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Geographical Analysis of Rainy Days Over West Coast Region And Islands of India

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ABSTRACT
Climate change (CC), due to natural and manmade causes has received the attention of atmospheric scientists during the last four to five decades. As a part of such studies worldwide, efforts have been made to ascertain the impact due to CC on the characteristics and dynamics of Indian summer monsoon rainy days. A detailed analysis of data pertaining to rainy days over the West Coast Region (WCR) and islands of India has been necessitated to understand the impact of CC on the Southwest monsoon behavior.

In this study, non-parametric test using the linear regression and student t-test were used to determine the existence and magnitude of any statistically significant trend in the seasonal rainy days, rainfall and cloud amount. To study the temporal trend of meteorological parameters, 60 years (1951-2010) daily rainy days data was collected for 16 selected stations distributed over 5 different Meteorological Subdivisions (MS) of India. The analysis reveals that the number of rainy days shows a significant decreasing trend during the monsoon season. However, the monsoon monthly trend shows mixed behavior. The decrease in rainy days was probed by the frequency of cyclones (1951-2010).The result indicates that the cloud amount and cyclonic systems prevailing over the WCR show decreasing trend. Further, investigations on rainy days indicate significant increasing trend during the last decade (2000-2010) over majority of the stations.

Key words: Geographical analysis, Climate change, Cloud amount, Cyclonic systems, West Coast Region, Linear regression, Student t-test, Meteorological Subdivisions, Rainfall trends

INTRODUCTION

It is a known fact, that Indian agriculture and allied sectors invariably depend on the Southwest monsoon system. Recently, climate variability in the form of flash floods and cyclones has resulted in destruction of crops, property and life. All of these impacts affect directly or indirectly the general socio-economic development of our country. Recent episodes of flash floods (Mumbai in July 2005, Leh-August 2010, Uttarakhand 2013) and monsoonal droughts (2002, 2009, 2012, 2014 and 2015) that engulfed the sub-continent have drawn the attention of the climate scientists to study the aberrant monsoon. Quantum of rain from the extreme rainfall events over a couple of days can cross the monthly mean and yet may not spread throughout the month or monsoon season. Hence, statistics pertaining to the extreme rainfall events provide a confusing picture, if data is collected randomly. In view of this a systematic data collection and analysis of extreme rainfall events is necessitated to understand characteristics and dynamics of abrupt changes in the number of rainy days over the country. Krishnan, R et al (2012) have noticed that rainfall and rainy days over the Western Ghats has been decreasing in the last decade or two compared to earlier period. This anomalous monsoon behavior in Western Ghats has raised various questions on the length or spatial extent of the monsoon season .Implications of this anomalous trend has assumed significance as, conversely, All India Summer Monsoon rainfall does not show any significant trend (Ramesh et al, 2007).

Understanding the extreme rainfall event is more important than the changes in mean pattern as they help proper crop planning, disaster management and mitigation. Planning is especially critical in regions that experience distinct wet and dry seasons. To ensure sustainable agriculture in a region, knowledge of the local climate (especially information about the rainy days) is important. Many analyses indicate that the second half of the 20th century has been dominated by variations on inter-annual to inter-decadal time scale and that trend estimates are spatially incoherent (Herath and Ratnayake, 2004). The annual rainfall and number of rainy days show a decreasing trend in the Southeast Asia region (ADB Climate Change Report, 2007; Suhaila et al, 2010). A study conducted by De et al (2004) found increasing trend in monsoon and annual rainfall in metro cities like New Delhi, Kolkata, Mumbai and Chennai. They attributed this to meso scale circulations near the cities. Extreme rain events play an important role in rainfall distribution, in relation to the above factor. Goswami et al (2006) investigated frequency and magnitude of extreme rain events in central India during monsoon season .They noticed increasing trend. Shrinking of the rainy season in India, may take place if the local trends conspire to change the land-ocean thermal gradients (Ramesh et al, 2007). Rajendran and Kitoh (2008) used a super high-resolution global model to study the impact of global warming on the Indian summer monsoon. Their analysis shows spatially varying rainfall projection, with increase in rainfall over interior regions and significant reduction in the orographic rainfall over the coastal regions of Kerala and Karnataka, and the eastern hilly regions around Assam. Rameshkumar, (2009) found decreasing trend in July rainfall and the monsoon season over India during 1951-2008. They also observed that there is changing moisture transport over the country between the excess and deficit monsoon years. The decreasing trend of rainy days was identified by Vijay Kumar et al (2011) at the annual and seasonal scale in 15 river basins of India. Guhathakurta et al (2011) also reported decreasing trend in the frequency of heavy rainfall events in major parts of Central and North India. They, however, noticed an increase in peninsular region and East & NE India. Kumar et al (2012) observed a significant decreasing trend in rainy days over Andaman and Nicobar region. Due to intense and periodic rain, huge quantity of water flows beyond the capacity of old drainage systems of the mega cities. Drainage system gets blocked due to siltation, dumping of waste material at the inlets of drainage, encroachment over natural drainage and water bodies (De et al 2013). The above studies used the rainfall data up to 2000.As noticeable change in monsoon pattern is noticed in the last decade and half, it is necessary for research studies to include recent updated data for better analysis.

