CHAPTER 1

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Contents

Rainfall, regarded as the most important climatic parameter in tropical regions, is characterized by high variability in both temporal and spatial scales [1]. Along with temperature, it governs the agricultural productivity, thereby, determine the socioeconomic status of an agrarian country such as India. The repercussions of variations in rainfall on various aspects of livelihood, such as food security, biodiversity and freshwater availability are enumerated well in the past literatures [2-6].

Climate change is considered as the greatest environmental threats to sustenance and livelihoods of human beings, especially in developing countries like India. The IPCC fifth assessment report draw attention to the impacts of human induced climate change on global temperature and precipitation regimes [7-8], altering their natural course. The induced changes in precipitation in terms of its frequency, amount, distribution and significance or changes in cryosphere may lead to quantitative and qualitative changes in the hydrology of the area [7-8]. In Plate 1.1 remarkable change in average temperature and precipitation from 1986-2005 to 2081-2100 under two representative concentration pathway (RCP) scenarios- RCP 2.6 and RCP 8.5 can be visualized [7]. The severity can be seen clearly in the projected changes in both temperature and precipitation from these plots. It was emphasized that under RCP 8.5 scenario the average precipitation might decrease in many mid-latitude and sub-tropical dry regions, while the precipitation was likely to increase in many mid-latitude wet regions by the end of the 21st century. In case of the monsoonal regimes, the monsoonal precipitation was predicted to intensify, and the duration of the monsoon season is predicted to be lengthened in many regions. The diagnostic analyses of model data indicate that higher temperatures lead to an increase in atmospheric moisture content, even without any change in the total precipitation. The intensity and frequency of occurrence of extreme events in precipitation are predicted to be stronger over the wet tropical regions, because of the increase in global mean surface temperature [7], although regional variability was expected in monsoon precipitation. In India where rainfed agriculture governs the livelihood and sustenance of the economy, studies pertinent to the nature of precipitation and its inter-links to other parameters governing the local climatology is a prior requisite to the understanding of induced changes happening in rainfall over the region.

