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Relationship between Rainfall Amounts, Mean Daily Rainfall Intensity and Rainy Days at Bundi and Kota Districts, Rajasthan, India

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Abstract—*In the present study, long-term daily rainfall data of 25 years (1990-2014) of Bundi and Kota district of Rajasthan was analysed to understand relationships between Rainfall Amount (RA), Mean Daily Rainfall Intensity (MDRI) and Rain Days (RD) on monthly, seasonal and annual basis. The study revealed erratic distribution of rainfall occurrence as MDRI with highly correlated values (0.83-0.90) was observed for different months, seasons and annual data series and corresponding normalised rainfall curves were plotted. For Bundi district, the value of X* (percent rain amount cumulated in first 50% of rain days) was found highest (23.61%) for January, whereas, among seasons, its highest value (58.61%) was observed for season S1 (Jan-Feb). For Kota district, the value of X* (percent rain amount cumulated in first 50% of rain days) was found highest (28.89%) for January, whereas, among seasons, its highest value (23.91%) was observed for season S1 (Jan-Feb). In the same way, for Bundi district the value of first 50% rainfall cumulated (Y*) was found highest for December month and among seasons with season S4 (October-December) (84.21%) and for Kota district the value of first 50% rainfall cumulated (Y*) was found highest for December month and among seasons with season S4 (October-December) (87.5%).*

Keywords*: Rainfall amount, Normalized rainfall curve*

1. INTRODUCTION

The most vital and critical input for agricultural production is rainfall and in Indian conditions, its distribution is very erratic and varies from region to region and year to year. It is a well-known fact that a few rain events with large rain amounts contribute to bulk of monthly, seasonal and annual rainfall. As crop yields depend on amount and distribution pattern of rainfall to a great extent, therefore, it is a matter of interest to study rainfall characteristics and its variation at different levels at a place into consideration. One of the most important problems in hydrology deals with interpreting a past record of hydrologic events in terms of furnishing valuable information for future use. In this study, association between cumulated percentage rain amount (X) and cumulated percentage rain days (Y) has been examined to study relationship of rainfall amount with rain events on monthly, seasonal and annual basis by drawing Normalized Rainfall Curves (NRCs) as relationship between these two, i.e., "X" and "Y" are best described in exponential terms (Ananthkrishnan and Soman, 1989). The earliest representation of association between rain amount and rain days was given by Olascoaga (1950) for climatic zones of Argentina in the form, x = ayg(bx), where "x" is cumulated percentage rain amount, "y" is cumulated percentage rain days and "a" and "b" are empirical constants with some definite values. They found that a single NRC gave satisfactory representation of rainfall with a variety of rainfall regimes.

On the basis of daily rainfall distribution in North and Central America for a period of 30 years, Martin (1964) found that single NRC could represent with a good degree of accuracy and regarded it as a "universal daily rainfall distribution curve". Similarly, Ananthkrishnan and Rajan (1987) examined analytical representation of NRCs and concluded that representation of rainfall series of different rainfall regimes is dependent on some measures of dispersion while De-sousa and De-Silva (1998) studied precipitation normalized curve by an analytical method to measure maximum probable rainfall intensity by using NRC for five stations at Brazil and obtained good results in all cases and stressed that estimates for maximum probable rainfall intensity are reliable and may be used in planning of small hydraulic projects. Tomar and Ranade (2001) also studied association of rainfall amount with rain events on the basis of 20 years of daily rainfall data and concluded that 21.23% rainfall was available in 71.04% rain days during monsoon season at Indore region of Madhya Pradesh.

2. MATERIALS AND METHODS

2.1 Data collection and analysis

The long-term daily rainfall data for 25 years (1990-2014) of Bundi and Kota district was collected from http://waterresources.rajasthan.gov.in/ and rain amount measuring greater than or equal to 0.10 mm was only considered for data series which is then sorted in ascending order for different months, seasons and years. In this study, available daily rainfall data has been examined for all 12 months of year individually; four Indian seasons {S_1 (January-February); S_2 (March-May); S_3 (June-September); and S_4 (October-December)}; and year as a whole. The available daily rainfall data has been examined and studied with the help of graphical representation between cumulated percentage rain amount (X) and cumulated percentage rain days (Y), prepared by progressive cumulating daily rainfall values after arranging series in ascending order for above specified periods individually. To understand it clearly, considering the month of January for 'P' number of years; total number of days will be 31P out of which if 'N' days have recorded measurable amount of rain ($\geq$ 0.1 mm), then after excluding rainless days, N < 31P, daily rainfall values were arranged in ascending order. Total rain recorded in N days (R) and Mean Daily Rainfall Intensity (MDRI) is then calculated by R/N where, $R = r_1 + r_2 + r_3 + \ldots + \ldots + r_N$. Rainfall for first '$k$' days ($R_k$) of ordered series is given by relation, $R_k = r_1 + r_2 + r_3 + \ldots + \ldots + r_k$ and cumulated percentage rain amount (X) for 'k' days is calculated by X_k= (100 * R_k)/R, whereas, cumulated percentage rain days (Y) for 'k' days are calculated by using equation, Y_k = (100 * k)/N

