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RESEARCH PAPER

Historical and Projected rainfall analysis for North Interior Karnataka, India

A. C. MAHADEVA PRASAD, R. H. PATIL, K. G. SUMESH AND JAYANTH BHAT

Department of Agricultural Meteorology, College of Agriculture
University of Agricultural Sciences, Dharwad - 580 005, Karnataka, India
E-mail: ravipatil2005@gmail.com

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Abstract: Indian agriculture is predominantly dependent on monsoon, which is experiencing changes over space and time with increased variance, mainly due to anthropogenic global warming and climate change.The daily rainfall (RF) data of past 40 years (1981-2020) was collected from India Meteorological Department (IMD) daily gridded data and future 20 years (2021-2040) was collected from CMIP-6 and analysed at district level. Basic statistics such as minimum, maximum, mean, standard deviation and coefficient of variation of annual RF and rainy days (RD) were analysed. Mann-Kendal trend test was used for analysis of trend across NIK. Results showed a positive trend in both RF&RD for the historical and projected period. In the past 40 years, the highest annual mean RF and RD was observed in Dharwad district (952.34 mm & 80) followed by Bidar (937.13 mm and 59 mm) and the lowest mean RF & RD was observed in Bagalkot district (527.52 mm & 39) followed by Vijayapur (535.33 mm & 38). For the next 20 years, the highest annual mean RF is expected in Haveri district (1559.07 mm) and the lowest in Kalaburgi district (1182.82 mm), the highest RD is expected in Vijayanagara district (127) and the lowest in Kalaburgi district (99).

Key words: Analysis, Projected, Rainfall, Rainy days

Introduction

Rainfall is a natural occurrence that has an impact on all life on Earth, either directly or indirectly. Both the amount and the intensity vary greatly across both time and space. Rainfall in India is mostly brought in by the monsoon. The monsoon, is derived from the Arabic word "*mausim"* meaning "season". It arises due to the difference in temperatures and atmospheric pressure between the land mass and the adjacent ocean. Indian monsoon is one of the most prominent monsoon systems of the world, which primarily affects the Indian sub-continent and its surrounding water bodies. The state of Karnataka in India has a bitter sweet relationship with rain. While its regions of Malnad and Coastal Karnataka receive copious amount of rainfall. State is predominately semi-arid. The year is divided into four seasons climatically; south-west monsoon season (June to September), north-east monsoon season (October to December), winter season (January to February) and summer season (March to May). The south-west monsoon accounts for almost 80 per cent of the rainfall that the state receives annually (Venkatesh *et al*., 2016).

North Interior Karnataka (NIK) meteorological sub division includes North-Eastern Transition Zone, North-Eastern Dry Zone, Northern Dry Zone and North Transition Zone, which cover 13 districts namely; Bagalkot, Belagavi, Ballari, Bidar, Dharwad, Gadag, Haveri, Kalaburgi, Koppal, Raichur, Vijayanagara, Vijayapura and Yadgiri. NIK predominantly has sustainable agriculture, where it is mainly dependent on southwest monsoon rainfall, and rainfall plays a major role in rainfed agriculture. The failure of monsoon or decrease in intensity of rainfall or ill distribution would cause drought condition or create water stress in plant and affect crop yield.

The analysis of long-term changes in weather parameters helps in detection of rate of change and trend. Agriculture in Karnataka mainly depends on South-West monsoon followed by North-East monsoon in few districts (Madolli *et al.,* 2015). Rainfall is one of the most decisive weather parameters for the detection of climate change and its effect on agriculture (Sridhara *et al.,* 2021). Any change in the climate during monsoon months severely affects the agricultural production, economy as well as water availability during non-monsoon months, thus systematic studies needs to be paid towards variability in rainfall. South west monsoon season is the main source of natural form of water for the soil to grow crop, especially in NIK. Analysis of rainfall and its trends, seasonal distribution may help in the planning of cropping pattern incoming years (Jain *et al.,* 2012). Farmers face greater risk in crop production if there is an uncertainty in intensity, amount and distribution of rainfall during monsoon seasons. This study intends to find the trends in rainfall pattern for historical and projected period.

Material and methods

The historical daily rainfall data for 121 long years (1901-2021) were collected from India Meteorological Department (IMD) gridded data platform at a spatial resolution of 0.25 x 0.25 degree. Future climatic scenario dataset for 2021-2040 was downloaded from Coupled Model Inter comparison Project Phase 6 (CMIP-6) with a resolution of 0.5 x 0.5 degree for the same study area. Other descriptive statistics on rainfall such as Maximum, Minimum, Standard Deviation (SD), Standard Error (SE) and Coefficient of Variation (CV) were computed to analyse the variation in rainfall over period of time. Spatial analysis of the same was also performed and presented here. Mann-Kendall trend test was adopted for testing the significance of trend (Bora *et al.,* 2022). It's a statistical test widely used to analyse trend in climatologic and hydrologic time series data which was tested for the significance at 95 % level.

The Mann-Kendall S Statistic was computed as follows:

$$S_0=\sum_{k=1}^{m-1}\ \sum_{j=k+1}^{n-1} sign(xj-xk)$$

Where, n is the number of observed data series, xj and xi are the values in period j and I respectively, j>i .