As the changing monsoon rainy days suggest significant influence of potential climate impacts in India , it is important to determine whether the characteristics of Indian summer monsoon over the mountainous Western Ghats, West Coast Region (WCR) (Gujarat Coast excluded for analysis) and islands are also showing a change or not. For this, there is a need to investigate the increasing and decreasing trend patterns of the rainy days. It is also essential to study the intensity of rainfall and its relation to global climate change. Aforesaid studies suggest that there could be some correlation with the trends and associated synoptic conditions. We do believe that the present study provides reasonable answers to some of the unresolved issues associated with weather forecasting.

Materials And Methods

Location details of the Meteorological Subdivisions (MS) over the West Coast viz., Konkan and Goa (MS 23), Coastal Karnataka (MS 32), Kerala and Lakshadweep Islands (MS36) for segregating the monthly and seasonal (June-September) data are shown in Figure.1. The Daily rainfall data during the period 1951-2010 for 16 rain gauge stations spread over West Coast of India are shown in Figure.2 and details provided in the Table 1. These selected rain gauge stations have a continuous rainfall data series. Even the islands stations of the Arabian Sea and Bay of Bengal are considered, as these islands are integral part of monsoon coverage areas and one can have an insight into onset and development of monsoon activity by studying the data generated by the stations located in the islands. The monthly and monsoon rainfall datasets were obtained from the India Meteorological Department (IMD), Pune for the period 1950-2010. Monsoon season and monthly time series of the relevant indices are constructed for these rain gauge stations. A rainy day is defined by the IMD as the rainfall at particular station, amounting to 2.5 cm or more. The rainy days were computed from the daily rainfall data and linear trends were plotted for all the available West Coastal rain gauge stations. Monthly rainfall data for the monsoon season (June-September) was acquired from IMD for the period 1951-2006, which was used to identify the relationship with rainy days.

While analyzing the dataset, it was noticed that some observations are missing pertaining to some years. To overcome this problem, average of a particular month that has missing data has been utilized. This has been done to minimize the errors due to missing records. Same methodology was extended to the decadal analysis. Trends of rainy days over the study region were then compared with monthly rainfall data, using MS. Further, linear trend lines of rainy days were employed for the decadal analysis. For testing the trend significance Student's t – test was used at above 95% level. In order to compare the increasing/decreasing rainy days over the study region, the MS monthly rainfall data was used to identify the monthly and seasonal trends.

Dataset covering synoptic features like cyclones and depressions, and low cloud amount (in Oktas) was received from IMD, Pune for the period 1951-2010. The monthly frequency of cyclones and depressions dataset was obtained from IMD website. This is tabulated as monthly and season wise data. The low cloud amount has two recordings in a day- 0800 and 1700 hrs. The daily average was obtained from these two readings. Further, monthly and monsoon seasonal (June-September) averages were computed for nine stations.

Present study has been taken up as no attempt has been made earlier to establish the relationship between rainy days and rainfall amounts over the WCR of India. In the present study the data range is updated to 2010 to make the study more authentic and relevant. Geographically, the study region lies on the West Coast that receives copious rainfall. This region acts as the catchment for river system that drains almost 40% of the land areas in India. Further, this region plays a significant role for the onset and progress of monsoon. WCR of India is one of the regions in India that records high mean and high variability of rainfall