It has been found that as 'k' takes values from 0 to N, X_k and Y_k takes values from 0 to 100. By plotting corresponding values of X_k and Y_k, NRC for given period can be obtained in the shape of graph for exponential functions shown in Fig. 1.

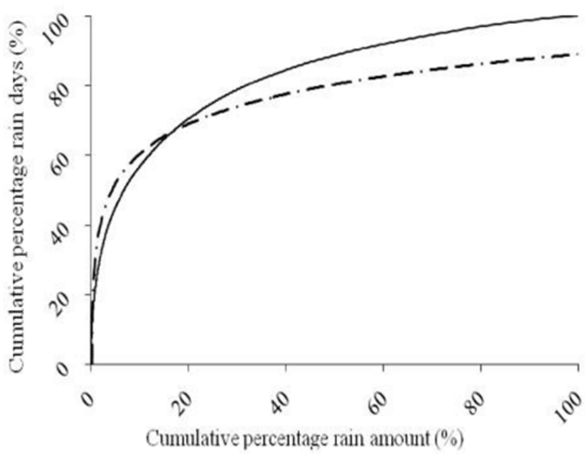

Fig. 1: Illustration of a Normalized Rainfall Curve (NRC)

By following same procedure and utilizing daily values of seasonal and annual rainfall for total period of 25 years, NRCs for different seasons and annual basis were also drawn. On NRC, two points (X*, 50) and (50, Y*) are of interest where X* is percentage rain amount cumulated in first 50% of rain days and Y* is percentage number of rain days in which first 50 percent of precipitation is cumulated. Since NRC is directly related to Coefficient of Variation (CV), cumulated percentage number of rain days, which contribute 50% rain amount in ordered rainfall series (calculated from zero end of NRC), is directly related to CV of rainfall series under consideration. The CV of rainfall on rainy days is an important statistical parameter and uniquely determines important properties of daily rainfall distribution. It is an established fact that if two rainfall series have same CV values, then ratio of their mean daily rainfall will be equal to ratio of their Standard Deviation (SD). When two such normalized series are arranged in ascending order, there is similarity between them and hence, they will be represented by same NRC. With larger values of CV of rainfall series, greater deviation is observed.

Previous studies have shown that NRC of stations with vastly different rainfall regimes is practically identical if CV values of rainfall series are close to one another.

3. RESULTS AND DISCUSSION

The findings of analysis of rainfall data series for Bundi and Kota districts on the basis of NRCs drawn for different months, seasons and annual rainfall series is presented in Table 1.

Table 1: Statistical Parameters

Period	Rainfall parameter	Bundi	Kota
January	Average rainfall, mm	12.86	9.85
	Standard deviation, mm	10.45	6.56
	Coefficient of variation, %	81.25	66.63
February	Average rainfall, mm	6.69	9.47
	Standard deviation, mm	7.22	8.10
	Coefficient of variation, %	107.96	85.62
March	Average rainfall, mm	5.65	11.42
	Standard deviation, mm	3.99	11.31
	Coefficient of variation, %	70.67	98.97
April	Average rainfall, mm	6.88	5.71
	Standard deviation, mm	6.56	5.79
	Coefficient of variation, %	95.36	101.39
May	Average rainfall, mm	18.69	12.93
	Standard deviation, mm	26.62	9.36
	Coefficient of variation, %	142.40	72.38
June	Average rainfall, mm	16.30	18.77
	Standard deviation, mm	19.23	19.68
	Coefficient of variation, %	118.01	104.86
July	Average rainfall, mm	18.69	18.24
	Standard deviation, mm	26.62	24.00
	Coefficient of variation, %	142.40	131.56
August	Average rainfall, mm	17.71	20.38
	Standard deviation, mm	24.27	25.72
	Coefficient of variation, %	137.05	126.17
September	Average rainfall, mm	14.70	13.97
	Standard deviation, mm	16.92	18.20
	Coefficient of variation, %	115.10	130.28
October	Average rainfall, mm	12.23	20.31
	Standard deviation, mm	10.86	27.90
	Coefficient of variation, %	88.79	137.38
November	Average rainfall, mm	12.00	6.81

