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Temporal Trends of Rainfall and Temperature over Two Sub-Divisions of Western Ghats

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Abstract

Rainfall, along with temperature, is the major component of the hydrological cycle, and its spatiotemporal variability is essential from both scientific and practical perspectives. Due to the recent rise in temperatures all over the world, there are quite a number of conflicting trends in inter-annual variability in monsoon rainfall and temperature over the Western Ghats. The Western Ghats, next to the Himalayas, are the major watershed for the major south Indian rivers. In this study, an attempt has been made to understand the monthly, inter-seasonal, and inter-annual trends of rainfall and temperature over the two meteorological sub-divisions, namely Konkan Goa, and Coastal Karnataka. Monthly rainfall data for the period of 1977 to 2016 and temperature data from 1980 to 2016 are used. According to the analysis, maximum rainfall occurs during the summer, whereas the least rainfall occurs during the winter. The parametric, linear regression analysis and student t-test have been used to identify the existence of trends and to determine the changes in rainfall over the time period. An effort has been made to understand the relationship between ISMR (Indian Summer Monsoon Rainfall) and the ENSO phenomenon and to investigate whether the rainfall over WG is influenced by the ENSO phenomenon or not. Results reveal that although there is increased rainfall over Konkan and Goa, while declining over coastal Karnataka, the changes over both the sub-divisions were statistically significant. Considering rainfall in different seasons, there is a significant change during the monsoon season only. The study further reveals that there is increasing rainfall over Konkan and Goa and decreasing rainfall over Coastal Karnataka. Furthermore, no statistically significant trend (positive or negative) was evident in any of the seasons. All temperature trends were positive. The results of this study may prove useful in the preparation of climate change mitigation and adaptation strategies by understanding the patterns of rainfall over WG.

Keywords: Climate Change; Rainfall; Variability; Trend analysis; ENSO Phenomenon; ISMR.

1. Introduction

Climate change is a complex phenomenon, and so it's very important to study the changes experienced over the time period. Since the inception of the earth, the driving mechanism behind the origin of life and the life-sustaining environment has recorded variations in climate. To accurately predict the future events and their environmental impact, we must accurately detect the path of previous climatic events. With the help of spatiotemporal data of past events, researchers will be able to estimate the different periods of warming or cooling of Earth's atmosphere. Different studies were conducted to examine the long-term trends in temperature and rainfall. Earlier approach to the study of climate change was aimed at examining the long-term trends in surface air temperature [1]. With the rapid

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advancement of technology, new approaches and methods for estimating the climate variability have been developed. There is general consent among geographers that global temperatures have increased in the past century. The Intergovernmental Panel on Climate Change (IPCC) report noted that there was a rise in the global mean surface temperature by 0.87 in 2006–2015 compared to 1850–1900 [2]. As a result of increase in temperature, hydrological cycle is disturbed which in turn leads to extreme rainfall events in the form of flash floods [3-5]. In the last few decades, it has been observed that recent rises in temperature have triggered extreme climatic events in and area around the Western Ghats (hereafter referred to as the WG).

The rapid increase in the world population leads to an increase in water demand along with an improved quality of life. Also, climatic variability draws the attention of scientists and engineers towards the availability of water in a place for sustainability. The main source of river flow in India is rainfall. As a result, extreme variability in rainfall leads to an increase in extreme hydrological events such as droughts and floods [6]. The lack of average annual rainfall in the area has a negative impact on agricultural produce. Approximately 60% of the Indian population depends on agriculture, which contributes about 20% in national gross domestic product (GDP). The recent changes in rainfall and temperature have led to more vagaries in climatic fluctuations. However, the impact is not uniform at all. Thus, there is a need to study the changing trends in rainfall and temperature patterns and their impacts on water resources. Existing literature that deals with the negative impacts of global warming staunchly supports the changing patterns of rainfall all over the world. [7, 8]. In the other studies, Rind et al. [9] and Mearns et al. [10] highlighted the future climate changes in rainfall and temperature patterns and their influence on rainfall trends. The spatial distribution of rainfall over India exhibits immense rainfall over the Konkan and Goa and Coastal Karnataka (Meteorological Sub-divisions). Both the regions have distinctive characteristics of mountainous terrain that act as a barrier to southwest monsoon winds. Both the sub-divisions lie within WG, which in turn is one of the most important World Heritage Sites, which is immensely rich in biodiversity, flora-fauna, and resources for the population residing in coastal areas. This is marked by an extensive geographic area, diverse topography, and enhanced rainfall in the summer monsoon. Vaticinate accurate weather conditions over this undulated terrain is a challenging task for climatologists as it impacts the efficient use of available resources in WG. The rainfall over WG is highly influenced by terrain and regional mountain summits. Patwardhan and Asnani [11] studied 10 years of rainfall data and observed that the uneven patterns of rainfall are associated with irregular terrain and also reported that rainfall in the funnel type gap of the WG in the Maharashtra region. Venkatesh and Jose [12] studied homogenous rainfall intensities in one of the coastal districts and its adjoining areas in Karnataka using mean rainfall of 10–15 years obtained from different rain gauge stations.

Rainfall patterns in a region are the result of a variety of factors that exist at both the local and global levels of ocean-atmospheric circulation. The global circulation incorporates El Nino and La Nina, ocean atmospheric interaction (ENSO) in the Pacific Ocean and the Indian Ocean dipole (IOD) in the Indian Ocean. During El Nino, equatorial precipitation tends to increase, while during La Nina, less precipitation is noticed over the equatorial region and precipitation is increased near the Pacific Northwest region. ENSO has a considerable impact on the ISMR. In general, El Niño phenomenon accompanying droughts like conditions while La Nina events associated with floods over Indian subcontinent. These variations over the equatorial Pacific Ocean cause major changes in pressure, precipitation, and wind speed and direction over the earth's surface. Ajayamohan and Rao [13] reported the fact that IOD events are moderately correlated with seasonal mean rainfall over central India. Analysis reveals that the departure of rainfall from its mean is associated with ENSO and IOD events. It has been concluded that rainfall intensity over WG in the south-west monsoon season is governed by ENSO and IOD events, but the El Nino/La Nina event seems to suppress the IOD effect over WG's rainfall. Therefore, the present study was focused on recent trends in annual, seasonal, and monthly rainfall and temperature over two meteorological sub-divisions, viz. Konkan & Goa and Coastal Karnataka. Another goal of this research project is to find out if the ENSO phenomenon affects the amount of rain that falls over WG by using a suitable, standard, and well-accepted statistical method.

2. Study Area

The WG is a chain of uplands running along the western edge of the Indian west coast, from the states of Gujarat, Maharashtra, Goa, Karnataka and Kerala. The study is focused on a region experiencing orographic rainfall bounded by latitudes of 8° to 21° N and longitudes of 70° to 78° E, as depicted in Figure 1. WG runs along the west coast of India, about 50 km away on average from the shoreline. The North-South and East-West extents of WG are about 1600 km and 100 km, respectively [14]. The average elevation of the study area is approximately 800 m, with some apexes rising above 2000 m elevation. The Indian Meteorological Department (IMD) divided India into 36 meteorological sub-divisions, from which we chose Konkan and Goa and Coastal Karnataka as the study areas. The study area is located in a humid and tropical climatic zone tempered by the proximity of the sea.

