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Changes in the Characteristics of Extreme Rainfall in Indian Monsoon

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Abstract—*Extreme events though occur rarely, have adverse impact on water resources management. Rarity often limits the application and efficiency of models in simulating these events. Recent revelation of rapid climate change further aggravates this issue. Water resources planning and management demands holistic analysis and modelling of extreme events considering future changing climate. Before looking into the changes projected by climate models, it is necessary to fathom the historical trend of the extreme events. In this study, three main characteristics, viz. Intensity, Duration and Frequency of extreme heavy rainfall have been analysed over India employing Extreme Value Theory using 0.25° resolution gridded data. The first two parameters are computed through the exceedance of threshold derived from the 95th percentile of climatological rainfall over 100 years. The block maximum series of intensity is modelled using Generalized Extreme Value Distribution and the parameter estimation is done using method of maximum likelihood. Moreover, nonparametric Mann-Kendall test has been used to observe the statistically significant trend for 5% significance level. Further, the above analysis has been repeated for pre-1950 and post-1950 data to analyse any significant changes over the century. The result reveals that the extreme event characteristics has undergone considerable variation from pre-1950 to post-1950. Particularly, majority of grids show significant increasing trend in intensity, while only few grids show any trend in duration of rainfall in post-1950. The result also indicates that a '1 in 20 year event' in pre-1950 occurred in '1 in 2 year' in post 1950. Overall, the result highlights more frequent and high intensity rainfall over a short duration.*

1. INTRODUCTION

The severity of extremely heavy rainfall, in general, depends on three main aspects: intensity, duration and frequency and their interrelationship is very important in the field of urban hydrology. Due to global warming caused by the anthropogenic gases as well as local changes (like urbanisation), the Indian Southwest Monsoon (June to September), which receives more than 80% of Indian rainfall, is highly unstable. Though conventional IDF curves are available, they often fail to capture the changing environment. Moreover, IPCCSREX [1] mentions the changes in the magnitude and frequency of extreme climatic events of heavy precipitation expected in Asia. Especially, the geographical distribution of flood risk is heavily concentrated over India, Bangladesh and China. However, there is only a medium confidence in the broader regional trends due to lack of observed data. Therefore, the analysis of the historical behaviour of these attributes (Intensity, duration and frequency) has become indispensable. Recently many analyses have been carried out on extreme rainfall over India. For instance, Goswami et al. [2] chose Central India to analyse the extreme rainfall event exceeding 100 mm/day for the period of 1951 to 2000 and the result shows increasing trend in extreme rainfall, though decreasing trend was observed for moderate events. However, this inference may not be applicable for entire country, since the monsoon pattern in India is purely heterogeneous. Further, Krishnamurthy et al. [3] investigated the frequency and intensity over India for the same period. In addition, they have performed field significance test to check the false trend. Finally, they concluded that trend is non-uniform over India, emphasising the importance of fine resolution spatial analysis. This surmise was further supported by Ghosh et al. [4], who observed spatial heterogeneity in the extreme events trends over India for the past half century. Their results show decreasing trend for mean rainfall but significant increasing trend for annual maximum rainfall with spatial variability. They also highlighted that the mitigation strategies' need to focus on the urbanization and change in land use, as well as global warming and greenhouse gas emission. Vital et al. [5] also detected major differences between the pattern of extremes in India during pre-1950 and post-1950. They also examined the change points, and found that in most of the grids, the change point were present after 1975. This is the same period of urbanization in India. All the above studies used 1°×1° spatial resolution data and stressed the need for fine resolution analyses. Recently, Indian Meteorological Department (IMD) has generated high spatial resolution of daily gridded rainfall data. Ali et al. [6] extracted data for 57 urban areas from the latest version of IMD gridded data. They noted significantly increasing trend in four urban regions only, contradictory to the result obtained by Vital et al. [5]. However, they did not carry out the analysis for entire India. Hence, the present study aims at analysing the changing trend and pattern of Intensity, Duration and Frequency of extreme rainfall over entire India, using high resolution data.

