Chapter 14
Study and Analysis of Precipitation Trends and Variability for Karnataka State in India

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Abstract In this study, the precipitation data for the period 1901–2015 was analyzed for the state of Karnataka enclosing 66 grid points spread throughout the state. Gridded rainfall data of 0.50×0.50 resolution has been investigated to draw a conclusion regarding long-term dimensional and temporal trends on an annual and seasonal scale in the state located in Southern India. The various statistical methods such as Mann–Kendall trend test and Theil–Sen's slope test were adopted in analyzing the data besides departure analysis being performed to determine the extent of precipitation deficit and to ascertain the drought years. The change point year has been ascertained to be 1956 by homogeneity test for the state. The annual mean precipitation was estimated to be 1069 mm. The yearly rainfall received in the state of Karnataka is contributed by four seasons, viz., southwest monsoon, post-monsoon, winter, and summer. Also, 70% of the annual rainfall (751.28 mm) is contributed by southwest monsoon following which 18% (186.81 mm) is contributed by post-monsoon. The mean precipitations for summer and winter seasons are 128 mm and 3 mm, respectively, and the corresponding contributions are 12% and 0.29%, which corroborates the fact that winter season has negligible contribution to annual precipitation.

Keywords Precipitation · Statistical analysis · Trend · Mann–Kendall test · Sen's slope estimator · Karnataka state · India

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Introduction

Precipitation is an important component of the hydrological cycle that affects the availability of water globally. Due to global warming and other anthropogenic issues, the earth is facing varying trends in precipitation. Concerning experimental data, it has been observed that over a hundred years climate and temperature have tuned to alter globally beyond normal averages, which result in variation of precipitation trend.

The analysis of seasonal trend is used to find out the dimensional pattern of precipitation in a region. Arun Kumar Taxak et al. (2014) studied the change in rainfall trends in the Wainganga basin of the Godavari river and reported that the annual series were prepared for each grid and scale trend analysis was carried out. Mann–Kendall test was employed to detect the presence of annual and seasonal precipitation trends. The magnitude of the trend was estimated by Theil–Sen's slope estimator test. Sheikh Hefzul Bari et al. (2016) aimed to study and examine 50 years (1964–2013) of seasonal and annual trends of rainfall and their variation over time in northern Bangladesh. Trends were detected with the use of nonparametric test such as Mann–Kendall test. Theil–Sen's slope test was performed to establish trend magnitude over a while. It was found that southwest monsoon and post-monsoon rainfall exhibited an upsurge in trend in most of the rainfall stations, whereas a decrease in seasonal rainfall trend was found after the early 1990s for most of the stations. Duhan and Pandey (2013) investigated the spatial and temporal investigation of rainfall at 45 districts of the Madhya Pradesh state in India for the period 1901–2002 on a seasonal and annual basis. Sen's slope test and Mann–Kendall estimator test were employed to investigate the trend direction and magnitude of change over a time array on a seasonal and annual basis. The significant decreasing trend was found in annual precipitation series at some stations, whereas in summer season significant increasing trend was found in other stations of Madhya Pradesh. Vijay Kumar et al. (2010) predicted that there is a decreasing trend in annual and monsoon rainfall and a rising trend in pre-monsoon and post-monsoon rainfall between the years 1871 and 2005. The statistical significance of the trend in monthly, seasonal, and annual series was analyzed using the nonparametric Mann–Kendall test, and the magnitude of the trend in the time series was determined using Sen's estimator. Jain SK and Kumar V (2012) carried out temperature data and trend analysis of rainfall for India and reported that there was a rising trend in the south, central, and western parts of India and a falling trend in the north and northeastern parts of India. In the study on basin-wise trend analysis, 15 basins were found to follow a downfall trend in annual rainfall; only one basin showed a significant down surge in trend. During rainy days at the annual and seasonal scale, most of the basin had a similar direction and trend of rainfall, but the mean minimum temperature has shown a rise as well as significant decreasing trend. Goyal MK (2014) studied an analysis of rainfall variation in Assam, India, for a period of 102 years from 1901 to 2002. Precipitation values from 21 stations were collected and analyzed for both seasonal and annual variation. No significant changes or trend

in annual rainfall were observed over the entire state in 102 years. From the study, it was predicted that the southwest monsoon season had the strongest correlation with seasonal and annual rainfall. Kundu S et al. (2014) concluded that there is a decline in trends of precipitation in the region of Maharashtra and Madhya Pradesh border region in India, Central Northeast India, and in the zones of homogeneous India in pre-monsoon and post-monsoon season. There were only two regions (northwest and peninsular India) which showed positive rainfall trends. The Sen's slope and Mann–Kendall test were applied in the study. Archana Nair et al. (2014) found that there was maximum average rainfall during pre-monsoon, winter, and post-monsoon over the southern part of Kerala. In contrast, in the monsoon season, maximum rainfall regime shifted to the northern districts of Kerala during 1901–2000. The study showed that there was a significant decreasing trend in the trend of rainfall in most of the 18 regions of Kerala, especially in the 3 months, viz., January, July, and November. Rajeevan M et al. (2008) analyzed rainfall data for 104 years from 1901 to 2004 to test variability and trends of extreme precipitation in central India. The probability of rainfall event exhibits enormous interannual and interdecadal variations along with a statistically significant trend for a more extended period. Detailed analysis showed that interannual, interdecadal extreme rainfall events were influenced by the sea surface temperature variations over the tropical Indian ocean.

Though many studies have been furnished to study the long-term temporal and spatial precipitation trends over many states in India, no papers have been found to analyze similar kinds of precipitation data over the gross state of Karnataka, and this chapter focuses on doing the same. Also, the runoff coefficient for the Cauvery river basin has been found to be low relative to the other major river basins such as Brahmaputra, Narmada, and Mahanadi river basins prevailing in India according to Mohan Z et al. (2005). So, the results of the analysis of precipitation data in the state of Karnataka may be helpful to elicit the reason for such lower runoff coefficient. Also, the study of variability will assist in framing the water management practices throughout the state.

Materials and Methods

Study Area

The study of the precipitation trends has been carried out for the entire Indian state of Karnataka, which is located $11°30'$ north and $18°30'$ north latitudes and $74°$ east and $78°30'$ east longitude. Karnataka lies on a mesa where the Western and Eastern Ghat ranges converge into the complex, in the western part of the Deccan Peninsular region of India. The various river basin systems prevailing in the state of Karnataka are Godavari, Krishna, Cauvery, North Pennar, South Pennar, and Palar. The catchment area of the Godavari river system for the state of Karnataka is 4406 sq. km. The drainage area for the river Krishna in the state of Karnataka is 1,13,271 sq. km, whereas for Cauvery it is 34,273 sq.km. Harangi, Hemavathy,
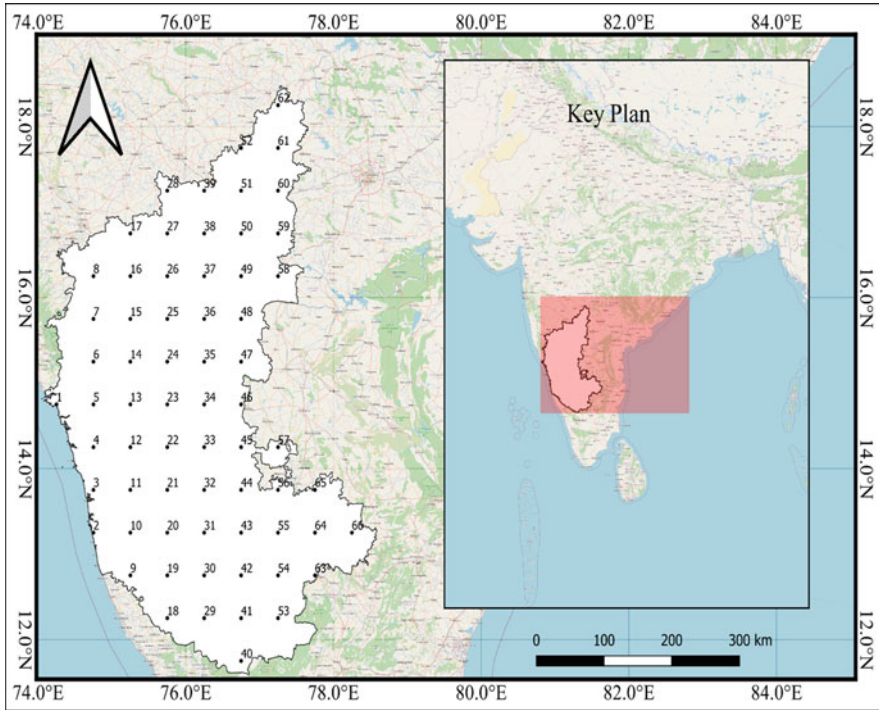
Fig. 14.1 Map for the study area (Karnataka state in the present study) enclosing 66 grid points

Lakshmanathirtha, Kabini, Shimsha, Arkavathi, and Suvarnavathy are the principal tributaries of Cauvery in Karnataka. All these rivers, except Kabini, Arkavathy, and Suvarnavathy, rise and flow fully in Karnataka (Fig. 14.1).

