CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 General

There are many "natural" and "anthropogenic" (human-induced) factors that contribute to climate change. Climate change has always happened on Earth, clearly seen in the geological record; it is the rapid rate and the magnitude of climate change occurring now that is of great concern worldwide. To understand climate change behavior, it is necessary to analyze the trend pattern of climate variables. Various statistical tools have been implemented to the climatic variables to determine the trend and trend behavior and correspondingly can be used to identify the best management practices for water resources conservation. Modelling changing climate is a complex phenomenon because various geographical features and hydro-climatological parameters are required to find the solution. Nowadays, the analysis of climatic parameters using various available tools has proven advantageous over several decades to address a range of climate change problems and support the decision-making for better management of water resources. Various statistical techniques have been applied to climatic variables in this study to determine the trend pattern over Uttar Pradesh and Jharkhand. The Novel tool VSCA was developed to assess the characterization of trend pattern and change point detection.

The ArcGIS 10.8 tool for digital image processing techniques occupies a prominent place among modern computer tools and constitutes invaluable support in the decision-making of a problem with a spatial decision. Geo-informatics techniques are viable in recent decades as a critical apparatus in deciding the quantitative portrayal of spatio-temporal analysis. In this study, the spatio-temporal variation of the climatic variables has been analyzed, and qualitative analysis proposes conservation measures. Geo-informatics methods made it simple to play out the spatio-temporal analysis of the climatic variables. In this study, ArcGIS proved to be an essential invention for managing the representation of the spatio-temporal variation of climatic variables for the state of Uttar Pradesh and Jharkhand. With the help of the ArcGIS tool, it became effortless to do digitization, modeling, and analysis in such a vast area. Water comes under the category of the essential natural resource on earth. Hence it is essential to manage natural resources sustainably to preserve them for the future.

Various statistical tools have been implemented in climatic variables for the analysis of the trend. Novel tool VSCA has been developed to understand the characterization of trend patterns and change point detection. The results of the VSCA tool illustrate the 3-D and 2-D graphical representation of the characterization of trend patterns and illustrate the graphical representation of change points. The statistical tools show that the computed values of the trend provide the behavior and strength of the significant trend.

The collection of climatic data is challenging and can be generated through different sources and techniques, particularly in the absence of direct field values. Results show that the obtained data from various sources are reliable and can be directly used for statistical analysis. These results also explain the same results as a result obtained from the developed Novel tool VSCA. Similar studies can be performed for other water-stressed areas for reliable water resources estimation so that better and efficient water resources planning and management can be done.

8.2 Result and Conclusions

We have investigated the rainfall pattern and its variability and changes based on 118 years of data in the present study. In the analysis, we have considered various seasons and annual scales. The spatial scale has been considered from state to divisional region to study rainfall total, and stations are considered to see rainfall intensities. The analysis brought many significant features of rainfall patterns and can be used for agricultural water management.

8.2.1 Uttar Pradesh

The application of VSCA demonstrated that the patterns of trend for precipitation over Lucknow, Gorakhpur, and Varanasi are similar and they displayed decreasing trends around 1990 onwards with major change in the decades of 1970-80. Contrarily, Saharanpur and Agra being part of western UP displayed increasing trends until 1940 and no-trend thereafter. Bareilly being in the western belt of Uttar Pradesh but closer to the Himalayan range showed marginal reduction in precipitation with no significant trend. Jhansi being in close proximity to the Bundelkhand also showed a reduction in precipitation. The present study investigated the rainfall pattern, variability, and changes based on recent 118 years of data. We have considered pre-monsoon, monsoon months, post-monsoon and winter season, and the annual scale also in the analysis. The spatial scale has been considered from state to district to study mean rainfall, and stations are considered to study rainfall intensities. The analysis brought many significant features of rainfall patterns and can be used for agricultural water management.

Some of the important results can be summarized as:

- Uttar Pradesh gets about 89% of its annual rainfall in the southwest monsoon season.
- The highest rainfall (34% of monsoon rainfall) is received in July, followed by August (31% of the monsoon rainfall).
- The monsoon season rainfall and the annual rainfall showed significant decreasing trends.
- The highest annual rainfall (1374.5 mm) is observed over Gorakhpur district, and the lowest annual rainfall (431.3 mm) is observed over the districts of Chitrakoot

division.

