An Exploratory Analysis of Rainfall: a Case Study on Western Ghats of India

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Abstract

In this study high resolution 0.250 ×0.250 (approximately 25Km×25Km) gridded daily rainfall data is used to analyze the effect of changing climate on distribution of rainfall in different topographical zones of Western Ghats (WG) of India over the period 1901-2013. The non parametric two tailed Mann-Kendall with Hamed and Rao's method of autocorrelation and Sen's slope estimator for obtaining magnitude of change over time period is used. The rainfall trend in annual, monsoon and post-monsoon is increasing in state of Goa and Coastal region of Karnataka state and significantly decreasing in some part of Kerala and Maharashtra state. Winter season rainfall has seen a declined trend in southern part of the study area and in high elevated region of Kerala state. Even the mean rainfall over the study area is declining from 1951-1960 with disturbance in alternate sequence of flood and drought year from period 1990. The frequency of heavy rainfall events (65mm-124.4mm) are increasing in recent decades with 40-50% contribution from 2000-2013 in regions of Maharashtra state. The trend of heavy rainfall events are increasing in West Coast of India at 5% significance level with no trend in very heavy to extreme rainfall events (>124.5mm).

Keywords
Western Ghats, Rainfall Trend, Extreme Events, Onset of Monsoon

1. Introduction

Mountains are the source of high quality water, storehouses of biological diversity, hydropower, food and building materials (Ives et al 1997; Beniston 2003). They supply up to 60% of fresh water in humid region and up to maximum of 90% in arid and semi arid regions (Viviroli and Weingartner 2004). Mountains can be said as "Sentinels to climate change" as they show more dynamic changes than in plains (Du et al 2004; Yao et al 2006). The changing climate due to human anthropogenic activities have contributed to elevated atmospheric greenhouse concentration (Meehl et al. 1996; Watterson and Dix 2003), build up the irregular distribution of hydrological resources (Trenberth et al. 2003) frequencies of irregular seasons and extreme events. These interns increasing threat to mountain biodiversity and also increasing the challenges of mountain water resources. The impact of these changes is not only of direct relevance to high mountains, but they will have serious implications for downstream regions (Beniston et al. 1997).

Due to the crucial impact of changing climate on natural resources, mainly on precipitation, several past studies have shed light on variation in precipitation pattern, trend of precipitation (Basistha et al. 2009; Guhathakurta and Rajeevan 2008; Joshi and Pandey 2011; Krishnakumar et al. 2009; Rajeevan et al. 2008; Singh and Mal 2014), variation in onset of South West Monsoon (Fasullo and Webster 2003; Joseph et al. 1994; Patwardhan et al. 2014; Raju et al. 2005) and the frequency of drought and extreme rainfall events in a changing climate over global and regional scales (Bharti et al. 2016; Guhathakurta et al. 2011; Krishnamurthy et al. 2009; Nandargi and Dhar 2011; Rajeevan et al. 2008; Rakhecha and Soman 1994).Most of the studies have used limited number of stations or carried out analysis for subdivisions of India. As the regional heterogeneity in Indian monsoon has become more prominent in recent years (Ghosh et al. 2012), the rainfall variation study needs to be carried out in region scale. Limited studies have been carried out on Western Ghats, an eco sensitive zone and top hotspot in India. This study aimed to carry out a detailed exploratory analysis on rainfall in and around Western Ghats of India. It includes, trend and variation in annual and seasonal rainfall, trend and frequency distribution of rainfall and variation in onset of monsoon.

2. Study Area and Materials

Western Ghats, the "Water Tower of South Indian Rivers" is a range of highlands that runs parallel to the western coast of the Indian peninsula. The range runs approximately 100Km (E-W) in width and 1600Km (N-S) in length from border of Gujarat and Maharashtra state to Kanyakumari of Tamil Nadu state (Dept. of biotechnology Gov. of India & Dept. of Space Gov. of India, 2002). The average altitude of the area is 900m with highest elevation of 2695m (Anamudi Peak). The region is characterised with complex precipitation pattern due to its complex and continues topography. Study considered all the districts through which Western Ghats bypass. Overall study area covers approximately 3, 16,000Km2 area. The location details are given in Figure 1.