Data and Methodology

In our study, the precipitation data for the period 1901–2015 at $0.5° \times 0.5°$ resolution was downloaded from the "Centre of Environmental Data Archival (http://badc.merc.ac.uk)" for the whole Karnataka state enclosing 62 grid points. The precipitation data was then processed by using MATLAB and MINITAB software. A detailed statistical analysis was carried out using MINITAB 2017 and XLSTAT 2018 software.

The statistical analysis of the precipitation data includes Mann–Kendall trend test and Theil–Sen's slope test. A similar kind of analysis has been done by Rangarajan S et al. (2018).

Mann–Kendall Trend Test

This test is applied to detect the presence of trend in annual and seasonal rainfall. This is the rank-based nonparametric test used to detect trends in precipitation data. Test statistic "S" is defined as

$$S = \sum_{x=i}^{n-1} \sum_{j=i+1}^{n} \text{sgn}\,(x_j - x_i)$$

where x_j are the sequential data values, and "n" has been taken as the length of the dataset and

$$\text{sgn}\,(y) = \begin{cases} 1\ldots..\text{if}\,(y > 0) \\ 0\ldots..\text{if}(y = 0) \\ -1\ldots..(y < 0) \end{cases}$$

It has been documented that when $n \geq 8$ the statistic S is approximately normally distributed with the mean $(S) = 0$ and variance as

$$V(s) = \left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i^2 - t_i \right)(2t_i + 5)],$$

where m has been taken as the number of tied groups and t_i is the size of the ith tied group. The standardized test statistic "Z" is

$$Z_{\text{MK}} = \begin{cases} \dfrac{S-1}{\sqrt{\text{Var}(S)}}\ldots..\text{when}\,S > 0 \\ 0\ldots...\text{when}\,S = 0 \\ \dfrac{S-1}{\sqrt{\text{Var}(S)}}\ldots..\text{when}\,S < 0. \end{cases}$$

Theil–Sen's Slope Estimator Test

The magnitude of a precipitation trend is estimated by Sen's slope test. Theil–Sen's estimator has been used to estimate slope of "n" pairs of data points by

$$Q_i = \frac{x_j - x_k}{j-k}\,\text{for}\,\,i = 1\ldots.N$$

where x_j and x_k are data values at time j and k, respectively, where $j > k$.

The median of these N values of Q is Sen's slope estimator of slope. If there is only one data in each period, then

$$N = \frac{n(n-1)}{2}$$

where "n" is the number of periods.

The median of the N estimated slopes is obtained in the usual way:

$$\text{Sen's Slope estimator} = \begin{cases} Q_{\frac{N+1}{2}} \ldots \ldots \text{if } N \text{ is odd} \\ 0.5\left(Q_{N/2} + Q_{(N+2)/2}\right) \ldots \ldots \text{if } N \text{ is even} \end{cases}$$

Results and Discussion

Precipitation Characteristics for Karnataka State

It was observed that the southwest monsoon season has maximum mean precipitation of 751.28 mm, which contributes to 70% of annual rainfall. This is followed by post-monsoon with mean precipitation of 186.81 mm with a contribution of 18% of annual rainfall. The mean precipitation for the summer and winter seasons was 128 mm and 3 mm, respectively, and corresponding contributions are 12% and 0.29%. So, it can be concluded that winter season was having a negligible contribution to annual precipitation.

The coefficient of variation of precipitation for the winter season over the state of Karnataka was computed to be 86%, while for the summer, southwest monsoon, and post-monsoon seasons, the coefficient of variation was found to be 40%, 82%, and 25%, respectively. This underlines the fact that, over the state of Karnataka, the coefficient of variation is maximum for the winter season followed by the southwest monsoon, summer, and post-monsoon seasons successively. For annual rainfall, the coefficient of variation was found to be 63%.

The elaborate statistics of the seasonal contribution of precipitation data for the entire state of Karnataka during the period of 1901–2015 is depicted in Fig. 14.2.

Departure Analysis of Rainfall

From the results obtained from departure analysis for Karnataka state, which is shown in Fig. 14.3, it is inferred that from 1901 to 2015, that is, in 115 years, normal, excess, deficient, and scanty rainfall was recorded for 79, 11, 23, and 2 years, respectively.

CONTRIBUTION OF SEASONS TO ANNUAL RAINFALL
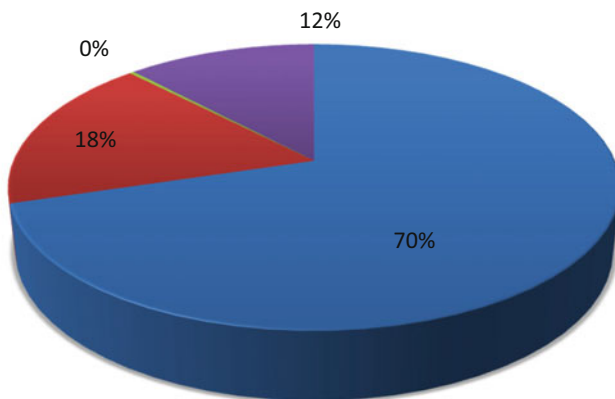
Fig. 14.2 Contribution of seasons to annual rainfall

RESULTS OF PERCENTAGE DEPARTURE ANALYSIS FOR KARNATAKA
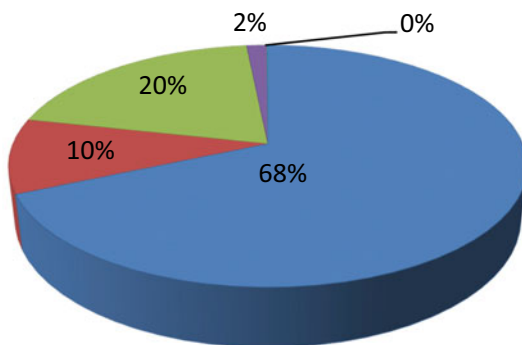
Fig. 14.3 Percentage departure analysis for Karnataka
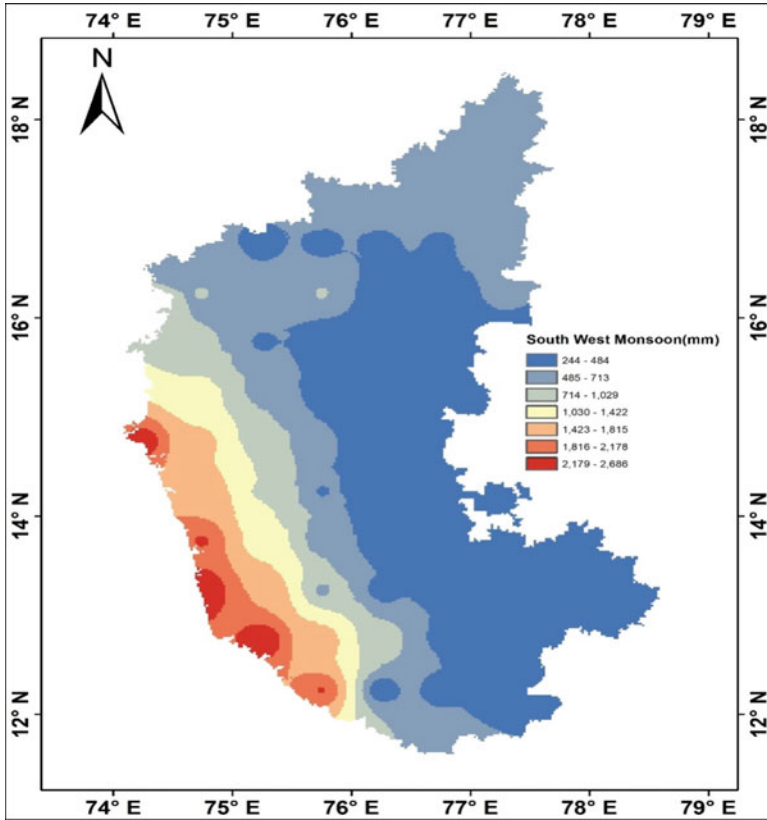
Fig. 14.4 Variation of southwest monsoon over the Karnataka state

Variation of Annual Precipitation, Southwest Monsoon, and Post-monsoon over the Karnataka State

The variations of the southwest monsoon, post-monsoon, and annual precipitation over the state of Karnataka are depicted in Figs. 14.4, 14.5 and 14.6, respectively.