- Gorakhpur and Gonda received the maximum amount of rainfall in annual time scale (1089-1374.5 mm), and divisions with a minimum amount of rainfall in annual time scale are Agra, Kanpur, Lucknow, Chitrakoot (431.3-798.6 mm).
- In monsoon, there is a significant increasing trend in Bareilly, Gonda, and Varanasi and a significant decreasing trend in Saharanpur, Ghaziabad, Meerut, Agra, Chitrakoot, Azamgarh, and Basti.
- In annual time scale, a significant increasing trend in Bareilly, Kanpur, Meerut, Faizabad, Mirzapur, and Varanasi and a significant decreasing trend in Saharanpur, Meerut, Chitrakoot, Allahabad, Gonda, Basti, and Gorakhpur districts are seen.
- Application of VSCA showed a decreasing trend of precipitation over Lucknow, Gorakhpur, and Varanasi around 1990 onwards with major changes in 1970-1980. Saharanpur and Agra contrarily displayed an increasing trend until 1940 and no-trend thereafter; however, Bareilly and Jhansi had reducing trends in precipitation.

The trends in mean, maximum, and minimum temperature (annually, monthly, and seasonally) were also determined for Uttar Pradesh state. That was carried out using the non-parametric Mann–Kendall (MK) test. The Sen's slope and percentage changes in rainfall and temperature were also estimated over the study period (1901-2018). Both positive and negative trends were observed in monthly, seasonal, and annual temperatures.

The conclusions drawn from the study are as follows

- The significant increase in minimum temperature is 0.011°C/year at Mirzapur (South) and Kanpur (Centre). While mean temperature is increasing 0.006°C/year at Jhansi (South-West) and maximum temperature 0.014°C/year at Lucknow (Central), The significant increase in maximum temperature is 0.012°C/year at Meerut (North-West) also.

- Analysis of the monthly time step indicates the significant warming trend in all months in the mean temperature during the analysis period of 1901 to 2018.
- The probable change year (shift) in temperature is between 1954-1955 and 1968 for minimum temperature and 1941 to 1951 for mean temperature and 1940 & 1945 for maximum temperature. The maximum & mean temperature is various change shift years.
- The trends analysis is extremely helpful to search out the probable influence of activity on a hydrologic circle, environmental resources, and future water resources management of the Uttar Pradesh state.

8.2.2 Jharkhand

Four predetermined climatic variables, namely rainfall, evapotranspiration, maximum temperature and minimum temperature over the Jharkhand state of Indian subcontinent, were systematically explored. The persistence effect has been removed prior to the statistical approach for trend analysis. The trend analyses for seasonal and annual time series were analyzed. Monotonicity in trend was detected in pre-monsoon and winter season for rainfall whereas, a positive and upward trend in the immediate study area was observed for the post-monsoon season. The significant decreasing trend for rainfall was perceived during monsoon season and annually. The decreasing rate of the trend for selected synoptic stations were observed in between 1.09-2.3 mm/year during the monsoon season and 1.2-2.4 mm/year annually. However, the underlying persistence effect observed in all seasons and throughout the year for all climatic parameters resulted in the time series with low-frequency fluctuations. Sequential Mann–Kendall test exhibits the periodic fluctuation of trends, which are more prominent in pre-monsoon and monsoon season. Severe restoration of water bodies is the challenge faced by the climatologists. The decrease in rainfall, coupled with elevated temperature levels, implies lesser storage and greater water stress, and thereby exaggerates the severity of the extreme climatic conditions and inflicts harsh living situations. The close insights of these climatic variables used in the study can help to achieve devastating results for the study region.