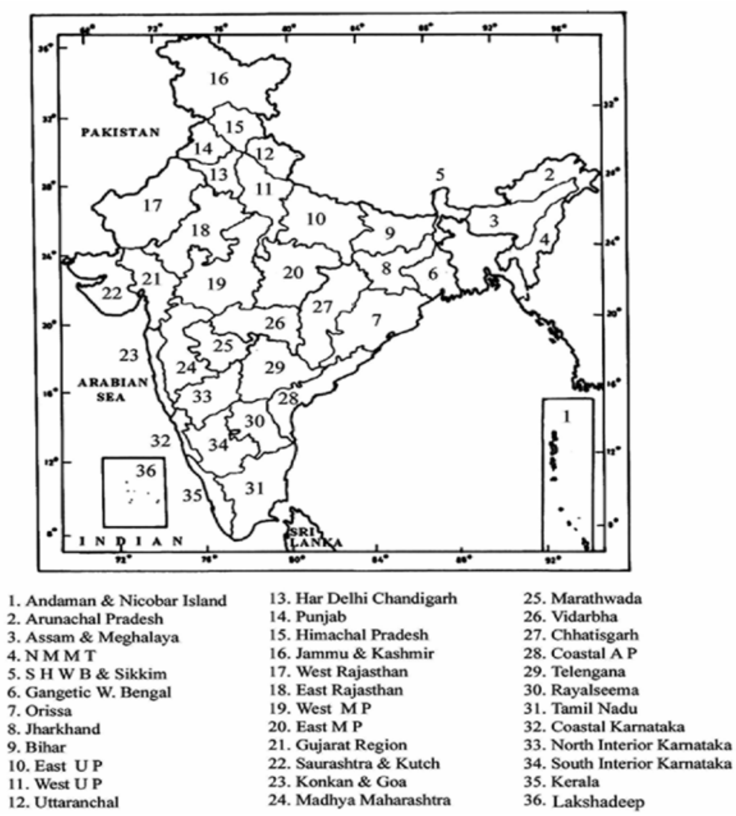

Figure 1. Meteorological subdivisions of India

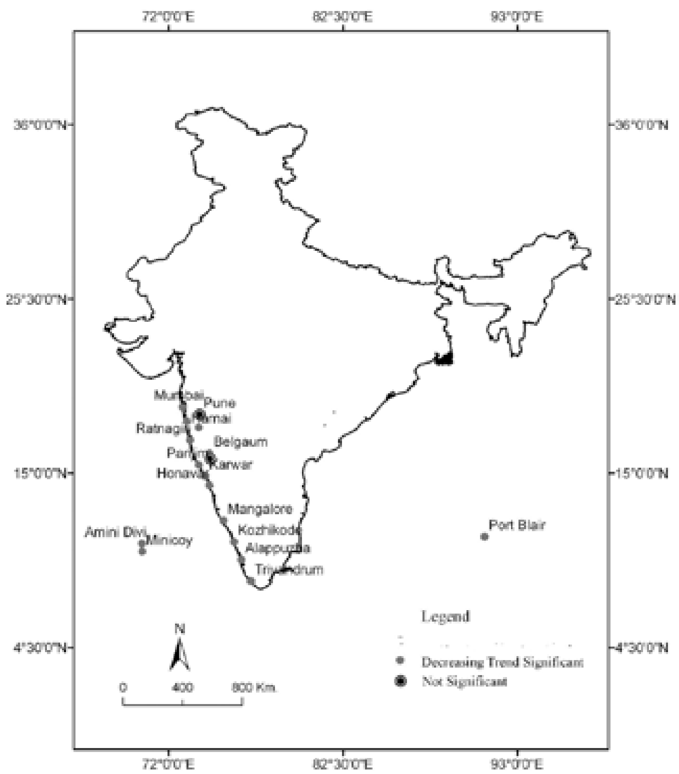

Figure 2. Rain gauge stations and Significant increase/decrease in June month rainy days

Table 1. Rain gauge stations in the study region

Meteorological subdivision (MS)	Stations	Elevation (m)	Latitude	Longitude
KONKAN and GOA (except Pune)	Harnai	67	17° 48' N	73° 6' E
	Mahabaleshwar	1,438	17° 55"N	73°40"E
	Mumbai	14	18°58'30"N	72°49"33"E
	Panjim	7	15°29′N	73°49′E
	Pune	560	18°31'13"N	73°51"24"E
	Ratnagiri	11	16°59′ N	73°18′E
COASTAL KARNATAKA (CK) MS-32	Belgaum	762	15°51′N	74°30′E
	Honavar	2	14°16′N	74°26′E
	Karwar	586	14°49′N	74°8′3″E
	Mangalore	22	12°54′N	74°51′21″E
KERALA MS-35	Alappuzha	1	9°29′54″N	76°20′19″E
	Kozhikode	1	11°15′32″N	75°46′49″E
	Trivandrum	10	8°29'15"N	76°56'54"E
LAKSHADEEP MS-36	Amini Divi	12	11° 7′ 27″N	72° 43′28″E
	Minicoy	2	8°17′N	73°3′41″E
ANDAMAN and NICOBAR (A and N) MS-1	Port Blair	1	11°37′ 25′"N	92°43'35″E

events and has a strong influence of local orography on the rainfall over this region.

It is inhabited by about 245 million people and also a hotbed for bio diversity and hence constitutes a unique eco-region. Therefore, studies on trends of rainy days, rainfall amount and sub divisional monsoon rainfall over these regions are relevant and essential. Keeping this in view an attempt is made to analyse and understand the spatial and temporal variations of both the series on monsoon and decadal trends over the region.

RESULTS AND DISCUSSION

Monthly and monsoon season

The trend analyses on monthly and monsoon season are discussed below. The results for the 16 stations representing the West Coast and island stations are given in Table 2 and shown in Figure. 2.

An effort has been made, as part of the study, to establish the contribution of each month's rainfall in the seasonal rainy days. The trend analysis shows that all the stations depict decreasing patterns for monsoon season as well as monthly rainfall. During the monsoon season, the decrease is significant at all the rain gauge stations. June records significant decrease at 14 stations (excluding two stations, Panjim and Belgaum). All the stations for the month of July report significantly decreasing trend.

In September, all stations except Mumbai, Kozhikode, Trivandrum and Amini Divi indicate significant decrease at 99% level. November shows conspicuous increase in rainy days at Mumbai and Karwar.

DECADAL TRENDS FOR MONTHLY AND MONSOON SEASON

The study was extended to identify decadal changes in rainy days during the monthly and monsoon season. The results from monthly and decadal trends in rainy days for all the 16 stations are detailed below and also indicated in Table 3.

