Original Research Article

GEOSPATIAL INTERPOLATIVE ANALYTICS OF GAUGED RAINFALL IN NETWORK UNDER SEMI-ARID SITUATION OF KRISHNA BASIN ON A WATERSHED SCALE

ABSTRACT

Kriging as a Geospatial interpolative delineation of optimal radial zones around existing rainfall stations with in the purview of flat land (1-3 %) watershed (Hti-2 4D7B3) situated in Krishna basin. The smaller (15 and 30 min) and medium (45 min to 1h 45 min) events of the were analyzed focusing on their distribution whereas events of longer duration (>2 h) analyzed with their depth across 14 gauging stations. Analysis of 14 gauged rainfall network stations and their corresponding rainfall data during 2014-2020 used to derive relationship between recurring events of classified duration (15 min to 2 h) vis-à-vis weighted influence of number and depth due to spatial morphology and limitations of watershed. The event vise rainfall network distribution of Huti-2 watershed found to be significantly uniform in number and depth within the radial zone upto 3 km around each station prevailed by strong coefficient of determinant (R^2) more than 0.8.

Key words:Gauged rainfall network, Geospatial variability, Krishna basin, Morphology,semi- arid, spatial rainfall.

Introduction

Rainfall seing phenomenon characterized by continuous variability both in space and time [1][2], rain gauges help provide representative and localized measurements of rainfall to alimited spatial extent. Over the vast areal space of the globe, rain gauge networks are too sparse (or completely missing) to capture the near to factual variability of the precipitation systems in space and time. The current knowledge regarding the impact of spatial variability of rainfall due to geomorphologic and climatological response is also limited[3]. There is strong need for evaluation of its significance in comparison to basin physiography and climatology. The study intends to assess the accountingof the spatial reliability of rainfall at watershed scale (about 40,000 ha)derived fromexisting network of stations characterized during the period of 2014 to 2020 in terms of depth and numbers. The observations which point about basin physiography which mitigates the impact of lower rainfall intensities, while higher rainfall intensities expected to supersede other factors are analysed for its effectiveness [4]. The spatial variability of median and higher depth of rainfall though complex is observed to have significant correlations with change in geographical location, latitude and topography [5].

Materials and Method:

The Huti-2 Watershed (4D7B3) being part of a Krishna Upper (KRU) sub-basin constitutes itself as a 3rd in order, among 36 number of watersheds. The watershed (430.36 sq. km) extends from North latitudes of 16°3‟20.93” to 16°15‟46.22” and East longitudes of 76°25‟32.60” to 76° 45‟48.49” covering its area in Lingsugur taluk of Raichur District in Karnataka. The main valley with a total length of 60.41 km, flows initially towards East (51.81 km), then turns northward and joins to the main valley of Krishna Upper Sub-Basin. During its course along the main valley, it losses 220.00 m (500.00 m to 280.00 m RL) of its elevation out of which it suddenly finds a steep fall of 176 m (487 m to 311 m RL) near to the outlet (Location: Golapalli Village limits near to the Tinthani Bridge).

Geomorphological and Rainfall Analysis:

The heirarchial the stream network system and its properties to were studiedusing appropriate procedures to quantify shapes and reliefwhere order ranges from 5th to 3rd(Fig 1and table 1). The temporal distribution of rainfall was measured in terms of 15 min interval in each year across the study period (2014-2020) gauging stations (14 No) that situated in the selected watershed (Fig.1). The depth in each rainfall events during the duration in multiple of 15 min,(30 min, 45 min 1 h, 1 h 15 min, 1 h 30 min, 1 h 45 min and 2 h) interval are analyzed to explore distinctions across the network in terms of number (mm) (table 2). The rainfall events of each year were divided into classes with those events with duration less than 2 hr and that of those with more than 2 hr duration. The former class was subjecting to analytics of the number of rainfall events where as later by subjecting the cumulative depth in their respective duration (table 4). The numbers accumulated in each interval of 15 min of duration and their multiples (<2 h) were subjected for interpolation adopting the kriging method. Similarly those depth accumulated over the period with 2h also subjected for interpolation.

Kriging-Based Geostatistical Approach

Event wise rainfall data from digital raingauge system during the observational years (2014-2020) sorted into periods from 15 min to larger duration event (maximum extent of 5 h) in the multiples of 15 min of spatial variability which varied from 150 No to 260 No across the stations recorded in years of observation (table 2). The rainfall data verified for its quality, completeness, and consistency and missing or erroneous data was identified removed at the same time. The spatial distribution of rainfall was explored using descriptive statistics and visualization techniques. This included generating interpolated maps of mean, standard deviation, and coefficient of variation of rainfall across the study area.Spatial analysis techniques such as variogram analysis, kriging, and geostatistics used to analyze the spatial structure of rainfall variability and identify spatial patterns and trends.The statistical models validated using goodness-of-fit tests (R^2) to assess the accuracy and reliability of the models[6].

Kriging is known as one of the best linear unbiased estimators in geographical statistics method. This method extracts values from surrounding known point to predict the unknown values at unsampled point. Ordinary kriging estimates unknown data linearly based on weight from observed data. It minimizes error occurred while estimating unknown value at desired point. This method prevents deviation in results by weight constraints, while the weight constraints rely on the semi-variogram. The variogram function describes the spatial correlation between rainfall variable as well as rainfall and elevation under a stochastic interpolation approach [7].

