

CHAPTER 1

INTRODUCTION

1.1 Preamble

Quantum, geographical distribution, intensity, time, and frequency of precipitation affect the management techniques of water resources used by decision-makers considerably. Besides the availability of surface water runoff for residential, agricultural, industrial, and recreational uses, infrastructure system that drains waste water from the urban population is also influenced by precipitation features. However, precipitation is the meteorological term for the substance that comes from air vapors condensing and falling under gravity. In nature, many types of precipitation occur, including drizzle, rain, sleet, snow, graupel, and hail. The major component of the water cycle is precipitation, and it is responsible for accumulating most of the fresh water on the Earth. Approximately $505,000 \text{ km}^3$ ($121,000 \text{ m}^3$) of water falls every year as precipitation, and out of the same, roughly $398,000 \text{ km}^3$ ($95,000 \text{ m}^3$) precipitates over the oceans. This amounts to global average-annual precipitation as 990 millimetres, i.e., 39 inches approximately. This huge quantum of precipitation becomes the primary basis of the survival of living species on Earth. The characteristics of precipitation over a terrain influence the land properties and its use also.

On the other hand, characteristics of the precipitation alter with the anthropogenic changes on the Earth. Thus, a dynamic interrelation exists between the features of precipitation and earth surface characteristics. These features of precipitation that alter with the changes on the Earth's surface need to be assessed. In order to evolve an effective plan and implement a water policy, spatial and temporal distributions of rainfall are also essential to be estimated. Water supply and demand may be mismatched due to the unequal distribution of rainfall. In such a case, new irrigation facilities must be planned and erected across rivers/streams to

redistribute water in line with the needs of particular areas. Estimating severe rainfalls and their frequency of occurrence are additional factors that influence dam design, spillways, flood protection structures, and drainage networks. Thus, for the same reason, trend analysis of rainfall becomes a matter of great concern, particularly under global climate change. Trend Analysis helps in the understanding of the changing pattern of the rainfall. This analysis provides a means for estimating the quantum of stream flows, soil moisture, and ground-water reserves and a framework for decision-makers who strive for sufficient water availability to various users. According to studies on rainfall patterns across the globe, rainfall variability is increasing on both a geographical and temporal scale. There was a substantially declining tendency in precipitation in Southwestern India, and a growing trend was seen during the post-monsoon season. Increasing rainfall patterns in the yearly and southwest monsoon occurred in Indian areas such as Punjab, Haryana, Rajasthan, and Madhya Pradesh from 1901 to 1982 (Pant and Hingane 1988). Several research on trend analyses of precipitation for different Indian states used grid-based averaged precipitation values, while trend analysis of precipitation based on station-scale data is still rare, especially for the states of Uttar Pradesh and Jharkhand.

For water resources planning, development, and management as well as disaster management, it is essential to know not only the overall trend of precipitation (Ghosh et al. 2009) but also intermediate outbursts of the changed behavior, if any, on a real-time basis to mitigate urban infrastructure disasters, as evidenced by the intense rainfall in the year 2017 in Mumbai (Parchure and Gedam 2019; Saha and Singh 2017) India; and a high Spatio-temporal variation has been claimed to be the reason of intense precipitation (Lokanadham et al. 2012; Saha and Singh 2017; Zope et al. 2015).

Climate change and anthropogenic activities play a vital role in the water resource (Li and Ren 2019; Reay et al. 2007) and introduce abrupt changes reflected by broad drifts, shifts, or

even sudden jumps in the behavior of observed precipitation (Pai et al. 2014). In order to assess the impact of anthropogenic changes on the climate, it is essential to analyze changes in the pattern and trend of precipitation (Gajbhiye et al. 2016), as illustrated by the decrease in rainfall during the century as a sudden shift, instead of a gradual monotonic trend of rainfall in Indian Himalayan terrain (Bisht et al. 2018). Further, precipitation data is often viewed as stationary, and parametric/ non-parametric test is applied to identify the trend as non-stationarity has received limited attention (Milly et al. 2008). The presumption of stationarity of dataset had also been questioned by (Saha and Singh 2017)

In fact, time-series data usually do not display a monotonic behavior but instead show non-periodic alternating behavior during an intermediate period. Thus, the traditional parametric/non-parametric tests for aggregated datasets may not unravel real-time information, which may differ from the aggregated character of the datasets. Changes in the mean precipitation, frequencies of occurrences of extremes, the magnitude of evapotranspiration, and river discharges result from non-stationarity in hydrologic processes. Complex interdependence and interactive dynamic mechanisms of climatic variables continuously update hydro-meteorological processes and add non-stationarity to climatic variables. Anthropogenic activities (Zhang et al. 2016) also perturb the interactive mechanisms by impacting the forcing, impacting the state of the climate.

In order to capture the intermediate character of precipitation trend which swings during a study period, the present study proposes to apply repeated test protocol of (Zhang et al. 2016), which was implemented for stream flow dataset of west-branch Susquehanna River in Bower watershed. By varying the flow dataset of the west-branch Susquehanna River in the Bower watershed, they repeatedly applied the MK test to discern the pattern of river flow pattern through color variation for abrupt or gradual changes. The methodology involved different data clusters of varying sizes with changed beginning and ending times of the data

series. The pattern of precipitation trend over Uttar Pradesh (UP) that falls in the middle range of the Ganges River basin of India is analyzed and plotted for ascertaining consistency/monotonicity of the trend. Most of the work about the analysis of precipitation trends in the Indian sub-continent accounted for spatially averaged datasets from various states or grid datasets from a large segment of India (Duhan and Pandey 2013) by assuming rainfall to be uniformly distributed over the large region of India, which appears to be unrealistic. Hence station (district) scale data was applied for a more realistic analysis of precipitation trends. Thus, rainfall data of seven important districts of Uttar Pradesh, India, were considered to obtain the overall view of the trend pattern. The approach involves the repetitive application of the Mann-Kendall test with a moving window. However, the varied beginning and ending times, i.e., varying size of the data cluster with the moving window, were applied to yield 3-D pictorial representation for the easy realization of rainfall trends over the districts of UP.