1. Harnai: The month of June during the period 1951-2010 shows increase in rainy days. However, for the decade (1991-2000) significant decreasing trend has been noticed for the months of July and August. But, this behavior is not reflected in monsoon season. It is observed that the last decade 2001-2010 shows increasing trend in rainy days.
2. Mumbai (Colaba): This is the only station that shows an increasing trend in the month of June from 1961-2010. All the months during the decade from 2001-2010 show the same pattern.
3. Pune: June and August show conspicuous increase in rainy days from 1961-1990. The period 1951-1980 during the monsoonal season reported the same behavior. During 2001- 2010, for the month of June, a decreasing trend has been noticed. This trend has an impact on the monsoonal rainy days.
4. Mahabaleshwar: For the decade 1981-1990, June shows significant increase at 95% level, which is reflected in the monsoon. However, for June and August period

Table 2. Monthly and Monsoon rainy days
(*indicate 95% and ** 99% levels of significance)

1950-2010	June	July	Aug	Sept	Monsoon (Jun-Sep)
Harnai	-**	-**	-**	-**	-**
Mahabaleshwar	-**	-**	-**	-**	-**
Mumbai	-**	-**	-**	-*	-**
Panjim	-	-**	-**	-**	-**
Pune	-**	-**	-**	-**	-**
Ratnagiri	-**	-**	-**	-**	-**
Belgaum	-	-**	-**	-**	-**
Honavar	-**	-**	-**	-**	-**
Karwar	-**	-**	-**	-**	-**
Mangalore	-**	-**	-**	-**	-**
Allapuzha	-**	-**	-**	-**	-**
Kozhikode	-**	-**	-**	-*	-**
Trivandrum	-**	-**	-**	-*	-**
Amini D	-**	-**	-*	-*	-**
Port Blair	-**	-**	-**	-**	-**
Minicoy	-**	-**	-**	-**	-**

(during the decade 2000-2010) a decreasing trend is noticed. This has led to significant decrease in monsoonal rainy days.

5. Ratnagiri: During this decade (1971-1980), the months from June to August reported increasing trend, significant at 99% level. The same behavior is reported during the decade 1980-1990. The amplitude of the trend, however, was not significant during the monsoon season.
6. Panjim: The decade 1971-1980 exhibits an increasing trend during the months of June and July .This led to significant increase in the monsoonal rains. The period 2001-2010 shows increasing trend in all the months, except June.
7. Belgaum: All the months for the decade 1991-2000 witnessed decreasing trend. The trend was significant in the months of August and September. This had an impact on the monsoonal rains.
8. Karwar: The decade 1981-1990 shows a significant deceasing trend, during all the months leading to decrease in monsoonal decade. However, 1991 onwards there is an increasing trend during all the months.
9. Honavar: The period 1981- 1990 shows deceasing trend during the months of July and August. The same pattern is observed in the next decade. However, the decade 2001-2010 depicts an increasing trend during July and September leading to significant increase in monsoonal rains.
10. Mangalore: An increasing trend is observed from 1961-1990 for the month of June. The decade 2001 to 2010 exhibits the same trend.
11. Alappuzha: This station shows a continuous decreasing trend for the period 1951-2000, during the month of August. However, from 1971-2000 amplitude of decreasing trend has been less significant. During the recent decade, 2001 to 2010, all the months except June show an increasing trend.
12. Kozhikode: July shows an increasing trend for the period 1951-1980, while 1990-2000 shows significant decreasing trend during the months of June and August. This has resulted in significant decrease in the monsoonal decade.
13. Trivandrum: This station (during the decade 1951-1960) particularly during the month of August reported significant increasing trend. However, this is not reflected in monsoonal decade. For the period from 1991-2000, June and July exhibited significant decrease. This is not reflected during the monsoon season. However, the year 2001 onwards there is an increasing trend.
14. Amini Divi: The period 1951-2000 for the decadal monsoon shows decreasing trend. However, the trend was not significant, in spite of significant decrease in August, during 1961-1970 and 1991-2000.
15. Port Blair: This station exhibits a significant increasing trend during the decadal monsoon of 2001-2010.
16. Minicoy: The decade 1970-1980 during the month of July to September shows a decreasing trend that led to significant decrease in the decadal monsoon. Likewise, the month of August during the period 1991-2000 reported significant decrease. This had an impact on the monsoon season. The last decade (2001-2010) shows significant increase in the month of June, leading to significant increase in monsoon season.