The study utilized the high spatial resolution (0.250×0.250) daily precipitation data of Indian Meteorological Department (IMD) of period 1901-2013 to study the spatio-temporal variations in the rainfall. The gridded 0.250×0.250 data have been prepared by using error free data of 6955 rain gauge stations in India. Detailed description about the quality control procedures used in preparation of this data set is available in Pai et al. (2014).High resolution of data and high number of station density used portray more realistic precipitation even in the complex topography, which makes it more suitable for precipitation studies over the Indian region (Prakash et al. 2015).

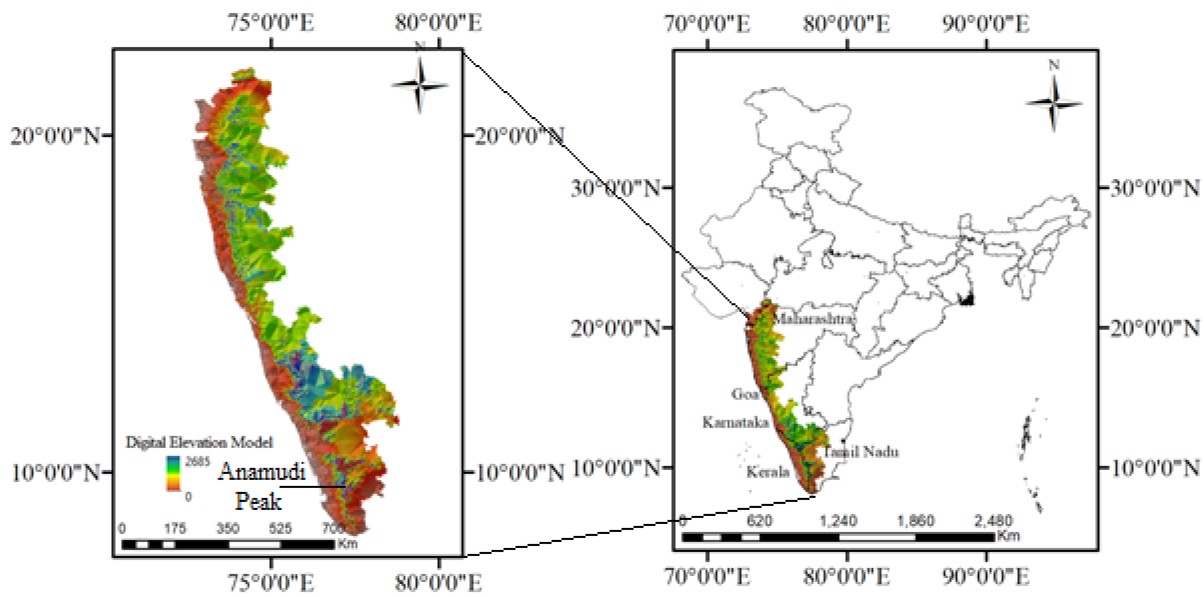


Figure1. Location Details of the Study area

3. Methodology

The region covers 426 grid points, historical daily rainfall values are accumulated to get the annual rainfall (January-December) and seasonal rainfall (Winter: January-February, Pre-Monsoon: March-May, Monsoon: June-September and Post-Monsoon: October- December) in accordance to the seasons of India specified by Indian Meteorological Department. The study region has different type of topographical and precipitation zones, the region near the coast and S-W facing of mountains receives high precipitation, whereas the S-E facing of mountains and leeward side of mountain for prevailing south west wind forms arid and semi arid climate. In order to explore the data based on its different climatic and topographic zones, the study area is divided into 4 sections. The section is made based on elevation and precipitation of the zones. The detail of number of grids, elevation is depicted in Table 1. The spatial pattern of cluster of rainfall in the study area is studied using Local Indicator of Spatial Autocorrelation (LISA) Statistics, considering rainfall value of five nearest neighbours, the details of LISA is given in (Anselin 1995). The long term (1901-2013) trend in annual rainfall and seasonal rainfall is analyzed by using Mann-Kendall's Test and Sen's Slope estimator method. Mann-Kendall test is one of the extensively used method for trend detection in different applications (Lettenmaier et al. 1994). To overcome the uncertainty in trend identification that could be due to the existence of significant autocorrelation, Hamed and Rao's autocorrelation method (Modified Mann-Kendall Test) is incorporated. The working principle of these test are given in (Hamed and Rao 1998;Yue et al. 2002). In Indian south west monsoon, there is an alternating sequence of multi-decadal periods having frequent droughts and flood years (Pant and Rupa Kumar 1997; Guhathakurta and Rajeevan 2008). Delineated the multi-decadal i) 1901-1930 as dry period ii) 1931-1960 as wet period iii) 1961-1990 as dry period iv) 1991-2013 as wet period in India based on the rainfall variation with the mean rainfall. The study area receives 80% of annual rainfall in south west monsoon season. Therefore it is expected to have multi-decadal trend variation in annual rainfall. The possible shift in the trend for every 3 decades drought and flood years is studied. The frequency distributions of rainfall and trend are studied by classifying the rainfall events based on the amount of rainfall received in a day. According to IMD rainfall intensity classification (Guhathakurta et al. 2011),