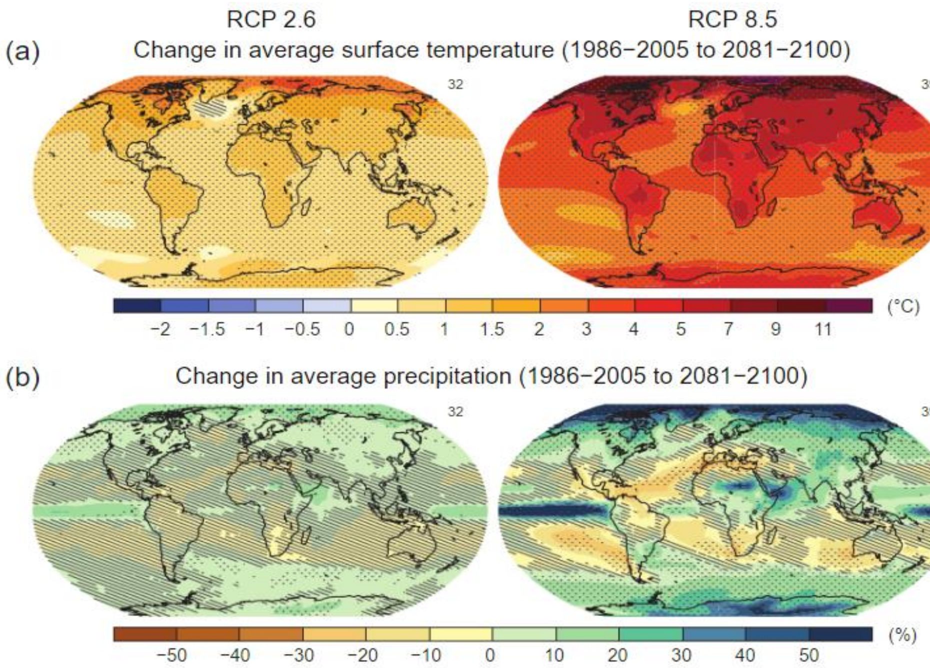

Plate 1. 1 Maps of CMIP5 multi-model generated results showing scenarios of RCP2.6 and RCP8.5 in (a) annual average change in global surface temperature and (b) average percentage of change in precipitation (1986-2005 to 2081-2100); the shaded areas with parallel lines indicate regions where the multi-model average is small compared to natural internal variability (<1σ of natural internal variability in 20-year averages) and the dotted areas are the regions where the multi-model avearge is large compared to natural internal variability (>2σ of natural internal variability in 20-year averages) and where at least 90% of the applied models agree on the sign of change. Source: [7]

As available in the literatures (presented in the next sections afterwards of this thesis), the studies on rainfall characteristics and its associated relationships with various meteorological parameters are well enumerated with the help of different time series methods. Based upon the assumptions of stationarity (discusses whether the statistical properties i.e., mean and variance of a time series remains constant or change over time) and linearity (discusses whether there exists proportionality between two or more variables of the time series), there are mainly two types of methods for analyzing a time series-time domain method that include autocorrelation and cross correlation analysis (tests the similarity between observations as a function of the time lag between them, helpful in knowing the presence or absence of any repeating pattern in the time series or in averaging), and the frequency domain method that includes spectral analysis and wavelet analysis (decomposes the time series into smaller intervals to find out the presence of any harmonic frequency). Both the time domain as well as frequency domain methods cover a broad area of sub-methods, which have their several applications including meteorology [9] and is useful to analyze the cause of variations and to compare the actual performances [10]. Time series plots can reveal patterns such as random trends, level shifts, periods or cycles, unusual observations, or a combination of patterns [11], and thus helps in finding the source, or, the cause of the changes, either long term, or short term, in the climatic conditions of a region.

The North-Eastern region of India (NER) is one of the richest biodiversity zones of the world, harbouring the 2nd largest global biodiversity hotspot- Indo-Burma Hotspot [12], World's highest rainfall zone- Mawsinram and Cherrapunji (https://www.guinnessworldrecords.com/world-records/greatest-monthly-rainfall-) and is considered for richness in diverse rice germplasm [13]. It is characterized by the variability in its physiography [14]. Entire Sikkim, parts of Assam and Arunachal Pradesh of NER represent a climate characterised by temperate summers as well as chilly winters. Parts of Eastern Assam and Arunachal, Nagaland, Mizoram, Tripura and Meghalaya are located within the Patkai range and its extensions; dominated by temperate to alpine climate according to the altitudes. The Major parts of Assam and lowlands of Manipur on the other hand are covered by the mighty Brahmaputra and Barak valley river systems, which are considered to be containing some of the most fertile soils in the world. These river valley systems exhibit many rain forests known for both floral as well as faunal biodiversity. Such variations in the physiographic components in the NE India also makes it most vulnerable to not only developmental pressures but also to climate change.

Rainfall is essential for the sustenance of life and livelihood in North-east India. It also characterizes the climate of the area. The information regarding the spatio-temporal distribution in rainfall across the NE region and the governing atmospheric processes is critical in nature in determining the climate change mitigation and adaptation strategies. As evident from the literature review presented in section 1.3, a rather limited studies were carried out on the inter-relationship among different meteorological parameters and rainfall distribution in NER. To address the issues highlighted above, the present study will be carried out with the following objectives.

1.1 Objectives

1. To characterize significant trends, present in the times series of rainfall and other meteorological parameters in NE India.
2. To characterize the significant spectral components and associated physical processes present in the time series of rainfall and other meteorological parameters.
3. To examine the behavior of the time series of rainfall and other meteorological parameters using linear statistical processes.
4. To develop multi-resolution model to examine the inter-relational sensitivity among meteorological parameters and rainfall for NE India.