Table 3: Decadal Trends for monthly and monsoon season

Harnai	**J**	**JY**	**A**	**S**	**M**	Karwar	**J**	**JY**	**A**	**S**	**M**
1951-60	+	-	-	+	+	1951-60	-	-	0	+	-
1961-70	+	0	-	-	-	1961-70	+	+	-	-	-
1971-80	+	+	-	-	-	1971-80	+	+	-	+	+
1981-90	+	+	+*	+	+	1981-90	-*	-**	-**	-**	-
1991-00	+	-*	-*	-	-	1991-00	+*	+*	+	+	+
2001-10	+	+	+	+**	+	2001-10	+	+	+	+**	+*
M'baleswar						Mangalore					
1951-60	-	-	-	+	+	1951-60	-	-*	0	+	+
1961-70	+	+	-	-	-	1961-70	+	+	-	-	-
1971-80	-	-	+	+	+	1971-80	+	0	-	+	+
1981-90	+*	+	0	+	+	1981-90	+	-	0	-	-
1991-00	-	-	-*	+	-	1991-00	-	-	-*	+	-
2001-10	-	+	-	+*	-**	2001-10	0	+	+	+*	+
Mumbai						Allapuzha					
1951-60	0	-	-	+*	+	1951-60	0	+	-	+	+
1961-70	+	-	-	-	-	1961-70	+	+	-	-	+
1971-80	+	+	-	-	+	1971-80	+	+	-	-	-
1981-90	+**	-	+	+	+	1981-90	-	-	-	0	-
1991-00	+	-	-*	0	-	1991-00	-*	-*	-	+	-
2001-10	+	+	+	+**	+*	2001-10	-	+*	+	+	+*
Pune						Kozhikode					
1951-60	-	+	+	+*	+	1951-60	-	+	-	+	+
1961-70	+	-	+	+	+	1961-70	+	+	-	-	-
1971-80	+*	+	+*	-	+	1971-80	+	+	+	-	+
1981-90	+	+	0	-	+	1981-90	0	0	-	-	-
1991-00	-	-	-	-	-	1991-00	-*	-	-*	0	-*
2001-10	+	+	+	+	+*	2001-10	-	+*	-	+	+
Ratnagiri						Trivandrum					
1951-60	0	-	0	+	+	1951-60	-	+	+*	+	+
1961-70	+	+	-	-*	-	1961-70	+	-	-	-	-
1971-80	+	+	+	-	+**	1971-80	0	-	+	0	+
1981-90	+*	+	+	0	+	1981-90	0	0	-	0	-
1991-00	0	-**	-*	-	-*	1991-00	-**	-*	-	+	-
2001-10	+	+	+	+**	+*	2001-10	+	+	-*	+	+**
Panjim						Amini Divi					
1951-60	+	-	+	+	+	1951-60	-	-	0	+	-
1961-70	+	+	-	-	-	1961-70	+	-	-**	-	-
1971-80	+	+	0	+	+*	1971-80	+	+	-	-	-
1981-90	+	-	0	+	0	1981-90	-	+	-	-	-
1991-00	+	-*	-**	-	-	1991-00	-	-	-**	0	-
2001-10	-	+	+*	+**	+*	2001-10	+	+*	+	+*	+
Belgaum						Port Blair					
1951-60	-	-	-	+	-	1951-60	-	0	+	+	+
1961-70	+	-	+	-*	-	1961-70	+	+	-	-*	-
1971-80	+*	+	+*	+	+	1971-80	-	+	+	-	+
1981-90	+	-	-*	-	-	1981-90	0	-	-	-	-
1991-00	-	-	-**	-*	+*	1991-00	-	-	-*	-*	-
2001-10						2001-10	+	+	-	+*	+**
Honavar						Minicoy					
1951-60	-	-	-	+	0	1951-60	-	-	+	+	-
1961-70	0	+	-	-	-	1961-70	+	0	-	-	-
1971-80	+	0	0	-	0	1971-80	+	-	-	-	-*
1981-90	+	-	-	+	+**	1981-90	0	-	-	-	-
1991-00	-	-*	-*	0	-*	1991-00	-	-	-**	+	-*
2001-10	0	+	-	+*	+**	2001-10	+*	0	+	+	+**

Note: **J**- June, **JY**- July, **A**-August, **S**-September and **M**- Monsoon season

