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Disaggregation of daily rainfall – A study with particular reference to Uttar Kannada District and Western Ghats

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Abstract: This study presents a methodology to disaggregate daily rainfall data into 15-minute rainfall depths in the area of Karnataka, with particular reference to the Uttar Kannada and Western Ghats. The daily rainfall data of eight stations used in this study was furnished by Karnataka State National Disaster Monitoring Centre (KSNDMC), Bangalore. The three main relationships; (i) Relationship between daily rainfall magnitude and duration (ii) Relationship between cumulative percentage rainfall and 15-minute intensities (Type 1 relation) and (iii) Relationship between cumulative percentage of rainy interval and 15-minute intensities (Type 2 relation) has been developed through this study. Linear regression was used to develop relationship between daily rainfall magnitude and duration, and the equation was generated for two sets of stations, Set-1 stations has annual rainfall depth greater than 5000 mm and Set-2 of stations has annual rainfall depth of 2000 to 4000 mm. By using these equations, the number of rainy intervals per day was calculated. Relationship between cumulative percentage rainfall and 15-minute rainfall intensities for individual stations were established, by using the exponential equation. The combination of data within the station of different rainfall ranges is considered and graphs are generated. The value of R^2 for Type-1 relations is found to be in the range of 0.88 to 0.99. Relationship between cumulative percentage of rainy interval and 15-minute rainfall intensities established by combining all different ranges of rainfall data for all the stations. The value of R^2 for Type-2 relations is found to be in the range of 0.90 to 0.99. By using the above mentioned Type-1 and Type-2 relationships, the disaggregation of daily rainfall into rainfall intensities exceeding 2 mm/ 15-minute, 4 mm/ 15-minute, 6 mm/ 15-minute, 8 mm/ 15-minute, 10 mm/ 15-minute, 12 mm/ 15-minute, 15 mm/ 15-minute, 20 mm/ 15-minute has been illustrated in the present study to disaggregate the daily rainfall.

1. INTRODUCTION

Disaggregation of rainfall is a technique used to separate a daily rainfall depth into smaller showers. The showers can then be further disaggregated into intensity patterns or classes, which may be used as input for time varying infiltration models (Woolhiser and Thomas w, 1987), higher emphasis is being placed on the use of physically-based infiltration models to estimate surface runoff, and these models are sensitive to the distribution of rainfall amounts in time periods as short as 5, 10, 15, 20 and 30 minutes.

1.1 15-Minute Rainfall Intensity and Their Importance

15-min Rainfall intensity is defined as the depth of rainfall per 15-min interval; they are expressed in terms of mm/15min. The 15-miute intensity is a very important parameter in hydrological analysis, particularly those pertaining to medium and large catchments, and it is used in developing the design storms to predict floods and urban drainage problems.

To convert the daily rainfall data into 15-minute intensities and to calculate rainfall intervals the disaggregation process is very important. So in the present study a method of disaggregation of daily rainfall data into 15-minute rainfall depth is attempted.

The input for hydrological models determines the accuracy with which processes can be simulated. In this respect, models that disaggregate input rainfall data into a sequence of individual storms of a finer time-scale are very useful. The certain work on this research by Hershenhorn and Woolhiser, 1990; De Lima and Grasman, 1999; Gyasi-Agyeri, 1998: has in common that sophisticated statistical techniques are used in the disaggregation procedure. The commonly used techniques are:

1) A parameter efficient model by Hershenhorn and Woolhiser.
2) The empirical scaling functions by a multifractal model by De Lima and Grasman.
3) Hybrid Model by Gyasi-Agyeri.

As these authors are interested in the characterization of hydrological processes on a small temporal scale, the outlined procedures aim at disaggregating rainfall into storms that resemble the natural rainfall as closely as possible. But in this present study a simple procedure is adopted which was developed by Putty et.al (2014) for disaggregation of daily rainfall. This method is similar to that given by Mertens et al. (2002). They have adopted a method of grouping the disaggregated daily rainfall under various intensity classes and estimating the contribution of each class.

2. STUDY AREA AND THE DATA USED

2.1 THE STUDY AREA AND THEIR IMPORTANCE

The Western Ghats and Uttar Kannada district form practically an unbroken relief dominating the west coast of the Indian peninsula for almost 1600 km. They extend from the mouth of river Tapti (21°N) to the tip of South India (8°N), the only gap in the chain being the Palghat. The Western Ghats receives very heavy rainfall during the Southwest Monsoon. These mountain ranges include some of the most beautiful, the thickest and the richest of the evergreen forest patches of the World (Pascal, 1988). Most of the important rivers of South India have their origin in these areas. Hence Western Ghats have played a very important role in the development of economy of the states involved. Most of the water resources projects of Karnataka have been taken up in these areas and the forest and mineral wealth of the area have been exploited. Also, in recent years the Karnataka Forest Department (Sunder et.al, 1986) has been actively taking up conservation in these areas. As such, Western Ghats form an area of hectic activity in Karnataka. Because of these reasons, special emphasis is being laid on the region in the present study.

2.2 DATA USED

The data necessary for the present study has been collected from The Drought Monitoring Cell (DMC) of the Karnataka State Natural Disaster Monitoring Centre (KSNDMC) Bangalore, Govt. of Karnataka.

The KSNDMC data has been obtained from Telemetric rain gauges. The unit consists of a Tipping Bucket Rain Gauge mounted on a 2" BSP pipe and a stainless steel enclosure that encloses a data logger, a GSM modem and a 12VDC battery. The original data obtained from this system is in the cumulative form. The data is converted into actual rainfall depths in mm to carry out this study.

The details of rain gauge stations used for the present study are listed in the Table 2.1. The location of the rain gauge stations is shown in Figure 2.1. More number of stations are selected from Western Ghats region and Uttar Kannada district because of large variation of rainfall in this region. It varies from as low as 1600 mm in the areas bordering plains to as high as 8000 mm along the ridges.

