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Analysis of rainfall data for storage and irrigation planning in humid south-eastern plain of Rajasthan in India

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Abstract: A study was carried out to analyze the rainfall data for storage and irrigation planning under humid south-eastern region of Rajasthan using a time series record for 32-year (1980-2011) periods. It was observed that most of the years under observation were having adequate rainfall for all round the year crop production provided the water were collected during the rainy season. The area received 921.5 mm annual rainfall out of which 92% occurred during southwest monsoon (June-September) season. Of the total study period of 32 years, 19% were drought years, 66% were normal years and the remaining 15% were the abnormal years. The annual rainfall during the period showed negative trend (-6.955 mm/year). It showed decreasing trend (-7.782 mm/year) during the month of August and positive trends with 0.864, 3.909 and 1.192 mm/year, respectively, during month of June, July and September. The analysis generally showed that water deficit appeared during the period of November up till May and rain water was excess during the period of June up till September. During these months, rain water can be stored with the help of rainfall harvesting system. If only 50% of total rain water is collected, it forms approximately 44.16 lacs litres of water on a unit hectare basis of land. This rainfall water will be adequate for all rounds the year crop production with conservation of rain water and judicious use of rain water resources.

Keywords: Abnormal, Drought, Irrigation planning, Normal, Rainfall, Storage

INTRODUCTION

The amount and distribution of rainfall in any particular area are very helpful in sound crop planning (Singh and Sharma, 2003). The average rainfall of the region is generally considered as the basis for deciding irrigation management and cropping pattern. But, it is has been observed that the knowledge of mean annual rainfall may not be that much useful to decide irrigation and water management activities for crop production. Long term analysis is vital for firm planning and execution of crop cultivation. Various authors have analysed rainfall data for crop planning and irrigation management. Momin *et al.* (2011) analyzed the distribution of rainfall characteristics for better planning in rainfed farming system. Several workers viz. Bhakar *et al.* (2008), Sheoran *et al.* (2008), Rai and Singh (2009), Singh *et al.* (2009), Solanki and Singh (2009), Srivastava and Shukla (2009), Upadhyay and Upadhyay (2009), Singh and Dev (2012) and Singh *et al.* (2012) have studied the rainfall analysis in relation to crop planning. Further, in view of deepening water crisis almost across the globe, water harvesting has been much sought after aspect for offering at least life saving supplemental irrigation to crop plants. In this context, rainfall becomes a matter of significant importance especially for planning and designing structures for rainwater harvesting (Murty, 1994) to feed the water requirement of crops. The rainfall distribution in India is most uneven and varies considerably from region to region and from year to year. Therefore, a study was carried out to analyze the pattern of rainfall for irrigation planning and management specific to humid south-eastern region of Rajasthan. Monthly estimation of rainfall data for assessment of normal years, abnormal years, drought years, normal months, abnormal months, and drought months has been made which is expected to be useful from the view point of cropping pattern, irrigation planning and management.

MATERIALS AND METHODS

The study pertains to humid south-eastern plain under Zone V of the Rajasthan which covers an area of about 2.7 million ha and represents 7.8 per cent area of the state. It consists of four districts - Kota, Bundi, Baran and Jhalawar. This region is commonly known as *Hadauti* region, the land of *Hadas*. Chambal is the main river along with its main tributaries like *Parvati, Kali Sindh, Parwan and Banas*. The region has the expansion of fertile black soils with natural vegetation in the form of woodlands, parklands and open forests though degraded. The annual rainfall ranges between 650 mm in north-west to 1100 mm in South-east. High rainfall along with rich soils provides adequate support to the agriculture in the region. Daily rainfall data of Jhalarapatan station (24^{0}33' N and 76^0 10' E) have been used for the present investigation. A time series of rainfall record for the period of 32 years

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Table 1. Annual drought analysis in the study area.