Variability pattern of rainfall (RF) and rainy days (RD)were analysed through ten year moving average. The CV was considered for the variability classification *i.e.,* < 20 % as less variability, 20 % to 30 % as moderate variability, > 40 % as high variability and if it is >70 % then was classified under rather heavy variability. Further, monthly, annual and seasonal rainfall and rainy days data were used for mapping by Arc GIS 10.4.1 software and thereby maps for spatial variations of rainfall and rainy days were prepared.

Results and discussion

Characteristics of annual rainfall and rainy days during historical period

Table 1 and 2 shows the numerical representation of annual characteristics of rainfall and rainy days, respectively, at the district level across NIK over a 40-year historical period (1981-2020). Fig.1 and 2 shows the graphical presentation of annual rainfall and rainy days characteristics, respectively, at district level across NIK. Fig. 5 and 6 shows the spatial map of annual rainfall and rainy days variation, respectively across NIK.

During historical 40 years (1981-2020), in Bagalkot district the maximum and minimum rainfall of 1083.2 mm and 205.3 mm, maximum and minimum number of 60 and 17 rainy days, respectively, was observed with the annual mean rainfall of 527.52 mm and 39 average rainy days. In Belagavi district the maximum and minimum rainfall of 1343.7 mm and 212.5 mm, maximum and minimum number of 106 and 23 rainy days, respectively, was observed with the annual mean rainfall of 878.00 mm and 63 average rainy days. In Bellary district the maximum and minimum rainfall of 1019.8 mm and 104.1 mm, maximum and minimum number of 60 and 13 rainy days, respectively, was observed with the annual mean rainfall of 536.06 mm and 41 average rainy days. In Bidar district, the maximum and minimum rainfall of 1754.9 mm and 460.3 mm, maximum and minimum number of 79 and 31 rainy days, was observed with the annual mean rainfall of 937.13 mm and 59 average rainy days. In Vijayapura district the maximum and minimum rainfall of 936.4 mm and 193.1 mm, maximum and minimum number of 66 and 19 rainy days, respectively, was observed with the annual mean rainfall of 535.33 mm and 38 average rainy days. In Dharwad district the maximum and minimum rainfall of 1630.5 mm and 198.5 mm, maximum and minimum number of 104 and 25 rainy days, respectively, was observed with the annual mean rainfall of 952.34 mm and 80 average rainy days. In Gadag district the maximum and minimum rainfall of 1221.9 mm and 82.1 mm, maximum and minimum number of 74 and 14 rainy days, respectively, was observed with the annual mean rainfall of 540.50 mm and 44 average rainy days. In Haveri district the maximum and minimum rainfall of 1196.1 mm and 174.1 mm, maximum and minimum number of 81 and 13

Table 1. District wise annual rainfall characteristics across NIK during the historical 40 years (1981-2020)

District	Mean RF (mm)	Maximum RF (mm)	Minimum RF (mm)	SD (mm)	CV (%)
Bagalkot	527.52	1083.20	205.30	184.08	34.89
Belagavi	878.00	1343.70	212.50	257.08	29.28
Bellary	536.06	1019.80	104.10	181.21	33.80
Bidar	937.13	1754.90	490.30	273.77	29.21
Vijayapura	535.33	936.40	193.10	155.18	28.98
Dharwad	952.34	1630.50	198.50	270.53	28.40
Gadag	540.50	1221.90	82.10	213.50	39.50
Haveri	652.03	1196.10	174.10	184.77	28.33
Kalburgi	717.87	1085.10	174.00	232.53	32.39
Koppala	655.24	1044.20	171.30	207.01	31.59
Raichur	636.51	1252.20	255.50	191.20	30.03
Vijayanagara	813.86	1429.30	212.90	317.26	38.98
Yadgiri	701.78	1464.60	163.50	217.12	30.93

Table 2. District wise annual rainy days characteristics across NIK during the historical 40 years (1981-2020)

District	Mean RD (no.)	Maximum RD (no.)	Minimum RD (no.)	SD	CV (%)
Bagalkot	39	60	17	12.07	31.08
Belagavi	63	106	23	18.00	28.63
Bellary	41	60	13	10.13	24.49
Bidar	59	79	31	11.75	19.90
Vijayapura	38	66	19	10.28	27.11
Dharwad	80	104	25	13.47	16.84
Gadag	44	74	14	12.58	28.38
Haveri	54	81	13	13.95	25.62
Kalburgi	52	78	15	12.37	23.88
Koppala	43	63	14	10.12	23.33
Raichur	44	76	21	12.49	28.31
Vijayanagara	60	85	20	11.83	19.75
Yadgiri	54	86	16	12.74	23.39

