CHAPTER 7

Evaluation of Dry and Wet Events Characteristics and their Transition

7.1 Overview

The concurrent occurrence of climate extremes (dry and wet) has become more common in the recent decade. The rapid transition between climate extremes magnifies the socio-economic consequences of these catastrophes relative to the effects of the individual occurrences of the extreme event. However, the changing characteristics of transitions between dry and wet periods remain poorly understood. This study aims to address several knowledge gaps by investigating the following aspects: (i) How comparatively frequent were the wet or dry events of different categories during the study period? (ii) What is the most likely time interval between the dry and wet event at a particular location? (iii) What is the average transition time of wet-to-dry and dry-to-wet events? (iii) The identification of hotspot regions that exhibit high rates of rapid wet-dry transitions. This chapter assesses the spatiotemporal evolution of dry-wet events and transitions characteristics over 18 synoptic locations of Uttar Pradesh, India for the period from 1971 to 2018. SPEI at 1-month timescale is used to detect and classify wet and dry occurrences with varying degrees of severity (moderate, severe, and extreme). Dry and wet event characteristics, such as the number of dry and wet events, severity, duration, and intensity estimated by applying run theory over SPEI output. The wet-dry (WD) ratio, wet-dry transition time, and wet-dry rapid transition

time assessment methods were employed in this study to understand the interplay of wet and dry extremes at the location.

7.1.1 Wet- dry event characteristics

This study focuses on assessing dry and wet events using SPEI-1 (SPEI at 1-month timescale) to investigate the frequent variations in climatic conditions and their interplay throughout the study area. Floods occur as a result of extreme precipitation occurring over a short period of time, whereas flash drought are the outcome of rapid temperature intensification occurring over a short period of time. Therefore, SPEI at a longer timescale is ineffective for estimating flood and flash drought conditions because the averaging effect of SPEI at a longer timescale overcomes the signal of extreme precipitation and temperature change. Flash droughts are described in the literature using various criteria, and it is frequently characterized by a sudden onset or intensification, a lack of rainfall, and extreme temperatures that last for at least three weeks (Otkin et al., 2018). Drought is slow on set disaster occurs over a prolonged duration. While "flash drought" has become commonly characterized by rapid development and intensification that cause a severe change in humidity conditions in a short period as "sudden onset, rapid intensification droughts" occurred for few weeks (Svoboda et al., 2002). This highlights the applicability of the SPEI-1 to determine occurrences of flood and flash drought events. The temporal variation of dry and wet events was estimated using the SPEI-1time series from 1971 to 2018 for the study area demonstrated in Figure 7.1, where blue color represents wet events, and red represents dry events. As the temporal variation plot of SPEI-1 illustrated, that research area is characterized by frequent dry and wet events of moderate to severe categories compared to extreme wet and dry events. The temporal variability plot shows the rare occurrence

of extreme dry (SPEI≤-2) and wet events (SPEI≥2) during the study period. From 2000 to 2018, seven extreme wet events and five extreme dry events have been recorded, compared to three extreme wet events and five extreme dry events between 1971 and 1999, demonstrating an increase in the frequency of such severe events over the time period under study.

The temporal variability plot of SPEI depicted the stability in the occurrence of wet-dry events across the study domain at 1-month to 12-month timescale (Figure 7.1 & Figure 6.1). The transition from dry to wet conditions occurs more rapidly for SPEI at a 1-month timescale than SPEI-3, SPEI-6, SEPI-9, and SPEI-12 (Figure 7.1 & Figure 6.1). Changes in monthly precipitation and temperature significantly affect monthly accumulation levels of water resources. This gradual and steady response of SPEI to changes in the climatic variables reflects the annual and multi-year dry and wet conditions and is highly indicative of these climatic states over the study region. It implies that the frequency of wet-dry transitions will decrease while their duration will increase as SPEI timescales get longer. The study region annually experiences 4.5% higher dry events compared to wet event over the study area.

