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Assessment of climate change in different regions of Karnataka state

G. S. SRINIVASA REDDY, N. G. KEERTHY, O. CHALLA*, L. G. K. NAIDU** and R. SRINIVASAN**

Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Government of Karnataka,

Major Sandeep Unnikrishnan Road, Yelahanka, Bengaluru - 560 064, India

**ICAR-National Bureau of Soil Survey & Land Use Planning, Nagpur, India*

***ICAR-National Bureau of Soil Survey & Land Use Planning, Regional Centre, Hebbal, Bangalore - 560 024,*

Karnataka, India Regional Centre, Hebbal, Bengaluru – 560 024, India

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e mail : srinivasan.surya@gmail.com

सार – क्षेत्रीय स्तर पर, जलवायु परिवर्तन का फसल उत्पादकता और खाद्य सुरक्षा पर महत्वपूर्ण प्रभाव पड़ता है। कर्नाटक में 58 वर्षों के जलवायु डेटा (1964-2017) से वर्षा की विशेषताओं, तापमान और आर्द्रता जैसे विभिन्न प्राचलिक सूचकांकों का उपयोग करके एक जलवायु परिवर्तन अध्ययन किया गया। जलवायु अवधि को पूर्व-जलवायु परिवर्तन अवधि - P1 (1964-1990) और जलवायु परिवर्तन अवधि - P2 (1991-2017) में 27 वर्षों में विभाजित किया गया। परिणाम से पता चलता है कि दक्षिण आंतरिक कर्नाटक (SIK) और मलनाड क्षेत्रों में वार्षिक वर्षा और वर्षा के दिन बढ़ गए और उत्तरी आंतरिक कर्नाटक (NIK) और तटीय क्षेत्रों में कम हो गए। दक्षिण कन्नड़, यादगीर, कालाबरुगी, उडुपी और कोडागु जिलों में वर्षा में उल्लेखनीय कमी देखी गई और पी1 से पी2 अवधि के दौरान शिवमोग्गा, हसन, कोलार और चित्रदुर्ग जिलों में वर्षा में वृद्धि देखी गई। मालनाड और तटीय क्षेत्रों की तुलना में NIK और SIK के क्षेत्रों में सूखे की आशंका अधिक है। सूखे की घटनाएं बढ़ रही थीं, तापमान की प्रवृत्ति बढ़ी और पी2 अवधि में सापेक्षिक आर्द्रता की प्रवृत्ति कम हो रही है। पी1 और पी2 में जलवायु परिवर्तनशीलता का आकलन कर्नाटक के विभिन्न क्षेत्रों में पानी, पोषक तत्व और विभिन्न फसल-विशिष्ट प्रबंधन के सटीक उपयोग को अपनाने में मदद करता है।

ABSTRACT. At the regional level, climate change has significant influences on crop productivity and food security. A climate change study was carried out using different parametric indices like rainfall attributes, temperature, and humidity from 58 years of climatic data (1964-2017) in Karnataka. The climatic period was divided into the Pre-climate change period- P1 (1964-1990) and the climate change period- P2 (1991-2017) with 27 years. The result shows annual rainfall and rainy days were increased in South Interior Karnataka (SIK) and Malnad regions and reduced in North Interior Karnataka (NIK) and Coastal regions. Dakshina Kannada, Yadgir, Kalabarugi, Udupi and Kodagu districts showed a significant reduction in receiving rainfall and an increase in Shivamogga, Hassan, Kolar and Chitradurga districts from the P1 to P2 period. NIK and SIK regions are highly prone to drought vulnerability compared to Malnad and Coastal regions. The occurrence of droughts wasincreasing,the temperature trend is increased and the relative humidity trend is decreasing in the P2 period. Assessment of climate variability in P1 and P2 helps to adopt preciseuse of water, nutrient and different crop-specific management in different zones of Karnataka.

Key words – Climate change, Rainfall, Vulnerability, SIK and NIK regions, Karnataka.

1. Introduction

Climate change is one of the substantial challenges facing the world today. Climate change is an ongoing event and over the years, the atmosphere factors have changed extensively around the world. However, in recent years, regular change in climatic factors and their impacts are of more concern (Mall *et al*., 2006). Climate change and factors are very difficult to assess at the small-scale level in like taluk or district of any state (Kumar and Parikh, 2001; Raju *et al*., 2017). Different agriculture operations are directly linked to climatic factors and crop

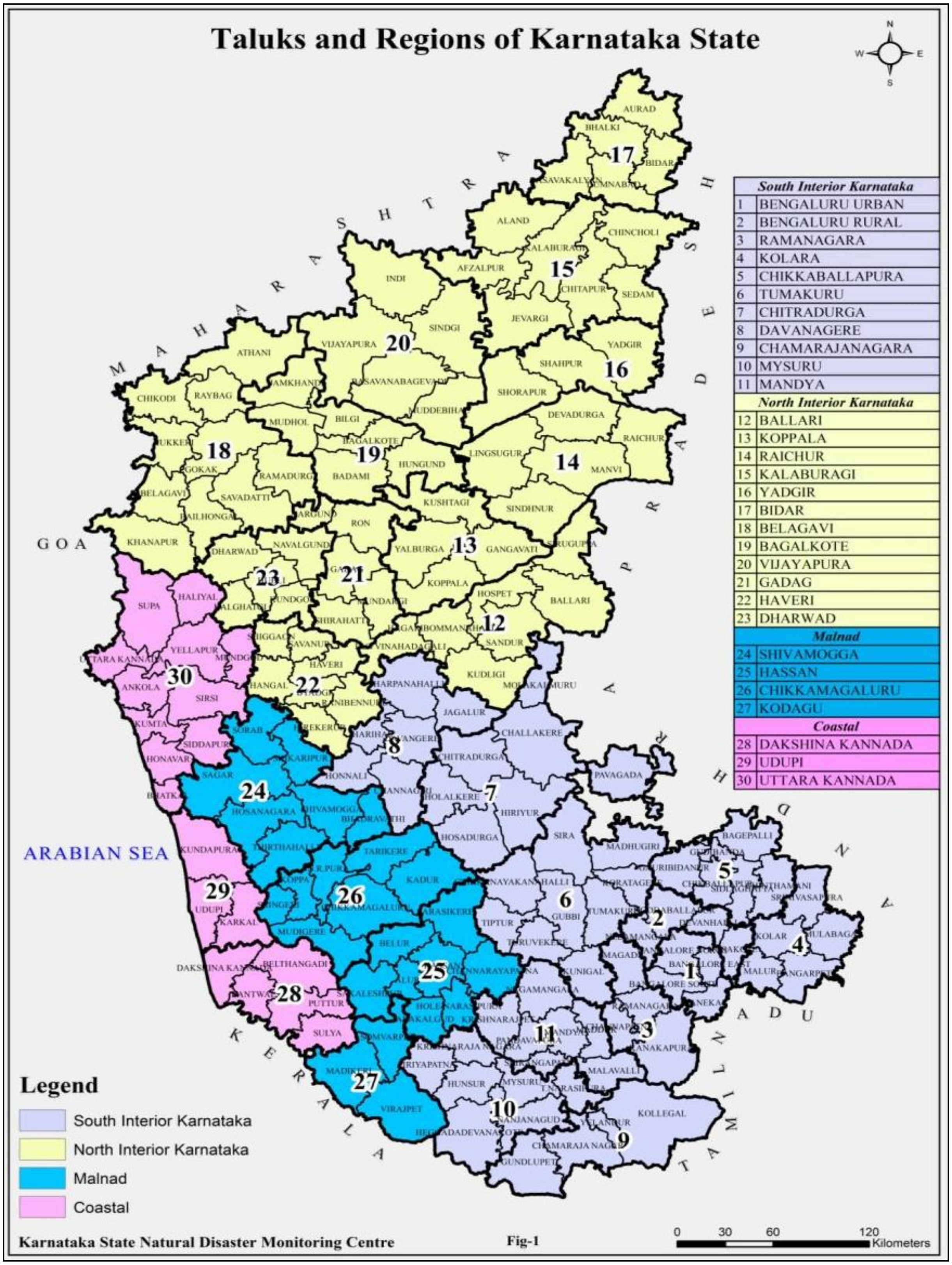

Fig. 1. Location map and different Taluks and regions of Karnataka state

productivity. Understanding global and regional level climate change will help to quantifythe food production and livelihood security of people. It's evidenced that vulnerability to climate change is closely related to poverty as the poor are least able to respond to climatic variation (Shankara *et al*., 2013).