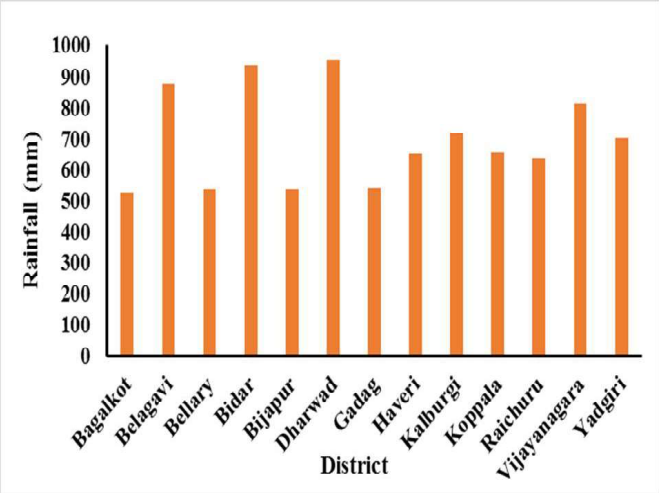

Fig. 1. Characteristics of annual rainfall across NIK over historical period (1981-2020)

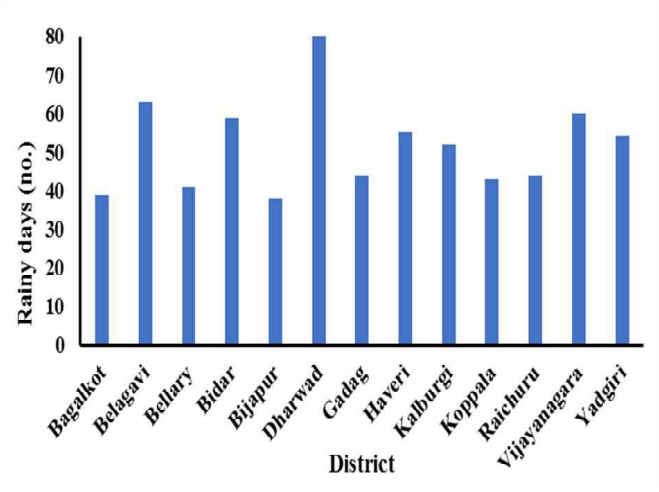

Fig. 2. Characteristics of annual rainy days across NIK over historical period (1981-200)

rainy days, respectively, was observed with the annual mean rainfall of 652.03 mm and 54 average rainy days. In Kalaburgi district the maximum and minimum rainfall of 1085.1 mm and 174.00 mm, maximum and minimum number of 78 and 15 rainy days, respectively, was observed with the annual mean rainfall of 717.87 mm and 52 average rainy days. In Koppal district the maximum and minimum rainfall of 1044.2 mm and 171.3 mm, maximum and minimum number of 63 and 14 rainy days, respectively, was observed with the annual mean rainfall of 655.24 mm and 43 average rainy days. In Raichur district the maximum and minimum rainfall of 1252.2 mm and 255.5 mm, maximum and minimum number of 76 and 21 rainy days, respectively, was observed with the annual mean rainfall of 636.51 mm and 44 average rainy days. In Vijayanagara district the maximum and minimum rainfall of 1429.3 mm and 212.9 mm, maximum and minimum number of 85 and 20 rainy days, respectively, was observed with the annual mean rainfall of 813.86 mm and 60 average rainy days. In Yadgiri district the maximum and minimum rainfall of 1464.6 mm and 163.5 mm, maximum and minimum number of 68 and 16 rainy days, respectively, was observed with the annual mean rainfall of 701.78 mm and 54 average rainy days.

Characteristics of annual rainfall and rainy days for projected period

In Table 3 and 4 the annual characteristics of rainfall and rainy days at the district level are represented numerically for NIK throughout a 20-year predicted time frame (2021-2040). The graphical representation of annual rainfall and rainy days characteristics at the district level across NIK are shown in Fig. 3 and 4, respectively. Fig.7 and 8 show the map of spatial variation in annual rainfall and rainy days, respectively. Because of the 0.5 x 0.5 degree data resolution, values for few districts were identical. This was the limitation of this study.

During coming 20 years (2021-2040), in Bagalkot district, the highest and lowest annual rainfall of 1790.23 mm and 976.54 mm, the maximum and minimum number of 138 and 85 rainy days are expected with an average annual rainfall of 1420.48 mm and 112 average days. In Belagavi, Vijayapura, Dharwad and Koppal districts the highest and lowest annual rainfall of 1790.23 mm and 976.54 mm, maximum and minimum number of 138 and 85 rainy days are expected with an average annual rainfall of 1419.91 mm and 112 average rainy days. In Bellary district, the highest and lowest annual rainfall of 1737.12 mm and 951.54 mm, maximum and minimum number of 149 and

Table 3. Annual rainfall characteristics at district level across NIK over next 20 years (2021-2040)

District	Mean RF (mm)	Maximum RF (mm)	Minimum RF (mm)	SD	CV (%)
Bagalkot	1420.48	1790.23	976.54	240.11	16.90
Belagavi	1419.91	1790.23	976.54	239.94	16.89
Bellary	1308.60	1737.12	951.54	214.51	16.39
Bidar	1183.71	1491.92	741.50	195.26	16.49
Vijayapura	1419.91	1790.23	976.54	239.94	16.89
Dharwad	1419.91	1790.23	976.54	239.94	16.89
Gadag	1494.06	2966.04	976.54	421.17	28.19
Haveri	1559.07	2079.30	1159.8	229.32	14.70
Kalburgi	1182.80	1491.01	739.98	195.02	16.48
Koppala	1419.91	1790.23	976.54	239.94	16.89
Raichur	1233.65	1565.87	864.89	204.78	16.59
Vijayanagara	1367.70	1922.40	1002.9	249.06	18.21
Yadgiri	1233.65	1565.87	864.89	204.78	16.59