The rainfall events (small and medium range) of shorter and medium duration (15 min to 1 h 45 min) received across the 14 gauging stations were segregated and analyzed in terms of their numbers using both kriging method and descriptive statistics (table 3). Those events with 2h duration (7 No)) assessed for their spread and advancement in terms of depth across the stations at step interval of 15 min (table 4). The probable occurrence of rainfall events has been estimated at buffering distance ranging from 1.0 km to 8.0 km in incremental way around each rain gauging station against measured numbers in each year. The statistical inference has been carried out to evaluate the mean of the events. The rate and extent of cumulative spread of rainfall event and its intensity across all stations at each time interval (15 min) were evaluated for probable depth of occurrence at buffer radial distance ranging from 1 km to 8 km.

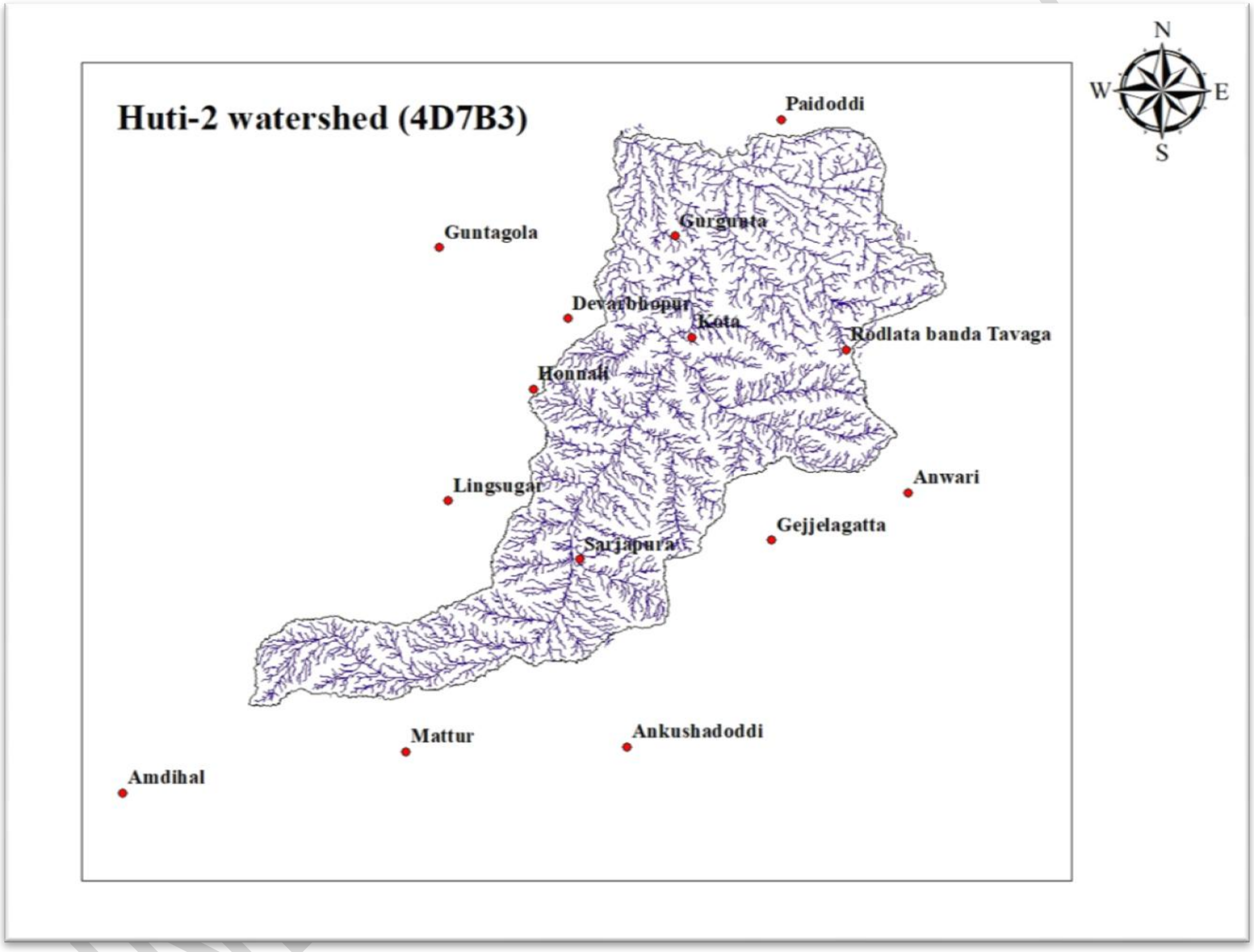


Fig 1. Study watershed (Huti-2) prevailed with semi-arid climatic condition watershedwith area of 40,000 ha in Raichur District of Karnataka

