

Original Research Article

Assessment of Diurnal Variability and Region-Specific Connection Across Intensity, Depth & Duration of Rainfall

Abstract

Rainfall remain foremost input entity for regulating any kind of dynamics of water resource systems on the earth. Its correct study and understanding of rainfall are highly crucial in hydrology or any kind of water resource system, to evolve and judge effective management and development of prevailing terrestrial and aquatic ecosystems. This study is focussed towards analysing the diurnal variability of rains with region-specific connectiveness across intensity, depth and duration of Rainfall for central region of Gujarat; having semi-arid climate. It investigates spatio-temporal dynamics of rains at multiple situations, for the situations where a majority of rainfall occurred during a single quarter of the day (i.e., a 6-hour period). An in-depth elaboration on quarter wise distribution of such daily rainy event (covering 20 years time span) is offered, which revealed that the maximum number of storms occurred in second quarter Q₂ (06:00 to 12:00 hours) while the least in first quarter Q₁ (24:00 to 06:00 hours). Three sets of time series of maximum rain intensities (one each for 20, 10 and 5 years, recurrence interval i.e. RI) are also attempted to demonstrate an inclusive scenario in regards to intensity-duration characterizations of rain, cutting across various locations and years of observations. Location specific relationships among depth & durations and intensity & duration are generated with exhaustive comparisons, under 3 specific recurring interval period (5, 10, 20 years) for all the 6 rain stations as adopted herein.

Key Words : Diurnal Variability of Rainfall, IDF, Rainfall Intensity, Rainfall Duration, GPM, Rainfall Modelling

1. INTRODUCTION

The intensity–duration–frequency characterization of rains, is always considered to have an important role in water resources engineering and management. Its true utilities and applications range from assessing rainfall events, classifying climatic regimes, deriving design storms, deriving loss functions to produce runoff patterns, assisting in designing drainage systems, etc. What even be the spatio-temporal scale, being a foremost input hydrologic entity it vastly regulate majority of water resource systems on earth. It remains a proven fact that rainfall based research happens to be one of the weakest link in hydrology, as the due investigations on rainfall variability have experienced pretty less priority and diminutive efforts (Lall, 2014 ; Sivakumar, 2005 ; Bates *et al.*, 2008 ; Allan, 2011). The quantity and quality of runoff from majority of watersheds (micro to macro) is highly influenced and regulated by spatio-temporal variabilities on rains. Performance evaluation and management of any water or watershed-based system gets accomplished by espousing variety of advanced hydrological models or modelling approaches. In all such efforts a compromise is always made via adoption of an inferior input, in-terms of rainfall, for which reason remains non-availability of region-specific rainfall observations at finer spatio-temporal steps. In majority of cases annual, monthly, weekly or at the most daily rainfall values are adopted with wider extent of interpolation/extrapolation; as in most cases the observed rainfall records remain exceedingly scanty, non-uniform & discontinuous. Such inferior input always results into equally mediocre outputs from hydrologic models/modelling approaches; even if they are of marvellous nature. The non-availability of region-specific rainfall observations at finer spatio-temporal steps is always reflected to have significant impacts on hydrological modeling and simulation results (Anandhi *et al.*, 2011; Gao *et al.*, 2018; Moges & Gebremichael, 2014; Tahir *et al.*, 2012; Wang *et al.*, 2019).

Accurate rainfall data is crucial for predicting and managing the impacts of rainfall on various aspects of land and water resources management and catchment health. The predominant duration and intensity of rainfall significantly influence the occurrence of floods in a catchment (Karamouz et al. 2018). The distribution of rainfall over time is also critical in determining the amount of soil erosion, with rain-intensity and durations having a significant impact on the magnitude of soil erosion (Reggiani et al. 2016; Zhang et al. 2019). In sediment dynamics and transport via rivers, rainfall intensity, duration, and distribution play a critical role (Wang et al. 2017; Chen et al. 2019). A clear understanding of rainfall variabilities specific to a region is necessary when attempting any kind of land and water development intervention in natural watersheds (Smith et al. 2018).

Furthermore, the magnitude and distribution of rainfall greatly affect groundwater recharge, which is crucial for sustaining ecosystems and meeting long-term human water needs (Sharma et al. 2017; Luo et al. 2018; Du et al. 2019). Accurate assessment of rainfall variabilities is also vital for agricultural productivity as crop yields have a direct proportional relationship with corresponding rainfall variabilities, which can affect long-term food security targets (Lobell et al. 2019). The dynamics of rainfall patterns and intensity also influence water quality parameters by transporting pollutants into drainage lines or other waterways (Deo et al. 2017).

