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Trends in Extreme Wet Events during Summer Monsoon Season over India

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Abstract India is a predominantly agrarian country with most of the agriculture in India being rainfed. Summer monsoon means life-giving rains for the entire Indian subcontinent. In India, the success or failure of the harvest and water scarcity in any year is always considered with the greatest concern. Extreme wet and dry events play a vital role in the intra-seasonal variability of monsoon rainfall. Particularly, in recent times, the occurrences of wet spells over India have led to widespread floods in the country. With changing climatic conditions, the occurrence and prediction of these extreme events have become a major stabilizing factor for the millions inhabiting the country. In this study, using 117 years (1901-2017) of high resolution daily gridded rainfall data, trends in extreme high rainfall events over six regions of India have been examined. The temporal change in extreme rainfall events during the time period 1901-1950 and 1951-2017 in summer monsoon months (June, July, August and September) has also been examined, in order to understand the increasing effect of anthropogenic factors after 1950. Using standardized scores (z-scores), each grid cell is analyzed to identify the number of extreme wet spells experienced during the study period. The analysis reveals that the number of extreme wet events showed an increasing trend in the month of June, as against a decreasing trend in July, after 1950, in most of the regions. In the recent period, the number of wet extreme events also show a decreasing trend in the northeastern region, which is considered as one of the rainiest zones of the world. As the present study tries to evaluate the changing trend of extreme wet events, it will help in formulation of hazard management strategies and policies by government planners.

Keywords: *summer monsoon, trend analysis, extreme wet events*

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1. Introduction

In context of the Indian subcontinent, monsoon means life-giving rains. To the inhabitants of this region, these monsoons are said to be a matter of life and death. Most of the people inhabiting the tropical monsoon climate are cultivators. The agricultural calendar of India is governed by monsoon. In India, rice is the major crop which provides food for millions of people. Since over half of the farmlands are rain-fed, monsoon is critical in achieving food sufficiency of the country. Besides agriculture, monsoon rains affect many other facets of life. Failure of any monsoon renders farmers jobless and forces them to migrate towards the cities. This situation crowds the city slums and further aggravates the job, infrastructure and sustainability of city life. Such is the magnitude of effects that monsoon casts on the lives of Indians. Variability in the onset and duration of monsoon has profound impacts on water resources, human life, agriculture, economics and ecosystems. Any fluctuations in the distribution or quantity of the monsoon rains may lead to conditions of floods or droughts causing the agricultural sector to suffer adversely. Besides its temporal variability, monsoon also exhibits large-scale spatial variability. Sometimes, the behaviour of monsoon is so erratic that in some parts of a country heavy rains causes disastrous floods, while in other parts there is severe drought. This space-time variation in rainfall has necessitated the need to study the monsoon variability in much detail.

Hydrological extreme events are typically defined in terms of floods and droughts. Floods are associated with heavy rainfall (from tropical storms, thunderstorms, orographic rainfall, widespread extra tropical cyclones, etc.), while droughts are associated with a lack of precipitation and often extremely high temperatures that contribute to drying. Floods are often fairly local and develop on short time scales, while droughts are extensive and develop over months or years [1]. These extreme heavy/deficit rainfall events may bring flood and drought-like situation, which have immense adverse impact on human lives and society including health, stability and economy. The spread of diseases and casualties during extreme events, such as heat wave, floods and droughts, increases. The increase in frequency of extreme events like very heavy rainfall, heat and cold wave during the recent times is seen as a manifestation of climate change.

The Indian southwest monsoon from June to September has some intra-seasonal oscillations and these oscillations are sometimes associated with very intense rain episodes causing floods and flash floods over different parts of India [2-8]. In recent years, the country has witnessed many catastrophic floods which led to irreparable damage to life, property, and infrastructure [9,10,11,12]. For example, during 2019, India had experienced 10 extreme rainfall events leading to flooding in Kerala, north Karnataka, Maharashtra, Assam, north Bihar, eastern Uttar Pradesh, south Gujarat and some parts of Punjab. Further, there are growing concerns that in the recent times climate change is making the monsoons more unpredictable and also may intensify the severity of events like floods. As the monsoon has become more uncertain, the effect of sharp deviations in the rainfall patterns on human habitation and the environment has become even stronger. With this in background, the present study tries to understand the nature of extreme wet events occurring over the country during the monsoon season and characterize their trends, with an effort to improvise the predicting skills of such extreme wet spells in advance and help in flood management strategies.