The effect of global warming and its extent across India are widespread and challenged. Climate change is affecting India comprehensively and its impacts are many and serious such as erratic monsoon, changes in agricultural zones, the spread of tropical diseases, sea-level rise, change in availability of freshwater, floods, droughts, heatwaves, storms, hurricanes, *etc*. Some studies have shown that climate change effects have already been observed in India, with pieces of evidence showing an increase of 0.4-0.6 °C in the past 100 years (Bhattacharya *et al*., 2007). Increasing trends in annual mean temperature and more marked warming during post-monsoon and winter have also been observed (Cruz *et al*., 2007). For India, the IPCC (2007) report projected an increase of 2.7-4.3 °C in temperature by the 2080s, an increase in rainfall of 6-8%, and a sea-level rise of 88 cm by 2100. There is a high likelihood that the projected scenario will have far-reaching, dramatic, and detrimental consequences for the livelihood and possibly for survival of rural communities that depend on agriculture, fisheries and animal husbandry.

The rise in average annual temperature by 1.3 °C in Karnataka from 1950 to 1990 has been observed. The mean annual rainfall trend from 1901 to 2000 has been reported as declining. There is a definite declining trend in rainfall in Kodagu, Chikmagalur and South Karnataka districts from 1950 to 2006 and Bangalore, Tumkur and Kolar districts have shown a considerable increasing trend in the annual rainfall (Sanjeevaiah *et al*., 2021). Karnataka is the eighth major State in India and the second most vulnerable State to be impacted by climate change, as North Karnataka regions have the arid and driest areas (BCCI, 2011). Agriculture is a crucial sector for Karnataka, where over 50% of the population's income comes from agriculture and more than 80% of the farms are rainfed. Recent study by KSNDMC (2020) reported that occurrence of natural disasters like drought, floods, hail storms, cyclone, landslide, heat wave, thunder storms and lightening are frequently observed in recent climate change period. The variation of climate might play an important role in farmers' livelihood security and to maintain the farmers' productivity, hence the importance to understand the current climate variability. Apart from these, experiencing intense extreme events like heat and cold waves, droughts and floods may become the norm of the day for the farming community (IPCC, 2007).

Climate change will have a marked influence on agriculture at the regional and national level. The potential impacts are seen in shifting sowing time and length of growing seasons, which may necessitate an adjustment in sowing and harvesting windows, change in genetic traits of cultivars and sometimes total adjustment of the cropping system itself. A warmer environment coupled with erratic rainfall distribution results in a higher rate of evaporation and depletion of soil moisture. Hence, sustaining crop productivity efforts should be made to enhance the water and nutrient efficiencies by adopting resilient management practices. With unpredictable weather, farmers keep changing crop management practices by seed rate, summer ploughing, adapting resistant varieties, water and nutrient management. Mendelsohn *et al*. (2000) suggested that adaptation was estimated to reduce the potential damages from climate change from 15 to 25% in Indian farming. The impacts of climate change are diversified and need to be understood to workout pragmatic strategies to mitigate the ill effects of climate change (Chandrakanth, 2015). Information on the spatial and temporal variability of climatic parameters especially rainfall is very important in understanding the hydrological balance on a regional scale. The distribution of rainfall is also important for water management in agriculture, power generation and droughtmonitoring. It often involves a combination of various individual responses at the farmlevel and assumes that farmers have access to alternative practices and technologies available to different regions of Karnataka to overcome the climate changes (Shashidahra and Reddy, 2012). In this background, we have attempted to the assessment of climate change in different regions, *viz*., NIK, SIK, Malnad and coastal Karnataka towards the identification of prioritization of districts for designing region-specific plans to address the growing challenges of climate change.

2. Methodology

2.1. *Study area*

Karnataka state is geographically situated between 11.50 - 18.50° N Latitude and 74.25- 78.50° E Longitude with a 19.1 M ha area. The state comprises 30 administrative districts, which are further divided into 176 Taluks (Fig. 1). It has four major regions namely (*i*) North Interior Karnataka (NIK), (*ii*) South Interior Karnataka (SIK), (*iii*) Malanad region and (*iv*) Coastal regions.

2.2. *Climate conditions*

Karnataka State experiences variable climatic types, *viz*., Central, Southern and Northern parts have semi-arid to arid, while Malnad and coastal regions have subhumid to humid climatic conditions. Rainfall in the state varied

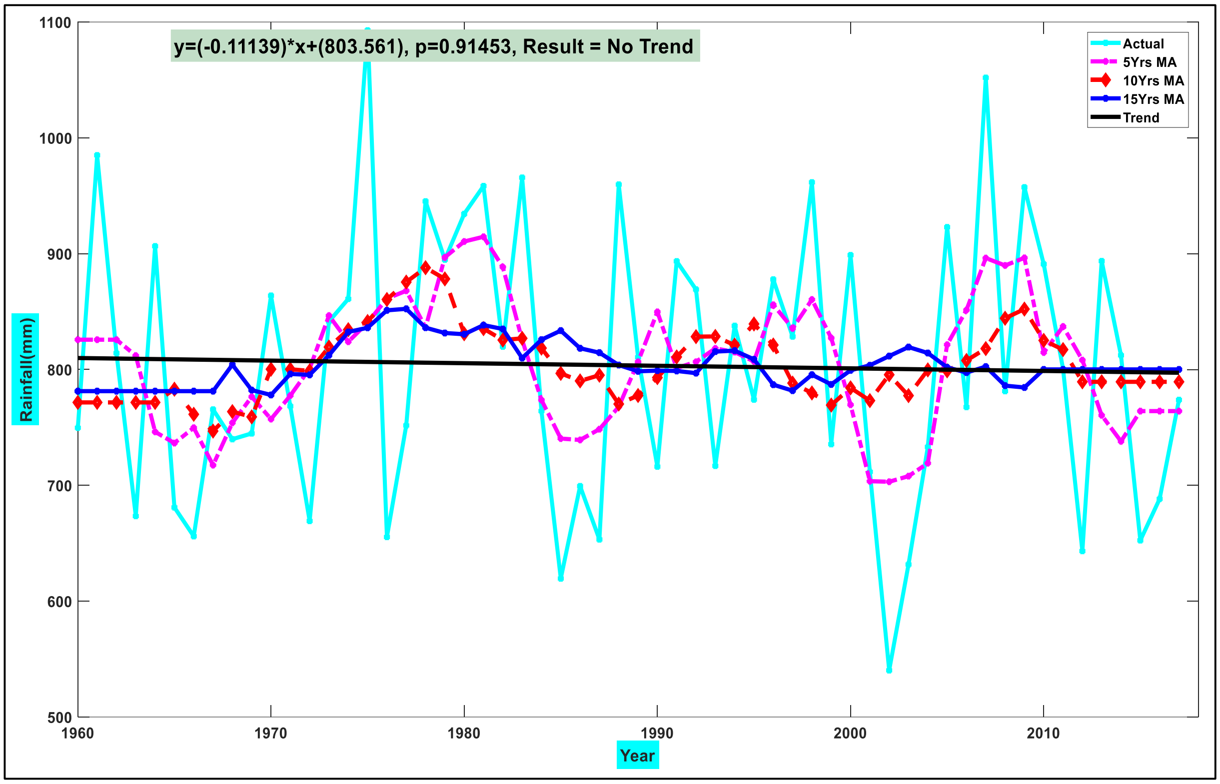

Fig. 2. State Rainfall Pattern and Moving Average (1960-2017) for Southwest Monsoon Rainfall (mm)