The diurnal variation in precipitation can have significant impacts on catchment response, affecting various aspects of water resources management and catchment health. These impacts include changes in the timing of peak flow, soil moisture dynamics, streamflow response, hydrochemical response, and evapotranspiration. Understanding these impacts is important for managing water resources and predicting the response of catchments to changing climate conditions (Delgado et al. 2019; Bales et al. 2011; Zhang et al. 2014; Zhao et al. 2019; Yuan et al. 2016). Present study aimed to analyse a broader spectrum of

rainfall variabilities at micro scales cutting across 6 rain stations covering a time span of about 20 years; and offering the on-ground scenario in regards to diurnal variability and region-specific connections across intensity, depth and duration of rainfall as prevailed in the central region of Gujarat.

2. MATERIAL AND METHODS

2.1 Study location

This study aims to analyse and quantify the variability of rainfall patterns in the central region of Gujarat, which is characterized by semi-arid climate. The research focuses on three key districts - Anand, Kheda, and Vadodara - which represent Agro-Climatic Zone-III of the state. These districts experience mean maximum temperatures ranging from 28.4°C in January to 41.8°C in May and mean minimum temperatures ranging from 11.7°C in January to 27°C in June. Two locations were selected from each of the study districts. Gudel and Sojitra from Anand ; Kathlal and Dakor from kheda and ; Pilol and Waghodiya from Vadodara district. The exact geographic locations of 6 study sites are well reflected in Fig. 1,

showing their wider spatial spreads in study area.