In Fig. 14.4, it can be noticed that the southwest monsoon has a descending trend on moving from the extreme western part of the state, which comprises the Western Ghats to the eastern part of the state. The southwest monsoon contributes maximum rainfall in the range of 2179–2686 mm in the regions represented by dark red color. The western districts of Karnataka, which are neighboring to states of Telangana and Andhra Pradesh, receive the least precipitation due to southwest monsoon, and the rainfall varies between 244 mm and 484 mm. The northern districts, which share border with Maharashtra state, receive average southwest precipitation of 600 mm.
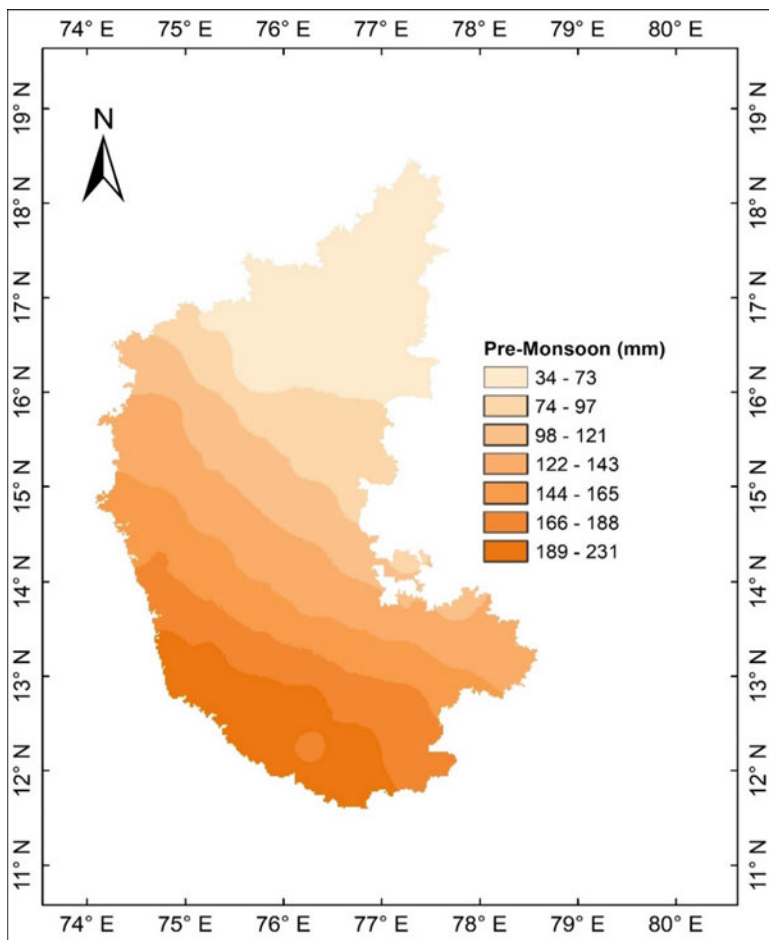
Fig. 14.5 Variation of pre-monsoon over Karnataka state

Figure 14.5 throws light on the fact that the pre-monsoon exhibits a decreasing trend from the southern to the northern part of the state with maximum precipitation ranging between 189 mm and 231 mm over the extreme southern districts. The precipitation goes on depressing as it moved to the northern districts through the central districts with the minimum in the range of 34–73 mm. The central districts receive precipitation of varied ranges, which has been shown in the figure.

From Fig. 14.6, it can be noticed that the precipitation received by Karnataka from post-monsoon season exhibits a decreasing trend as we move from southern districts to northern districts. The precipitation over the extreme southern region ranges from 257 mm to 296 mm and 232 mm to 256 mm, respectively. Central Karnataka receives precipitation over a wide range, which has been depicted in the figure. The ranges between which these precipitation values lie are 207–231 mm,
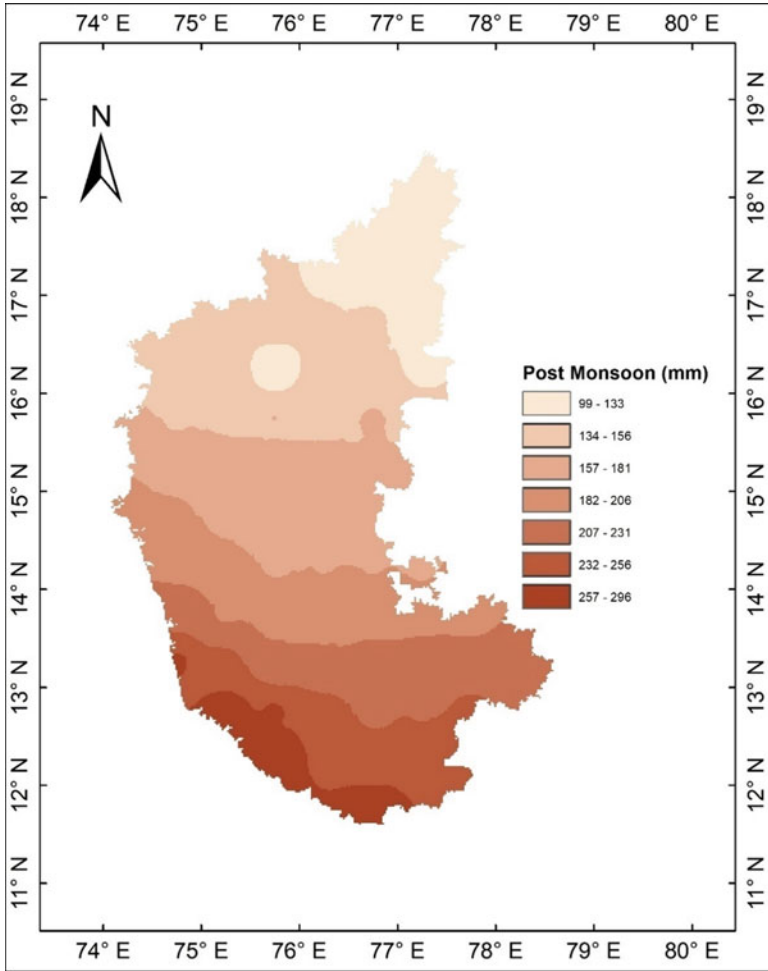
Fig. 14.6 Variation of precipitation due to post-monsoon over Karnataka state

182–208 mm, 157–181 mm, and 134–156 mm. The northern districts receive post-monsoon contributed precipitation of 99–133 mm.

Figure 14.7 depicts the variation of annual precipitation over the state of Karnataka. It is observed that the annual precipitation exhibits a decreasing nature as it moved from the Western Ghats comprising extreme western districts to the eastern districts through the central districts. The western districts of the coastal belt receive annual precipitation in varied ranges of 2387–3155 mm, 1950–2386 mm, and 1556–1949 mm, respectively. The annual precipitations in the central districts show values in the range of 1202 mm to 921 mm. A major portion of central Karnataka receives annual precipitation in the later range of lowest ambit of 505–713 mm. The annual precipitation over the northern districts sharing borders with Maharashtra ranges between 714 mm and 921 mm.
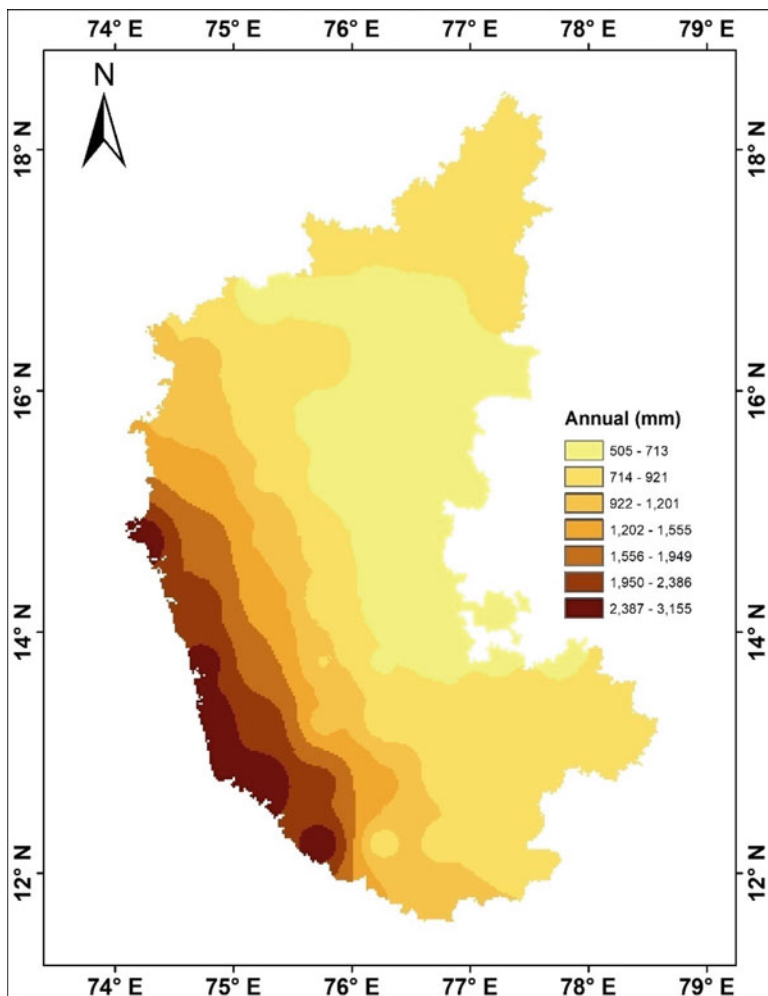
Fig. 14.7 Variation of annual precipitation over Karnataka state

Results of Mann–Kendall's Test (1901–2015)

For Mann–Kendall's test statistic, a positive value of Z indicates an increasing trend and a negative value of Z indicates a declining trend. When the Z value is greater than 1.96, it confirms a significant rising trend, while if Z is less than -1.96, it establishes a significant falling trend at 5% level of significance.

It can be observed that in the annual array of precipitation all the grid points spread over the Karnataka state exhibited an increasing trend in precipitation except grids 4–8 and 12–14, which showed a nonsignificant decreasing trend in

precipitation. Among the remaining grid points, which show an increasing trend of precipitation, grids 26–28, 37–39, 49–52, 54–56, and 58–62 show a significant increasing trend, which constitutes 33% of the total 66 grid points spread over the state of Karnataka.