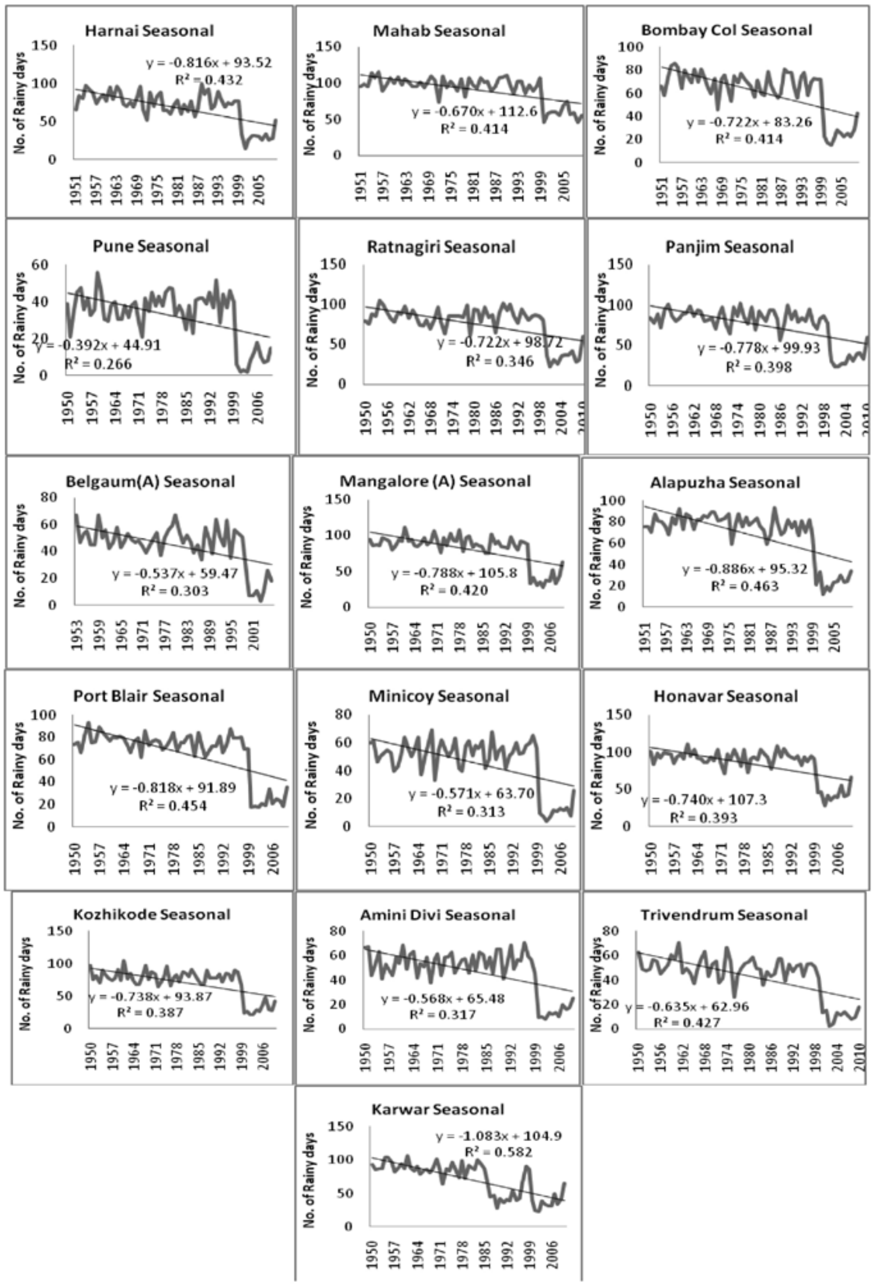

Figure 3. Trend lines of rainy days over the stations during the monsoon season

The above decadal trends for almost all the stations in the WCR (during the period 1950-2010) show decreasing trend. However, sudden increase in the number of rainy days from 2000 onwards is observed. The decadal study shows that the last decade 2001-2010 exhibits an increasing trend in majority of the stations.

Trends In Monthly And Seasonal Rainfall

Fourteen stations that have long and continuous data series were used. However, Honavar and Alapuzha are omitted as they have gaps in data series. Trend lines in rainfall on monthly and seasonal basis are shown in Table 4. During the monsoon season, majority of the stations (9/14) show significant decreasing trend. The decrease in rainfall at Mumbai Colaba is due to the decrease during June and July, while at Belgaum the decrease in rainfall in the rest of the months, especially during July contributed to the decreasing trend. Five stations show marginally increasing trend.

Table 4. Monthly and seasonal rainfall (* indicate 95% and ** 99% levels of significance)

Sr No.	Stations	June	July	Aug	Sept	Mon
1	Mumbai Colaba	-	-	+	+	-*
2	Pune	+**	-	+*	+	+
3	Harnai	-	-	-	-	-
4	Ratnagiri	+	-	+	+	+
5	Mahabaleshwar	+	-*	-	-	-
6	Panjim	+	-	-	-	-
7	Belgaum	+	-**	-	-	-*
8	Karwar	+	-	+	-	-
9	Mangalore	+**	-	+	-*	+
10	Kozhikode	-	-*	-	-	-
11	Trivandrum	-	-	+	+	-
12	Minicoy	+	+	+	-	+
13	Amini Divi	-	-	+	+	+
14	Port Blair	-	-	-	-	-

Table 5. Correlation of monsoon rainy days and seasonal rainfall amount (* indicate 95% and ** 99% levels of significance)

Sr. No.	Stations	Monsoon (b values)	level of significance
1	Mumbai Colaba	0.060x	**
2	Pune	0.054x	*
3	Harnai	0.058x	**
4	Ratnagiri	0.045x	*
5	Mahabaleshwar	0.015x	*
6	Panjim	0.086x	**
7	Belgaum	0.146x	**
8	Karwar	0.046x	**
9	Mangalore	0.062x	**
10	Kozhikode	0.088x	**
11	Trivandrum	0.110x	**
12	Minicoy	0.187x	**
13	Amini Divi	0.133x	**
14	Port Blair	0.126	**

Monthly rainfall analysis shows that Mahabaleshwar, Belgaum and Kozhikode are experiencing significant decrease, particularly in the month of July.