2. Study Area

India is situated north of the equator between 8°4' north to 37°6' north latitude and 68°7' east to 97°25' east longitude. With a total area of 3,287,263 square kilometers, India measures 3,214 km from north to south and 2,933 km from east to west. In the present study, the country is divided into 6 regions (based on homogeneity of climatic conditions) as shown in Figure 1.

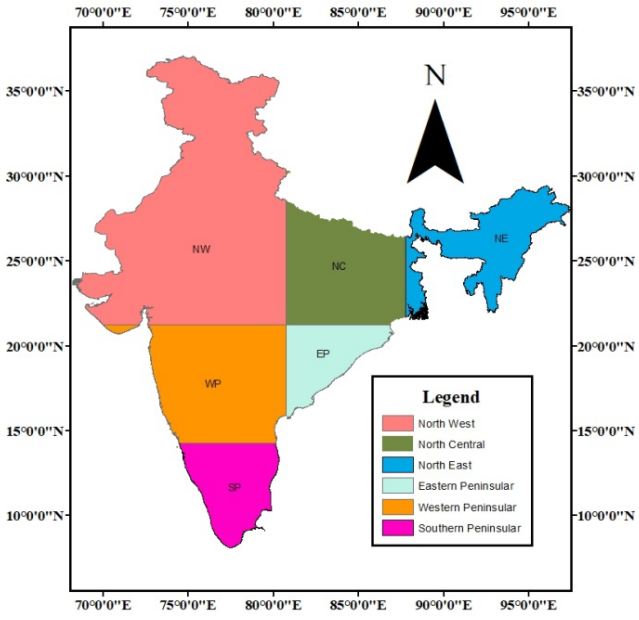


Figure 1. Six regions considered for analysis of extreme wet events

As the present research study is based on gridded data, the regions were demarcated along straight lines of latitudes and longitudes for sake of convenience of spatial analysis. Accordingly, the latitudinal and longitudinal extent of the six regions is as follows:

1. North West region; NW (68°E - 80°45' E: 37°15' N - 21°15' N)
2. North Central region; NC (80°45' E - 87°45' E: 30°30' N - 21°15' N)
3. North East region; NE (87°45' E - 97°45' E: 29°30' N - 21°15' N)
4. Eastern Peninsular; EP (80°45' E - 87°45' E: 21°15' N - 14°15' N)
5. Western Peninsular; WP (69°45' E - 80°45' E: 21°15' N - 14°15' N) and
6. Southern Peninsular; SP (74°15' E - 80°45' E: 14°15' N - 8° N).

3. Data and Methodology

Daily gridded rainfall data with a high resolution of 0.25°*0.25° from India Meteorological Department (IMD) has been used [13]. The daily rainfall records from 6955 rain guage stations are used for the interpolation and preparation of this gridded data set. The data was analysed for the summer monsoon months during 1901 to 2017. Daily normals are calculated for the months June to September for the entire time period and the anomalies were obtained for each grid cell. From the anomalies, the standard deviation and later standardized scores (z-scores) were derived for each grid cell, using the following formula:

$$z - score = \frac{x - \overline{x}}{\sigma} \quad (1)$$

Using the following criteria [14], the extreme wet events and extreme dry events were identified for each grid cell.

Table 1. Different categories of rain events according to standardized scores

Category	Standardized scores
Extremely Wet	2.00 and above
Severely Wet	1.50 to 1.99
Moderately Wet	1.00 to 1.49
Near Normal	-0.99 to 0.99
Moderately Dry	-1.00 to -1.49
Severely Dry	-1.50 to -1.99
Extremely Dry	-2.00 and less

In accordance with the above table, extreme wet events were identified for all those grids where standardized scores were equal to or more than 1.5, which includes two categories, namely Extremely Wet and Severely Wet. The sum of all such grids was computed for each of the six regions. The daily sums were added up to get the monthly values for each region. Monthly trend analysis was carried to understand the temporal variation in the number of these extreme events and the significance of the trend analysis was tested at 95% confidence level.