2. DATA AND METHOD

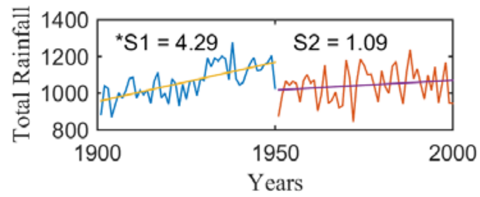
High resolution daily data of 0:25°×0:25° grid obtained from Indian Meteorological Department (IMD) [7] has been used in this study. Observed data from 6995 rain gauge stations have been interpolated [8] to generate the data for the period of 1901-2013. The quality of the data is trustworthy over the heavy rainfall areas as well as the low rainfall areas due to its high resolution. Recently, this data was used by Ali et al. [6] to analyse the changing behaviour of extremes in urban areas. Though, they had station data, they used gridded data because of its continuity, and also mentioned that these data were able to capture the orographic effects because of its high spatial resolution. In this paper, rainfall data of Southwest monsoon spanning 100 years (1901-2000) have been used. Further, the data are divided into two segments: pre-1950 and post-1950, to observe the changing behaviour of the extremes over the century. The extreme event is characterised using Percentile based Peak Over Threshold approach to account the spatial heterogeneity of Indian Monsoon. The selected threshold is 95^{th} percentile of the climatological mean of daily rainfall for 100 years. The grids receiving rainfall above this threshold is classified as extreme rainfall. The successive days of extreme events are grouped together as a cluster, whose length is defined as duration, and the ratio of total accumulated depth to the length of each cluster is known as intensity. The maximum intensity in a year is called as critical intensity and respective duration is called as critical duration. Annual Maximum Series (AMS) based Extreme Value Theory (EVT) has been used for modelling the critical intensity. The return period for average critical intensity has been computed using Generalized Extreme Value Distribution (GEV). This distribution is commonly used for modelling extreme precipitation which comprises three families (Gumbel, Frechet and Weibull). The parameters involved in this distribution are location parameter (μ), shape parameter (k) and scale parameter (σ). These parameters are estimated using Method of Maximum Likelihood [9]. The return period is computed from the Cumulative Distribution Function (CDF) using the relation in Equation 1.

$$T = \frac{1}{1 - F(X)} \tag{1}$$

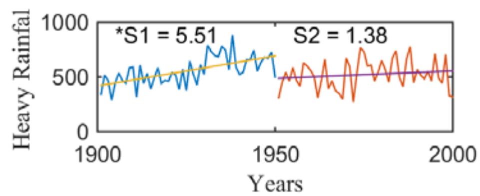
Finally, the monotonic upward and downward trends are analysed for all grids using non-parametric Mann-Kendall test. Statistical significance is estimated at 5% significance level using standardized test static (Z) and p-value. More details regarding this method can be obtained from Mann [10], Kendall [11], Yue and Wang [12] and Sonali and Nagesh Kumar [13].

3. RESULTS AND DISCUSSION

Analysis of spatially averaged Southwest monsoon of India (Fig. 1) reveals that the amount of total and extreme heavy rainfall has significant steadily increasing trend in pre-1950, while post-1950 shows no significant trend. High increasing trend has been observed in extreme event when compared to total rainfall.



Total Rainfall



(b) Extreme rainfall (above 95% threshold)

Fig. 1: Trend of spatial mean

Further, using fine resolution data, the three main characteristics of extreme rainfall event has been analysed spatially, for the period of 100 years, for Southwest monsoon. As mentioned in Section 2, the extreme event characteristics are analysed using 95^{th} percentile threshold, which varies from 0.8 mm to 88 mm over India.

4. CRITICAL INTENSITY

As mentioned earlier, critical intensity is the maximum intensity in a year. The average critical intensity for 100 years is mapped in Fig. 2a. Approximately, it varies from 10 mm/day to 216 mm/day over India. The highest average critical intensity is observed in North East and Western Ghats region varying from 120 mm/day to 200 mm/day. Further, the critical intensity difference of pre-1950 and post-1950 is shown in Fig. 2b. In post-1950, the critical intensity has increased in Jammu and Kashmir, North East and some other parts of India. Overall 54% of grids show increase, while 46% of grids show decrease in post-1950.

Moreover, the trend variation of critical intensity in pre-1950 and post-1950 has been analysed and is plotted in Fig. 3. Significant increasing and decreasing trend has been observed in 8% and 6% of grids respectively in Pre-1950, whereas 16% and 5% of grids show increasing and decreasing trend respectively in post-1950. Though the percentage of grids with decreasing trend is approximately equal in pre-1950 and post-1950, the dissimilarity in location is prevalent. A drastic change is noticeable in the Karakoram Range, with negligible trend before 1950, and significantly increasing trend after 1950. Moreover, many grids in Western Ghats show increasing trend in pre-1950 and decreasing trend in post-1950, although the results are contrasting in remaining part of Peninsular India.

