International Journal of Bio-resource and Stress Management https://pphouse.org/ijbsm.php

Crossref

IJBSM February 2023, 14(2):229-236 Print ISSN 0976-3988 Online ISSN 0976-4038 **Article** AR3282a

Research Article *Natural Resource Management*

DOI: HTTPS://DOI.ORG/10.23910/1.2023.3282a

Investigation on Variability, Broader Types and Patterns of Daily and Sub-daily Rains Using Satellite Sub-Daily Rainfall Records based in Western Indian Province

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ABSTRACT

The present study was conducted during 2021 at middle Gujarat. The objectives of the study remained inclined towards the challenging task, where limited observed rainfall records (daily and sub-daily both) were utilized to project corresponding regional design hyetographs for providing the design hyetographs at similar ungauged sites in the region. This script explores suitability, appropriateness and end efficacies of blended (ground based as well as remotely sensed) precipitation data attained for a data deprived region, which was ultimately utilized to derive location specific rainfall curves adopting satellite based observed rainfall records. A set of representative type curves on rainfall (daily & sub-daily) for study region were conceived, which could be potentially utilized for better rainfall-runoff modelling even under purely ungauged scenarios. Voluminous precipitation data retrieved via GPM (IMREG) satellite precipitation products was endeavoured and used to create values envelope of design curves for use in ungauged situations. 21 years of daily & sub-daily rainfall records (2000–2020) were thoroughly examined and used to retrieve valid understanding towards annual, monthly, daily and even hourly based variability of rainfall across six different stations as adopted in the study. The net magnitude of dispersals in all the derived sets of mass curves/Hyetographs were worked out and suitably compared across 6 specific locations as well as their categorization in terms of storm depths, storm durations and peak rain intensities which could be of high practical importance for water resource planners other relevant research and development.

KEYWORDS: GPM, hyetographs, mass curves, rainfall, runoff modelling

***Citation* (VANCOUVER):** Ram et al., Investigation on Variability, Broader Types and Patterns of Daily and Sub-daily Rains Using Satellite Sub-Daily Rainfall Records based in Western Indian Province. *International Journal of Bio-resource and Stress Management,* 2023; 14(2), 229-236. HTTPS://DOI.ORG/10.23910/1.2023.3282a.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 05th October 2022 RECEIVED in revised form on 09th January 2023 ACCEPTED in final form on 28th January 2023 PUBLISHED on 16th February 2023

1. INTRODUCTION

Rainfall is one of the prime hydro-meteorological term having massive prominence towards its location specific understanding in terms of variability in coverage, magnitude and frequency. Its variability is caused by many factors that, for instance, atmospheric processes, effects of orography, global and local climate change influences, large water bodies and land use change etc. The ultimate effect of all such factors on rainfall variability, differs from region toregion making prediction of rainfall variability a difficult task. The variation in daily, monthly and annual rainfall as caused by factors such as terrain elevation, slope and aspect are relatively well explored by past researchers (Basist et al., 1994; Buytaert et al., 2006) offering some generic understanding. However, variability of sub-daily rainfall, as caused by above factors is still not well explored (Allamano et al., 2009). Studies by past researchers (Segond et al., 2007, Younger et al., 2009) revealed that rainfall variability can largely affect hydrological model outputs and it sizeably affects estimation of parameters for majority of rainfall-runoff models.

Present study remains more inclined towards this challenging task, where limited observed rainfall records (daily & sub-daily both) were suitably utilized making vast clusters of single station hyetographs (6 locations) representing sizeable homogeneous region/s to project corresponding regional design hyetographs for making it useful for providing the design hyetographs at similar ungauged sites in the region. Any kind of improvement in above described hydrologic 'input', certainly going to offer multiple advantages like, enhanced predictive performances from plethora of hydrological models, better efficiencies of rain water harvesting and recycling plans, higher overall water productivity levels via region specific accurate irrigation planning/land use planning, effectual management planning of land degradation and soil erosion, smarter and accurate crop planning/scheduling, precise drainage management at watershed scale, conjunctive water utility planning for surface-sub surface-under-ground water fluxes, better point sourced and non-point sourced polluting and nutritional management planning, and dozens of alike vital rewards under natural resource management. As part of an effort to overcome rainfall data unavailability, various models/modelling approaches are projected in literature to synthetically generate rainfall data along with its dispersals. Examples include models that are based on dimensionless event hyetographs (Huff, 1967;Garcia-Gazman and Aranda-Olivier, 1993) and models that are based on the scaling properties of rainfall (Over and Gupta, 1994; Olsson, 1998).