Table 4. Annual rainy days characteristics at district level across NIK over next 20 years (2021-2040)

District	Mean RD (no.)	Maximum RD (no.)	Minimum RD (no.)	SD	CV (%)
Bagalkot	112	138	85	15.20	13.62
Belagavi	112	138	85	15.17	13.60
Bellary	119	149	89	16.23	13.64
Bidar	100	127	63	17.24	17.33
Vijayapura	112	138	85	15.17	13.60
Dharwad	112	138	85	15.20	13.62
Gadag	117	230	85	30.55	26.06
Haveri	118	143	95	12.98	10.98
Kalburgi	99	130	63	17.05	17.21
Koppala	112	138	85	15.17	13.60
Raichur	109	137	83	16.04	14.78
Vijayanagara	127	160	105	14.94	11.73
Yadgiri	109	137	83	16.04	14.78

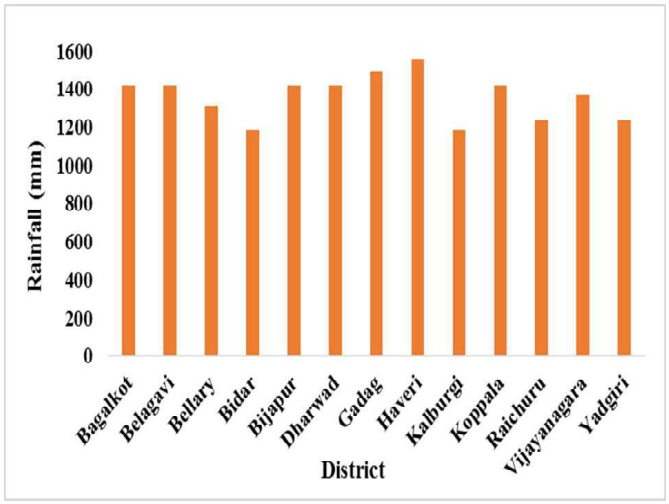

Fig. 3. Characteristics of annual rainfall across NIK for the projected period (2021-2040).

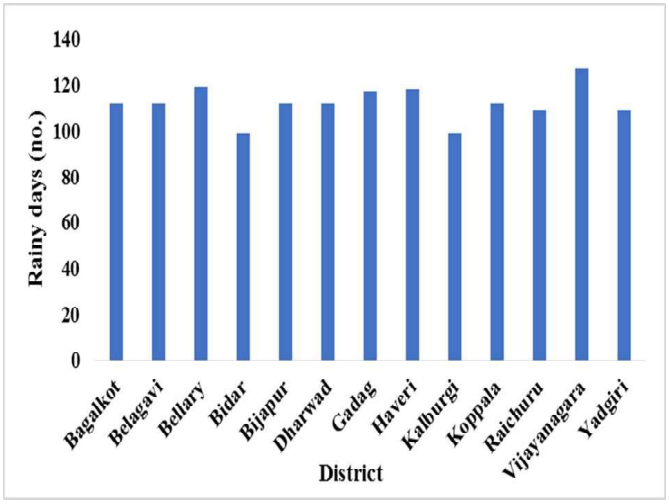

Fig. 4. Characteristics of annual rainy days across NIK for the projected period (2021-2040).

89 rainy days is expected with an average annual rainfall of 1308.60 mm and 119 average rainy days. In Bidar district, the highest and lowest annual rainfall of 1491.92 mm and 741.5 mm, maximum and minimum number of 127 and 63 rainy days is expected with an average annual rainfall of 1183.71 mm and 100 average rainy days. In Gadag district, the highest and lowest annual rainfall of 2966.04 mm and 976.54 mm, maximum and minimum number of 230 and 85 rainy days is expected with an average annual rainfall of 1494.06 mm and 117 average rainy days. In Haveri district, the highest and lowest annual rainfall of 2079.3 mm and 1159.8 mm, maximum and minimum number of 143 and 95 rainy days are expected with an average annual rainfall of 1559.67 mm and 118 average rainy days. In Kalaburgi district, the highest and lowest annual rainfall of 1490.01 mm and 739.98 mm, maximum and minimum number of 130 and 63 rainy days are expected with an average annual rainfall of 1182.8 mm and 99 average rainy days. In Raichur and Yadgiri districts, the highest and lowest annual rainfall of 1565.87 mm and 864.89 mm, maximum and minimum number of 137 and 83 rainy days is expected with an average annual rainfall of 1233.65 mm and 109 average rainy days. In Vijayanagara district, the highest and lowest annual rainfall of 1922.4 mm and 1002.9 mm, maximum and minimum number of 106 and 105 rainy days is expected with an average annual rainfall of 1367.7 mm and 127 average rainy days.