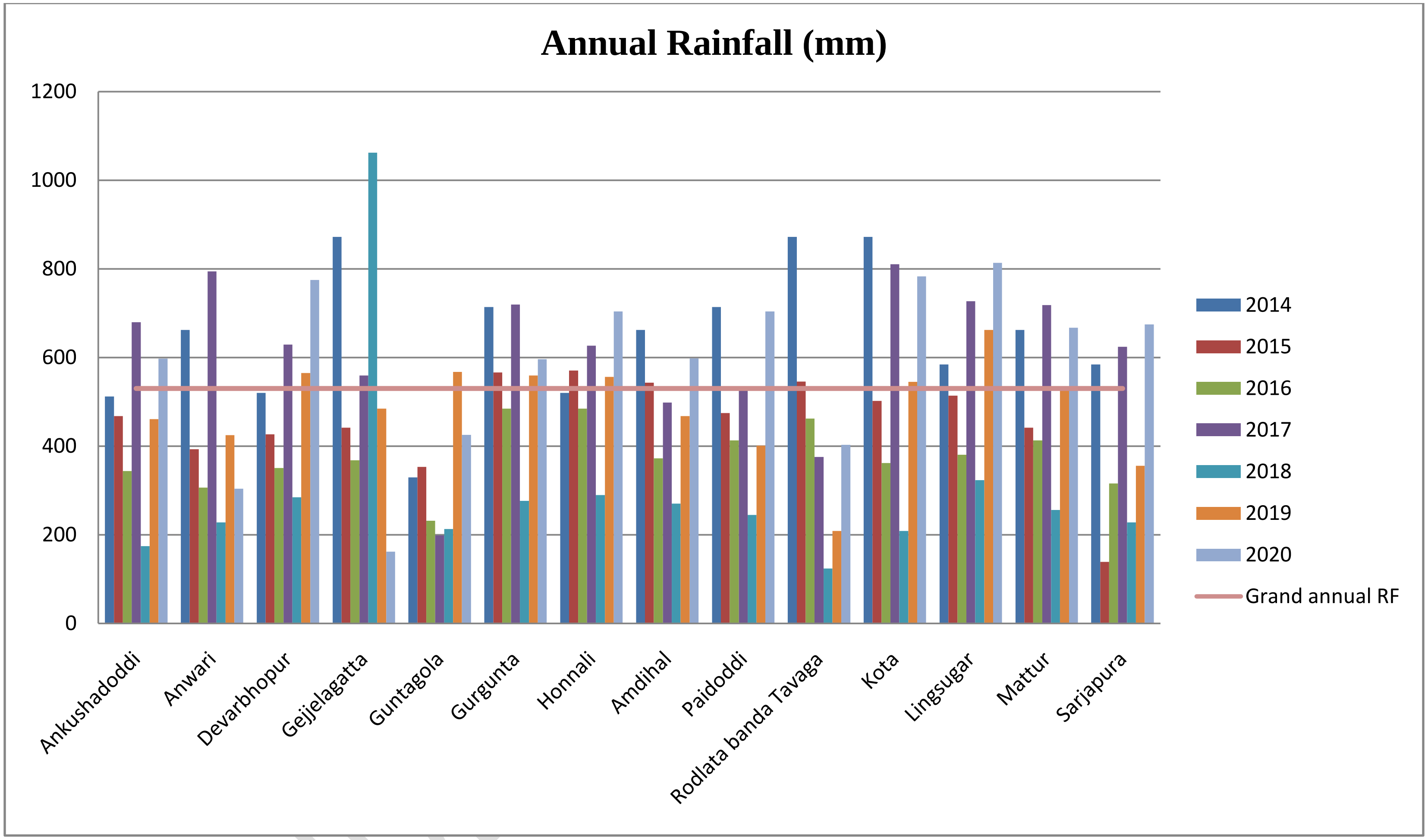


Fig 2. Annual Rainfall in mm for the study area from 2014-2020

Table 1. Stream network properties of Huti-2 watershed (4D7B3) in Raichur District of Karnataka

<table>
<tr><th>Stream network</th><th>Watershed scale</th><th>Time of concentration range (min)</th><th>Number of stream network (No.)</th><th>Range of Main valley length (km)</th><th>Area (ha)</th><th>Relief Ratio (per cent)</th><th>Elongation ratio</th><th>Circular ratio</th><th>Bifurcation ratio</th><th>Compactness coefficient (Cc)</th><th>Shape factor</th></tr>
<tr><td>6th</td><td rowspan="5">Synoptic scale</td><td>500.24 and 577.31</td><td>1</td><td>60.41</td><td>43036</td><td>0.36</td><td></td><td></td><td rowspan="5">3.42-6.37</td><td></td><td></td></tr>
<tr><td rowspan="4">5th</td><td>450-400</td><td>1</td><td>39.2</td><td>18988</td><td>0.26</td><td rowspan="4">0.40-0.52</td><td rowspan="4">0.26-0.44</td><td rowspan="4">1.50-1.97</td><td rowspan="4">4.79-8.09</td></tr>
<tr><td>250-200</td><td>1</td><td>16.93</td><td>5768</td><td>0.55</td></tr>
<tr><td>200-150</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>150-100</td><td>1</td><td>10.66</td><td>2370</td><td>1.49</td></tr>
<tr><td rowspan="3">4th</td><td rowspan="6">Meso scale</td><td>211-150</td><td>12</td><td>6.29-17.7</td><td>749-2946</td><td>0.37-1.14</td><td rowspan="3">0.34-0.80</td><td rowspan="3">0.16-0.49</td><td rowspan="6">0.25-0.75</td><td rowspan="3">1.43-2.46</td><td rowspan="3">2.01-11.34</td></tr>
<tr><td>150-100</td><td>9</td><td>4.15-6.33</td><td>327-1604</td><td>0.43-1.49</td></tr>
<tr><td>100-50</td><td>1</td><td>2.711</td><td>284</td><td>0.77</td></tr>
<tr><td rowspan="3">3rd</td><td>211-150</td><td>1</td><td>8.27</td><td>749</td><td>0.69</td><td rowspan="3">0.36-0.83</td><td rowspan="3">0.24-0.61</td><td rowspan="3">1.25-2.04</td><td rowspan="3">1.85-9.75</td></tr>
<tr><td>150-100</td><td>36</td><td>2.96-8.03</td><td>126-872</td><td>0.34-1.53</td></tr>
<tr><td>100-50</td><td>82</td><td>1.06-4.27</td><td>50-386</td><td>0.30-2.41</td></tr>
<tr><td>Total</td><td></td><td></td><td>145</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 2. Distribution of rainfall events (15 min to more than 5 hperiod) received across situated Rain gauge stations (14 No) during 2014-20 across rain gauging station.