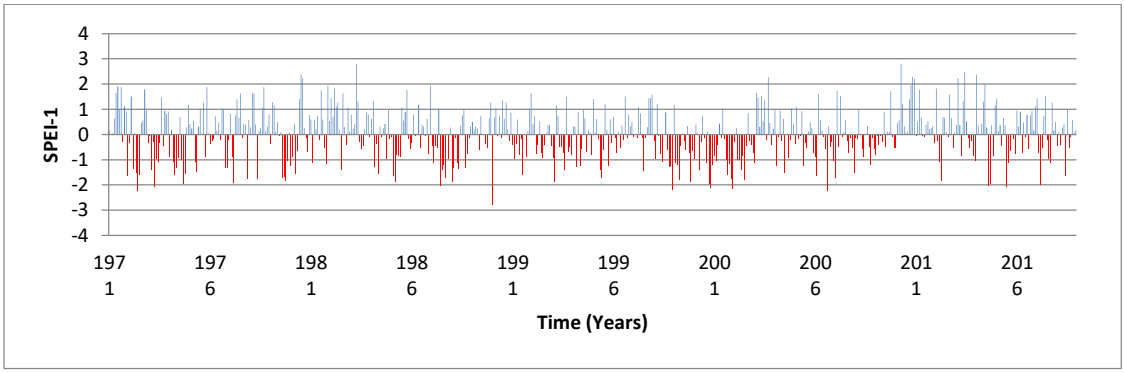

Figure 7.1 Temporal variation of SPEI-1 time series between 1971 to 2018 at a timescale of 1-month time series

This chapter presents dry and wet event severity, duration, and intensity estimates for SPEI-1 over 18 synoptic locations from 1971 to 2018. The research area has roughly the same amount of average dry and wet months with a difference of two to three weeks during 48 years time period over the study area. The average wet duration ranges from 1.27 to 1.58 months, and the average dry duration ranges from 1.29 to 1.82 months. The spatial pattern of average dry and wet durations shown in Figure 7.3 (a). The assessment of average dry duration indicated that dry periods lasted slightly longer than a month, indicative of flash drought occurrences over the studied area. Ge et al. (2016) also showed the occurrence of short-term drought of lesser intensity over the eastern region of Uttar Pradesh. Figure 7.2 (a) demonstrates the variation of total dry duration TDD and total wet duration TWD where the blue color bar represents the TWD and the red color indicate TDD over the 18 synoptic locations of Uttar Pradesh from 1971 to 2018. Over a 48-year period, the study area experiences slightly more total dry duration (TWS) than total wet duration (TWD), with TWS ranging from 83 to 101 months and TDD ranging from 91 to 103 months. The synoptic location over the eastern plain has the highest value of TWS, while the locations among the western plain and the Bundelkhand region experienced higher TDD. This is likely caused due to spatially heterogeneous climates over Uttar Pradesh, where humid subtropical climates dominate over most parts of the region and semi-arid climates over the part of western plane Uttar Pradesh, India.

The spatial distribution of the average severity of dry and wet events is portrayed in Figure 7.3 (b). Unlike the duration distribution map, the average severity of dry and wet events ranges over the study area with a difference in magnitude. The higher average severity of drying events recorded over the study area, where the average

severity varies for the wet event, is from 1.89 to 2.30 whereas dry events are 1.89 to 2.60. Figure 7.2(b) demonstrates the variation of total dry severity (TDS) and total wet severity (TWS), where the blue color bar represents the TWS and the red color indicate TDS over the 18 synoptic locations of Uttar Pradesh from 1971 to 2018. On average, the study area accounts for a higher TDS of 143, whereas TWS is 137. The study area with higher TDS occurred over the synoptic locations Lucknow, Moradabad, and Agra. It indicates that the study records relatively higher total dry severity (TDS) than total wet severity (TWS). The central and western parts of the study area are experiencing intense drying events. Basti, Varanasi, Allahabad, and Azamgarh are among the locations of the eastern plane that recorded the higher TWS (TWS>140). The above discussion illustrates the eastern plane of the study experiences intense wet event occurrences. Bhatt et al. (2019) also demonstrated that the north-eastern plane of the study zone was experiencing a considerable number of extreme rainfall events over the study region.

The average intensity of dry and wet events is shown spatially distributed over the research region in Figure 7.3 (c). The spatial map illustrates that the study area prevailed by the wet event of higher intensity, where the average wet intensity ranges from 1.39 to 1.51, while the average dry event intensity ranges from 1.35 to 1.50. Intense dry events predominated over the location throughout the central and western regions of the study region, whereas the central and east planes of the study region are the hotspot of intense wet events. Figure 7.2 (c) illustrates the variation of the total dry intensity (TDI) and total wet intensity (TDI) over 18 synoptic locations of Uttar Pradesh. Wet events with higher intensity also predominated over a larger spatial extent.