	Standard deviation, mm	12.84	8.51
	Coefficient of variation, %	107.04	124.94
December	Average rainfall, mm	7.83	24.75
	Standard deviation, mm	9.98	28.33
	Coefficient of variation, %	127.51	114.48
S_1 (Jan-Feb)	Average rainfall, mm	8.18	9.58
	Standard deviation, mm	8.38	7.55
	Coefficient of variation, %	102.37	78.80
S_2 (Mar-May)	Average rainfall, mm	17.64	10.82
	Standard deviation, mm	25.73	9.35
	Coefficient of variation, %	145.83	86.35
S_3 (Jun-Sep)	Average rainfall, mm	17.47	18.29
	Standard deviation, mm	23.98	23.24
	Coefficient of variation, %	137.25	127.03
S_4 (Oct-Dec)	Average rainfall, mm	11.47	16.65
	Standard deviation, mm	11.15	22.75
	Coefficient of variation, %	97.23	136.61
Annual	Average rainfall, mm	17.02	17.83
	Standard deviation, mm	23.59	22.76
	Coefficient of variation, %	138.59	127.64

The uniformity of rainfall distribution is assessed by two methods, firstly, by using common measures of dispersion (e.g., mean, standard deviation, coefficient of variation and correlation coefficient) and secondly, by analysing duration of rain days for the first 50% of rain amount to happen (*Y**) and rain amount which occurred in first 50% of rain days (*X**). From corresponding approximate values for all months, seasons and years, it is clear that for Bundi district From Table 4.1, it is evident that CV is found lowest in the month of March (70.67%) while its largest value was observed in July (142.40%) during the study period. Deviation from mean was found minimum for month of March (3.99%) and maximum for July (26.62%). Data was found to be highly correlated as correlation coefficient for all months, seasons and years were found positive i.e. with increase of one variable, another variable increases and was found good with values in the range of 0.83-0.90. As far as rainy days are concerned, December is found with lowest (6) rainy days followed by January (8), March (10) and November with 11 rainy days. April had a total number of 20 rainy days, followed by October (21) and February, (25), whereas highest number of rainy days were observed in August (321), followed by May and July (320), September and June (123). The MDRI values were found highest during months of May and July (18.69 mm), followed by August (17.71 mm), June (16.30 mm), September (14.70 mm), January (12.86 mm), October (12.23 mm), while March had its minimum value (5.65 mm) among seasons season S_3 (June-Sept) was found to have maximum MDRI (18.29 mm), whereas, season S_1 (Jan-Feb) observed minimum MDRI value as 9.58 mm. In case of seasonal rainfall, skewedness was found maximum in season S_2 (March-May) and minimum in season S_1 (Jan-Feb). Similarly, largest CV value was observed for season S_2 (Mar-May), and its lowest value was found in season S_4 (October-December).The variation of SD and MDRI and CV and number of rain days on monthly, seasonal and annual basis are shown in Figures 2 and 3 respectively. It is a well-known fact that a few number of rain events with large rain amounts contribute to bulk of monthly, seasonal and annual rainfall. Fig. 1 shows average rainfall among Bundi and Kota districts.