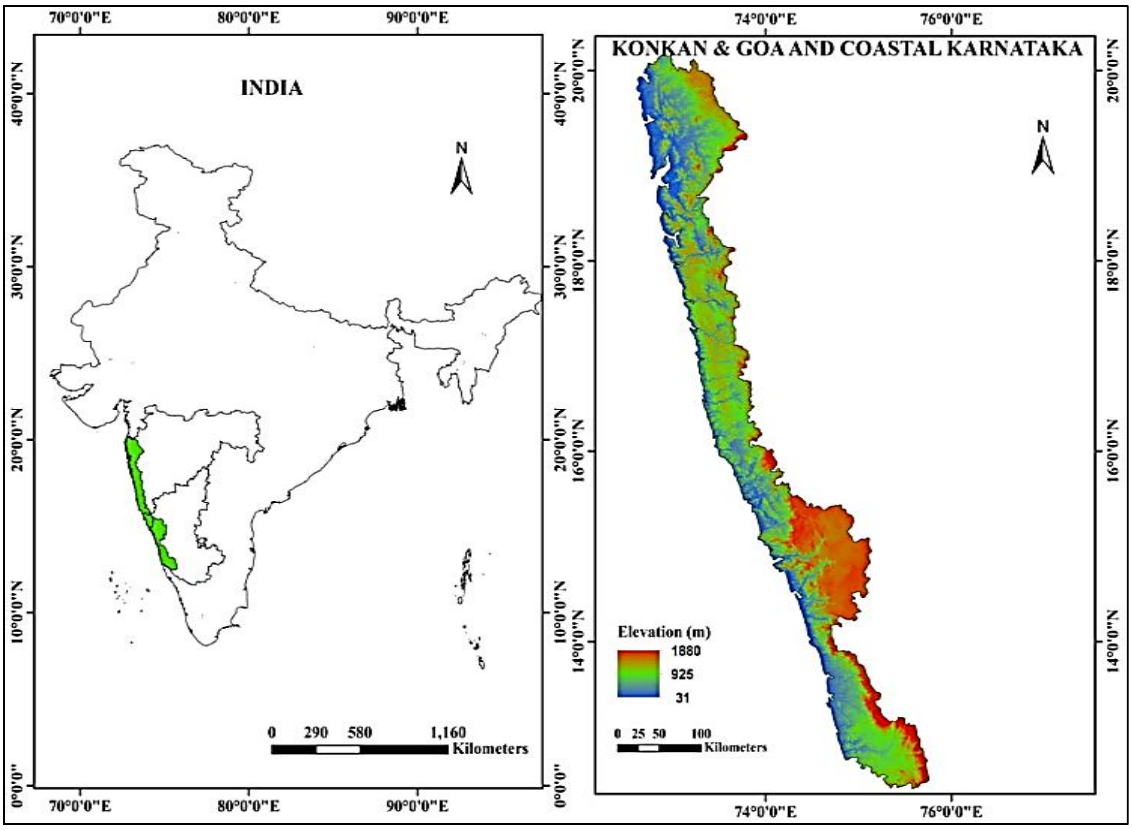


Figure 1. Location Map of the study area

3. Database and Methodology

Monthly rainfall data for the period 1977-2016 was obtained from the IITM [15] under an autonomous institute of the ministry of Earth sciences, Government of India. And daily temperature data for the period 1980-2016 was acquired from MERRA-2 [16] a web-service available worldwide that delivers time series data in association with NASA on their platform *(http://www.soda-pro.com/web-services/meteo-data/merra)*. The data on the phenomena associated with El Nino and La Nina years is obtained from the website of GGW [17] from ONI (Oceanic Nino Index).We have used 40 years rainfall and 37 years temperature data to carry out the present analysis. One of the initial steps in trend detection analysis is data quality assessment. Therefore, the present study is conducted to keep the authenticity of the dataset in mind and special emphasis was given to quality control and validation. Annual, seasonal and monthly analysis has been performed by taking monthly averages of rainfall and temperature records from both IMD and MEERA-2 dataset. The whole year is categorized into different seasons, mainly winter (January–February), pre monsoon (March–May), monsoon (June–September) and post-monsoon (October–December) in obedience with the scheme of seasons demarcation by IMD. To investigate the long term temporal trends in rainfall and temperature using parametric test, linear regression analysis was used. The student t-test has been employ to measure the significance of rainfall and temperature trends. If P value (probability) is less than 0.05 the trend is significant at 0.05 level and if P value is greater than 0.05 the trend is insignificant. Usually 0.05 level of significance means that the trend has the chance of 95% of being true [18]. To examine the degree of variability in rainfall, coefficient of variation (CV) has been computed.

$$Coefficient\ of\ variation: CV = \frac{\sigma}{\bar{X}} \times 100$$

Where, σ: Standard deviation, and $\bar{X}$: Mean.

4. Results and Discussion

4.1. Trends in Rainfall on Annual, Seasonal and Monthly Basis

Annual: Temporal distribution of long-term (40 years) annual and seasonal mean rainfall over both the sub-divisions unfolds interesting results as shown in Table 1. The annual rainfall is maximum (approximately 4506.3 mm) over coastal Karnataka minimum over Konkan and Goa (approximately 1590.4) Figure 2. High Intensity rainfall appears near the west coast and its adjacent oceanic region [19].The combined average annual rainfall of the whole region shows that minimum rainfall recorded over the time period was 362.9 mm and maximum 1058.60 mm (Figure 2).

Table 1. Annual and Seasonal Variation In rainfall over both the meteorological sub-divisions

Season	Mean (mm)	S.D. (mm)	C.V. (%)
Annual and Seasonal Variation in Rainfall Over Konkan & Goa			
Season	**Mean (mm)**	**S.D. (mm)**	**C.V. (%)**
Winter	0.89	2.34	262.1
Pre-Monsoon	42.1	78.25	185.87
Monsoon	**2549.11**	**483.69**	**18.97**
Post-Monsoon	133.11	111.44	83.72
Annual	**2725.12**	**504.16**	**18.5**
Annual and Seasonal Variation in Rainfall Over Coastal Karnataka			
Season	**Mean (mm)**	**S.D. (mm)**	**C.V. (%)**
Winter	2.4	7.84	326.66
Pre-Monsoon	186.1	173.11	93.02
Monsoon	**2957.9**	**421.63**	**14.25**
Post-Monsoon	263.55	146.63	55.61
Annual	**3410**	**436.1**	**12.78**

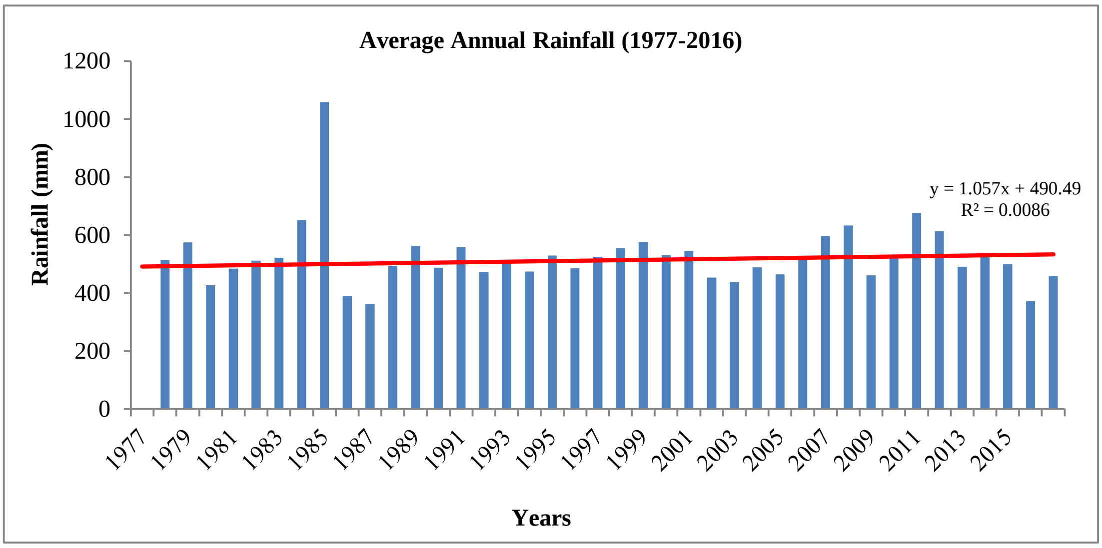
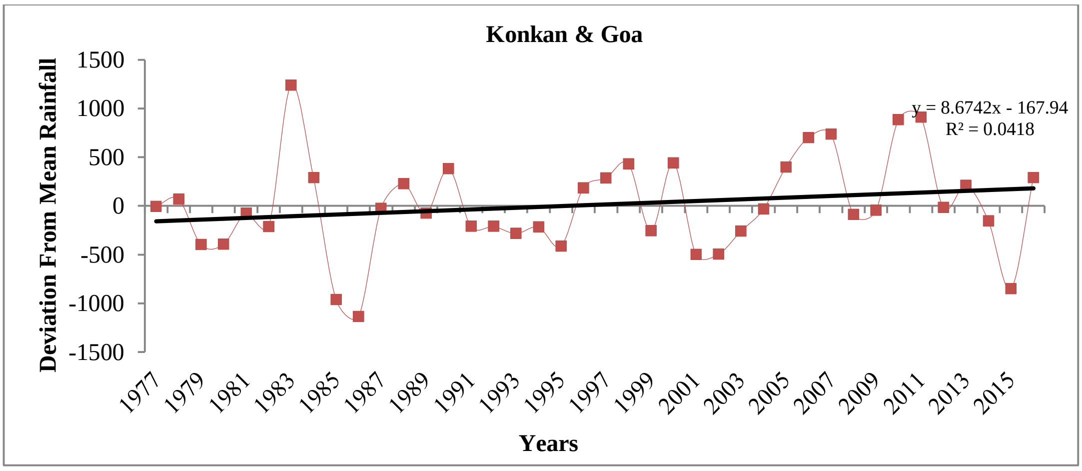


Figure 2. Average Annual Rainfall in the study area

Rainfall intensity progressively steps down from north to south which is in accordance with some earlier studies Soman et al. [20], Simon and Mohankumar [21]; Krishnakumar et al. [22]. The rainfall variability is high over Konkan and Goa (18.5%) than over Coastal Karnataka (12.78%) (Table 2). The rainfall varies from 1590.4 to 3663.9 with SD of 504.16 over Konkan and Goa (Figure 3, and Table 2); 2580.4 - 4506.3 with SD is over Coastal Karnataka (Figure 3).