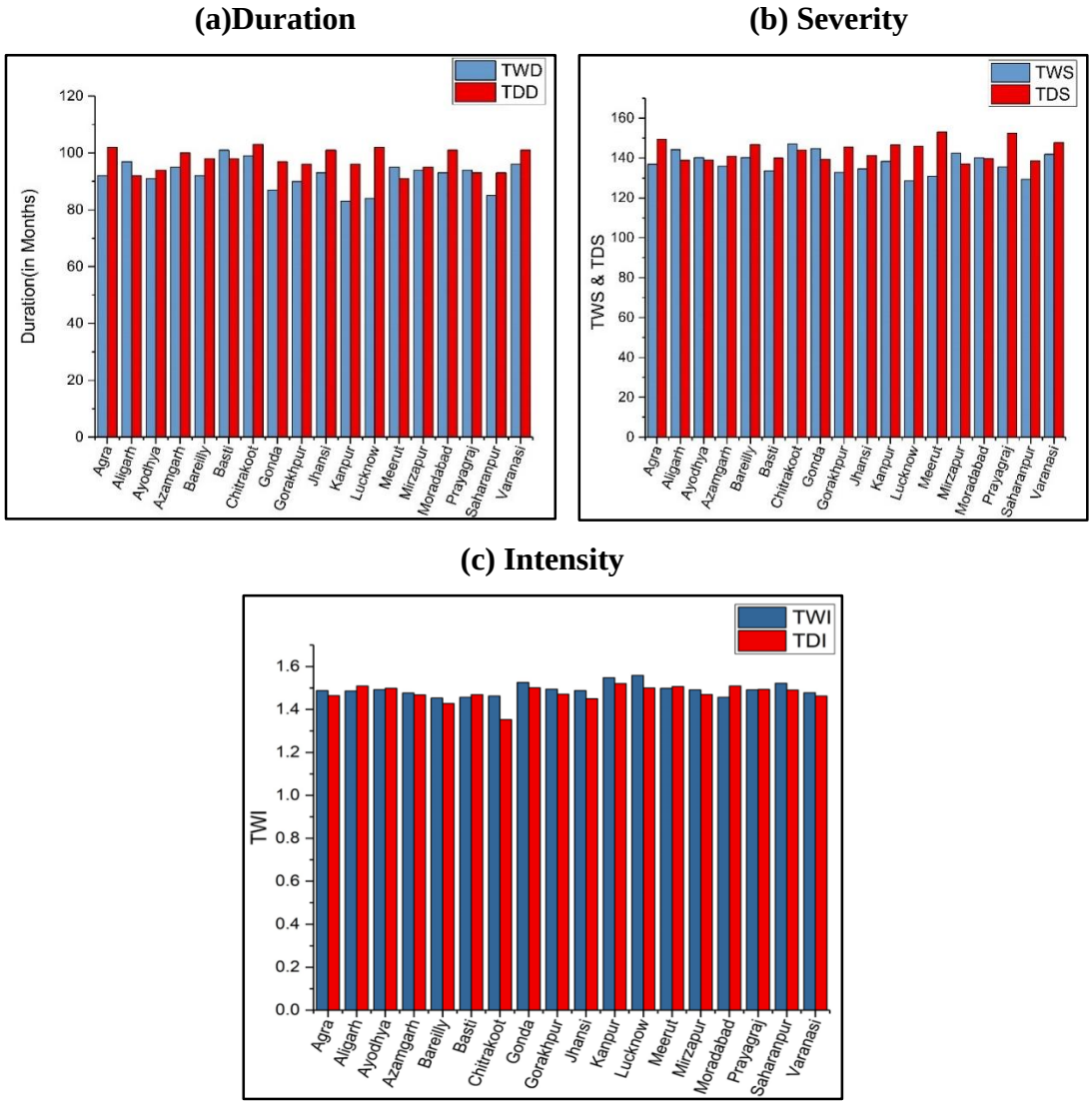

Figure 7.2 The variation of Total wet duration (TWD) and total dry duration (TDD), Total wet severity (TWS), total dry severity (TDS), Total wet intensity (TWI), and total dry intensity (TDI) across the study area for the period of 1971 to 2018