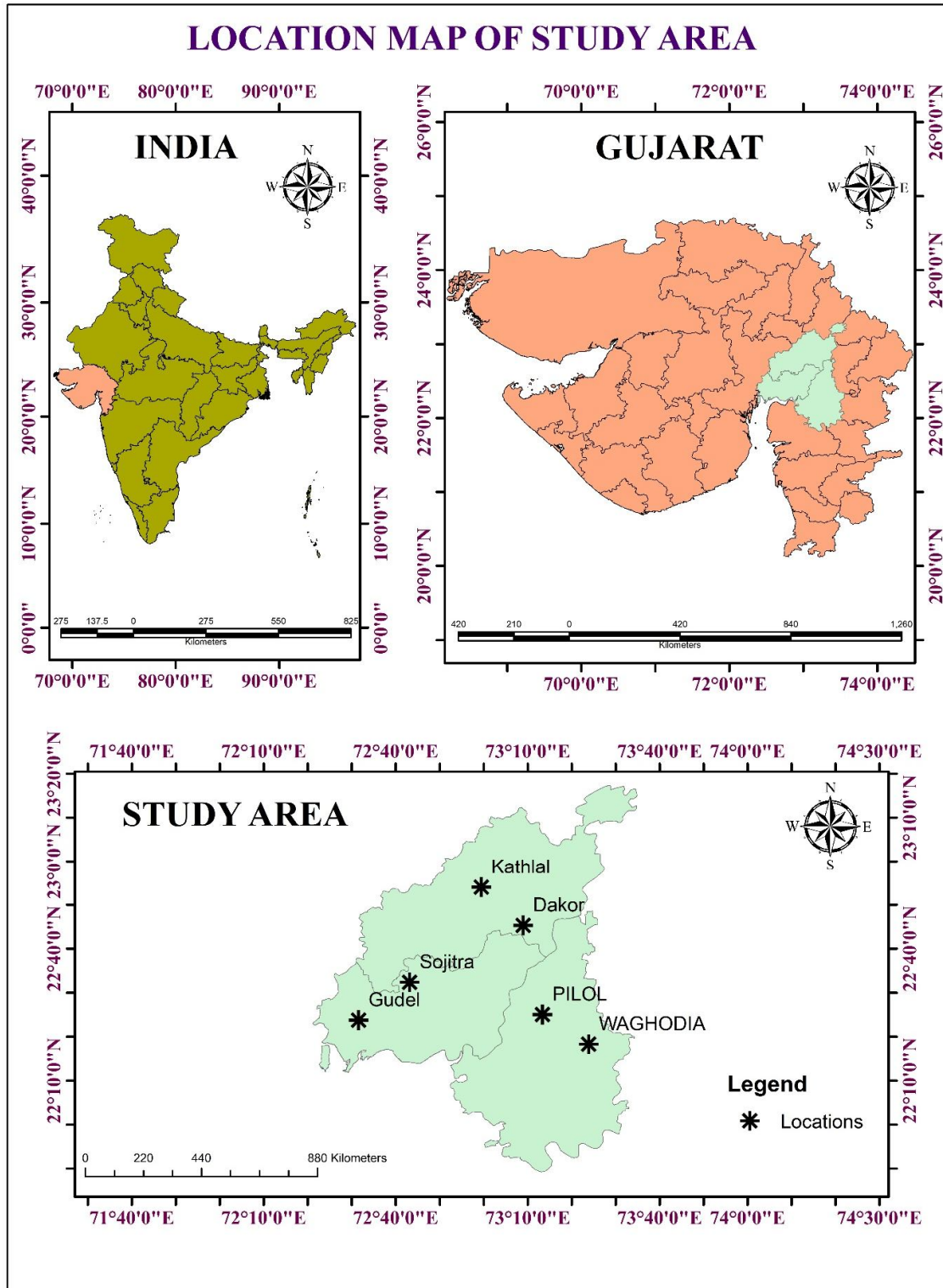


Figure 1. Location Map of the study area

2.2 Data

To gather the necessary data for this study, satellite-based precipitation products were utilized. Global Precipitation Measurement (GPM_3IMERGHH) is an international satellite mission jointly developed and managed by NASA and the Japan Aerospace Exploration Agency (JAXA) (Huffman *et al.*, 2019). The mission aims to provide global measurements of precipitation every half hour using a constellation of satellites that use advanced radar and radiometer instruments to measure precipitation from space. Rainfall records for all the study stations in the three districts were collected for a 21-year period from 2000 to 2020. The rainfall records had a temporal resolution of 30 minutes and a spatial resolution of 11.1 km x 11.1 km.

2.3 Methodological Description

Events were treated differently from daily rainfall data, as they were independent, isolated, and continuous rainstorms of varying durations, ranging from 1 hour to even longer durations well beyond 24 hours. To categorize the smart rainfall data appropriately, a valid check was performed to extract the actual rainfall hours or cells that contained information on rainfall, using R programming applications. The time series data contained significant periods of zero precipitation, which were omitted during the analysis. Upon preliminary analysis of the rainstorms, it was deemed appropriate to exclude those with durations exceeding 24 hours. For other remaining storms (across 1 hr to 24 hr durations) following categorised distribution was adopted in four different categories as provided below. Rainstorms having continuous rains for 1) 1 to 3 hours duration, 2) 3 to 6 hours duration, 3) 6 to 12 hours duration, and 4) 12 to 24 hours duration.

Table 1. Portrayal of isolated continuous rain storms (4 categorized durations) for study locations

Sr. No.	Storm Duration	Number of Storms Extracted					
		Dakor	Kathlal	Gudel	Sojitra	Pilol	Waghodiya
1	1-3	386 (43)	371 (43)	381 (43)	350 (40)	405 (42)	461 (45)
2	4-6	266 (30)	265 (31)	281 (31)	276 (31)	295 (31)	309 (30)
3	7-12	178 (20)	168 (20)	168 (19)	180 (20)	197 (21)	188 (18)
4	13-24	64 (7)	51 (6)	63 (7)	76 (9)	63 (7)	67 (7)
Total		894	855	893	882	960	1025

(The numbers in parenthesis shows % of total number of storms)

After obtaining the precipitation data from the Global Precipitation Measurement (GPM_3IMERGHH), the following steps were taken.

Examining Distribution of Daily Rainfall: The next step is to examine the distribution of daily rainfall at a finer temporal scale of approximately 1 hour. This enables the identification of the quarter of the day where the bulk of the rainfall occurred.

Identifying Concentrated Storm Events: The analysis includes a large amount of data and focuses on identifying concentrated storm events. Rainfall data is examined at an hourly level to identify days where over 75% of the rainfall occurred during a single quarter of the day.

Investigating Burst Storms: The objective of this analysis was to gain a better understanding of burst storms and their concentration during specific periods of the day.

Identifying Peak Rainfall Intensities: The next step is to identify peak values of rainfall intensities for 24 specific time durations ranging from 1 hour to 24 hours. The occurrence of

these peak intensity values is found to be dependent on both the reoccurrence interval and the frequency period.

Segregating Data into Sub-Groups: To account for the dependence on reoccurrence interval and frequency period, the observed data set is segregated into three sub-groups based on predetermined categories or groups, namely pooled data for five years, ten years, or twenty-year spans.

Examining Local Trends: Additionally, the analysis examines the local trends and the relationship between the depth of rainfall and its duration for each station.

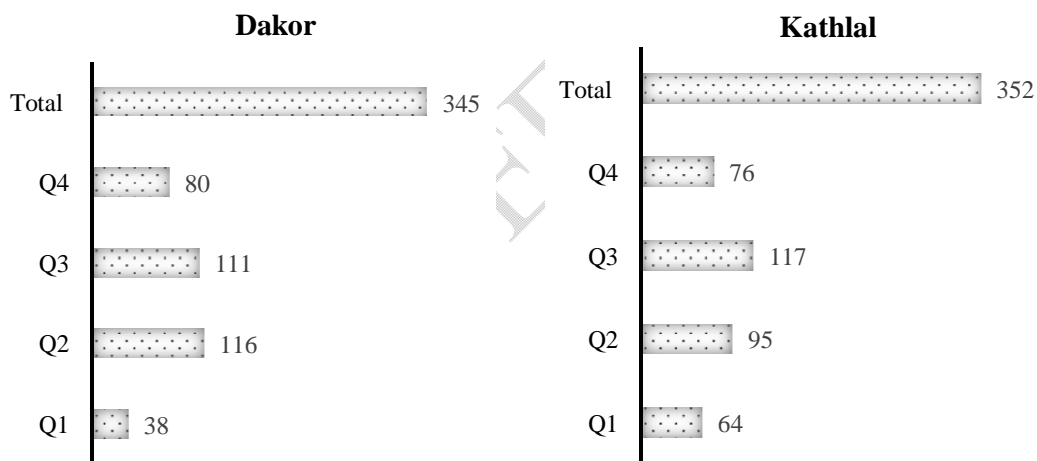
Segregating Precipitation Data: Similar to the analysis of intensity duration, the observed precipitation data set for each station is also segregated into three groups, namely pooled data for five years, ten years, or twenty-year spans.