Year	Small duration events		medium duration events					Large duration events				
	15 min RF event (No	30 min RF event (No)	45 min RF event (No)	1 h RF event (No)	1 h 15 min RF event (No)	1 h 30 min RF event (No)	1 h 45 min RF event (No)	> 2 h RF (2-3 h) events (No)	3-4 h RF events (No)	4-5 h RF events (No)	>5 h RF events (No)	Annual RF depth (mm)
2014	93-117	16-34	10-21	4-11	3-8	1-6	0-5	60	24	19	3	648.68
2015	41-87	10-24	1-13	1-10	0-5	0-4	0-5	35	10	6	0	455.79
2016	51-125	14-29	2-16	3-16	0-8	0-5	0-3	16	6	1	0	377.86
2017	41-125	14-39	3-22	2-12	1-9	0-5	0-4	57	18	5	1	606.75
2018	49-96	5-23	1-16	1-6	0-4	0-5	0-1	7	4	0	2	298.82
2019	66-153	13-35	4-18	3-12	0-4	0-5	0-4	31	9	1	0	484.75
2020	29-184	9-42	3-21	1-12	1-8	0-4	0-5	33	12	17	8	586.32
Average	72 -112	17-28	8-15	4-10	2-5	1-3	1-2					

Table 3. Goodness of fit (R^2) of predicted rainfall events (15 min to 1 h 45 min duration) with incremental radial distance (1km to 8Km) around each gauging station

Year	Small duration events		Large duration events				
	15 min	30 min	45 min	1 h	1 h 15 min	1 h 30 min	1 h 45 min
2014	0.79	0.11	0.92	0.30	0.01	0.75	0.90
2015	0.96	0.35	0.01	0.46	0.01	0.04	0.68
2016	0.16	0.26	0.84	0.64	0.19	0.08	0.93
2017	0.95	0.74	0.02	0.10	0.00	0.03	0.02
2018	0.63	0.94	0.02	0.25	0.06	0.17	0.04
2019	0.95	0.24	0.03	0.27	0.06	0.75	0.91
2020	0.60	0.95	0.92	0.99	0.00	0.52	0.63
No. of year where R^2 0.6-0.8	03	01	0	01	0	02	02
No. of year where R^2 >0.8	03	02	03	01	0	0	3

Table 4. Variability of Cumulative rainfall depth (mm)of rainfall events (7) of Longerduration(2 h)observed at Rainfall gauging stations (14 No) located in Huti-2 watershed

Year	Date and time	15 min RF (mm)	30 min RF (mm)	45 min RF (mm)	1 h RF (mm)	1 hr 15 min RF (mm)	1 hr 30 min RF (mm)	1 hr 45 min RF (mm)	2 hr RF (mm)
2014	25/10/2014 (15:30 pm-17:30 and ± 30 min time lag)	0-3	0-5	0-12	0-20	0-22.5	0-24	0-26	0-28
2015	08/09/2015 (20:15 pm-22:30 with ± 30 min time lag)	0.5-29	1-40	1.5-43	2-45	2-45.5	2-51.5	2-54.5	2-62
2016	09/09/2016 (18:45 pm-20:45 pm with ± 30 min time lag)	0-15.5	0-34	0-35	0-36	0-38	0-38.5	0-39	0-39.5
2017	06/09/2017 (6:00 am-8:00 am with ± 30 min time lag.)	0.5-28	1-29	1.5-30	2-32.5	2.5-36.5	3-38	3.5-38.5	4-39.5
2018	18/09/2018 (00:00 am-2:00 am with ± 30 min time lag.)	0.5-2	1-3.5	1.5-5.5	2-9	2.5-10	3-11	3.5-16	4-17.5
2019	19/09/2019 (00:00 am-2:00 am with ± 30 min time lag.)	0.5-22.5	1-29.5	1.5-34	2-34.5	3-35	4.5-36	5.5-45.5	6-55
2020	16/08/2020 (04:00 pm-06:00 pm with ± 30 min time lag.)	0.5-8.5	1-9.5	2-10	3-10.5	4.5-12.5	5-15	6-15.5	7-17.5
Mean		16	22	24	27	29	31	34	37

Table 5. Goodness of fit (R^2) of predicted rainfall depth(2 h duration)with buffering radius (1-3Km) corresponding to each gauging station

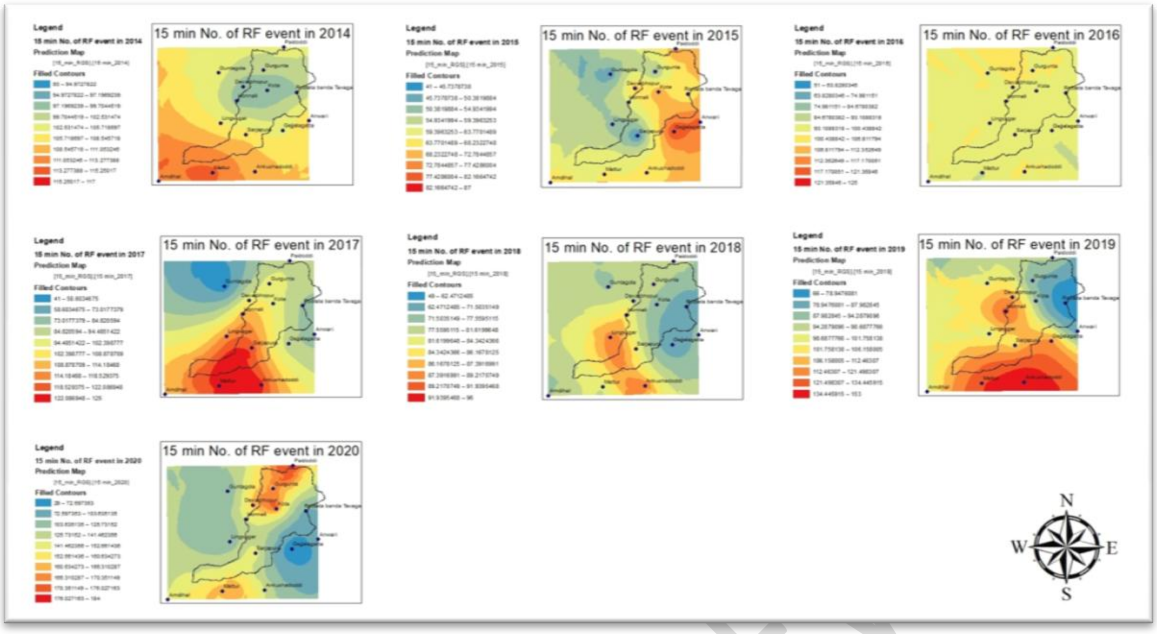
Year	15 min	Cumulative 30 min	Cumulative 45 min	Cumulative 1 hr	Cumulative 1 hr 15 min	Cumulative 1 hr 30 min	Cumulative 1 hr 45 min	Cumulative 2 hr
2014	0.86	0.91	0.95	0.98	0.96	0.97	0.94	0.87
2015	0.83	0.84	0.88	0.93	0.97	0.86	0.92	0.96
2016	0.86	0.86	0.87	0.83	0.81	0.97	0.94	0.94
2017	0	0.01	0.06	0.03	0.09	0.13	0.16	0.16
2018	0.95	0.92	0.89	0.84	0.87	0.96	0.97	0.98
2019	0.04	0.05	0.17	0.25	0.27	0.25	0.03	0.19
2020	0.97	0.96	0.96	0.96	0.93	0.92	0.92	0.93