Correlation between seasonal rainy days and seasonal rainfall for 14 stations are presented in Table 5. Positive correlation between these two variables (at 95% level) is noticed in all the stations, except Pune. The highest rate of increase is observed at Minicoy followed by Amini Divi, Port Blair, Trivandrum and Belgaum. The stations having highest rate of slope (b values), particularly south of 10^{o} N latitude indicate a positive relation.

Sub Divisional Rainfall Trends

The study was extended to investigate both monthly and seasonal rainfall trends over MS. This analysis suggests the link between the rainy days and rainfall trend over the five MS. The rainfall trend analysis reveals that during the monsoon season, Kerala and Andaman & Nicobar (A and N) Islands show significant decreasing trend (Table 6). This could be attributed to significant decrease in rainy days in rain gauge stations of both MS.

It is observed that Konkan & Goa and Lakshadweep

Table 6. Monthly and Monsoon rainfall
(* indicate 95% and ** 99% levels of significance)

MS	June	July	Aug	Sept	Monsoon	b- values for monsoon
Andaman and Nicobar (MS1)	-**	-	-	-*	-**	-3.480x
Konkan & Goa (MS 23)	+	-	+	+	~	0.389x
CK (MS 32)	+**	-	+	+	+*	3.62x
Kerala (MS 35)	-*	-**	-	+	-**	-4.445x
Lakshadweep (MS 36)	-	~	-	~	~	0.116x

Note: ~ no trend

Table 7. Trends in Low cloud amount (* indicate 95% and ** 99% levels of significance)

Sr. No.	Stations	Data Period	Low cloud Increase/ decrease	R^2
1	Harnai	1970-2002	+	0.003
2	Mumbai	1969-2006	-**	0.221**
3	Pune	1969-2005	+*	0.002*
4	Panjim	1964-2003	-	0
5	Mahabaleshwar	1969-2005	-*	0.049*
6	Karwar	1952-2003	-**	0.036
7	Honavar	1951-2002	-**	0.033
8	Mangalore	1969-2004	-**	0.361**
9	Kozhikode	1951-2000	-**	0.026
10	Allapuzha	1954-2000	-**	0.004
11	Trivandrum	1969-2003	+	0.025
12	Amini Divi	1969-2005	+	0.012
13	Minicoy	1969-2005	+**	0.251**
14	Port Blair	1969-2005	-	1E-05

show no trend, while CK reported significant increasing trend. Month wise analysis indicates that during the month of June, Konkan & Goa and CK reported increasing trend. The magnitude of the trend was significant for CK. Rainfall is significantly decreasing at Kerala. CK and Konkan & Goa have similar monthly trends, except during July. During the monsoon season, A and N and Kerala indicate significant decreasing trend. However, CK reported significant increase in monsoon rainfall.

Rainy Days And Low Clouds

Rainfall is influenced by different meteorological parameters, including cloud cover and cyclonic systems. Clouds are important in the earth's climate system because of their influence on solar radiation, terrestrial radiation and precipitation. The effects of clouds depend on the geographical location, albedo and temperature of the underlying surface, seasons and time of day (Warren et al, 2007). Cloud types are the manifestation of the changing weather systems. High clouds are generally not rain bearing, while a low cloud gives rainfall. Hence, the association of low/medium clouds and rainy days are of interest for forecasting. Different clouds result from different meteorological processes and have different effects on rainfall and number of rainy days. The contributions of high/medium clouds are less reliable compared to those from low clouds. High/ medium clouds are often partially or totally obscured.

In this study an effort is made to properly evaluate the trend of low cloud amount and its influence and implication on the seasonal rainfall. The analysis reveals that out of fourteen stations nine show decreasing trend, with seven being significant. Dash et al (2007) also found decreasing trend in cloud amount over South India in the last two decades.

On the contrary, five stations (Harnai, Pune, Trivandrum, Amini Divi and Minicoy) indicate increasing trend, with two being significant. However, the association between low cloud amount and the seasonal rainfall shows a significant negative correlation at two stations - Mumbai and Mangalore. The decreasing trend in low cloud cover