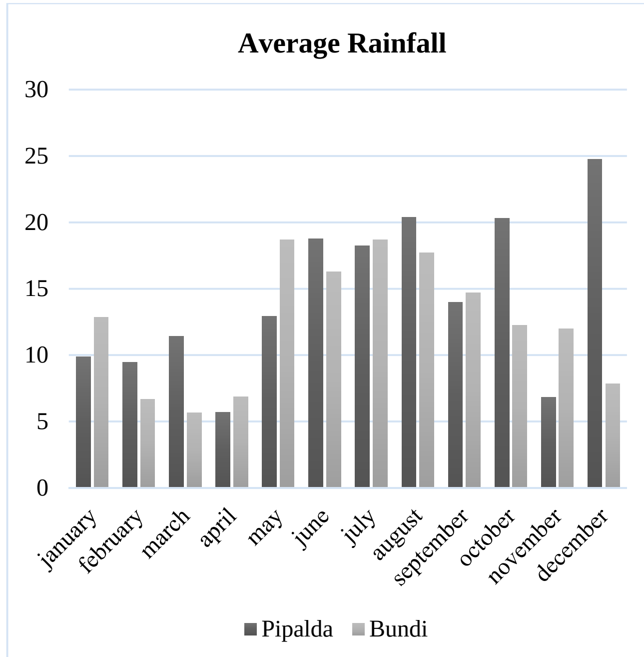

Fig. 1: Average Rainfall

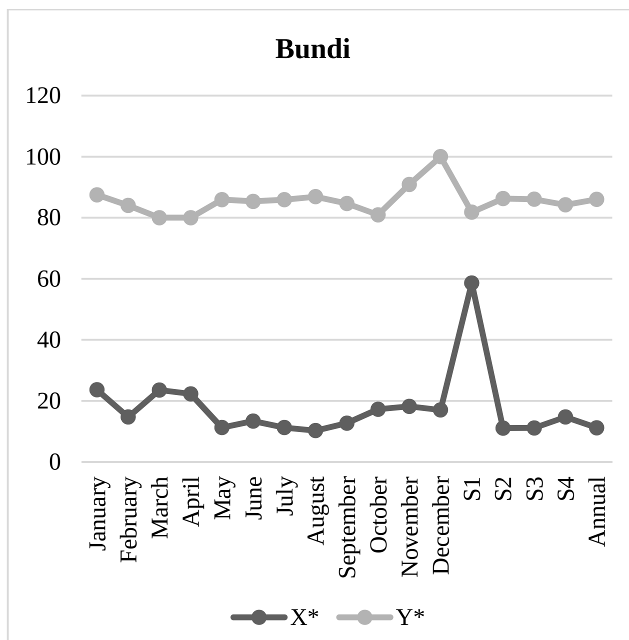

Fig. 2: Relationship between X* and Y* for Bundi districts.

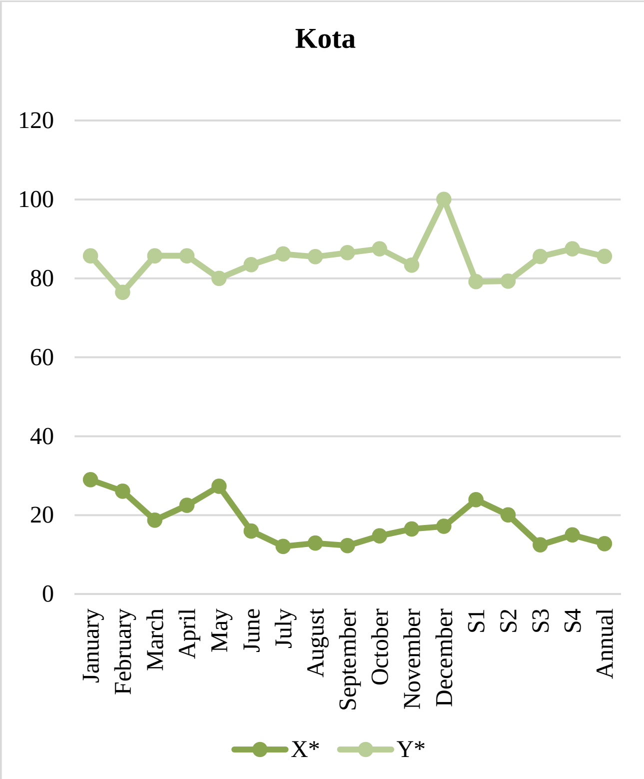

Fig. 3: Relationship among X* and Y* for Kota district

In this study, relationship between rain days and rain amount by nearest logarithmic trendline has been presented and is expressed in the form of a logarithmic equation, $y = a \ln(x) + b$ where "x" is cumulative percentage rain amount, "y" is cumulative percentage rain days and "a" and "b" are constants having different values for different months, seasons and annual rainfall series. The respective equations of good fit trendlines of NRCs for different months, seasons and annual rainfall series are presented in Table 2. The values of X^* and Y^* effectively help in determining nature of rainfall uniformity as well as its skewedness as in July, first 50% of rain days accounted for only 8.19% rainfall amount while last 13.56% rain days yielded 50.00% of monthly total, which shows highly skewed nature of rainfall. The monthly, seasonal and annual variation of X^* and Y^* during study period is shown in Fig. 4.