During the entire period of June to September (monsoon month), there is a significant increase in rainy days in stations in the North Chotanagpur division (Hazaribagh, Giridih, Dhanbad, Bokaro, Ramgarh,), Santhal Pargana (Pakur), South Chotanagpur division (Ranchi and Gumla). At the same time, there is a significant decrease in Rainy days in stations Palamu division (Garhwa, Palamu, Latehar), North Chotanagpur division (Chatra, Hazaribagh, Giridih, Dhanbad, Ramgarh), Santhal Pargana (Deoghar, Godda, Dumka, Jamtara), South Chotanagpur division (Lohardaga), Kolhan division (Saraikela Kharsawan and West Singhbhum). While remaining districts did not show any significant change.

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Some of the important results can be summarized as:

- Jharkhand gets maximum rainfall in July (31% of monsoon rainfall) followed by August (28 % of monsoon rainfall).

- 84% of annual rainfall receives during southwest monsoon rainfall (June – September).
- Palamau district receives 90-91% of annual rainfall in the monsoon season, while Santhal Pargana (Dumka and Godda) and Kolhan Division (East Singhbhum) receive 80-81% annual rainfall in the monsoon season.
- Significant decreasing trends were found in June, July, August, September monthly rainfall.
- Maximum rainfalls receive during the monsoon season over Santhal Pargana (Pakur district) (1275.2 mm), while Palamau district receives the lowest rainfall of 840.5mm.
- During the year over Pakur district (1571.8mm), maximum rainfalls occur, while Palamu receives the lowest annual rainfall of 925.4mm.
- A significant decreasing trend in monsoon rainfall has been noticed in Palamu division (Garhwa), North Chotanagpur (Chatra, Koderma, Dhanbad, Bokaro), Santhal Pargana (Godda, Sahebganj), and South Chotanagpur (Simdega) districts show a significant increasing trend.
- In annual rainfall, Palamu division (Garhwa), North Chotanagpur (Chatra, Koderma, Dhanbad, Bokaro, Ramgarh), Santhal Pargana (Godda, Sahebganj), and South Chotanagpur (Simdega) districts of their division show a significant decreasing trend while no other district shows a significant increasing trend.

Considering temperature effects, the result of trend analysis of minimum temperature conducted for the winter season (December-February) and pre-monsoon season (March-May), projects a colder drift in the central regions, particularly, in Palamu and Ranchi with a decrease of 0.39-0.79 °C. The significant decreasing trend were observed for annual minimum temperature which fluctuates with a decrease of 0.78-0.37 °C in the Palamu and Ranchi and increasing trend with an increase of 0.59-0.41 °C in Hazaribag, Dumka, and West

Singhbhum. An overall increasing trend of maximum temperature during pre-monsoon (March-May) and monsoon season (June-September) over Jharkhand is extremely noteworthy. Apart from the high increase of up to 1.5 °C in northwestern part a moderate increase of temperature with 0.14–0.82 °C is observed in the northern and southwestern parts of the state which affects the evapotranspiration and relative humidity of the study region. However, the underlying persistence effect observed in all seasons and throughout the year for all climatic parameters resulted in the time series with low-frequency fluctuations. Severe restoration of water bodies is the challenge faced by the climatologists. The decrease in rainfall, coupled with elevated temperature levels, implies lesser storage and greater water stress, and thereby exaggerates the severity of the extreme climatic conditions and inflicts harsh living situations. The close insights of these climatic variables used in the study can help to achieve devastating results for the study region. The trends in mean, maximum, and minimum temperature (annually, monthly, and seasonally) were also determined for Jharkhand state.

The conclusions drawn from the study are as follows

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- Apart from the high increase of up to 1.5 °C in northwestern part a moderate increase of temperature with 0.14–0.82 °C is observed in the northern and southwestern parts of the state which affects the evapotranspiration and relative humidity of the study region. However, the underlying persistence effect observed in all seasons and throughout the year for all climatic parameters resulted in the time series with low-frequency fluctuations.
- New waterbodies need to be planned considering the existing waterbodies (ponds) through convergence of schemes run by different government/non-government departments/agencies.