Class 1 – Heavy rainfall ($64.4 < R \leq 124.4$ mm)
Class 2 – Very heavy rainfall (124.4mm$< R \leq 224.4$ mm) and
Class 3 – Extremely heavy rainfall ($R > 244.4$ mm)

Table 1. Details of Topographic Zones and Grid points

Zone	**Flat Coastal (CF)**	**S-W Hilly (SWH)**	**S-E Hilly (SHE)**	**Deccan Plateau (DP)**
Elevation(m)	1-400	400-2695	2695-1200	1200-400
Grid No	114	48	118	180

4. Results and Discussions

In four zones of WG, as there is a variation in rainfall in different seasons and zones, the distribution pattern is different. In most of the zones, the rainfall has right skewed leptokurtic distribution. The region which receives higher mean rainfall shows less variability and less mean rainfall showed high variability.

4.1 Spatial Autocorrelation of Rainfall

The spatial autocorrelation of mean rainfall is examined by univariate Local Moran's I (LISA) index at the 5 % significance level is given in Table 2. The high similarity of 99th percentile rainfall in neighboring areas results in the positive spatial autocorrelation.

Table 2: Local Moran's Statistics

Time	**Moran's I**	**P value**
Annual	0.839353	0.001000
Winter	0.904911	0.001000
Pre-Monsoon	0.935911	0.001000
Monsoon	0.852215	0.001000
Post-Monsoon	0.941876	0.001000

The rainfall variation in the study area clustered in regions which is varying in different seasons. In general, it is expected to have high rainfall near the coast region and low rainfall in rain shadow regions of mountain. This scenario is true only during heavy rainfall periods. In monsoon season, the study region receives 80% of total rainfall. Therefore the cluster pattern in annual rainfall is similar to monsoon season rainfall. The regions of Kerala state in premonsoon, regions of Kerala and Tamil Nadu state in postmonsoon and winter recieves significantly higher rainfall than Coastal part of Karnataka state. Northern part of the study area (South Maharashtra and small part of Gujarath state) recieves rainfall during monsoon season, with light or no rainfall in other seasons. Figure 2 explains the cluster patter of mean rainfall in annual and seasonal scale.