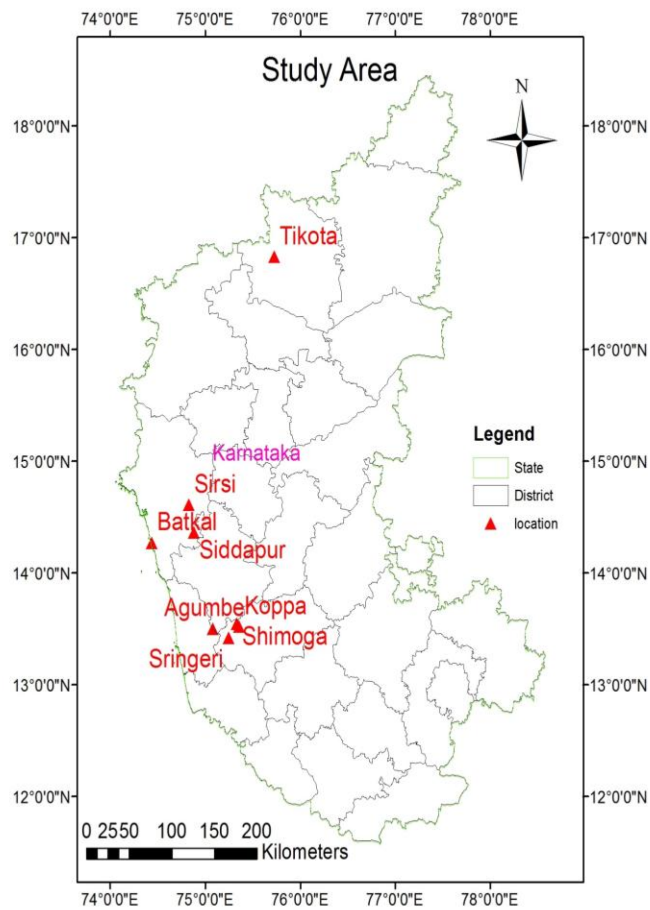


Figure 2.1: Location of Rain Gauge Stations used in the present study

Table 2.1: Details of rain gauge stations

Region	station	Latitude	Longitude	Altitude (mts)	Mean annual Rainfall (mm)
Uttar Kannada	Bhatkal	N 13.96⁰	E 74.56⁰	602	4146
	Siddapura	N 14.36⁰	E 74.88⁰	702	3038
	Sirsi	N 14.61⁰	E 74.83⁰	680	2457
Western Ghats	Agumbe	N 13.50⁰	E 75.09⁰	645	7640
	Koppa	N 12.55⁰	E 75.35⁰	763	2908
	Sringeri	N 13.25⁰	E 75.35⁰	634	3160
Plains	Tikota	N 16.83⁰	E 75.73⁰	659	765
	Shimoga	N 13.55⁰	E 75.34⁰	569	907

3. METHODOLOGY

The present study is based on the methodology developed by M R Y Putty et.al (2014) in which annual rainfall data is used for disaggregation purpose. In the present work, an effort is made to disaggregate the daily rainfall magnitude in to 15-minute amounts, which would be useful in estimating surface runoff. The relationship similar to the one developed by M R Y Putty et.al (2014) as shown Figure 3.1, is used for estimating the number of rainy intervals during a normal rainfall and the intensity - prevalence - contribution curves Figure 3.2, are used to estimate 15-minute rainfall depths. To develop these relationships the procedure followed is as given below:

(i) The range of all possible 15-minute intensities in the region are grouped in to five classes, as shown in Table 3.1. The percentage time for which rainfall under each of the five classes lasts and the contribution of such falls to total rainfall are obtained from Figure 3.2 and the values are tabulated.

(ii) Based on the data of normal annual rainfall, the number of rainy intervals and the contribution of rainfall corresponding to each of the intensity classes are estimated (Table 3.1). The data of eight stations, whose 15-minute rainfall values are furnished by Karnataka State Natural Disaster Monitoring Centre (KSNDMC), are used in the present work.

(iii) The total amount of rainfall within each class interval is now distributed in to the estimated number of intervals assuming that "all possible values of intensity have an approximately equal chance of being present". The method followed is as shown in Figure 3.3. Here, the continuous range of intensity variation is broken in to discrete events, grouped into a few classes and each class assigned an intensity value such that total rainfall is equal to that estimated empirically in Step (ii) above. Hence, for the case shown in the figure, $\Sigma i_j n_j$ is equal to the total rainfall in the class.

The procedure described above requires the following three important relationships:

(i) Relationship between Daily Rainfall Magnitude – Durations,

(ii) Relationship between Cumulative percentage rainfall and 15-minute intensities, and

(iii) Relationship between Cumulative percentages of rainy intervals and 15-minute intensities.

The aim of the present study is to develop these relationships applicable on these areas. The relation in (ii) is here after called as Type-1 relation and the relation in (iii) is here after called as Type-2 relation.

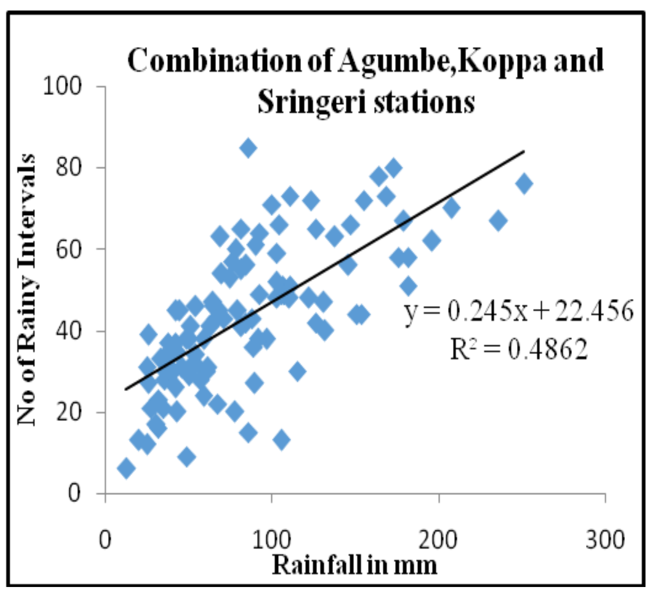


Figure 3.1: Relation between total annual rainfall and the number of rainy intervals

