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Climate Change and Consequential Rainfall Trends: An Indian Perspective

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ABSTRACT

This article presents an overview of different studies pertaining to the trends observed in rainfall over India and its constituent regions. The spatial scale of trend estimation considered in the reviewed studies is an important aspect that dictates the overall trends over a given scale and helps in ascertaining the influence of anthropogenic activities upon the resultant trends. In this article, Indian trend analysis studies conducted on a national, meteorologic sub-divisional, river basin and agro-climatic zonal level as well as for different time periods and time scales have been reviewed. One of the more recent national-scale studies were able to detect overall negative trends in the annual rainfall over India with a more prominent decline observed during the latter half of the 20th century and first decade of 21st century. Also, 17 out of 30 meteorological sub-divisions for which trend analysis was carried out exhibited increasing tendencies though, all were insignificant. Most of the river basins of India have shown an increasing trend in annual rainfall with Indus (lower) and Tapi basins observing maximum rise. Decreasing trends were however, recorded over most of the basins especially after 1970. The conclusions drawn from the review of suitable studies highlight the variation in trends across different studies due to a different set of variables and factors involved in individual studies. The practical significance of trend analysis has also been discussed along with a need of a more subjective assessment of the mathematical outputs obtained from commonly used trend analysis methods.

Key words: *Rainfall, Trend, Meteorologic sub-division, River basin, Agro-climatic zone*

Introduction

India occupies an area of about 3.28 million km^2 and supports an estimated population of 1,368.6 million with an annual growth rate of almost 1% as per World Bank data. Agriculture sector in India, which provides employment to about 60% of the nation's population, is heavily dependent upon rainfall with 51% of the net sown area in the country being rainfed and bearing the responsibility for 40% of the total food production as per the annual report of Department of Agriculture, Cooperation and Farmers' Welfare (2020). However, Indian agriculture and allied sectors may be headed towards dire circumstances due to its high sensitivity towards climatic variations with rainfall and temperature having a significant impact upon agricultural production (Thornton *et al.*, 2014). The annual rainfall in India is considerably skewed towards the monsoon season (June – September) with almost 80% of the total annual rainfall of India falling during this period. Water is a key natural resource (Upadhyay *et al.*, 2019) with rainfall being its primary source and any variation in the magnitude or distribution of rainfall would also impact runoff distribution (Ramanathan *et al.*, 2001), aquifer and soil moisture

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storage (Raucher, 2011), and also the recurrence interval of extreme events such as droughts and floods (Mirza, 2002; Sinha Ray and Srivastava, 2000), gradually causing distress to cropping patterns and agricultural productivity (Gadgil, 2012; Mall *et al.*, 2007). These consequences are accompanied by indirect influences upon the physical system in the form of increasing soil erosion as well as decreasing water supply, groundwater level and irrigation water (Houghton *et al.* 2001). Thus, it is crucial to understand the nature of rainfall variations over the Indian sub-continent so as to develop suitable strategies against predicted scenarios.

Spatial Scales for Analysis

The available literature consists of a plethora of studies which have analyzed trends in the climatic variables at different spatial scales such as national, regional, zonal, river basin-scale, state-wise and district-wise. Large-scale studies of trends such as those conducted on continental or national-scale are able to capture trends in rainfall regime due to a global climatic shift (Baines, 2006) or a weakening monsoonal circulation (Duan and Yao, 2003; Pant, 2003) whereas, relatively smaller-scale studies conducted in a region or river basin tend to better capture the effects of anthropogenic activities (Basistha *et al.*, 2009) comprising of decline in forest cover (Gupta *et al.*, 2005; Ray *et al.*, 2003; Ray *et al.*, 2006), local land use changes (Pielke Sr. *et al.*, 2007; Ramankutty *et al.*, 2006) as well as increase in fossil fuel and aerosol emissions (Lelieveld *et al.*, 2019; Ramanathan *et al.*, 2005; Sarkar and Kafatos, 2004) which, if left uncontrolled, accumulate over time to such an extent that their influences over the climate become more pronounced. Moreover, it has been ascertained that any climatic observations recorded at a global or continental scale are less than useful for local or regional scale planning (Barsugli *et al.*, 2009; Brekke *et al.*, 2009) implying the need for evaluating historical trends or future projections on a local scale as well (Ghosh, 2018).