1.2 Global Scenario

Mearns et al. [15] analyzed the extreme high temperature events in the Corn Belt of USA. They established a relationship between the probability of occurrence of extreme high temperature events with fluctuations in mean temperature. They observed that the relationship was non-linear and had significant impact on the corn yields in the US.

Jones et al. [16] presented a compilation of the monthly mean surface temperature in Northern Hemisphere for the years 1851-1984. They carried out homogeneity test for meteorological station data and fixed position weather ship data. They observed that over the period 1921-1984, the mean temperature in the N. Hemisphere was warmer by 0.4^0C than the prevailing over the periods from 1851-1920.

Time series data of individual as well as multiple stations in coastal regions of equatorial and South Africa zone were analyzed by Nicholson and Entekhabi [17]. They determined the rainfall variability and its relationship with temperature at the selected stations. They observed that the variability of Sea Surface Temperature (SST) was more pronounced in the periods of 5-6 years and strong relationship with rainfall throughout the equatorial and S Africa region were found to be evident in the spectral analysis.

Karl et al. [18] analyzed monthly mean maximum and minimum temperature series for Northern and Southern Hemisphere landmasses, like US, China, Australia, Sudan, Japan, Denmark, northern Finland, some Pacific island stations, Pakistan, South Africa, and a few other long-term stations in Europe, out of which monthly mean maximum and minimum temperature accounting over 50% and 10% of the Northern and Southern Hemispheric landmasses respectively, indicated the rise of the minimum temperature occurring at a rate three times that of the maximum temperature during the period 1951-90. The decrease of the diurnal temperature range was found to be approximately equal to the increase of mean temperature.

Karl et al. [19] examined linear trends in temperature and precipitation variabilities (from diurnal to inter annual ranges) in records from globally distributed stations during parts of the twentieth century. Using surrogate bootstrap resampling from AR(1) and ARMA models fitted to the residuals, they found, that the day-to-day temperature variability has decreased in the northern hemisphere. The result findings were contrary to the previous work of Kahl et al. (1993), when they did not find any significant upward trend in the temperature data recorded at the Arctic Ocean region during 1950–1990.

Kunkel et al. [20] studied the long trend of extreme precipitation events over USA and Canada. They described the trend analysis of short duration (1–7 days) extreme precipitation events that have a recurrence interval of 1 year or longer for stations in the United States and Canada. The results indicate a highly significant (<0.05) and upward trend covering the period 1931–96 over the southwest United States, in a broad region from the central Great Plains across the middle Mississippi River and southern Great Lakes basins, while the annual trend for Canada was upward for the period 1951–93, but not statistically significant. The analyses were performed by using The Kendall τ statistic and the Kendall slope estimator algorithm for detection of significance and magnitude of a trend respectively.

Tank and Können [21] determined the trend in indices of climatic extremes in Europe on the basis of daily series of temperature and precipitation observations from more than 100 meteorological stations in Europe. They found, that, all Europe-average indices of wet extremes increase in the period 1946–99. A reduction in temperature variability was detected during 1946-1975 and after that, till 1999, an increase in temperature variability was found in the temperature.

You et al. [22] selected data over eastern and central Tibetan Plateau during the period 1951–2004, for time series analysis, where they tested for the detection in the spatial patterns of the weekend effect in DTR in the data series. The annual and seasonal mean DTR anomalies in the eastern and central Tibetan Plateau by days of the week showed a distinct weekly cycle in most cases.

1.3 Indian Context

A large no. of climatological studies has been carried out for the Indian sub-continent by various investigators. Kothwale et al. [23] showed absence of significant change in day-to-day amplitude of fluctuations of pre-monsoon maximum and minimum temperatures, but the daily maximum and minimum temperatures becoming less variable within the season. The Mann-Kendall's non-parametric test is widely used to determine the presence of any trend in many hydrological data series [24-25].