For the southwest monsoon array of Table 14.1, grids 1, 4–8, and 12–14 showed nonsignificant decreasing trends in precipitation. All other grids establish an increasing trend in which grids 26, 38, 53–55, 58, and 63–66 show a significant increasing trend constituting 15% of the total 66 grid points. No grids indicated significant decreasing trends.

For the post-monsoon array, grids 1–6, 9–14, 18–24, 29–34, and 40–44 indicate a nonsignificant decreasing trend in rainfall and no grid points establish significant decreasing trend. Hence, 45% of the total 66 grid points establish a declining trend in rainfall. The grid points 27, 28, 38, 39, 49–52, and 58–62 constituting 14% of the total 66 grids show a significantly increasing trend.

And for the summer array, 10 grids establish a nonsignificant decreasing trend and for the winter nearly 58 grids showed decreasing trends with most of them falling under a significant range.

Results of Theil–Sen's Slope Test (1901–2015)

The Sen's slope estimator test was done for obtaining the true slope for the precipitation data. Percentage deviation is median slope (β) times the period length divided by the corresponding mean expressed as a percentage.

For the annual array shown in Table 14.1, the grid points 17, 26–28, 36–39, and 46–66 establish an increase in precipitation of magnitude greater than 10% to the mean of the array. These grid points constitute about 44% of the total grid points. The grid points 4–8 and 12–14 showed negative percentages. The remaining grid points indicated a positive value of less than 10%. From Fig. 14.8, it is observed that the annual precipitation has increased by a magnitude of 18–24% in the northeastern and southeastern regions of the state, whereas in the western region encompassing the Western Ghats, the precipitation has dipped by 0.3–5%. Central Karnataka has experienced increasing precipitation in the range of 4–9%.

For the southwest monsoon, grid points 17, 26–28, 37–39, 41–44, and 49–66 establish more than 10% increase in precipitation, and these constitute 48% of the total number of grid points. Grids 4–8 and 12–14 indicated negative percentages as that of annual array. The remaining grid points indicated a positive value in slope. When interpreted spatially as depicted in Fig. 14.8, the precipitation received during the southwest monsoon almost has a similar trend like annual rainfall. This proves the fact that the southwest monsoon has a dominant impact on annual precipitation being the major contributor.

For the post-monsoon season, 33% of the total grid points 16, 17, 26–28, 37–39, 49–52, and 57–66 undergo an increase in precipitation of more than 10% in magnitude, and some of the grids show a decline in precipitation with a magnitude

Table 14.1 Results of Mann–Kendall test and Sen's slope test (1901–2015)

Grid point	Grids LONG_LAT	Annual Z	% change	Winter Z	% change	Summer Z	% change	S-W monsoon Z	% change	Post-monsoon Z	% change
1	74.25_14.75	0.174	1.472	−1.767	0.000	−0.563	−5.474	−0.130	1.298	−0.228	3.149
2	74.75_13.25	0.865	5.582	−0.008	0.000	0.198	2.785	0.986	7.214	−1.300	−14.914
3	74.75_13.75	0.372	2.690	0.488	0.000	−0.198	−3.082	0.585	4.947	−0.955	−11.099
4	74.75_14.25	−0.302	−1.885	−2.389	0.000	−0.317	−5.156	−0.017	−0.275	−0.341	−5.216
5	74.75_14.75	−0.938	−5.709	−1.226	0.000	−0.537	−6.243	−1.068	−7.761	−0.155	−2.468
6	74.75_15.25	−0.534	−3.097	0.182	0.000	−0.350	−4.065	−0.981	−6.172	−0.005	0.394
7	74.75_15.75	−0.624	−3.858	−0.580	0.000	0.150	2.399	−1.051	−7.319	0.145	1.623
8	74.75_16.25	−0.143	−0.935	0.134	0.000	−0.160	−2.407	−0.215	−1.809	0.459	6.094
9	75.25_12.75	0.638	3.934	−1.611	−25.213	0.164	2.928	0.911	6.824	−1.537	−17.313
10	75.25_13.25	0.614	3.983	−1.609	−22.352	0.331	4.372	0.894	6.717	−1.477	−17.200
11	75.25_13.75	0.372	2.203	−1.901	−17.578	0.123	1.463	0.595	4.807	−1.027	−12.268
12	75.25_14.25	−0.529	−3.074	−1.698	−12.028	−0.222	−2.103	−0.493	−3.330	−0.800	−8.907
13	75.25_14.75	−0.856	−4.645	−1.536	0.000	0.000	0.000	−1.051	−7.689	−0.425	−4.925
14	75.25_15.25	−0.382	−2.407	0.171	0.000	0.288	2.876	−0.819	−5.616	−0.348	−3.653
15	75.25_15.75	0.566	3.434	0.071	0.000	0.080	1.314	0.276	1.864	0.457	5.242
16	75.25_16.25	1.093	6.838	0.588	0.000	0.068	1.051	0.715	5.263	1.102	15.071
17	75.25_16.75	1.726	10.717	0.183	0.000	−0.242	−3.524	1.421	11.393	1.363	20.958
18	75.75_12.25	0.798	4.471	−2.034	−41.872	0.012	0.052	0.834	6.130	−0.962	−10.646
19	75.75_12.75	0.875	5.364	−1.831	−33.043	0.094	1.092	1.233	8.669	−1.107	−11.793
20	75.75_13.25	0.365	2.480	−2.362	−44.152	0.263	2.790	0.914	7.690	−1.252	−13.917
21	75.75_13.75	0.488	3.149	−2.430	−43.604	0.894	9.354	0.522	4.295	−0.718	−8.673
22	75.75_14.25	0.111	0.738	−2.659	−43.070	0.331	3.416	0.331	2.752	−0.967	−10.745
23	75.75_14.75	0.498	3.052	−2.206	0.000	0.439	6.319	0.416	3.467	−0.503	−5.921
24	75.75_15.25	0.713	4.196	−1.932	0.000	0.916	10.865	0.300	2.412	−0.070	−0.941

(continued)

Table 14.1 (continued)

Grid point	Grids	Annual		Winter		Summer		S-W monsoon		Post-monsoon	
	LONG_LAT	Z	% change	Z	% change	Z	% change	Z	% change	Z	% change
25	75.75_15.75	1.073	6.692	−1.464	0.000	1.095	13.918	0.534	4.125	0.300	3.964
26	75.75_16.25	2.006	16.063	−2.350	−36.939	−1.112	−19.85	2.069	16.714	1.250	24.293
27	75.75_16.75	2.560	17.936	−0.632	0.000	0.517	6.504	1.392	11.837	1.958	27.888
28	75.75_17.25	2.864	19.650	0.227	0.000	0.114	1.495	1.929	14.717	2.071	38.092
29	76.25_12.25	0.343	1.677	−2.417	−55.758	−0.529	−5.758	0.326	2.541	−0.802	−8.010
30	76.25_12.75	1.008	5.356	−0.292	0.000	0.224	4.819	0.808	8.368	−1.226	−8.320
31	76.25_13.25	0.771	4.107	−0.002	0.000	0.945	8.194	0.875	7.775	−0.848	−9.358
32	76.25_13.75	0.863	4.807	−2.879	−63.889	1.298	11.816	0.686	5.765	−0.653	−7.497
33	76.25_14.25	0.486	3.054	−2.774	−55.779	0.950	9.059	0.541	4.518	−0.425	−5.473
34	76.25_14.75	0.672	4.222	−2.695	0.000	0.508	4.675	0.616	5.236	−0.549	−7.072
35	76.25_15.25	1.477	9.511	−2.083	0.000	1.397	14.282	0.638	6.505	0.198	2.452
36	76.25_15.75	1.719	11.349	−2.309	−29.745	1.777	20.821	0.735	6.330	0.551	7.464
37	76.25_16.25	2.453	16.271	−1.286	0.000	1.564	19.555	1.300	10.313	1.603	22.261
38	76.25_16.75	3.304	23.945	−1.057	−8.016	1.129	17.573	1.975	17.550	2.930	44.811
39	76.25_17.25	2.879	20.295	−0.812	−5.164	0.701	11.029	1.678	15.102	2.758	45.939
40	76.75_11.75	0.621	3.046	−2.954	−74.223	0.000	0.000	0.464	3.104	−0.051	−0.486
41	76.75_12.25	1.322	8.106	−2.778	−67.958	0.256	2.404	1.673	12.197	−0.036	−0.272
42	76.75_12.75	1.537	9.336	−2.502	−54.181	0.703	6.734	1.516	13.479	−0.285	−3.559
43	76.75_13.25	1.419	8.845	−0.176	0.000	0.817	7.499	1.450	12.495	−0.372	−4.157
44	76.75_13.75	1.400	8.471	−0.224	0.000	1.199	12.617	1.165	10.564	−0.227	−3.409
45	76.75_14.25	1.247	8.371	−0.190	0.000	1.281	12.475	1.056	8.794	0.048	0.583
46	76.75_14.75	1.482	10.369	−2.694	−59.899	1.726	16.865	0.969	8.710	0.430	5.805
47	76.75_15.25	1.885	12.632	−2.501	−45.654	1.750	19.888	1.134	9.551	0.752	9.184
48	76.75_15.75	1.719	11.349	−2.309	−29.744	1.777	20.822	0.735	6.330	0.551	7.464