River basin-scale trend analyses have been conducted widely across India with the results for all the river basins usually compiled together to be a representative of the climatic trends across the entire country. The Central Water Commission of India (2012) has divided the country into 22 river basins consisting of 12 major river basins, referring to the basins with catchment areas greater than 20,000 km^2 among which Ganga river basin is the largest besides which there are also 7 medium-sized basins formed by Sabarmati, Mahi, Narmada and Tapi rivers flowing west and the Subarnarekha, Brahmani, Baitarani and Cauvery rivers flowing east together which cover up to 15% of the total drainage area of India (Jain and Kumar, 2012). Some river basins have been formed as a coalescence of multiple rivers with smaller individual catchment areas and are categorized as different combinations of east and west flowing rivers.

Trend analyses have also been conducted over various agro-climatic zones in India. A region can be divided into agro-climatic zones (CZs) based on homogeneity in weather variables that have greatest influence on crop growth and yield (van Wart *et al.*, 2013), while agro-ecological zones are defined as geographic regions having similar climate and soils for agriculture (FAO, 1978). Based on these factors, three governmental bodies viz., erstwhile Planning Commission, National Agricultural Research Project (2009) andNational Bureau of Soil Survey and Land Use Planning (NBSS & LUP) have come up with their own classifications dividing the country into 15, 127 and 60 zones, respectively. Trends estimated in these zones may be useful to assess any deviations from their standard climate.

Trend analysis studies have also been carried out in the meteorological sub-divisions of India. A meteorologic sub-division is defined by its homogeneous climate and according to Blanford (1877), a sub-division also requires some resemblance in language, tradition, culture, thoughts and political aspirations among its residents. The Indian Meteorological Department (IMD) has classified the country into 36 meteorological sub-divisions of which 9 have been named after a state, 6 after a group of smaller states or union territories with similar climate, 12 after larger states divided into two parts, 7 after larger states divided into three or more than three parts with greater variations in climate and 2 after the islandic regions of India (Kelkar and Sreejith, 2020). Similar to agro-climatic zones, climatic trends over meteorologic sub-divisions can also be used to evaluate any divergences from the homogeneity of their respective climatic systems.

Rainfall Trends Over India and its Meteorologic Sub-divisions

There is a great number of studies that have made an attempt to evaluate the overall spatio-temporal variabilities in rainfall across India. A majority of previous research concluded that there were no significant trends in the average annual rainfall across the nation (Lal, 2003; Sarkar and Thapliyal, 1988). However, a separate set of studies (Dash *et al.* 2004; Kumar and Jain, 2009) were able to identify certain regions across the country which exhibited significant variabilities in long term rainfall.

Jagannathan and Parthasarathy (1973) examined the trends in annual rainfall of India with data of 70 years from 48 stations providing coverage for the entire country. The results were a mix of increasing and decreasing trends across different stations most of which were not significant except at few randomly distributed places.

Mooley and Parthasarathy (1984) attempted to develop an understanding of the inherent long-term interannual variabilities of the summer monsoon (June – September) rainfall across India for a period of 108 years (1871 to 1978). There are 13/9 years of large-scale deficit/excess in the 108-yr period. Significant trends were discovered at 5% level for 10-year time periods of 1896-1905, 1899-1908 and 1965-1974. Two time periods viz., 1899-1932 and 1933-1964, were identified as periods exhibiting increasing and decreasing trends in the annual rainfall of the country, respectively.

Thapliyal and Kulshrestha (1991) attempted to establish a clear explanation of whether there is any climate change and corresponding rainfall trend over India and reached a conclusion that despite the presence of random fluctuations in rainfall along with marked increasing and decreasing tendencies during certain time periods, there was no systematic climate change or trend over India.

Rajeevan *et al.* (2008) used 104 years (1901 – 2004) of daily gridded rainfall data to assess the nature of extreme rainfall trends over India and found significant interannual as well as interdecadal trends with a 6% increase in very high rainfall (equal to higher than 150 mm/day) events which was apparently lower than the 10% increasing trend observed by Goswami *et al.* (2006) between the years of 1951 and 2000.