The aim of this study is to quantify the relative importance of parameters for effective rainfall in study region at finer spatio-temporal steps for a data deprived area, hence the specified objectives are set as follows, Modelling spatio-temporal variability of daily rainfall to generate specific relationships among its intensity, depth and duration along with seasonal hyetographs using daily rainfall records by adopting historic approaches and Synthesizing and investigating broader types & patterns of sub-daily hyetographs using observed sub-daily rainfall records available in study area.

2. MATERIALS AND METHODS

2.1. Study area

Present study was designed and employed to understand and quantify the variabilities of prevailing rains in region of middle Gujarat by considering not only annual, monthly, weekly, daily scenarios but also to sail across sub-daily spectrums of rains. 21 years rainfall records starting from 2000 to 2021 from three vital districts (Anand, Kheda and Vadodara) of middle Gujarat were made part of this work. They represent Agro-Climatic Zone-III of the state, which experiences mean maximum temperature in the range of 28.4°C (January) to 41.8°C (May) and the mean minimum temperatures as 11.7°C (January) to 27°C (June) (Figure 1).

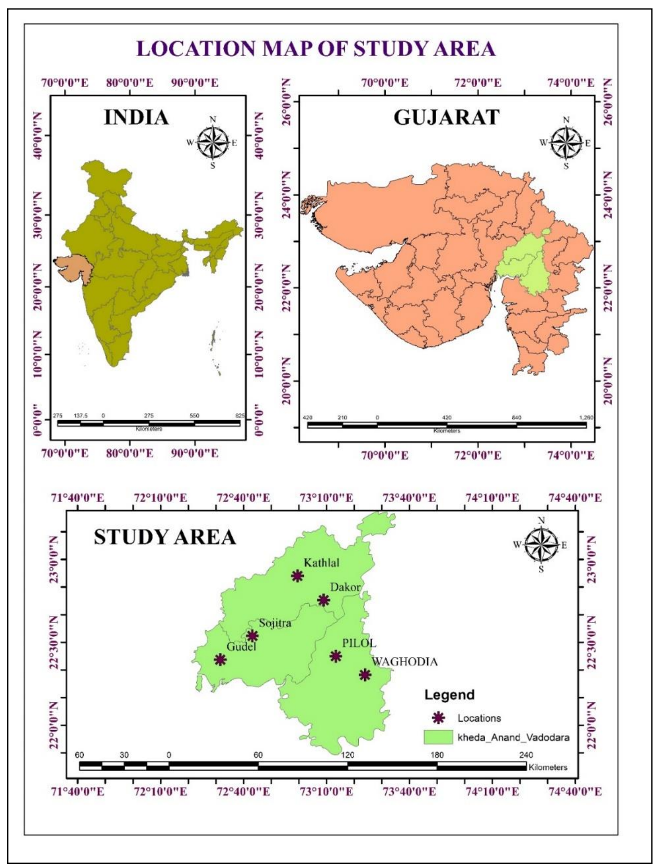

Figure 1: Location Map of the study area

2.2. Datasets

The key sets of data adopted in this study were regained via satellite observed precipitation products that are now a days are available on NASA's web portal for the entire globe. Utility of the Global Precipitation Measurement (GPM) (Huffman et al., 2019) the joint mission (JAXA and NASA) & other international space agencies, which greatly facilitated the obtaining of frequent observations of Earth's precipitation. Being part of NASA's Earth Systematic Missions program, it was found of great utility to work with a satellite constellation to provide full local coverage too. Precipitation records for all the study stations were obtained for the 21 years' time period starting from 2000–2020. These Rainfall records are at 30-minute temporal resolution and 11.1 km×11.1 km spatial resolution. A part of finally attained GPM precipitation products were randomly validated by matching few simultaneous observations at ground using data obtained from other sources as quoted above. The GPM precipitation estimates are often considered of great worth for hydrological modelling in semi-arid regions (Chen et al., 2019;Saouabe et al., 2020,). Beside rain some of the relevant hydrological, physiographic, geomorphological and land use related data on natural watersheds located in study districts was also retrieved from suitable reliable source points.