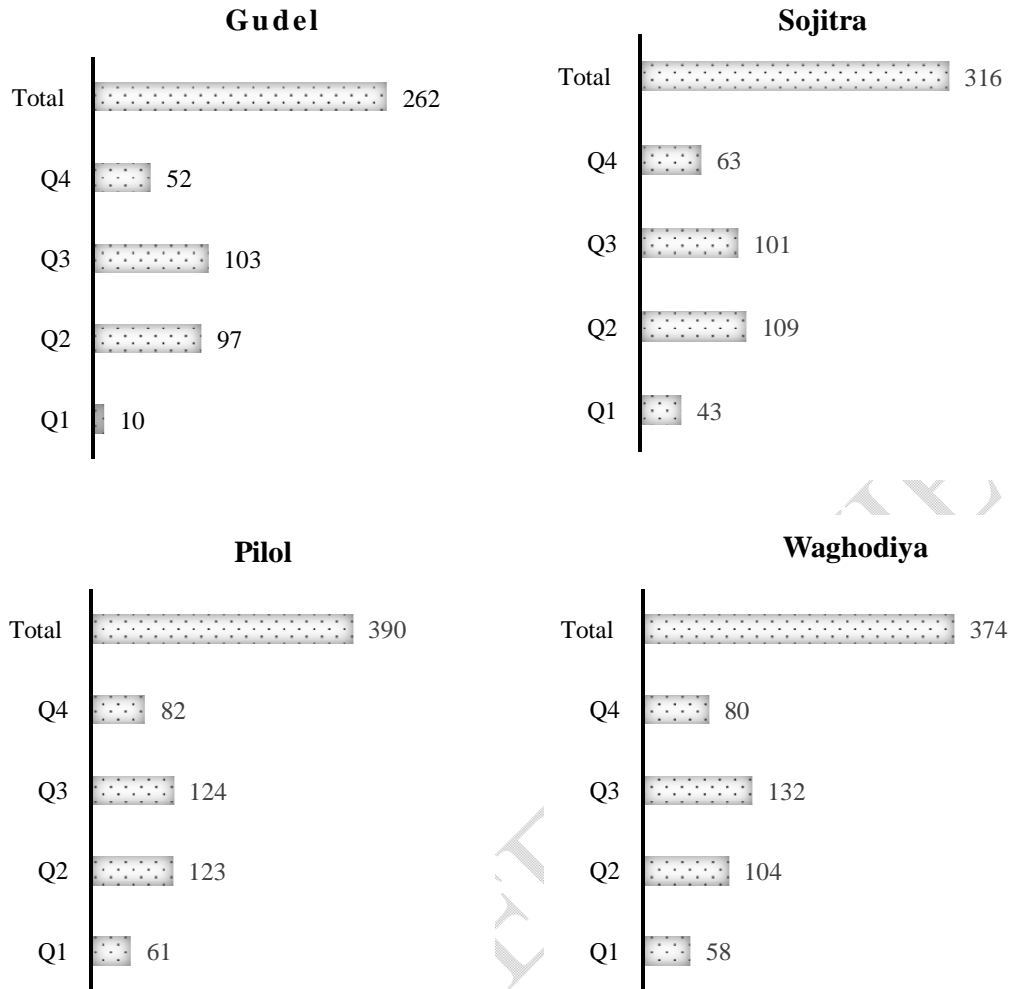
3. RESULTS AND DISCUSSION

3.1 Quarterly Temporal Dispersal across 20 years

This study was carried out to examine scenarios where most of the daily rainfall took place within a specific quarter of the day, which equates to a 6-hour period. The number of storms detected across all the stations remained 345, 352, 262, 316, 390 and 374 for Dakor, Kathlal, Gudel, Sojitra, Pilol and Waghodiya respectively, where its more than 75 % rain fallen in any of the single quartile (6 hr) of the day. A detailed illustration in regards to quarter wise distribution of such event is provided in figure 2. For Dakor such storms were found highest in number being 116 (occurred in Q₂) and 111 (occurred in Q₃). Least occurrence of such events was detected in Q₁. Similar quantified information in regards to occurrence of such events for other five stations are evidently depicted in figure 2. On the same line evidences were also generated to identifying and locate occurrence of rain event where their more than 50 % rain depth fallen in any of the single quarter of the day. The