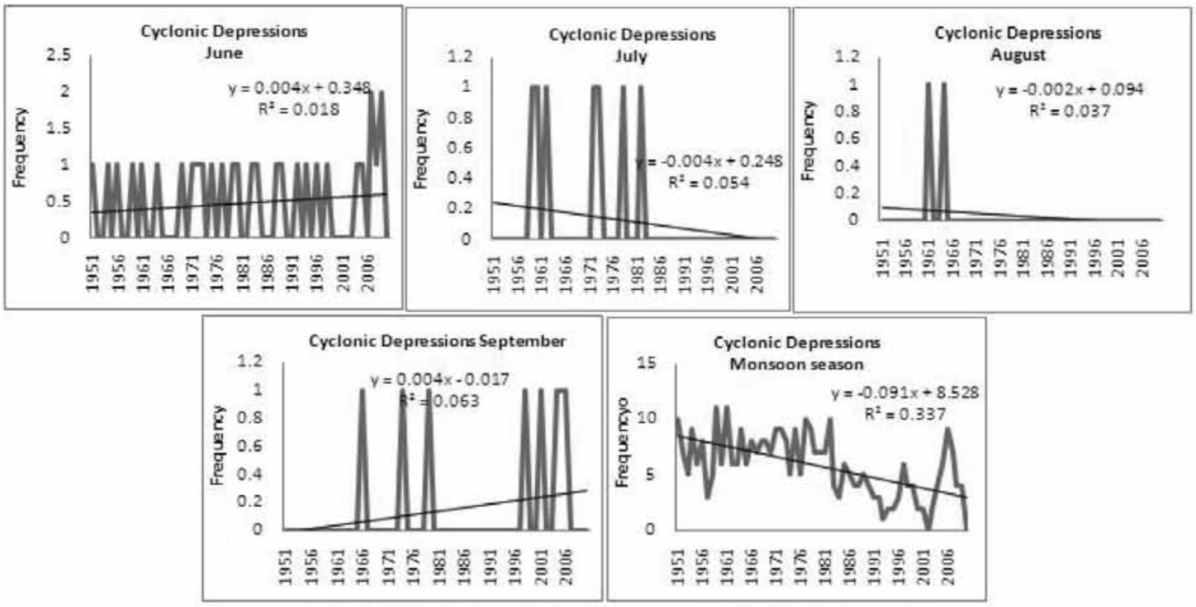

Figure 4. Monthly and Seasonal Trends of Cyclonic depressions

has been supported by earlier studies (Prakasa Rao et al, 2004).They reported significant decreasing trend in eleven stations. However, they did not associate the decreasing trend either with rainfall or temperature changes. Sarkar and Kafatos (2004) observed that the anthropogenic aerosol induces the creation of clouds.

Trend Of Rainy Days And Associated Synoptic Conditions

Kumar et al, (2004) have found significant decreasing trends of tropical cyclones and linearly increasing/ decreasing trends in decadal and epochal frequencies. Krishnakumar et al, (2008) have identified warm regions, which bear strong relationship with tropical cyclones over North Indian Ocean. We have also examined the changes in the circulation and synoptic patterns over the region, which may be useful to explain the corresponding changes in the rainfall pattern. There are synoptic features that give rainfall over the country.However, in this study, only the cyclones and depressions that originate from Arabian Sea have been considered. The monthly frequency data are obtained from IMD website. The trend of cyclones and depression are depicted in Figure. 4. The Figureures reveal that during June and September months the frequency shows an increasing trend, while trends in July and August exhibit decreasing trend. The trend analysis for the monsoon season shows significant decreasing trend. This might have led to the decrease in rainy days over the WCR. The decrease in rainy days is in agreement with the observations made by Rameshkumar (2009). He concluded that large columns of moisture are moving out of the Indian landmass into adjoining seas. This indicates weakening of the monsoon activity in the recent years and divergence of moisture carrying winds from the region. Krishnan R et al (2012) studied the frequency of moderate to heavy rain events over Western Ghats and reported decreasing trend.

CONCLUSIONS

The diagnostic study reveals the noticeable changes in the rainy days and monsoon rainfall over the WCR, during the last 60 years. It also throws light on the dynamics of rainfall and rainy days over the region. The nature of noticed change has been explored through trend analyses. The non-parametric test and linear trend analysis pointed out decreasing trends in the rainy days. Trend analysis of rainy days shows significant decrease monthly and seasonally at Harnai, Mahabaleshwar, Mumbai Panjim, Pune, Ratnagiri, Belgaum, Honavar Karwar, Mangalore, Allapuzha, Kozhikode, Trivandrum, Amini D, Port Blair and Minicoy.

The change in rainy days is more conspicuous from 2000 onwards over WCR particularly during the monsoon season. This suggests that wet days are decreasing over the region with increasing dry spells. Decrease in rainy days is mostly evident by the increasing flashfloods. This analysis is in agreement with researchers who have found increasing trend in high rainfall events in WCR (Sen and Roy, 2009, Pattanaik et al, 2010). An increase in flood frequency has been reported by Tongdi et al (2008). However, when there is a decrease in rainy days, flashfloods should indicate decrease but IPCC (2007) confirms an increase in both. This could be due to intense precipitation during the reported less number of rainy days.

This study has yielded some significant findings:

- The analysis indicates significant decrease in rainy days on one hand while monthly and seasonal amount of rainfall shows no significant trend except at two stations.
- Correlation analyses reveal close association between rainfall amount and rainy days. So, decrease in rainy days is also affecting the amount of monthly and seasonal rainfall.
- The decreasing trend in rainy days and rainfall amount is supported by the significant decrease in low cloud amount in majority of the stations in the WCR.
- The decline in rainy days and monsoon rainfall were due to the decrease in cyclones and depressions forming over the Arabian Sea.
- Extreme rainfall events pose a serious threat to many populated and urbanized areas worldwide, while decrease in rainy days poses a greater threat to the farming community.
- Significant decrease in rainfall and number of rainy days would curtail agricultural production.
- Decrease in rainfall leads to over-extraction of groundwater and fall in groundwater table levels.
- Since flash floods are reported during days of extreme events it is essential to store flood waters in surface and subsurface storage facilities to overcome more severe adversities in future.

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