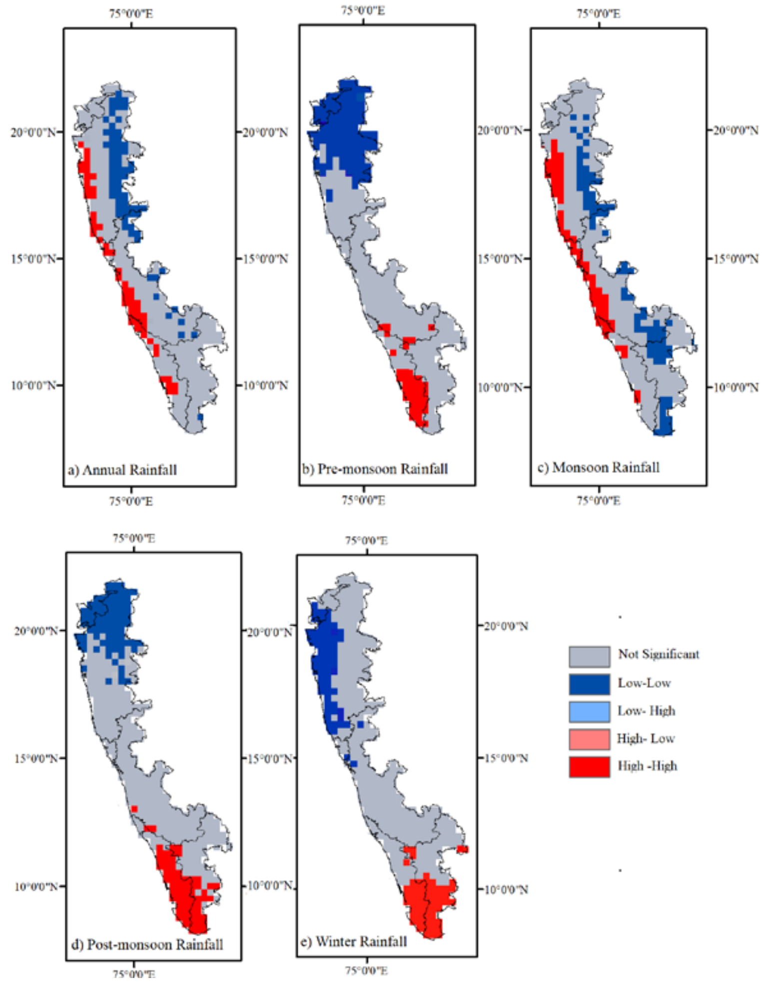


Figure 2: Cluster Pattern of Mean Rainfall over the Study Area in Different Seasons

4.2 Annual and Multi-decadal Trend in Rainfall

Figure 3 shows the decadal rainfall mean anomaly over the region. The year 1951-60, has initiated the different pattern of mean annual rainfall over the region. The most of the regions which had deficit rainfall in history received excess mean rainfall and in region of excess rainfall it received deficit rainfall. Decade 1981-1990 and 2000-13 received high deficit rainfall in entire study area. The period 1990-2013, which is delineated as wet period (Pant and Rupa Kumar 1997; Guhathakurta and Rajeevan 2008) has high rainfall deficiency rather than having excess mean rainfall. This observation is in confirmation with the conclusion given by Kulkarni (2012) in all India scale. The increase in occurrence of El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events in mid 1970s has led to large rainfall anomalies in Indian summer monsoon (Kulkarni 2012).

In the annual rainfall trend analysis (Figure 4) from 1901-2013, most of the grid points located in the coastal flat region shows significant trend at 5% significance level than the other region grid points. There is an increasing trend in rainfall in Goa state, coastal region of Karnataka state and border region of Rathnagiri and Sindhudurg, Northern part of Nashik, district of Nandurbur and connected part of Dhule and Tapi districts to Nandurbur of Maharashtra state. High decreasing trend in Wayanad, Kozhikode, Mallapuram, Thrissur, Ernakulam, pattanamittha and Kollam of Kerala state at 95% confidence level.