Jagannathan and Parthasarathy [26] determined trends by the Mann-Kendall rank statistic and periodicities by power-spectrum analysis in the annual data set of 70 years rainfall of India for 48 stations. Increasing or decreasing rainfall trends were found over large continuous areas in India, though, were not significant over all the stations in the areas but only at a few randomly distributed places. The present significant trends showed a periodicity of more than 40 yr.

Jagannathan and Bhalme [27], in another study, performed the polynomial trend analyses and power spectrum analyses of the time series of the annual rainfall of a network of 105 stations distributed over India. The times series indicated oscillatory features and the power spectrum analyses revealed certain significant periods corresponding to the sunspot cycle or some higher harmonics with regional preferences.

Mann-Kendall rank statistics, low pass filter and power spectrum analysis were carried out to determine trend and periodicities in the sixty years of annual rainfall data of 31 meteorological sub-divisions of India by Parthasarathy and Dhar [28]. The positive trend in the annual rainfall was observed over Central India and the adjoining parts of peninsula and also over the two smaller areas in North West (NW) and North East (NE)

India. The negative trend was observed over some parts of Eastern India. Also, the power spectrum analysis showed a significant cycle of range 8.5-12 years, observed mainly in and around arid and semi-arid regions of Rajasthan, Central India and extreme South Indian peninsula, whereas a cycle of 2-3.5 years was also observed over Central peninsular India, NW and some parts of NE India.

Rakhecha and Soman [29] using standard statistical tests analyzed the annual extreme rainfall series in the time scale of 1-3 days duration at 365 stations over India, from 1901-1980 and in most of the stations they observed absence of trend in the annual extreme rainfall, however, the extreme rainfall series at stations over the west coast north of 12°N and at some stations to the east of the Western Ghats over the central parts of the Peninsula showed a significant increasing trend at 95% level of confidence. The data series of the stations which showed trends were subjected to a 10-year moving average and the resulting smoothed series was discussed.

Kothyari and Singh [30] reported trends in the rainfall and temperature data of the Ganga basin in India and India as a whole. Long-term data on the monsoon and annual rainfall and the average annual temperature for India as a whole, and on the annual maximum temperature, monsoon rainfall, and number of rainy days of the Ganga basin were selected for the analysis using nonparametric methods as Mann Kendall's (MK) test. The results of this study showed a decreasing trend in the rainfall variables and an increasing trend in the temperature, from the second half of 1960s.

Roy and Balling [31] analyzed the seasonal trends in the maximum and minimum temperature, diurnal temperature range (DTR), and cloud cover for the time period 1931–2002; and found significant increase in maximum and minimum temperature over the Deccan plateau. Trends in DTR were not significant except for a decrease in northwest Kashmir in summer. The effect of cloud cover on the DTR was expectedly negative for most of the country for winter and summer seasons.

Goswami et al. [32], analyzing a daily rainfall data set, in their findings, showed significant rising trends in the frequency and magnitude of extreme rainfall events and a significant decreasing trend in the frequency of moderate events over central India during monsoon seasons from 1951-2000.

Trend analysis was performed too by Guhathakurta et al. [33], where monthly, seasonal, and annual rainfall time series of 36 meteorological subdivisions of India were constructed using the monthly rainfall data for the period 1901–2003. Linear trend analysis examined the long-term trends in rainfall over different subdivisions and monthly contribution of each of the monsoon months to annual rainfall. The contribution of June, July and September rainfall to annual rainfall was found to be decreasing for few subdivisions while contribution of August rainfall was increasing in few other subdivisions.

Rajeevan et al. [34] determined the trends and variability in the extreme rainfall events over Central India, using 104 years of gridded rainfall data. They used the interpolation method for interpolating station rainfall data into regular grids. The quality control was achieved by comparing them with the similar kind of data set developed for the period 1951–2004. The time series of average frequency of very high rainfall events over the central India for the period 1901–2004 was determined, where large year to year as well as significant inter-decadal variations were observed, and the study concluded that the increasing trend of sea surface temperatures and surface latent heat flux over the tropical Indian Ocean could be associated with the increasing trend of extreme rainfall events in the last five decades.