Annual rainfall and rainy days trend during historical period

The results of trend analysis by Mann-Kendall test for annual rainfall and rainy days are shown in Table 5. During historical 40 years (1981-2020), out 13 districts of NIK at 5 % level of significance, Bagalkot, Bellary and Dharwad districts showed a positive non-significant trend for both annual rainfall and rainy days. Belagavi showed a negative non-significant trend for both annual rainfall and rainy days. Bidar district showed a positive non-significant trend for annual rainfall, but a negative non-significant trend for annual rainy days. Vijayapura district showed a positive non-significant trend for annual rainfall, but a positive significant trend for annual rainy days. Gadag district showed a positive significant trend for both annual rainfall and rainy days. Haveri district showed a positive non-significant trend for annual rainfall, but a positive significant trend for annual rainy days. Kalaburgi district showed no trend for annual rainfall, but a positive non-significant trend for annual rainy days. Koppal district showed a negative non-significant trend for annual rainfall, but a positive non-significant trend for annual rainy days Raichur and Yadgiri districts showed a positive non-significant trend for both annual rainfall and rainy days. Vijayanagara district showed a positive non-significant trend for annual rainfall, but positive significant trend for annual rainy days.

Table 5. Trend significance and coefficient for annual rainfall and rainy days at district level across NIK for the historical 40 years (1981-2020).

District	Annual RF		Annual RD	
	p value	Z-stat	p value	Z-stat
Bagalkot	0.313	0.113	0.351	0.104
Belagavi	0.424	-0.090	0.300	-0.115
Bellary	0.360	0.103	0.234	0.133
Bidar	0.880	0.018	0.408	-0.092
Vijayapura	0.509	0.074	0.024*	0.251
Dharwad	0.206	0.141	0.299	0.116
Gadag	0.004*	0.313	0.008*	0.292
Haveri	0.060	0.208	0.044*	0.225
Kalaburgi	0.991	0.000	0.253	0.127
Koppal	0.790	-0.031	0.288	0.119
Raichur	0.685	0.046	0.333	0.108
Vijayanagara	0.054	0.213	0.027*	0.246
Yadgiri	0.064	0.205	0.172	0.152

*Significant trend at 5%

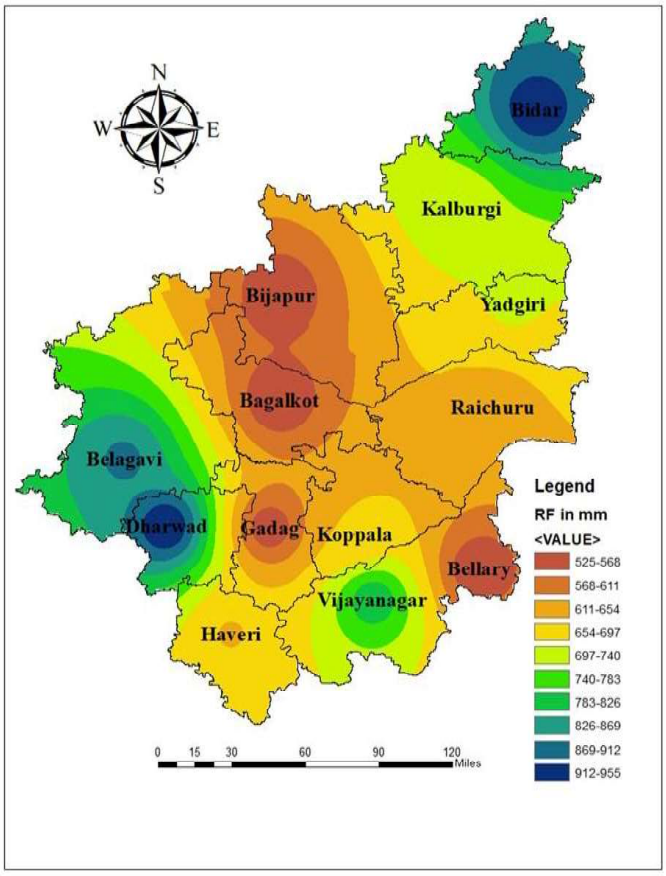

Fig. 5. Spatial variation in annual rainfall (mm) across NIK for historical 40 years (1981-2020)