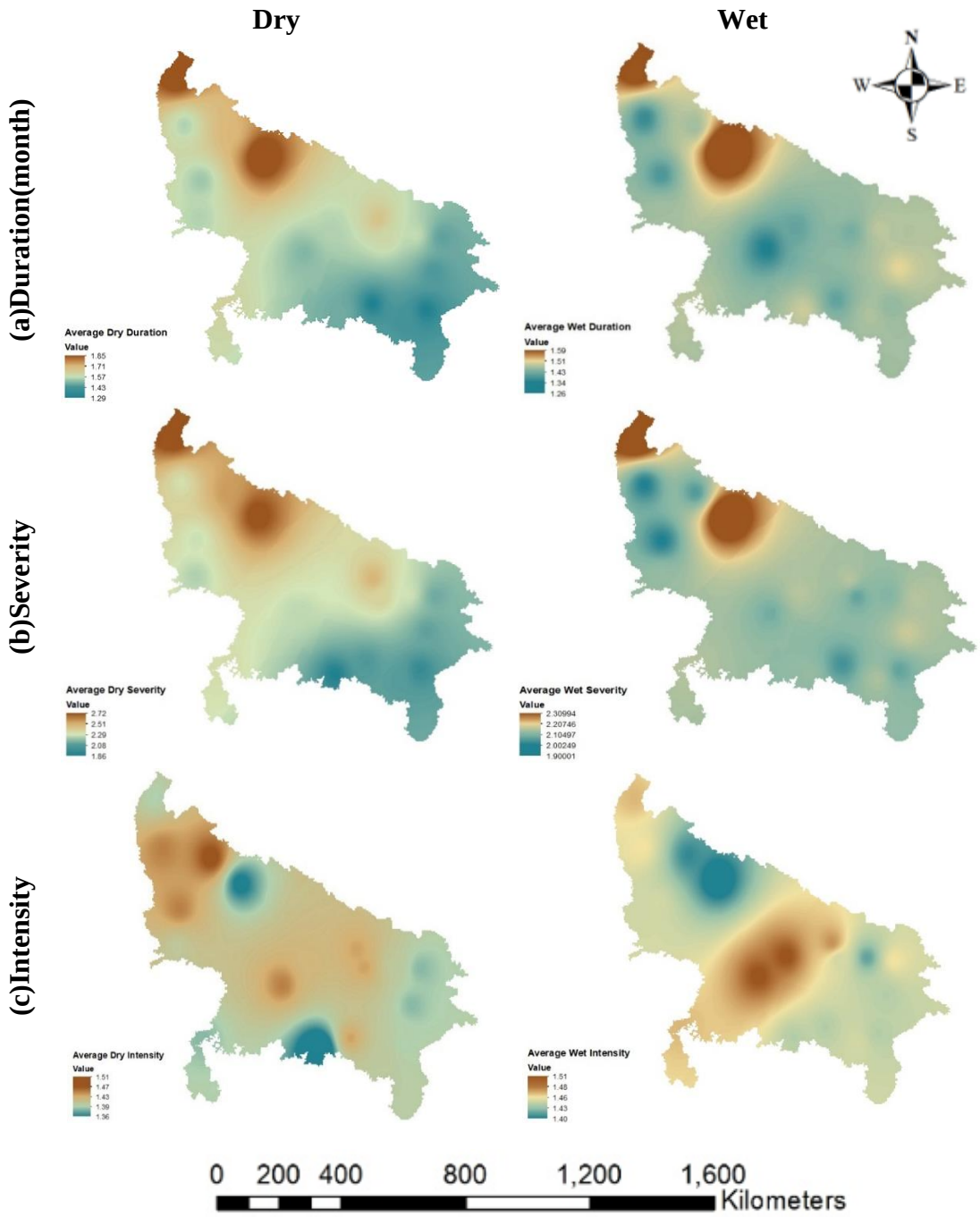

Figure 7.3 Spatial distribution of average dry duration (AWD), average dry duration (AWD), average dry duration (ADD), average wet duration (AWD) and average dry intensity (ADI), and average wet intensity (AWI) of over the study area for the period of 1971 to 2018

7.1.2 Wet–dry ratio

The present study evaluates the Wet–Dry (WD) ratio, which determines the dominance of dry or wet events of different severity (moderate, severe, and extreme) over the 18 synoptic locations of Uttar Pradesh, India, from 1971 to 2018. Positive and negative WD ratio values indicate the prevalence of wet and dry events, respectively. The spatial distribution of the WD ratio of moderate, severe, and extreme severity exhibited in Figure 7.4. Seventy-seven percent of the synoptic locations were more likely to experience dry events of the moderate to severe category, whereas Aligarh, Azamgarh, Faizabad (Ayodhya), Bareilly, Basti, and Moradabad were more likely to experience wet events of the moderate category. Except for Aligarh, Allahabad (Prayagraj), Chitrakoot, Meerut, and Mirzapur, 66% of the synoptic locations are more susceptible to frequent severe wet occurrences. The spatiotemporal map demonstrates the prevalence of a higher frequency of dry events of moderate to severe category throughout the study region (Figure 7.4). The wet event of the extreme category is more prevalent over 66 % of the synoptic location of the study area (Figure 7.4 a & b). Whereas dry event of the extreme category is more frequent over Aligarh, Prayagraj (Allahabad), Faizabad (Ayodhya), Chitrakoot, Meerut, and Mirzapur. The highest positive WD ratio values for extreme wet events were found in the northeastern and eastern plains of the study region, where annual precipitation exceeds the average of 1025 mm, indicating a higher sensitivity to their occurrence.

