IMPACT OF CLIMATE VARIABILITY AND CHANGE ON DROUGHTS OVER INDIA

SYNOPSIS

Submitted in partial fulfilment of the
requirement for the award of the degree
of
DOCTOR OF PHILOSOPHY
in
HYDROLOGY
by

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OCTOBER, 2019

1. Introduction

The alteration of the hydrological cycle due to climate change and rapid growth in demand for freshwater due to population growth has posed increasingly complex challenges related to water resources management in 21st century (Goyal & Surampalli, 2018). The problem is more concerning in the developing countries such as India which has the second-largest population in the world with more than 1.3 Billion people living in highly population-dense environment. Moreover, 59% of the total workforce in India is dependent on agriculture, and almost 70 percent of rural households are primarily dependent on agriculture and its allied sector to make a living (FAO, 2019). The significant dependence of such a large number of people on agriculture makes India significantly vulnerable to climate change and extreme hydro-meteorological events such as floods and droughts.

Drought is a state of environment which represents the deficiency in the water availability for a prolonged period. Each year many parts of the world face drought. Hazard caused by drought costs more than any other natural calamity. United States suffers approximately $6-8 billion loss per year due to drought hazard which was as high as $40 billion in 1988. In 1980s drought has killed over half a million people in Africa. Severe droughts of 1910s, 1960s, 1970s and 1980s were followed by famine in Sahel nation of Africa. In 2009-2010 China experienced a severe drought which affected almost 21 million people and caused an economic loss of over $30 billion (Yang et al., 2012). The drought situation in many European countries is becoming more severe with time (Hisdal et al., 2001). However, the negative impacts of drought can be alleviated with careful monitoring and efficient planning.

India faces one drought in approximately every three years. The frequency of drought has been reported to increase in various parts of the world, however, for India not much emphasis has been given previously toward the assessment of future droughts. Therefore, the major focus of this study is to develop a framework and enhance the methodological aspects of drought modelling to understand the changing nature of drought conditions over India under changing climatic conditions for different development pathways.

2. Problem statement

The problem of water resource management in a region under climate change scenarios is twofold. Firstly, the decision/policy makers should have reliable lead time predictions related to floods and droughts, both for short and extended time periods to enable them to take informed decisions to manage current state of storages accordingly. Secondly, information on the long-term future projections should also be available to develop the water-resilient infrastructure accordingly to mitigate the risk due to climate change.

In the recent years, models of seasonal monsoon forecast have actively used ENSO indicators to improve on the prediction. For India, a wide variety of literature exist which reports the significant link between ENSO and the Indian Summer Monsson Rainfall (ISMR) (Ashrit et al., 2001; Cash et al., 2017; Jha et al., 2016; Shukla et al., 2011). However, the influence of ENSO is not limited to only precipitation, but it also influences the other meteorological parameters such as temperature, evaporation, radiation, and wind speed (Kothawale et al., 2010). Many studies previously have found the significant influence of coupled ocean-atmospheric circulation process, especially of ENSO, on drought occurrence globally. However, the influence of ENSO on drought need to be studied in greater details in Indian context.

Moreover, today it is a big concern to understand how the droughts are going to change regionally as well as globally with changing climate (Cayan et al., 2010; A. Dai, 2011; Touma et al., 2014). Recent studies suggest that global aridity is increasing with the continuous warming of atmosphere and this drying is going to get worse in many regions of the world in upcoming future if the warming trend remains same (Burke et al., 2006; A. G. Dai, 2013; Sheffield et al., 2012). Climate change affects the global hydrologic cycle due to which spatiotemporal variability in the precipitation may exhibit a changing pattern. Coupled Model Intercomparison Project Phase 5 (CMIP5) based Global Climate model datasets have been widely utilized to examine the projections of extreme climatic conditions (Chen & Sun, 2017; Rajendran et al., 2016; Sandeep & Ajayamohan, 2015; Smitha et al., 2018; Vittal et al., 2016). Kim et al., (2015) analyzed severity duration frequency curves in Korea for time period 2011 to 2099 and found that more severe droughts are expected in the Korean peninsula. Overpeck & Udall (2010) analyzed the hydrological droughts in Colorado River basin and concluded that climate change will affect the

droughts more severely in Colorado River than expected. Penalba and Rivera (2016) analyzed the multi model ensemble of 15 different GCM scenarios and found that drought duration is decreasing with no significant change in severity in South America. Study conducted by Yu et al. (2014) suggested that severe and extreme severe droughts have become more severe since 1990. Asadi Zarch et al., (2015) analyzed the global drought characteristics using Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) for the past and future datasets derived from CMIP5 climate data and found that different indices show different conclusions, however, in general, a drying trend can be observed with intensification of climate change.

Touma et al., (2014) analyzed data from 15 global climate models achieved in the CMIP5 simulation and assessed the global drought characteristics and found that there is continuously increasing risk of drought-related stress for natural as well as anthropologic system. Cayan et al., (2010) analyzed drought in southwest US using CMIP4 data and VIC model and found that later part of 21st century may experience drier and more severe drought. Dai (2011) suggested that aridity predicted by models is consistent with observed aridity and there may be severe and widespread drought in the next 30 to 90 years resulting from either decreased precipitation or increased evaporation. Lin et al. (2015) found drying tendency in south-western China in the 21st century, which may intensify due to the augmented carbon emissions. Cook et al. (2014) argued that the drought risk in the 21st century is going to exceed the driest century of the Medieval Climate Anomaly for both moderate and high emission scenarios in Southwest and Western North America. Swain & Hayhoe (2015) reported that northern regions of North America show consistent trends of wetting, however, south-western part of the continent show trends of drying which may further intensify due to the increased warming. For India, many studies are available in the literature that have analyzed the occurrence and distribution of different types of droughts occurred in the past (Das et al., 2016; Guhathakurta & Rajeevan, 2008; Reddy & Ganguli, 2012; Saha et al., 2015); however, more studies are needed to understand the drought characteristics of the projected future.