| 49	76.75_16.25	3.121	23.032	-2.175	-34.865	2.101	28.981	1.946	17.107	2.013	32.208
50	76.75_16.75	2.840	21.319	-1.484	-18.153	1.866	25.949	1.697	15.383	2.497	40.571
51	76.75_17.25	2.586	18.815	-1.140	-6.935	1.453	21.363	1.484	13.350	2.432	41.880
52	76.75_17.75	2.676	19.096	-0.989	-7.131	1.201	17.561	1.379	13.715	2.495	42.118
53	77.25_12.25	1.859	11.505	-2.556	-55.314	0.022	0.452	2.001	16.524	0.737	7.042
54	77.25_12.75	2.446	15.779	-2.379	-54.447	0.769	7.001	2.349	21.698	0.604	8.182
55	77.25_13.25	2.301	15.660	-2.059	-40.528	0.776	8.885	2.045	19.768	0.181	2.479
56	77.25_13.75	2.040	13.540	-0.149	0.000	1.158	11.458	1.641	15.923	0.384	5.125
57	77.25_14.25	1.919	13.343	-0.030	0.000	1.218	12.439	1.424	13.409	1.049	10.847
58	77.25_16.25	3.070	22.884	-1.496	-18.657	2.432	31.719	1.960	16.653	2.146	33.319
59	77.25_16.75	2.905	21.408	-1.487	-18.904	2.028	30.324	1.868	15.045	2.316	37.771
60	77.25_17.25	2.562	18.178	-1.015	-9.293	1.448	20.290	1.576	12.694	2.296	38.536
61	77.25_17.75	2.608	18.696	-1.048	-7.786	1.367	19.738	1.480	13.253	2.408	40.845
62	77.25_18.25	2.642	18.896	-1.019	-7.459	1.284	18.650	1.430	13.484	2.452	41.482
63	77.75_12.75	2.843	18.438	-2.649	-60.653	1.027	11.635	2.538	23.145	1.143	13.673
64	77.75_13.25	2.780	18.796	-2.343	-57.547	1.105	12.525	2.582	23.046	1.071	11.956
65	77.75_13.75	2.594	18.506	-2.292	-57.164	1.842	19.031	1.965	18.190	1.281	14.296
66	78.25_13.25	2.852	18.969	-1.776	-34.107	1.832	22.770	2.611	21.861	1.390	14.343
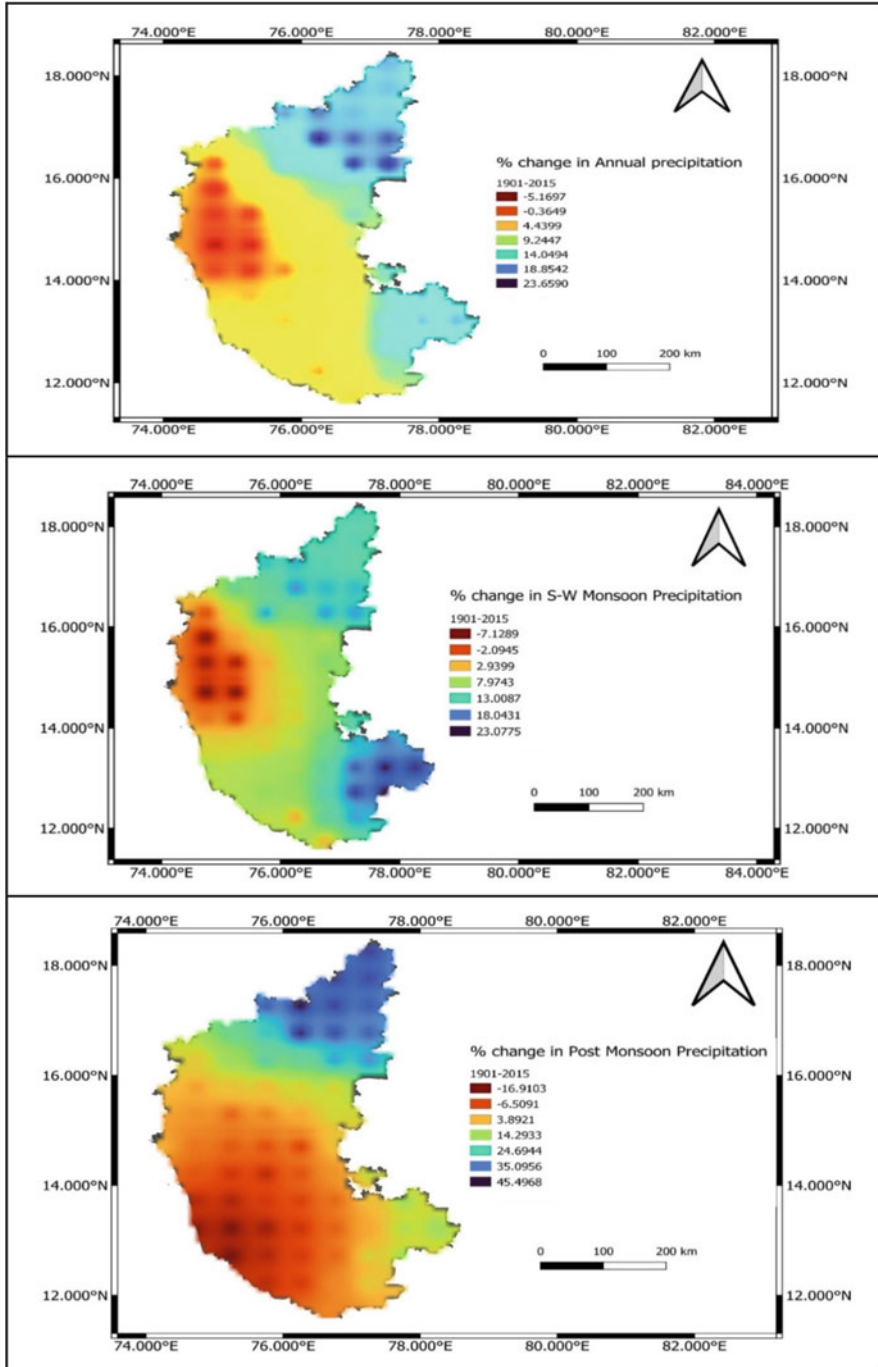
Fig. 14.8 Spatial representation of percentage change in precipitation for time array 1901–2015

greater than 10%. Southern Karnataka indicates a dip in post-monsoon precipitation throughout the period 1901–2015, but the scenario alters as it moved toward the northern districts. The magnitude of dips and increments with respect to spatial distribution over the state is shown in Fig. 14.8.

Grids 24, 25, 32, 35–39, 44–52, and 56–66 indicate a greater than 10% increase in precipitation for the summer season. Other grids undergo less than 10% increase or decrease in precipitation except grid 26, which records a decline of greater than 10% in precipitation.

Homogeneity Test

Homogeneity tests have been conducted to ascertain whether a series may be considered homogeneous over time or whether there is a time at which a change occurs. The variety of the tests comes from the fact that there are many possible alternative hypotheses: changes in distribution, changes in average (one or more times), or presence of trend. Pettit's test and Buishand's test were employed to test the homogeneity of a precipitation series. Pettit's test is based on rank and is a nonparametric test that does not require any assumption of normality. Buishand's test is based on cumulative deviations from the mean or partial sums. The test is carried out for monsoon, post-monsoon, and annual time series.

Homogeneity Results for Annual Precipitation Series

The ultimate change point year for Karnataka turns out to be 1956 for both Pettit's test and Buishand's test.

Homogeneity Results for Southwest Monsoon Series

The year 1956 is the change point for the southwest monsoon array by both Pettit's test and Buishand's test.

It is to be noted that from the result of the seasonal contribution of rainfall it has been observed that 70% of the annual rainfall is contributed by the southwest monsoon. So, it was expected that the change point year for the annual rainfall series and southwest monsoon series will not vary to a considerable extent. Being coherent with the expectation, the homogeneity analysis results indicate the change point year to be the same for both annual series and southwest monsoon series. Also, it shows the precision of estimation.

Homogeneity Test Results for Post-monsoon Series

The change point year was found to be 1952 from Pettit's test and 1951 from Buishand's test for the post-monsoon array.

Mann–Kendall Test and Theil–Sen's Slope Test Results for Two Successive Time Series

After performing the homogeneity analysis, the change point year was determined to be 1956 for Karnataka state. As the change point year was fixed, Mann–Kendall test and Theil–Sen's slope test were performed for the precipitation values of all the 62 grid points in two phases for determining the trends in precipitation in two successive time series. In the first phase of analysis, time series was taken from 1901 to 1956, and for the second phase of analysis, time series was taken from 1957 to 2015 (Tables 14.2 and 14.3).

