing trends, respectively. The trend results evaluated at 5 % significant level (corresponding threshold value of ±1.96) and the null hypothesis (H_o) rejected, when $/Z_S/ \geq Z_\alpha/2$ at α = 0.05 level of significance.

$$Z_S = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}}, & \text{for } s > 0 \\ 0, & \text{for } s = 0 \\ \frac{S+1}{\sqrt{VAR(S)}}, & \text{for } s < 0 \end{cases} \qquad (4)$$

Sen's slope estimator

Linear trend in a time series can be estimated using a simple non-parametric procedure developed by (Sen, 1968). Mann-Kendall test is used to evaluate a significant increase or decrease in parameter under consideration. Kendall's correlation of coefficient is (Kendall's tau), a useful and general measurement of the correlation between two variables. Therefore, non-parametric Sen's method is a linear model (Gilbert, 1987), is used to estimate the value and confidence interval for the slope of an existing trend. The statistic- Sen's Slope estimates the slope (unit change per time) or the magnitude of the trend. Sen's method calculates the slope of the line using all data pairs, as shown in the following equation (5).

$$Q_i = \frac{X_j-X_k}{j-k} \qquad (5)$$

Where,

X_j and X_k = sequential data values for the time series data of length n
J and k= If there are n values x_j in the time series, we get as many as slop estimate
Q_i = Sen´s estimator of the slope given by the median of these N values of Q_i's.

$$Q_i = \begin{cases} Q_{[(n+1)/2]} & \text{If N is odd} \\ Q_{\frac{n}{2}} + Q_{\frac{N+2}{2}} & \text{If N is even} \end{cases} \qquad (6)$$

Where,

Q_i is the slope between data points X_j and X_k, Q_{med} is median slope estimator which reflects the direction of the trend in the data.

Standardized Anomaly Index (SAI)

It is a measure of deviation in standard units, between a data value and its mean. This index is used for rainfall variability and the number of standard deviations that a rainfall event deviates from the average of the years considered (Funk *et al.*, 2015). The Standardized Anomaly Index calculated with the following equation (7).

$$\text{SAI} = \frac{(x-\mu)}{\sigma} \qquad (7)$$

Where,

x = Annual rainfall

μ= Long term mean

σ = Standard deviation

Spatial analysis

A Spatial Analysis Tool in the ArcGIS V. xx software used for investigating spatial patterns in data.

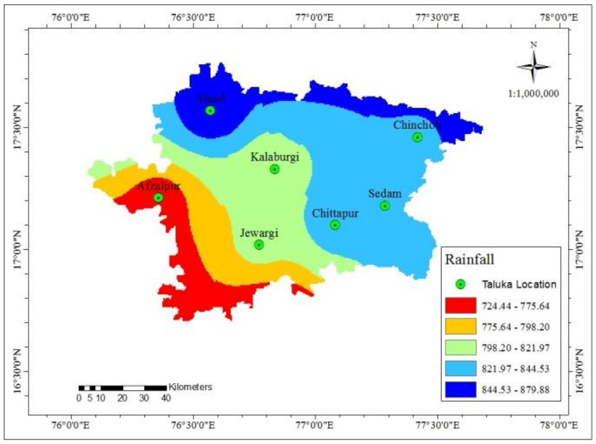
Spatial Interpolation

Spatial interpolation or the estimation of a variable at an unsampled location using data from surrounding sampled locations have great importance in all-natural and atmospheric sciences. The spatial analyst tool in the ArcGIS V. xx software used for interpolation creating and analyzing the map of long term annual rainfall data. The Inverse Distance Weighting (IDW) interpolation technique used to create the map of rainfall data of the study area. IDW method chosen here, because this technique gives more accurate results than the kriging and spline or any other interpolation technique. The spatial interpolation by IDW performed with the assumption that the concept of distance weighting (Po *et al.*, 2017).