As a result, the current research will focus on the states of Uttar Pradesh and Jharkhand. The Ganges River drains the state of Uttar Pradesh, it flows west to east, and its economy depends mainly on agriculture. It is one of India's fastest-growing states. The land cultivated in the state of Uttar Pradesh is about 16,81 million hectares, making over 70% of the entire geographical area. The irrigated area is above 73%, and the cultivation intensity is 153%. At the same time, the Jharkhand state's cultivated land covers about 1.8 million hectares, representing 22% of the geographical area. Net irrigated area is about 0.16 million hectares or 9.3% of the area planted. The state has a cropping intensity of 126 percent because it is mainly rainfed. In the economies of the examined states, rainfall thus plays a key role, depending mainly on agriculture. Drying is also not new for Uttar Pradesh and Jharkhand since it is practically often encountered. Every year, droughts of variable size and percentage occur in one or more regions. The precipitation pattern during the monsoon period, which ends in October, does not precisely reflect well for the state, and the overall precipitation

across the state may be termed deficient rainfall in plain meteorological terms. However, it may be viewed as highly deficient when viewed from an agricultural perspective, which significantly affects the state's agricultural production. Over the last decade, annual paddy, legumes, olive seeds, potatoes, onions, and other plants have declined. To determine why agricultural yields should be reduced while increased irrigation and other agricultural inputs in the area, the changing environment, i.e., inadequate soil-moisture availability due to unpredictable precipitation patterns, may provide a better explanation.

1.2 Research Gap

Many studies are available on the observed trends and variability of rainfall and extreme rainfall events, but all the studies are based on past 100 years or more data. Trend analysis of precipitation and temperature relying on the station-scale data is yet scanty, particularly for the districts of Uttar Pradesh and Jharkhand. Thus, the present study adds significant novelty in the current state. Also, there are limited studies available for Uttar Pradesh state and Jharkhand state. In the present research work, all the analyses of observed rainfall patterns, trends, and variability have been done based on the recent past 118 years (1901-2018) that will help to have an idea of the recent changes for climate change adaptation and management by the state authorities. Therefore, the current study also seeks to carry out a trend analysis of precipitation across eighteen Uttar Pradesh districts and five Jharkhand districts. These districts were chosen to provide a visible result of the status and significance of the district in the region examined.

1.3 Objectives of the Work

The primary objectives of this research work are to estimate the trend pattern of the climatic variables and their behavior towards climate change. To determine the principal cause of climate change, we need to understand the change in the behavior of climatic variables and the impact of climate change and global warming; for this, we have to analyze the trend

characteristics of climatic parameters. The results of this study would be further utilized for water conservation purposes in the studied area, which is majorly covered by the river Ganges basin.

The specific objectives of the present study are narrated as hereunder:

1. Collection of the precipitation data for 118 years from 18 divisional districts of Uttar Pradesh and five divisional districts of Jharkhand.

To determine the segregated climatic variable (precipitation) data set for trend analysis based on annual, pre-monsoon, monsoon, post-monsoon, and winter season basis.

2. Various statistical methods such as non-parametric Mann-Kendall, Spearman's Rho, and Sen's slope estimator has been used to determine the trend of climatic variables (precipitation and temperature).
3. Identify the spatial pattern of the annual rainfall and understand district-wise rainfall trends and variability in annual.
4. The development of a Novel tool, Variable Sized Cluster Analysis (VSCA), determines the characteristics of trend pattern and change point detection of climate variables.
5. Application of VSCA for the precipitation.

1.4 Organization of the Thesis

The contents of the dissertation have been organized into six chapters. The chapter 1 entitled 'Introduction' lays the foundation for the present work, with motivation and objectives explicitly outlined. Chapter 2 presents a thorough literature review relating to precipitation trend analysis over various regions of the different continents. The shortfalls in those studies were identified to define the scope of the present work. Chapter 3 discusses the

characteristics of the states Uttar Pradesh and Jharkhand region for which the study has been carried out. It will further explain the methodology for obtaining the segregated sets of annual, pre-monsoon, monsoon, post-monsoon, and winter season data from the daily data set. Chapter 4 gives mathematical details of the nonparametric statistical method named the Mann-Kendall test, Spearman's Rho method, and Sen's slope method to quantify the trend magnitude. Chapter 5, results obtained from the Mann-Kendall and Sen's slope, etc., methodologies are discussed and interpreted vis-à-vis the observed data to derive the inferences relating to the climate variables in the states of Uttar Pradesh and Jharkhand. In Chapter 6, A Novel tool has been developed named Variable-Sized Cluster Analysis (VSCA), and the implementation of VSCA in precipitation to characterize trend patterns for Uttar Pradesh and Jharkhand states has been explained in chapter 7. Chapter 8 summarizes the findings of the study and provides a direction for future work. The last section enlists the references which were referred to for undertaking the present study.