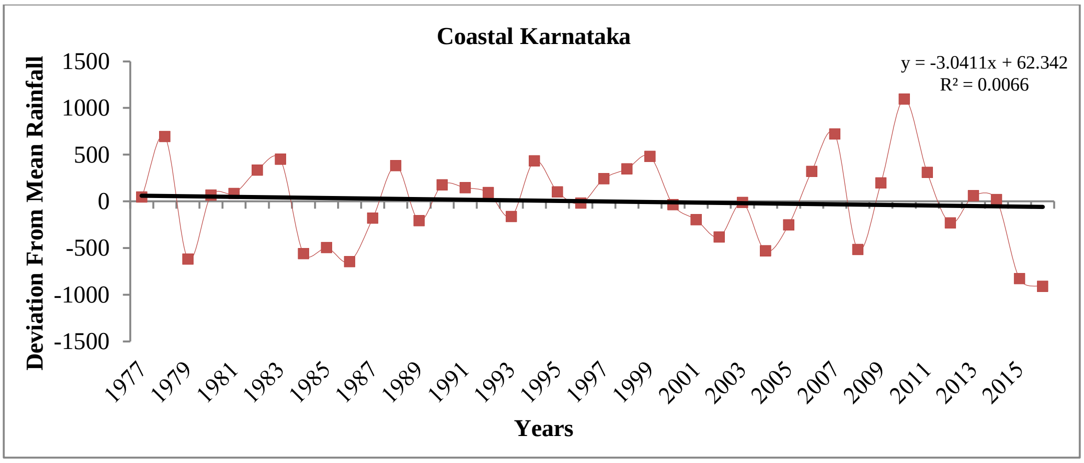


Figure 3. Average Annual Rainfall

Table 2. List of Extreme rainfall events over the time period

Sr. No.	Station	Date	Rainfall (mm)	State	Region	Source
1.	Dapoli	3 June, 1882	540	Maharashtra	Konkan & Goa	IMD
2.	Chiplun	4 June, 1882	530	Maharashtra	Konkan & Goa	IMD
3.	Roha	18 June, 1886	630	Maharashtra	Konkan & Goa	IMD
4.	Jawhar	28 July, 1891	660	Maharashtra	Konkan & Goa	IMD
5.	Matheran	24 July, 1921	660	Maharashtra	Konkan & Goa	IMD
6.	Karjat	18 July, 1958	610	Maharashtra	Konkan & Goa	IMD
7.	Khandala	19 July, 1958	520	Maharashtra	Konkan & Goa	IMD
8.	Harnai	5 Aug., 1968	800	Maharashtra	Konkan & Goa	IMD
9.	Mumbai (Colaba)	5 July, 1974	570	Maharashtra	Konkan & Goa	IMD
10.	Mumbai	31 July, 1975	110	Maharashtra	Konkan & Goa	Disaster Department (BMC)
11.	Bhira/Jambulpada	24 July, 1989	713	Maharashtra	Konkan & Goa	IMD
12.	Mumbai	16 June, 1990	113	Maharashtra	Konkan & Goa	Disaster Department (BMC)
13.	Mumbai	27 June, 1998	100	Maharashtra	Konkan & Goa	Disaster Department (BMC)
14.	Panjim	23 July, 1998	129.5	Goa	Konkan & Goa	Disaster Department (BMC)
15.	Mormugao	24 July, 1998	125.5	Goa	Konkan & Goa	Disaster Department (BMC)
16.	Karwar	19 June, 1998	105	Karnataka	Coastal Karnataka	Disaster Department (BMC)
17.	Mumbai (Santacruz, Vihar)	27 July, 2005	944, 1011	Maharashtra	Konkan & Goa	IMD
18.	Mumbai (Santacruz, Colaba)	30 June, 2007	343.1, 227	Maharashtra	Konkan & Goa	IMD
19.	Mumbai (Worli)	11 June, 2011	1058.89	Maharashtra	Konkan & Goa	Disaster Department (BMC)
20.	Mumbai (Worli)	19 June, 2015	320.3	Maharashtra	Konkan & Goa	Disaster Department (BMC)

The annual change in rainfall variability over both the meteorological sub-regions is statistically significant at 0.05 level with increasing rainfall over Konkan and Goa and decreasing over coastal Karnataka.

It has been observed that the pace of increase in rainfall from 2000 to 2016 was high because of greater fluctuations in temperature over the time period. The increase in temperature was high during 2000-2016 as compared to 1980-2000 in both the subdivisions. Thus, we can arrive at the possible generalizations for these two different trends in rainfall during the two periods. During the first period, the increase in both rainfall and temperature is relatively low. This leads to a reduction in land-sea thermal contrast and affect the patterns of wind flow over the study region. Thus, there is further reduction in moisture supply from sea to land which in turn explain the low rise in both rainfall and temperature. However, rainfall over coastal Karnataka was influenced by locally produced factors like length, width and height of the mountain summits. In the second period, the pace was high because of rapid increase in global temperature due to the phenomena of urbanization and industrialization.

Seasonal: Seasonal rainfall values range from 0 to 12 mm with SD of 2.34 mm (Winter); 0 – 261 mm with SD of 78.25 mm (pre-monsoon) (Figure 4, and Table 1); 1550–3555 mm with SD of 483.69 mm (monsoon); and 7.8 – 388 mm with SD of 504.16 mm (Post-monsoon)(Figure 5, and Table 1) over Konkan and Goa Sub-division. The Seasonal rainfall values range from 0 to 48 mm with SD of 7.84 mm (Winter); 10 – 607 mm with SD 173.11 mm (pre-monsoon) (Figure 4, and, Table 1); 2131– 3654 mm with SD 421.63 mm (monsoon); and 36 – 705 mm with SD 146.63 mm (Post-monsoon) (Figure 5, and Table 1)over coastal Karnataka.

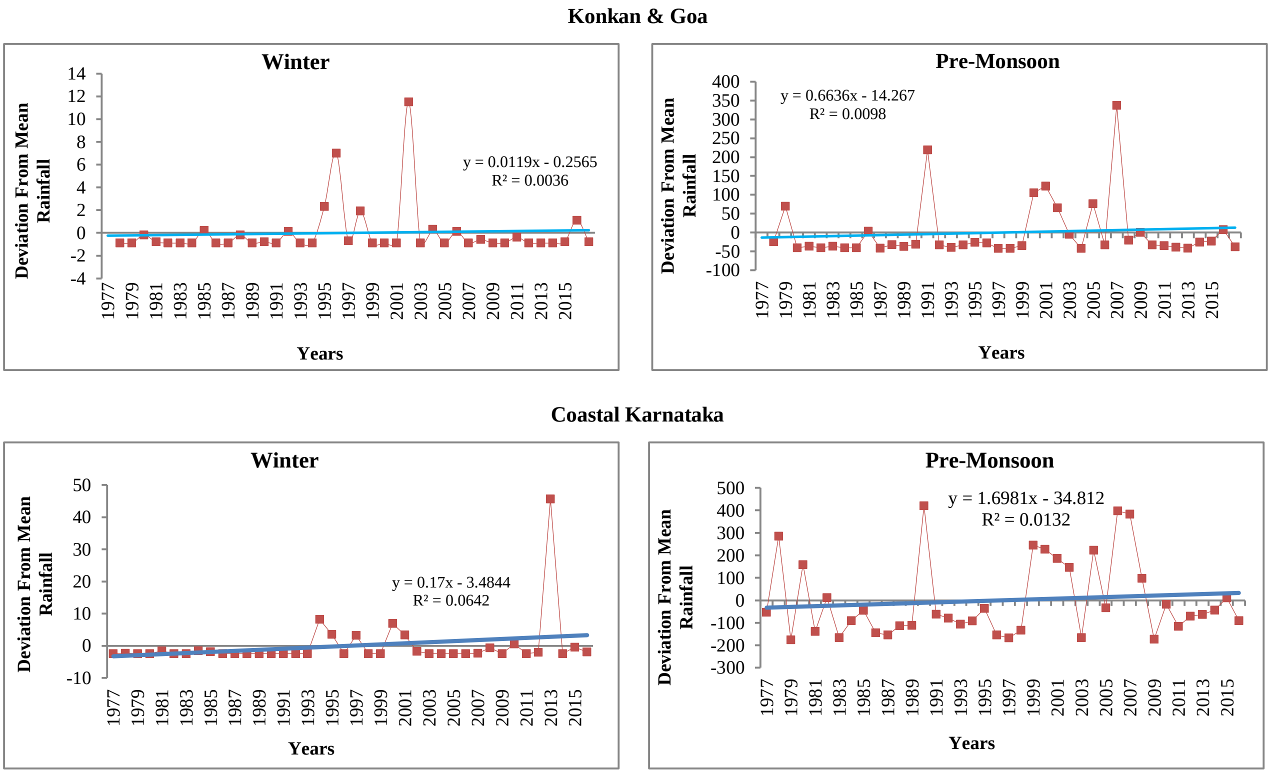


Figure 4. Winter & Pre- Monsoon rainfall trends of both the meteorological sub-divisions