3. RESULTS AND DISCUSSION

Spatial variability

The spatial variability maps of rainfall data prepared to display the spatial distribution of weather parameters in the study area. The spatial variability analysis of total annual rainfall carried out in ArcGIS V. xx in spatial analyst tool by IDW interpolation technique. The spatial variability maps of total annual rainfall prepared for the selected study area from 1981 to 2018 and shown in Fig. 2 (a to e) and Table 1. The spatial distribution of average total annual rainfall from 1981-1990 Fig. 2 (a) observed higher in Aland, Chincholi, Sedam and part of Kalaburgi and Chittapur between 821.97 to 879.88 mm as compared to other parts of the study area in the range 724.44 to 821.97 mm. During 1991 to 2000 Fig. 2 (b) the spatial distribution of average total annual rainfall observed lower over the Afzalpur and Jewargi from 668.25 to 730.56 mm and higher in Aland, Chincholi, Sadam and part of Kalaburgi between 757.36 to 839.84 mm. The spatial distribution of average total annual rainfall from 2001 to 2010 presented in Fig. 2 (c) and observed higher in Aland, Sedam, Chincholi and part of the Chittapur and Kalaburgi in the range of 782.21 to 874.56 mm with lower in the range 724.44 to 751.17 in other places. The spatial variability of average total annual rainfall from 2010 to 2018 Fig. 2 (d) observed sparsely distributed all over the places than last three decades with range 535.68 to 648.52 mm. The average total annual rainfall in the last 38 years from 1981 to 2018, shown in Fig. 2 (e) spatially distributed in the range 656.25 to 842.60 mm over the study area. In overall, last four decades observed the better distribution of total annual rainfall in Aland, Chincholi, Sedam and part of Chittapur with a range from 800 to 900 mm and sparse distribution in the range of 600 to 700 mm over the Afzalpur, Jewargi, and part of Kalaburgi and Chittapur. Because the Afzalpur and Jewargi area having more temperature and also less area under vegetation, so the rainfall in these areas observed minimum. In Chincholi and part of Sedam is having more forest area and this part lies in transition belt of Konkan hills, this influence the more rainfall in these areas.



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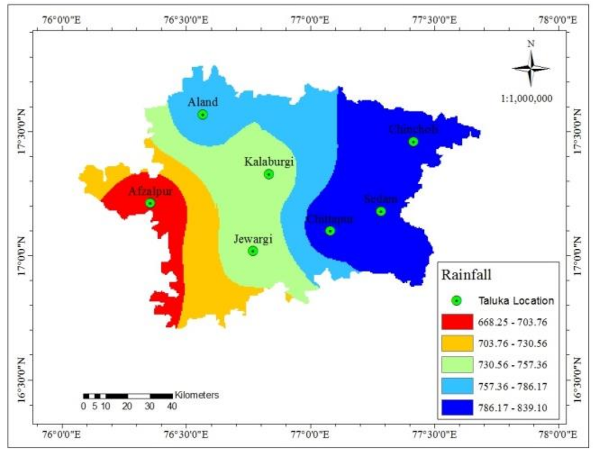

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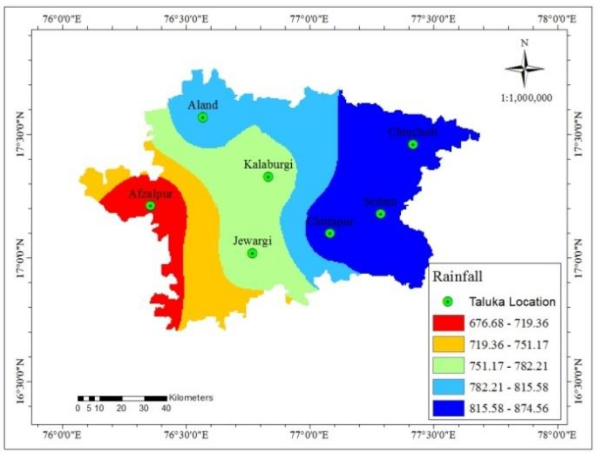