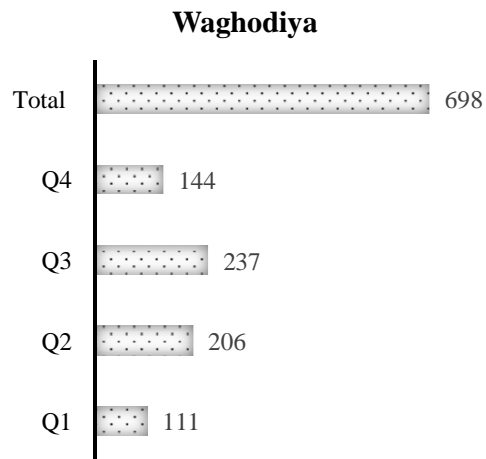
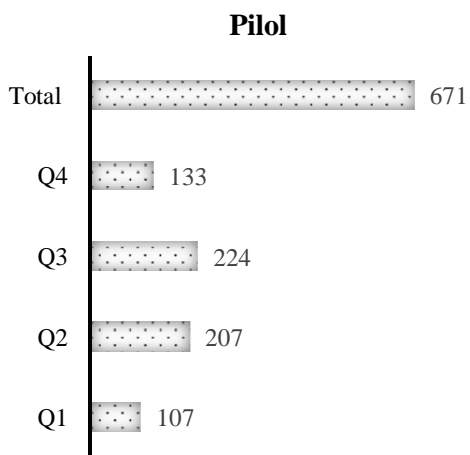
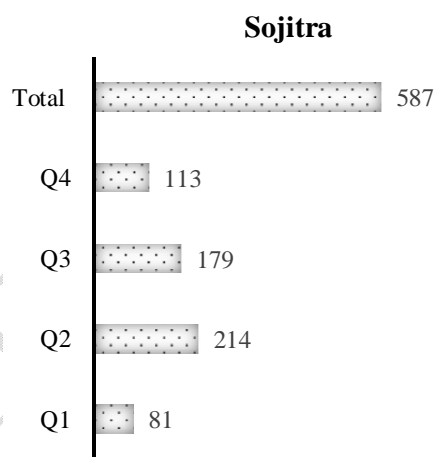
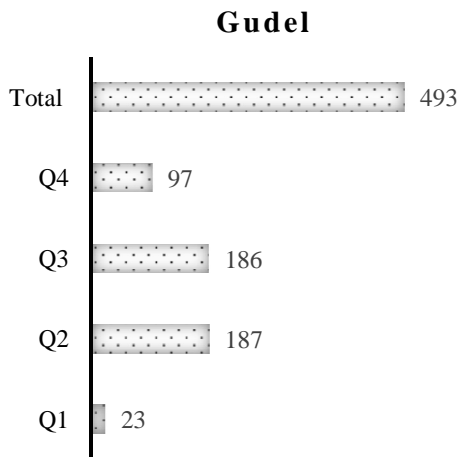
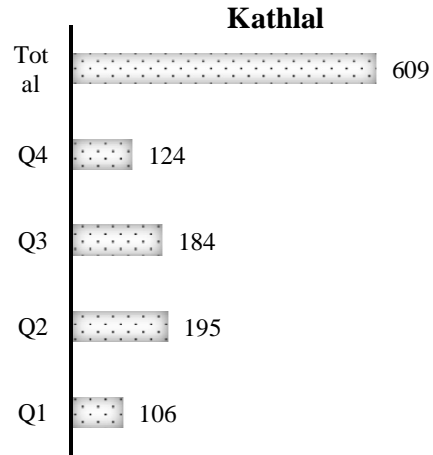
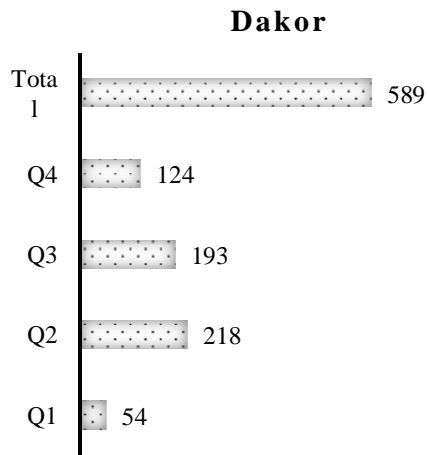
detailed quantified information and dispersals are numerically as well as graphically presented in figure 3, which are self-explanatory in their contents. This information is going to be a vital key of information for planer engineering, irrigation schedulers, water resource managers and other policy planners for the cause of rural development. The diurnal pattern of rainfall was influenced by any of the reason like local topography, surface heating and atmospheric stability, local convective processes and resulted with higher numbers of rainfall events occurring in late afternoon and early evening (Seleshi, et.al., 2018 ; Carbone & Tuttle, 2014 ; Marengo et al., 2012).