3. Objectives of the Thesis

i. Statistical analysis of spatiotemporal variation of precipitation and understanding the influence of the land surface elevation, global warming and large-scale climatic circulation phenomenon on precipitation extremes over India.

ii. Studying the climatic variability of drought and investigating the causal teleconnection between El Nino Southern Oscillation (ENSO) and drought occurrence over various parts of India.

iii. To assess the impacts of climate change on severity, frequency, and duration of meteorological drought throughout the country.

iv. To examine the impacts of climate change and associated uncertainty in drought projections for various major river basins of India.

4. Brief Methodology

Above mentioned objectives have been achieved as follows:

- A correlation and linear regression-based approach have been used to assess the impact of land surface elevation and global warming on the precipitation extremes in India.
- Investigating the teleconnections between El-Nino southern oscillation (ENSO) and droughts in India using Granger causality and incorporating the multilayer perceptron neural networks in Granger causality to relax it from linearity assumption.
- For analyzing the regional drought characteristics, six homogeneous drought regions have been identified using K-means clustering.
- For developing the insights into the changing characteristics of droughts, an analysis of spatial variation of temporal trends of various drought characteristics such as severity, duration, and intensity was conducted. Further, for various regions, temporal variation of area under drought and maximum drought intensity have also been analyzed.
- The multivariate nature of droughts has also been analyzed using Severity-Area-Frequency (SAF) and Severity-Duration Frequency (SDF) curves. A methodological enhancement in the development of SDF curve is also proposed which uses Markov Chain Monte Carlo simulation for parameter estimation of copulas under Bayesian framework.

- A sophisticated fuzzy clustering-based Modified Drought Hazard Index (MDHI) is proposed which has been compared with the traditionally used Drought Hazard Index (DHI).
- Climate change uncertainty pertaining to droughts and the uncertainty in the multivariate dependence and their joint return period has been estimated using copulas for 22 different basins of India.

5. Results Drawn from the Study

The results of this study suggest that a large heterogeneity exists in trends of extreme precipitation across India; however, larger parts of the country showed increasing extremes. Climatologically, the land surface elevation has little impact on the extreme precipitation for areas having elevation lower than 1500m; however, for higher elevation than 1500m, the elevation value has been found to have significant correlation with extreme precipitation indices. The influence of global warming on precipitation extreme is not consistent and varies across various regions. Southern Oscillation Index (SOI) and Northern Oscillation Index (NOI) were found to have positive correlation over Rajasthan, Madhya Pradesh, Uttar Pradesh, and West Bengal. However, NINO3 and NINO3.4 SST indices revealed patches of higher correlation mainly over southern-central India. Furthermore, nonlinear Granger causality test has been found to be an excellent tool for causality analysis of drought with the link to ENSO. Drought over most parts of Indian was found to be influenced by the variation of ENSO. Further, impact of climate change in northern India was found significant for near future (2020-2049) as compared to other parts of the country. However, for far future (2070-2099), very high vulnerability over all parts of the country has been found. Also, drought hazard for far future was significantly higher than both near future and historical period (1970-1999). A shift from central India towards southeast-central India in drought hazard has been projected. Periodicities of dominant cycles in the range 2 to 3.6 years have been observed to be distributed over all parts of India which were not found to be affected due to climate change. The joint return period showed more frequent co-occurrence of two drought characteristics exceeding their individual 5, 10- and 50-year return values in same year for far future than near future. Frequent extreme drought events were projected for most of the analyzed basins; therefore, better preparedness and efficient decision making would be require to mitigate these extremes.

6. Thesis Organization

The thesis is organized in different Chapters to address the above-mentioned objectives in a comprehensive manner. Each Chapter investigates many aspects related to various objectives and developed scientific knowledge for the identified gaps in the literature. Results acquired from each Chapter are summarized at the end of each Chapter.

The brief outline of each Chapter is as follows:

Chapter 1 presents a brief introduction to the subject, motivation, and insight into the problem statement and objectives of the present investigation.

Chapter 2 presents a comprehensive analysis of precipitation characteristics over India. In this Chapter, extreme precipitation has been characterized using six different extreme precipitation indices. Modified Mann-Kendall test and Sen's slope have been used to characterize the spatial variation of temporal trends in extreme precipitation. Furthermore, the impact of land surface elevation, Global warming and ENSO has also been analyzed and discussed in this Chapter.

In Chapter 3, climate variability aspect of droughts has been presented. A framework for analyzing the causal teleconnection between ENSO based indices and dry/wet conditions in India has been studied. Further, improvement based on neural network to include the nonlinearity in tradition Granger causality test has also been presented in this Chapter.

In Chapter 4, an analysis of changing nature of various drought characteristics has been presented. In this Chapter, first the drought regionalization using K-means clustering algorithm is performed. Then, changing drought intensities and area under droughts are analyzed for past and future periods. Furthermore, impacts of climate change on drought periodicity has been analyzed and presented.

Chapter 5 extends the results presented in Chapter 4 and delves in to multivariate nature of drought characteristics. In this Chapter, we have explored the Severity-Area-Frequency (SAF) curves and Severity-Duration-Frequency (SDF) curves. Further, we also present the methodological advancement in SDF curves and drought hazard index.

Chapter 6 presents a basin wise outlook of probabilistic characteristics and uncertainty of drought projections. Changing nature of univariate and copula based bivariate return period has been analyzed and presented in this Chapter.

Chapter 7 presents the overall conclusions, limitations and scope for the future work.

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