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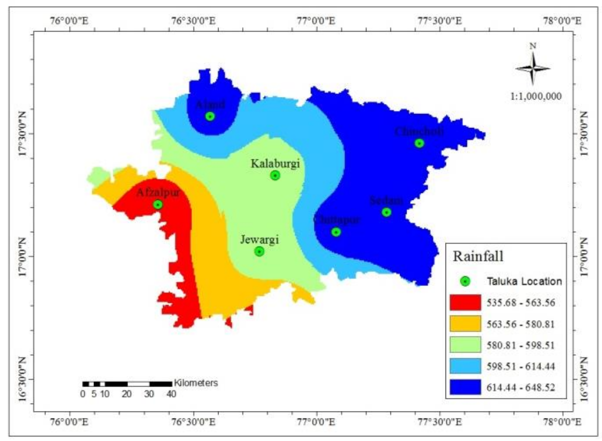

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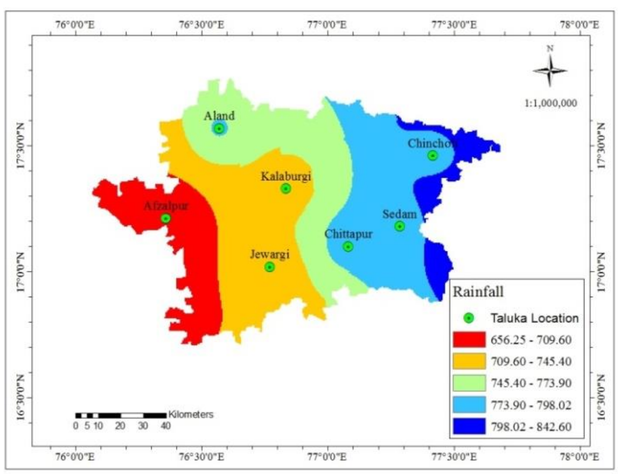


(e)

Figure 2 Spatial variability maps of total annual rainfall, mm, for a) 1981 to 1990, b) 1991 to 2000, c) 2001 to 2010, d) 2011 to 2018 and e) 1981 to 2018.

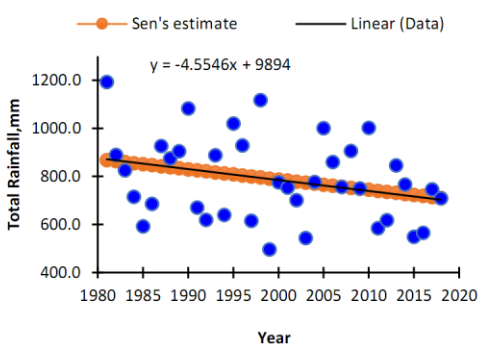
Table 1 Decadal average of Rainfall (mm)

Places	Latitude	Longitude	1981-1990	1991-2000	2001-2010	2011-2018
Aland	17.5700	76.5694	869.46	777.23	805.29	621.93
Afzalpur	17.2116	76.3575	759.66	668.24	676.66	542.21

Chincholi	17.4605	77.4188	838.73	807.95	839.84	624.61
Chittapur	17.1002	77.0827	838.53	807.79	839.53	624.17
Sedam	17.1797	77.2869	838.43	807.59	839.64	624.59
Jewargi	17.0197	76.7700	804.01	739.22	761.91	586.23
Kalaburgi	17.3297	76.8341	804.61	739.72	761.23	586.71