Year	Rainfall (mm)	SD (S)	Skewness	Category
1980	454.9	74.45	2.14	D
1981	714.1	87.10	1.54	N
1982	1207.8	187.48	2.24	N
1983	920.2	120.19	1.70	N
1984	1082.6	181.78	2.67	N
1985	1331.2	203.29	2.61	A
1986	1890.8	342.69	2.66	A
1987	1247.7	205.08	2.95	A
1988	955.6	123.69	1.40	N
1989	478.8	94.06	3.11	D
1990	792.9	124.62	1.77	N
1991	741.0	136.23	2.07	N
1992	869.0	122.32	2.14	N
1993	943.8	116.39	0.96	N
1994	914.8	124.70	1.51	N
1995	828.2	110.77	1.67	N
1996	1247.8	194.06	2.04	A
1997	1168.2	99.40	0.74	N
1998	594.3	65.30	1.04	D
1999	1205.8	168.22	2.14	N
2000	655.2	125.74	3.10	N
2001	924.6	162.85	2.60	N
2002	559.8	90.26	2.47	D
2003	935.2	115.80	1.05	N
2004	929.2	162.28	2.25	N
2005	743.0	131.93	2.85	N
2006	1560.2	244.92	2.67	A
2007	497.4	66.12	1.53	D
2008	636.0	83.18	1.59	N
2009	834.0	145.84	3.01	N
2010	524.6	62.83	1.17	D
2011	1099.4	141.75	1.42	N

(1980-2011) have been collected from Water Resource Department, Government of Rajasthan, *Sinchai* Bhawan, Jaipur. Daily rainfall data was converted on monthly basis to estimate normal months, abnormal months and drought months. Yearly analysis has also been done to estimate the normal years, abnormal years and drought years. The criteria as used by Sharma *et al.* (1979) were adopted for computing drought. Any month receiving rainfall less than 50% of the average monthly rainfall has been taken as drought months; between 50% and 200% of the average monthly rainfall as normal month and that receiving rainfall more than twice of the average monthly rainfall as wet month. Also, if X is the mean annual rainfall and S is the standard deviation, then a year has been counted under drought, normal and wet if it receives rainfall less than X-S, in the interval [X-S, X+S] and more than X+S, respectively (Bora *et al.*, 2008).

The Mann–Kendall trend test (Mann 1945; Kendall 1975) has been used to analyze the trends of rainfall. Details of Mann-Kendall test can be obtained in Sneyers (1992). Some trends may not be evaluated to be statistically significant while they might be of practical interest (Basistha *et al.*, 2007). In the present study, linear trend analysis was also carried out and the magnitude of trend is estimated by Sen's Slope method (Sen, 1968). Sen's Slope method gives a robust estimation of trend (Yue *et al.*, 2002). Sen's method calculates the slope as a change in measurement per change in time.

Table 2. Annual and monthly rainfall trend in the study area (Q-Sen's Slope).

Month/Year	M-K test	Trend (Q) (mm/year)
June	0.859	0.864
July	1.119	3.907
August	-2.108*	-7.782
September	0.714	1.192
October	-1.641	0.000
November	0.000	0.000
December	0.000	0.000
January	-0.882	0.000
February	-0.555	0.000
March	0.000	0.000
April	-0.123	0.000
May	-0.738	0.000
Annual	-0.957	-6.955

*Significant at 0.05 level

RESULTS AND DISCUSSION

From the analysis of data for the period of 32 years (1980 to 2011), the average annual rainfall of Jhalarapatan station appeared as 921.50 mm with a standard deviation of 326.07 mm and a coefficient of variation of 35.38 percent. Hence, the years receiving rainfall less than 595.43 mm can be term as drought (D) years, more than 1247.57 mm as abnormal (A) years and these between 595.43 mm and 1247.57 mm as the normal (N) years. Standard deviation varied from 62.83 mm to 342.69 mm. Coefficient of skewness varied from 0.74 to 3.11. For analysis of normal, abnormal and draught months the average monthly value of mean and standard deviation are presented in Table 1. Of the total study period of 32 years, 6 years (19%) i.e. 1980, 1989, 1998, 2002, 2007 and 2010 were drought years; 21 years (66%) i.e. 1981, 82, 83, 84, 88, 90, 91, 92, 93, 94, 95, 97, 99, 2000, 2001, 2003, 2004, 2005, 2008, 2009 and 2011 were normal years and the remaining 5 years (15%) i.e. 1985, 86, 87, 96 and 2006 were the abnormal years. The seasonal distribution of rainfall was also computed. The m*onsoon* (June-September) season had contribution of 93% of total annual rainfall in the region (Fig. 1).