Jhajharia et al. [35] in their work determined trends in maximum, minimum and mean temperatures, the diurnal temperature range (DTR) and sunshine duration at eight sites of NE India, namely, Margherita, Silcoorie, Thakurbari, Tocklai in Assam and Chuapara, Gungaram, Nagrakata and Nagri Farm in North Bengal; among which three sites showed decreasing trends in DTR in annual, seasonal (pre-monsoon and monsoon) and monthly time scale. Mann–Kendall (MK) non-parametric method and linear regression statistics were applied to establish trends in temperature and DTR Temperature remained trendless in winter and pre-monsoon seasons over NE India. However, temperature increase was observed in monsoon and post-monsoon seasons. Decreasing trends in sunshine duration were also observed mainly on annual, seasonal and monthly (January, February and March) time scales. The decrease in sunshine hours was assumed to be the cause of decrease in DTR.

Chattopadhyay et al. [36] performed a time series analysis of monthly maximum temperature data over NE India through an autoregressive approach. Through autocorrelation analysis of the maximum temperature time series of NE India was identified as non-stationary with a seasonality of twelve months and it was also found to show an increasing trend by using both parametric and non-parametric methods. The

Yule-Walker equation was used to generate the autoregressive models of the reduced temperature time series that became stationary on removal of the seasonal and the trend components from the original time series. Subsequently, autoregressive neural networks were generated as a multilayer perceptron to forecast a time series.

A recent study by Jain et al. [37] performed trend analysis of temperature and rainfall data in monthly, seasonal and annual basis on the subdivision and regional scale for the NE regions of India. The trend analysis of temperature data series for 1871-2008 did not show any clear trend for the region as a whole, while seasonal trends were present for some seasons and for some regions. The similar analysis of rainfall data showed increasing trend.

The present work is organised as follows:

1. Details of the study area and data are presented in Chapter 2.
2. The 1st objective is covered in Chapter 3, discussing the identification and characterisation of significant trends present in the rainfall as well as the other selected meteorological time series.
3. Chapter 4 deals with the detection of the spectral components, their characterisation and the associated physical processes present in rainfall and other meteorological parameters.
4. Chapter 5 presents a study on the behaviour of rainfall time series using statistical processes.
5. Chapter 6 provides the link between objective 3 and 4. Here singular spectrum analysis is performed to detect the components of rainfall time series and wavelet analysis to detect the oscillatory components constructing the rainfall time series in both time-frequency domain. The chapter also includes the inter-association of rainfall with other meteorological variables with the help of wavelet cross-spectrum and wavelet coherence. Wavelet decomposition provided the differentiation of the time series into different resolutions, which are further used in developing a multi-resolution model with vector autoregression and impulse response technique, which is described in the next chapter.
6. In the next chapter- Chapter 7, the inter-relational sensitivity of rainfall with different meteorological variables is explored.
7. Finally, the conclusion of the thesis is given in Chapter 8.

1.4 References

[1] Joshi, M. K. and Pandey, A. C. Trend, and spectral analysis of rainfall over India during 1901–2000. *Journal of Geophysical Research*, 116(D06104), 2011. DOI:10.1029/2010JD014966.

[2] Lal, M. Implications of climate change in sustained agricultural productivity in South Asia. *Regional Environmental Change*, 11:79–94, 2011. DOI: https://doi.org/10.1007/s10113- 010- 0166-9

[3] Muluneh A, Biazin B, Stroosnijder L et al. Impact of predicted changes in rainfall and atmospheric carbon dioxide on maize and wheat yields in the Central Rift Valley of Ethiopia. *Regional Environmental* Change, 15:1105–1119, 2015. DOI: https://doi.org/10. 1007/s10113-014- 0685-x

[4] Chu, H., Wei, J., Qiu, J. et al. Identification of the impact of climate change and human activities on rainfall-runoff relationship variation in the Three-River Headwaters region. *Ecological Indicators*, 106:105516, 2019. DOI: https://doi.org/10.1016/j.

