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A Review of Monsoon Rainfall over the Driest and Heaviest Meteorological Sub-Divisions of India

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Abstract-Indian agriculture still depends on monsoon rainfall. Changes in the rainfall over the country have a significant impact on the economy. This article aims to review studies pertaining to trends in rainfall over the driest (West Rajasthan) and wettest meteorological sub-divisions (Coastal Karnataka) over the country. The results indicate that West Coast river basins show decreasing trend in rainfall intensities of 50% (significant at 5%) and 75% during the monsoon season as well as in annual rainy days significant at 95%. Grid point wise studies (1901-2013) show significant decreasing trend up to -107.27 mm/year in many coastal areas. However, heavy rainfall amount and the highest rainfall value in 24 hours over West coast region from 1901-2009 indicate significant increasing trend in annual and monsoon season. Monsoon rainfall over Konkan & Goa and Coastal Karnataka show significant increasing trend at 1% and 5% respectively; the same pattern emerge when individual stations are analyzed - Mumbai, Raigad and Sindhudurg. Western Rajasthan (l901-2009) indicates insignificant increase by 0.15 mm/year and from 1960-2011 it showed insignificant rise (0.56 mm/year) however from 1971-2005 annual and monsoon rainfall show decreasing trend at 10% level of significance.

Keywords - *Climate change; Decreasing; Increasing, Significant.*

1. INTRODUCTION

The world witnessed rapid economic growth with profound negative effect on the climate. Climate change is a global environmental problem but the worse impact is on developing country like India. These global changes will have an impact on the regional and local scales also. With the impacts of global climate change, a review on rainfall on spatial and temporal scales is important. An understanding of the rainfall in regional scale would help to solve problems related to floods and droughts especially over the driest and wettest sub division in India. Changes in climate over the country, particularly the SW monsoon, would have a significant impact on the economy. These changes in rainfall patterns are closely linked with agriculture. Changes in rainfall quantity and frequency would change the whole system. This necessitates a review of work done earlier which will lead to proper management of policies.

During the last few decades, as a result of the climate change investigation on various sectors have been studied widely. Most parts of the country faces decline in monsoon and annual precipitation impacting the agriculture. In this situation, it is relevant to assess the rainfall since it's is directly related with agriculture. The Indian summer monsoon (June–September) rainfall covers 80% of the total precipitation over the country is very important for the economy of the country. In spite of growth in the industrial sector, the economy of India is still dependent on agriculture. Deficient in monsoon rainfall therefore becomes serious problem to the country. Therefore, it is important to assess the rainfall on these two regions.

India is in the tropical region and it is characterized by wide variation of weather and climate across the country. These two study region has unique climatological characteristics (low and heavy rainfall, low and high humidity, less and high diurnal temperatures range). The climate of these two regions is strongly influenced by the Thar Desert and Arabian Sea. In contrast- Konkan/Goa and Coastal Karnataka witnessed more frequent rain while West Rajasthan recorded least amount of rainfall. This pattern is also reflected in number of rainy days over both the regions. Konkan/Goa and Coastal Karnataka is on the windward side (Coastal) while West Rajasthan is on the leeward side (Interior). The Aravalli Hill Range and Western Ghats bordered both the regions respectively. In view of these, an attempt has been made to assess the trend of rainfall over these two regions. Trends in seasonal and annual rainfall on the subdivisions were assessed in this study.

2. STUDY AREA

Konkan/Goa and Coastal Karnataka lies between 12° N - 20° N and 73° - 74° E while West Rajasthan in the North West region of India lies between 23° – 30° N and 69^{o} -76^{o} E (Fig. 1).