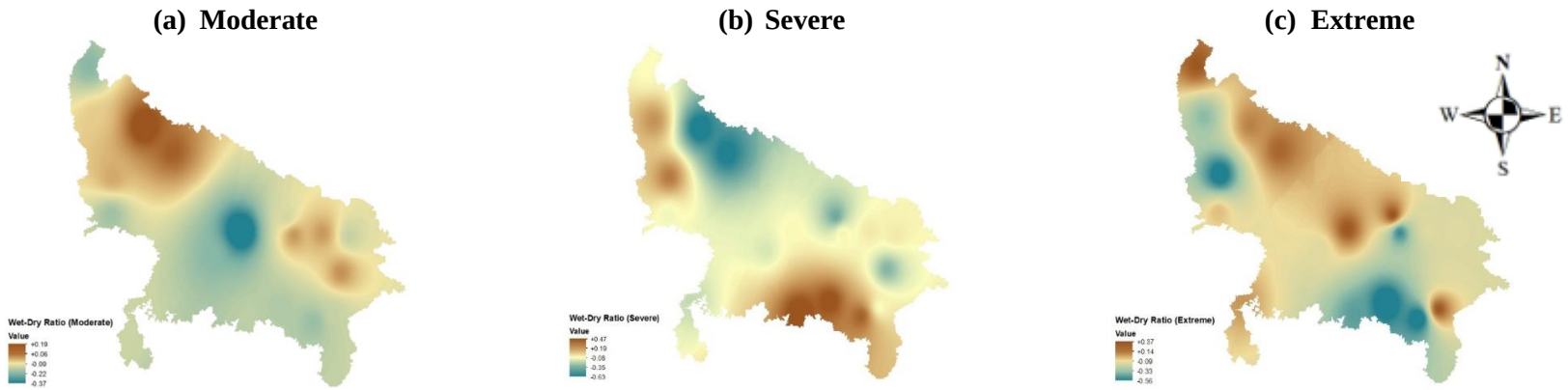

Figure 7.4 Spatial distribution of wet-dry (WD) ratio of different categories (a) Moderate, (b) Severe, and (c) Extreme across the study area for the period of 1971 to 2018

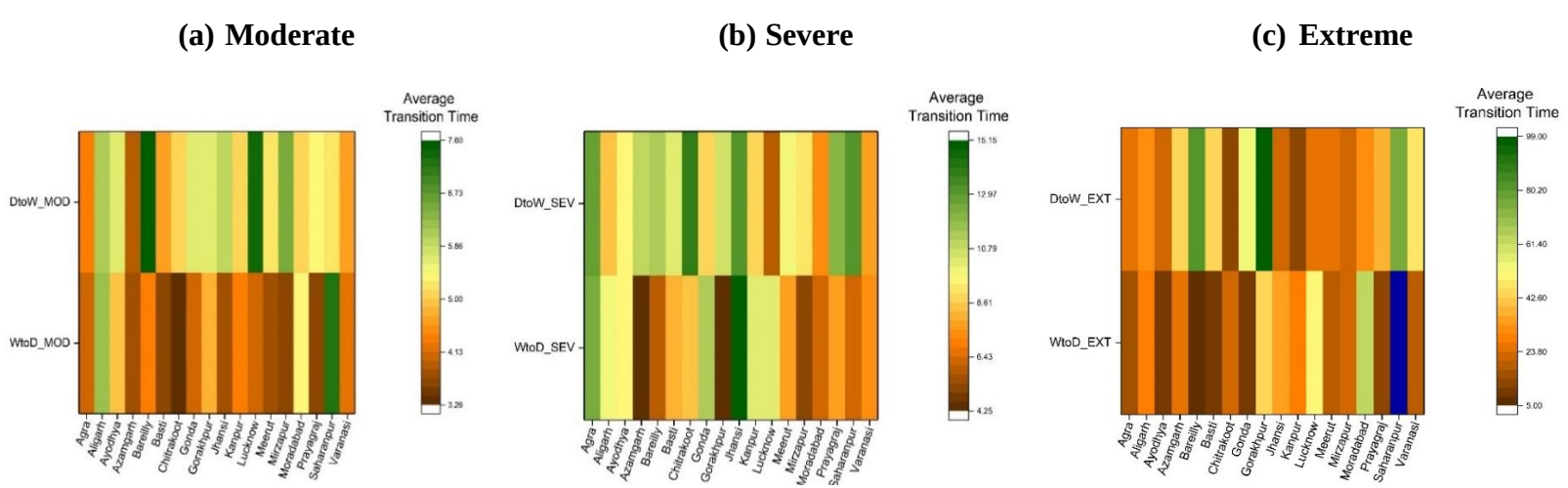

Figure 7.5 The variation of average transition time (Tt) from dry-to-wet event (D to W) or wet-to-dry event (W to D) of different categories (a) Moderate (MOD), (b) Severe (SEV), and (c) Extreme (EXT) across the study area for the period of 1971 to 2018