During the period 1980-2011, annual rainfall showed negative trend (-6.955 mm/year) in the study area (Table 2). The rainfall showed decreasing trend (-7.782 mm/year) during the month of August which was statistically significant at 0.05 level of significance. It showed positive trends i.e. 0.864, 3.909 and 1.192 mm/year, respectively, during month of June, July and September but they were statistically not significant. The rainfall values for normal, abnormal

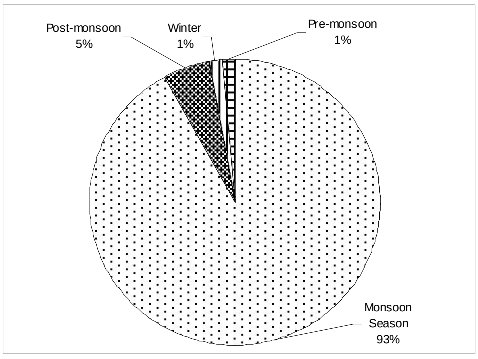

Fig. 1. *Seasonal distribution of rainfall.*

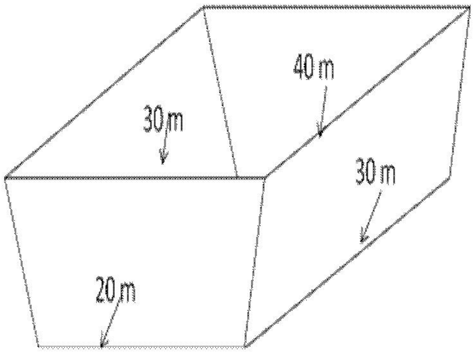

Fig. 2. *Structural dimension of trapezoidal shape of pond.*

Table 3. The amount of rainfall (mm) for abnormal or normal classification.

Month	Average rainfall	Drought (less than)	Abnormal (more than)	Normal (Range between)
June	89.65	44.83	179.30	44.83-179.30
July	294.98	147.49	589.97	147.49-589.97
August	345.57	172.78	691.13	172.78-691.13
September	116.32	58.16	232.64	58.16-232.64
October	28.88	14.44	57.75	14.44-57.75
November	14.06	7.03	28.11	7.03-28.11
December	5.77	2.88	11.54	2.88-11.54
January	6.32	3.16	12.63	3.16-12.63
February	6.69	3.34	13.38	3.34-13.38
March	3.48	1.74	6.95	1.74-6.95
April	3.04	1.52	6.09	1.52-6.09
May	6.76	3.38	13.52	3.38-13.52
Annual	921.5	595.43	1247.57	595.43-1247.57

Table 4. Decadal shift in rainfall (mm) pattern in the study

Month/Period	1980-89	1990-99	2000-09	2010-11
June	90.28	77.48	100.24	94.40
July	279.89	299.59	320.24	221.15
August	452.15	320.77	276.22	283.35
September	102.35	142.98	92.84	170.30
October	56.90	26.90	8.60	0.00
November	17.52	17.26	7.10	15.50
December	3.60	13.40	1.46	0.00
January	6.87	8.02	0.62	23.50
February	5.66	10.64	5.10	0.00
March	0.00	4.28	6.84	0.00
April	3.10	5.56	1.08	0.00
May	10.05	3.70	7.12	3.80
Annual	1028.37	930.58	827.46	812.00

and drought with average were estimated (Table 3). Maximum mean monthly rainfall in the region varied from 3.04 mm in the month of April to 345.57 mm in the month of August. Monthly mean values were found to be 76.79 mm. There is a large variability among the monthly values of rainfall for different years. The coefficient of variation varies from 0.578 in the month of August to 3.045 in the month of December. Variance is maximum during June-September. It indicates atmospheric instability during *monsoon* season. The minimum value of standard deviation was observed 6.88 during April. It indicates better weather stability during month of April. A decrease trend in decadal average rainfall has been observed during past 32 years. The highest average rainfall of 1028.37 mm was recorded during the decade (1980-89) and the lowest average rainfall of 712.00 mm was received during 2010-11 (Table 4). The data as regard to normal, abnormal and draught months are presented in table 5. It indicates that the sufficient rainfall appeared during the month of June–September and most water deficit occurred during the months of November till May. Hence, the *monsoon* season was observed as normal. During these months storage of rains water can be done for irrigation purpose. Therefore, there is need for water storage systems for irrigation planning and manage-

Table 5. Monthly drought, normal and abnormal period in respective years.