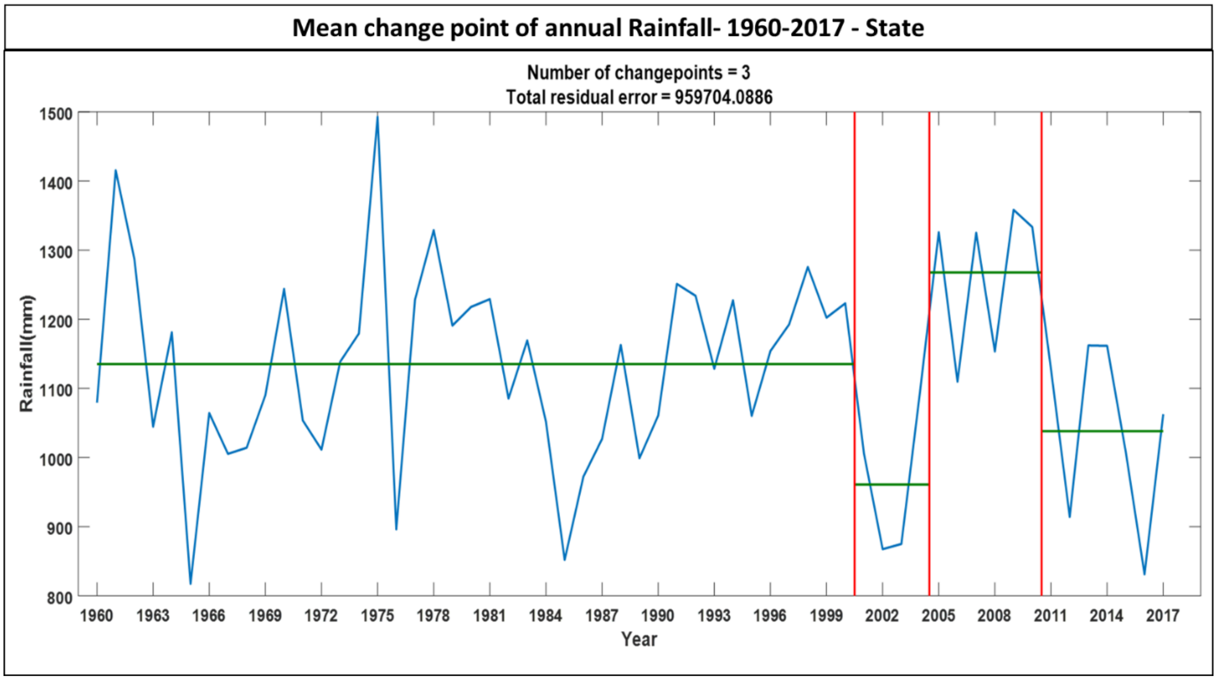

Fig. 3. Mean change point at the state level

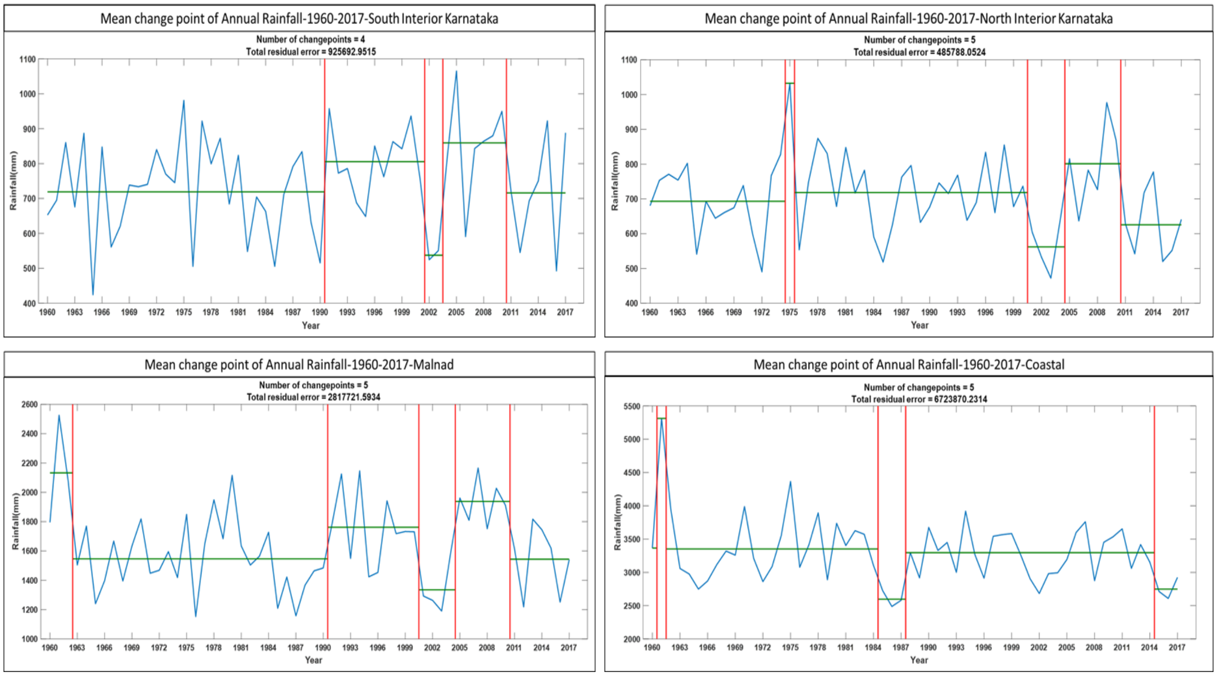

Fig. 4. Climate change points at the regional level in Karnataka

from as low as 477 mm (Challakare in Chitradurga district) to the highest of 5051 mm (Karkala in Udipi district). The major part of the state receives less than 750 mm annual rainfall. Temperatures in the state vary from 23 °C to 43 °C in summer and 9 °C to 27 °C in winter seasons.

2.3. *Land use and crops*

A total geographical area is 19.1 million hectares area with 10.5 million hectares as net cultivated and 7.8 million landholdings of 1.55 ha area. The small and marginal holdings account for 76% of the total holdings in the state which occupy about 40% of the operated area (DES, 2012). Of the total cultivated area, the net irrigated area is about 4.09 million hectares (33%) and the net rainfed cultivated area is about 6.41 million hectares. Karnataka state has three cropping seasons namely (*i*) *Kharif* (6.92 M ha), (*ii*) *Rabi* (3.03M ha) and (*iii*) Summer (0.59 M ha). Among the crops, cereals (49%), pulses (24%), oilseeds (15%), cotton (6%), sugarcane (5%), and tobacco (1%) occupy the major area in the state. About 2.1 Mha (17%) of the cultivated area is occupied by different horticultural crops such as Mango, Banana, Pomegranate, Papaya, Vegetables, and Plantation crops like Coconut, Arecanut, Coffee, Cardamom and Pepper.

2.4. *Climatic analysis*

Karnataka State Natural Disaster Monitoring Centre (KSNDMC) institute records climatic parameters and monitors natural disasters occurring in the state. Rainfall datahave been analyzed for various parameters, *viz.*, change in rainfall amount, coefficient of variation (CV), rainy days, the intensity of rainfall (rainfall events), onset and withdrawal of monsoon, below normal years, patten of drought occurrence, temperature and relative humidity trend. Different climatic parameter data was used in the identification of climate change point detection over the years. Daily rainfall data is further converted into weekly, monthly, seasonal and annual data. Further normal rainfall was calculated by averaging over the years of long-period data for the districts, regions and states.

Onset and withdrawal of rainy season (June - September) were computed from weekly rainfall data by forward and backward accumulation methods respectively. In this method,weekly rainfall was summed by forwarding accumulation (20+21+…+52 weeks) until a certain amount of rainfall was accumulated. Seventy five millimeters of rainfall accumulation has been considered as the onset time for the growing season of rainfed crops and land preparation. The withdrawal of the rainy season was determined by the backward accumulation of rainfall (48+47+46+…+30 weeks) data. Twenty millimeters of rainfall accumulation was chosen for the end of the rainy season, which is sufficient for ploughing fields after harvesting the crops. The 58 (1960 to 2017) years of rainfall data have been used to find out significant change or mean change point of rainfall. Mean change points were computed by using the Matlab software.