7.1.3 Dry-wet transition time

The average transition time (T_t) plotted as heatmap (Figure 7.5) demonstrate the spatial distribution of T_t from dry-to-wet event (D to W) or wet-to-dry event (W to D) for various category (moderate, severe, and extreme) over 18 synoptic locations in Uttar Pradesh, India from 1971 to 2018. The change in color (from brown to green) indicate the change in average transition time (T_t) recorded in month for each location. The average transition time significantly varies for moderate, severe, and extreme, from 3.90 to 7.40 months, 4.60 to 13.10 months, and 5 to 99 months, respectively. There is a substantial increase in the transition time from moderate to extreme category where dry-to-wet event transitions take longer duration over the study area than wet-to-dry events. Figure 7.5 (c) indicate that the average transition time is highest for the extreme category followed by severe category. In Figure 7.5 (c), the Saharanpur location portrayed with blue color represents zero average transition time from wet to dry event for extreme category. The transition time from dry to wet is longer in 77%, 66%, and 66% of the synoptic location of the study region, respectively, than in the wet-to-dry transition time in the moderate, severe, and extreme categories. Figure 7.6 depicts the spatial distribution of the number of transitions between climatic extremes (dry-to-wet or wet-to-dry event) at different categories (a) moderate, (b) severe, and (c) extreme during the study period. As depicted on the spatial map (Figure 7.6), the number of transitions between dry and wet events of the moderate category ranges from 11 to 30, while the number of transitions in the severe category ranges from 5 to 15, and the number of transitions in the extreme category ranges from 0 to 5 over the period of 48 years. The spatial map illustrates that the research area is the hotspot of the frequent transitions between the dry and wet events of the moderate category. In comparison to

the other parts of the study region, the eastern region undergoes a higher number of transitions.

7.1.4 Rapid transition event

The rapid transition evaluates the consecutive occurrence of wet and dry events irrespective of any severity level. The number of rapid transitions between the dry and wet event and the transition time (dry-to-wet event or wet-to-dry event) was estimated for 18 synoptic locations in Uttar Pradesh, India, from 1971 to 2018. The spatial distribution of the number of transitions and the rapid transition time (in months) from dry-to-wet and dry-to-wet events are portrayed in Figure 7.7. The number of rapid transitions (dry month followed by wet month or wet month followed by dry month) evaluates the hotspot region of frequent transition of this consecutive event over the study region. Figure 7.7 (a) illustrate that the number of transition ranges from 16 to 42 events during the period of years. Among all the synoptic locations Saharanpur and Bareilly experienced the least rapid transition over the study period, whereas Basti, Kanpur, Meerut, and Agra are the hotspot location with higher rapid transition events over the study region. Figure 7.7 b and c, illustrate the spatial distribution of rapid transition time from dry- to wet event (D to W) ranges from 2.5 to 4.1 months, and for wet- to-dry event (W to D) is 2.05 to 5.25. This rapid transition time result highlights the fact that across the study region, 11 synoptic locations have a lengthier dry-to-wet transition time compared to wet-to-dry events. The study region experiences an average transition time of roughly 2.80 months. Saharanpur location had minimum number of rapid transitions from wet-to-dry events. This can be explained by Saharanpur's location in the Terai region of the study area, which is adjacent to the foothill zone of the Himalayas and receives an average of 1,150 mm of precipitation annually. The

locations where transition occurs most frequently are Kanpur, Basti, Agra, Meerut, and the Basti had shorter period transition times than other stations, indicating that the monsoon region was characterized by the frequent and rapid transition between dry and wet events across the study period. The Bundelkhand region of the study region is regarded as a region afflicted by persistent drought occurrence (Chaurasia & Chandra, 2021). The study region is vulnerable to climatic extremes due to frequent transitions, except for some zones like the Tarai region. The rapid transitions between the dry and wet events dominated over dry sub-humid to semiarid regions, whereas monsoon dominated regions also have a large number of rapid transition events, with an average transition time of about 2.60 months.