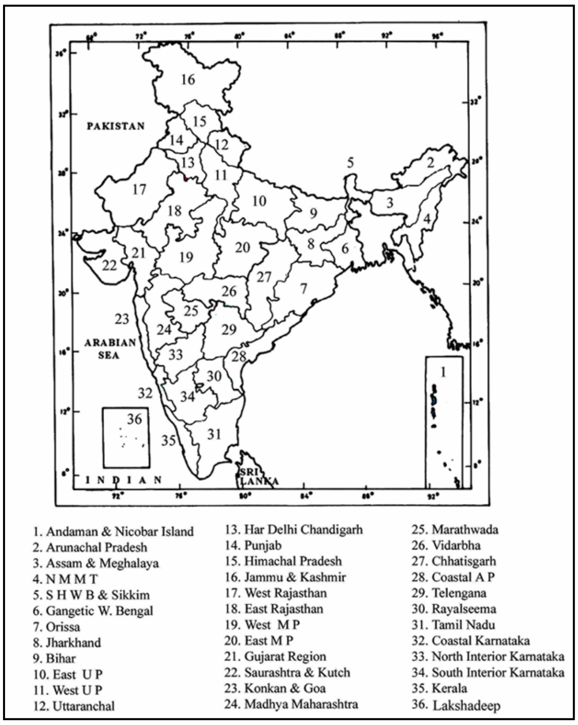

Fig 1: Study Area (17, 23 and 32)
(Source: Manjunatha et al. 2016)

Konkan/Goa and Coastal Karnataka in the west coast is situated between Sahyadris and the Arabian Sea. It is 48-64 km wide and 900 km from north to south. Physiographically, this region is a distinct strip of lowland, interspersed by hills, rising in elevation from the sea level to 60 m; however, in some places it reaches more than 300 m. It is composed of one or more of the following features; sandy beach, coastal sand dunes, mud flats, alluvial tracts along the rivers, lagoons/estuary, laterite platforms and the residual hills. The west coast region occupies a narrow strip of land between the crest of the Western Ghats on the east, which is 1,200 m high, and the Arabian Sea on the west running parallel to the coast. The Western Ghats are a continuous mass running from south to north that slopes towards the Arabian Sea which is access only through gaps or passes. The west coast region lies on the windward side of the Western Ghats gets heavy orographic rainfall. Often spurs of the hills that reach up to the coast interrupt it. With high rise scarps of the Western Ghats maintaining an altitude of 1000 m on the east and the Arabian Sea defining its western margin, the general slope of the land is from east to west.

The western plain covers a large areas of Rajasthan state. It is bordered on the north by Punjab and the southwest by Gujarat and on the west by Pakistan. The eastern boundary of the western sandy plain is bordered by the Aravalli ranges. The Aravalli range running across the Rajasthan like a curve from southwest to north-east is the main mountain range of the region. The Aravalli range has been deeply eroded with some summits over 1225 m in height. The Aravalli range is higher in altitude in the south as compared in the north. Western sandy plain a vast Thar Desert and is a wide expanse of windblown sand plain. Only thin patches of prickly grass and other xerophytes could be seen. West Rajasthan is a peneplain in which rocky outcrops appear through sand. The region slopes from east to west and north to south. In the northeast of the region it is about 300 meter but towards the south is about 150 meter in elevation.

3. DATA AND METHODS

Sub-divisional monthly rainfall data of India prepared by the Indian Institute of Tropical Meteorology (IITM, Pune) and rainfall data obtained from the India Meteorological Department (IMD, Pune) were used by the researchers. Further, daily rainfall data based on Grid points (GP) using 0.25º x 0.25º, 1◦ × 1◦ and 0.5° × 0.5° from IMD were also analyzed. Seasons were classified as winter (December–February), pre-monsoon (March–May), monsoon (June–September), and post-monsoon (October–November). However, some researcher classify as winter (January and February), Pre-monsoon (March, April and May), Southwest Monsoon (June to September) and Post Monsoon (October, November and December). For each of the location, long-term trends in monthly, seasonal and annual rainfall were worked out by fitting a linear regression equation. Linear regression test was performed to identify the existence of any trend or persistence in the rainfall series. The magnitude of the trend in the time series was determined using Sen's estimator [1]. This method has been widely used for determining the magnitude of trend. The statistical significance of the trend in monthly, seasonal and annual series was analyzed using the non-parametric Mann-Kendall (MK) test – Mann [2]; Kendall [3]. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