TABLE 1

Change in amount of rainfall in different districts, regions and state

S. No.	District	Southwest Monsoon Rainfall (mm)		Change(mm)	Change (%)
		*P1	*P2		
1.	Bengaluru Urban	465	501	36	8
2.	Bengaluru Rural	453	455	2	0
3.	Ramanagara	434	454	20	5
4.	Kolar	367	417	50	13
5.	Chikkaballapura	394	410	16	4
6.	Tumkuru	382	406	24	6
7.	Chitradurga	280	325	45	16
8.	Davanagere	372	398	26	7
9.	Chamarajanagara	328	306	-22	7
10.	Mysuru	345	375	30	9
11.	Mandya	312	328	16	5
12.	Bellari	388	376	-12	3
13.	Koppala	381	377	-4	1
14.	Raichur	472	430	-42	9
15.	Kalaburgai	642	530	**-112**	**18**
16.	Yadgir	658	502	**-156**	**24**
17.	Bidar	616	642	26	4
18.	Belagavi	547	551	4	1
19.	Bagalkote*	371	341	-30	8
20.	Vijayapura	439	395	-44	10
21.	Gadag	366	347	-19	5
22.	Haveri	479	485	6	1
23.	Dharwad	486	466	-20	4
24.	Shivamogga	1365	1480	**115**	**8**
25.	Hassan	590	651	**61**	**10**
26.	Chikkamagalur	1441	1445	4	0
27.	Kodagu	2141	2054	-87	4
28.	Dakshina Kannada	3444	3085	**-359**	**10**
29.	Udupi	3631	3512	-119	3
30.	Uttara Kannada	2476	2441	-35	1
Region & State					
31.	SIK	367	390	23	6
32.	NIK	488	460	-28	6
33.	Malnad	1232	1281	49	4
34.	Coastal	2915	2783	-132	5
35.	State	805	802	-3	0

*P1-Period-1(1964-1990) 27 years; *P2-Period-2 (1991-2017) 27 yearsBold values are 90% significant

TABLE 2

Change in number of rainy days in selected taluks of different regions and state from P1 to P2

Taluk/ region	Pre-Monsoon			Southwest Monsoon			Northeast Monsoon			Annual		
	P1	P2	Change	P1	P2	Change	P1	P2	Change	P1	P2	Change
Challakere (SIK)	5	7	2	15	18	4	7	9	2	28	34	6
Vijayapura (NIK)	6	6	0	27	25	-3	8	8	0	41	38	-3
Shivamogga (Malnad)	8	8	0	46	51	5	10	11	1	64	70	6
Udupi (Coastal)	7	9	2	93	94	1	12	14	2	111	117	6
State	9	9	0	39	40	1	10	10	0	59	58	-1

The total period of 58 years is divided into two periods for finding the climate change pattern. For the sake of an equal number of years in each period, the total period has been divided into Period-1 (P1) from 1964-1990 and Period-2 (P2) from 1991-2017 (each period has 27 years). To knowthe change in the mean rainfall, the mean rainfall of P2 is subtracted from that of P1 and expressed as a percentage change. Further, the mean rainfall changes in P1 and P2 are statistically tested for significance using a *t*-test. The statistical *p*-value is calculated from the test in Matlab software and the '*p*' values are categorized into (*i*) 90% significantly increasing, (*ii*) 90% significantly decreasing and (*iii*) insignificant based on *p*-value at a 10% level of significance.

The percent of coefficient of variation (CV) is calculated for all the taluks and between the two periods (P1 and P2). For studying different trends of temperature and relative humidity, average values of district temperature and relative humidity data for the period of 2002-2018 were considered. For finding the magnitude of change, a linear equation of the following form has been used.

$$y = bx + c$$

where 'y' is a dependent parameter and 'b' is the slope, 'x' is the independent data series and 'c' is the constant. The slope b is calculated in excel by fitting the linear trend method. The slope represents the magnitude change per year. From negative or positive 'b', it can be classified as an increasing and decreasing trend in temperature and relative humidity over the years.

3. Results and discussion

3.1. *Climate change point detection*

In Karnataka, South West Monsoon rainfall distribution moving from 1960 to 2017 is shown in Fig. 2. Results show no definite trend, except with some peaks showing aberrant rainfall in some years beyond normal. Fig. 3 indicated the mean change point of state rainfall observed in the year 2002 and normal rainfall observed from 2005 to 2011. Fig. 4 indicated that SIK and Malnad regions showed a mean change point of rainfall during 1991, while the Coastal region showed 1988. For NIK the change point is seen in 2002. Hence, the year 1990 has been considered the mean change point year for climate change. The above findings are in line with Shanabhoga *et al*. (2019).

3.2. *Changing Rainfall pattern and amount*

Change in rainfall pattern in different districts, regions, and overall state was presented in Table 1. Southwest West Monsoon (SWM) rainfall (mm) was assessed districts wise in P1 and P2, with rainfall reduction of -156 mm in Yadgir district accounting for 24% indicating a significant reduction. In receiving rainfall, which showed a loss of the high amount of rainfall, similarly in other districts of Kalaburgai (18%), and Dakshina Kannada (10%) a reduction in rainfall was observed. Positive effect was observed by receiving higher amount of 8% more rainfall (115 mm) from P1 to P2 in Shivamogga. Similarly, Hassan district 61 mm and 10% change. The region-wise rainfall gain was in SIK (23 mm) and Malanad (49 mm) from P1 to P2, whereas NIK (-28 mm) and coastal (-132 mm) regions witnessed decreasing trends. The overall state showed -3 mm from P1 to P2.

3.3. *Change in Rainy days*

It is evident from Table 2 that the average annual rainy days showed an increase for Challakere (28 to 34), Shivamogga (65 to 72), Udupi (114 to 119), whereas Vijayapura taluk showed 3 days decrease (42 to 39). At the state level, there is no change in the number of rainy days. Many taluks in the state showed an increase in rainy