Guhathakurta and Rajeevan (2008) compiled the rainfall trends across 36 meteorological sub-divisions of India, which consisted of 1476 raingauge stations during the course of study, in order to analyze the overall monthly, seasonal and annual rainfall trend of the country and concluded that no significant trends were observed in summer monsoon season of India as well as in the individual months of the season.

Kumar *et al.* (2010) evaluated the trends in monthly, seasonal and annual rainfall obtained from a monthly dataset of 135 years (1871 – 2005) and spanning 30 Indian sub-divisions and discovered that only three (Coastal Karnataka, Haryana and Punjab) of the 15 sub-divisions, which indicated increasing tendencies in annual rainfall, were significant whereas the remaining sub-divisions possessed a decreasing trend of which only one sub-division (Chhattisgarh) faced a significant reduction. The entirety of India however, witnessed no significant trends in its monthly, seasonal and annual rainfall.

Subash and Sikka (2014) evaluated the monthly, seasonal and annual patterns in the rainfall over all the meteorologic sub-divisions and the homogeneous regions of India for a period between 1904 and 2003 which resulted in detection of no significant temporal variabilities in any of the time series with 17 of the 30 sub-divisions considered in the study exhibiting an increasing trend while the remaining 13 sub-divisions showed a reducing trend.

Radhakrishnan *et al.* (2017) investigated 114 years (1901 – 2014) of seasonal and annual mean rainfall over India and a statistically significant decreasing trend was detected in the summer and annual rainfall of last 30 years and a reduction in rainfall was inferred over the entire time period which became more prominent in the years between 1985 and 2014.

Sinha *et al.* (2019) used the 63 years (1951 – 2013) worth of rainfall dataset prepared by Indian Meteorologic Department to examine the trends in pre-monsoon (March –May) rainfall over India and found that there was a significant decline in rainfall in the whole season and its individual months as well with a maximum reduction of 0.55 mm occurring in the month of March.

Praveen *et al.* (2020) were able to detect a significantly falling trend in the overall annual rainfall across the nation with an increasing trend between 1901 – 1950 followed by a declining trend from 1951 to 2015.

Rainfall Trends in Indian River Basins and Agro-climatic Zones

The seasonal and annual variability of rainfall, rainy days and heavy rain during the last century was analyzed by Singh *et al.* (2008) for nine river basins in north-west and central India by utilizing raingauge station data available at 43 stations maintained by IMD. The study revealed the presence of increasing trends in annual rainfall for most of the river basins, the magnitudes of which varied from 2 – 19% of the mean rainfall over the century. The Indus (lower) and Tapi basins witnessed the maximum rise in rainfall. An increasing trend, ranging from 9 – 27 mm per 100 years across different river basins, was also observed in the annual peak rainfall series with the Brahmani and Subarnarekha riverbains showing a maximum increase of 27 mm.

Study conducted in the Ganga-Brahmaputra-Meghna river basins by Kumar and Jain (2010) who employed a gridded rainfall dataset having a spatial resolution of 1° × 1° over a time period of 54 years (1951 – 2004) which was further averaged for all the grid points located in a particular basin, revealed increasing and decreasing trends in annual rainfall over the Meghna and Brahmaputra basins, respectively, while Ganga river basin contained no clear variation. It was inferred from the seasonal rainfall analysis that the monsoon rainfall exhibited an increasing trend for Brahmaputra and Meghna river basins whereas a decreasing trend was detected in case of Ganga basin.

In order to study the effects of rainfall variations on the productivity of Maize crop under the All India Coordinated Maize Improvement Project (AICMIP), Mahajan *et al.* (2015) conducted trend analysis of the rainfall during Kharif season and its individual months in four agro-climatic zones using historical records of rainfall distributed over 22 years from 1991 to 2012. The rainfall patterns were found to vary across different zones and months and the results showcased a decreasing trend in total rainfall during the growing season of Maize in all the zones except one which exhibited the only significant increasing trend. The insignificant trends resembled the findings of a similar study conducted in Orissa by Patra *et al.* (2012) and it was suggested that the lack of significant trends may not be important from a practical perspective (Daniel, 1978).