4. LITERATURE REVIEW

Seasonal and annual wise analysis on sub divisional rainfall were undertaken by Vijay Kumar et al. [4], which showed that pre-monsoon rainfall increased over 23 subdivisions; monsoon rainfall increased over 10; post monsoon rainfall increased over 27 while winter rainfall increased over 20. In annual, increasing trend is reported at West Rajasthan, Konkan/Goa and Coastal Karnataka but significant at the later. During the monsoon season, West Rajasthan show insignificant decrease in rainfall but increase is witnessed in Coastal Karnataka (1.81 mm/year) followed by Konkan & Goa. Rathore et al. [5] analyzed state wise annual average rainfall trends in the country during the period 1951-2010. However, annual rainfall has decreased over Karnataka and Maharashtra but not significant. Winter season rainfall has shown increasing trends over Karnataka, Maharashtra and Rajasthan which is not significant. Goa showed no trend in averaged winter rainfall. Monsoon season rainfall has increased over Karnataka while decreasing trend is seen over Goa, Maharashtra and Rajasthan which is not significant. Post monsoon season rainfall has shown increasing trends over Goa and Karnataka but decreased over Maharashtra and Rajasthan.

Kumar and Jain [6] investigated the trends in rainfall amount and the number of rainy days during the period 1951–2004 in Indian River basins using daily gridded rainfall data at 1° ×1° resolution. The magnitude of trend in annual and seasonal rainfall and rainy days were studied. Increasing trend in annual rainfall is reported in 6 river basins while 15 river basins shows decreasing trend. The increase in annual rainfall varied between 0.45 mm/yr (EFR4 basin) and 4.93 mm/yr (EFR3 basin); the decrease range from WFR1 basin (–10.16 mm/yr) to Krishna basin (–0.27 mm/yr). Majority of the basin indicate insignificant trend. Decrease is reported in WFR2 with 95% significant. The decreasing trend in annual rainy days is reported in WFR2 and EFR5 river basins which were statistically significant at 95% confidence level. During the monsoon season, the maximum increase was 2.58 mm/yr for EFR3 and maximum decrease was reported for WFR1 (–8.47 mm/yr). Monsoon rainfall indicated negative significant trend in WFR1 river basins. Deshpande and Singh [7] used Daily gridded monsoon rainfall dataset for the period of 57 years (1951–2007) with the resolution of 1˚ × 1˚ covering the entire country. It is observed that West Coast river basins shows decreasing trends have been observed with the rainfall intensities of 50 and 75% during the wet periods. In the case of 50% wet period the trend is significant at 5% level. According to the studies Attri and Ajit Tyagi [8], all India annual and monsoon rainfall for the period 1901-2009 do not show any significant trend. During the monsoon season, three subdivisions show significant decreasing trends while eight subdivisions including Konkan & Goa (95%), show significant increasing trends. The contribution of rainfall for each month towards the annual total rainfall in percentages suggest that contribution of June and August rainfall exhibited significant increasing trends whereas July rainfall exhibited decreasing trends. Guhathakurta and Elizabeth Saji [9] investigate monsoon rainfall along the Konkan and adjoining areas. The results indicate that nine districts including Mumbai, Raigad and Sindhudurg have showed significant increase in rainfall. It is also observed that monsoon and annual rainfall shows increasing in Konkan region. Long term trend were also studied by Tongdi and Manjunatha [10] which shows that southwest monsoon rainfall during period 1875-2006 reveals that Kerala in the West coast region show decreasing trend significantly while significant increasing trend is reported from Coastal Karnataka. Vinay et al. [11], investigate variability in rainfall during the period 1901 to 2013. The annual rainfall coefficient of variation (CV) of the grid points in the coastal region ranging from relatively a minimum of 15.74 % to a maximum of 45.27%. During the period 1901-1930, most of the grid points are insignificantly increase/decrease trend with less variation up to 34 mm/year and - 6.69 mm/year in the coastal region, respectively. During the period from 1931-1960, there is a significantly high increase in rainfall in the grid points of the coastal region up to 102 mm/year. High value of significant increasing/ decreasing trend up to 87.18 mm/year and -140 mm/year, respectively were noticed in the period 1961 to 1990. Finally, during the study period (1901-2013) shows reverse in rainfall trend where many grid points show significantly decreasing trend up to -107.27 mm/year. However, few grid points were significantly increasing trend 79.34 mm/year. Therefore, comparing the four periods, except the first, all the others showed more variation in rainfall over the coastal region. Analysis on daily rainy days over west coast region were investigated by Manjunatha et al. [12] during the period (1951-2010) 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. Further, investigations on rainy days indicate significant increasing trend during the last decade (2000-2010) over majority of the stations. Kothawale and Rajeevan [13], studied monthly, seasonal and annual rainfall for the country, the result indicate that summer monsoon rainfall do not show any significant trend. During the entire period 1871-2016 summer monsoon rainfall over Konkan & Goa and Coastal Karnataka show significant increasing trend at 1% and 5% respectively. The significance of change is tested by student t-test. Further, the result also shows that the probability of occurrence of deficit monsoon is very less (10%) over Konkan & Goa.