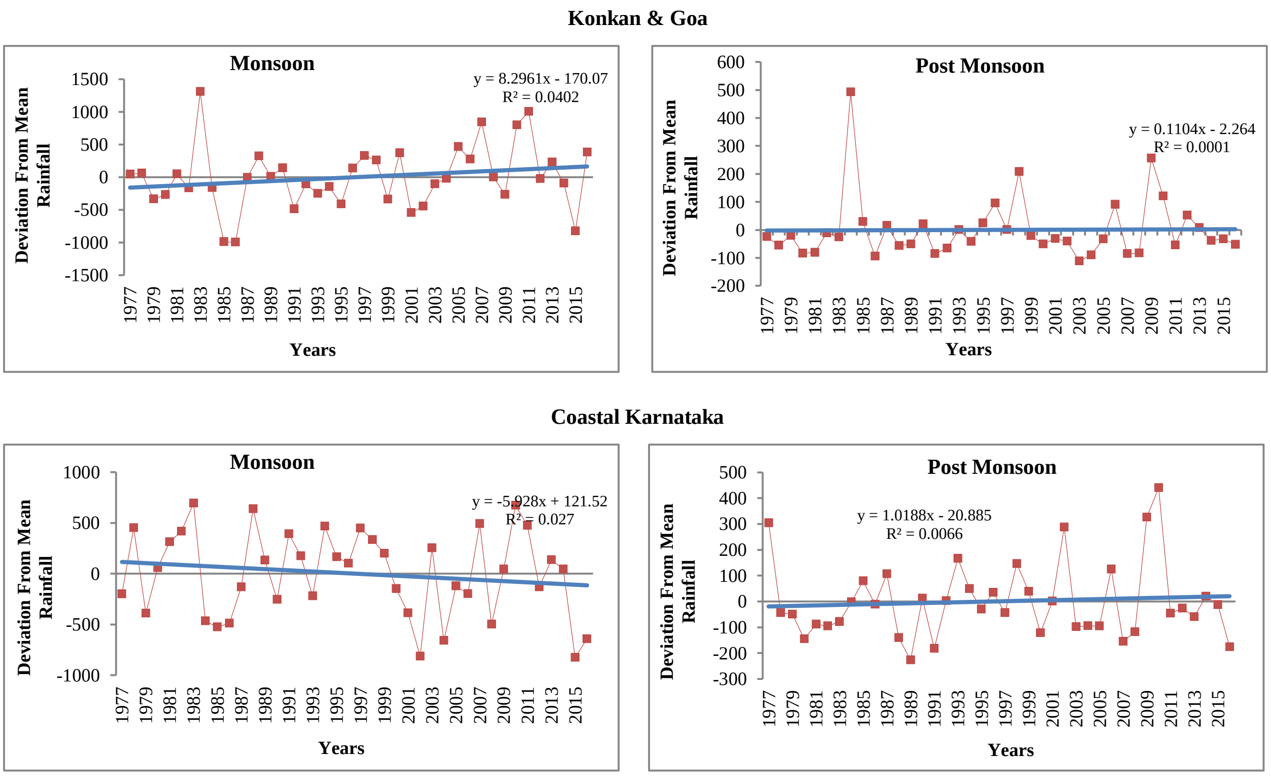


Figure 5. Monsoon & Post Monsoon rainfall trends of both meteorological sub-divisions

Monthly: Behaviour of monthly rainfall has been studied for individual months by subjecting them to student T-test. The monthly analysis of rainfall data shows that deviations in rainfall can be noticed in the month of January only. Remaining months of the first quarter are more or less the same over both the meteorological sub-divisions. The trend line in the months of April and May are straight shows that rainfall over both the regions is constant while in the month of June rainfall over Konkan and Goa and Coastal Karnataka is increasing and decreasing respectively. The deviations trend of third quarter shows that rainfall is increasing in the month of July and September and decreasing in the month of August over Konkan and Goa sub-region. However it is decreasing in the month of July and August and increase in September over Coastal Karnataka. The rainfall analysis of last quarter shows that rainfall is decreasing in the month of November and December and increasing in October over Konkan and Goa whereas it is increasing in October and December and decreasing in November over Coastal Karnataka (Figures 6 and 7).

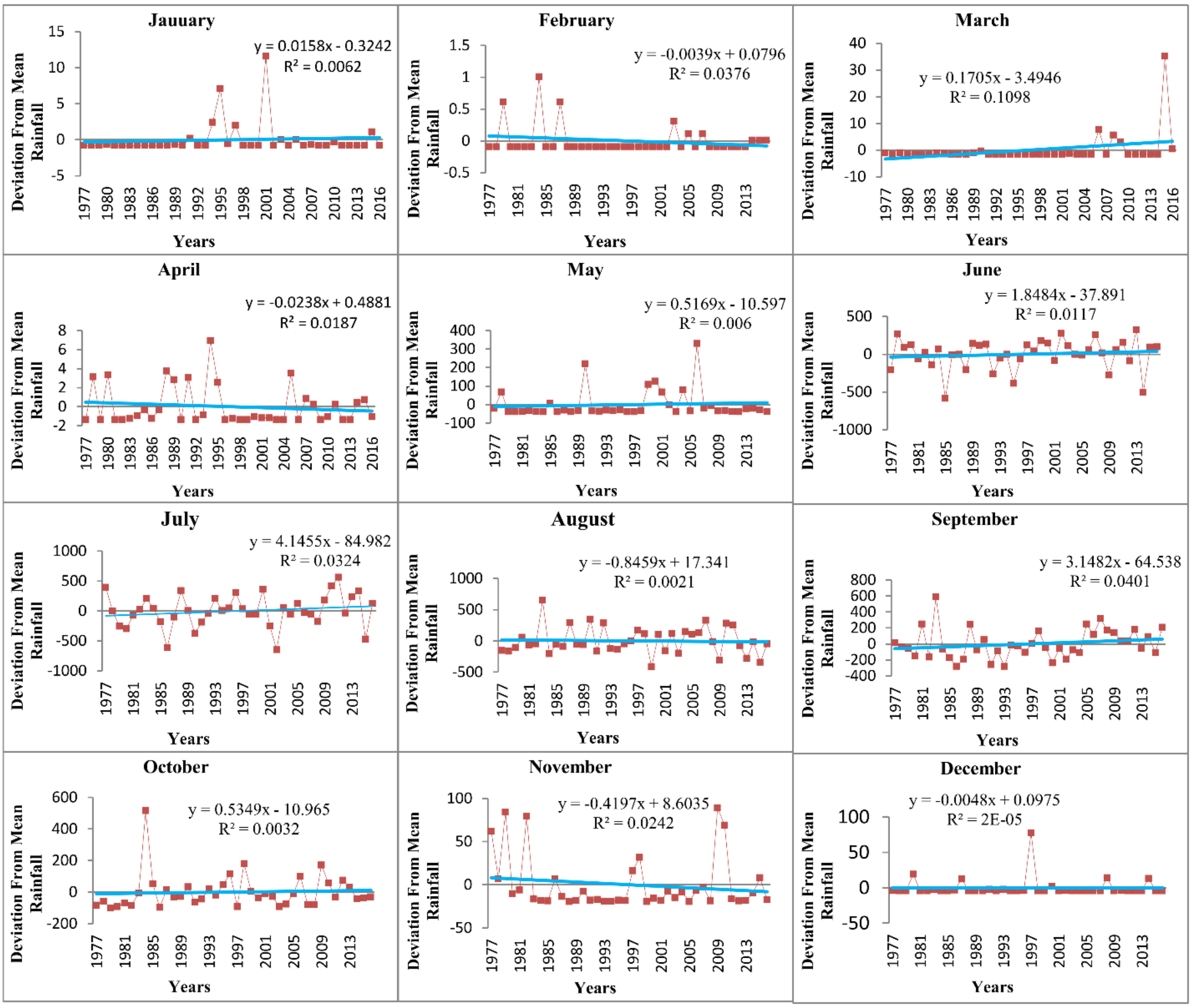


Figure 6. Monthly Rainfall Trends over Konkan & Goa

High intensity rainfall is observed in the month of June and July, whereas moderate to low rain was experienced in the month August and September. According to Xavier et al. [23] the main driving force behind the heavy rainfall in June and July could be the positive meridional temperature gradient of troposphere temperature over Indian region. Some of the other possible reasons as explained by Lau and Kim [24], Bollasina et al., [25] reported that in the month of May, the absorbing aerosol concentration increases over the northern Indian region which strengthens the meridional temperature gradient and enhances the monsoon precipitation during June to July. And in the month of August and September, suppressed rainfall activity over both the sub-divisions can be attributed to reduced thermal contrast between land and adjacent ocean. Another phenomenon was observed by Sivaprasad and Babu [26], an increased in marine aerosol concentration (i.e. sea salt) over Arabian Sea in early monsoon period. These aerosols act as a giant CCN (cloud condensation nuclei) and help in early formation of warm rain [27].