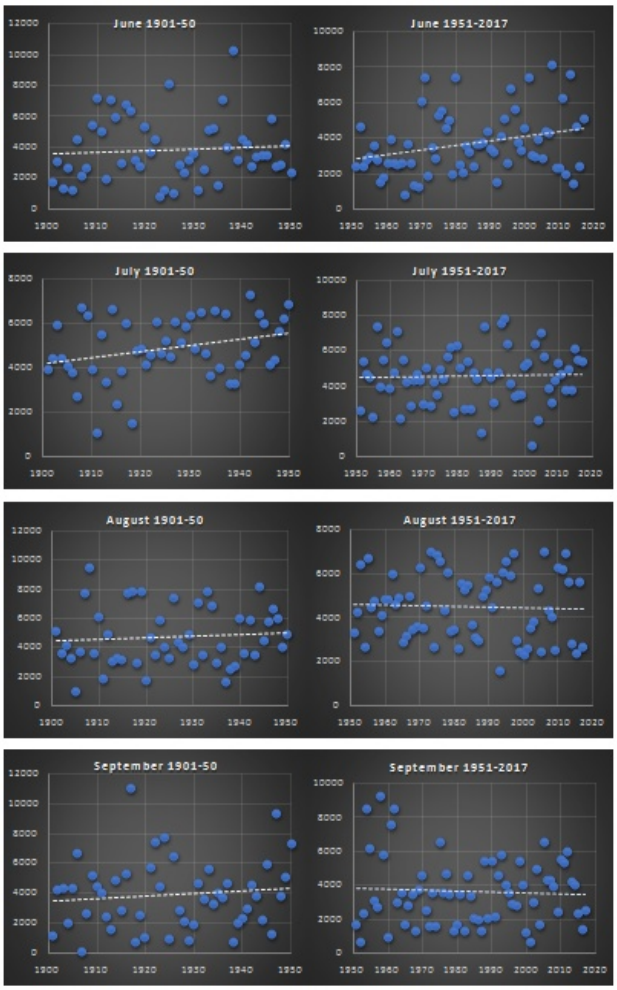
For understanding the nature of extreme wet events in the present period, it was thought appropriate to divide the entire study period into two time spans. Monthly trend analysis was performed for each of the six regions in order to get a comparison of trends for 1901 – 1950 and 1951 – 2017.

4. Result and Discussion

There have been some previous attempts to examine the trends in extreme rain events in India by using station data as well as gridded data [15,16]. All these studies give an indication of changing trends in the occurrences of extreme rainfall events, as was observed in the present analysis.

4.1. North West Region

Figure 2 represents the trend analysis of extreme wet events occurring over different grids covering the North West region. It can be observed from the graphs that there is a significant increase in the occurrences of extreme rainfall events in the period of 1951-2017 in the month of June. Normally, the onset of monsoon in the northwest India commences in July, with June receiving very scanty rainfall. However, as revealed from the above diagram, it can be said that the increasing trend of wet spells in the month of June may have contributed to substantial amount of rainfall in this month. The new onset dates suggested by the India Meteorological Department have also indicated earlier monsoon onset over this region [17].



Y axis: Number of grids depicting extreme wet events (z-core = 1.5)
X axis: Years

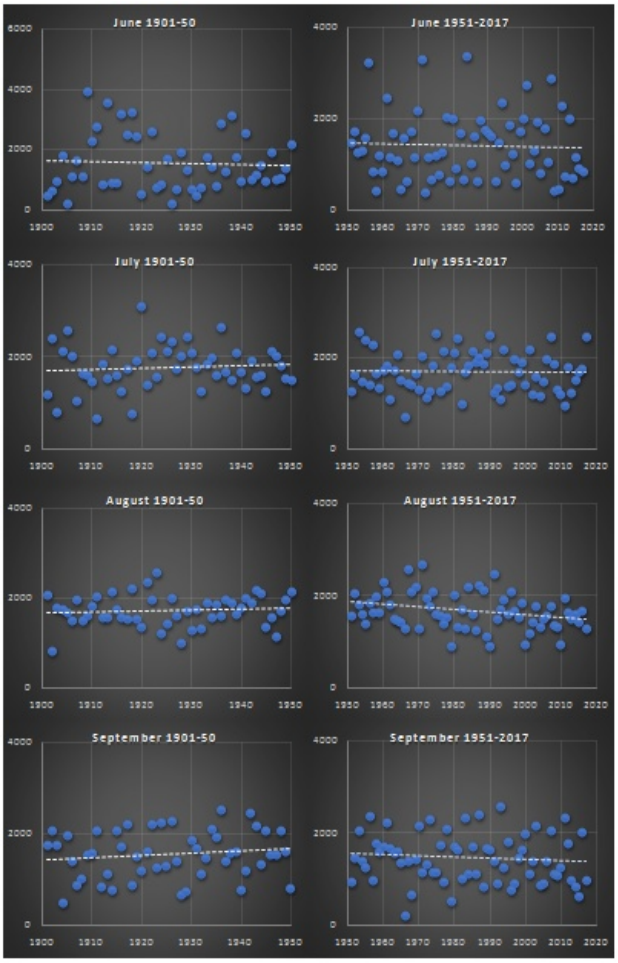
Figure 2. Trend Analysis of extreme wet events over North Western region