Table 2: Trendline Equations

Period	Trendline equations for	
	Bundi district	Kota district
Jan	y = 22.99ln(x)-15.04	y=27.49ln(x)-32.45
Feb	y = 20.66ln(x)-0.22	y=20.00ln(x)-4.97
March	y = 24.60ln(x)-21.35	y=23.10ln(x)-9.16
April	y = 22.16ln(x)-11.98	y=24.33ln(x)-14.82
May	y= 15.74ln(x)+17.66	y=24.43ln(x)-22.14
June	y= 16.59ln(x)+12.97	y=16.47ln(x)+11.13
July	y=15.74ln(x)+17.66	y = 16.26ln(x)+15.03
Aug	y= 16.02ln(x)+17.56	y = 15.97ln(x)+15.06
Sept	y= 16.63ln(x)+13.26	y = 16.95ln(x)+13.03
Oct	y= 17.69ln(x)+7.99	y = 18.30ln(x)+7.58
Nov	y= 20.37ln(x)-0.54	y = 20.89ln(x)-3.76
Dec	y = 28.18ln(x)-27.48	y=30.08ln(x)-35.35
S_1	y = 19.16ln(x)+3.87	y=19.89ln(x)-5.39
S_2	y = 16.00ln(x)+16.92	y=19.30ln(x)-0.13
S_3	y = 15.84ln(x)+17.14	y=15.95ln(x)+15.29
S_4	y = 18.05ln(x)+6.94	y=17.79ln(x)+8.92
Annual	y= 15.87ln(x)+16.97	y = 16.02ln(x)+14.87

4. CONCLUSION

In this study, long-term daily rainfall data of 25 years (1990-2014) of Bundi and Kota districts was used to study rainfall variation with the help of statistical parameters namely average rainfall, correlation coefficient, standard deviation and coefficient Of variation to establish association between rainfall amounts, mean rainfall intensity, and rain days for Bundi and Kota districts on monthly, seasonal and annual basis with the help of NRCs. From the foregoing study, following conclusions may be drawn:

The following can be concluded for Bundi and Kota districts:

- For Bundi district CV is found to be highest for August (137.05%), whereas, for season S_2 (March-May) and annual series, it was 145.83% and 138.59% respectively. For Kota district CV is found to be highest for October (137.38%), whereas, for season S_4 (Oct-Dec) and annual series, it was 136.61% and 127.64% respectively.
- For Bundi district SD is found to highest for July (26.62), whereas, for season S_2 (March-May) and annual series, it was obtained as 25.73 and 23.59 respectively. For Kota district SD is found to highest for December (28.33), whereas, for season S_3 (Jun-Sep) and annual series, it was obtained as 23.44 and 22.76 respectively. For Kota district SD is found to highest for December (28.33), whereas, for season S_3 (Jun-Sep) and annual series, it was obtained as 23.44 and 22.76 respectively.
- For Bundi district Mean Daily Rainfall Intensity in case of different months varies in the range of 5.65-18.69 mm, whereas, their seasonal variation was observed in the range of 8.18-17.64 mm and it was 17.02 mm for annual data series with highly correlated values in the range of 0.88-0.95. For Kota district value of MDRI in case of different months varies in the range of 5.71-24.75 mm, whereas, their seasonal variation was observed in the range of 9.58-18.29 mm and it was 17.83 mm for annual data series with highly correlated values in the range of 0.89-0.96.
- For Bundi district value of X* (percent rain amount cumulated in first 50% of rain days) was found highest

(23.61%) for January, whereas, its highest value (58.61%) was observed for season S_1 (Jan-Feb) and for annual series, it was found as 11.16%. For Kota district value of X* (percent rain amount cumulated in first 50% of rain days) was found highest (28.98%) for January, whereas, its highest value (23.91%) was observed for season S_1 (Jan-Feb) and for annual series, it was found as 12.78%.

- For Bundi district value of percent rain days in which first 50% rainfall is cumulated (Y*) was found highest for December (100%), among seasons S_2, (March-May) as 86.28% and for annual series it was observed as 86.04%. For Kota district value of percent rain days in which first 50% rainfall is cumulated (Y*) was found highest for December (100%), among seasons S_4 (Oct-Dec) as 87.5% and for annual series it was observed as 85.56%.

- For Bundi district for season S_1 (January-February), 33.33% rain days cumulated 34.93% rainfall, whereas, during season S_2 (March-May), 75.63% rainfall accumulated in 31.74% rain days. In case of season S_3 (June-September), 32.64% rain days accounted for 78.14% of rainfall while for season S_4 (October-December), 36.84% rain days accounted 75.84% rainfall. For Kota district for season S_1 (January-February), 0.67% rain days cumulated 70% rainfall, whereas, during season S_2 (March-May), 67.83% rainfall accumulated in 0.47% rain days. In case of season S_3(June-September), 9.67% rain days accounted for 73.72% of rainfall while for season S_4 (October-December), 0.43% rain days accounted 5.75% rainfall.

- For Bundi district for annual rainfall data series (January-December), 4.72% rain days with rainfall greater than Mean Daily Rainfall Intensity accounted for 75.45% rainfall. For Kota district for annual rainfall data series (January-December), 3.59% rain days with rainfall greater than MDRI accounted for 5.56% rainfall

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