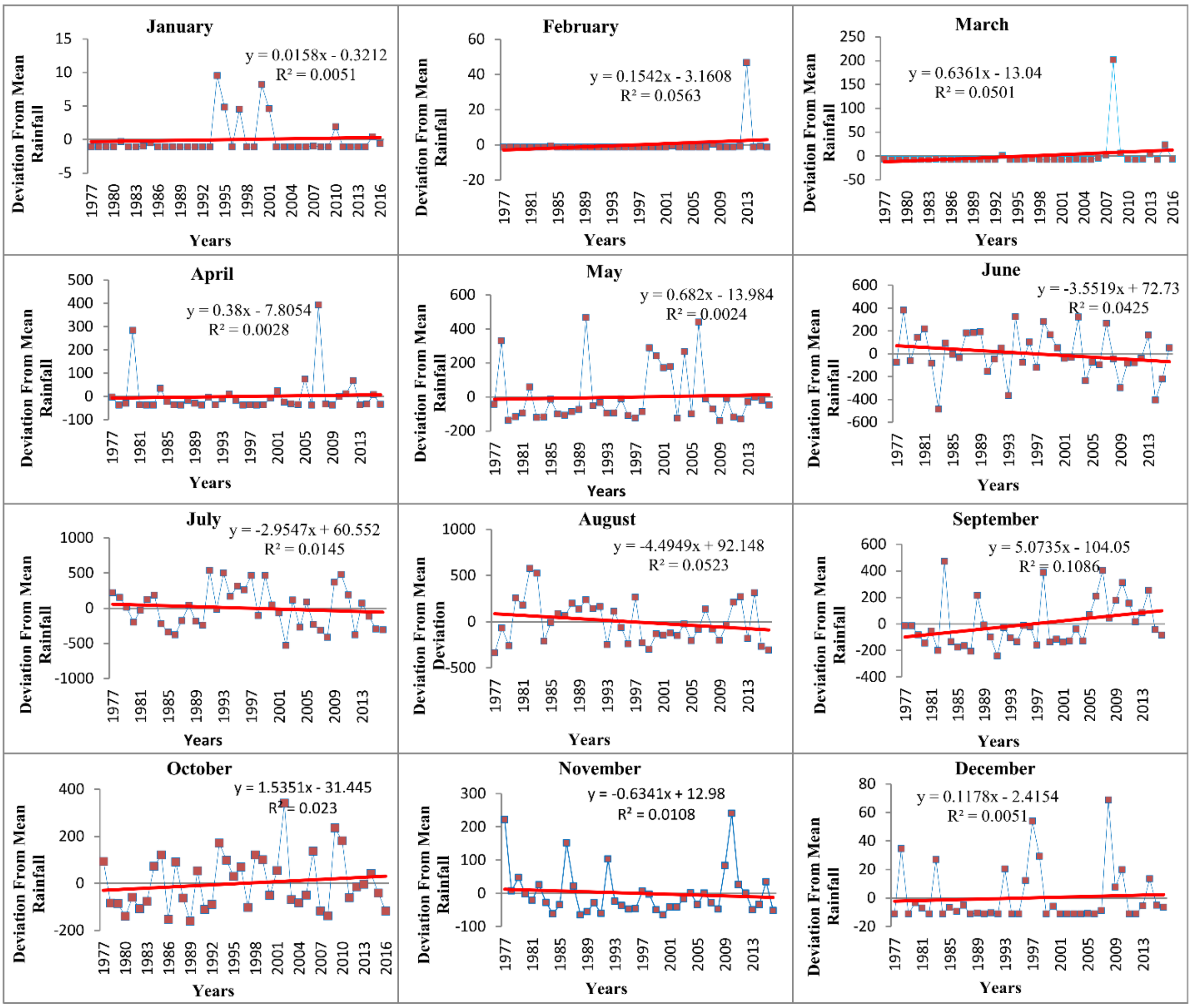
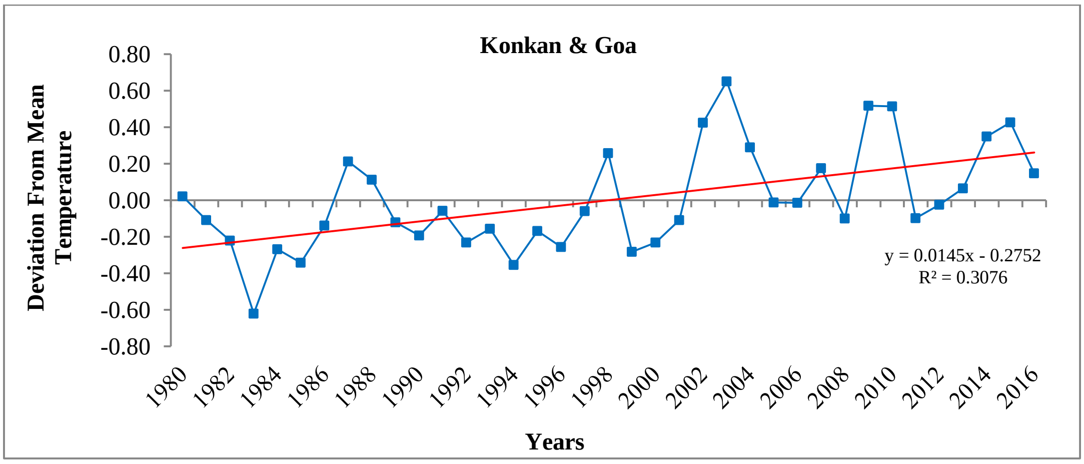


Figure 7. Monthly Rainfall Trends over Coastal Karnataka.

4.2. Linear Trends in Temperature on Annual, Seasonal and Monthly Basis

Annual: Annual trends over both the meteorological sub-divisions were positive and significant (Figure 8). The temperature trend for both the regions suggests a warming of 0.4°C over Konkan and Goa and 0.23°C over Coastal Karnataka during 1980-2016. The variation in temperature records typically ranges from 0.1 to 0.53°C. Possibly the rapid urbanization was the main cause behind this enormous warming. There are several studies that link temperature rise with rapid urbanization. Chung et al. [28] reported that mean monthly temperature at night over Korea was 0.5°C higher during 1971-2000 as compared to 1951-1980. He described rapid urbanization was the main cause behind this change in temperature. This provides a good encouragement for further analysis of climate warming in the region.



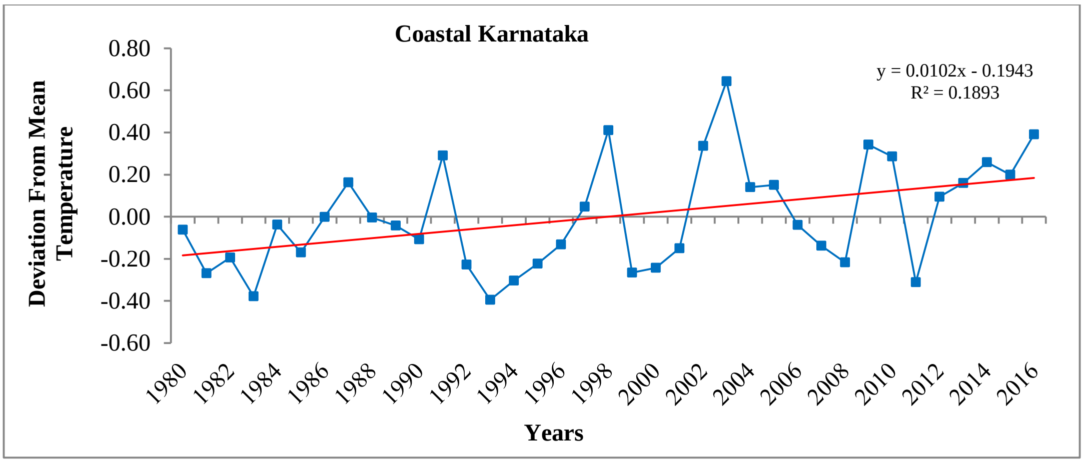


Figure 8. Average Annual Temperature

Seasonal: The Western Ghats remain an important part of the country due to its climatic influence on the Indian subcontinent. Temperature trends of all the seasons are shown in Figures 9 and 10. The slope of trend line in winters of both the sub-divisions was almost uniform shows a slight increase in winter temperature over the time period and the trends were not significant. Increase in winter temperature is 0.2°C over Konkan and Goa during 2001-2016. However, there was significant increase in pre-monsoon temperature only over Konkan and Goa which is 0.5°C. The change in monsoon and post-monsoon temperature were significant over both the meteorological sub-divisions which is 0.3°C in Monsoon months and 0.4°C in Post-Monsoon season. However, the intensity of increase in temperature is high in post-monsoon season.