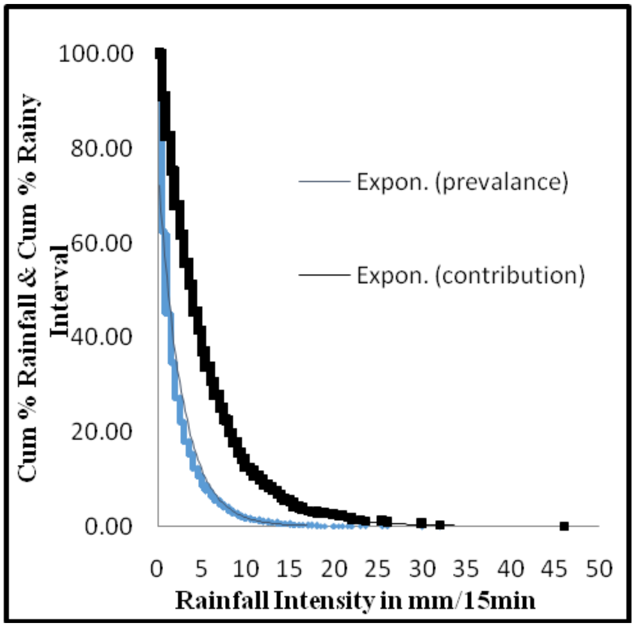


Figure 3.2: Percentage contribution of falls exceeding various 15 minute intensities to the total rainfall in a year and the percentage time duration for which such intensities last.

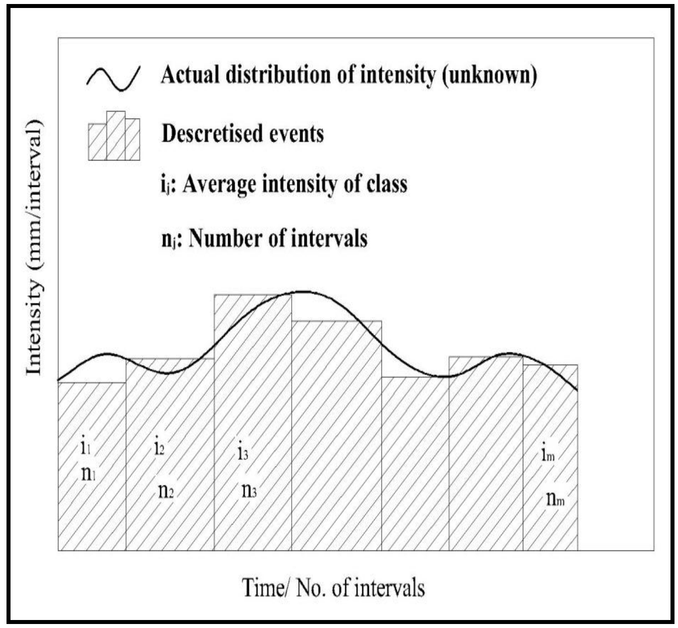


Figure 3.3: Splitting the continuous rainfall (with an unknown intensity pattern) in to discrete events. (Source: M R Y Putty et.al, 2014)

Table 3.1: Rainfall contribution by falls exceeding various intensities and the duration for which they prevail (Source: M R Y Putty et.al, 2014)

Station	Annual Rainfall(mm)	Percentage contribution of rainfall by falls exceeding intensities (mm/hour) of					Percentage of 15 min. intervals in which intensities exceeded (mm/h)				
		24	32	40	60	80	24	32	40	60	80
Agumbe	7558	41.00	28.00	19.20	6.20	2.00	10.80	6.00	3.80	1.30	1.00
	5960	23.30	11.80	2.40	1.20	0.00	5.40	2.30	0.30	0.10	0.00
	4853	25.30	13.90	4.60	1.40	0.00	6.40	2.80	0.70	0.20	0.00
Bhagamandala	4758	24.80	13.40	8.30	1.80	1.30	5.00	2.00	1.20	0.10	0.07
	5485	34.00	22.00	12.90	4.50	2.20	6.80	3.60	1.80	0.60	0.40

4. RESULTS AND DISCUSSIONS

4.1 DISAGGREGATION AND 15-MINUTE INTENSITY OF RAINFALL

Eight stations namely, Bhatkal, Siddapura, Sirsi, Agumbe, Koppa, Sringeri, Shimoga and Tikota have been considered in this work for the analysis. Of these, three stations are in Uttar Kannada district, three stations are in Western Ghats and two are in the plains. All the stations in Uttar Kannada district and Western Ghats have similar rainfall pattern. But, Agumbe experiences high rainfall, Sringeri, Sirsi, Siddapura have a moderate rainfall, while, Bhatkal and Koppa gets comparatively low rainfall. The region experience different kinds of rainfall within the study area. The only wet days are considered for the present study and these data are used for estimating the Contribution of falls exceeding various 15-minute intensities. Then the Type-1 and Type-2 relations are established by plotting 15-minute intensities on X-axis and the cumulative percentage rainfall contribution or the cumulative percentage rainy interval on Y-axis. Graphs are plotted for individual days of the consecutive three year. Only graphs of Agumbe and Bhatkal are shown in Figure 4.1. Curve fitting is done using EXCEL Spread sheet for both Type-1 and Type-2 relations. Two types of equations are tried. The R^2 value obtained for the exponential equations is found to be more as compared to the polynomial equations. Further, polynomial curves were found falling in the negative quadrant for many of the cases, Figure 4.2. Therefore use of polynomial equations was not continued for further studies. Hence, only exponential equations are considered for all subsequent analysis. The value of R^2 for Type-1 relations is found to be in the range of 0.88 to 0.99, while that for Type-2 relations is found to be in the range 0.90 to 0.99, except in a few cases.

One can conclude by observing Figure 4.1 that nearest range of rainfall data within a station can be combined. To verify this, graphs are drawn together by considering a few nearest ranges of rainfall data, as shown in Figure 4.3.

4.1.1 Use of Combined Data to develop relationships

The rainfall data for different range are shown in Figure 4.3. By observing these graphs, it can be inferred that the relations are similar within the stations, for certain ranges of values of daily rainfall. Hence, certain ranges of data are combined and the relations are generalized. The rainfall ranges considered are as follows:

(I) Range below 50 mm, (II) range from 50 to 100 mm, (III) range from 100 to 150 mm, (IV) range from 150 to 200 mm and (V) range above 200 mm and Graphs drawn by including all the rainfall data in each of the ranges, as shown in Figure 4.4 and Figure 4.5 (Type-1 and Type-2 relations).