Inter-annual variability in average annual rainfall were studied by Rao and Purohit [14], for 12 arid districts of Western Rajasthan during the period (l901-2009), which indicates that the rainfall show insignificant increase by 0.15 mm per annum over a period of 109 years. The monsoon season rainfall was decreasing at 37 out of 65 locations covering 43% area, at 7 locations in post monsoon (October and November) covering 5% area, at 16 locations in winter

(December to February) covering 19% area and at 15 locations during summer (March to May) covering 18% area. Arnab et al. [15] investigate annual means of daily precipitation (Udaipur) during the period 1979-2010; S statistics, Zc statistics and Kendall's tau for the precipitation were 28, 0.437883 and 0.056452, respectively at 95% confidence level. The positive value of Kendall's tau and S statistics showed increasing trend in the time series data of precipitation. From Zc statistic, it was revealed that trend was statistically significant over the period of 1979-2010.Surendra and Rao [16] reported that annual rainfall (1960-2011) for Thar showed no significant rise (0.56 mm/year), however, the rainfall trend at different locations showed that the annual rainfall is likely to increase by +100 mm at Bikaner, +124 mm at Jaisalmer, -40 mm at Jodhpur and +21 mm at Pali. Thus, the projected rainfall is likely to increase from 252 mm to 308 mm at Bikaner, from 176 mm to 234 mm at Jaisalmer and from 487 mm to 613 mm at Pali. Whereas, in Jodhpur the rainfall is likely to be decreased from 325 mm to 275 mm. Santosh et al. [17], reported (1971–2005) decreasing trend in annual and monsoon rainfall in West Rajasthan 10% level of significance. Tongdi et al. [18]; study the trends in heavy rainfall amount and the highest rainfall value in 24 hours over West coast region (WCR) of India with the period ranging from 1901-2009. A standard statistical analysis concludes that the majority of the stations in WCR indicates significant increasing trend in annual and monsoon rainfalls. Ila et al. [19], investigated annual, monsoon and month wise precipitation in grid-wise over Western Rajasthan and Western Gujarat during the period 1964-2013**.** The trend in annual rainfall indicated an increasing trend in most of the basin except some northern and north-eastern grids which exhibited decreasing trend. TS slope estimates detected that overall slope ranges from -3.9 to 9.6 mm/yr and 87.93% of all grids exhibit a positive slope. The monsoon season trend also indicated an increasing trend in most of the basin except some northern and north-eastern grids which exhibited decreasing trend. TS slope estimates indicated that 96.55% of all grids exhibited upward/downward trend ranging from -3.2 to 9.6 mm/yr. 89.37% of all grids exhibited a positive slope with higher slope (>8mm/yr) clustering in southern and south-western part of the basin and higher declining slope in the north-eastern part of the basin. Annual and seasonal rainfall during the period 1951-2015 was studied by Nandargi and Aman [20] which show increase over west Rajasthan and coastal Karnataka while Konkan/Goa shows decreasing trend. In annual and monsoon season not much difference can be seen as these sub-divisions receive more than 80% of annual rainfall during the monsoon months. West Rajasthan showed increasing during the 65 years period. Annual precipitation concentration index (PCI) in 11 sub-divisions recorded irregular precipitation distribution of which one in west coast. Highest PCI (31-35) was recorded along with West Rajasthan. Annual PCI values broadly goes on decreasing from west to east. Monsoon precipitation concentration index showed that West Rajasthan sub-divisions also experienced highest PCI. It is also reported that higher PCI values (that is, 11 to 13) are recorded in extreme west, north and northwest India, along the west coast regions during wet and dry seasons.