July, being the principal rain-bearing month, shows significant increasing trend in the number of wet spells before 1950. However, from 1951 – 2017, the extreme wet events do not show any significant trend in July, suggesting a probable shift in the rainfall pattern over this region.

Both the months of August and September do not show any significant trend throughout the study period. However, it is clear from the graphs that there is slightly decreasing trend, although not significant, observed during these two months after 1950. This shows a marked reduction in the amount of rainfall in the northwest region, making it drier.

4.2. North Central Region

The trend analysis pertaining to extreme wet events occurring over different grids covering the North Central region is depicted in Figure 3. There are no any significant changes are observed in month of June and July in both the time periods. However, in August, the number of extreme wet events has significantly decreased in the recent period. (1951 – 2017).



Y axis: Number of grids depicting extreme wet events (z-core = 1.5)
X axis: Years

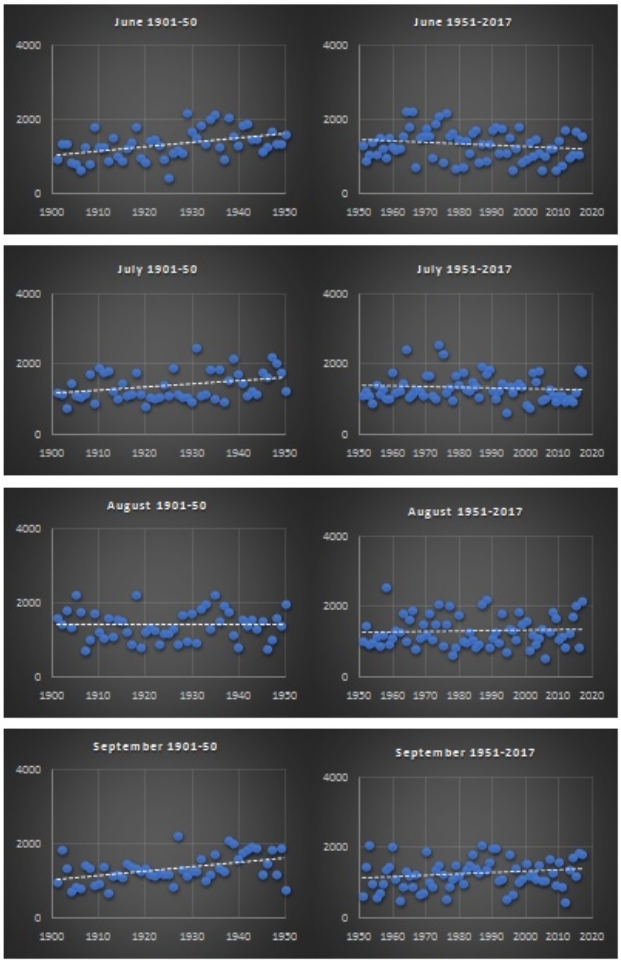
Figure 3. Trend Analysis of extreme wet events over North Central region

The North Central region covers most of the Indo-Gangetic plains, where agriculture flourishes on the fertile plain land in association with the ample rainfall received

over this region. But, the trend showing sharp decrease in the number of wet spells in the recent period will definitely affect the food grain production in the country. The results obtained for this region also correspond with another study relating to wet spells and dry spells after 1951 carried by Singh and Ranade [18].

In September the trend gradually increases over time during 1901-50, although not significant. However, there is a complete opposite trend observed in the period of 1951-2017, revealing a decrease in the total rainfall attributable to wet spells over this region.