2.3. Detailed elucidations on rainfall features

Standards considered for various rainfall are delineated as under by encompassing few typical definitions on standard parameters of rain storms or daily rainfall whatever considered during phase of interpretation or inference drawing,

2.3.1. Rainy day

A day when total rainfall depth of the day is equal or greater than 2.5 mm.

2.3.2. Storm

Aa a total depth of rainfall of particular duration which is equal to or more than 1 mm. If time between two successive storms is equal or exceeded 1 hr and total cumulative depth of rainfall during entire storm duration is equal or exceed 1 mm, the event/storm was considered as an individual storm.

2.3.3. Storm duration

It happens to be the total elapsed time (in hours) on time line, from the beginning to the end of a storm.

2.3.4. Storm volume

Total volume, or depth of rainfall measured during a storm

2.3.5. Storm Intensity

The average rainfall rate during a storm, in mm per hour, calculated by dividing a storm's volume by its duration.

2.3.6. % Time

Amount of time, expressed as a % of total storm duration.

2.3.7. % precipitation

That amount of precipitation, expressed as a % of total storm precipitation.

2.4. Steps Adopted for generating data

After identifying watershed and location of study stations in 3 districts of middle Gujarat, coordinates of locations were explored using google earth engine. Then, available rainfall and runoff records were collected from Gujarat state water data centre, Gandhinagar. Enter details of the coordinates, temporal and spatial resolution on the NASA's web portal to get area averaged half hourly precipitation time series data for above selected study location (https://giovanni.gsfc.nasa.gov). Then, download Time Series half hourly precipitation data for above selected area (Area-averaged of multi-satellite precipitation with gauge calibration). Combine data and generate a single csv file for each station. Check the homogeneity of rainfall data collected for each station.

2.5. Classificastion of the rainfall records

2.5.1. Daily rain (Depth-based Sorting)

A day was considered rainfall depth of the day is equal or greater than 2.5 mm. Based on the depth range of the daily rainfall, hourly data series with all 24-hr rainfall data were classified in five categories for further analysis and inferences (Table 1).

Table 1: Portrayal on observed daily rainfall records (5 depth categories) for 6 opted across study locations (year 2000 to 2021: based on GPM data)

Sl. No.	Rainfall Category (mm)	Number of rainy days					
		Dakor	Kathlal	Gudel	Sojitra	Pilol	Waghodiya
1	2.5–10	263(38)	268 (39)	278(40)	250 (36)	288(38)	299(38)
2	10–25	191(28)	189 (27)	187(27)	191 (28)	217 29)	236 (30)
3	25–50	120(17)	129 (19)	132(19)	132 (19)	127(17)	131 (17)
4	50–100	84 (12)	7911)	79(11)	86(12)	90 (12)	90 (11)
5	>100	32(5)	25(4)	25(4)	30(4)	33(4)	36 (5)
Total	690	690	691	689	755	792	

2.5.2. Storm based classification of the rainfall events

Table 2: Overall Portrayal of isolated continuous rain storm events (4 categorized durations) adopted across study locations

S l. No.	Storm duration (hr)	No. 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

3. RESULTS AND DISCUSSION

3.1. General characterization of rainfall

In prevailing smart technological era of information technology, information communication technology and artificial intelligence, there has been a drastic shift (specifically in in developed nations) by giving importance and harnessing potential benefits from most recent precipitation datasets that are now being offered by Global Precipitation Measurement (GPM) satellite constellations combined in the Integrated Multi-satellite Retrievals (IMERG). A need is being raised to come over and above the traditional ways and means of rainfall analysis, where not only the methods but accurate and plentiful data too is given equal values. These locations remain parts of three major districts (Kheda, Anand and Vadodara) of middle Gujarat, where the stations remain located relatively closer (within 100 km) for such a fine resolution of space, a prolonged time series data of 21 years (2000–2021) was critically analysed to reflect the overall characteristic features of daily rains in this region. Some of the key features of this globally accepted advanced rainfall data are analysed, discussed and used for their explicit as well as implicit utilities in the region.