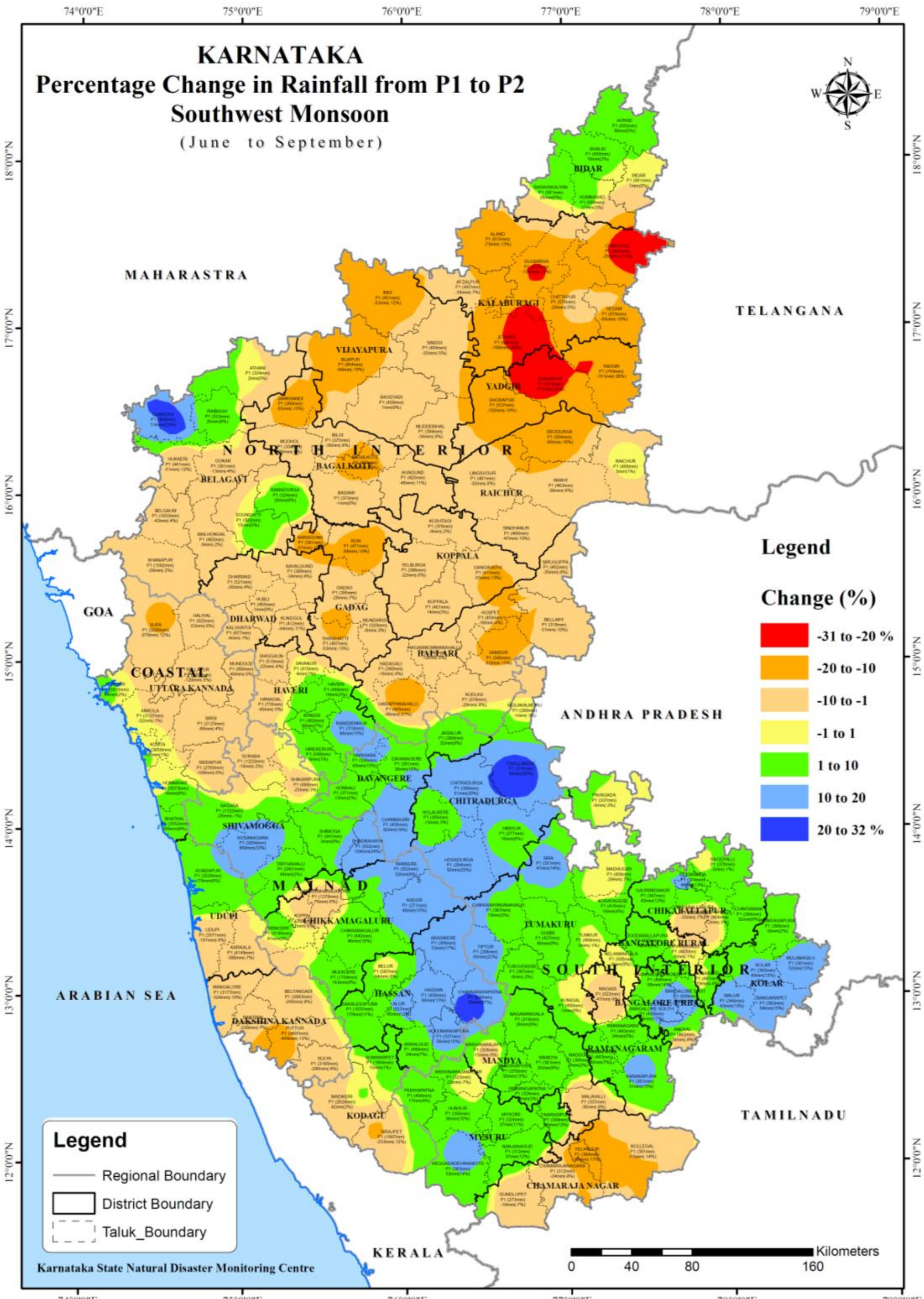

Fig. 5. Percentage change in the Southwest Monsoon Rainfall from P1 to P2

days during the pre-monsoon season. During pre-monsoon two daysincreasing in SIK area (Challakere) and oneday in coastal area (Udupi) from P1 to P2, whereas in Southwest monsoon positive change in rainy days observed in SIK (4), Malnad(6), coastal (1), negative in NIK (-2). Northeast monsoon positive changes from P1 to P2 in all regions, high in the coastal region. Annual change inthe number of rainy days was positive in SIK

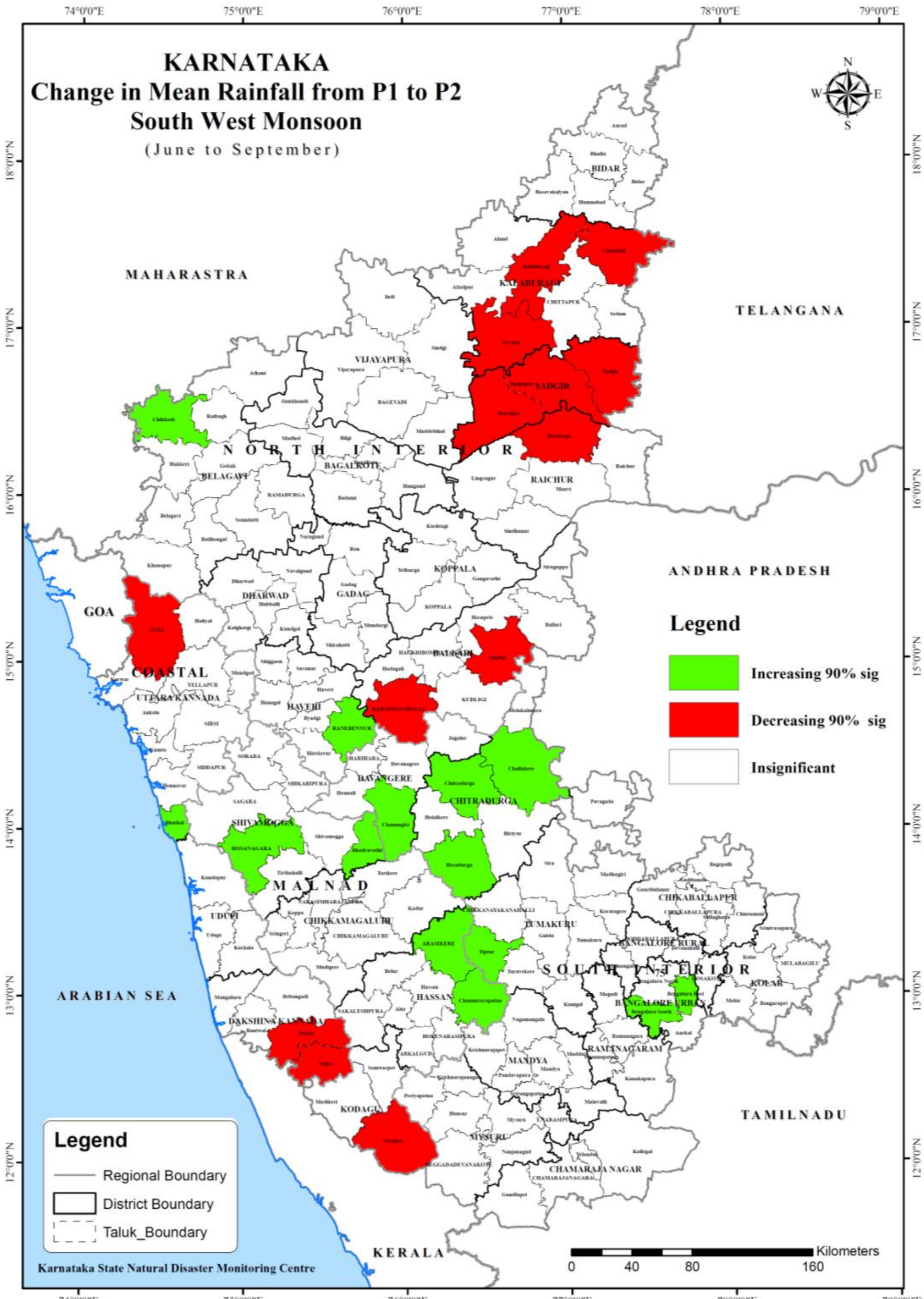

Fig. 6. Change (90% significance) in the SWMonsoon rainfall (mm) from P1 to P2

(7), Malnad (7), coastal (5), and negative in NIK (-3), the overall state was losing one rainy day. The SWM seasonal rainfall (mm) has varied in the state from P1 to P2 (Fig. 5). SIK and Malanad regions showed an increase in the amount of rainfall and the majority of the taluks in NIK and Coastal regions shows a decrease in the amount of rainfall from P1to P2. The significant change in the SWM rainfall from P1 to P2 taluks is given in Fig. 6.