Q1: 00:00 to 06:00 hrs Q2: 06:00 to 12:00 Hrs Q3: 12:00 to 18:00 Hrs Q4: 18:00 to 00:00 Hrs

Figure 2. Observed number of rainy days having 75% rains in a single Quarter of the day at different stations



Q1: 00:00 to 06:00 hrs Q2: 06:00 to 12:00 Hrs Q3: 12:00 to 18:00 Hrs Q4: 18:00 to 00:00 Hrs

Figure 3 Observed number of rainy days having 50% rains in a single Quarter of

the day at different stations

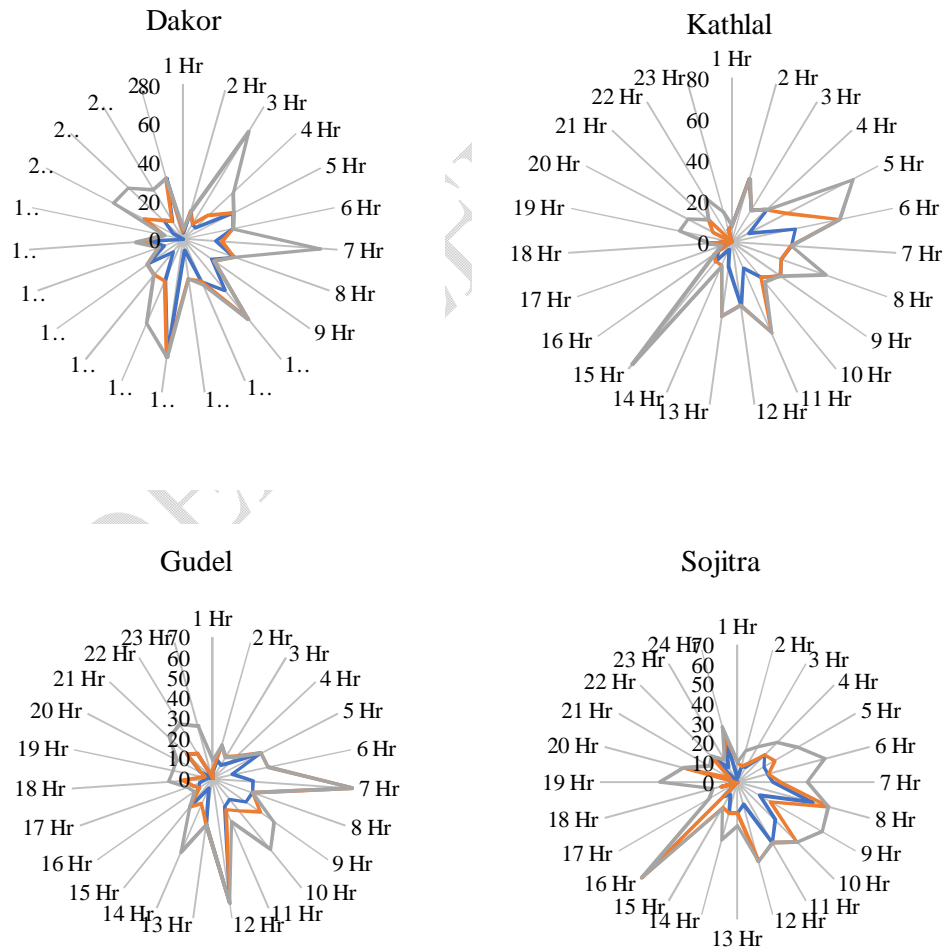
3.2 Intensity Duration Relationships

The analysis of rainfall data is crucial in understanding the intensity, duration, and frequency of rainfall events in a particular region. We aimed to identify the highest recorded values of rainfall intensity across 24 distinct time intervals ranging from one hour to 24 hours. The data was collected from six stations in the study location, and the highest values of peak rainfall intensities were identified for each station. The results of the analysis were presented graphically in Figure 4, which shows the peak rainfall intensities observed under real space time spans. The figure also includes three sets of time series of maximum rain intensities for recurrence intervals (RI) of 20, 10, and 5 years to provide a comprehensive view of intensity-duration configurations across the study location. The data presented in Figure 4 can be used to understand the rainfall patterns in the study location and design appropriate measures to manage the risks associated with extreme rainfall events.

The comparison of the temporal existence of the three most peaked values of maximum rainfall intensities across all durations (1-24 hrs) for all six stations provides clues on intensity-duration relations for each station and specific RIs. For example, at Dakor, the existence of the three highest peak rain intensities for an RI of 20 years were found to be located for 3, 7, and 13 hours durations. Similarly, at Kathlal, Gudel, Sojitra, Pilol, and Waghodiya, the three highest peak rain intensities for an RI of 20 years were found to be located in different durations.

However, the comparison of the above features for other sets of RIs (10 years and 5 years) for all the stations shows that the three highest peak intensities do not follow the same trend as found for an RI of 20 years. The occurrences of these values are located in different

durations, as shown in Figure 4.. These further highlights the fact that different recurrence intervals can lead to varying magnitudes and durations of extreme rainfall events (Kundzewicz et al., 2014; IPCC, 2014; Sharma et al., 2017), which can have significant impacts on the hydrological cycle, flooding, and water resources management in any given region. The analysis of rainfall data provides insights into the intensity-duration relations for each station and specific RIs, which can be useful in understanding the rainfall patterns and designing appropriate measures to manage the risks associated with extreme rainfall events. The data presented in Figure 4 can also be used to develop rainfall models that can aid in predicting the frequency and intensity of rainfall events in the study location.