8.3 Limitations of the Study

At the time of writing (mid-2021), the statistical methodology of trend estimation is well elaborated. Some development may come in the form of GLS estimation techniques for nonlinear regression functions, such as the break or the ramp models. Furthermore, the fitting of multiple change-point models (i.e., more than two change points) is of genuine interest. That is technically challenging and likely necessitates the implementation of advanced optimization techniques. The reward of such a technology may consist in a reduction of the problem of fit-interval selection. As regards nonparametric regression, it appears that the potential of that method (standard-error band and derivative estimation) for climatology has only occasionally been appreciated.

The statistical methodology of uncertainty determination for climate time series is well elaborated, as far as uncertainties stemming from measurement or proxy errors in the climate variables are concerned. Bootstrap methods take into account deviations from Gaussian shape. Blocking variants of the bootstrap, such as the MBB, take into account autocorrelation. That means that the two significant climate peculiarities, time series-non-Gaussian shape and autocorrelation-can be successfully dealt with in the statistical analysis. As a result, it is possible to avoid unrealistically small error bars from ignored autocorrelation, leading to overstatements. On the other hand, as regards timescale errors in the variable *T*, this is a topic where further research will be pretty relevant for paleoclimatology. Some algorithms, simulation tests, and references are in that emerging field. Also, the Bayesian view of probability can be adopted for the research.

As time proceeds, new data sources become available, and existing time series are updated, which leads to new insights. That is a part of normal science, and the climate community should not expect too many big surprises. This example illustrates that the selection of the fit interval for trend estimation also has a moral aspect. Climate researchers should be aware of this.

8.4 Recent Natural Calamities

- *Western Europe Flooding (July 19, 2021):* A major storm system stalled over Western Europe on July 14-15, leading to record-setting rain over Belgium, Germany, Luxembourg, Switzerland, France and the Netherlands. The storm system dumped 40 gallons of water per 10 square feet (148 liters of water per square meter) in 48 hours – almost double the usual rainfall for a month. The sheer scale of the flooding has shocked climate scientists worldwide as they draw direct links between this incident and human-caused climate change. Although increased flooding has always been identified as a potential impact of climate change, the massive scope of this deluge has scientists worried. The rainfall and the heat wave that struck the North American West Coast earlier in 2021 far exceeded the expected range of climate change, leaving scientists worried that the effects will be even worse than predicted.

- *North American wildfire Season 2021:* It includes the changing climate, in which extreme heat makes everything drier and thus more flammable. Plus there's the century-long policy of putting out every fire that sparks, which has actually made fires worse, because there's no room for new growth and fuel builds up.
- *Atlantic Hurricane Season 2021 (July 15, 2021):* The 2021 Atlantic hurricane season is already on a faster pace than 2020, season's fifth storm, Elsa, was record earliest in any season, and the season's first hurricane was over three weeks earlier than 2020.
- *Bushfires, Australia- 2019-2020:* Signs of bushfires in Australia officially started to show in October of 2019 due to prolonged droughts around the country. Over the next few months, the bushfires spread fast and wide, showing no signs of stopping.

8.5 Scope for Future Work

1. It was determined in the present study that the trend pattern of climatic variables is continuously altering; it may be either increasing or decreasing. This changing behavior of climatic variables may be due to an increase in greenhouse gases which are the leading cause of global warming and climate change. So with the help of scientific experiments, the exact amount of GHGs emissions can be evaluated, and severe attention can be given to the carbon budget dynamics due to anthropogenic activities.
2. The prioritization and identification of climate change were analyzed for Uttar Pradesh and Jharkhand, which can be caused by climate extremes like floods and drought. The same can be done in other parts of the country. That will help in handling natural calamities for farming, agriculture, and the ecosystem.
3. Climate forecasts predict weather averages and other climatic properties from a few weeks to a few years in advance. Increasingly, forecasters are using comprehensive models of Earth's climate system to make such predictions.

4. ArcGIS 10.8 worked well for the assessment of spatio-temporal variation. These techniques can be further used for the same and other applications like hydrological modeling and sediment yield modeling for the provided area.
5. Best management practices are proposed in this study for changing the climate and its impact. These measures can be modeled physically to find out the exact amount of increase in temperature as well as rainfall.