Exploring Climate Patterns in Karnataka, India: A Comprehensive Examination of Rainfall and Temperature Variability Over Time and Space

ABSTRACT

Examining the manifestations and effects of climate change is critically dependent on the spatiotemporal analysis of meteorological variables, particularly in areas where agriculture depends on rainfall. The present study analyzes the change in temperature and rainfall using Mann-Kendall and Sen's slope estimator and also identifies the variations in rainfall by using the Rainfall Anomaly Index (RAI). The main purpose of this study is to assess the variation in climatic variables (temperature and rainfall) among four taluks of Karnataka over 42 years (1981–2022), which might help identify strategies that can aid in addressing the consequences of extreme climate events in the future and in formulating appropriate taluk-specific strategies. The trend analysis of the temperature series revealed a significant increasing trend for the minimum temperature for both seasons, whereas the maximum temperature in the Kharif season shows a decreasing trend. However, there is a significant increasing trend in kharif season rainfall and a nonsignificant increasing trend for rabi season rainfall. The RAI value indicates a relatively greater number of dry periods in Gurmitkal taluk in comparison to Chittapur, Sedam and Yadgigi taluks. The findings of the study can be useful in developing plans to manage water resources effectively and reduce the adverse impacts of droughts, mainly in the study area taluks.

Keywords:Agriculture,climate change, Drought,Trend,Temperature,Rainfall,RainfallAnomalyIndex,Mann-Kendalltest and Sen'sslope

1. INTRODUCTION

“The increase in global surface air temperature during recent decades is one of the most sensitive issues of recent times. The global mean temperature is steadily increasing and is projected to increase by 2°C by 2100, leading to significant economic damage at the global level” [1]. “The climate projections over India indicate that temperature rise is likely to be around 3°C and rainfall increase is expected to be 10–20 percent over the central part of India by the end of this century. Whether the projections become real or not, the occurrence of weather extremes like floods and droughts, cold and heat waves will not be uncommon across the country. The continued growth in greenhouse gas emissions is predicted to cause further global warming and climate change, increasing the likelihood of severe and irreversible impacts on people and ecosystems” [2]. “Climate change includes increases in the frequency and intensity of extreme events that have reduced water and food security, hindering efforts to meet Sustainable Development Goals” [3]. “India as a developing country is more vulnerable to climate change. The major reasons behind this are its reliance on agriculture, small landholdings, limited financial resources, insufficient technology, and inadequate institutions to manage the adverse impacts of climate-related shocks” [4]. “The farming community in India is also facing a significant challenge posed by climate change. The alterations in climatic variables such as temperature, rainfall, relative humidity, wind speed, and solar radiation have both direct and indirect impacts on farm productivity” [21]. “The summer monsoon precipitation (June–September) has a direct impact on the total foodgrain yield during the Kharif season in India. It also indirectly affects the Rabi crop yield through water and soil moisture availability” [5]. “Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still playing key roles in Indian agricultural productivity and, thereby national prosperity. The southwest monsoon, the source of about three-fourths of India's annual rainfall is deciding the crop harvest and economy. The recent trend in climate variability alters the timing and intensity of the monsoon from year to year causing floods or droughts. Increasing evidence over the past few decades indicates that significant climate changes are taking place worldwide due to enhanced human activities. Climate change and global warming also affect the abundance, spawning and availability of commercially important marine fisheries. The estimates suggest that climate change is likely to worsen food and livelihood security, resulting in a decrease in the yield of major crops by approximately 9–18%” [6].

“Karnataka is typically an agrarian state. About 66 percent of the total population lives in rural areas and the main source of income is from farming alone. Out of ten agro-climatic zones, five fall under dry zones” [14]. “A large portion of the area falls under semi-arid conditions facing severe agro-climatic and resource constraints. Karnataka is one of the few states with the lowest proportion of area under irrigation and is second only to Rajasthan in the share of drought-prone areas. Karnataka is a leading producer of coarse cereals (maize, ragi, jowar, etc.) and sunflowers in the country. Nearly 70% of the total cultivated area is under rainfed farming” [7]. Given the limited water sources for irrigated agriculture and the uncertainty and improper distribution of rainfall, crop productivity suffers to a great extent. In addition to these natural vagaries, the dissemination of technologies concerning various agricultural practices is also a limiting factor in productivity and production. Hence, the vagaries of the weather—drought and floods—play havoc on the livelihood of farmers. It is crucial to ensure the health of the agricultural sector for the state's gross state domestic product to grow at a robust rate for the next couple of decades, which in turn is necessary, if not sufficient, to alleviate poverty.

"The spatial and temporal analysis of temperature and rainfall is an essential tool to assess climate variability and change in the climate. Although climate change has a global impact, it also affects taluks and localities differently, highlighting the significance of evaluating trends, making projections, and developing localized strategies to mitigate its impact. In order to assess the impact of climate change in the case of drought events, a study on the historical pattern of rainfall is important" [10]. "Examining the time-series trends of different meteorological variables is crucial for both adapting to and mitigating the adverse impacts of climate change" [11]. Therefore, a study has been undertaken to analyze the changes in temperature and rainfall during 1981–2022 in Karnataka state by using Mann-Kendall and Sen's slope estimator statistical tests. It also assessed the extent of drought severity by using the Rainfall Anomaly Index (RAI),which will be helpful for developing region as well as district-level strategies for mitigation and building resilience against extreme climate events.