4.3. North East Region



Y axis: Number of grids depicting extreme wet events (z-core = 1.5)
X axis: Years

Figure 4. Trend Analysis of extreme wet events over North East region

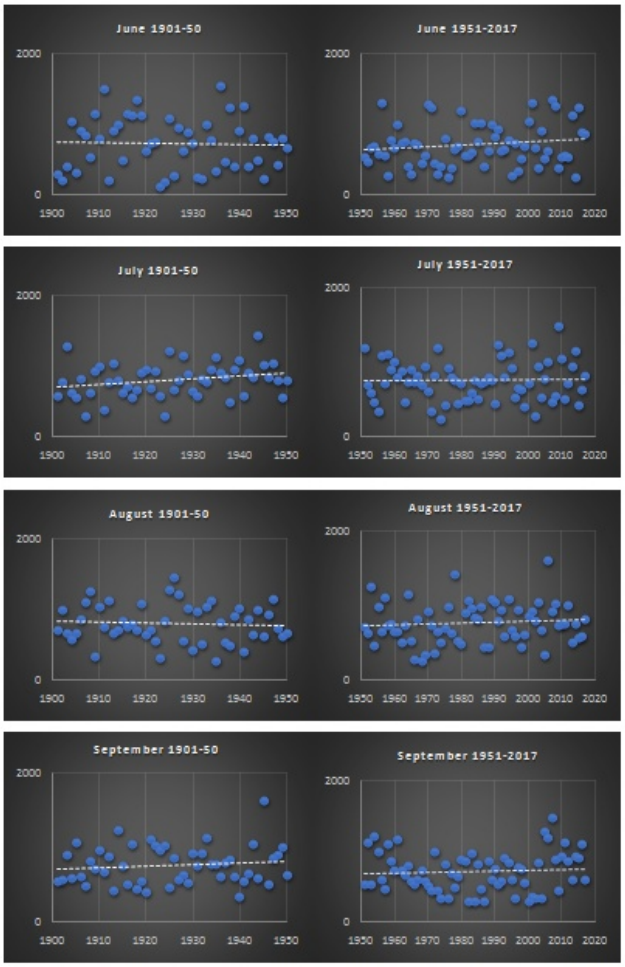
One of the recent studies indicated that Northeast India, the wettest place on Earth, has experienced a rapid decrease in summer monsoon rainfall in the last 40 years. [19]. Bearing in mind the consequence of decreasing rainfall trend and its serious implications over the region, it becomes much essential to look into the monthly trend analysis of extreme wet events from 1901 -2017 during the summer monsoon season (Figure 4).

In the month of June, the region experienced a significant positive trend in the frequency of extreme events during 1901 to 1950. However, it is observed that the region experiences a decreasing trend of extreme wet events from 1951 onwards. In July there is significant increasing trend observed in the time period 1901-1950 but this trend is not continuous in the period of 1951 to 2017.

No significant trends observed in August in both time periods. However, during September, there was significant increasing trend observed during time period 1901-50, indicating an increase in the number of wet spells. But, in the latter period (after 1950) the observed trend in the number of wet spells has lost its significance.

On similar lines, a decrease in heavy rainfall occurrences in northeast India was reported by Mahanta et. al, in their study of extreme events occurring during the pre-monsoon and monsoon season from 1971 – 2001 [20].

4.4. Eastern Peninsular



Y axis: Number of grids depicting extreme wet events (z-core = 1.5)
X axis: Years

