Regional Meteorological Drought Characterization using Standard Drought Indices under Observed and Changing Climate Scenarios over Uttar Pradesh, India

Thesis submitted in partial fulfillment for the

Award of Degree

Doctor of Philosophy

By

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Dedicated to My Grandfather, Parents, and Late Dr. Sanjay K. Gupta

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ACKNOWLEDGEMENT

It is a great privilege for me to submit my thesis in the garden of "*Baba Vishwanath*" and "*Tapobhumi*" of Bharat Ratna *Pt. Madan Mohan Malviya*. This work is the culmination of several years of effort, and I am grateful to many individuals who have supported me along the way.

Firstly, I express my sincere gratitude and indebtedness to my venerated teacher and supervisor, *Late Dr. Sanjay K. Gupta*, whose encouragement, guidance, and support throughout my study at the Department of Civil Engineering, Indian Institute of Technology (BHU), from the initial stage to completion of this work enabled me to develop a thorough understanding of the subject. It is a great honour for me to work under his extraordinary and charismatic personality. His in-depth knowledge, inspiration, energy, and effort have tremendously helped me carry out my research work. I cannot find words to express my gratitude for his splendid supervision. I will lifelong remain indebted to my brilliant supervisor *Late Dr. Sanjay K. Gupta*

I would like to express my deepest sense of gratitude and veneration to my supervisor *Prof. P. K. S. Dikshit*, and Co-Supervisor *Prof. S.B. Dwivedi*, Department of Civil Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, for their meticulous guidance, constructive suggestions, and sustained interest, suggestions and kind encouragement for completion this research work. It is my sublime duty to express my heartfelt gratitude to my RPEC member *Prof. Subir D*as, Department of Mathematics, and *Prof. K.K. Pathak*, Department of Civil Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi for their insightful suggestions, encouragement, and timely assistance throughout my Ph.D. journey.

I would like to offer my whole-hearted indebtedness to my family. I wish to express my deep and heartiest gratitude to my parent *Shri Ramshringar* and *Sanyogita,* who taught me the value of learning. I would like to express my sincere gratitude to my grandfather *Shri M. Lal,* without whom none of this would have been possible. He provided me with a great deal of encouragement, taught me the importance of perseverance, and helped lay the foundation for my life. The constant encouragement and support during my education from uncle *Shri Ramdular* and *Shri Suresh* gave me extra strength and moral support for doing better and better and better. The cooperation, moral support, and constant encouragement that I have always received from my colleagues at IIT (BHU) Varanasi. In particular, I am grateful *to Dr. Ahin Banerjee, Mr. Jitender Patel, Mr. Pradeep Mahato, Mr. Shubham Dixit,* and *Mr. Ashish Kumar Agnihotri* for the stimulating discussions during the days we were working together and for all the fun we had during the journey. I want to convey my sincere gratitude to my senior *Dr. Nitesh Gupta* for his precious time, enlightenment support, and assistance during my research work. It is often said that good friends are rare to get and, in this context, I found myself very lucky to myself so many good friends like *Nibedita, Jyoti, Shivam, Jimmy, and Ravi Ranjan.* Their friendly affection, timely help, and encouragement never help to achieve the goals. I sincerely thank *Dr. Neha* who taught me how to be strong, live, and dream in the toughest times and always endorsed my determination. I am also thankful to MHRD for providing financial assistance during my research work. Lastly and above all, deeply grateful to the invisible yet present helping hands of *Lord Shiva,* with which he has made my life complete and meaningful.

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ABSTRACT

Climate change causes a detrimental impact on the hydrological cycle resulting in frequent occurrences of drought events which pose a severe threat to the availability of water resources. Therefore, it is essential to assess the change in the meteorological variable and drought under changing climate scenarios. Drought has recently been more frequent and severe in several sections of the northern Indian plains, raising concerns about its effects on agricultural output, particularly on crop yield. Uttar Pradesh, one of India's most densely populated states is chosen as the study region given its heterogeneous climate that ranges from humid in the east to semi-arid in the west and relies on the majority of agriculture activities on rainfall. The present study investigates the change in the climate through trend analysis of rainfall and temperature. This study explores the respective assessment of meteorological drought characteristics under observed and changing climate scenarios taking Uttar Pradesh in northern India as a study region. The impact of climate change on future drought characteristics is done by using a statistical downscaling model (SDSM) for the future period. In addition, this study also analyses concurrent assessment of dry and wet events and their transition to identify and locate the most vulnerable hotspot providing the basis for the adaptation and mitigation measures.

The changes in magnitude and pattern of temperature and rainfall are responsible for changes in extreme hydrologic events like droughts. The nonparametric Mann-Kendall test and Sen’s slope test were applied over the seasonal and annual rainfall and mean temperature time series in this study to estimate a monotonic trend over 18 synoptic locations of Uttar Pradesh from 1971 to 2018. The trend assessment