1. METHODOLOGY

1.1 Study Area

Geographically Karnataka is situated on a tableland where the Western and Eastern Ghat ranges converge into the Nilgiri hill complex, the State of Karnataka is confined roughly within 11°50'Nto18°50' N latitudes and 74°00'Eto78°50' E longitude. The State extends to about 750 km from North to South and about 400 km from East to West and covers an area of about 1,91,791 sq. km being the 6th largest state holding 5.83% of the total geographical area of India [12]. "With a population of approximately 61 millionpeople,itistheeighthmostpopulousstatein the country" [13]. There are three distinct geographical regions in Karnataka: the Coastal Plains, the Western Ghats and the Deccan Plateau. The southwest monsoon is the principal rainy season during which the State receives 80% of its rainfall. Rainfall in the winter season (January to February) is less than one percent of the annual total, in the hot pre-monsoon season (March to May) about 7% and in the post-monsoon season about 12%. The climate in this region is hot with excessive rainfall during the monsoon season i.e., June to September. The southern half of the State experiences a hot and seasonally dry tropical savanna climate while most of the northern half experiences a hot, semi-arid and tropical steppe type of climate. The major rivers flowing through Karnataka are Cauvery, Kabini, Krishna and Tungabhadra.

"The salient features of Karnataka State are about 77% of the total geographical area of the state is arid or semi-arid; drought is a threat to consider as two-thirds of the state receives less than 750 mm rainfall per annum. 54% of the total geographical area of the state is drought-prone, affecting 19 of the 31districts" [8]."The state is endowed with limited water resources that are already stressed and fast depleting. The sectoral water demands are growing rapidly on account of the increase in population, urbanization, rapid industrialization and rising incomes. Karnataka has seven river basins and receives a total of 236 billion m3 of water every year, 92% of it through rainfall. Around 47% are 'lost' through evapotranspiration and another 46 % flow into the Arabian Sea, into Andhra Pradesh and Tamil Nadu. The state meets its requirement from the remainder of about 7.5% paired with groundwater. There are nearly 37,000 tanks and lakes with a water spread area of 6.9 lakh hectares and more than 20,000 irrigation tanks" [9].Groundwater provides for 45% of irrigation in the state. 64.6% of the total geographical area of the state is said to be under cultivation; farmers and agricultural laborers account for 56.5% of the total workforce of Karnataka. The state experiences rich and diverse agriculture practices which contribute 16.21% to the Gross State Domestic Product (GSDP). Rice, ragi, jowar, maize and pulses apart from oil seeds and cash crops form the major crops of Karnataka. The state also produces cashews, coconuts, cardamoms, chilies, cotton, sugar cane and tobacco.

1.2 Trend Estimation

A taluk-wise yearly time series data on rainfall and temperature has been collected for 42 years (1981-2022) from the India Meteorological Department (IMD). "The detection of significant trends in time series data on climate variables can be calculated using either parametric or nonparametric methods. Parametric trend tests necessitate that the data be both independent and normally distributed, whereas nonparametric trend tests only require that the data be independent" [16]. This study utilized two nonparametric methods, namely Mann-Kendall and Sen's slope estimator, examining the direction and magnitude of trends in maximum temperature, minimum temperature, and rainfall. The Mann-Kendall test is a non-parametric method for detecting trends in time series data. It involves assessing the significance of the trend using a normalized test statistic, known as the Z-value. By examining the signs of the Z-values, it is possible to determine whether the trend is increasing or decreasing. A positive Z-value indicates an increasing trend, whereas a negative Z-value denotes a decreasing trend.

2.2.1 Mann-Kendall trend test

The Mann-Kendall test statistic is calculated as

$$s = \Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} sgn(x_j \text{-} x_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where n is the number observations, xi and xj are the values of climatic variable in time series i and j respectively given j>i

$$sng\ (x_j \text{-}\ x_i) = \begin{cases} +1 \text{ if } (x_j - x_i) > 0 \\ \ \ 0 \text{ if } (x_j - x_i) = 0 \\ -1 \text{ if } (x_j - P_i) < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

If the number of observations is more than 10, Mann-Kendall statistic assumed to follow a normal distribution with variance equal to

$$\sigma^2 = \frac{n\ (n-1)(2n+5)}{18} \quad \text{……………..} \ (3)$$

We can use Z test to test the significance of the trend. The standard Z statistic is computed by using following equation,

$$z_s = \begin{cases} \frac{s-1}{\sigma} if S > 0 \\ 0\ if S = 0 \\ \frac{s+1}{\sigma} if S > 0 \end{cases} \quad \text{……………} \ (4)$$

If Zs >Z table value, the null hypothesis is rejected that no significant trend exists in the variable under consideration.