Trend Analysis

For annual array, Mann–Kendall standardized test statistic Z-value indicates that 32 grid points that constitute 48% of the total 66 grid points undergo a change in the phase of precipitation between the series. The grid points undergoing change in the phase were 1–17, 21–25, 27, 35–37, 39, 48, 50–52, and 60. Only four grid points, namely, 7, 8, 15, and 16, exhibit a significant increase ($Z > 1.96$) of precipitation in the first time series and only two grid points 7 and 8 exhibit a significant decrease ($Z < -1.96$) of precipitation in the second time series. Of the 32 grid points that exhibit a phase change, 28 grids have a change in phase from positive to negative. This implies that these 28 grid points exhibit an increasing trend in precipitation from 1901 to 1956, but the precipitation trend decreases in the next time series from 1957 to 2015. These 28 grid points comprise grids 1, 4–8, 11–17, 21–25, 27, 35–37, 39, 48, 50, 51, 52, and 60. The remaining four grid points out of the 30 grids establish a change in phase from negative to positive, that is, the precipitation increases in the second time interval from 1957 to 2015. These grid points include grids 2, 3, 9, and 10.

For annual array, from Sen's slope test, the grid points 1, 5–8, 13–17, 24, and 25 (12 out of 66 grid points), which had a significant boom in magnitude of precipitation (greater than 10%) in the first time interval, exhibit an abrupt alteration in the second time interval, where there has been a significant decline in precipitation showing negative magnitude in the range of -5 to -25%. Grid points 27, 35–37, 39, 48, 50–52, and 60 (10 out of 66 grid points) exhibit an increase in the magnitude of 10–20% in rainfall for the first time series but exhibit a decrease in precipitation

Table 14.2 Man–Kendall test and Theil–Sen's slope test results during the period 1901–1956

Grid points	Grids LONG_LAT	Annual Z-value	% change	S-W monsoon Z-value	% change	Post-monsoon Z-value	% change
1	74.25_14.75	1.322	12.442	0.629	7.021	2.226	44.481
2	74.75_13.25	−0.177	−2.244	−0.770	−7.456	0.092	0.663
3	74.75_13.75	−0.233	−2.413	−0.516	−5.628	0.820	9.957
4	74.75_14.25	0.191	1.514	−0.205	−2.396	1.520	31.086
5	74.75_14.75	1.011	8.567	−0.021	−0.537	2.127	42.757
6	74.75_15.25	1.746	12.772	0.968	8.698	1.986	45.694
7	74.75_15.75	2.361	17.393	1.392	12.746	1.922	42.275
8	74.75_16.25	2.184	14.942	1.293	11.827	1.618	38.923
9	75.25_12.75	−0.247	−1.894	−0.502	−6.963	−0.580	−8.741
10	75.25_13.25	−0.219	−2.564	−0.629	−7.141	−0.254	−6.622
11	75.25_13.75	0.219	1.877	−0.445	−5.387	0.403	6.794
12	75.25_14.25	0.671	4.989	−0.375	−3.785	1.046	18.771
13	75.25_14.75	1.166	9.470	0.049	0.224	1.830	33.843
14	75.25_15.25	1.618	14.220	0.714	6.228	1.604	32.232
15	75.25_15.75	1.965	17.627	1.138	11.605	1.725	34.182
16	75.25_16.25	2.000	16.987	1.237	11.519	1.576	33.802
17	75.25_16.75	1.746	16.349	1.124	10.869	1.244	33.060
18	75.75_12.25	1.279	7.417	0.452	5.375	−0.163	−2.229
19	75.75_12.75	0.403	3.448	0.134	1.260	−0.113	−1.509
20	75.75_13.25	0.686	5.546	0.007	0.305	−0.191	−2.842
21	75.75_13.75	0.912	5.947	−0.021	−0.840	0.155	2.434
22	75.75_14.25	0.841	7.556	0.000	0.024	0.247	6.109
23	75.75_14.75	1.159	9.952	0.168	1.771	0.921	18.04
24	75.75_15.25	1.675	13.787	0.601	6.475	1.315	24.500
25	75.75_15.75	1.505	15.635	1.088	11.864	1.152	25.736
26	75.75_16.25	1.477	16.380	1.067	10.545	1.965	47.610
27	75.75_16.75	1.668	16.517	0.855	9.191	1.124	27.971
28	75.75_17.25	1.336	13.544	1.152	12.392	0.728	22.228
29	76.25_12.25	1.039	7.459	0.431	4.020	0.219	5.037
30	76.25_12.75	1.004	6.887	0.459	5.208	0.318	5.160
31	76.25_13.25	1.025	9.540	−0.007	−0.253	0.318	5.963
32	76.25_13.75	1.194	10.781	−0.028	−0.612	0.474	10.643
33	76.25_14.25	0.940	8.751	−0.120	−1.053	0.481	9.596
34	76.25_14.75	0.954	8.996	0.021	0.360	0.290	7.708
35	76.25_15.25	1.237	11.479	0.431	4.506	0.735	17.124
36	76.25_15.75	1.746	17.219	1.053	11.970	1.145	26.088
37	76.25_16.25	1.618	13.377	1.138	13.956	0.954	22.002
38	76.25_16.75	1.774	18.524	1.223	17.809	1.209	28.371
39	76.25_17.25	1.760	19.549	1.180	15.849	0.954	26.194
40	76.75_11.75	0.770	5.851	−0.134	−0.732	0.353	4.557
41	76.75_12.25	0.919	7.573	0.254	1.901	0.891	12.622

(continued)

Table 14.2 (continued)

	Grids	Annual		S-W monsoon		Post-monsoon	
Grid points	LONG_LAT	Z-value	% change	Z-value	% change	Z-value	% change
42	76.75_12.75	1.315	10.586	0.544	4.840	0.827	16.701
43	76.75_13.25	1.166	10.059	0.219	2.144	0.587	12.568
44	76.75_13.75	1.067	10.742	0.092	1.489	0.671	15.045
45	76.75_14.25	0.912	9.211	−0.049	−1.047	0.601	13.989
46	76.75_14.75	0.997	12.499	0.148	2.270	0.636	12.003
47	76.75_15.25	1.124	12.155	0.290	4.341	0.671	12.578
48	76.75_15.75	1.746	17.219	1.053	11.970	1.145	26.088
49	76.75_16.25	1.703	20.843	1.336	17.432	0.954	25.683
50	76.75_16.75	1.675	19.626	1.293	20.502	1.039	29.640
51	76.75_17.25	1.583	19.316	1.307	17.853	0.841	25.767
52	76.75_17.75	1.626	18.384	1.180	16.115	0.841	23.507
53	77.25_12.25	0.770	7.494	−0.155	−1.723	0.855	17.772
54	77.25_12.75	1.053	8.880	0.353	4.541	1.053	21.682
55	77.25_13.25	1.293	10.320	0.141	1.767	0.848	17.708
56	77.25_13.75	1.329	12.704	0.035	1.102	0.876	14.651
57	77.25_14.25	0.813	9.231	−0.021	−0.650	0.594	9.990
58	77.25_16.25	1.703	19.672	1.187	16.507	1.279	33.956
59	77.25_16.75	1.647	17.214	1.124	15.629	1.053	29.633
60	77.25_17.25	1.534	16.286	1.053	14.644	0.728	18.561
61	77.25_17.75	1.581	17.995	1.180	16.204	0.803	22.612
62	77.25_18.25	1.604	18.190	1.180	16.160	0.822	23.060
63	77.75_12.75	1.025	9.722	0.148	3.208	0.855	16.301
64	77.75_13.25	1.230	11.176	0.247	3.691	1.018	15.822
65	77.75_13.75	1.088	12.232	0.120	1.279	0.834	16.914
66	78.25_13.25	0.558	5.392	−0.233	−1.959	0.368	7.615

magnitude of −0.656% to −5.402% in the successive time series. The grid points 28, 32, 38, 42–44, 46, 47, 49, 58, 59, and 62 (12 out of 66 grids) exhibit a change in magnitude from greater than 10% increase in the range of 10.059% to 20.843% to less than 10% increase in the magnitude of range 0.414–5.433% as it moved from the first time series to the second time series.

From Figs. 14.9 and 14.10, it can be observed that in the gross northern Karnataka state the annual precipitation has declined to a considerable extent. Throughout the first time array, where there is an increase in precipitation magnitude of 16–20% in these regions, after the change point year, change in magnitude of precipitation is recorded to be −25% to −4%. The phase change in precipitation, that is, from 15% to −22%, has specially been underscored in the northwestern ghats. The southern districts exhibit an average percentage increase in precipitation from 7.5% to 10% as it moved from the first to the second time series.