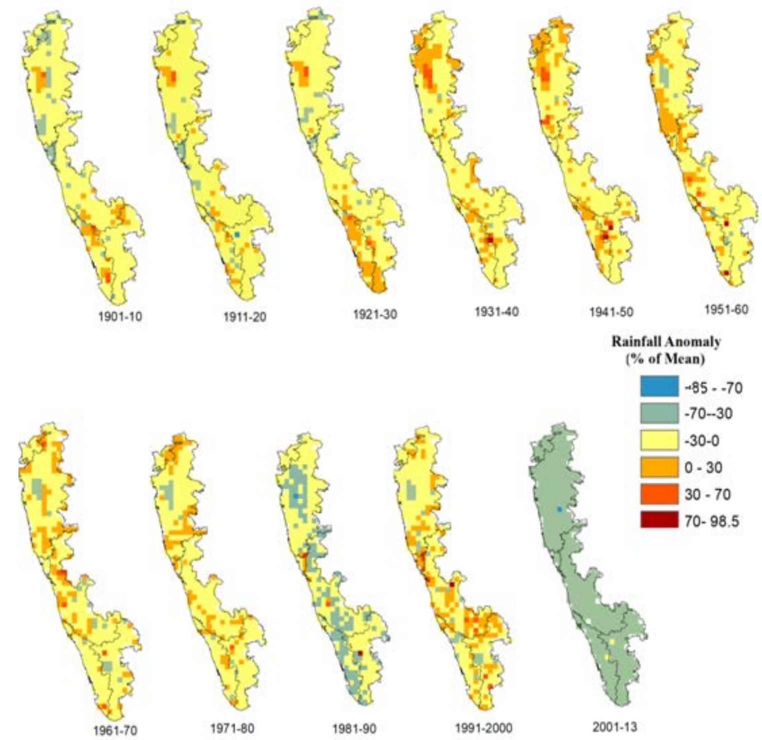


Figure 3: Rainfall Mean Anomaly

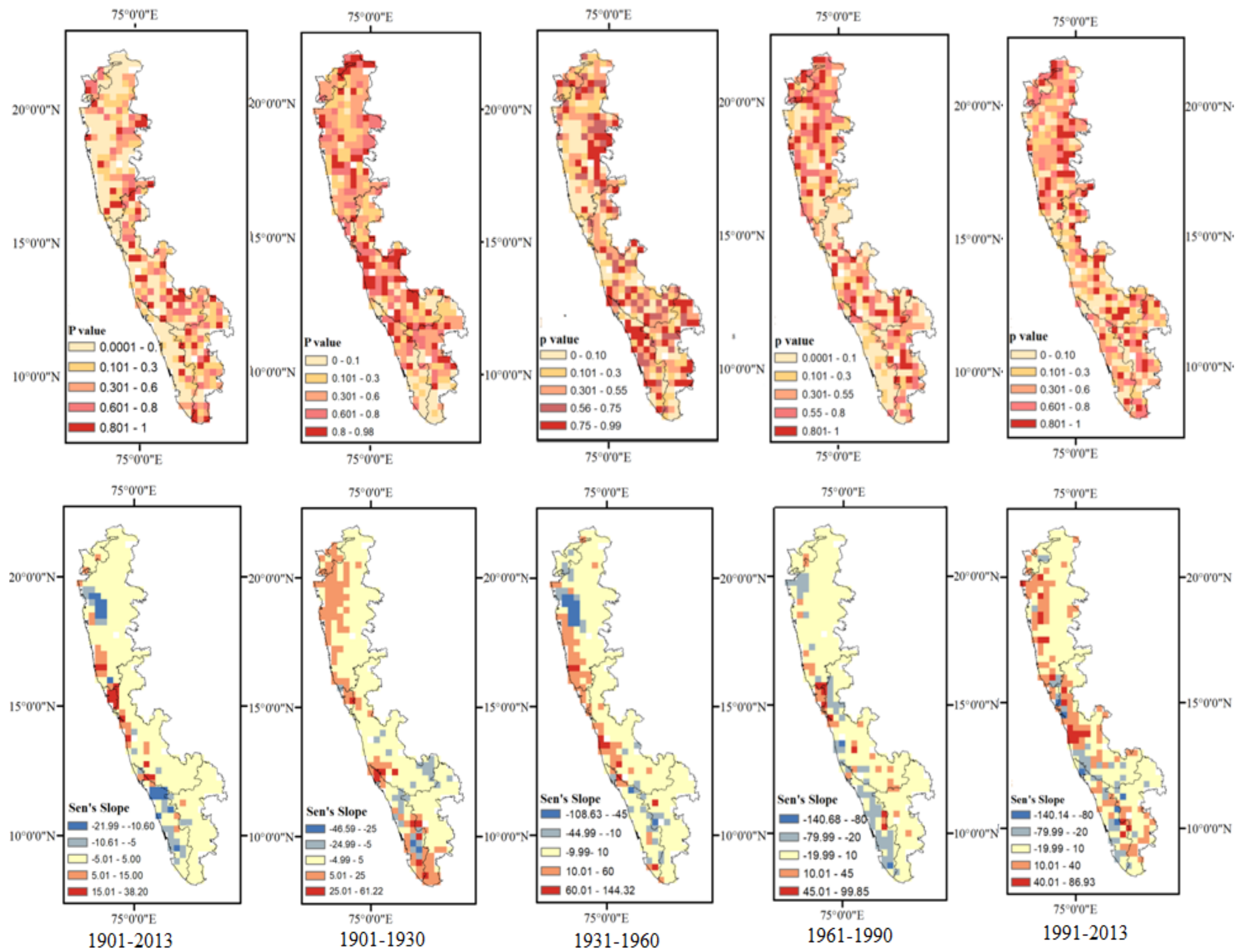


Figure 4: Annual and Multi-Decadal Rainfall Trend Significance Level (above figure) and Magnitude of Trend (lower figure)