Results and discussion:

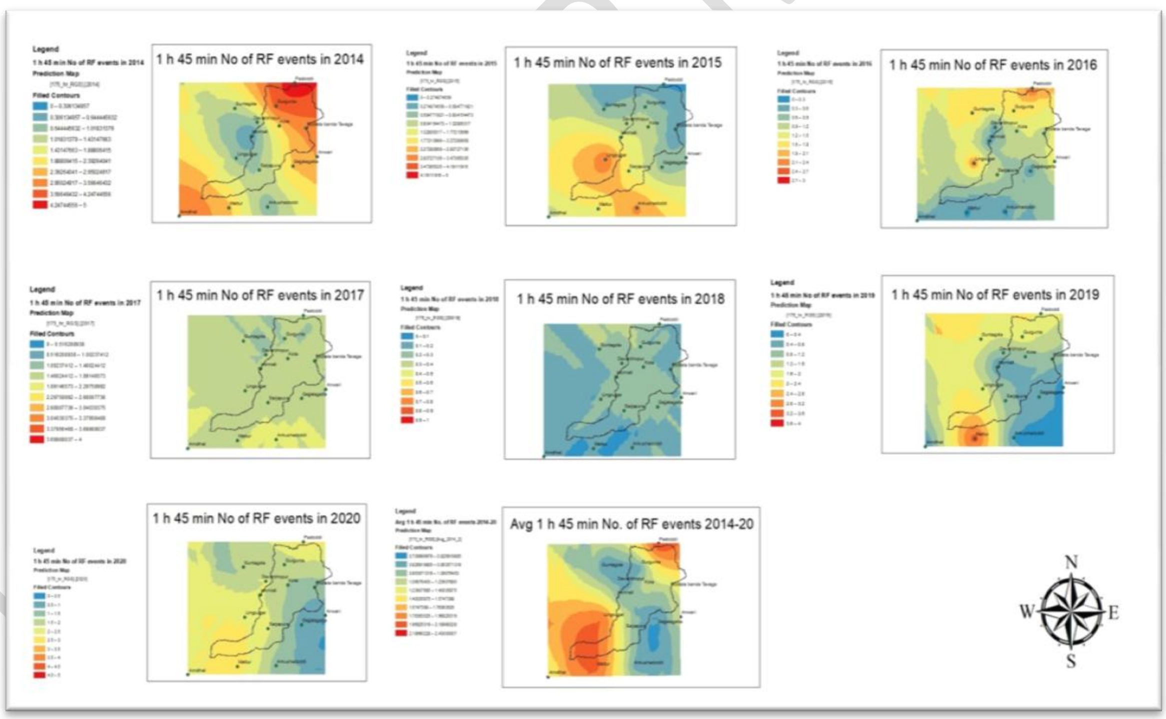
The variance due to distribution of rainfall in terms of depth, frequency and intensity are considered to be valid to anlimited radial extent [7]hypothesis has been analysed and tested by considering the study of diverse rainfall events received within theboundary of Huti-2, atypical flat landwatershed (43035.79 ha) in Krishna basin. In case of Huti-2 watershed which represents semi-arid situationsreceivablelarge number ofrainfall events are smaller duration (<15 min), medium duration (15 min to 1 h 45 min) with lesser size and a fewer larger durations (>2 h and above). The analysis of rainfall events for the period of 2014-2020 across 14 rainfall gauging stations fairly receive small duration events in the range of 9-184 numbers where as medium duration ones with 1-21 numbers and a few longer duration onesof 0-60 numbers indicating the complexity of occurrence both in terms of space and time within theextent of watershed scale(43035.79 ha)[8].

Suchvariability has provided scope for need of assessing of spatial variance and as a pre curser for relative positioning of rain gauging stations with in the watershed area.The short and medium range rainfall events are relatively higher in number but lower depth of incidence and hence, their analysis carried out separately, whereasa few events (07 No) with longer duration(2 h) studied from the perspective of intensity of spread of individual event across all gauging stations with the passage of time and at step interval of 15 min till it subsides in 2 h.