3.2. Spectrum of daily rainfall

21 years of daily and sub-daily rainfall records (2000–2020) were thoroughly examined and used to retrieve valid understanding towards annual, monthly, daily, and even hourly based variability of rainfall across six different stations as adopted in the study. Since it involves a huge volume of data and its computerization, only rainy season days (122, June–September) were considered while analysing and presenting inferences from them. It was considered with a background that most of the rains in this location are received in monsoon season and this season in fact remains the sole driver to use these rains for better water productivity nincome for farmers. Traditionally adopted approach of assessing daily based magnitude and trends of rainfall, was tackled by using voluminous precipitation data retrieved via GPM (IMREG) satellite precipitation products. Location specific trends of daily rains were analysed, understood, and interpreted herein. The study considered rainly days only active monsoon period i.e. rainy season (June–September) for the purpose. An abstract information with regards to average daily rain across four different months of rainy season (2000–2020) is illustrated in table 3 where a contrast in respect of few key parameters are accommodated for all the six study locations. A sample abstract on such monthly records on rains observed across 6 stations is provided in appendix I, to reflect the basic benchmark architecture of supplementary data and information utilized for various purpose.

The results (Table 3) well demonstrated that the average daily rains were highest (21 mm) for August month at Sojitra, while the overall range of this monthly based average value remained 3–21 mm Results also reflected the standard deviation alues all across six station and four months, revealing that its value remained highest (69) at Sojitra.

Table 3: Key characteristics of daily rainfall during different months of rainy season in study region

Station	Parameter	June	July	August	September
Dakor	Average	3.7	12.8	19.4	7.7
	SD	15.1	28.3	65.1	27.3
	% Dry days	50	20	30	50
Kathlal	Average	3.0	12.3	18.3	5.9
	SD	12.1	27.1	60.8	17.7
	% Dry days	50	20	30	50
Gudel	Average	4.4	12.7	17.5	7.2
	SD	17.0	29.4	58.3	22.6
	% Dry days	50	20	20	50
Sojitra	Average	3.9	13.5	21.0	5.4
	SD	14.3	29.4	69.5	16.9
	% Dry days	50	20	30	60
Pilol	Average	4.3	13.0	20.1	5.7
	SD	19.9	26.7	66.6	18.9
	% Dry days	50	20	30	50
Waghodiya	Average	4.5	12.8	18.6	5.7
	SD	17.4	23.8	61.5	16.9
	% Dry days	50	20	20	40

For any agricultural planning, occurrence of rain plays a decisive role to harness optimum benefits. Occurrence of dry spells or non-rainy days, specifically during active monsoon season too have their prominence in agricultural water management. Based upon plethora of daily rainfall records, there remained varied proportion of dry days during above cited four months. The exact incidence of non-rainy days was highly variable across region and months. Results revealed that in study area, about 40–60% of days remained non rainy (specifically in June and September) based upon a long time series data of 21 years. Further details are self-explanatory.

3.3. Inferences on dispersals in daily rains via whisker and box plots

Looking in to highly voluminous rainfall archives (15000 days rainfall records for 21 years) tackled in present study, it was highly cumbersome and difficult to visualize and judge whole matrix of variations from real applied angles (other than stochastic or probabilistic shapes). The wholesome distribution of these observed records was judged by adopting box and whisker plots for appropriate categories of rainfall magnitudes. Figure 2 and 3 illustrates overall pattern of spatial and temporal distributions for five depth-group categories.

An overview of boxes figure 2 and 3 across six locations, it is evident that in common of cases for depth range of 2.5–10 mm, the majority of rainy days were having high level of agreement with each other, showing level of disagreement to the tune of just 3–4 %. Similarly, they showed considerable normal distribution of daily rains across whole 21 years of record. Such variations were found to be highest for rainy days in categorised rain-depths of 100mm or above. The quantified dispersals in this regard still remained highly variable across the six study locations. The observed records plotted in figure 2 established the fact that the tallest boxes remained under the rainy days of rain-depth category having values as 100 mm or more reflected that these rainy days quite different opinion about their relevant aspects i.e depth, intensity and duration-based variability. The inter quartile range (IQR) for such taller boxes was found to vary from 60.5 (Waghodiya) to 82.1 (Gudel).