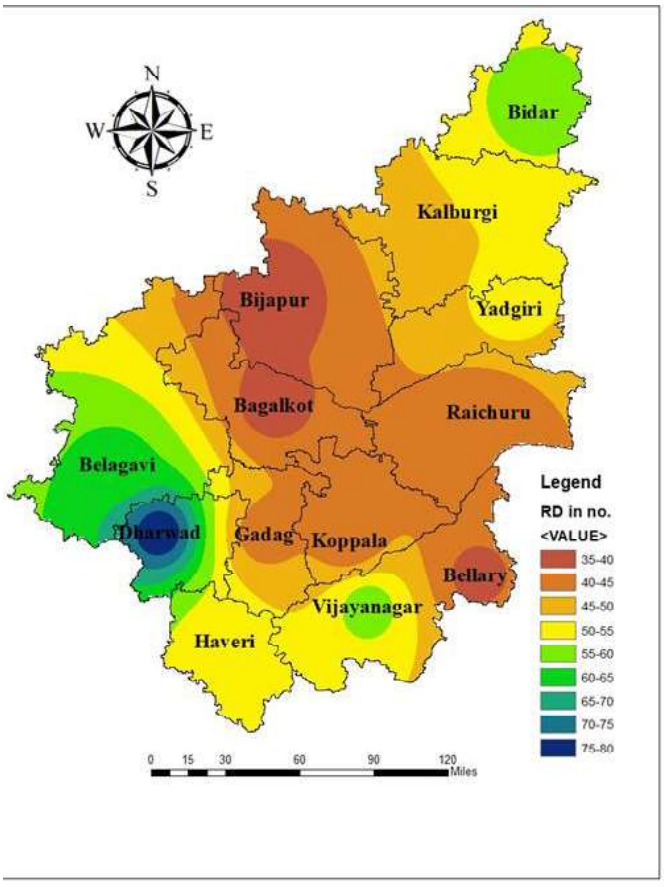

Fig. 6. Spatial variation in annual rainy days(no.) across NIK for historical 40 years (1981-2020)

Annual rainfall and rainy days trend for projected period.

The results of trend analysis by Mann-Kendall test for annual rainfall and rainy days at district level across NIK for the projected 20 years (2021-2040) is shown in Table-6. Here because of coarse resolution (0.5 x 0.5 degree) the values were identical among 13 districts. All 13 districts are expected to show a positive non-significant trend for both rainfall and rainy days at 5 % level.

Variability in annual rainfall and rainy days

During historical period, eight out of 13 districts showed higher variability for annual rainfall (>30 %; Fig. 9), but moderate variability in annual rainy days (Fig. 10). For projected period, expect for Gadag district, all the districts are expected to show lower variability for both annual rainfall (Fig. 11) and rainy days (Fig. 12).

Conclusion

Out of 13 districts of NIK, for historical 40 years, high annual mean rainfall was observed in Dharwad followed by Bidar (> 900 mm) and low annual mean rainfall was observed in Bagalkot, Bijapur and Gadag (< 550 mm) low variability in rainfall was observed in Haveri, Dharwad, Bijapur, Bidar and Belagavi districts, moderate variability was observed in Bagalkot, Bellary,

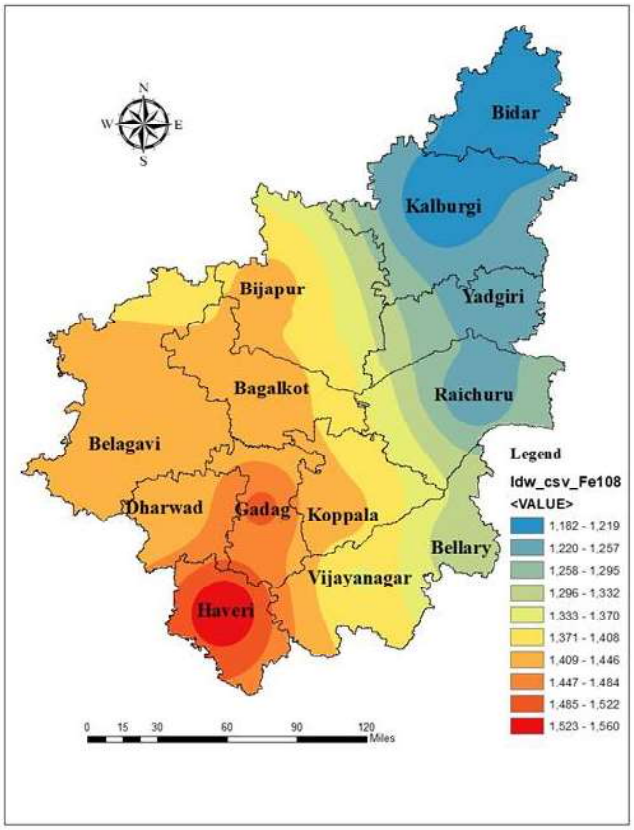

Fig. 7. Spatial variation in annual rainfall (mm) across NIK for the projected 20 years (2021-2040)