The interpolation of numbers in case of short and medium events, and respective depths in case of duration more than 2 h through ordinory kriging (circular model) which interpretated probable distinction at a radial distance of 1 to 8 km with incremental step of 1 km from each station. The depth of accumulation in the buffering zone with varied radial distance (1 km-8km) has influenced by intensity and duration of event. The measured rainfall events for an interval of 15 min varied between 72 -112 number (fig 3 (a)) across all gauging stations (14 No) which reduced to 17-28 No (in case of 30 min event followed by 8-15 (45 min event), 4-10 (1 h event), 2-5 (1 h 15 min event), 1-3 (1 h 30 min event) and 1-2 (1 h 45 min event) (fig 3 (b) and table (2)) indicating decreasingnumber of with incremental increase in order of duration[9],this scenario represents variability of rainfall across prevailing semi-arid condition with lower elevation (300-400 m MSL) and located at leaward side of western ghats of South India.

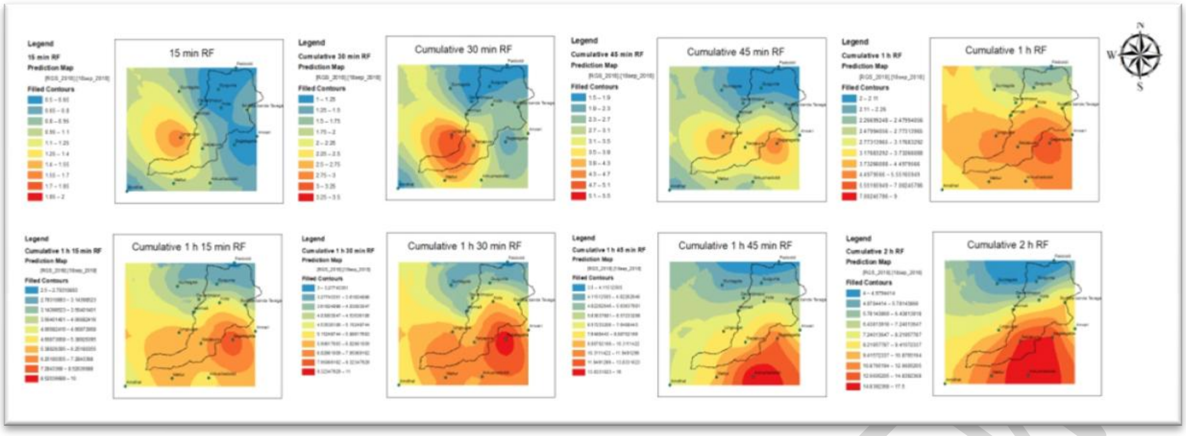


(a)

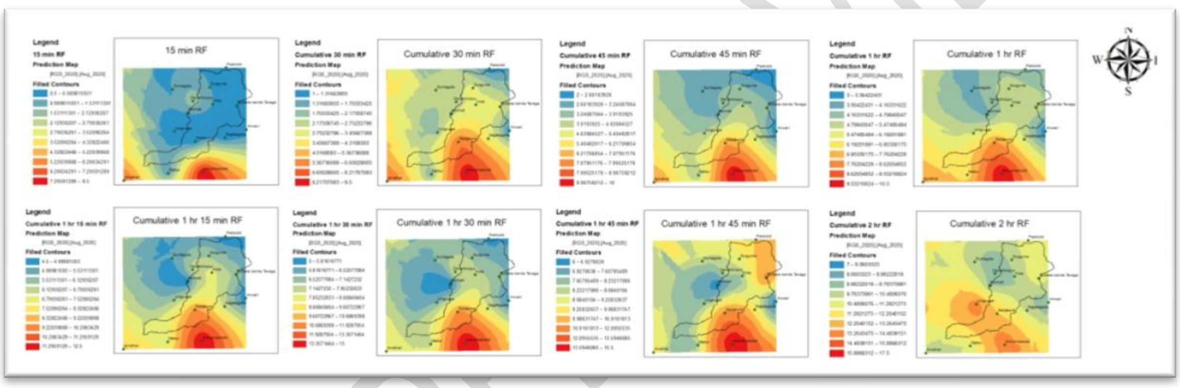


(b)

Fig 3. Distribution of interpolated rainfall events (No) across watershed due to prevailing rain gauging stations with duration (a) 15 min (b) 1 h 45 min



(a)



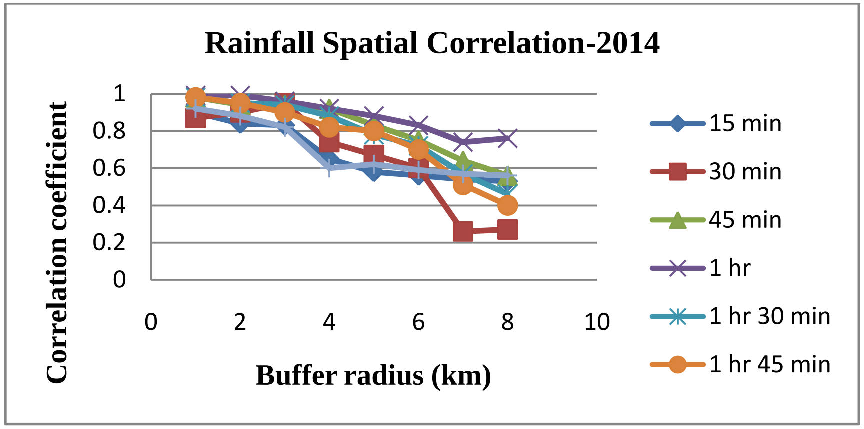
(b)

Fig4. Sequential interpolated distribution of rainfall depth at 15 min interval measured across existing gauging station (a) event date18th September 2018(depth 9.32 mm), (b) event date 16th August 2020(depth 10.82 mm)

The depth of rainfall appended cumulatively under jurisdiction of rainfall station at an interval of 15 min to 2 h duration. There were 7 events selected based on their wide coverage and substantial depth. The maximum depth of an event of 2 h duration was observedin 2015 (62 mm) whereas minimum in the year 2018 and 2020 (17.5 mm) as observed in table 4, and figure 4 (a) and (b) as the similar echo results found in Othman et al., 2016 [10].