With a catchment area of 1.32 million km^2, Ganga basin forms the largest river basin in India and to study its rainfall variability, Bera (2017) utilized 100 years (1901 – 2000) of monthly rainfall data obtained from IMD collected from 236 districts distributed over the entirety of the basin. Reducing trends were detected for exactly half of the districts in the basin of which, significant trends were recorded over 39 districts. A total of 184 districts observed falling trends during the pre-monsoon season (January – May), 54 of which were statistically significant. The annual as well as pre-monsoon and post-monsoon season rainfall were also found to be significantly reducing in most of the districts lying in the sub-basins of Gandak, Kosi and Sone.

Daily gridded rainfall data of high spatial resolution, i.e., 0.25° × 0.25°, recorded by IMD over 85 river basins was evaluated by Bisht *et al.* (2017) for the time period between 1901 and 2015 which was further divided into pre-urbanization (1901 – 1970) and post-urbanization era (1971 – 2015). The study illuminated the heterogeneous nature of trends across the basin and positive trends were discovered in 1-day, 2-day, 3-day and 5-day maximum cumulative rainfall in tandem with a rise in extreme rainfall events over most of the constituent sub-basins during the post-urbanization era. The overall annual and monsoon rainfall trends were however, decreasing, which became more prominent after 1970 and highlighted the effects of urbanization on the basin rainfall.

Biswas *et al.* (2019) employed various statistical methods to analyze spatio-temporal variabilities in the seasonal and annual rainfall over upper Godavari river basin by making use of the rainfall data of 100 years (1911 – 2010) collected for 6 districts by IMD and found an overall decreasing trend in the rainfall of the area. There were significant increasing trends though, in annual rainfall of the south-eastern region of the basin while the remaining segments of the study area experienced a significantly decreasing trend. Summer rainfall also possessed decreasing tendencies with significant changes in the eastern region of the basin while the variation rate was insignificant in a major portion of the study area except in Beed district where a significant reduction of 5.8 mm every 100 years was estimated. The average winter rainfall was also found to be significantly reducing at the rate of 4.8 mm for every 100 years. The monsoonal rainfall trends were not spatially consistent throughout the basin with the central region witnessing the maximum reduction in rainfall over the time period of the study and Ahmednagar district recording a significant decrease in rainfall of 113 mm in 100 years.

Trends in extreme rainfall events over various Indian river basins were analyzed by Chaubey *et al.* (2022) using a 119-year (1901 – 2019) high resolution gridded dataset obtained from IMD. A marked spatial shift in the trends of extreme rainfall events from the basins of north-eastern India to the west-Indian river basins was detected in the decades following the year 1981. The peak annual rainfall for return periods of 10-year, 30-year and 100-year underwent a statistically significant rise across multiple Indian river basins which may result in greater floods thus, posing a threat to agriculture, human life and infrastructure.

Gill *et al.* (2010) studied the annual variability of rainfall using weekly rainfall data of 26 years (1984 – 2009) for three stations namely, Ballowal Saunkhri, Ludhiana and Bathinda which acted as the representative of their corresponding agro-climatic zones with average annual rainfall of 1025, 753 and 549 mm, respectively. An increasing trend was detected by Hundal *et al.* (1997) in the annual and kharif season rainfall at Ludhiana within 30 years. The present study however, revealed a slightly increasing trend at Ludhiana whereas the rainfall in Ballowal Saunkhri and Bathinda were found to be decreasing.

Rainfall trends at four stations namely, Pusa, Madhepura, Patna and Sabour which represented three agroecological zones viz., Zones I, II, III A and III B, respectively, in the state of Bihar, were examined by Abdul Haris *et al.* (2010) using the monthly, seasonal and annual rainfall datasets collected for a period of 1961 – 2005 from Patna and Pusa, 1961 – 2003 from Madhepura and 1972 – 2005 from Sabour. The annual rainfall during the pre-1990 (1961 – 1990) and post-1990 (1991 – 2005) periods were found to possess a rising trend at all the stations except Madhepura during the pre-1990 period with Patna and Sabour exhibiting statistical significance while Patna recorded significant rainfall in post-1990 period as well. Monsoonal rainfall trends came across as significantly increasing at Patna and Sabour for the pre-1990 period.