2.2.2 Sen's slope estimator

Sen's slope estimator is used to determine the magnitude of the underlying trend by calculating the slope, which represents the amount of change in measurement per unit of time.

$$Q = \frac{X_{j-}\ X_k}{j-k}, K \neq j \text{……………} \ (5)$$

For a time, series X within observations, there are possible N = n (n -1)/2 values of Q that can be calculated. According to Sen's method, the overall estimator of slope is the median of Q's N values. The overall slope estimator, Q* is thus:

$$Q^* = \begin{cases} Q_{[(N+1)/2],} & if\ N\ is\ odd \\ \frac{Q_{\left(\frac{N}{2}\right)} + Q_{[(N+2))/2]}}{2} & if\ N\ is\ even \end{cases} \text{………} \ (6)$$

The Q* represent the trend in data, while its numerical value represents the degree of steepness of the trend.

2.3 Rainfall Anomaly Index (RAI)

Data on annual precipitation of the four taluks of Karnataka viz., Chittapur and Gurmitkal taluks of kalbugai district and Yadgiri and Sedam taluks of Yadgiri District has been collected for 42 years (1981-2022). RAI is basically developed to classify positive and negative anomalies in precipitation data. To determine these anomalies, the annual rainfall data was arranged in descending order and the ten highest values are averaged to establish a threshold for positive anomalies, while the ten lowest values are averaged for negative anomalies. The mean of the ten most extreme positive and negative anomalies are assigned arbitrary threshold values of +3 and -3, respectively. It uses a scale of numerical values to assign nine abnormality classes, which range from extremely wet to extremely dry conditions. Positive anomalies are characterized by values above the average, while negative anomalies are characterized by values below the average.

For positive anomalies

$$RAI = 3 \ \left(\frac{RNF - RNF_m}{X - RNF_m}\right)$$

For negative anomalies

$$RAI = -3 \ \left(\frac{RNF - RNF_m}{Y - RNF_m}\right)$$

Where,
RNF = current yearly rainfall (mm)
RNF_m = yearly average rainfall of the historical series (mm)
X= average of the ten highest yearly rainfall of the historical series (mm)
Y= average of the ten lowest yearly rainfall of the historical series (mm)

3 RESULTS

3.1 TrendAnalysis

"Toanalyzetheimpactofclimatevariables on crop production, it is importanttofirst understand the rate of change and directionofchangesinthemaximumandminimumtemperatures over time. Mann-Kendall (MK) testwasusedtotestthesignificanceoftrendsin temperature and rainfall. Whereas the magnitude of the trend was computed using Sen's slope estimator" [22]. The results for the Kharif season temperature are presented in Table 1. As evident from the table, the negative sign of Kendall's tau statistics indicated the maximum temperature decreased over time in all the selected taluks and the minimum temperature has been increased except in Yadgiri taluk. The annual rate of decrement in maximum temperature was found to be highest for Chittapur (-0.0260°C) followed by Yadgiri (-0.0259°C), Sedam (-0.0240^{o}C) and lowest in Gurmitkal taluk (0.0234°C). A significant increasing trend was observed in minimum temperature in all the taluks except Yadgiri taluk, with the highest rate in Sedam (0.0138°C) and the lowest reported in Gurmitkal (0.0001°C). Overall, all taluks show a consistent decreasing trend in maximum temperatures (Tmax). Minimum temperatures (Tmin) exhibit more variability, with some taluks showing weak increasing trends and others having stable or decreasing trends.

Table 2 demonstrates the trend in maximum and minimum temperatures in rabi season. Unlike kharif season, the MK trend test result revealed that both maximum and minimum temperatures had increased significantly. The rabi season maximum temperature indicated highly significant (at 1% level of significance) increasing trends for all the taluks. Similarly, the minimum temperature registered an increasing trend with a 99% confidence level in all the taluks. Among the taluks, Chittapur reported the highest rate of warming in terms of both maximum and minimum temperature (0.9320°C and 0.0255°C, respectively). It was also observed that, across all taluks, the trend of rising temperatures at the minimum temperature was greater than the maximum temperature. Further, Yadgiri taluk reported the highest maximum (29.93°C) and minimum (19.37 °C) temperatures.

Table1.Talukwisetrendinkharif seasontemperature (1981-2022)

Taluk	T_{max}				T_{min}			
	Mean (°C)	Kendall's tau	Z-Statistics	Sen's Slope	Mean (°C)	Kendall's tau	Z-Statistics	Sen's Slope
Chittapur	30.84	-0.2683	-2.49**	-0.0260	23.48	0.0035	0.02	0.0001
Gurmitkal	30.42	-0.2381	-2.21**	-0.0234	23.30	0.0012	0.00	0.0001
Sedam	30.11	-0.2613	-2.43**	-0.0240	23.04	0.0058	0.04	0.0003
Yadgir	31.05	-0.2636	-2.45**	-0.0259	23.71	-0.0267	-0.24	-0.0008

,and***denotessignificant at1,5and10percent,respectively.*
Source:Author'scalculationbasedondataavailabilityfromIMD(1981-2022)

Table2.Talukwisetrendinrabiseasontemperature(1981-2022)