Table 14.3 Mann–Kendall and Theil–Sen's slope test results during the period 1957–2015

	Grids	Annual		S-W monsoon		Post-monsoon	
Grid points	LONG_LAT	Z-value	% change	Z-value	% change	Z-value	% change
1	74.25_14.75	−0.916	−9.508	−0.889	−9.812	−0.281	−8.334
2	74.75_13.25	0.314	2.566	0.249	2.210	0.216	3.729
3	74.75_13.75	0.013	0.049	0.092	1.306	0.222	3.256
4	74.75_14.25	−0.438	−5.292	−0.347	−4.205	0.118	2.256
5	74.75_14.75	−1.256	−12.899	−1.112	−12.673	−0.275	−5.120
6	74.75_15.25	−1.785	−17.436	−1.615	−17.286	−0.347	−8.224
7	74.75_15.75	−2.629	−25.963	−1.877	−21.539	−0.425	−8.538
8	74.75_16.25	−2.485	−25.564	−1.602	−17.219	−0.033	−0.442
9	75.25_12.75	0.000	0.151	0.183	2.590	0.575	10.278
10	75.25_13.25	0.327	3.507	0.458	5.339	0.366	7.524
11	75.25_13.75	−0.026	−0.431	0.353	3.354	0.314	5.483
12	75.25_14.25	−0.556	−5.217	−0.262	−3.215	0.229	4.643
13	75.25_14.75	−1.177	−11.454	−0.772	−8.810	−0.085	−2.205
14	75.25_15.25	−1.537	−14.627	−1.092	−13.529	−0.183	−4.787
15	75.25_15.75	−1.779	−17.983	−0.850	−10.409	−0.183	−2.411
16	75.25_16.25	−1.713	−16.666	−0.680	−7.735	0.150	2.139
17	75.25_16.75	−1.491	−14.737	−0.275	−3.717	0.163	3.269
18	75.75_12.25	0.340	2.477	0.432	5.383	0.987	14.947
19	75.75_12.75	0.641	5.858	0.889	9.811	0.700	9.033
20	75.75_13.25	0.307	3.606	0.837	10.133	0.510	6.150
21	75.75_13.75	−0.249	−3.084	0.419	5.456	0.405	6.617
22	75.75_14.25	−0.379	−4.471	0.157	1.728	0.242	3.808
23	75.75_14.75	−0.641	−8.06	−0.167	−1.666	0.113	4.104
24	75.75_15.25	−1.046	−8.256	−0.327	−2.809	−0.157	−2.670
25	75.75_15.75	−1.033	−9.948	−0.170	−2.525	−0.007	−0.103
26	75.75_16.25	0.419	5.887	0.811	12.860	0.719	19.754
27	75.75_16.75	−0.497	−5.402	0.183	2.720	0.209	2.800
28	75.75_17.25	0.549	5.146	−0.183	−2.122	0.994	26.250
29	76.25_12.25	0.327	3.586	0.602	6.695	0.785	12.510
30	76.25_12.75	0.549	4.810	1.046	12.701	0.680	9.936
31	76.25_13.25	0.451	2.813	1.040	15.108	0.347	5.950
32	76.25_13.75	0.334	1.959	0.530	8.043	0.386	5.815
33	76.25_14.25	0.092	0.817	0.517	5.407	0.543	7.060
34	76.25_14.75	0.039	0.389	0.275	3.228	0.451	4.400
35	76.25_15.25	−0.157	−0.656	0.000	0.000	0.046	0.782
36	76.25_15.75	−0.340	−3.642	−0.092	−1.581	−0.183	−3.169
37	76.25_16.25	−0.157	−0.900	0.353	3.834	0.294	3.899
38	76.25_16.75	0.078	1.771	0.523	6.138	0.536	11.000
39	76.25_17.25	−0.013	−0.174	0.294	3.214	0.569	9.848
40	76.75_11.75	0.255	2.081	0.778	7.755	0.497	5.112
41	76.75_12.25	0.405	4.768	1.046	11.465	0.641	8.611

(continued)

Table 14.3 (continued)

Grid points	Grids	Annual		S-W monsoon		Post-monsoon	
	LONG_LAT	Z-value	% change	Z-value	% change	Z-value	% change
42	76.75_12.75	0.523	5.372	0.909	11.760	0.235	4.585
43	76.75_13.25	0.634	5.433	0.987	11.589	0.229	4.979
44	76.75_13.75	0.602	4.673	0.706	8.986	0.105	2.287
45	76.75_14.25	0.883	7.363	0.693	8.817	0.693	7.910
46	76.75_14.75	0.804	7.810	0.523	6.068	0.831	12.147
47	76.75_15.25	0.111	1.022	0.379	5.655	0.360	4.802
48	76.75_15.75	−0.340	−3.642	−0.092	−1.581	−0.183	−3.169
49	76.75_16.25	0.366	3.307	0.301	3.883	0.628	11.573
50	76.75_16.75	−0.065	−0.861	0.275	2.570	0.458	10.088
51	76.75_17.25	−0.137	−1.284	0.039	0.317	0.347	7.615
52	76.75_17.75	−0.059	−0.718	0.167	1.766	0.569	11.894
53	77.25_12.25	1.007	8.190	0.994	11.690	0.438	6.800
54	77.25_12.75	1.072	9.562	1.138	13.402	0.157	4.346
55	77.25_13.25	1.269	14.159	1.216	14.981	0.327	4.905
56	77.25_13.75	1.275	11.600	0.844	10.573	0.785	10.620
57	77.25_14.25	1.334	11.386	0.667	7.996	1.347	16.301
58	77.25_16.25	0.288	3.645	−0.052	−0.638	0.706	13.523
59	77.25_16.75	0.039	0.414	−0.209	−1.372	0.791	14.761
60	77.25_17.25	−0.026	−0.755	−0.196	−1.841	0.791	18.218
61	77.25_17.75	1.559	17.801	1.180	16.249	0.713	18.741
62	77.25_18.25	0.750	8.532	0.674	9.008	0.641	15.318
63	77.75_12.75	1.713	14.947	1.177	15.148	0.510	8.333
64	77.75_13.25	1.746	15.891	1.079	14.059	0.765	10.924
65	77.75_13.75	1.556	13.172	0.772	9.074	1.059	12.572
66	78.25_13.25	1.648	12.791	0.929	12.291	0.994	11.457