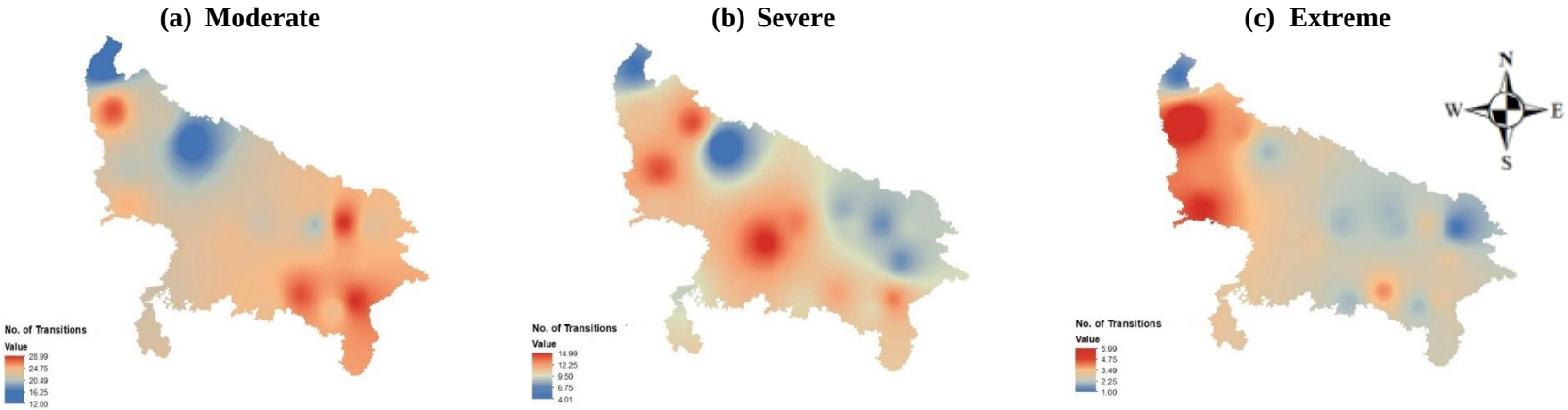

Figure 7.6 Spatial distribution of number of transitions between climatic extremes (dry-to-wet or wet-to-dry event) at different category (a) Moderate, (b) Severe, and (c) Extreme across the study area during the period of 1971 to 2018

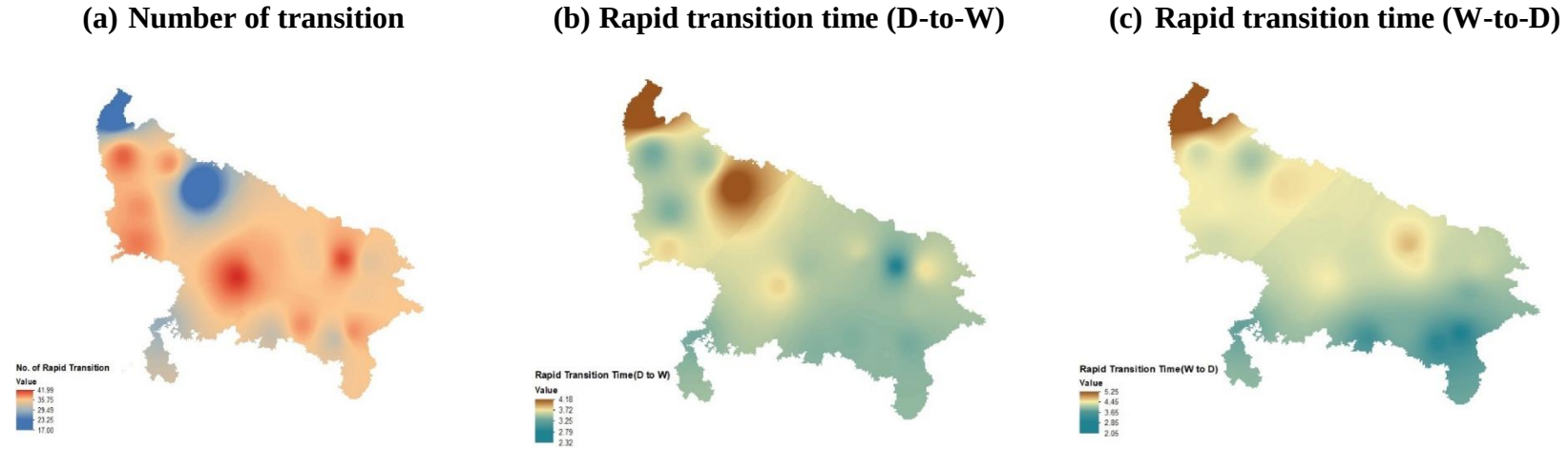

Figure 7.7 Spatial distribution of number of rapid transitions between wet and dry event of across the study area for during the period of 1971 to 2018