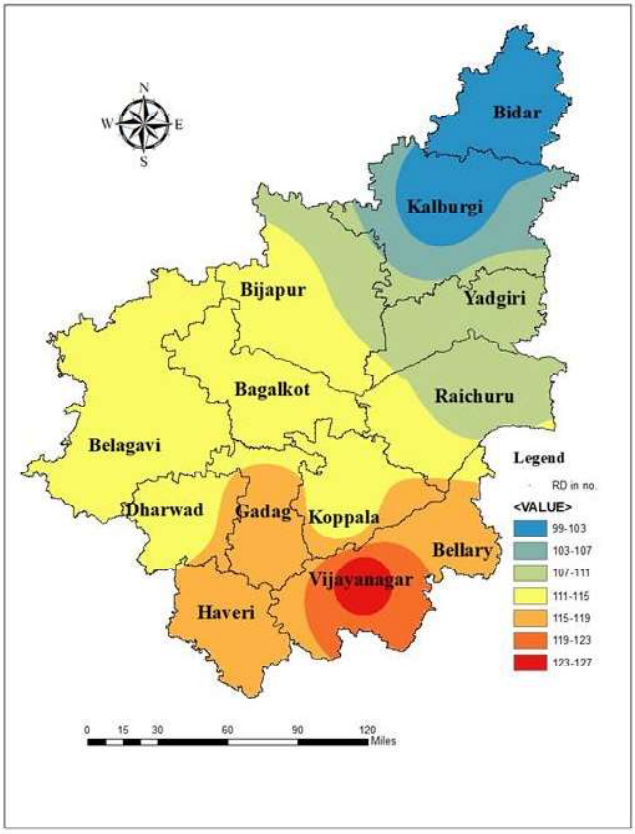

Fig. 8. Spatial variation in annual rainy days(no.) across NIK for the projected 20 years (2021-2040)

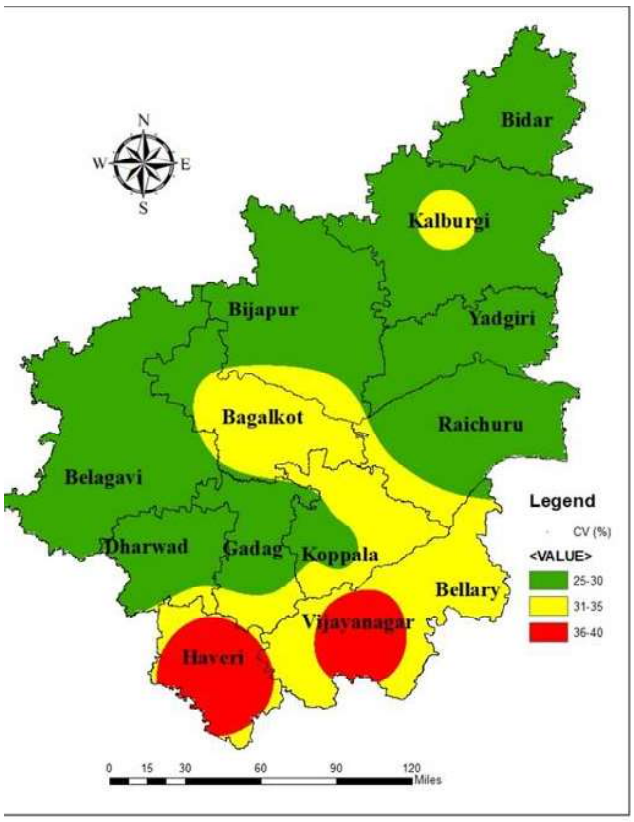

Fig. 9. Annual rainfall variability (%) across NIK for historical 40 years (1981-2020)

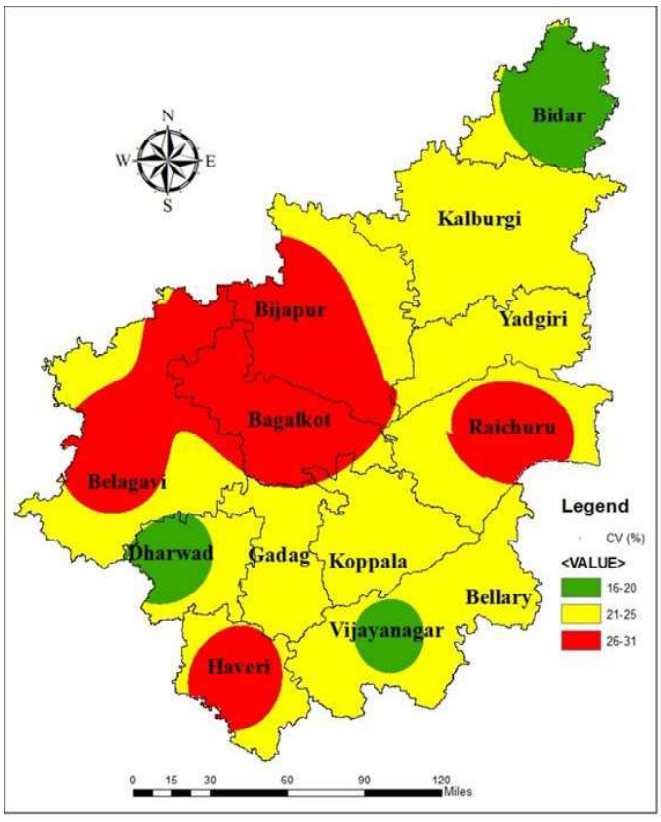

Fig. 10. Annual rainy days variability (%) across NIK for historical 40 years (1981-2020)

Table 6. Trend significance and coefficient for annual rainfall and rainy day at district level across NIK for the projected 20 years (2021-2040).