Figure 5. Trend Analysis of extreme wet events over Eastern Peninsular region

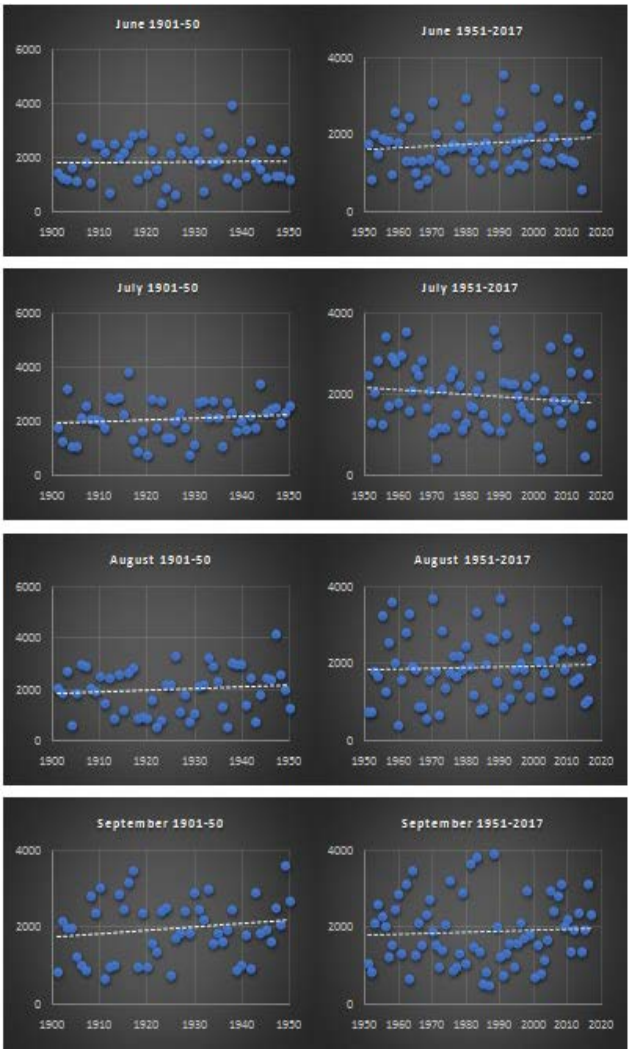
Figure 5 represents the trend analysis of extreme wet events occurring over different grids covering the Eastern Peninsular region. In June the extreme wet events mark an increase in its number in the period 1951 to 2017. The month of July, even though being the principal rain-bearing month, does not show an increase in the number of extreme wet events from 1951 onwards. However, before 1951, the number of extreme wet conditions showed an increasing trend. This clearly indicates the shift in rainfall patterns between June and July, where June has

started experiencing a greater number of heavy rainfall events while July has seen a drop in the number of extreme wet events after 1950.

Rice is the staple food of most of the people inhabiting the eastern peninsular region. For the cultivation of rice, it is the temporal distribution of rainfall, rather than the total amount of rainfall that is decisive. The shifts in the rainfall pattern due to the changes in the number of extreme wet events observed in the present study will probably lead to increased risk of growing crops in monsoon season, as suggested by [21].

There are no any significant changes are observed in Eastern Peninsular in the months of August and September in both the time periods. However, slight increase in the number of extreme wet events have been registered in both the months after 1950.

4.5. Western Peninsular



Y axis: Number of grids depicting extreme wet events (z-core = 1.5)
X axis: Years

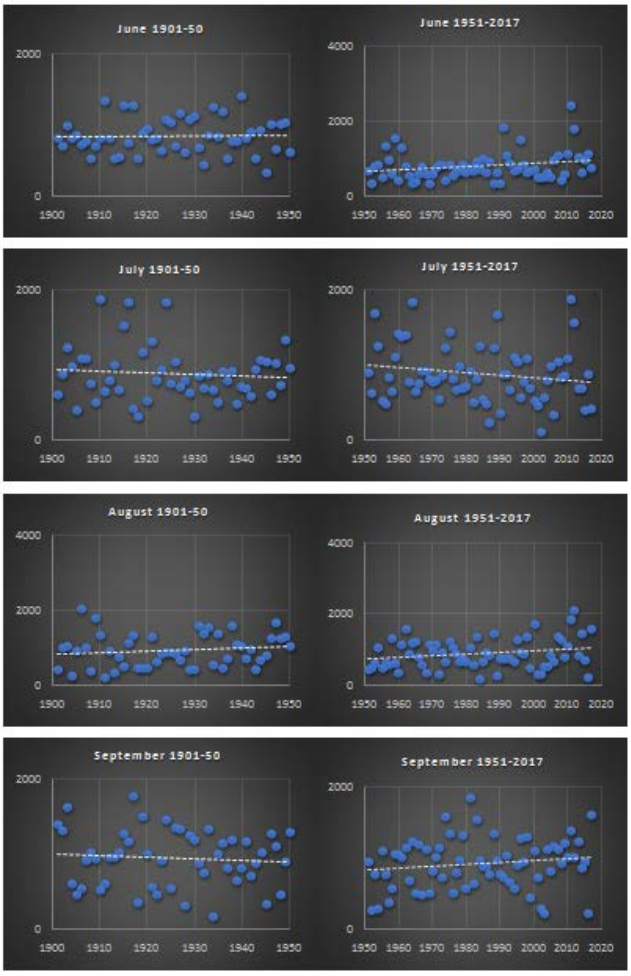
Figure 6. Trend Analysis of extreme wet events over Western Peninsular region

The trend analysis pertaining to the occurrences of extreme wet events over different grids covering the Western Peninsular region is depicted in Figure 6. It is observed from the graphs that in the month of June there is a gradual increasing trend from 1951 onwards, although not significant. Prior to 1951, the number of heavy rainfall occurrences did not show any increase over a period of 50 years from 1901 – 1950.