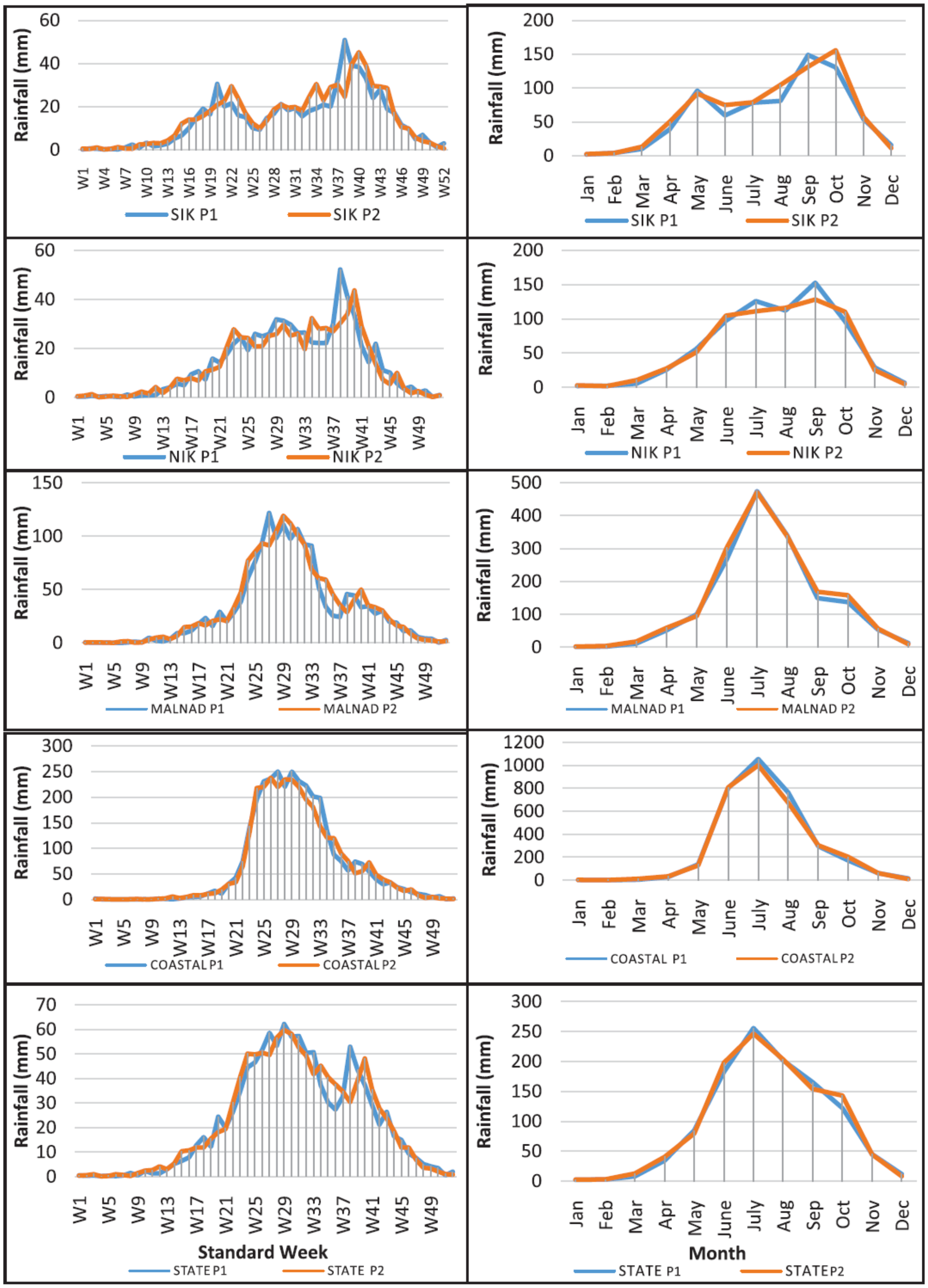

Fig. 7. Weekly and monthly mean rainfall patterns for P1 and P2

3.4. *Weekly and Monthly mean Rainfall*

The State level weekly mean rainfall pattern is represented in Fig. 7. The result shows a considerable decrease in the 38th week from P1 to P2. Whereas the monthly mean rainfall of the state shows an increase during June and October. The region-wise weekly mean rainfall pattern shows that the SIK region showed a decrease in weekly rainfall in the 38th week, while the monthly rainfall shows an increase in all the months

TABLE 3

Change in Onset & Withdrawal of rainfall in different regions and state (P1 & P2)

Region	P1-Std Week		P2-Std Week	
	Onset	Withdrawal	Onset	Withdrawal
SIK	24	45	23	45
NIK	25	44	24	42
Malnad	24	45	24	44
Coastal	24	45	23	45
State	24	45	24	44

Dry spell pattern (>=3 weeks)

TABLE 4

Number of droughts declared taluks during Kharif Season (2001-2018)

Region\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
SIK	7	63	63	17	nil	63	nil	14	41	nil	51	63	51	25	49	63	nil	45
NIK	10	69	69	58	nil	58	nil	66	45	nil	65	68	61	7	68	52	nil	51
Malnad	10	22	25	5	nil	8	nil	4	0	nil	7	22	10	2	13	20	nil	4
Coastal	6	5	5	0	nil	0	nil	0	0	nil	0	4	3	0	6	4	nil	0
Total	33	159	162	80	nil	129	nil	84	86	nil	123	157	125	34	136	139	nil	100

except September. Further, the SW-Monsoon (SWM) and Annual rainfall also show an increase in the SIK region from P1 to P2. The NIK region shows a rainfall decrease in the 38th week and the monthly rainfall also decreased in July and September. The amount SW-Monsoon annual rainfall, also shows a decreasing trend in the region from P1 to P2. In the Malnad region, a decrease in weekly mean rainfall is observed in the 27th and 33rd weeks, while the 35th and 36th weeks show an increasing trend in the region. The mean SW-Monsoon annual rainfall show an increase from P1 to P2. In the Coastal region, mean weekly rainfall showed a decreasing trend from the P1 to P2 period. The SW-Monsoon and annual rainfall also show a decreasing trend. All four regions in Karnataka state as a whole showed a decrease in weekly rainfall in the 38th week, the standard week indicating a clear-cutshift in the weekly rainfall pattern from the P1 to P2 period.

3.5. *Change inmonsoon onset and withdrawal weeks*

It's observed that the onset of the Southwest monsoon indicatedan early onset by one week in the SIK region (from std week 24 to 23), Coastal region (from std week 24 to 23) and NIK region (from 25 to 24), while no change is observed in the onset of the SWM in Malnad region (std week 24). In case of withdrawal, the NIK region showed 2 weeks early (from std week 44 to 42), one week early in the Malnad region (from std week 45 to 44) and it remained the same in SIK and Coastal regions (Std week 45). Overall, Karnataka showed a marginal change in the onset and withdrawal patternin SWM (Table 3).

3.6. *Occurrence of drought*

Karnataka is the most drought-prone state after Rajasthan in India. Nearly 80% of taluks in the state are drought-prone. In the last two decades, Karnataka experienced a drought of different severity patterns. The total number of taluks and the percentageof total taluks affected by drought from 2001 to 2010 and 2011 to 2018 are compiled in Table 4. From 2001-2010 about 105 Taluks on an average (59%) are affected by drought in all the regions. In recent times during 2011-2018 on average, 116 Taluks (66%) are affected by drought. It shows that on average increase (7%) in the number of drought affected taluks within 8 years in the state indicating high vulnerability. Among the regions, NIK showed the highest average number of taluks (54) prone to drought in both 2001-2010 and 2011-2018 (53) while the Coastal region is the least prone to drought. Percent of drought-affected

TABLE 5

List of tropical cyclones developed in Arabian Sea since 2011

Year	Name of the cyclone	Duration
2011	Keila	29 Oct – 4 Nov
2012	Murjan	23 Oct – 26 Oct
2013	Nanauk	11 Jun – 14 Jun
2014	Nilofar	25 Oct – 4 Nov
2015	Chapala megh	28 Oct – 4 Nov
		5 Nov – 10 Nov
2018	sogon	16 May – 20 may
2018	Luban	6 Oct – 15 Oct
2019	Vayu	10 Jun – 17 Jun
	Hikka	22 Sept – 25 Sept
	Moha	30 Oct – 7 Nov
	Pawan	4 Dec – 7 Dec
2020	Nisarga	1 Jun – 3 Jun

(*Source* : KSNDMC-2020)

Taluks in different regions during 2001-2010 follows in the order: NIK (78%) > SIK (61%) >Malnad (42%) >Coastal (12%) region. Whereas during 2011-18 period, drought occurrence pattern showed increasing order of SIK (79%) > NIK (77%) >Malnad (45%) >Coastal (13%). SIK region showed a significant increase (61 to 79 taluks) in drought decreased taluks, in 2011-2018 as compared to 2001-2010. The result observed (Table 4) from 10 years (2001-2010) indicated 7 years of drought, whereas, in the recent period (2011 to 2018) also, the result showed 7 years as drought years. Over all it indicates that Karnataka state drought vulnerability is increasing in the recent period.

3.7. *Floods*

Floods are another kind of disaster causing huge loss of life property damage and crop failures resulting in social and economic losses to individuals and the state of India. Karnataka experienced severe floods in 2005, 2009, 2018 and 2019. Flood occurrence was not frequent during the pre-climate change (P1) period.

3.8. *Cyclones*

Karnataka state has about 320 km of Coastal line in western part bordering to Arabian Sea. Historically, the state has not experienced any major cyclone event, but in recent decade the frequency of cyclonic storms in the Arabian Sea has increased (Table 5). There were about 16 cyclone storms developed in Arabian Sea in last 10 years, in which 5 of them were in 2019 and 1 in 2020. In addition to these, there were about 24 cyclones recorded during the same period (2011 to 2020) from Bay of Bengal. KSNDMC has been issuing early warning system the connecting roads to nearest highways, bridges, saline embankments are also built in vulnerable areas along with shelters with basic amenities.