[5] Suescun D, Villegas JC, Leon JD et al (2017) Vegetation cover and rainfall seasonality impact nutrient loss via runoff and erosion in the Colombian Andes. *Regional Environmental Change*, 17:827–839, 2017. DOI: https://doi.org/10.1007/s10113-016-1071-7.

[6] Said, M., Komakech, H.C., Munishi, L.K., Muzuka, A. Evidence of climate change impacts on water, food and energy resources around Kilimanjaro, Tanzania. *Regional Environmental Change*, 19:2521–2534, 2019. DOI: https://doi. org/10.1007/s10113-019-01568-7

[7] Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (eds.) Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2013.

[8] Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S.,

Levy, A. N., MacCracken, S, Mastrandrea, P. R. and White, L., L. (eds.) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Technical report WGIIAR5, IPCC, 2014.

[9] Pollock, D.S.G. *A Handbook of Time-series analysis, Signal Processing and Dynamics*. Academic Press, 1999.

[10] Maragatham, R.S. Trend analysis of rainfall data -a comparative study of existing methods. *Intyernational Journal of Physics and Mathematical Sciences*, 2(1):13-18, 2012.

[11] Montgomery, D.C., Jennings, C.L., and Kulahci, M. *Introduction to time series analysis and forecasting*. Hoboken, N.J.: John Wiley & Sons. Inc, 2015.

[12] Myers N., Mittermeier, R. A., Mittermeier, C. G., de Fonseca, G. A. B. and Kent, J. Biodiversity hotspots for conservation priorities. *Nature*, 403:853-858, 2000.

[13] Ngachan, S. V., Mohanty, A. K and Pattanayak, A. Status Paper on Rice in North East India. Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Rajendranagar, Hyderabad 500030.

[14] Dikshit, K. R. and Dikshit, J. K. *North-East India: Land, People and Economy.* Advances in Asian Human-Environmental Research, 2014, DOI: 10.1007/978-94-007-7055-3_1.

[15] Mearns L. O., Katz R. W., Schneider S. H. Extreme High-Temperature Events: Changes in Their Probabilities with Changes in Mean Temperature. *Journal of Climate and Applied Meteorology*, 23:1601-1613, 1984.

[16] Jones P. D., Raper S. C. B., Bradley R. S., Diaz H. F., Kelly P. M., Wigley T. M. L. Northern Hemisphere Surface Air Temperature Variations:1851-1984. *Journal of Climate and Applied Meteorology,* 25(2):161-179, 1986.

[17] Nicholson, S., Entekhabi, D. Rainfall Variability in Eqatorial and Southern Africa: Relationships with Sea Surface Temperatures Along the Southwestern Coasts of Africa. *Journal of Climate and Applied Meteorology*, 26(5):561-578, 1987.

[18] Karl, T. R., Jones, P. D., Knight, R. W., Kukla, G., Plummer, N., Razuvayev, V., Gallo, K. P., Lindseay, J., Charlson, R. J., Peterson,T. C. Asymmetric Trends of Daily Maximum and Minimum Temperature. *Bulletin of the American Meteorological Society*, 74(6):1007-1023, 1993.

[19] Karl, T. R., Knight, R. W., Plummer, N. Trends in High-Frequency Climate Variability in the Twentieth Century. *Nature*, 377(6546):217–220, 1995.

[20] Kunkel, K. E., Andsager, K. Long-Term Trends in Extreme Precipitation Events over the Conterminous United States and Canada. *Journal Of Climate*, 12:2515-2527, 1999.