Year	Drought	Normal	Abnormal
1980	July, Sep, Oct, Nov, Jan, Feb, Mar, Apr, May	June, Aug	Dec
1981	June, Dec, Jan, Feb, Mar, Apr	July, Aug, Sep, Oct, May	Nov
1982	June, Sep, Dec, Feb, Mar	July, Aug, Oct, May	Nov, Apr,
1983	July, Nov, Dec, Jan, Feb, Mar	June, Aug	Sep, Oct, Apr, May
1984	Oct, Nov, Dec, Feb, Mar, Apr, May	June, July, Aug, Sep, Jan	
1985	June, Nov, Dec, Jan, Feb, Mar, Apr	July, Sep	Aug, Oct, May
1986	Sep, Oct, Nov, Dec, Mar, Apr	June, Aug, Jan	July, Feb, , May
1987	June, July, Nov, Mar, Apr	Sep, Feb, May	Aug, Oct, Dec, Jan
1988	Nov, Dec, Jan, Feb, Mar, Apr, May	July, Aug, Sep, Oct	June
1989	July, Sep, Oct, Nov, Dec, Jan, Feb, Mar, Apr, May	June, Aug	
1990	June, Oct, Nov, Dec, Jan, Mar, Apr, May	July, Aug, Sep, Feb	
1991	June, Sep, Oct, Nov, Dec, Jan, Mar, May	July, Aug, Feb	Apr
1992	June, Dec, Jan, Feb, Mar, Apr	July, Aug, Sep, Nov	Oct, May
1993	Oct, Nov, Dec, Jan, Feb, Apr, May	June, July, Aug	Sep, Mar
1994	Oct, Nov, Dec, Feb, Mar, Apr, May	June, July, Aug, Sep	Jan
1995	June, Oct, Nov, Feb, May	July, Aug, Sep, Apr	Dec, Jan, Mar
1996	Oct, Nov, Dec, Feb, Apr	June, July, Aug, Sep, Jan, Mar, May	
1997	Feb, Mar	June, July, Aug, Sep, Jan, May	Oct, Nov, Dec, Apr
1998	Aug, Nov, Dec, Jan, Feb, May	June, July, Sep, Oct	Mar, Apr
1999	Aug, Nov, Dec, Jan, Mar, Apr, May	June, July, Oct	Sep, Feb
2000	June, Aug, Oct, Nov, Dec, Jan, Feb, Mar, Apr	July, Sep	May
2001	Sep, Oct, Nov, Dec, Jan, Feb, Mar	June, July, Aug, Apr	May
2002	July, Oct, Nov, Dec, Jan, Mar, Apr, May	June, Aug, Sep	Feb
2003	Oct, Nov, Jan, Mar, Apr	June, July, Aug, Sep, Dec Feb, May	
2004	Sep, Nov, Dec, Feb, Mar, Apr, May	June, July, Aug, Oct, Jan	
2005	Aug, Oct, Nov, Dec, Jan, Feb, May	June, July, Sep, Apr	Mar
2006	Nov, Dec, Jan, Feb, Apr	June, July, Sep, Oct, May	Aug, Mar
2007	Aug, Oct, Nov, Jan, Mar, Apr, May	June, July, Sep, Dec, Feb	
2008	Sep, Oct, Dec, Jan, Feb, Mar, May	June, July, Aug, Apr	Nov
2009	June, Aug, Dec, Jan, Feb, Mar, Apr, May	July, Sep, Oct, Nov	
2010	July, Aug, Oct, Dec, Feb, Mar, Apr, May	June, Sep, Jan	Nov
2011	Oct, Nov, Dec, Feb, Mar, Apr	June, July, Aug, Sep, May	Jan

ment. This information may be useful for making rainwater harvesting system at household level at farmer's field or on common land for irrigation planning and

$$\text{Area} = 1\ \text{ha}$$
$$= 100 \times 100\ \text{m}$$
$$\text{Rainfall recorded} = 921.5\ \text{mm}$$
$$= 92.15\ \text{cm}$$
$$\text{Volume of rainfall} = \text{Area of field} \times \text{Depth of rainfall}$$
$$= 1\ \text{ha} \times 92.15\ \text{cm}$$
$$= 100\ \text{m} \times 100\ \text{m} \times 92.15\ \text{cm}$$
$$= 9215\ \text{m}^3$$
$$= 9215000\ \text{litres}$$

their management in this region.