Time series analysis

Long term trend analyses of seven weather stations from the study area carried out for 38 years for total annual rainfall. The Fig. 3 (a to g) and Table 2 presents Mann- Kendall trend (Z), Sen's slope value (Q) long term average, yearly highest and lowest values of Rainfall, mm, over the Aland, Afzalpur, Chincholi, Chittapur), Kalaburgi, Sedam and Jewargi respectively from 1981 to 2018. The highest rainfall observed in 1981 with 1193.15 mm, lowest in 2015 with 549.71 mm and average with 668 mm presented in Fig. 3 (a). The statistical analysis carried out for Aland shows Mann- Kendall test (Z) with -1.76 and Sen's slope (Q) with 4.886. In the Afzalpur total annual rainfall received highest in 1981 with 1052.08 mm, lowest in 2003 with 419.73 mm and average with 793.03 mm presented in Fig. 2 (b). The statistical analysis results for Afzalpur shows, Mann- Kendall test (Z) and Sen's slope (Q) with -1.91 and -4.928, respectively. The Chincholi received the highest rainfall in 1981 with 1155.11 mm, lowest in 2016 with 450.05 mm and average 802 mm shown in Fig. 2 (c). The statistical analysis resulted in the Mann- Kendall test (Z) with -1.31 and Sen's slope (Q) with -3.722 for Chincholi. The annual rainfall received in Chittapur averages about 801.96 mm, highest in 1981 with 1155.11 mm and lowest in 2016 with 523.32 mm shown in Fig. 2 (d). The statistical analysis results for Chittapur shows Mann- Kendall test (Z) with -1.31 and Sen's slope (Q) with -3.722. The Kalaburgi received highest annual rainfall in1981 with 1110.96, lowest in 2011 with 514.70 mm and averaged about 745 mm, Mann- Kendall test (Z) with -1.63 and Sen's slope (Q) with -4.287 presented in Fig. 2 (e). The Sedam and Jewargi received the highest rainfall in 1981, and 1155.11 mm and 1110.96 mm respectively, lowest in 2018 and 1999 with 467.74 mm and 467.03 mm respectively and average with 796.42 mm and 730.42 mm respectively. The statistical analysis results for Sedam and Jewargi exhibited Mann- Kendall test (Z) with -1.31 and -1.63 and Sen's slope (Q) with -3.722 and -4.287, respectively. The overall rainfall data and Sen's estimate showed the decreasing trend in series for the last 38 years.



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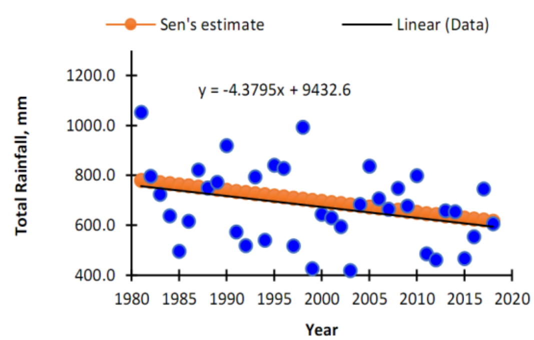

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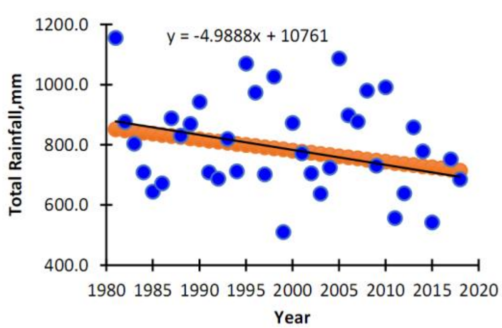

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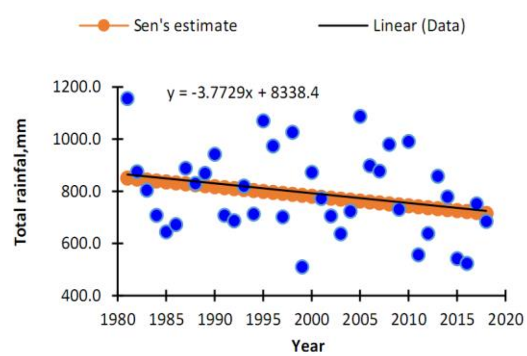

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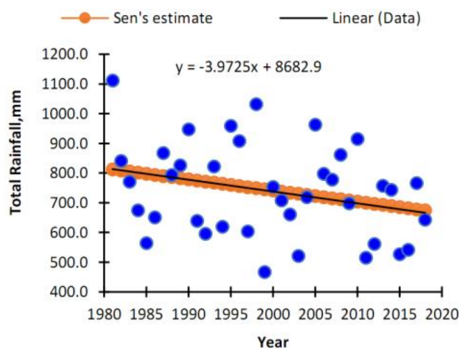