4.1.2 Importance of certain Combining data

By observing the graphs in Figure 4.4 and Figure 4.5 (Type-1 and Type-2 relations), it can be found that the patterns are similar for some of the stations. The analysis of Graphs in Figure 4.6 shows that stations in plain regions do not fit with the stations in Western Ghats because of R^2 values and even rainfall in plains is very less.

The percentage contribution of various 15 minute rainfall intensities and their duration is higher for Western Ghats stations as compared to plain stations. For example, as shown in Figure 4.6, the percentage contribution of rainfall and duration for the rainfall intensities of 10mm/15 min and 15mm/15 min are 28% and 12% for the Agumbe station and 15% and 3% for the Shimoga station. This indicates the higher chances of flash floods in the Western Ghats. Hence, for further studies, stations of plains are not considered. Further, observation of average rainfall values for the stations in Western Ghats depicts similar pattern of the two curves for stations with nearly same magnitude of rainfall. Therefore, rainfall data of such stations is combined and graphs are generated.

Refer Figure 4.7 gives combined graph of Type 2 relation for Agumbe, Koppa and Sringeri because the R^2 values of those stations are almost same. The equations are generated in Table 4.1 and details are tabulated in Table 4.2.

4.1.3 Analysis of data by combining all the stations

In order to develop generally applicable relations, an effort was made to combine the data of all the stations to plot the graph, as there was similarity between some stations. The graphs for type-2 relations resulted in similar pattern, thus reducing all the equations to one equation with respect to the range of rainfall. The graphs are generated and shown in Figure 4.8. These graphs show the similarity between different ranges of rainfall. The different ranges of rainfall are also combined to represent type-2 relations and a single equation is generated, furnished in Table 4.3 and Figure 4.9. The values generated from these curves are shown in Table 4.4.

4.2 DAILY RAINFALL MAGNITUDE - DURATION RELATIONSHIPS

The first step in disaggregation of a given daily rainfall is to determine the number of rainy intervals on the day. For calculation of the number of rainy intervals, equations are generated for Uttar Kannada district and Western Ghats region by using the graph shown in Figure 4.10. The wet day's data are used for generating these graphs. The value of the correlation coefficient for these relationships is found to be in the range 0.48 to 0.59. The equations for different set of stations in Western Ghats region is given in Table 4.5.

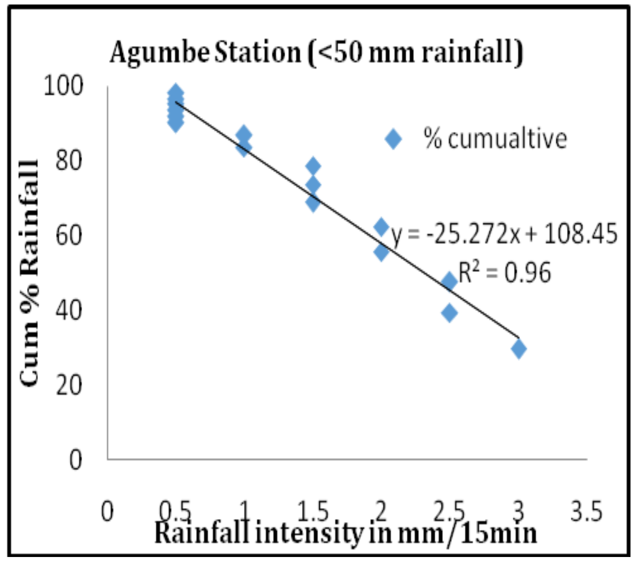
These equations together with the relations presented in Table 4.2, Table 4.3 and Table 4.5 can be used for disaggregation of rainfall as illustrated in the example below.

4.3 AN ILLUSTRATION OF THE METHOD DISCUSSED

The total rainfall of the day is taken as 172 mm for the region of Western Ghats near Agumbe, for illustrating the method of disaggregation. The following steps are followed for disaggregation.

1. Total number of intervals: 65 (obtained using equation in Table 4.5)
2. Intensity ranges considered: (a) *less than 2 mm/15-minutes, (b) between 2-4 mm/15- minutes, (c) between 4-6 mm/15-minutes, (d) between 6-8 mm/15-minutes, (e) between 8-10 mm/15-minutes.*
3. **Intensity range: less than 2 mm / 15 minutes.**
   No. of 15 minute interval: 41 (obtained using Table 4.3), Total rainfall for the class: 70 mm (obtained using Table 4.2).
   Suggested pattern of distribution: Falls of 0.5 mm are two numbers, 1mm are four numbers, 1.5 mm is ten numbers and 2 mm are twenty five numbers.
4. **Intensity range: between 2-4 mm / 15 minutes.**
   No. of 15 minute interval: 13 (obtained using Table 4.3), Total rainfall for the class: 41 mm (obtained using Table 4.2).
   Suggested pattern of distribution: Falls of 2.5 mm are five numbers, 3 mm are two numbers, 3.5 mm are three numbers and 4mm are three numbers.
5. **Intensity range: between 4-6 mm / 15 minutes.**
   No. of 15 minute interval: 6 (obtained using Table 4.3), Total rainfall for the class: 29 mm (obtained using Table 4.2).
   Suggested pattern of distribution: Falls of 4.5 mm are three numbers, 5 mm are two numbers and 5.5 mm is one numbers.
6. **Intensity range: between 6-8 mm / 15 minutes.**
   No. of 15 minute interval: 2 (obtained using Table 4.3), Total rainfall for the class: 14.5 mm (obtained using Table 4.2).
   Suggested pattern of distribution: Falls of 7 mm is one number and 7.5 mm is one number.
7. **Intensity range: between 8-10 mm / 15 minutes.**
   No. of 15 minute interval: 1 (obtained using Table 4.3), Total rainfall for the class: 9 mm (obtained using Table 4.2).
   Suggested pattern of distribution: Falls of 9 mm is one number.

From the above example it can be said that for total of 65 intervals taken, 172 mm of daily rainfall is distributed at the intensity of 15-minutes. It may be noted that this method of converting continuous rainfall into discrete events is purely arbitrary. Yet, it is rationally based and is applied within small ranges of intensity, the contribution of which to total rainfall is estimated empirically. The method serves the purpose of obtaining a data set of 15-minute rainfall depths for the daily rainfall.