Taluk	T_{max}				T_{min}			
	Mean (°C)	Kendall's tau	Z-Statistics	Sen's Slope	Mean (°C)	Kendall's tau	Z-Statistics	Sen's Slope
Chittapur	29.40	0.1010	0.93	0.9320	18.59	0.3449	3.21*	0.0255
Gurmitkal	29.35	0.1754	1.63	0.0144	19.22	0.3868	3.60*	0.0236
Sedam	28.96	0.1312	1.21	0.0136	18.45	0.3682	3.42*	0.0253
Yadgir	29.93	0.1359	1.26	0.0154	19.37	0.3519	3.27*	0.0234

,and***denotesignificant at1,5and10percent,respectively.*
Source:Author'scalculationbasedondataavailabilityfromIMD(1981-2022)

The Sedam taluk receives the highest mean kharif season rainfall (683.66 mm) with a standard deviation of 182.90 mm (Table 3). It also depicts the large difference between maximum and minimum rainfall. On the other side, the lowest mean rainfall was observed in

Yadgiri (606.70 mm). MK test statistics and Sen's slope estimates for all the taluks show a significant increasing trend in kharif season rainfall. Karnataka receives its kharif season rainfall mainly from the southwest monsoon, and its dependency and variation in monsoon rainfall affect the crop production and livelihood of the people. The state is more prone to significant climate fluctuations, which have resulted in recurrent droughts leading to agricultural poverty and distress, as evidenced by the high suicide rates [17]. Whereas, rabi season rainfall indicated a non-significant increasing trend. The highest mean rainfall for the rabi season was received by Yadgiri taluk (39.74 mm) with a standard deviation of 55.34 mm, and the lowest was reported for Chittapur (36.62 mm).

Table 3. Taluk wise trend in kharif season rainfall (1981-2022)

Taluk	Minimum	Maximum	Mean	Std. deviation	Kendall's tau	Z-Statistics	Sen's Slope
Chittapur	370.93	1059.03	625.70	172.41	0.2195	2.04**	4.5766
Gurmitkal	424.84	1109.47	659.55	180.45	0.2846	2.64*	4.6687
Sedam	437.23	1121.95	683.66	182.90	0.2334	2.17**	5.0130
Yadgir	374.15	1033.09	606.70	169.40	0.2636	2.45**	4.5647

,and***denotessignificant at1,5and10percent,respectively.*
Source:Author'scalculationbasedondataavailabilityfromIMD(1981-2022)

Table 4. Taluk wise trend in rabi season rainfall (1981-2022)

Taluk	Minimum	Maximum	Mean	Std. deviation	Kendall's tau	Z-Statistics	Sen's Slope
Chittapur	36.62	228.52	119.36	54.15	0.0755	0.69	0.6182
Gurmitkal	36.90	225.65	122.21	54.09	0.0825	0.76	0.6043
Sedam	36.87	220.83	118.89	52.33	0.0732	0.67	0.5478
Yadgir	39.74	240.15	120.97	55.34	0.0662	0.61	0.5019

,and***denotessignificant at1,5and10percent,respectively.*
Source:Author'scalculationbasedondataavailabilityfromIMD(1981-2022)

3.2 RainfallAnomalyIndex(RAI)

Based on Rainfall Anomaly Index (RAI) values, 42 years have been categorized into a total of nine categories, viz., extremely wet, very wet, moderately wet, slightly wet, near normal, slightly dry, moderately dry, very dry, and extremely dry years as depicted in Fig. 1. The distribution of years in all categories is not similar across the taluks. The Gurmitkal taluk experiences greater fluctuations in rainfall and a higher number of years with below-average precipitation. Over 42 years, 9 years are categorized as slightly wet years, while 7 years are characterized by being extremely dry. In contrast, only 3 years fall within the near-normal range. On the other side, Sedam and Yadgiri show less variation in rainfall, with a greater number of years falling within the near-normal category. Specifically, 7 years in the Sedam taluk and 6 years in Yadgiri exhibit the near-normal years. The Chittapur taluk experienced dry conditions for almost half of the years, with 20 years of the total considered period falling under the categories of slightly dry to extremely dry. On the other hand, only 5 years are characterized by near-normal levels of rainfall.