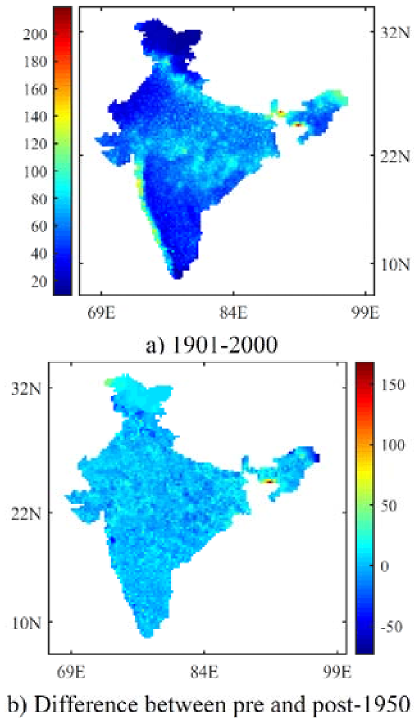


Fig. 2: Average Critical Intensity

5. CRITICAL DURATION

The average critical duration for 100 year period is shown in Fig. 4a. The critical duration varies from 1 day to 6 days with highest duration observed in Western Ghats. North East region shows average critical duration of 1 to 2 days, though the intensity is high in these regions. Fig. 4b shows maximum 4-day increase from pre-1950 to post-1950 in Western Ghats and 1 or 2 days increase in Himalayan Ranges. However, 37% of grids show 1 to 4 days decrease in post-1950 compared pre-1950.

Significance of trend variation in duration has been analysed for pre-1950 and post-1950 as shown in Fig. 5. When compared to intensity, duration shows trend in very few grids. In pre-1950, 4% and lesser than 1% of grids shows increasing and decreasing trend respectively. In contrast 2% of grids show increasing trend and 4% of grids show decreasing trend in post-1950. This clearly demonstrates high intensity rainfall with short duration. Moreover, further analysis of pre-1950 and post-1950 shown in Fig. 5 agrees with this inference.