Konkan & Goa

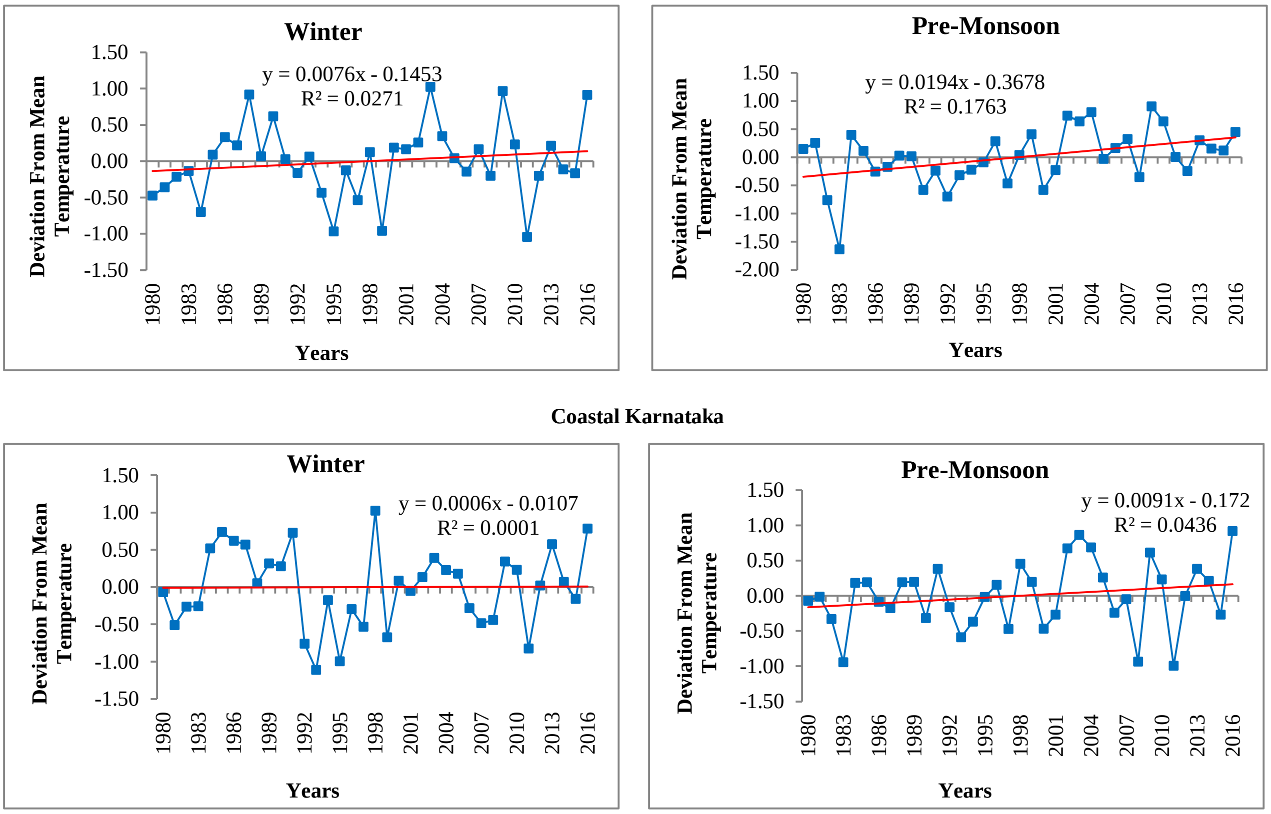


Figure 9. Trends in temperature of winter and pre-monsoon over both the subdivisions

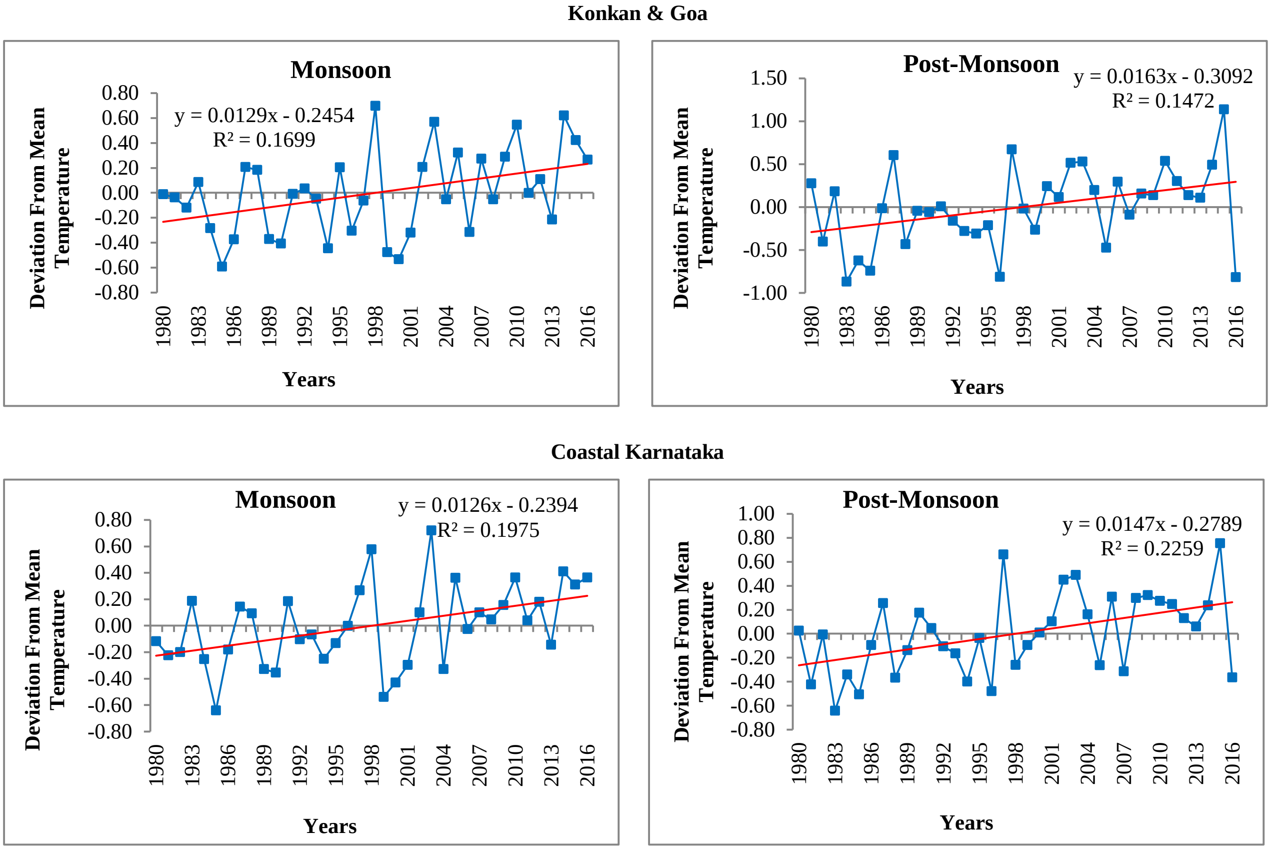
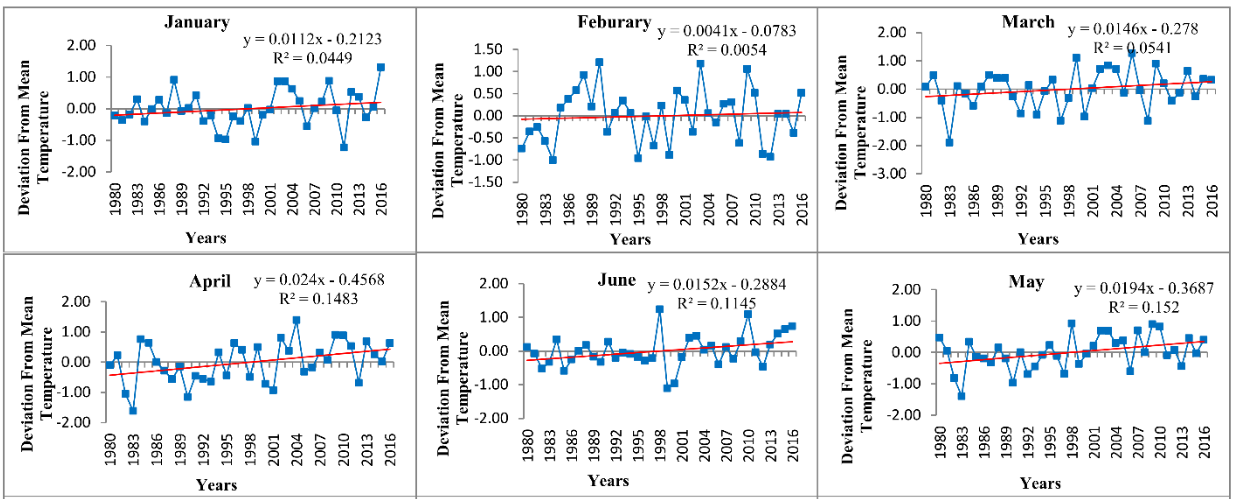