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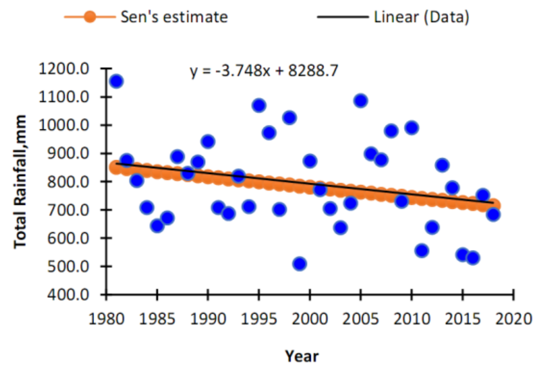

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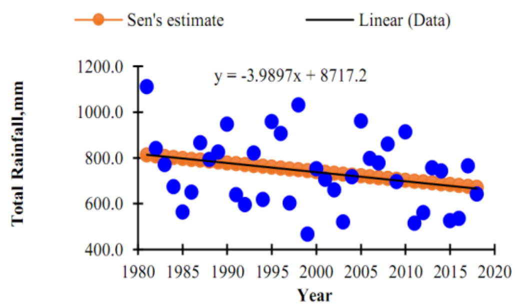

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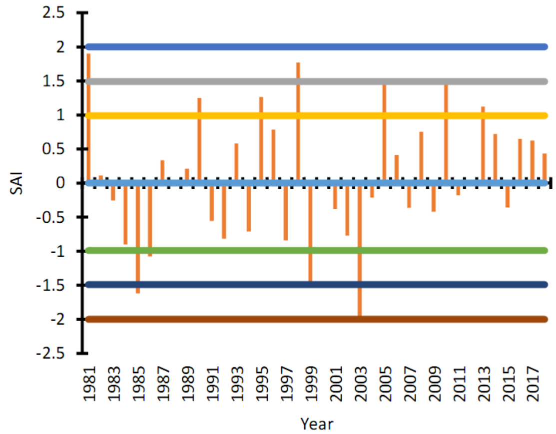
Figure 3 Long term trend analysis of total annual rainfall, mm, from 1981 to 2018 for a) Aland b) Afzalpur c) Chincholi d) Chittapur e) Kalaburgi f) Sedam and g) Jewargi.

Table 2 Mann- Kendall trend (Z) and Sen's slope value (Q) Long term average, yearly highest and lowest values of Rainfall, mm

Places/ Indices	Rainfall, mm				
	Z	**Q**	**Highest**	**Average**	**Lowest**
Aland	-1.91	-4.928	1193.15(1981)	788.70	496.19(1999)
Afzalpur	-1.76	-4.886	1052.08(1981)	667.82	419.73(2003)
Chincholi	-1.79	-4.190	1155.11(1981)	785.65	509.67(1999)
Chittapur	-1.31	-3.722	1155.11(1981)	794.86	506.67(1999)
Kalburgi	-1.08	-3.390	1110.06(1981)	730.42	467.03(1999)
Sedam	-1.63	-4.287	1155.11(1981)	785.65	509.67(1999)
Jewargi	-1.63	-4.287	1110.96(1981)	730.42	467.03(1999)

Standardized Anomaly Index (SAI)

The extreme rainfall analysis based on Standardized Anomaly Index (SAI) for the all the Talukas of Kalaburgi district is shown in Fig. 4 (a to g) for the period of 38 years 1981 to 2018. The Fig. 4 (a) represents the SAI for the place of Aland, in this graphs found that years 1981 and 1998 are severe wet, 1990, 1995, 2005, 2010 and 2013 are found moderate wet, the year 1986 and 1999 found moderate dry, the year 1985 and 2003 found severe dry. The Fig. 4 (b) represent the SAI for place of Afzalpur, in this graphs found that, years 1981 and 1998 are severe wet, 1990, 2005, 2010 and 2017 found moderate wet, the year 1999 found moderate dry, the year 1985 and 2016 found severe dry and the year 2013 found extremely dry. A Fig. 4 (c, d, and f) representing the place of Chincholi, Chittapur and Sedam respectively. In the Fig. 4 (c, d, and f) observed the year 1981 is extremely wet, 1995 and 2005 are severe wet, 1998, 2010 and 2013 are moderately wet, years 1985, 1986 and 2003 are moderately dry, the year 1999 is found as a severe dry year. The Fig. 4 (e) represent the SAI for Kalaburgi, observed for 1981 and 2005 severe wet years, similarly 1995, 1998 and 2010 moderately wet year, and 1985, 1999 and 2003 severe dry years and the extremely dry year noticed in 2016. The SAI calculated for Jewargi presented in Fig. 4(g) and observed extremely wet years in 1981 and 1998, 1995, 2010 and 2016 with moderately wet years, 1986 with the moderately dry year and 1985, 1999 and 2003 were very dry years. It shows that 1981, 1995, 1998 and 2005 were extremely wet years of widespread flooding in the region and 1985, 1999, 2003 and 2016 were found as extreme drought years for 1981 to 2018.