Comparing five different boxes for a particular station revealed that storms in the categories of 2.5–10 mm, 10–25 mm and 25–50 mm remained quite close showing a least level of difference across these three groups. Contrarily, for other two groups of rainy days (50–100 mm and >100 mm) there exist substantial variance to imitate high discrepancies. Also, there was observed a sizable dissimilar value of mean and median in different magnitudes. These variations across mean and medians were ranging from -0.3–27.8%, being highest in case of Waghodiya and Pilol. Moreover,

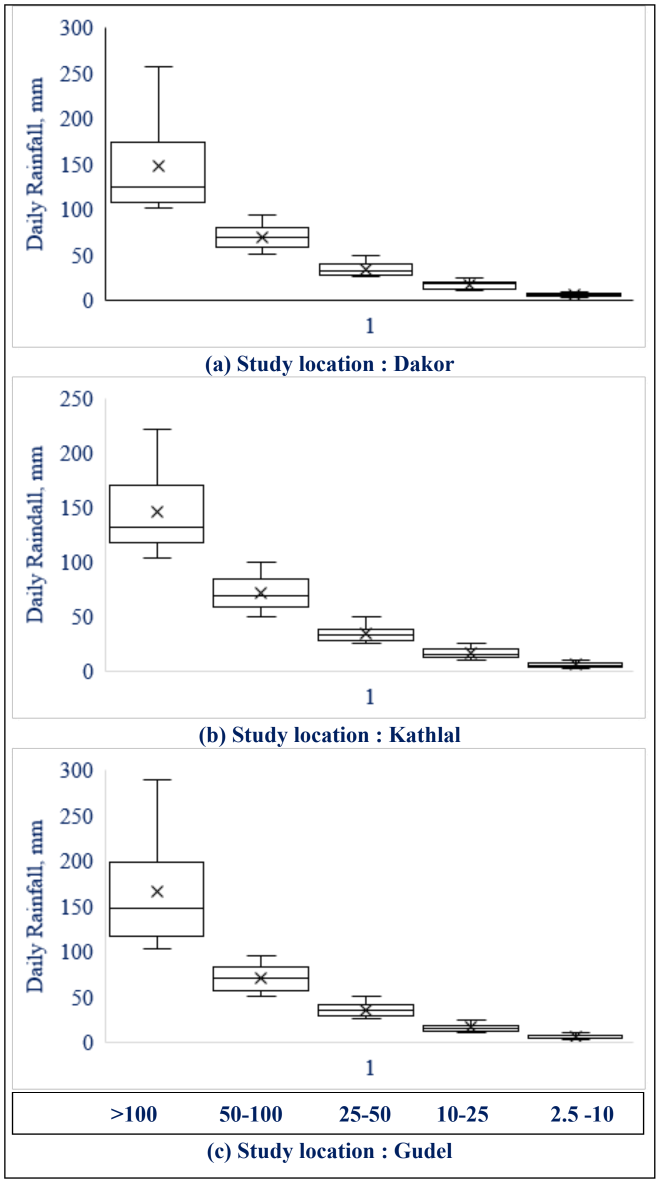

Figure 2: Spectrum of daily rainfall (mm) under categorized depth across various study locations (Dakor, Kathlal and Gudel)

the overall range of mean values ranged between 5.6 (Waghodiya- 2.5–10 mm depth) to 165.4 (Gudel- More than 100 mm depth).

The ranges of median, across all four depth categories were found to be 6.4–124.5, 5–132, 4.9–147, 5.2–125, 5.3–128.9 and 5.3–126.1 for Dakor, Kathlal, Gudel, Sojitra, Pilol and Waghodiya respectively. Similarly, from first quartile (Q1) it is clear that above ranges for similar stations remained 4.4–107.3, 3.8–117.7, 3.6–116.9, 3.7–106.8, 3.8–109.4 and 3.7–113.4 in similar fashion. These dispersals across mean and medians reflects sizeable inconsistencies in spreading patterns of rainy days across 6 different closely located