Mall *et al.* (2016) investigated the rainfall trends in nine agro-climatic zones spread over Uttar Pradesh using daily rainfall data ranging from the years 1971 up to 2013 obtained from various organizations. Four out of the nine zones considered for the study, i.e., South-western Semi-arid, Central Plain, Western Plain and Eastern Plain zones were characterized to have a decreasing trend in annual rainfall, two zones namely, North Eastern Plain and Bundelkhand zones lacked any clear annual trends while the remaining zones viz., Vindhyan, Mid Western Plain and the Bhabar and Tarai zones showcased an increasing trend with the annual rainfall trend in Bhabar and Tarai zone being statistically significant and its rising rate was estimated as 1.8 mm per year. More detailed analysis in this region using the same rainfall dataset was conducted by Bhatt *et al.* (2019) in order to study the effects of various climatic parameters upon the yield of rice in the state by analyzing the seasonal (kharif season) and annual trends in rainfall with respect to the different agro-climatic zones in the state and discovered that there was a 1.7 and 0.7 mm/yr increase in the average annual and kharif season rainfall, respectively. These trends however, were influenced heavily by unusually high change of 13 mm/yr in the magnitude of annual rainfall witnessed in Bhabar and Terai zone, the data of which when excluded from the analysis, resulted in an overall negative trend of 0.8 mm/yr. Based on the rainfall of individual agro-climatic zones, there was no clear direction of trend due to large spatial-temporal variations across the zones.

Paul and Birthal (2016) investigated the rainfall patterns during a period of 102 years (1901 – 2002) over various agro-climatic zones of India using district-level rainfall data. Based on the annual temperatures and length of cropping periods, four broadly classified homogeneous agro-climatic zones were created viz., arid, humid, semi-arid temperate and semi-arid tropics, by grouping suitable Indian districts (Rao *et al.*, 2005). The dataset was divided into two periods, i.e., 1901 – 2002 and 1939 – 2002 termed as long-term and short-term periods. No significant long-term trends were detected on a national-scale however, there were some regions of fluctuations. The only significant trend was observed in case of arid zone rainfall which was interestingly increasing in nature whereas insignificantly falling trends were observed in case of the rest of the zones.

Singh *et al.* (2020) attempted to explain the variability in rainfall over the agro-climatic zones of the mid-Mahanadi river basin making use of gridded rainfall dataset of 0.25° × 0.25° resolution obtained from IMD for the years between 1979 and 2013 which were classified into monthly, seasonal and annual time scales. The results highlighted the dominance of significantly reducing trends in non-monsoonal rainfall across most of the agro-climatic zones. With the exception of zone AZ64, significantly increasing trends were estimated in high intensity rainfall events over all the agro-climatic zones.

Rainfall trends over the West Coast Plain and Hill agro-climatic zone of India were examined for a period of 117 years (1901 – 2017) by Saini *et al.* (2020)

using gridded rainfall dataset of 0.25° × 0.25° resolution maintained by IMD. The analysis revealed statistically significant trends in the monthly rainfall of January, July, August, September along with the rainfall during Winter season amongst which, the months of January and July exhibited a decreasing trend with the variations in July being the highest of all the other time series. Monthly rainfall of August and September apparently rose through the time period considered for the study while the winter rainfall seemed to reduce over time.

Conclusion

The variations in the results of individual studies may be attributed to different areal extents, estimation methodologies employed, rainfall datasets used (IMD observatories, hydro-meteorology or agro-meteorological observatories maintained by state government organizations, universities etc.), time period and temporal scale of datasets. Careful assessment of statistical significance was also crucial as some studies indicated that significant trends may not carry any practical implications due to set of variables, such as yield of certain crops, being extremely sensitive to even the most trivial changes in rainfall. Furthermore, trends over a particular area of interest may be subjected to bias due to presence of high magnitude of trends in the dataset of one or more stations while the majority of stations in the area may not exhibit such an occurrence hence, implying the need of providing suitable weights to the rainfall recorded at each station.

It may also be concluded that a better comprehension of mathematical and statistical evaluations of rainfall trends, resulting from global as well as local climate change, can be derived from a diligent and logical subjective assessment of the rainfall scenario.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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