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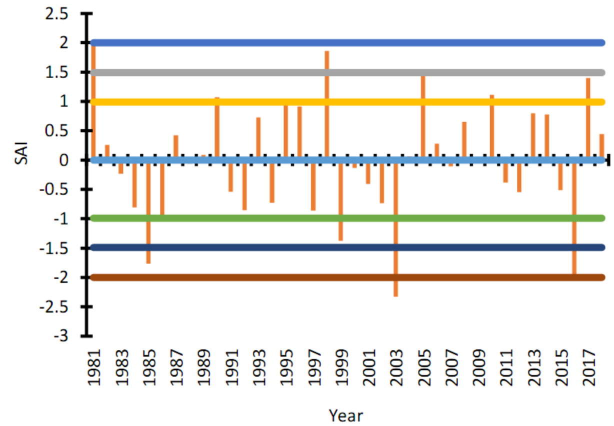

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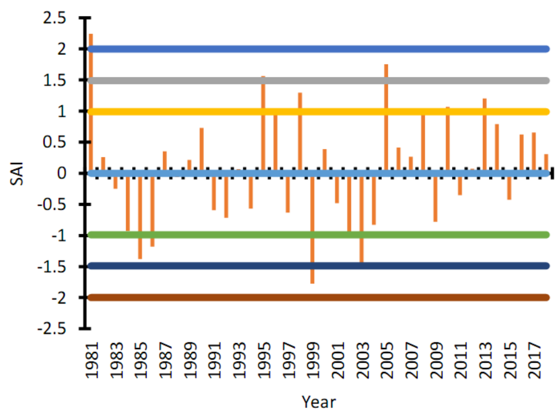

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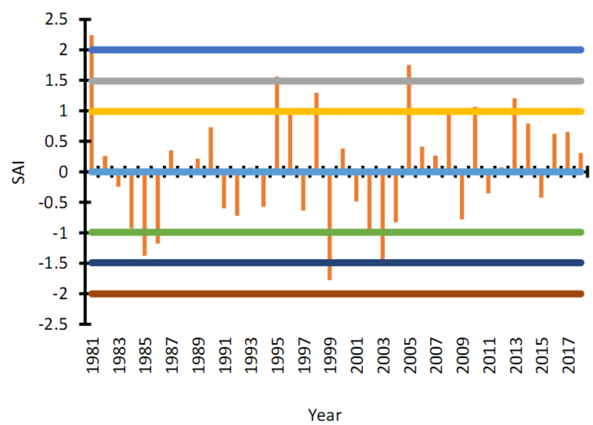

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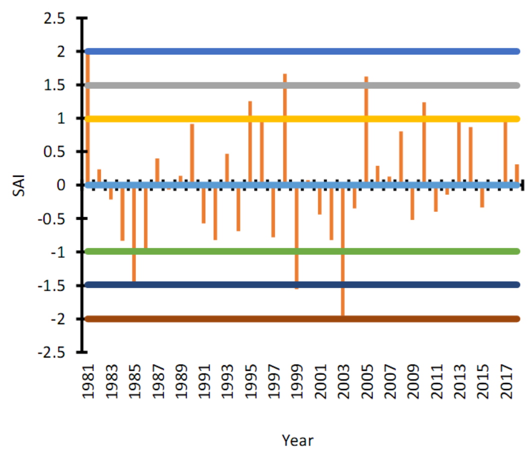