The range of goodness of fit (R^2) as an estimator of spatial correlation in each year between rainfall event (No) vis-à-vis incremental radial with respect to from each of the station located within the purview of watershed was found to spread in the range of 0-0.99 randomly (Table 3). However,on an annual average value of (R^2), there were 3 years with 0.6-0.8 in case of 15 min, which reduced to 2 years in case of 1 h 30 min and 1 h 45 min, and further fallen down to 1 year in case of 1 h duration and except encase of 45 min and 1 h 15 min (0 years). The number of year where annual average R^2value more than 0.8 in case of 15 min, 45 min and 1 h 45 min were 3 years and which is reduced to 2 years in 30 min duration and 1 year in case of 1 h duration having exception in case of 1 h 15 min and 1 h 30 min.

When the rainfall event with larger duration (>2 h) events subjected to their cumulative depth (mm) for analysis of events of 15 min to 2 hreliableinfluencing zone with upto3 km radial distance, (R^2>0.8) in case of more than 5 years of data except in two years (2017 and 2019) where R^2 value reduced to 0-0.27(table 5 andfig 5). The rainfall distribution in terms of number has exhibited significance for smaller to medium duration events, whereas depth of rainfall receivable during large duration events (2-4 No. per year) would be suitable for their interms of distribution with advancemental of rainfall. The results show that radial influence to an extent 3 km from the gauging station located within the watershed would be reliable to highlighting the influence of topographic relief, land forms and location of watershed itself with respect of mean sea level and such influence rainfall pattern and indirectly as location and number of rain gauges in a optimal networks[11][12] [13].


Rainfall Spatial Correlation-2014
Correlation coefficient
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0.8
0.6
0.4
0.2
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4
6
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1 hr 30 min
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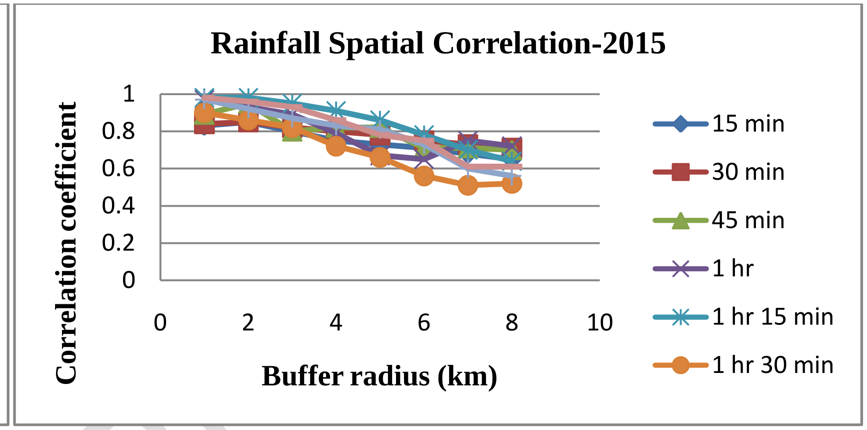
Rainfall Spatial Correlation-2015
Correlation coefficient
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0.6
0.4
0.2
0
0
2
4
6
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10
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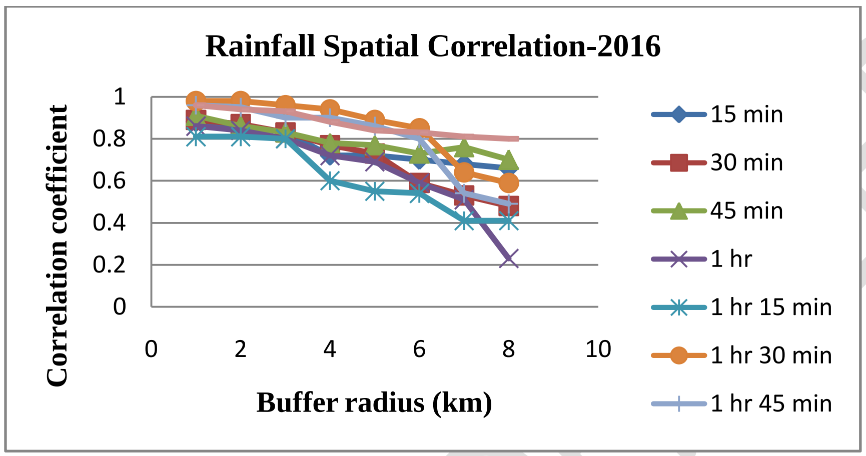
45 min
1 hr
1 hr 15 min
1 hr 30 min


Rainfall Spatial Correlation-2016
Correlation coefficient
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0.6
0.4
0.2
0
0
2
4
6
8
10
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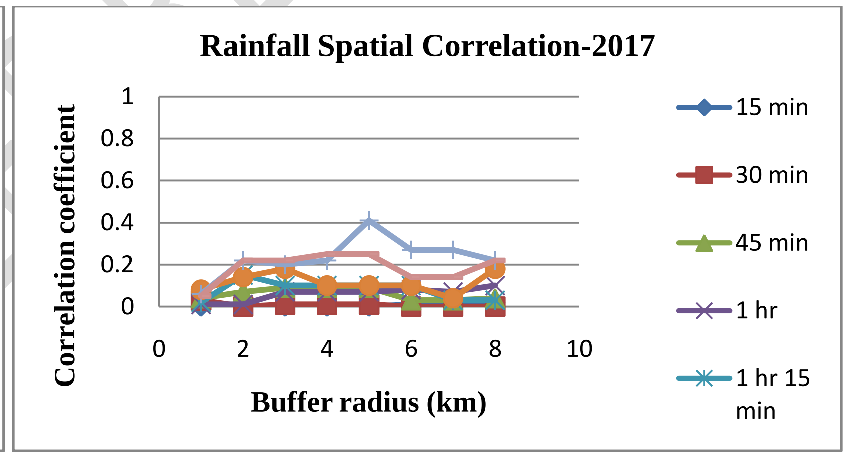
45 min
1 hr
1 hr 15 min
1 hr 30 min
1 hr 45 min