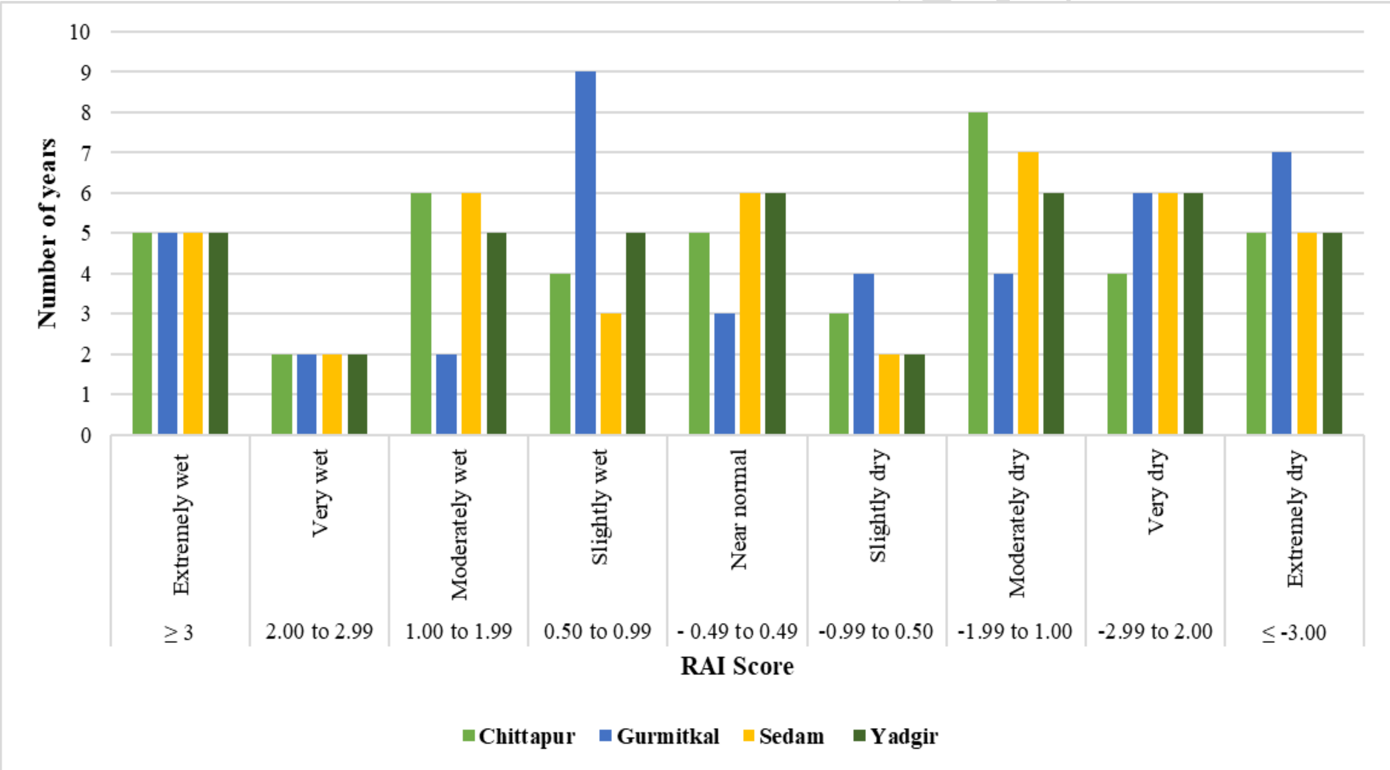

Fig.1.Classificationof rainfallanomalyindex

Source:RAIclassificationadaptedfromVan-Rooy[18]

Fig. 2 - Fig. 5 illustrates the RAI values over the 42-years period (1981–2022) for Chittapur, Gurmitkal, Yadgiri and Sedam taluks, respectively. The precipitation in the years 1982, 1984, 1985, 1986, 1987, 1989, 1990, 1991, 1992, 1993, 1994, 1997, 1999, 2002, 2003, 2004, 2011, 2012, 2015 and 2018 shows a dry period across all the taluks (RAI < 0). The severe drought (RAI < -3) was faced by all the taluks with varying intensity in the years 1986 and 1992. The maximum RAI values for 1986 are reported by Gurmitkal taluk (-3.92), followed by Yadgiri (-3.74), Chittapur (-3.23), and Sedam (-3.04).

The RAI values for Chittapur taluk vary from - 4.55 (2003) to 4.78 (2020). Out of 42 years, 17 were wet periods, 4 were normal, and 20 were dry periods. The extreme dry period (RAI >-3) occurred in 1986, 1992, 1997, 2003 and 2015; the extreme wet periods occurred for 5 years in 2005, 2007, 2011, 2020 and 2022. In Gurmitkal, the dry years were observed for 21 years, with 7 severe drought years reported in 1982, 1984, 1985, 1986, 1992, 2003 and 2015 and the RAI values for these years are -3.48, -4.18, -3.00, -3.92, -3.58, -4.37 and -3.26 respectively. About 5 years (2000, 2007, 2010, 2020 and 2022) are in the extreme wet category. In Sedam, the dry years were observed for 20 years (RAI < 0). Out of these 5 years recorded, there was an extremely dry period in the years 1982, 1986, 1992, 2003 and 2015 with an RAI value less than -3. About 5 years (2000, 2007, 2010, 2020 and 2022) fall under extremely wet years. The majority of the years fall into the dry category, followed by the wet category and only 6 years show normal rainfall years. Whereas Yadgiri taluk reported a weak and medium drought for about 19 years, with RAI values ranging from -0.03 to -4.10. The extreme drought conditions occurred in the years 1984, 1986, 1992, 1997 and 2003 (< -3 RAI). Only six years fall into the near-normal category.

The findings of the present study highlight the less variations in rainfall in Yadgiri taluk. In contrast to this, Gurmitkal, Chittapur and Sedam taluks can be considered the most vulnerable drought zones since they have been more prone to drought occurrence for 20 years with a smaller number of near-normal years during the study period of 1981–2022.