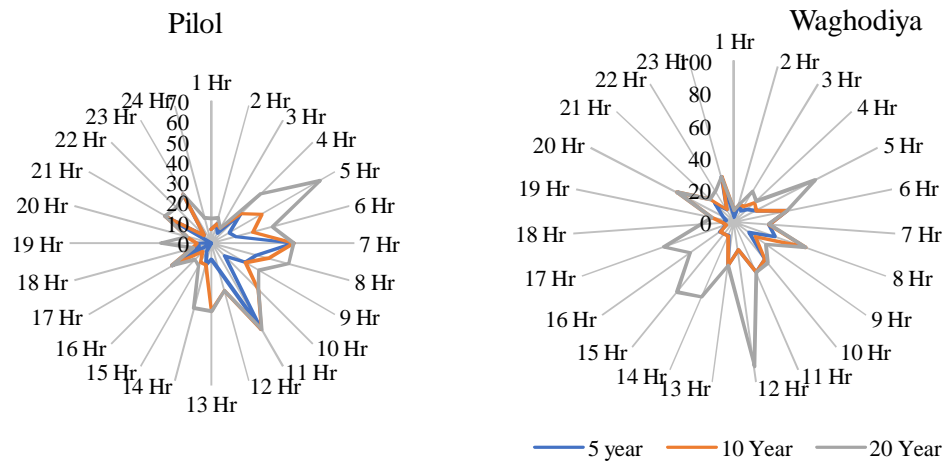


Figure 4. Inter relationship across observed sets of peak rain intensity (mm/hr) v/s duration (hr) of rains for 5, 10 and 20 years RI at 6 study locations

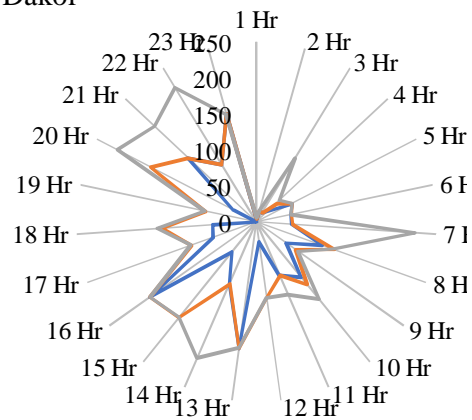
3.3 Depth Duration Relationships

The rainfall data was analysed to identify the maximum depth of rainfall that occurred during distinct time intervals ranging from one hour to 24 hours. The results of this analysis were illustrated graphically in Figure 5, which showed the maximum depth of rainfall in any particular hour across all 24 hours. Some preliminary conclusions can be drawn from these figures. For example, at Dakor, it was found that the three highest depths of storm rains for a recurrence interval (RI) of 20 years were located during rain storms of 7, 14, and 20 hours durations. Similarly, for Kathlal, Gudel, Sojitra, Pilol, and Waghodiya, the three highest depths of rainfall (20 year RI) were located during rain storms of 15, 11, and 19 hours; 23, 22, and 12 hours; 16, 19, and 24 hours; 23, 13, and 19 hours; and 12, 17, and 20 hours durations, respectively.

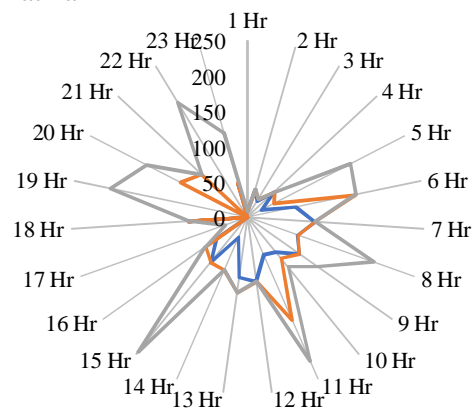
However, when comparing the above features for other sets of recurrence intervals (10 years and 5 years) for all the above stations, the three highest depths of rainstorms did not

follow the same trend as found for the 20 years RI and described above. The occurrences of these values were fallen under different durations, as shown in Figure 5. These findings suggest that the duration of rainfall events can play an important role in determining the maximum depth of rainfall, and that this relationship can vary depending on the recurrence interval being considered (Smith et al., 2014 ; Schmitt et al., 2016 ; Woldemeskel et al., 2020). Therefore, it is important to analyze rainfall data for different recurrence intervals and durations to gain a better understanding of the characteristics of extreme rainfall events in a given region. This information can be used to develop appropriate strategies for managing the risks associated with extreme rainfall events.