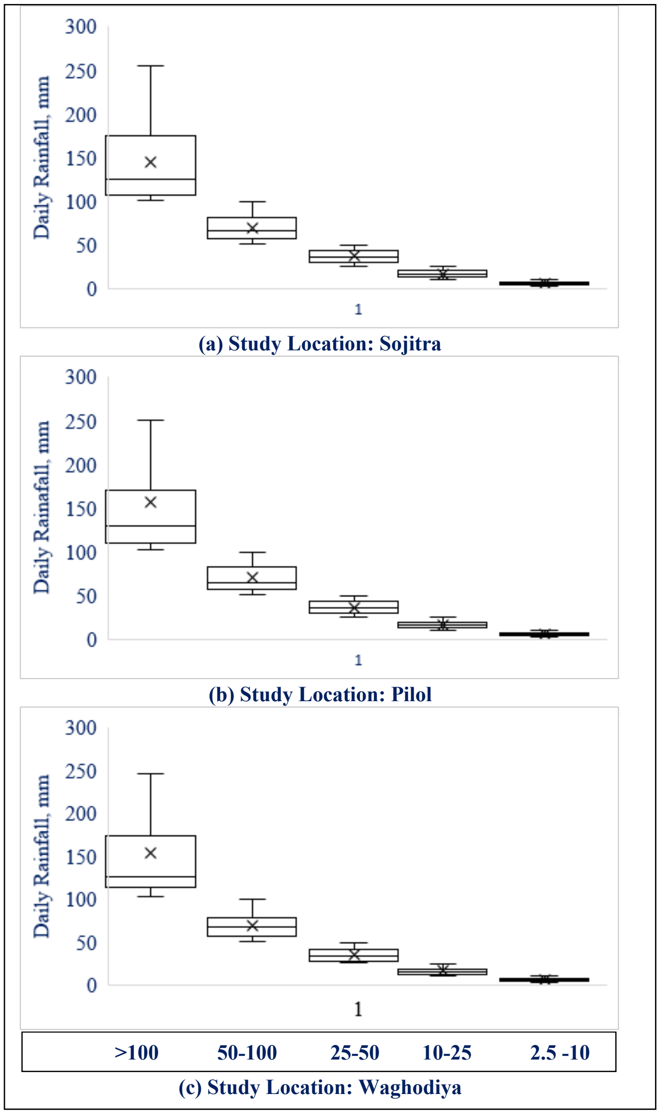

Figure 3: Spectrum of daily rainfall (mm) under categorized depth across various study locations (Sojitra, Pilol and Waghodiya)

locations in similar region. It inevitably invited greater attention while chalking out crop plans, irrigation plans, drainage plans, rainwater harvesting and recycling plans, soil and later conservation plans, command and watershed development plans and many forecasting aspects with regards to floods and droughts.

Comparision of whiskers cross the plots, revealed that the largest upper whiskers are detected for more than 100 mm depth categories, which indicates the fact that magnitude of daily rains in this category varied amongst the most positive quartile group and differed much similar for the least positive quartile group. Data in this range has further scope for its explanation to sub categorised interpretations for judging depth and duration-based heterogeneity across this specific rainfall depth groups. The tallest whisker observed was found for rain depth category > 100 mm at Gudel being 289, which could be of prime standing from practical aspects like flood control views at such locations.

While comparing values of 3rd quartile two specific inferences emerged were, (1) among highest values the range of this quartile was from 170 (Kathlal- >100 mm category) to 199 (Gudel- >100 mm category) showing that 75% of rainy days were found to have daily rainfall below 170 and 199 mm respectively and (2) among lowest values the range of 3rd quartile , remained between 6.7 (Gudel- 2.5–10 mm category) to 7.7 (Dakor-2.5–10 mm category) showing that for these categories more than 75 % of rainy days were having 6.7 and 7.7 mm daily rains respectively.

To compare quantitative variations across whiskers (sort and long), quartiles lower, medium and higher, mean, median, inter quartile range and relevant level of mathematical dispersals were derived in depth and details. Results are self-expressive to locate the magnitude as well as trends of dispersals across various indicators as well as various locations for numerical values conceived for whole set of daily rain data which are concisely described in preceeding paragraphs (Figure 4).