District	Annual RF		Annual RD	
	p value	Z-stat	p value	Z-stat
Bagalkot	0.351	0.158	0.974	0.005
Belagavi	0.351	0.158	0.974	0.005
Bellary	0.288	0.179	0.283	0.176
Bidar	0.146	0.242	0.602	0.086
Vijayapura	0.351	0.158	0.974	0.005
Dharwad	0.351	0.158	0.974	0.005
Gadag	0.165	0.232	0.673	0.069
Haveri	0.677	0.074	0.649	0.074
Kalaburgi	0.086	0.284	0.328	0.161
Koppal	0.351	0.158	0.974	0.005
Raichur	0.319	0.168	0.721	0.058
Vijayanagara	0.319	0.168	0.922	0.016
Yadgiri	0.319	0.168	0.721	0.058

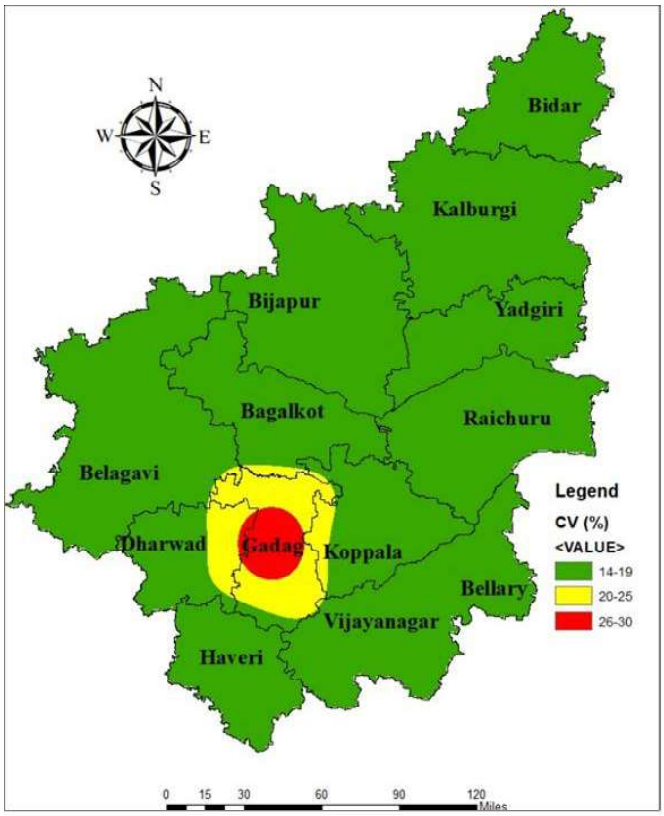

Fig. 11. Annual rainfall variability (%) across NIK for the projected 20 years (2021-2040)

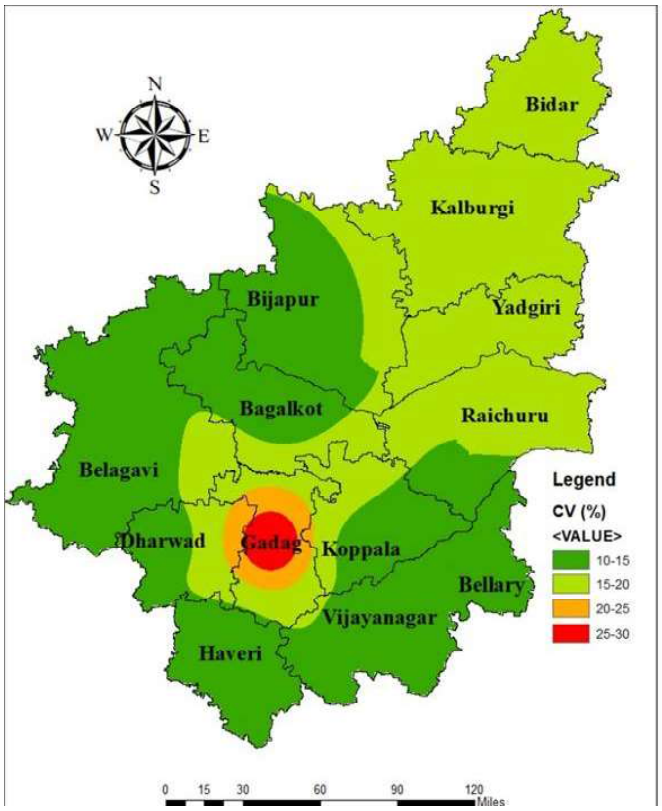

Fig. 12. Annual rainy days variability (%) across NIK for the projected 20 years (2021-2040)

Kalaburgi, Koppal, Raichur, Vijayanagar and Yadgiri districts and more variability was observed in Gadag district. Out of 13 districts of NIK, for historical 40 years a greater number of annual mean rainy days were observed in Dharwad (80) followed by Belagavi (63) and the least annual mean rainy days were observed in Vijayapur (38), Bagalkot (39) and Bellary (41). Out of 13 districts of NIK, for coming 20 years high annual mean rainfall is expected in Haveri district (1559.07 mm) and low annual mean rainfall is expected in Bidar (1183.71 mm) and Kalaburgi (1182.80 mm) districts. Out of 13 districts of NIK, for coming 20 years, a greater number of annual mean rainy days are expected in Vijayanagara district (127) and the least annual mean rainy days are expected in Kalaburgi (99) district and low variability in rainfall is expected in all the districts expect Gadag, which is expected to show moderate variability in coming 20 years. Increasing trend was observed in both rainfall and rainy days during historical period, and increasing trend is also expected for projected period.

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