[21] Tank, A. M. G. Klein, Können, G. P. Trends in Indices of Daily Temperature and Precipitation Extremes in Europe, 1946–99. *Journal Of Climat*e, 16:3665-3680, 2003.

[22] You, Q., Kang, S., Flögel, W. A., Arturo, S. L., Yan, Y., Xu, Y., Huang, J. Does A Weekend Effect in Diurnal Temperature Range Exist in the Eastern and Central Tibetan Plateau? *Environmental Research Letters,* 4:1-7, 2009.

[23] Kothawale, D. R., Revadekar, J. V., Rupa Kumar, K. Recent Trends in Pre-Monsoon Daily Temperature Extremes over India. *Journal Of Earth System Science,* 119 (1):51–65, 2010.

[24] Krishnakumar, K.N, Rao, G.S.L.H.V. Prasada, Gopakumar, C.S. Rainfall Trends in Twentieth Century over Kerala, India. *Atmospheric Environment,* 43:1940-1944, 2009.

[25] Bhutiyani, M. R., Kale, V. S., Pawar, N. J. Climate Change and the Precipitation Variations in the Northwestern Himalaya: 1866–2006. *International Journal of Climatology,* 30:535–548, 2010.

[26] Jagannathan, P., Parthasaraty, B. Trends and Periodicities of Rainfall over India. *Monthly Weather Review,* 101(4):371-375, 1973.

[27] Jagannathan, P., Bhalme, H. N. Changes in the Pattern of Distribution of Southwest Monsoon Rainfall over India Associated with Sunspots. *Monthly Weather Review*, 101(9):691-700, 1973.

[28] Parthasarathy, B., Dhar, O. N. Secular Variations of Regional Rainfall over India. *Journal of the Royal Meteorological Society,* 100:245-257, 1974.

[29] Rakhecha, P. R., Soman, M. K. Trends in the Annual Extreme Rainfall Events of 1 to 3 Days Duration over India, *Theoretical and Applied Climatology*, 48(4):227-237, 1994.

[30] Kothyari, U. C., Singh, V. P. Rainfall and Temperature Trends in India. *Hydrological Processes*, 10:357-372, 1996.

[31] Roy, S. S., Balling, Jr. R. C. Analysis of Trends in Maximum and Minimum Temperature, Diurnal Temperature Range, and Cloud Cover over India. *Geophysical Research Letters*, 2005. DOI: 10.1029/2004GL022201.

[32] Goswami, B. N., Venugopal, V., Sengupta, S., Madhusoodanan, M. S., Xavier, P. K. Increasing Trend of Extreme Rain Events over India in a Warming Environment. *Science*, 314(5804):1442-1445, 2006.

[33] Guhathakurta, P., Rajeevan, M. Trends in the Rainfall Pattern over India, *International Journal of Climatology*, 2:1453-1469, 2008.

[34] Rajeevan, M., Bhate J., Jaswal, A. K. Analysis of Variability and Trends of Extreme Rainfall Events over India Using 104 Years of Gridded Daily Rainfall Data. *Geophysical Research Letters*, 35, L18707, 2008. DOI: 10.1029/2008gl035143.

[35] Jhajharia, D., Dinpashoh, Y., Kahya, E., Singh, V. P., Fakheri-Fard, A. Trends in Reference Evapotranspiration in the Humid Region of Northeast India. *Hydrological Processes*, 8140, 2011.

[36] Chattopadhyay, S., Jhajharia, D., Chattopadhyay, G. Univariate Modelling of Monthly Maximum Temperature Time Series over Northeast India: Neural Network Versus Yule-Walker Equation Based Approach. *Meteorological Applications*, 18(1):70-82, 2011.

[37] Jain, S. K., Kumar, V., Saharia, M. Analysis of Rainfall and Temperature Trends in Northeast India. *International Journal of Climatology*, 33:968-978, 2013.