7.2 Summary

This chapter focuses on the concurrent assessment of dry and wet events and their transition, spatially and temporally, over Uttar Pradesh, India, from 1971 to 2018. The dry and wet characteristics such as severity, duration, and intensity and their transition time were estimated over 18 synoptic locations of Uttar Pradesh, India. The dry and wet event characteristic are estimated based on the SPEI, which include the impact of temperature on the estimation of dry and wet characteristics. The term "flash drought" refers to drought occurrences with rapid onset and intensification. Flash droughts can be caused by substantial precipitation deficits and/or abnormal increases in temperature. The dry and wet event characteristics were evaluated using the SPEI 1-month timescale because of its efficiency in estimating flash drought and flood conditions over the study region. This study uses SPEI at longer timescales to assess drought characteristics, but its averaging effect makes it inefficient to estimate flood conditions at longer scales. Therefore 1-month timescale of SPEI has been chosen for the assessment of seasonal or interannual variability of the study period. The result of temporal variation of dry and wet event outline that the research area is the hotspot of the frequent occurrence of dry and wet event of moderate category. Extreme dry and wet events infrequently occurred over the study period. The study area on an annual basis encounters 4.5% higher dry event compared to wet event. The results of the evaluation of the characteristics of dry-wet events spatiotemporally indicate that the semi-arid climate-dominated region and the central plane of the study area had more severe, prolonged, and intense dry events. Dry episodes lasted slightly longer than a month on average, which is indicative of flash drought condition over the study area.

Eastern region characterizes with humid to sub-humid climates, experienced a substantially high number of dry events throughout the study period. The western and Bundelkhand regions experience more intense dry events, whereas the eastern region is characterized by intense wet events. The outcome of the WD ratio indicate the prevalence of a higher frequency of dry and wet events of moderate to severe category throughout the study region. Except for a few locations, the study area is subject to a higher frequency of extreme wet events. Moderately severe dry events were more prevalent than wet events across 77% of the research region. The northeastern and eastern plains of the study area had the highest positive WD ratio values for extreme wet events indicating a higher sensitivity to their occurrence. The average transition time from dry-to-wet or wet-to-dry type varied spatially for different severity "moderate", "Severe" and "extreme". Overall higher percentage of the synoptic location of the study area requires less time to transition from wet-to-dry events than from dry-to-wet. In addition to the average transition time, the region under study experienced rapid changes between wet and dry weather. The rapid transition time over the study area ranges from dry-to-wet event is ranges from 2.50 to 4.10 months, and for wet-to-dry events is 2.05 to 5.25. This rapid transition time result highlights the fact that across the study region, 11 synoptic locations have lengthier dry-to-wet transition time compared to wet-to-dry transition time.

Increasing evapotranspiration rates due to a temperature rise could make droughts more likely and dangerous in a warmer climate. As evapotranspiration rates increase, the chances of a single heavy rainstorm causing flooding are expected to increase (He & Sheffield, 2020). Finally, understanding wet-dry event features and their transition offers valuable information into the hotspot region of concurrent climatic

extremes occurrence. The results help with risk analysis and hydrological forecasting. This leads to better disaster-prevention and risk-management management, ensuring regional water, food, and economic safety and calm in a changing environment. As this study concluded that at SPEI at 1-month higher number of dry events characterizes with greater severity over the study region. The next step is to estimate dry events occurrences under changing climate over Uttar Pradesh, India.

The impact of wet-dry events and their transition had not been assessed previously over the study region, despite clear evidence of climate change. The region has already experienced an increase in extreme meteorological events in recent decades, and these events are expected to become even more pronounced in the future. The study aims to examine historical patterns in the transition between dry and wet periods at a regional scale over Uttar Pradesh, identifying hotspots of dry-to-wet transitions and exploring their dynamic evolution in response to the warming climate. The study also investigates the interrelationships between characteristics of dry-to-wet transitions and variability at different spatial and temporal scales, aiming to improve our understanding of dry-to-wet transition mechanisms and develop effective risk mitigation strategies. The study employs the Standardized Precipitation Evapotranspiration Index (SPEI) to analyze deviations in climatic features, with shorter timescales used for detecting frequent seasonal and inter-annual variations, and longer timescales providing insight into the events' signature over the region. Furthermore, the SPEI time-series plots effectively capture observed floods and flash drought events, confirming its valuable contribution to this type of analysis. However, the study also highlights the need for further investigation into whether drier conditions are expected to continue in the future. Many researchers have reported a close association between variations in atmospheric

circulation patterns and climatic variables, extreme weather phenomena like drought and flood. However, the study emphasizes the need for further investigation into the association of change in atmospheric circulation patterns with extreme event occurrence over Uttar Pradesh, India.