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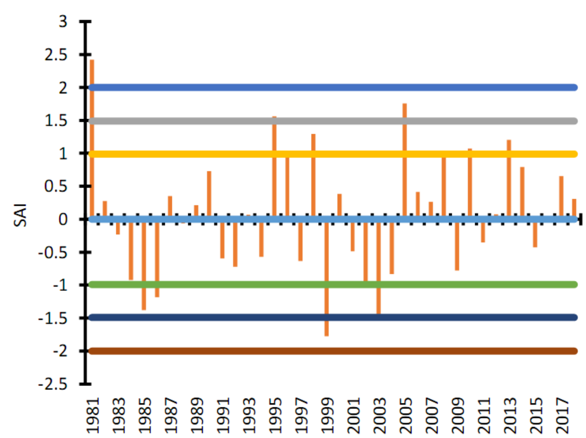

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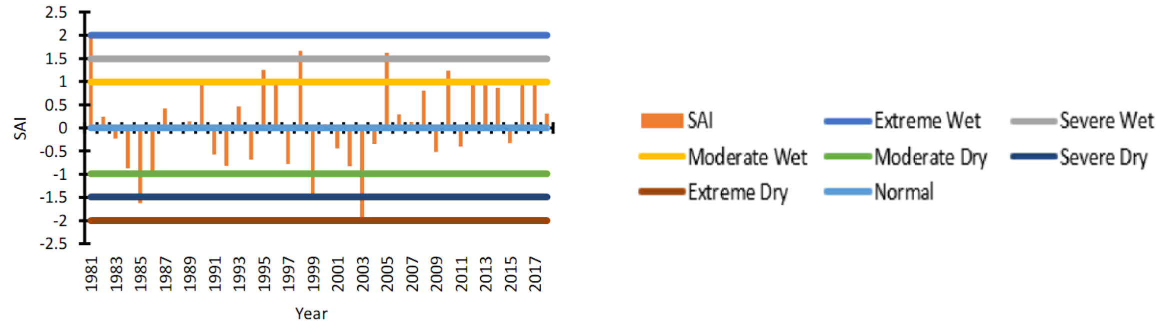

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Figure 4 Standardized Anomaly Index of total annual rainfall from 1981 to 2018 for a) Aland b) Afzalpur c) Chincholi d) Chittapur e) Kalaburgi f) Sedam and g) Jewargi.

Because of rapid urbanization, greenhouse gas emission, industrialization influence the increase of air temperature, this also effects on the rainfall like change in intensity of rainfall, rainfall pattern and duration of rainfall. Further, this affects the crop water requirement, agriculture production, and changing the cropping pattern in the study region. Similar results obtained by (Larbi *et al.*, 2018) shown that extreme rainfall analysis based on Standardized Anomaly Index (SAI) for the Vea catchment over the period 1985–2016 and indicated 1999 and 2003 as extremely wet years, while 1989, 1991, 1994, 1999 and 2010 were all wetter than usual.

4. SUMMARY AND CONCLUSION

The southwest monsoon is the primary source of water for the major parts of India, and millions of people depend on the monsoon for the livelihood. It is highly variable for space and time. Monsoon rain occurs during four months with intermediate dry spells. More than half of the net sown area is dryland and rainfall dependent. Since food production in India is mostly dependent on the vagaries of monsoon, a deeper investigation is required to understand the behaviour of annual and monsoon rainfall and predict its trend. About 38 years of weather data of the study area were analyzed to determine the variability in climatic parameters. The non-parametric statistical methods Mann Kendall test and Sen's slope estimator used to establish the trend in weather parameters. The overall rainfall data and Sen's estimate showed the decreasing trend in series for the last 38 years. The study shows that 1981, 1995, 1998 and 2005 are extremely wet years of widespread flooding in the region and 1985, 1999, 2003 and 2016 were found as extreme drought years for 1981 to 2018.

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