3.4. Assessed dispersals in hourly rains via whisker and box plots

Sub-daily deviations in rainfall values remains one of the

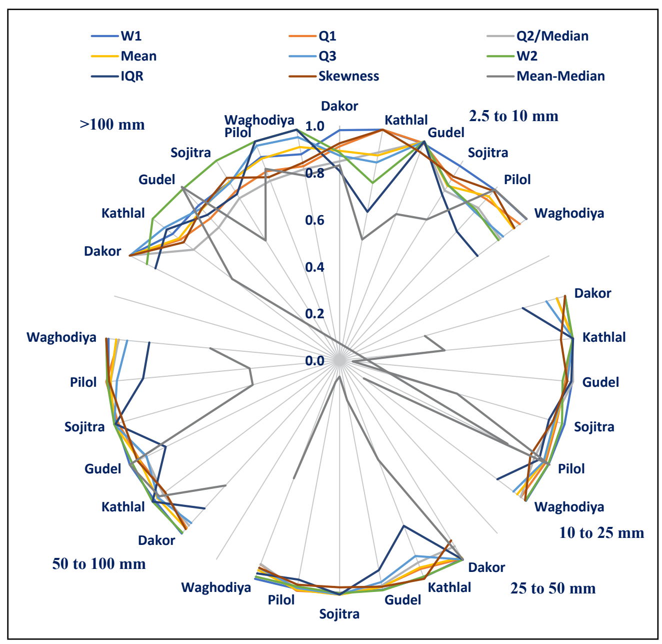

Figure 4: Overall dimensionless trends of variability of box and whiskers across 6 stations for 5 categories of daily rainy depths (>100 mm, 50–100 mm, 25–50 mm and 2.5–10 mm)

most sensitive issue for water resource planners, as the net dispersals in regional rainfall (depth, intensityand duration) always forms highly uncertain and non-uniform trends.

In preceding sections, it was described that such kind of dispersals in rainfall for all the six stations, moreover, their basis remained daily rains i.e. cumulative depth of rain experienced in 24 hrs. Vast volume of hourly rainfall data was critically processed and analysed for retrieving information on its actual depths that occurred during specific durations of 1, 3, 6 and 12 hrs. The salient inferences that are evolved from these plots for all the 6 stations under above categories remained as follows,

For storm depths under 1 h duration categories, majority of time series data remains unique with a high level of agreement with each other. It remained true for all the six locations adopted in the study, because of the fact that the Inter quartile range happens to be in the range of 0.7–1.0 across all data and locations. Contrarily the tallest box plots were found for the rain depth under 12 h durations, which reflected that values holds quite different opinion about their aspect or sub aspect in terms of intensity or depth duration variabilities. The IQR ranged from 22.9 (Dakor) to 75.3 (Kathlal) in such categories across varied stations . The magnitude of lower whiskers remained extremely low for all the rain depths that occurred for the durations of 1 and 3 h. Moreover, they remined negligible in case of rain depths under 6 or 12 h durations, and highest for rain fall depth series under 12 hrs duration, which varied from 12.6 (Pilol) to 22.7 (Kathlal). Comparison of first quartiles across all the data domain, revealed the fact that for stations viz. Sojitra, Pilol, Waghodiya and Kathlal values remains quite low for rainfall depths under the duration of 1–3 h, moreover, this magnitude remains quite different in case of Dakor and Gudel. The overall range of first quartile says that in extreme situation the value of first quartile remains highest (Waghodiya 12 hrs category) being 29, which depicts that less than 25% storm rains under this category of storm rain depth were had rainfall depths less than 29 mm. Appendix III depicts all the detailed numerical values in this regard for all whisker plots accommodating 6 locations and 4 specific storm durations.

Upon comparing second quartile values in figure 4.4, it is found that for 1 h duration, the average value of Q2 was around 1.4–1.5 for all the stations. It altogether reveals that about 50% values of rain storm depths were of the magnitude that remains less than 1.4 mm. It could be an important outcome to reflect small storms and their potential utilities towards in situ soil moisture enhancements. Upon comparing the similar range for 3 h duration it was found that same range very 4.1–4.4, however, in case of storm rains that occurred in 6 h durations, more than 50% rain depths remained under 14–17 mm, where the highest values remained in category of 12 h. It gives a sound clue for its utilizations in medium sized catchments to reflect dynamics of runoff thereupon. Category showing that more than 50% values remained varied from 40–58 mm across six different stations. Similar was the trend for quartile 3 where more than 75% values of the storm rainfall depth under 1 h duration remained in the range 2–2.3 mm across all six stations. For durations 3, 6 and 12 hrs these ranges of storm rain depth remained 5.9–6.8, 21–29 and 50–107 mm.

The central tendency of observed data and its distribution across different durations and locations is well reflected by mean values. As far as skewness is concerned all the data series under 1 and 3 hrs durations were found to be approximately of normal distribution with either no or negligible magnitude of skewness. Moreover, in case of storm depth series for the durations 6 and 12 hrs their remained ample magnitude of skewness in the data. In most of the cases such skewness remain positive except one case of pilol where rain storm depth series under 6 hrs duration were found negatively skewed (Figure 5).