of precipitation depicted the decreasing rainfall trend in all seasons except during the pre-monsoon season. The annual precipitation time series depicted a significant declining trend over 14 stations out of 18 synoptic locations. The study region recorded a higher negative slope of rainfall trend over the southern and western parts of the study regions. The trend assessment of monthly temperature indicated a significant increasing trend for 61% of the synoptic locations in the studied regions. The trend assessment study provided the basis to assess the meteorological drought assessment under observed and changing climate scenarios for which the performance of widely used drought indices Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) at different timescales are evaluated for 18 stations in Uttar Pradesh state for the period 1971 to 2018. Drought characteristics such as intensity, duration, and frequency of different categories at different severity (moderate, severe, and extreme) are evaluated and compared based on SPI and SPEI. Drought characteristics are estimated by applying the run theory approach at the threshold of SPI/SPEI≤-1. The patterns of drought intensity, duration, frequency of occurrence, and trend are assessed through various statistical assessments and portrayed through various spatial maps. Spatiotemporal trend variability of SPEI and SPI was investigated at a significance level of 0.05 using the non-parametric Mann- Kendall (MK), test indicating that nearly 85% percent of the synoptic locations of the state experienced a negative trend which implies an increase in the severity of drought events and higher magnitude of negative trend is associated with the SPEI time series. SPEI provides a better estimation of drought characteristics due to its consideration of temperature change in the drought severity. In addition, station proportion is estimated at a different timescale, providing a better insight into the temporal variability drought of a specific

category. The greater areal extent of the study region is affected by the drought event of moderate to severe category. The more significant number of drought events accounted for a timescale of 3-month and 6-month, reflecting the higher variability of the seasonal fluctuation of water balance over the state. At 9-month and 12-month timescales, SPI and SPEI fluctuate gradually with considerable differences between the duration and severity of the drought event. This study reveals that there has been a substantial number of drought events over the state during the last two decades (2000 to 2018). The study region experienced a higher frequency of drought of a short timescale of moderate severity and has vulnerability to increase in the near future. The results conclude that the study area is at risk of erratic meteorological drought conditions where the western part is more severely affected compared to the eastern part of Uttar Pradesh (India).

In addition to drought assessment, this study analyses the concurrent occurrence of climate extremes (dry and wet), and their transition at spatial and temporal scales. The dry and wet event characteristics were evaluated using the SPEI at 1-month time series because of its efficiency in estimating flash drought and wet conditions over the study region. Dry episodes lasted slightly longer than a month indicating flash drought conditions over the studied region. The study area experienced 4.5% higher dry events compare to wet events. The western and Bundelkhand regions experienced more intense and prolonged dry events, whereas intense wet events characterized the eastern region. The rapid transition time for the dry-to-wet event ranges from 2.5 to 4.1 months, and for the wet-to-dry event is 2.05 to 5.25 months. The result of this rapid transition time between the dry and wet event shows that 11 synoptic locations have longer dry-to-wet transition times across the research region than wet-to-dry events. The larger

percentage of the study region experiences a more frequent transition from wet-to-dry events compared to dry-to-wet.

The projected change in drought characteristics under changing climate scenarios is critical for mitigating the effects of drought on water resource systems. This study assesses the impact of climate change on the meteorological drought over the 18 stations in Uttar Pradesh, India. SDSM was employed to downscale daily precipitation, maximum temperature (Tmax), and minimum temperature (Tmin) under the climate change scenario for the future time period. The observed daily Tmax, Tmin, and rainfall time series data of 18 synoptic locations for the period of 1971-2005 are used. The second-generation Canadian Earth System Model (CanESM2) under representative concentration pathway RCP 4.5 and RCP 8.5 scenarios data is used to develop future scenario climate variables. Precipitation will gradually increase in the near future, with significant variations in the magnitude of precipitation change; 66% of synoptic locations will experience an increase of less than 10% over the study area. Drought characteristics were estimated using SPEI at the timescales of 3, 6, 9, and 12-month under projected climate scenario scenarios RCP 4.5 and RCP 8.5 for the future period from 2019 to 2050. Drought characteristics under observed and changing climate assessed and compared. The study region will likely experience more frequent drought occurrences in the future under RCP 4.5. However, the drying tendency is more pronounced and has a broader spatial extent under the RCP 4.5 scenario than in the RCP 8.5 scenario. The spatial distribution indicated that the majority of the study region is at high risk for experiencing a frequent occurrence of drought events of a relatively short duration of moderate category in the near future.

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ABBREVIATIONS AND SYMBOLS USED

%	Percent
AR	Assessment Report
°C	Degree Celsius
CCCma	Canadian Centre for Climate Modeling and Analysis
CGCM4	Fourth-Generation Atmospheric General Circulation Model
CMIP5	Climate Model Inter-comparison Project Phase 5
CanESM2	Second-Generation Canadian Earth System Model
GCM	General Circulation Model
GHG	Green House Gases
GIS	Geographic Information System
ha	Hectare
HadCM3	Hadley Centre Coupled Model, version 3
IDW	Inverse Distance Weighting
IPCC	Intergovernmental Panel on Climate Change
ISMR	Indian Summer Monsoon
MK	Mann-Kendall
NCEP	National Center for Environmental Protection
NCAR	National Center for Atmospheric Research
OGCM4	Fourth generation ocean general circulation model
PET	Potential Evapotranspiration
RCM	Regional Circulation Model
RCP	Representative Concentration Pathways
S.D.	Standard Deviation
SPI	Standardized Precipitation Index
SPEI	Standardized Precipitation Evapotranspiration Index

SDSM	Statistical downscaling model
T_t	Average Transition Time
Tmax	Daily temperature maximum
Tmin	Daily Temperature Minimum
WD	Wet-Dry ratio
WMO	World Meteorological Organization