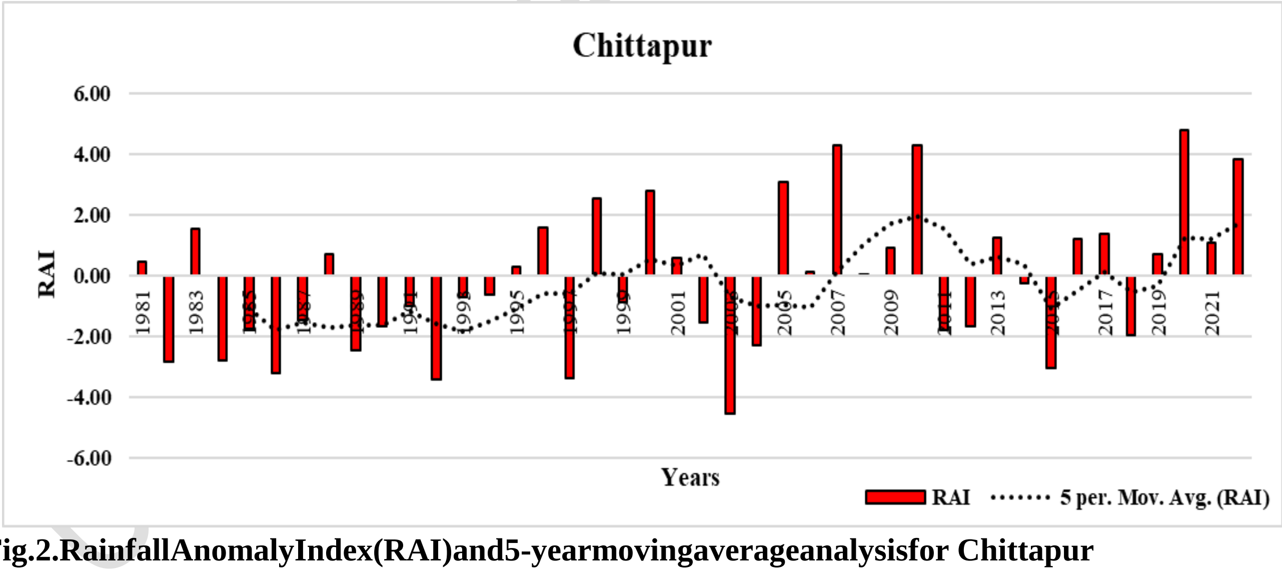

Fig.2.RainfallAnomalyIndex(RAI)and5-yearmovingaverageanalysisfor Chittapur

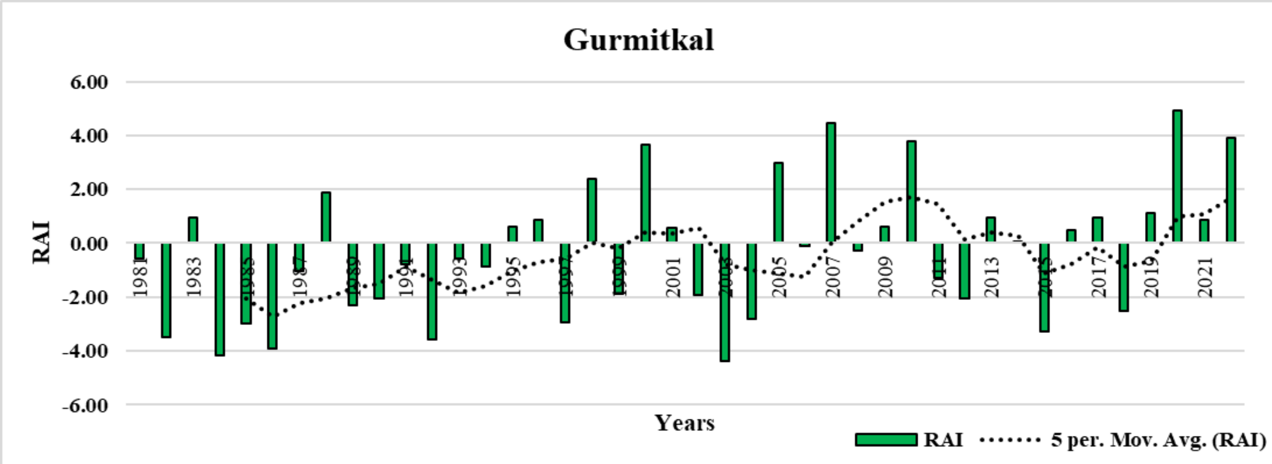

Fig.3.RainfallAnomalyIndex(RAI)and5-yearmovingaverageanalysisfor Gurmitkal

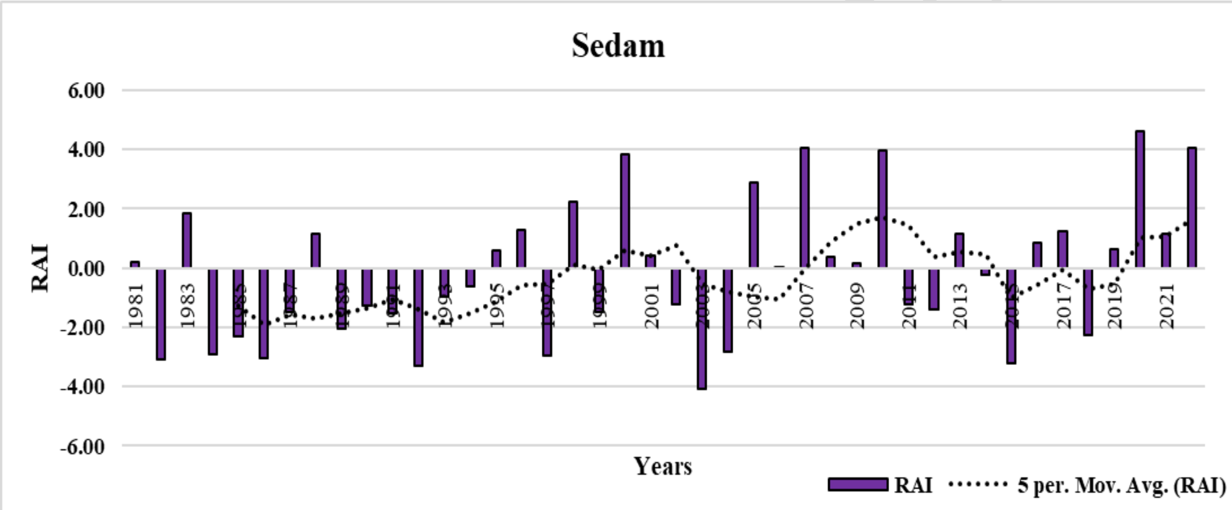

Fig.4.RainfallAnomalyIndex(RAI)and5-yearmovingaverageanalysisfor Sedam

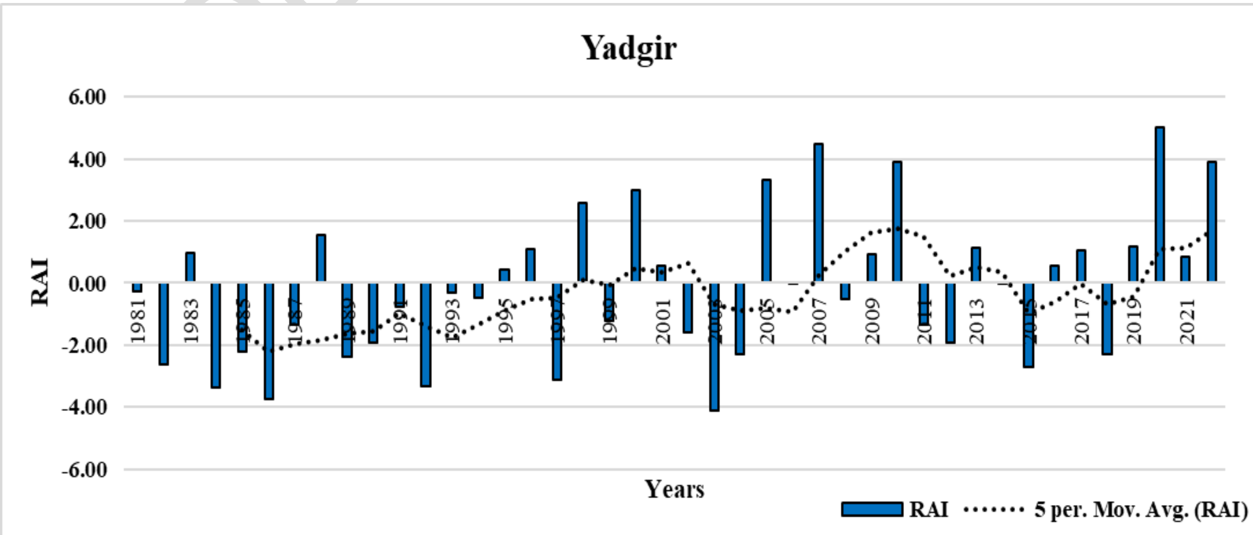

Fig.5.RainfallAnomalyIndex(RAI)and5-yearmovingaverageanalysisfor Yadgiri

4. DISCUSSION

The trend analysis over the study period (1981–2022) on temperature series for the kharif season revealed a significant increasing trend for minimum temperature in all the taluks, whereas there was a decreasing trend for maximum temperature. But in the rabi season, both the minimum and maximum temperatures in all the taluks have an increasing trend. However, a significant increasing trend for kharif and a non-significant increasing trend in rabi rainfall were observed. This long-term trend suggests that the climate change impact in the study area is primarily driven by the increase in temperature and not much by the rise in rainfall. In all the taluks, the rate of change was faster at the minimum temperature in comparison to the maximum temperature, which may lead to a decrease in the diurnal temperature range. Similar finding was also reported by Dhorde et al. [19] that over the period of 1969–2006, there was an increasing trend of mean maximum temperature and mean minimum temperature on an annual and seasonal basis. The rainfall variability across the taluks has resulted in a higher frequency of dry periods. Moreover, the study has observed spatial inconsistencies in rainfall deficiency across the taluks, which holds the potential for developing taluk-specific adaptation strategies. The RAI value indicates a relatively greater number of dry periods in Gurmitkal taluk in comparison to Chittapur, Sedam and Yadgigi taluks. On a similar line, Harad et al. [20] also found that the districts in north Karnataka were at greater risk due to monsoon variability and needed immediateattention from policymakersand scientists.