4.3 Seasonal Trend of Rainfall

The intraseasonal variation in trend of rainfall is highest in coastal region than high elevated ranges (Figure 5). In the mountain region of Kerala which receive reasonably higher rainfall than other region during winter, has significant decreasing trend in a range of 0.4-0.73mm/year with no significant trend at 5% significance level in other regions. In season of pre-monsoon, there is an insignificant increasing trend in region of Dakshina Kannada and Udupi districts of Karnataka state. The significant decreasing trend in part of Kerala in a range of 0.5-1mm/year in Wayanad of Kerala and Kodagu district of Karnataka (located at elevation>700m).

During monsoon season trend over Kerala is decreasing at 95% confidence level. High decreasing trend in Wayanad, Kozhikode, Kottayam and Mallapuram districts of Kerala in a range of 5-21mm/year. The part of Shimogga has seen decreasing trend with increasing trend in part of Udupi, and coastal region of Uttara Kannada districts of Karnataka. The rainfall has increasing trend in state of Goa, Rathnagiri and Sindhudurg district of Maharastra and significant decrease in Thane and Western Part of Pune.

During post-monsoon Wayanad, Ernakulam, Kozhikode, Kottayam, Pattanamittha and northern part of Kollam districts of Kerala has negative trend and significant increasing trend in coastal part of Goa, border region of Rathnagiri and Sindhudurg respectively. In deccan plateau region of the study area, there were no significant trend at 5% significance level in any of the season.

4.3 Frequency Distribution and Trend of Different Rainfall Classes

The frequency distribution of rainfall from period 1901-2013 under different rainfall classes are represented in Figure 6. The frequency of heavy and very heavy rainfall is high in state of Maharashtra and Coastal Karnataka. The extremely heavy rainfall events high in West Coast of Maharashtra state than Coast of Karnataka state which receives high amount of rainfall than other coast (Figure 6). The southern region of study area (includes Kerala and part of Tamil Nadu state) has less frequency of heavy rainfall events.

In part of Pune, Satara and Aurangabad of Maharashtra state the frequency of heavy rainfall events occurred in period 2000-2013 contributes up to 50% of total heavy rainfall events occurred in 113 years. The flood occurred in the year 2005 in state of Maharashtra is responsible for 30-40% contribution of heavy rainfall events in the region in that decade in same three locations. The increase in heavy rainfall spells with decrease in mean rainfall over the region represents the increase in dry spells in this region (Singh et al. 2014). Other reason may be the warming in the central Indian Ocean which increases the water vapour in the atmosphere, which ultimately provides more moisture to the central Indian region (Goswami et al. 2006; Rajeevan et al. 2008) increased air pollution (Krishnan et al. 2016) and land use changes (Krishnan et al. 2016).