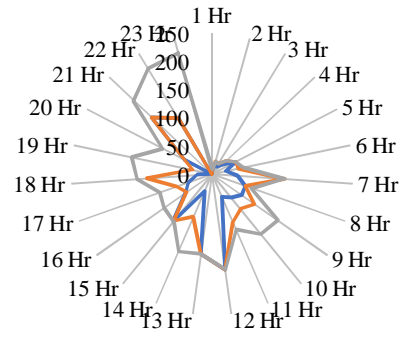
Dakor



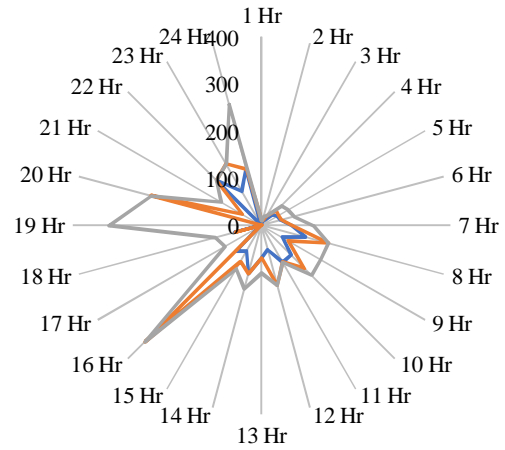
Kathlal



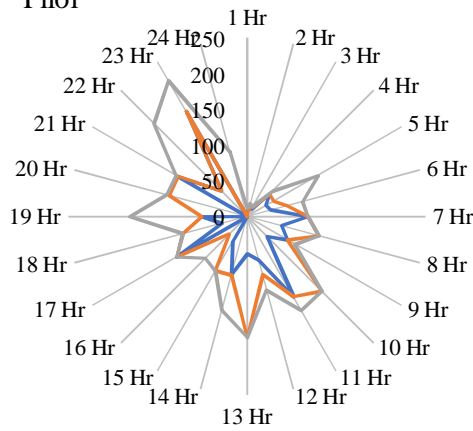
Gudel



Sojitra



Pilol



Waghodiya

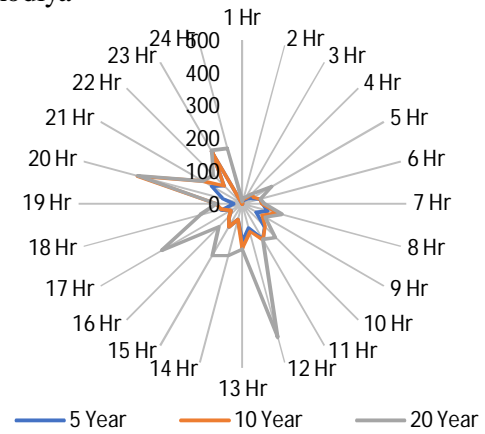


Figure 5. Inter relationship across observed sets of depth (mm) v/s duration (hr) of rains for 5, 10 & 20 years RI at 6 study locations

4. CONCLUSION

Rainfall data from GPM was collected using standard protocols and analysed for 6 locations in 3 districts of middle Gujarat. The data included discrete and continuous rainfall values, patterns, and uncertainties for various storm durations. This study was focussed towards analysing the diurnal variability of rains with region-specific connective ness across intensity, depth and duration of Rainfall for central region of Gujarat; having semi-arid

climate. The relationships between depths, durations, and intensities of rainfall for different recurrence intervals were determined using mass curves. Maximum rainfall intensities were derived for each rainstorm, and the relationships among depth and duration, intensity and duration, and other combinations for 3 specific recurring interval periods were analysed for all 6 stations.

This study investigated instances where most of the daily rainfall occurred within a 6-hour period (a quarter of the day). The number of such storms detected across the six stations varied. The information on quarter-wise distribution of these events can be useful for planners, engineers, irrigation schedulers, water resource managers, and policy planners. From the diurnal study of rainfall storms, it was revealed that highest number of storms occurred in Q₂ (06:00 to 12:00 hours) and least occurrence of such events was detected in Q₁ (24:00 to 06:00 hours) in semi-arid regions like study area. The diurnal pattern of rainfall was found to be influenced by factors such as local topography, surface heating and atmospheric stability, and local convective processes, resulting in higher numbers of rainfall events occurring in the late afternoon and early evening.

It is important to note that extreme rainfall events can have varying magnitudes and durations depending on the recurrence interval, which can greatly impact the hydrological cycle, flooding, and water resource management in a given region. Analysing rainfall data can provide valuable information on intensity-duration relationships for each station and specific recurrence intervals, which can aid in understanding rainfall patterns and developing appropriate strategies to mitigate the risks associated with extreme rainfall events. The results revealed that the three highest depths of rainfall for a 20-year recurrence interval were located during rainstorms of certain durations for each station. The duration of rainfall events is a significant factor in determining the maximum depth of rainfall and this relationship varies with different recurrence intervals. It is important to analyze rainfall data for different

recurrence intervals and durations to better understand the characteristics of extreme rainfall events and develop appropriate strategies for managing the associated risks.

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