5. CONCLUSION

The effects of climate change on agriculture areextensive because of its heavy dependence onclimateandhaveinterconnectionswithsocio-economic systems on a regional, national, andglobal scale. The analysis of variations and trendsinclimatevariablessuchastemperatureandrainfall at the regional level highlights its importanceinformulatingadaptationandmitigationstrategiestocopewiththe adverseimpactsof extreme weather events at the regional level. The present study has been undertaken to understand the trend and variation for fourtaluks of Karnataka. The trend analysis of the temperature series revealed a significant increasing trend for minimum temperature for both seasons, whereas maximum temperature inthe kharif season shows a decreasing trend. however significantincreasingtrendin kharif season rainfall and a nonsignificant increasing trend for rabi season rainfall. The findings of the present study can be useful in developing plans to manage water resources effectively and reduce the adverse impacts of droughts basically in the study area thaluks, which are more vulnerable to climate change and dominated by monsoon rainfall.

REFERENCES

1. Malhi GS, Kaur M, Kaushik P. Impact ofclimatechangeonagricultureanditsmitigationstrategies:Areview.Sustainability.

2021; 13:1318.

2. EdmondsHK,LovellJEandLovellCAK.Anewcompositeclimatechangevulnerabilityindex.EcologicalIndicators.2020; 117:106529.

3. IntergovernmentalPanelonClimateChange (IPCC). Climate change 2021: Thephysicalsciencebasis.Contributionofworking group I to the sixth assessmentreport of the Intergovernmental Panel onClimateChange,CambridgeUniversityPress;2021.

4. RaoVUM,RaoAVMS,KumarPV,DesaiS,SaikiaUS,SrivsatavaNN,VenkateswarluB.Agriculturaldrought:Climate change and rainfed agriculture. In:LectureNotesofthe5thSERCSchool,CentralResearchInstituteforDrylandAgriculture, Hyderabad, India. 2011;324.

5. Prasanna V. Impact of monsoon rainfall onthe total foodgrain yield over India. JournalofEarthSystemScience.2014;123(5):1129–1145.

6. PathakH.Impact,adaptation,andmitigationofclimatechangeinIndian agriculture. EnvironmentalMonitoringandAssessment.2023;195(52):1-22.

7. Karnataka State Action Plan for Climate Change & Human Health (KSAPCCHH) ,2020 Department of Health & Family Welfare, Government of Karnataka

8. Hanumanthappa, M., Ananda, M.R., Sridharaherle,P., Nagesha, L. and Sudhir kamath, K.V.,2010, Annual and seasonal rainfall variability in coastal district of Karnataka. J. Agrometeorology. 12(2): 266-267.

9. Karnataka Climate Change Action Plan, 2011 Bangalore Climate Change Initiative – Karnataka (BCCI-K) Government of Karnataka.

10. WilhiteDA.Managingdroughtriskinachangingclimate.ClimateResearch.2016;70(2-3):99-102.
11. Mudelsee,M.Trendanalysisofclimatetime series: A review of methods. Earth-Science Reviews.2019; 190:310-322.

12. Planning, Programme MonitoringandStatistics Department,GovernmentofKarnataka.EconomicSurveyof Karnataka;2022-23.

13. Census ofIndia. Dataonpopulation.Officeof the Register General and Census Commissioner, NewDelhi; 2011.
Available: https://censusindia.gov.in/census.website/data/census-tables

14. NationalDairyDevelopmentBoard(NDDB).DairyinginKarnataka:Astatisticalprofile;2

015.

15. M. B. Rajegowda, B.T. Ravindra Babu, N.A. Janardhanagowda and K.S. Muralidhara. Impact of Climate Change on Agriculture in Karnataka Journal of Agrometeorology 11 (2): 125-131 (2009)

16. Gocic M, Trajkovic S. Analysis of changesinmeteorologicalvariablesusingMann-KendallandSen'sslopeestimatorstatisticaltestsinSerbia.GlobalandPlanetaryChange.2013; 100:172–182.

17. Climate Change Scenario in Karnataka: A Detailed Parametric Assessment, 2020, Karnataka State Natural Disaster Monitoring Centre (KSNDMC). Revenue Department (Disaster Management), Government of Karnataka.

18. Van-Rooy, M.P. A rainfall anomaly index(RAI), independent of the time and space.Notos.1965;14:43–48.

19. DhordeAG,KoradeMS,DhordeAA.Spatialdistributionoftemperaturetrendsandextremesover MaharashtraandKarnataka states of India. Theoretical andAppliedClimatology.*2*016; 130:191–204.

20. Harad K. Jain and Vijay Kumar, 2012. Trend analysis of rainfall and temperature data for India. Current Science,102(1), 1-13

21. Mall, R. K. Ranjeet Singh. Akhilesh Gupta. Srinivasan, G. and Rathore, L. S. 2006. Impact of climate change on Indian agriculture: A Review. Climate Change, pp. 445-478.

22. Krishnakumar, K.N.and Prasada Rao, G.S.L.H.V., 2008, Trends and variability in north east monsoon rainfall over Kerala. J. Agrometeorology. 10(2): 123-126.