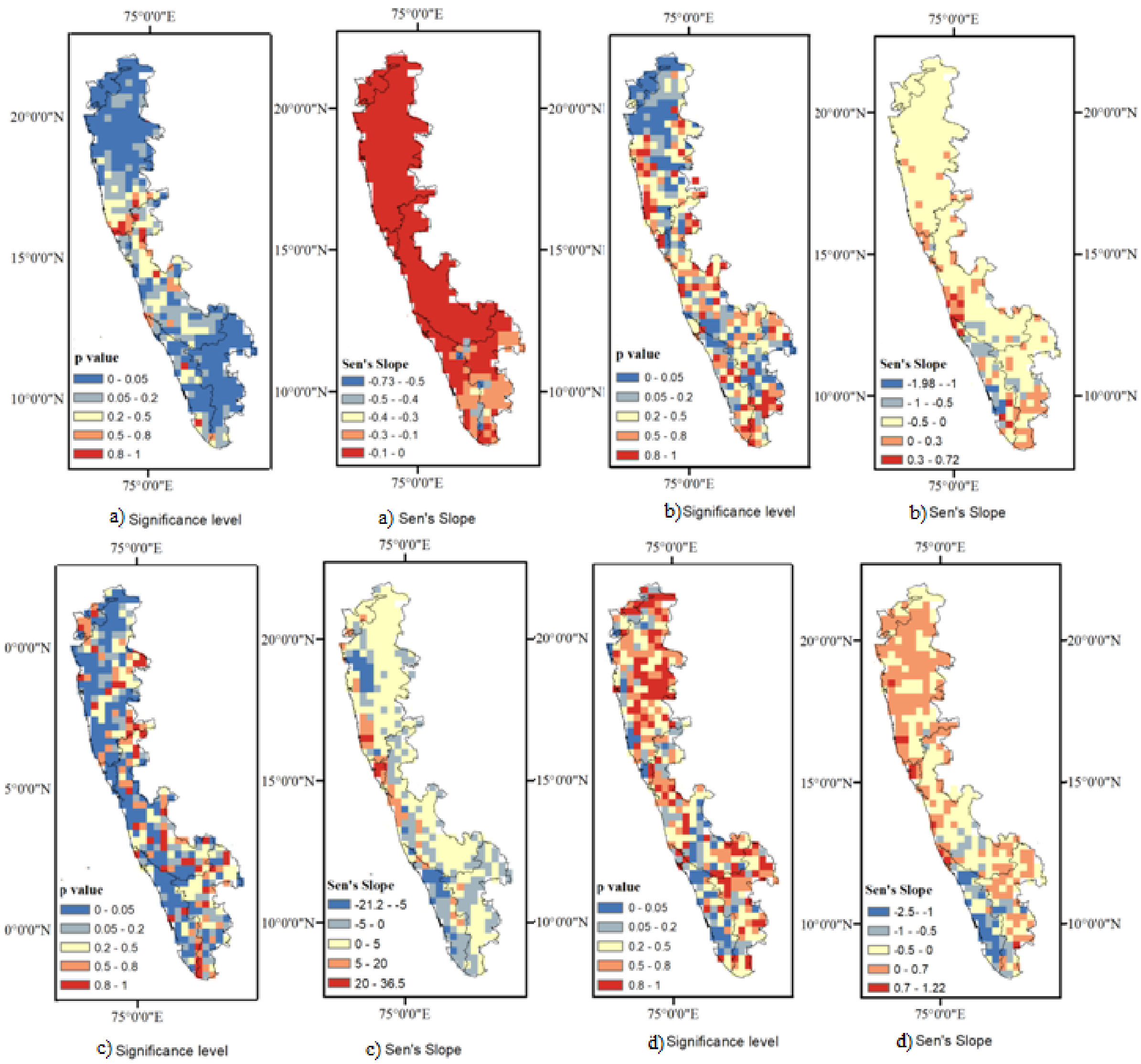
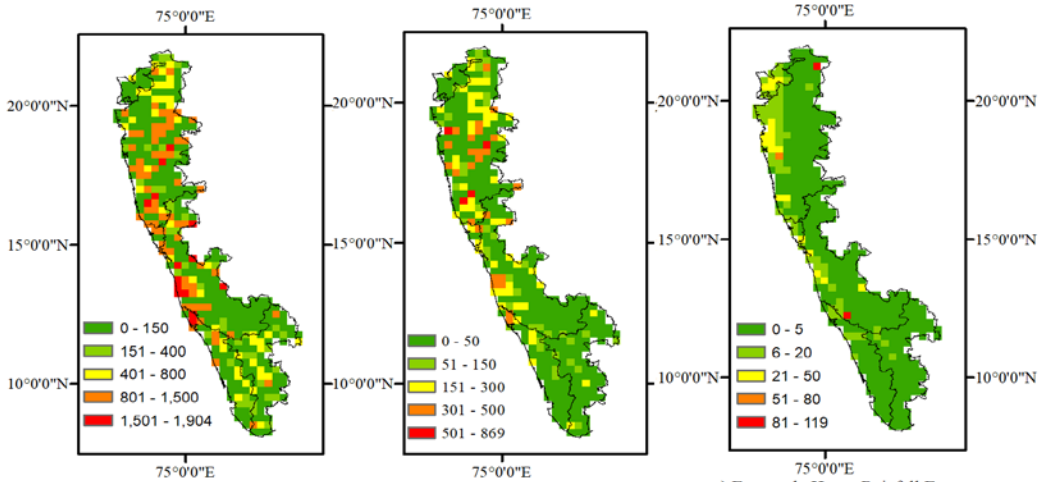
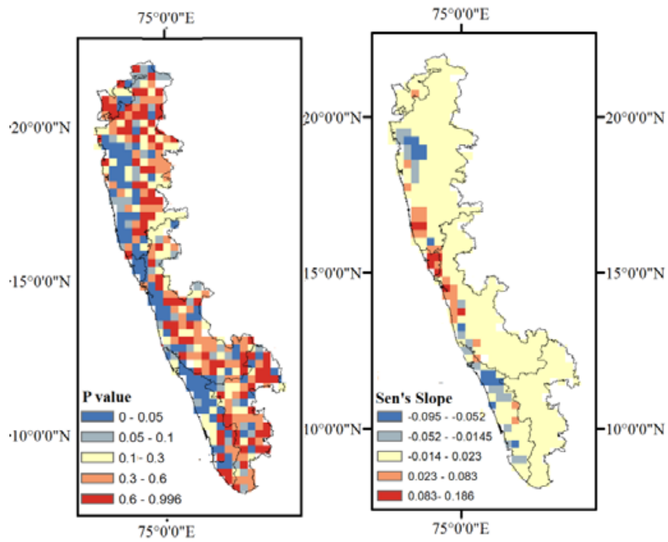