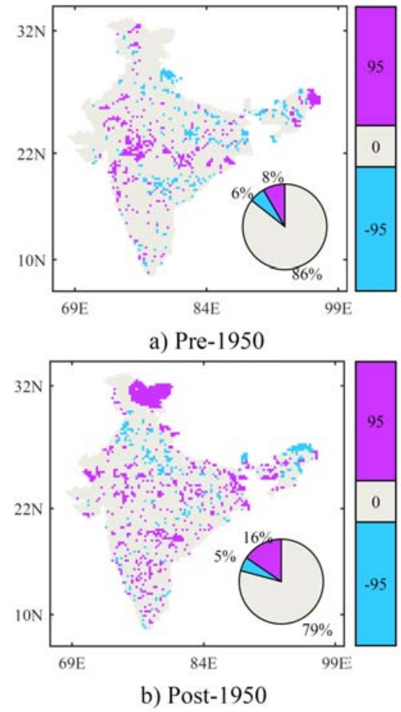


Fig. 3: Trend of critical intensity

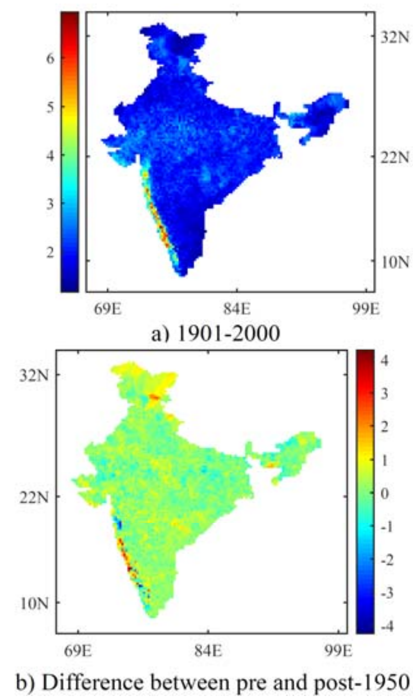


Fig. 4: Average duration of critical intensity

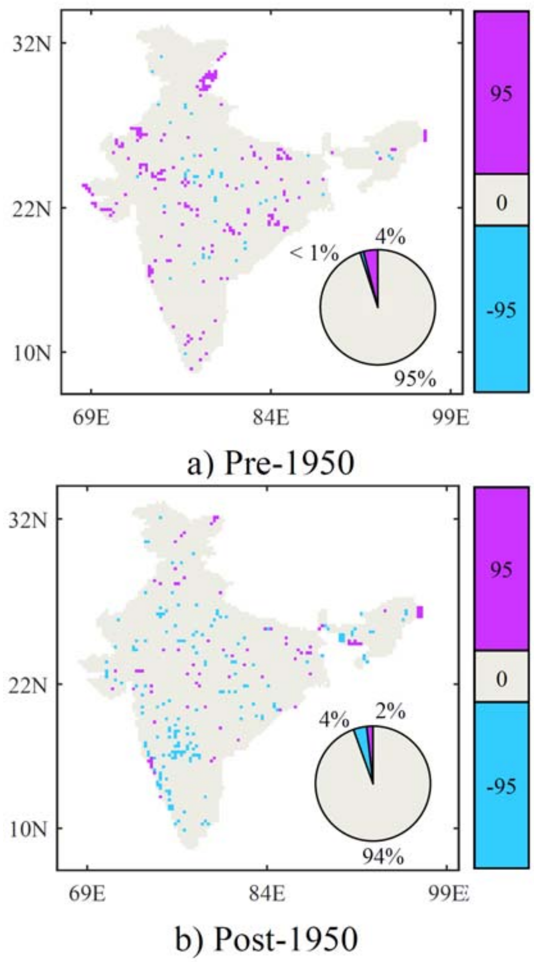


Fig. 5: Trend of Critical Duration

6. RETURN PERIOD (FREQUENCY) FOR AVERAGE CRITICAL INTENSITY

To observe the change in return period, average critical intensity (shown in Fig. 2) has been assigned as a fixed value for each grid. For that particular intensity, the return period has been computed as shown in Fig. 6. The return period using 100 year data varies from 2 to 4 years. While analysing the pre and post-1950, it has been observed that the extreme event occurrence was more frequent in post-1950. Especially, in Himalayan ranges, extreme events, having 1 in 10 or 1 in 30 years return period in pre-1950 has become 1 in 2 years in post-1950.

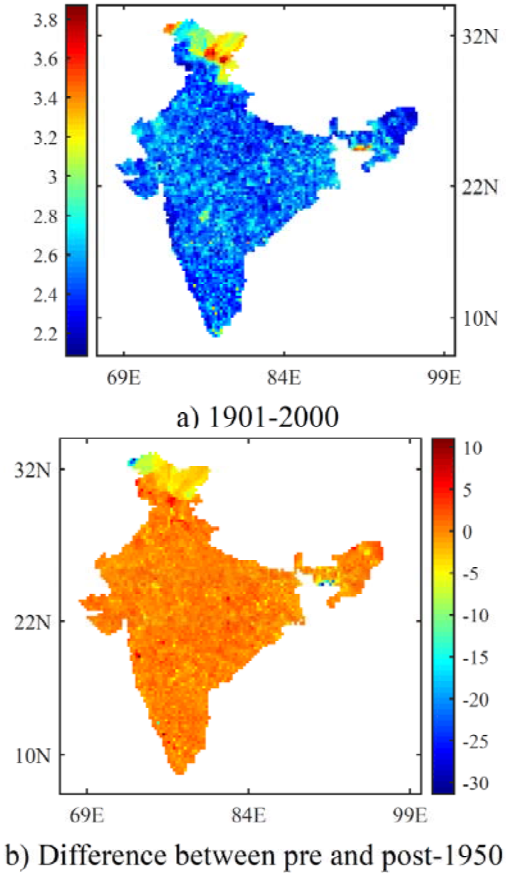


Fig. 6: Return Period (Frequency) of Average Critical Intensity

7. CONCLUSION

This study emphasises the changes in the characteristics of extreme rainfall in terms of Intensity, Duration and Frequency. This has been statistically analysed using EVT utilizing the gridded rainfall data of IMD for the period of 100 years (1901 to 2000). A rainfall event above 95th percentile of climatological mean is defined as an extreme event. Results show that the average intensity of each event varies spatially with the range of 10 to 216 mm/day, while duration varies from 1 to 6 days. Most of the grids in NE and CI were identified with high intensity and short duration. The classified dataset of pre-1950 and post-1950 shows significant differences between the patterns of extreme rainfall characteristics. It has been observed that in post-1950 the average intensity of rainfall increases approximately from 50 to 100 mm/day.

Further, Mann-Kendall's test has been used to detect the trends separately for pre-1950 and post-1950, which reveals that the variation of trend between these two series is significantly high. Moreover, it has also been noted that majority of grids show increasing trend in post 1950. In case of duration, only 6% of grids show significant trend. However, the changes observed in pre and post-1950 contradicts: in Pre-1950 4% of grids show increasing trend whereas in post-1950 the same amount of grids shows decreasing trend at different location. Further, it has been observed that the number of occurrence of extreme event has increased in post-1950. These analyses clearly show that the characteristics of extreme events have changed considerably in the last half century. Therefore, it is recommended that the modelling of extreme event for future climate should also incorporate the changing behaviour (nonstationary) of these events.

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