For the southwest monsoon series, from the Z-value of Mann–Kendall test, 33 grid points indicate a change in phase of precipitation between the series. Also, 19 grid points exhibit a transition from positive phase to negative phase between the series and 14 grid points exhibit a transition from negative phase to positive phase between the series. No significant increase or decrease in precipitation is established in any of the grids constituting both the arrays for S-W monsoon. Three grid points 7, 8, and 15 have greater than 10% increase in precipitation for the early time series but undergoes greater than 10% decrease in precipitation for the successive time series. Nine grid points 16, 17, 25, 28, 36, 48, and 58–60, which has greater than 10% increase in magnitude of precipitation in the first half, show a negative magnitude of less than 10% in the second half of time array. Finally, grid points 37–39 and 49–52 and 62, that is, 8 grid points, exhibit greater than 10% increase in precipitation from 1901 to 1956 but less than 10% increase in precipitation from 1957 to 2015.
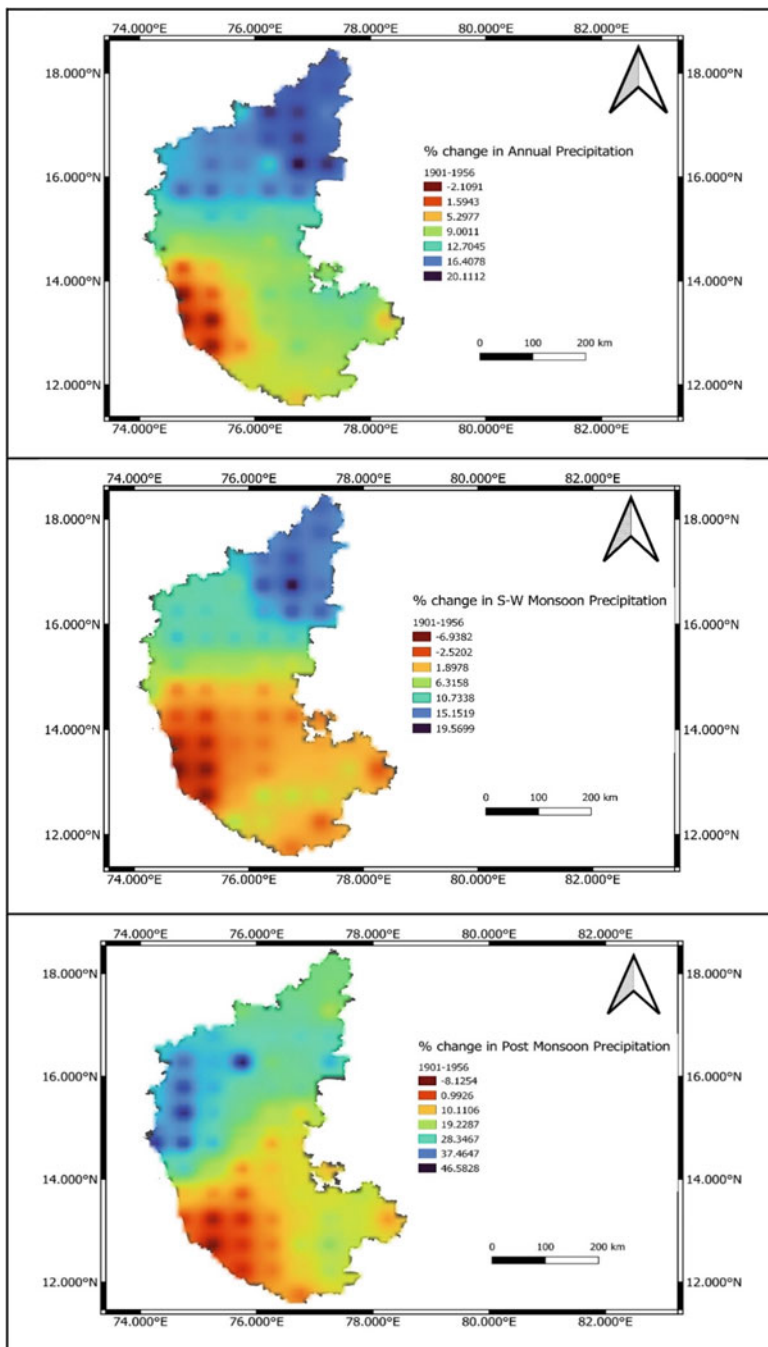
Fig. 14.9 Spatial representation of percentage change in precipitation for time array 1901–1956
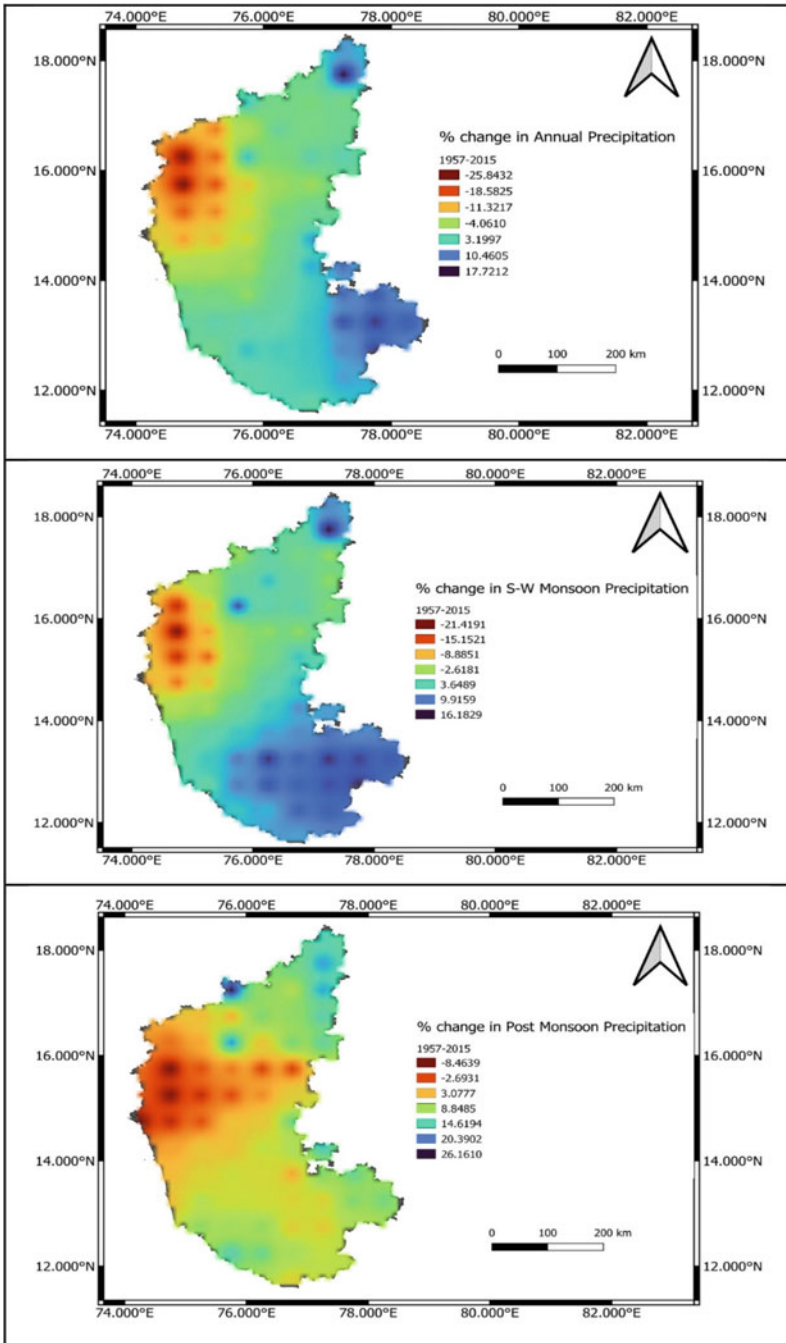
Fig. 14.10 Spatial representation of percentage change in precipitation for time array 1957–2015

Table 14.4 Mann–Kendall test and Sen's slope estimator test results for the basin of Karnataka

Year range	Annual			S-W monsoon			Post-monsoon		
	Z-value	β-value	% change	Z-value	β-value	% change	Z-value	β-value	% change
1901–2015	1.344	0.635	6.834	0.904	0.495	5.715	0.232	0.054	3.298
1901–1956	1.095	1.464	7.788	0.318	0.498	2.848	0.841	0.546	16.264
1957–2015	0.013	0.027	0.150	0.288	0.453	2.643	0.628	0.249	7.922

When the percentage change in precipitation received in southwest monsoon is projected spatially over the map of Karnataka state, it is noted that a sharp boom in precipitation becomes pervasive over the southern districts of the state in between the two successive time series under study. Throughout the period 1901–1956 in the southwestern region, the southwest monsoon precipitation has an average decline of 4%. But in the southeastern districts, the average increase in precipitation throughout the same time array is found to be 4%. In the successive time series (1957–2015), the entire southern domain of the state establishes boom in precipitation, the magnitude of boom ranging from 3% to 16%. The northwestern ghat districts experienced a pathetic decrease in precipitation throughout the successive time series. In this regard, the former time array in which a 6–10% increase in southwest monsoon precipitation is recorded witnesses a pathetic decline in the range of 8–21% in the later time array. The extreme north districts also witness a dip in precipitation increment magnitude but no decline is recorded.

For post-monsoon array, 17 grid points exhibit a change in phase of precipitation between the series, and 12 grid points undergo alteration from a positive phase to a negative phase. Five points undergo a transition from a negative phase to a positive phase. Grid points 1, 5, 6, 7, 8, 13–15, 24, 25, 36, and 48, which have a greater than 10% increase in magnitude of precipitation in the first half, show a negative magnitude of less than 10% in the second half of the time array.

When analyzed spatially, the post-monsoon precipitation has shown changes in southern districts as it moved from the first time series to the second time series, but the changes vary both with respect to phase and magnitude. In the first half, the precipitation change is ascertained to be -8% to 1% in the southwest region, which transforms to 8–14% in the second half. Again in the northern districts, the post-monsoon precipitation increases by 20–46% throughout the time array of 1901–1956, but the magnitude of increment reduces to 3–20% throughout the period 1957–2015. Also, some of the regions in northwestern Karnataka register a dip in precipitation as compared to the boom on moving from the first to second time array (Table 14.4).

For annual precipitation, the trend suggests that the increase in the magnitude of precipitation dips from 7.788% to 0.15% when it moved from the first time series to the second. Southwest monsoon exhibits a nonsignificant increase in trend. However, the percentage change remains almost identical for both the time series. Post-monsoon exhibits a decrease in the percentage increase of rainfall from 16.264% in the first time series to 7.922% in the second time series.

Conclusion

The present study analyzes the precipitation trends over the entire state of Karnataka from 1901 to 2015 by employing CRU $0.5° \times 0.5°$ gridded rainfall data. Karnataka receives a mean annual precipitation of 1073 mm with southwest monsoon contributing 70% of it, followed by the post-monsoon season, which contributes about 18%. The summer and winter seasons have negligible contribution to annual precipitation. The coefficient of variation for annual precipitation is 68%. The departure analysis for 115 years of precipitation data underlines the fact that 79 years received normal precipitation, 11 years received excess precipitation, 23 years received deficient precipitation, and only 2 years had scanty precipitation.

The results obtained from the analysis of spatial distribution of precipitation throughout the south Indian state under study reveal that the southwest monsoon has a descending trend on moving from the extreme western part of the state, which comprises the Western Ghats, to the eastern part of the state, whereas the pre-monsoon exhibits a decreasing trend from the southern to the northern part of the state. The precipitation received by Karnataka from the post-monsoon season exhibits a decreasing trend as we move from the southern districts to the northern districts. It is observed that the annual precipitation exhibits a decreasing nature as it moved from the Western Ghats comprising extreme western districts to the eastern districts through the central districts.

From the trend analysis results, it is observed that the precipitation in the western region of Karnataka comprising the Western Ghats and its adjoining areas has decreased over the period under consideration. Of the 32 grid points spread throughout the state, which exhibit a phase change, 28 grids have a change in phase from positive to negative. This implies that these 28 grid points exhibit an increasing trend in precipitation from 1901 to 1956, but the precipitation trend decreases in the next time series from 1957 to 2015. The precipitation in this region establishes increasing precipitation in the first time series, and the trend reverses in the second time series. The change point year is estimated to be 1956. Also, the annual precipitation over the entire state of Karnataka increases by 7.78% in the first time array (1901–1956) and the increasing trend dips too much, reduced 0.15% in the second time array (1957–2015). The southwest monsoon and post-monsoon seasons being the influential contributors to the annual rainfall also echo the same trend over the successive time series. Also, the central and eastern parts of the state experience a decreasing trend of rainfall, but the extent of decrease in the trend is less as compared to the Western Ghats and adjoining areas.

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