Figure 5: Seasonal Trend p value and Sen's slope in a) Winter (JF) b) Pre-monsoon(MAM) c) Monsoon(JJAS) d) Post-Monsoon(OND)



a) Heavy Rainfall Events (64.5mm-124.4mm/day) b) Very Heavy Rainfall Events (124.5mm-244.4mm/day) c) Extremely Heavy Rainfall Events (>244.5mm/day)

Figure 6: Frequency Distribution of Rainfall of Different Classes



b) Significance level c) Sen's Slope

Figure 7: Trend in Heavy Rainfall events

The heavy rainfall spells are most common during monsoon season in SW peninsular regions. There is an significant increasing trend in heavy rainfall events in coastal flat region of Karnataka and Maharashtra in a range of 0.023-0.186mm/year and in region of Kerala and Thane, Pune region of Maharashtra, there is a negative trend in heavy rainfall in the range of 0.014- 0.095mm/year where even the monsoon rainfall is decreasing. In the study area, there is no significant trend in very heavy to extreme rainfall events in any location.

5. Conclusions

The rainfall variation in the study area is clustered in regions, indicates its association with regional parameters. The mean annual rainfall over the study area is declined from previous 5 decades. The period 1951-60, has initiated the different pattern of mean annual rainfall over the region. Coastal Flat region, South West facing of Hilly region, South East facing of Hilly region and Deccan Plateau region has insignificant increasing trend in the study region with decreasing trend in South East facing of Hilly region. There is a significant decreasing trend in region of Kerala and Maharashtra in monsoon and post monsoon rainfall which intern shows decreasing trend in annual scale. Also, decreasing trend in winter rainfall in southern part of study area and in hills of Kerala. There is a significant increasing trend in rainfall over the coastal zones of Karnataka and border region of Sindhudurg and Rathnagiri districts of Maharashtra state in annual rainfall and significant increasing trend in state of Goa in monsoon, pre-monsoon and post-monsoon seasons. The heavy to extreme rainfall spells are more common in coastal zone, but the frequency of extreme events are more coastal Maharashtra than Coastal Karnataka which receives higher rainfall than that. There is a significant increasing trend in heavy rainfall events (64.5mm-124.4mm) in coastal zones of Maharashtra and Karnataka with contribution of up to 50% of heavy rainfall spells in period 2000-2013 with decrease in mean rainfall. Overall, the abrupt change in precipitation pattern due to changing climate has been initiated in the mid 1950s.

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