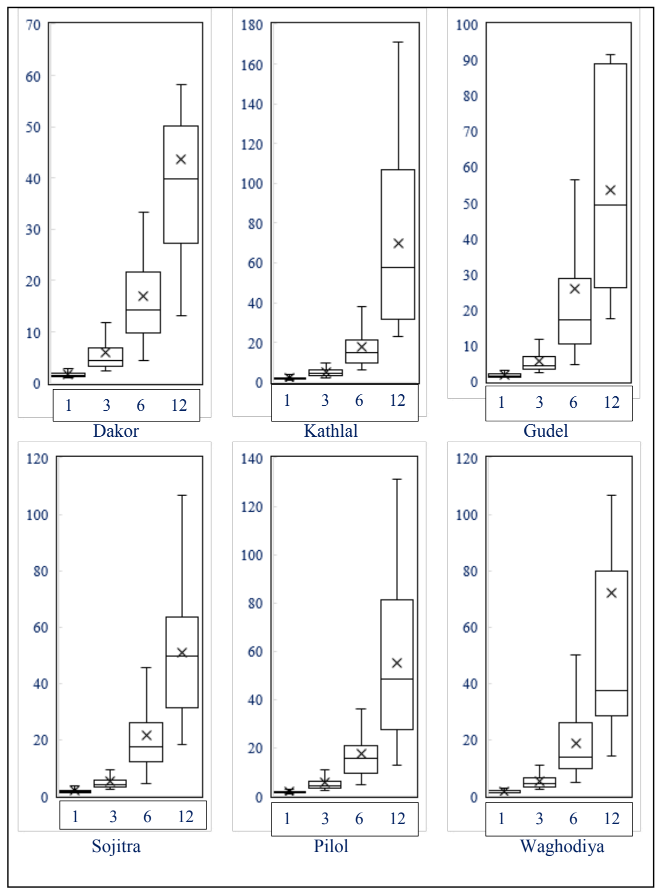

Figure 5: Box and wishker plot showing spectrum of rain storm depths for 1, 3, 6, 12 hrs duration

Further relativity and quantitative comparisons of various key elements of boxes and whiskers were too attempted in a consisted manner to reflect the generalized magnitudes as well as trends of variabilities of storm-based rainfall depths for different storm durations. A pictorial illustration by accommodating wholesome set of storm rainfall depth series for all the duration as well as study sites are reflected in figure 6 are self-expressive to locate the magnitude as well as trends of dispersals for various indicators (Figure 6).

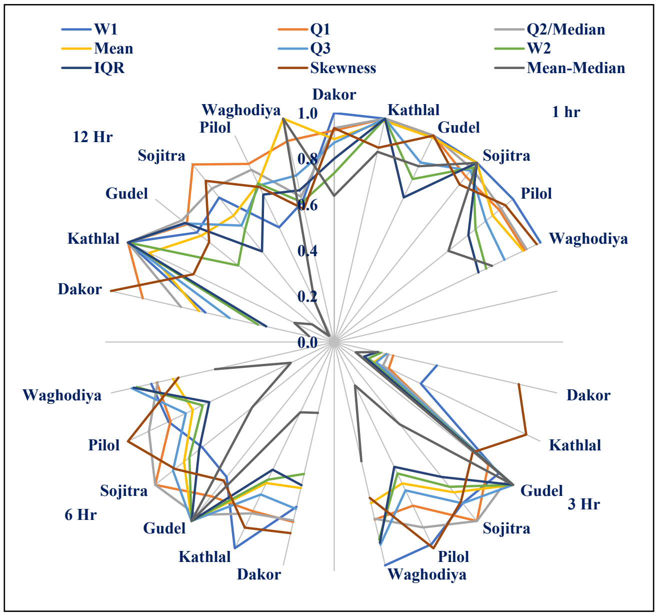

Figure 6: Overall dimensionless trends of variability of box and whiskers across 6 stations for 4 categories of rain depths (1, 3, 6, 12 hrs)

4. CONCLUSION

The overall characteristics and key stochastic indicators of wholesome sets of mass curves under varied categories of depths (2.5–10, 10–25, 25–50, 50–100 and 100 mm) and durations (1, 3, 6, 12, and 24 hrs) is very critically examined. Many sound inferences in regards to populations, trends, inter quartile distributions, practical inferences towards type of distributions and ranges of values and also the skewness and other vital properties of categorized sets of data that is adopted for developing standard type curves and predictive equations for location specific master hyetographs i.e. synthetic design hyetographs for varied spatio-temporal scales.

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