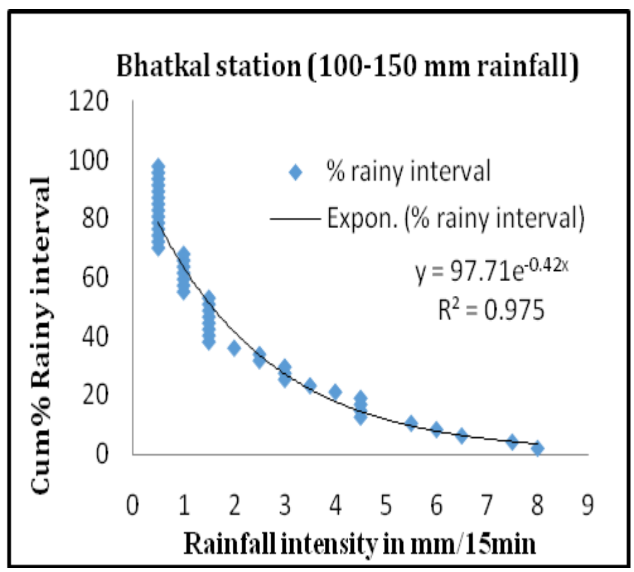


Figure 4.1: Cum % Rainfall or cum % rain interval vs rainfall intensity in mm/15min