TABLE 6

Heat wave events in Karnataka 2017-2018

District	Taluk	Location	Date	Temperature (°C)
District wise heat waves events in 2017				
Bagalkote	Jamkhandi	Jamakhandi	20-04-17	45.3
Ballari	Siruguppa	Tekkalakote	24-05-17	45.3
Belagavi	Raibagh	Kudchi	19-04-17	43.3
Bidar	Bidar	Bidar south	06-05-17	44.1
Chitradurga	Molakalmuru	Devasamudra	19-04-17	42.9
Davanagere	Davanagere	Davangere	14-04-17	42.5
Dharwad	Hubballi	Chabbi	19-04-17	42.1
Gadag	Ron	Hole alur	16-04-17	42.8
Haveri	Savanur	Savanur	28-04-17	42.9
Kalaburagi	Jevargi	Nelogi	24-05-17	45.1
Koppala	Koppala	Hitnal	05-03-17	41.8
Raichur	Sindhanur	Turvihal	28-03-17	43.6
Vijayapura	Sindgi	Sindhagi	17-04-17	44
Yadgir	Yadgir	Saidapur	25-05-17	45.3
District wiseheat waves eventsin 2018				
Bagalkote	Chittapur	Chittapur	03-05-18	42.9
Ballari	Ballari	Ballari	25-04-18	44.7
Belagavi	Raibagh	Kudchi	28-04-18	41.6
Bidar	Bhalki	Lakangaon	03-05-18	44.4
Chitradurga	Challakere	Parasurampura	19-04-18	42.5
Davanagere	Harihara	Harihara	03-04-18	43.1
Dharwad	Hubballi	Chabbi	24-04-18	41.8
Gadag	Mundargi	Dambal	20-04-18	41.4
Haveri	Hanagal	Bommanhalli	25-04-18	40.9
Kalaburagi	Chittapur	Chittapur	30-04-18	45.3
Koppala	Gangavathi	Marali	23-04-18	43
Raichur	Sindhanur	Sindhanur	22-04-18	43.7
Vijayapura	Sindgi	Sindhagi	30-04-18	43.8
Yadgir	Yadgir	Hattikuni	02-05-18	45

(*Source* : KSNDMC, 2020)

TABLE 7

Year wise number of deaths due to lightning in Karnataka (2009 to 2019)

Years	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Deaths	132	64	93	27	36	8	96	64	108	134

(*Source*: KSNDMC, 2020)

3.9. *Landslides*

High-intensity rainfall (>300 mm in 24 hrs) triggered landslides in steeply sloping hillyareas of the Malanad region. Regular landslides cause damage to roads, bridges, settlements and extensive losses to high-value plantation crops, *i.e*., coffee, pepper, and cardamom. Landslides cause entire fertile top soil washed away and trees are uprooted in 2018, many districts *i.e*.,Kodagu, Hassan, Chikkamongalur, Shimogga, Belgaum, Dharwad and Dakshina Kannada districts experienced severe floods and landslides during the SW monsoon period in 2018.

3.10. *Heat waves*

Heat waveis a period of abnormally high temperature more than the normal maximum temperature that occur during summer season especially between March to May. Extreme temperature and resultant atmospheric conditions adversely affect people as they cause Physiological stress and sometimes even death (Table 6). Large part of Karnataka state has arid to semi-arid climate causing heat waves conditions particularly in North interior Karnataka during 2014 to 2019 (KSNDMC-2020). KSNDMC has been issuing heat wave bulletins for the vulnerable district (NIK) to protect the people. Very high temperature (>45 °C) Recorded in Kalburgi, Bagalkote, Yadgir, Ballari moderately high temperature (42 to 45 °C) in Raichur, Vijayapura, Chitradurga, Belgavi, Davangere, Bidar, Haveri, Gadag and Dharwad. High temperature (40 to 42 °C) Usually recorded in Koppal and Chamarajnagar.

3.11. *Lightning*

It is a sudden electrostatic discharge that occur during a Thunder Storm which discharge huge amount of energy (about 1 billion joules) causing a loss of human life and livestock and property every year in the state (Table 7). KSNDMC has installed a lightning detection sensors network in the state and providing lightning strike related early warnings to the community through audio visual clips explaining the impact of lightning strikes and related safety measures and are being made available to public through mass media.

TABLE 8

District with high rainfall deviations (Gain/reduction)

District	Region	Annual Rain(mm)		Deviation	Change (%)
		P1	P2		
Gain					
Bengaluru Urban	SIK	836	943	107	13
Kolar		715	841	126	18
Chitradurga		533	638	105	20
Shivamogga	Malanad	1595	1761	166	10
Hassan		951	1058	107	11
Reduction					
Kalaburgi	NIK	830	729	-101	-12
Yadgir		872	730	-142	-16
Dakshina Kannada	Coastal	3901	3712	-189	-5

3.12. *Climate change induced high rainfall Deviations*

The districts namely Bengaluru (Urban), Kolar, Chitradurga (SIK), Shivamogga and Hassan (Malanad) showed increase in annual rainfall (Gain) in P2 Period. On the contrary, Kalaburgi, Yadgiri (NIK) and Dakshina Kannada (Costal region) districts recorded reduction in annual rainfall in recent climate period (P2). Among the district, high amount of rainfall gain recorded in Shivamogga (166 mm) followed by Kolar (126 mm), Bengaluru urban and Hassan (107 mm) and Chitradurga (105 mm) with percentage variation ranging from 10 to 20%. On the other hand Dakshina Kannada district reported high reduction (189 mm) followed by Yadgir (142 mm) and Kalaburgi (101 mm). The percent reduction was high in Yadgiri (16%) followed by Kalaburgi (12%) and Dakshina Kannada (5%) (Table 8).

3.13. *Climate change aberrations and relavant mitigation masures*

In low rainfall areas (<650 mm), *viz*., Bagalkote, Raichur, Koppala, Ballari, Vijayapura, Gadog, Chitradurga districts, 2 weeks early withdrawal result in drastic reduction in length of growing period during *kharif* season. For such area short duration millets and pulses are recommended to overcome the shortening growing period. Medium rainfall areas (650-750 mm), *viz*., Yadgir and Kalaburgi districts, medium duration cereals/ pulses and commercial crops are recommended. Appropriate soil and water conservation measures are to be adopted. In high rainfall (gain) areas (>750 mm), *viz*., Bangalore, Ramnagara, Kolar, Mysore districts, there is lot of scope

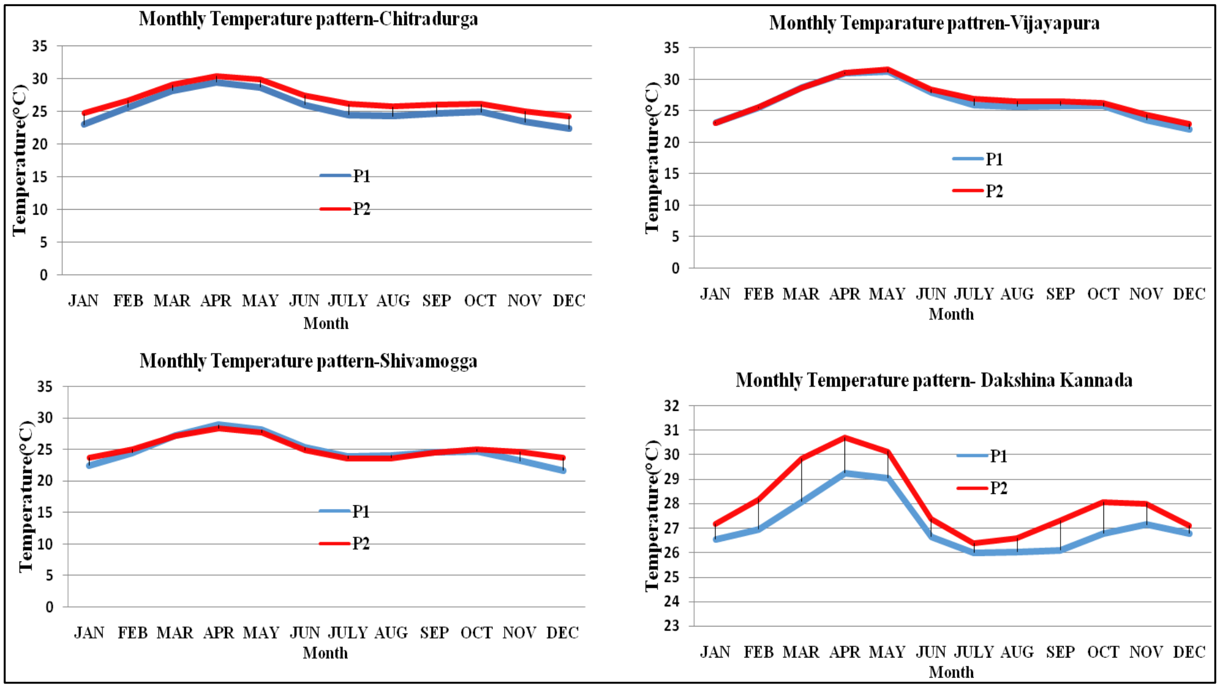

Fig. 8. Monthly average temperature pattern for selected districts during P1 (1901-1978) and P2 (2002-2018)