Storage of rainwater: Based on study for the period under context (1980-2011), it is manifested that the long term average rainfall 921.5 mm in the region. The rain water falling on the ground can be quantified on the hectare basis as under:

Assume that 10 per cent of rain water is lost as runoff losses. It means available water which can be stored = 9215–9215×(10/100) = 8293.5m^3. Average annual rainfall in the region is 921.5 mm; even then water scarcity is encountered even with the cessation of rainfall. As per the availability of the land and rainfall, at least 50 per cent rainwater can be stored at the farm level to fulfill the irrigation requirements of the crops. Accordingly, the proposed design has been depicted through Fig. 2. The design of trapezoidal shape pond to store at least 50 per cent water has been hypothesized as under:

Bottom width = 20 m, Bottom length = 30 m, Depth = 5 m and Side slope = 1:1

Volume of pond:

$$V = \frac{(A + 4B + C) \times D}{6}$$
$$= (1200 + 3500 + 600) \times (5/6)$$
$$= 4416\ \text{m}^3$$

where,

$$A = \text{Top length} \times \text{Top width of pond}$$
$$= \{30 + (5\times 2)\} \times \{20 + (5\times 2)\}$$
$$= 1200\ m^2$$
$$4B = 4(\text{Mid length} \times \text{Mid width of pond})$$
$$= 4\{30 + (2.5\times 2)\} \times \{20 + (2.5\times 2)\}$$
$$= 3500\ m^2$$
$$C = \text{bottom length} \times \text{bottom width}$$
$$= 30 \times 20$$
$$= 600\ m^2$$

If constructed, the pond can store approximately $4416m^3 \approx 4416000$ litres of rains water (assuming no seepage). This amount of water may be useful for irrigation purpose. Singh (2011) quantified the quantity of water and highlighted the utility of water management.

Irrigation planning for crop production: Excessive use and poor management of rain water has had, in some cases, detrimental effects on soil quality, causing whole areas to be taken out of production or requiring the construction of expensive drainage works. Rainfall is, in most parts of the world, for at least part of the year, insufficient to grow crops and food production is heavily affected by the annual variations in precipitation. Irrigation is an obvious option to increase and stabilize crop production. Defining strategies in irrigation planning and management of stored rain water for crop production is very important for Indian agriculture. The effective use of rain water for crop production will be one of the main requirements. Crop water use need to be optimized through a more effective use and conservation of rainwater and by measures to increase crop production. Traditional cropping systems and genetic characteristics of the local crop types are adapted to minimize drought risks and to maintain minimum production levels under erratic rainfall supplies.

The introduction of better yielding varieties combined with a more secured water supply through improved water conservation will increase crop production per unit of water and also the introduction of measures to conserve rain water irrigation combined with appropriate plant nutrition and cultural practices, will lead to increased production levels per unit of water with equal water availability. Examples of practical procedures to assess crop water use and crop production levels under restricted rainfall and water supply are discussed (Steduto *et al.*, 2012 and Aiken *et al.*, 2013) by estimating crop evapotranspiration. The introduction of computerized procedures linked to digital data bases will greatly enhance the use of appropriate planning and management techniques for water use in irrigated and rainfed agriculture (Smith, 2000).

Water use for crop production is depending on the interaction of climatic parameters that determine crop evapotranspiration and water supply from rain. The analysis of climatic information for crop water use is therefore a key element in developing appropriate strategies to face the global water crisis and looming food shortages. A better understanding of the intricate interactions between climate, water and crop growth needs to be a priority area in agrometeorological studies.

Conclusion

It was concluded from the analysis that the rainfall of the study area is having decreasing trend year after year. These changes are manifested at monthly, seasonal and annual levels. It highlights less water availability for crops and natural vegetation. For most of the years, annual rainfall was adequate for all rounds the year crop production. Provided the water is stored there cannot be sustainable crop production. Options to increase water use efficiency include a more effective use and conservation of rain water as well as an increase in production per unit of water used.

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