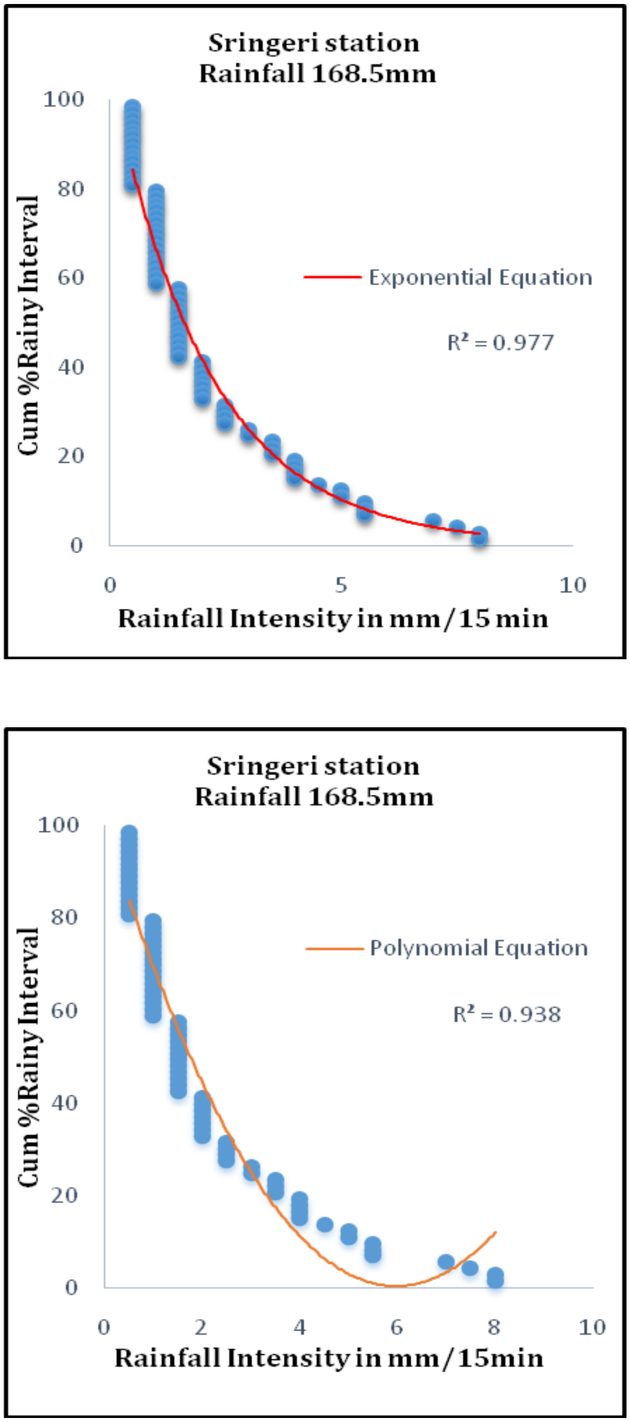


Figure 4.2: Comparison of Polynomial and Exponential curves for Sringeri station

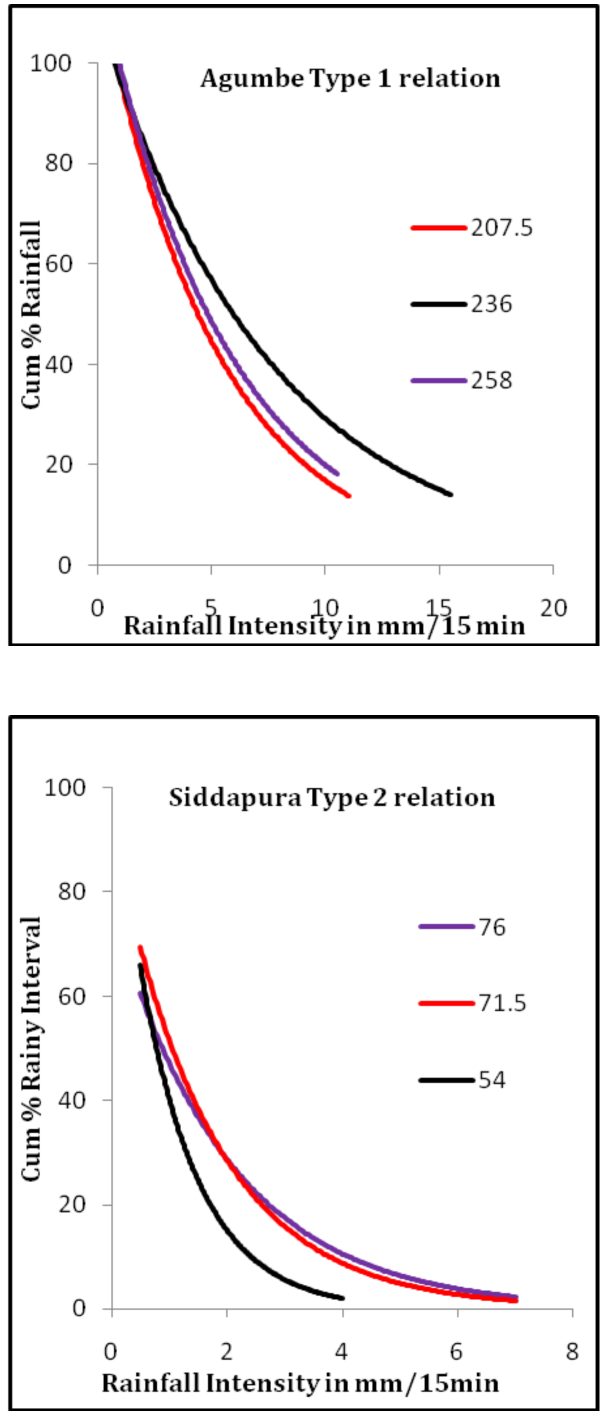


Figure 4.3: Type-1 and Type-2 relations curves for different range of rainfall within the stations

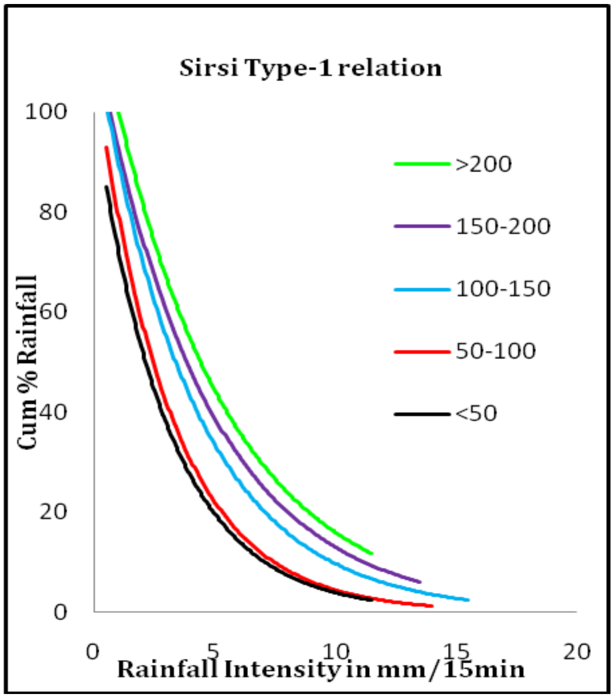


Figure 4.4: Plot of Type-1 relation for different range of rainfall vs. cumulative % rainfall pertaining to Sirsi Station

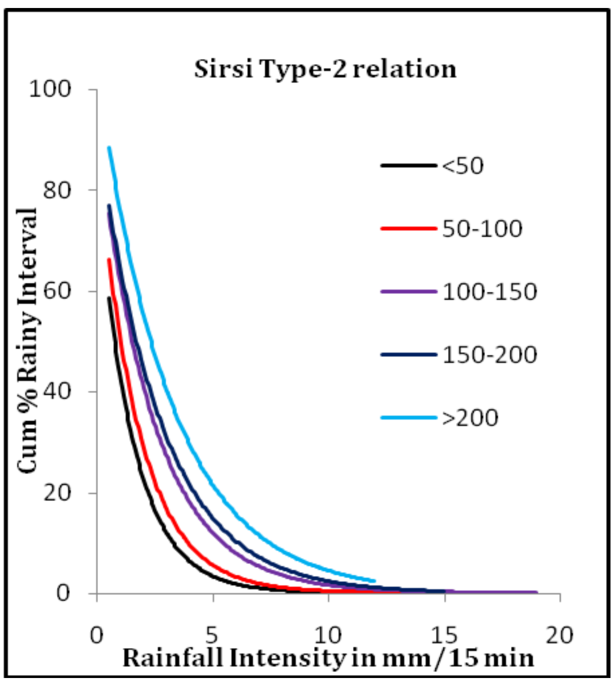


Figure 4.5: Plot of Type-2 relation for different range of rainfall vs. % Rainy Interval pertaining to Sirsi station