Figure 10. Trends in temperature of monsoon and post-monsoon over both the subdivisions

Monthly: Mere analyses of Mean monthly surface temperature records are susceptible to errors because of possibilities of various inconsistencies. The main aim of present study was to detect the degree of warming or cooling in the region using regression technique which is known to produce 'true' estimates of the climate change as compared with the other available methods. The study was aimed at extending the knowledge of historical temperature change by combining the temperature data acquired from MEERA-2 and meteorological data from IMD. Monthly trends of temperature over Konkan and Goa were shown in Figure 11. The diagrams were clearly stated that all monthly trends were positive but the intensity of change is high in the months of January (0.42°C), March (0.43°C), April (0.53°C), May (0.49°C), October (0.41°C) and in December (0.42°C). Figure 12 shows monthly temperature trends over coastal Karnataka. All months shows positive change i.e. temperature over the time period is increasing and its intensity is high in the month of March (0.3°C), April (0.3°C), July (0.3°C), August (0.31°C), September (0.32°C), October (0.33°C) and November (0.34°C). This approves that the warming obtained by the analysis of temperature data carries the characteristics of climate of the region and establishes that Western Ghats region of India has witnessed a significant increase in temperature during a time-spam of 40 years i.e., 1980-2016.



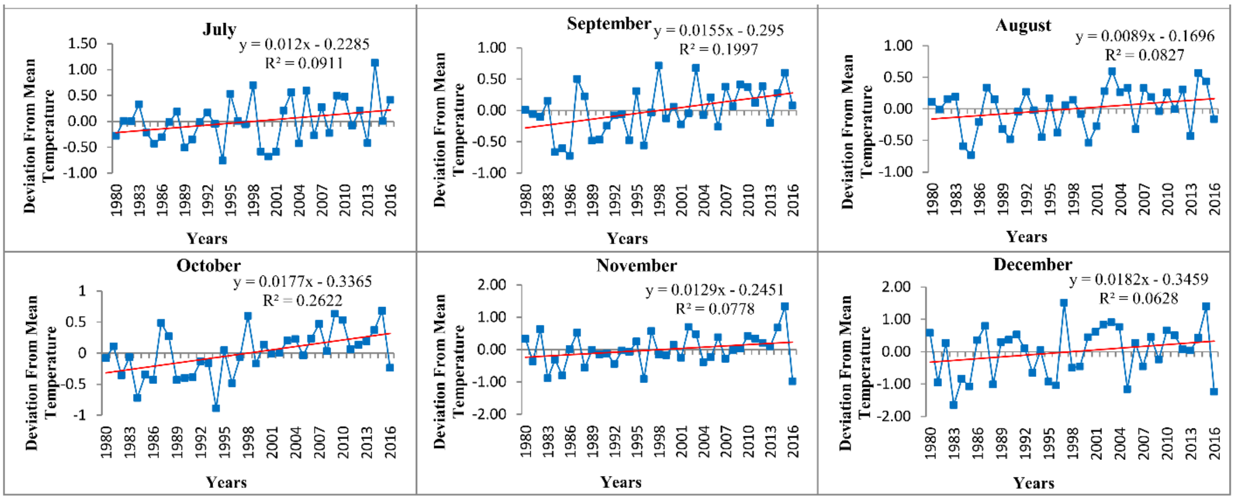


Figure 11. Monthly Temperature trends over Konkan and Goa

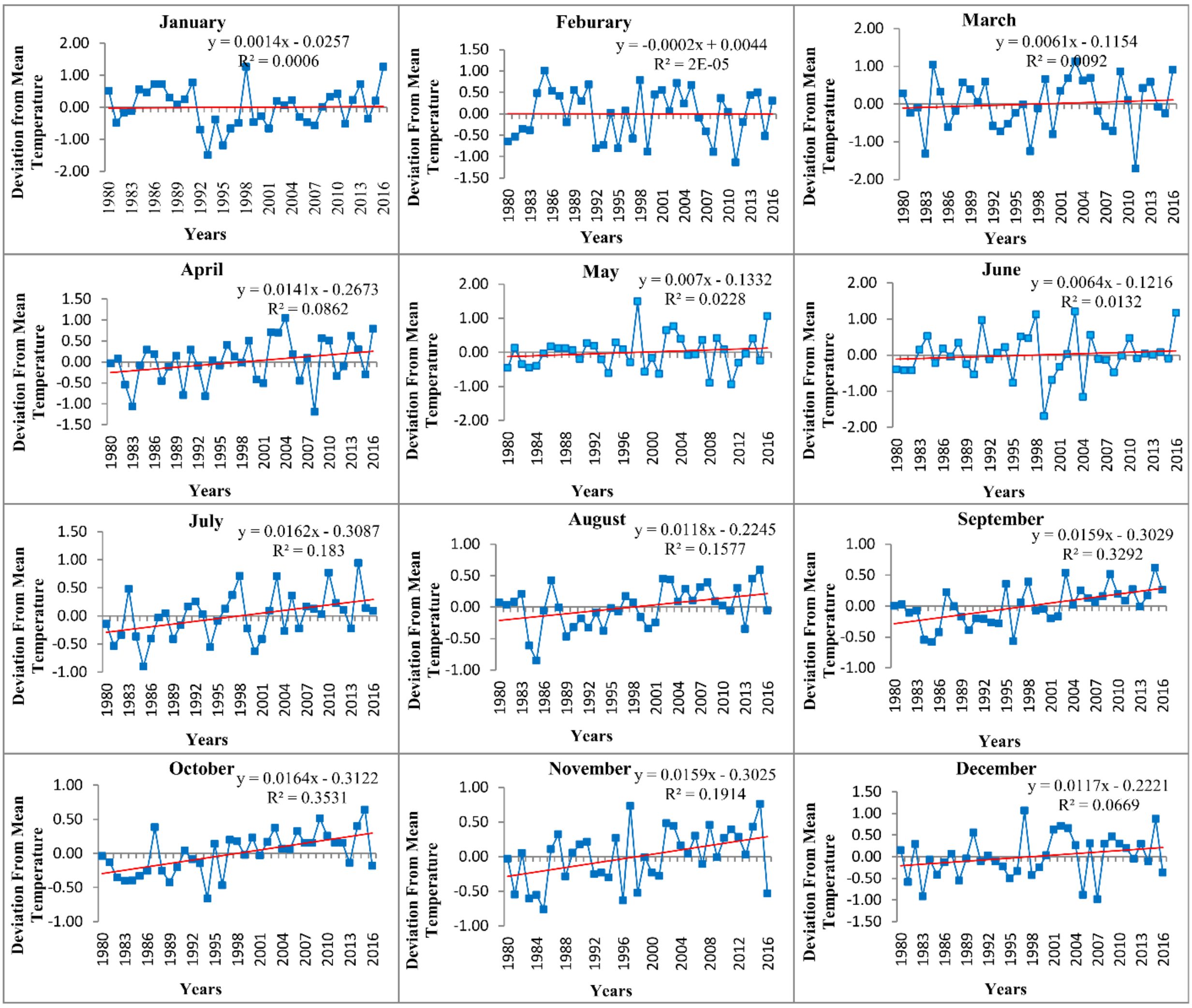


Figure 12. Monthly Temperature trends over coastal Karnataka

4.3. Heavy Rainfall Events

Table 3 shows a list of heavy and very heavy rainfall events in the study area from 1882 to 2016. Twade and singh [19] studied the patterns of heavy and very heavy rain events on the hilly terrain of WG and categorized event with a threshold of precipitation (R) in the range $150>R>120$ mm/day as heavy and exceeding 150 mm/day as very heavy using probability distribution of TRMM 3B42 v7 rainfall. The list is prepared by collecting data from different sources. The main aim behind the collection of data from 1882 was to understand the patterns and frequency of their occurrence over the time period. Results shows that heavy rainfall is observed in Konkan and Goa sub-division and only one event is observed over Coastal Karnataka in 1998. Tawde [29] examined that heavy rain bouts are least observed in Kerala and the prone area of heavy rainfall events (threshold $150 > R > 120$ mm/day) between 16.25–17.25 ∘N and 73.25–73.75 ∘E in Maharashtra with approximately two events per year. In Maharashtra, the area between 16.25–16.50 ∘N and 73.25–73.50 ∘E receives approximately three very heavy rain events ($R > 150$ mm.day^{-1}) per year. Another place catches the attention in and area around Mumbai between 18^{o} and 19^{o} N. The frequency and intensity of extreme rainfall events is increasing in the last few decades due to phenomenon of urbanization and industrialization.