Rainfall Spatial Correlation-2017
Correlation coefficient
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0.8
0.6
0.4
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0
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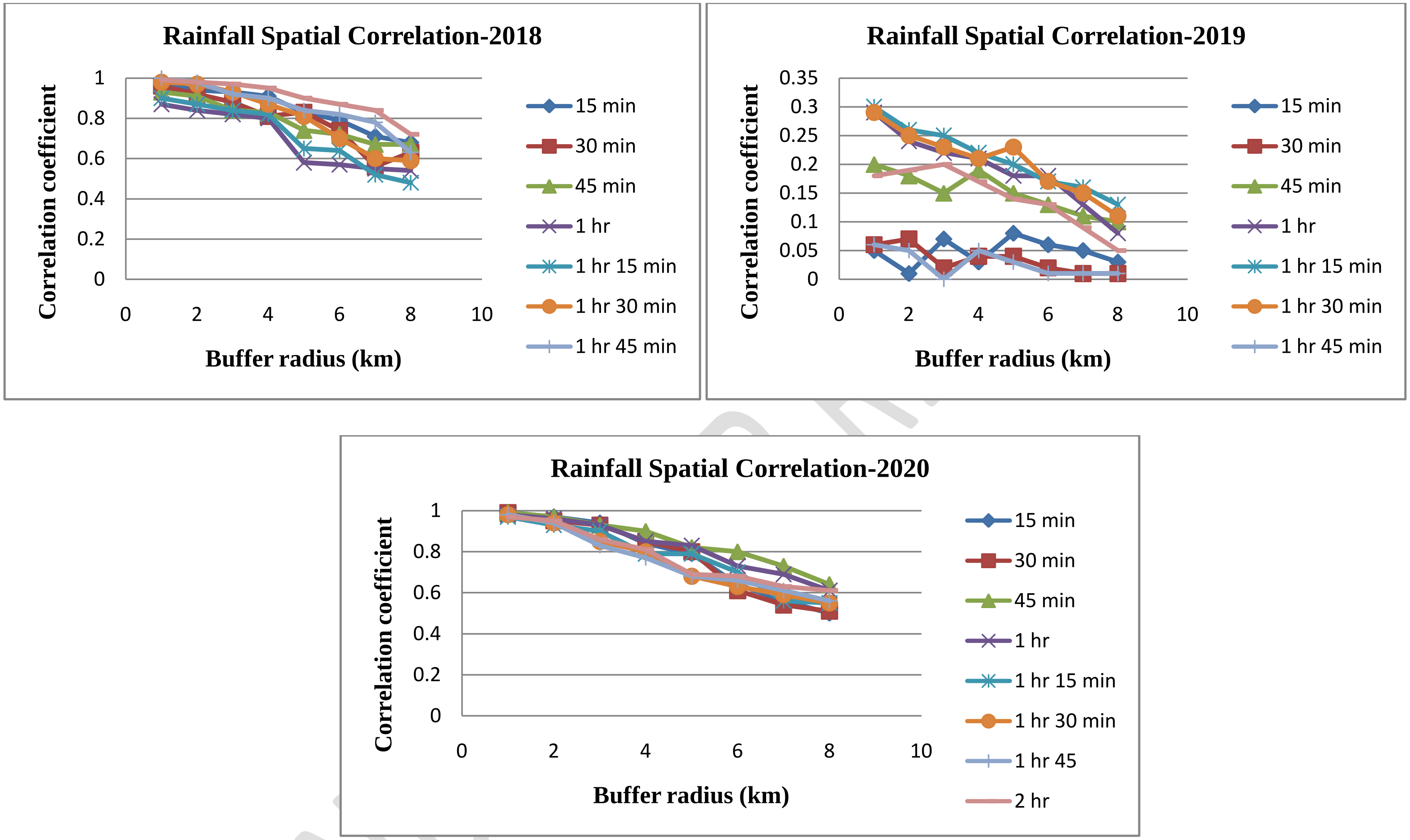

Fig 5. Rainfall Spatial Correlation vis-à-vis rain gauge station from 2014-2020

Conclusions:

The observation made with respect to rainfall analysis revealed strong regional trends, with an increase in rainfall from Bengal branch i.e. SE to NE. Locally, significant correlations were found with aspect, topography, slope and altitude.A strong daily pattern can be observed, with most rainfall occurring in the afternoon, between 14 to 19 h and followed by in mid night 0: 15 am to 4: 00 am.The small scale intermittency of rainfall could affect the comparison between rain gauge measurements and remote-sensing based rainfall estimates. 15 and 30 min duration rainfall events are localized in manner and these are anticipate to be controlled by local micro climate.Long duration rainfall events are uniformly spread across the watershed and it is depends on elevation, location (latitude and longitude) and vegetation and land cover. Depth of rainfall in the study area is depends on direction of wind flow, cloud movement, distance from sea shore. Spatial variability in rainfall at varied location is very high. Although rainfall is strongly correlated at distances of 3km with goodness of fit (R^2) more than 0.8.

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