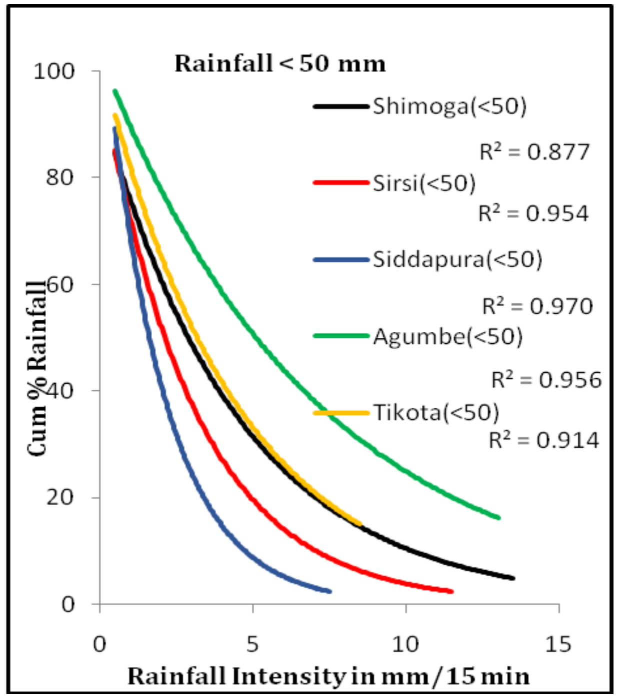


Figure 4.6: Comparison of different stations including plains

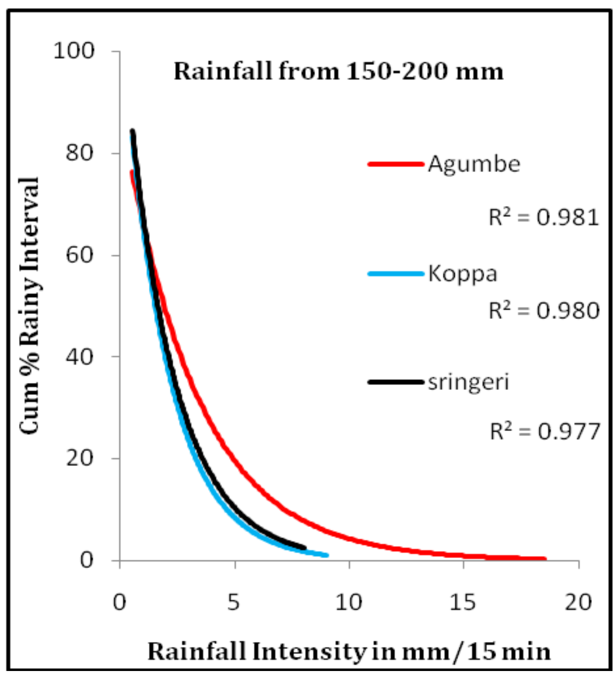
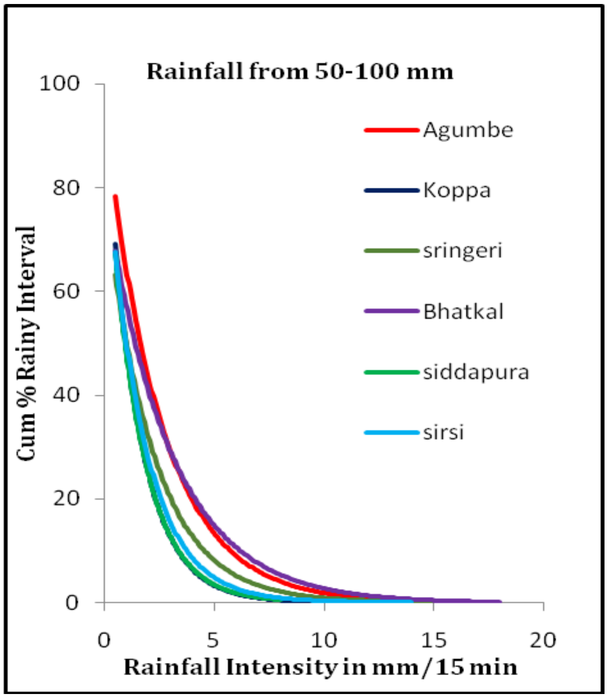


Figure 4.7: Plot of Type-2 relation for different range of rainfall vs. % Rainy Interval of Agumbe, Koppa and Sringeri Stations



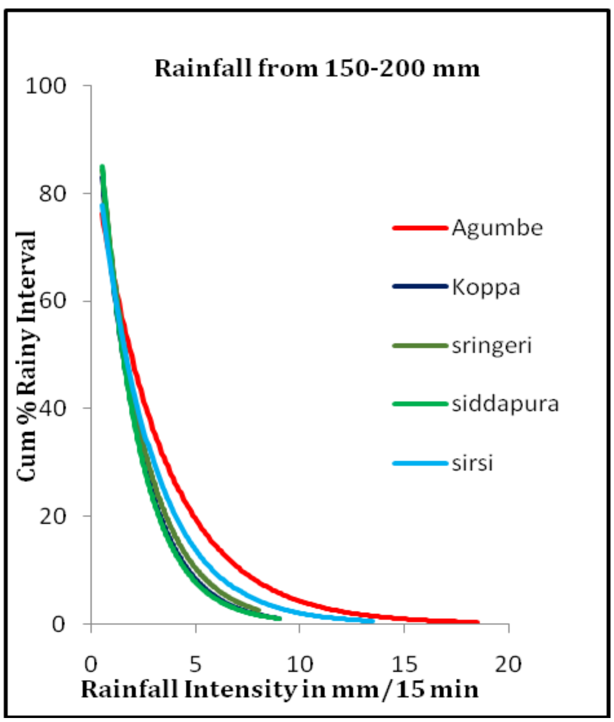


Figure 4.8: Plot of Type-2 relations for different range of rainfall vs. % Rainy Interval of all Stations

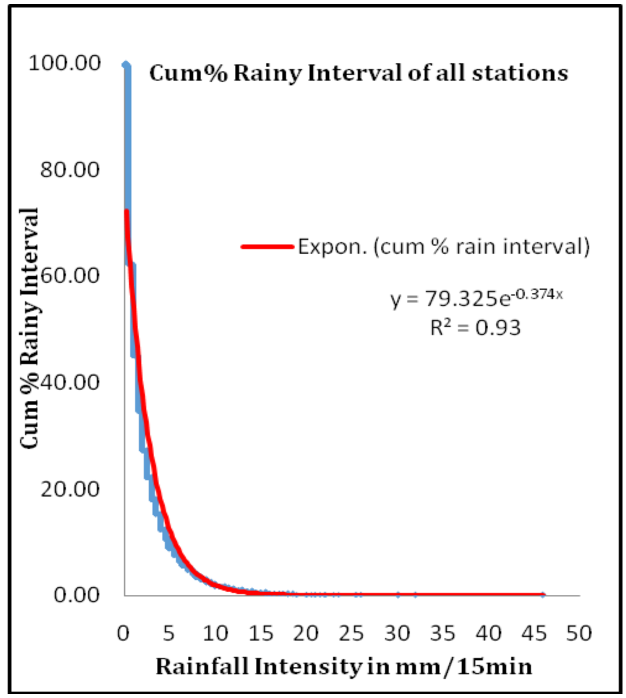


Figure 4.9: cum % rainy interval for combination of all the stations

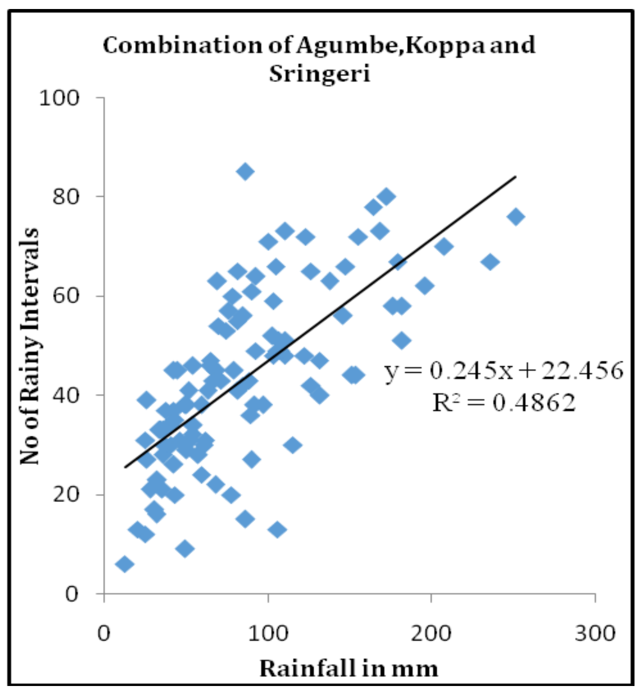


Figure 4.10: Relation between Daily rainfall magnitude and duration

Table 4.1: Equations of Rainfall Contributed by Falls Exceeding Various intensities Agumbe, Koppa and Sringeri Stations