Table 3. List of El-Nino and La-Nina Years

Sr. No.	Categories							
	Very Strong El-Nino	**Strong El-Nino**	**Moderate Eli-Nino**	**Weak El-Nino**	**Neutral**	**Weak La-Nina**	**Moderate La-Nina**	**Strong La-Nina**
1	1982	1987	1986	1977	1978	1984	1989	1988
2	1983	1997	1991	1979	1980	1985	2011	1998
3	2015	-	2004	2005	1981	1993	-	2007
4	2016	-	-	2009	1990	1995	-	2010
5	-	-	-	-	1992	1999	-	-
6	-	-	-	-	1994	2000	-	-
7	-	-	-	-	1996	2001	-	-
8	-	-	-	-	2002	2008	-	-
9	-	-	-	-	2003	-	-	-
10	-	-	-	-	2006	-	-	-
11	-	-	-	-	2012	-	-	-
12	-	-	-	-	2013	-	-	-
13	-	-	-	-	2014	-	-	-

4.4. ENSO Effect on ISMR (Indian Summer Monsoon Rainfall)

The performance of monsoon rains on longer temporal scale are influenced by the planetary scale features such as the intensity of Hadley Cell and Walkar circulation which depend upon the variations in meridional and zonal temperature gradients respectively. "The tendency of pressure at stations in the Pacific and rainfall in India and Java (presumably also in Australia and Abyssinia) to increase, while pressure in the region off the Indian Ocean decreases" [30-32]. The deviations in annual rainfall over both the meteorological sub-divisions are associated with the El-Nino and La-Nina phenomena. The relationship between ENSO and ISMR is negatively correlated, i.e., the rainfall over the Western Ghats is influenced by locally produced factors like topography (length and width), elevation, aspect of slope, and SST (Sea Surface Temperature) over the Arabian Sea. This can be shown in the annual and monsoon diagrams of both the sub-divisions given below. This phenomenon seems true when we look at the bars of 1982, 1983, 1997, 1999, 2001, 2005, and 2016 (Figure 13, and 14). These variations may exist because of internal epochal variability and other climatic factors. However, there were also some other factors which could influence the Indian monsoon, like Australian summer monsoon onset, Eurasian snow cover, Indian ocean dipole and many more.

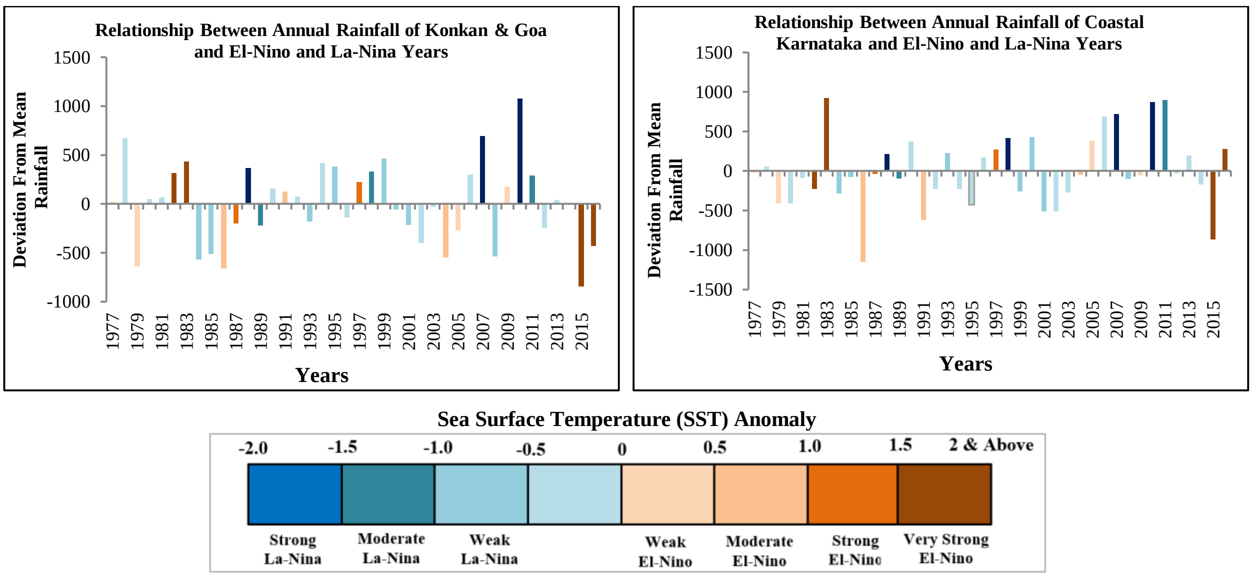


Figure 13. Relationship between annual rainfall and El-Nino and La-Nina Years

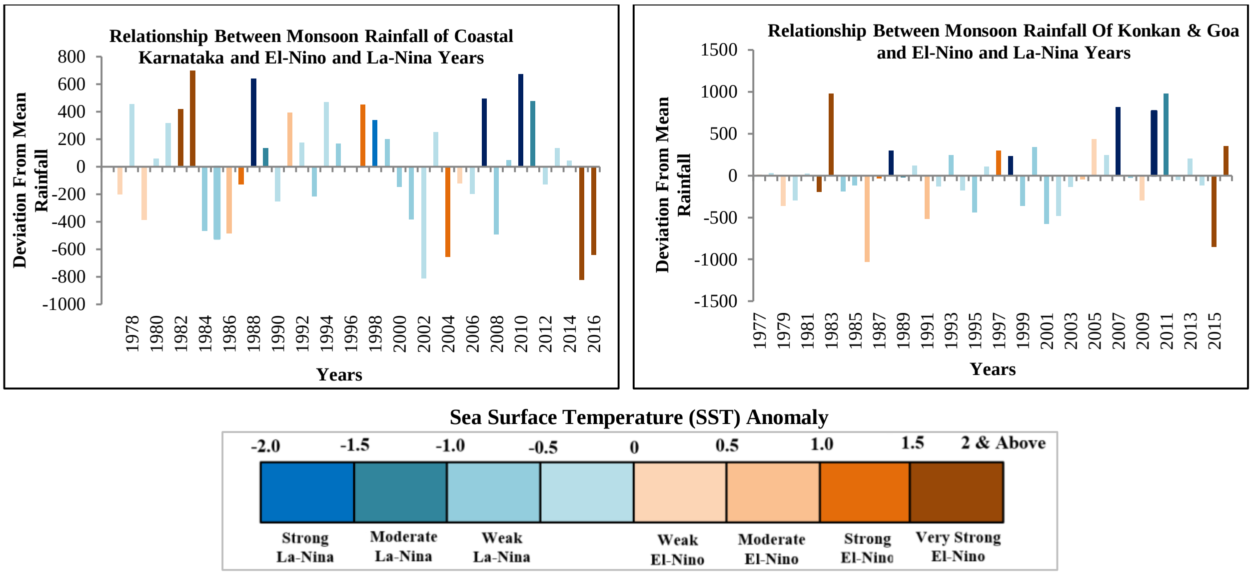


Figure 14. Relationship between Monsoon rainfall and El-Nino and La-Nina Years

5. Conclusion

The main aim of the present study was to investigate the changing trends and patterns in rainfall and temperature over the Konkan & Goa and Coastal Karnataka (India). The present work concludes that the combined average annual trend of rainfall over both the meteorological sub-divisions shows that rainfall is increasing over Konkan and Goa and decreasing over Coastal Karnataka. The change in annual rainfall is significant at a 0.05 level, while temperatures show positive trends over the time period. The change in rainfall patterns was significant only in the monsoon season, with increasing and decreasing trends over the Konkan and Goa and Coastal Karnataka respectively. Monthly trends of both the sub-divisions show that rainfall over Konkan and Goa is increasing in the months of July and September, whereas it decreases in July and August and increases in September over coastal Karnataka. The coefficient of variation (%) shows that rainfall over both the meteorological sub-divisions is uneven. The variations are high over Konkan and Goa (18.5%) than coastal Karnataka (12.78%). Further the intensity of heavy rain showers is high in the months of June and July as compared to August and September, i.e., the orography of WG does not influence the temporal variability of rainfall as it impacts the spatial variability of rainfall over both the meteorological sub-divisions. Heavy and very heavy rainfall events are more common over the Konkan and Goa. And their frequency and intensity have been increasing in the last few decades. Further rainfall over WG is influenced by locally produced factors like length, width and height of a mountain summit, local relief and apexes. These variations in rainfall and temperature exist because of internal epochal variability and other climatic factors as well. Possibly, recent changes were due to global warming and some anthropogenic factors like rapid urbanization, which contributed a lot to changing the patterns of rainfall and temperature over WG.

6. Declarations

6.1. Author Contributions

Conceptualization, R.M. and A.G.; methodology, R.M.; software, R.M.; validation, R.M. and A.G.; formal analysis, R.M.; investigation, R.M.; resources, R.M.; data curation, A.G.; writing—original draft preparation, R.M.; writing—review and editing, A.G.; visualization, R.M.; supervision, A.G.; project administration, A.G. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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