5. DISCUSSION

Irrespective of data range or type of methods being used; the above review concludes that there is a positive change in rainfall behavior over the two study regions. Analysis based on stations, state and sub divisional wise on annual or seasonal indicate significant increase but show insignificance in some cases. Rainfall over India shows spatial as well as temporal variability but both the region show increase in rainfall trend. The increase in rainfall could be attributed to global warming (IPCC, 2007) [21]. Hence, the increase in rainfall trend is reflected in flood frequency and associated human casualties and economic losses have increased in the recent decade according to Tongdi et al. [22]. It is also observed that the frequency of floods has increased during the last 3 decades. During the period (1980-1989) there were 63 events of floods in the state of Rajasthan, which increased to 72 and 71 during 1990-1999 and 2000-2009 respectively as reported by Upadhyaya [23]. Earlier studies also reveals increased in number of wet days. Analysis of one-day extreme rainfall series has shown that the intensity of extreme rainfall has increased over east Rajasthan. The flood risk was more in the decades 1981–1990, 1971–1980 and 1991–2000. The increase of flood risk has increased during the last two decades mostly over the Konkan region also (Guhathakurta et al.) [24]. According to (Rajasthan State Action Plan on Climate Change, 2011) [25], mean annual rainfall will decrease slightly, but the extreme rainfall is expected to increase in frequency and intensity. 2071-2100 projections show an increase of 20mm for maximum 1- day rainfall and 30 mm for maximum 5 - day rainfall. There is an also significant change in rainfall over Konkan/Goa and Coastal Karnataka during the last century. The non-parametric test as well as the linear trend analysis identified increasing trends in the rainfall amount over the study regions. The majority of the stations over Konkan/Goa and Coastal Karnataka reported significant increase in annual and monsoon rainfall extremes. Further, the synoptic systems associated with this shows that there is an increased in formation of monsoon trough, cyclonic circulations, depressions and lows (Tongdi et al.) [18]. The current review reveals that it is in general agreement with (IPCC, 2007) [21] whereby there will be an increase in the frequency of intense precipitations over South Asia; heavy precipitation events and also frequency (or proportion of total rainfall from heavy falls) increases in many land areas of the globe (Cubasch et al, 2013) [26]. Hence, changes in heavy rainfall will increase proportionally in the future. The result of this study shows that proper planning and preparedness should taken by the respective state government (Maharashtra, Goa, Karnataka and Rajasthan) as there is greater chance of flash floods and higher frequency of flood over the study regions.

6. CONCLUSIONS

Change in rainfall is likely to affect all facets of life and notably for a country like India where agriculture is an important sector. An understanding of the spatial and temporal distribution and changing patterns in rainfall is a basic and important requirement for the planning and management of water resources. In trend analysis studies, the results significantly depend upon the period of data and the stations data being used. Trend in rainfall also vary according to the data usage - grid wise, individual station (surface observation), basin wise, sub divisional wise and homogenous wise. An important aspect of the present study reveals that both the region - West Rajasthan and West coast region (Konkan/Goa and Coastal Karnataka) indicate increasing trend but significant at the later. Both the increase and decrease will have a significant impact on agriculture as increase in rainfall will lead to flood thereby damaging agriculture whereas decrease in rainfall amount will affectively destroy the crops. Hence, water harvesting and land use planning is very important for West Rajasthan whereas check dams and diversification of the water from the rivers to leeward side of the Western Ghats will be beneficial from damaging agriculture during the monsoon seasons.

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