Station	Rainfall Interval	Equations
Agumbe, koppa and Sringeri	<50	$y = 100e^{-0.34x}$
	50-100	$y = 100e^{-0.26x}$
	100-150	$y = 100e^{-0.17x}$
	150-200	$y = 100e^{-0.18x}$
	>200	$y = 100e^{-0.16x}$

Table 4.2: Rainfall Contributed By Falls Exceeding Various Intensities of Agumbe, Koppa and Sringeri Stations

Station	Rainfall in mm	Total rainfall in the interval	Equations	Percentage contribution of rainfall by falls exceeding various intensities							
				2	4	6	8	10	12	15	20
Agumbe, koppa and Sringeri combined	1134.5	<50	$y = 100e^{-0.34x}$	50.66	25.66	13	6.58	3.33	1.69	0.6	0.11
	2511.5	50-100	$y = 100e^{-0.26x}$	59.45	35.34	21.01	12.49	7.42	4.41	2.02	0.55
	2579.5	100-150	$y = 100e^{-0.17x}$	71.17	50.66	36	25.66	18.26	13	7.8	3.33
	2209.5	150-200	$y = 100e^{-0.18x}$	69.76	48.67	33.95	23.69	16.52	11.53	6.72	2.73
	952.5	>200	$y = 100e^{-0.16x}$	72.61	52.72	38.28	27.8	20.18	14.66	9.07	4.07

Table 4.3: Equation of Rainfall Contributed By Falls Exceeding Various Duration

Station	Rainfall Interval	Equations
Combination of all stations	Rainfall of all the Interval	$y = 79.32e^{-0.37x}$

Table 4.5: Equation for number of rainy intervals for different combination set of stations

Stations	Equations
Agumbe, Koppa and Sringeri	$y=0.245x+22.45$

Table 4.4: Rainfall Contributed by Falls Exceeding Various Duration of All the stations

Station	Rainfall Interval	Rainfall in mm	Equations	Percentage of 15.min interval in which falls of various intensities exceeded							
				2	4	6	8	10	12	15	20
For all the stations considered	For all range of Rain Interval	21,534	$y= 79.32e^{-0.37x}$	37.54	17.77	8.41	3.98	1.88	0.89	0.29	0.04

4.4 CONCLUSIONS

The procedure for Disaggregation of daily rainfall into 15-minute rainfall depths requires 3 important relationships; they are (i) Relationship between cumulative percentage rainfall and 15-minute intensities (Type 1 relation) (ii) Relationship between cumulative percentage of rainy interval and 15-minute intensities (Type 2 relation) and (iii) Relationship between daily rainfall magnitude and duration. Following are the conclusions drawn:

(i) Relationship between cumulative percentage rainfall and 15-minute intensities for individual stations are established (Refer Figure 4.1). In this present study two types of equations were tried out, they are Exponential equation and Polynomial equation. As the polynomial curves were falling on the negative quadrant in most of the cases (Refer Figure 5.2), hence use of polynomial equations were ruled out and only exponential equations were considered to carry out the further study. The combination of data within the station of different rainfall ranges i.e. (a) ranges below 50 mm (b) ranges from 50 to 100 mm (c) ranges from 100 to 150 mm (d) ranges from 150 to 200 mm (e) range above 200 mm (Refer Figure 4.4) were used to generate type 1 relationship. Graphs were generated for these data and it was found that graphs were similar for some of the stations. But the rainfall data for the Plain regions did not fit with the stations in Uttar Kannada and Western Ghats regions (Refer Figure 4.6). Thus, for further studies, stations of Plains were not considered. The value of R^2 for Type-1 relations is found to be in the range of 0.88 to 0.99.

(ii) Relationship between cumulative percentage of rainy interval and 15-minute intensities (type-2), in which graphs were generated for combination of data within the station of different rainfall ranges i.e. (a) ranges below 50 mm (b) ranges from 50 to 100 mm (c) ranges from 100 to 150 mm (d) ranges from 150 to 200 mm (e) range above 200 mm (Refer Figure 4.5). These graphs were found to be more similar. Then for set of station, data were combined i.e.
Agumbe, Koppa and Sringeri stations, and for these stations graphs are generated (Refer Figure 4.7). The equations are furnished in the Table 4.1, the value of R^2 for Type-2 relations is found to be in the range of 0.90 to 0.99. Then all the stations of different range of rainfall data were combined and graph was generated (Refer Figure 4.8). The value of R^2 for Type-2 relation is found to be in the range of 0.90 to 0.99. The equation is furnished in Table 4.3.

(iii) Relationship between daily rainfall magnitude and duration was obtained by using linear regression method and the equation was generated for set of stations shown in Table 4.5. Set consist of Agumbe, Koppa and Sringeri stations (annual rainfall depth greater than 5000 mm) shown in Figure 4.10. By using these equations, numbers of rainy intervals per day were obtained.

By using the 1^{st} and 2^{nd} relationship the percentage contribution and duration of prevailance of rainfall intensities in the range of 2 mm/ 15-minute, 4 mm/ 15-minute, 6 mm/ 15-minute, 8 mm/ 15-minute, 10 mm/ 15-minute, 12 mm/ 15-minute, 15 mm/ 15-minute and 20 mm/ 15-minute has been illustrated in the present study to disaggregate the daily rainfall.

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