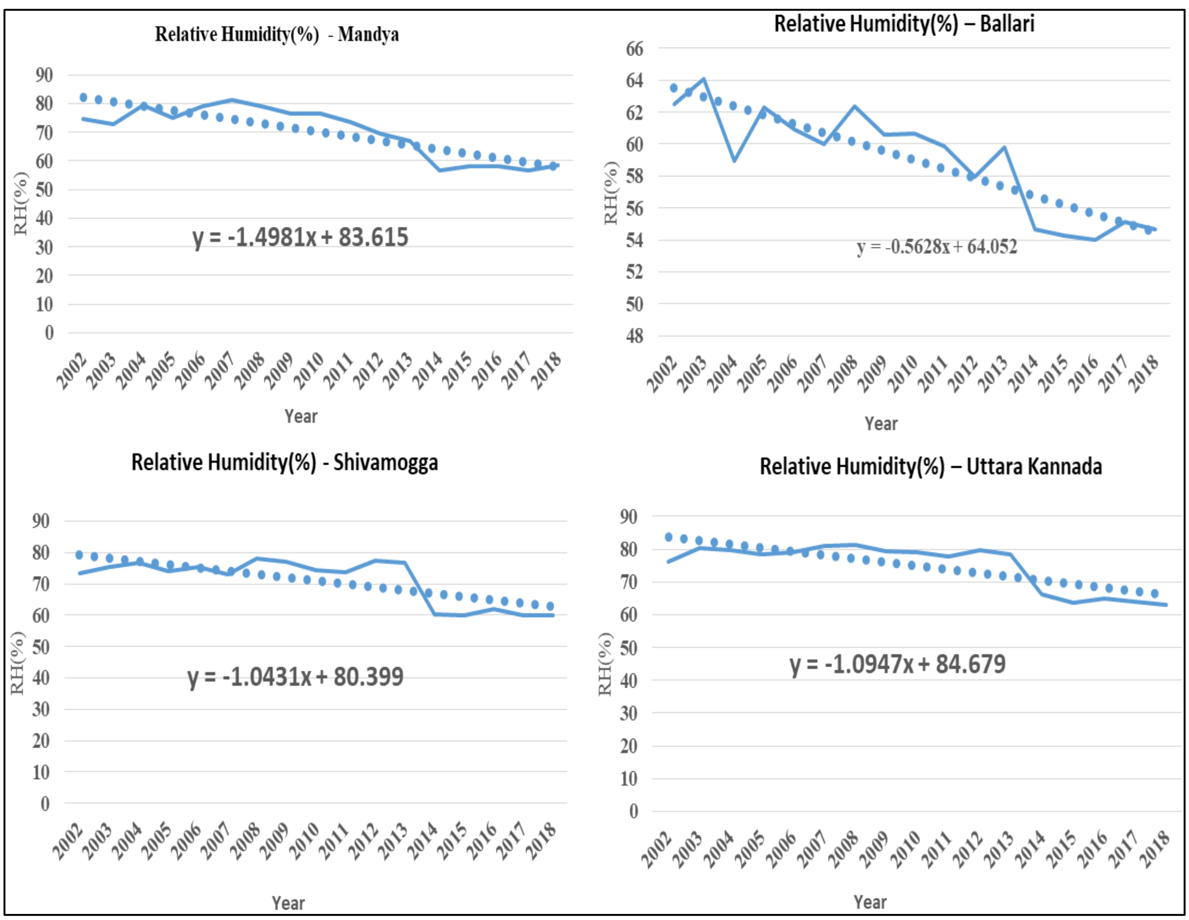

Fig. 9. Relative humidity pattern for selective districts in Karnataka

for high runoff collection suring the SWM season. Constrcting of farm ponds to give life saving irrigation during dry spells, strengthening of village tank bunds to store more water and ground water recharge structure are recommended along with long duration cereals, pulses and comerical crops in rainfed area.

3.14. *Change in temperature and relative humidity*

Temperature and relative humidity (RH) are prime climate parameters that influence crop growth. The temperature and relative humidity data from 2002 to 2018 were considered. The monthly average temperature showed an increasing trend (Fig. 8) in selected districts studied from the P1 to P2 period in Chitradurga (SIK), Vijayapura (NIK), Shimogga (Malnad), and Dakshina Kannada. Among them, the coastal region had maximum temperature variation from P1 to P2 followed by SIK, NIK, and Malanad. The average annual relative humidity (RH) on the contrary showed a decreasing trend in Mandya (SIK), Ballari (NIK), Shimogga (Malnad) and Uttara Kannada (coastal) district (Fig. 9) in the P2 period. Coastal and Malanad regions showed less variation on RH in different years compared to SIK and NIK. These results confirm with studies of Sinha *et al*. (1998). They opined that average annual minimum and maximum temperatures had been increasing every decade.

Observations made: The climate change study in the state revealed the following observations.

(*i*) The long-term rainfall (58 years) data analysis revealed that the climate change point started around the year 1990 in the state.

(*ii*) Rainfall amount, distribution, onset and withdrawal of southwest monsoon (SWM), rainfall intensity, and drought proneness varied across the region and state from the P1 and P2 periods.

(*iii*) Annual rainfall and rainy days increased in SIK and Malnad regions. There is reduction in the amount of rainfall and a marginal increase in rainy days observed in NIK and Coastal regions from the P1 to P2 period. Kodagu, Kalaburgi, Yadgir, Dakshina Kannada, and Uttara Kannada districts showed a significant reduction in the amount of rainfall and an increase in Shivamogga and Hassan districts in the P2 period.

(*iv*) Parts of Vijayapura, Bagalkote, Raichur, Koppal, Ballari, Gadag, Dharwad, Belagavi, Haveri, Davanagere, Chitradurga, Chikkamgaluru, Bengaluru, and Ramanagara districts showed higher variability (CV) in rainfall of southwest monsoon season between the years. The remaining districts showed lesser variability (CV) from P1 to P2.

(*v*) The onset of the southwest monsoon showed early setting by one week in SIK, NIK and Coastal regions and no change in Malanad region in the majority of the years. Early withdrawal of southwest monsoon is observed by two weeks in NIK, one week in Malanad, and no change in SIK and Coastal regions.

(*vi*) Very light and light rainfall events increased in all the regions. Moderate and heavy rainfall events could not found in any distinct.

(*vii*) NIK and SIK are more prone to drought in the state. The frequency of occurrence of droughts increased in the P2 period.

(*viii*) Temperature showed an increasing trend in the whole state. While relative humidity showed a decreasing trend in all districts and regions in the P2 period.

(*ix*) Occurrence of natural disasters *viz*., droughts, floods, hail storms, cyclones, landslides, heatwaves, thunder storms and lightning are observed more frequently in recent years of the P2 period.

(*x*) In rainfed farming, in recent years majority of the farmers are adopting early sowing, constructing farm ponds to collect runoff water, installing drip irrigation systems and providing supplemental irrigations during prolonged dry spells.

4. Conclusions

Results of the study indicate the importance of block-level climatic analysis in documenting micro-level changes witnessed during the recent 27 years (1991-2017) as compared to earlier 27 years (1964-1990). This type of study helps in framing climate change policies and plans in different sectors for adaptation and taking up mitigation programs. The study documented the local level changes in rainfall amount, co-efficient of variations and number of rainy days in two periods. It also shows that the intensity and frequency of droughts, floods, hailstorms, thunderstorms and lightning have increased and are becoming more frequent during recent years.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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