In July, opposite trends are observed in two different time periods, in 1901-50 there is an increasing trend and during 1951-2017 significantly decreasing trend in the number of extreme wet events is observed. July, being the principal rain-producing month and receiving the most amount of rainfall has probably undergone considerable changes in the recent period. In this era of global warming, many studies [22,23,24,25] have shown a decrease in the summer monsoon rainfall, which was mostly attributable to July rainfall. As the number of extreme wet events have decreased sharply in July, it may have reduced substantial amounts of rainfall received in the region, which in turn, may have affected the overall seasonal performance of summer monsoon rainfall.

No significant increasing or decreasing trends can be noticed in the months of August and September in both the time periods.

4.6. Southern Peninsular



Y axis: Number of grids depicting extreme wet events (z-core = 1.5)
X axis: Years

Figure 7. Trend Analysis of extreme wet events over Southern Peninsular region

The Southern Peninsular region experiences the first onset of monsoon and as the monsoon gets established over this region, monsoon advances further across the

country. The region also consists of several important cities for trade and economic growth. Hence, understanding the rainfall variability over this region becomes much crucial. Figure 7 represents the trend analysis of extreme wet events occurring over different grids covering the Southern Peninsular region. The trends in the number of extreme wet events do not exhibit significant changes in any month during the entire study region. However, slight increasing trends are observed in the months of June, August and September after 1951, indicating that the region is experiencing wetter climates in the recent period. From 1901- 1950, the month of June experience nearly no change in the number of extreme wet events; the month of August experiences a slight increase in the number of heavy rainfall events (which remain continued even after 1950), and unexpectedly, there was a negative trend notice in the month of September during this time span.

July stands out most conspicuously among all the four months, displaying a decreasing trend in the number of extreme wet conditions. It must be noted that this decrease in the number of extreme wet events have remained consistent over most of the regions.

5. Conclusion

India has witnessed some of the most destructive extreme precipitation events, which have affected urban transportation, agriculture, and infrastructure. Projecting extreme rainfall is a challenge for climate models. However, understanding the trend of such extreme events will definitely help in identifying the cause of such trends and in turn might become helpful in preparedness of such unexpected events. One such attempt has been made in the present research study, where monthly trend analysis of extreme wet events was carried out for the summer monsoon period. It is revealed from the study that there has been considerable change in the number of extreme wet events that had occurred during 1901 – 1950 and 1951 – 2017. It was found that during June there was a significant increasing trend in the number of extreme wet events over Northwest region and the Peninsular region (Eastern, Western and Southern Peninsular) in the recent period (1951 – 2017).

At the same time, it was also observed that July experienced an increasing number of extreme wet events before 1950. However, there has been a shift in the pattern of the occurrences of wet events during this month post 1950. There is a significant decrease in the number of extreme wet events in western and southern peninsular region during July. The study thus reveals that June has seen more events of extreme wet conditions in the recent period, while July, the principal rain-bearing month, is experiencing a decrease in the number of extreme wet events.

There were no significant trends in the frequency of extreme events in the month of August and September over the six regions, with the exception of North Central region where August experienced significant decreasing trend in the number of wet events.

The most dramatic change in the number of extreme events was observed in the North-eastern region. During both June and July, there was significant increasing trend in the number of extreme wet events during 1901 – 1950. However, post 1950, there was a significant decrease in the number of occurrences of extreme wet events. Considering the North-east region as one of the regions with highest rainfall in India, there has been a remarkable change in the number of extreme wet events in this region.

The observed variability in the occurrences of the extreme events in the recent period, both with respect to spatio-temporal dimension, can be attributable to anthropogenic factors such as urbanization effects, aerosol concentration, changes in land use and land cover, deforestation, etc. In this connection, reference is invited to Vinnarasi and Dhanya, who conducted a similar study on the changing characteristics of extreme wet and dry spells of Indian monsoon rainfall from 1901 – 2013 [26].

Thus, the present study points out the increasing need to carry out more such research studies to evaluate the relation of local factors with occurrences of extreme heavy rainfall events, and the changing trends can be incorporated in water resources modelling and hazard management strategies.

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