

Hydrometeorology of the Rajasthan desert rainfall

Abstract

The Western part of the Rajasthan state in India called 'West Rajasthan' is characterized by a desert environment with low and erratic rainfall and sandy soil. This paper deals with some interesting features of rainwater resources in West Rajasthan based on rainfall data of stations for the 124 years (1871-1994) in a manner that the information becomes useful for utilization of its water resources for human activities. The study involves the seasonal features of climate, rainwater of its different districts and of the whole area of West Rajasthan, rainstorms that produced heavy point and areal rainfalls and amount of water generated by them, variability of rainwater that produced droughts and floods in West Rajasthan and evaluation of probable maximum precipitation (PMP). The average annual rainfall of West Rajasthan is 29.5cm in 14 rainy days and is the lowest rainfall area in India. The highest and lowest annual total rainfalls in the same period were 72.3cm in 1917 and 3.7cm in 1918 and the 75% dependable rainfall is 22.5cm. Although, rainfall is quite low, widespread flood rainfalls do occur anywhere in West Rajasthan and produce millions of cubic meters of runoff water. The human population in the desert area revealed that about 33% of the total human population of the Rajasthan state with a density of 114 persons per square kilometer lives in the arid environment of West Rajasthan where the source of fresh water from rainfall is quite low. When looked at densities of 10 to 20 persons in other desert areas of the world, it becomes obvious that West Rajasthan desert area is uniquely populous.

Keywords: hydrometeorology, desert, monsoon, depression, rainstorm

Introduction

There is considerable variation of the climatic features across the state of Rajasthan in India. The state has broadly been divided into three main climatic regions: arid or desert region, semi arid region and sub- humid region on the basis of rainfall. West Rajasthan comprising of the 10 districts of Barmer, Bikaner, Churu, Ganganagar, Jaisalmer, Jalore, Jodhpur, Hanumangarh, Nagaur and Pali with an area of 195091km² is characterized by a desert or arid environment of India (Figure 1). It is a part of the Great Indian Desert or Thar Desert that forms a natural boundary between India and Pakistan. Extremely low rainfall with high aridity index, long hot summers with very high temperatures going as high as 50°C and cold winters with the temperature as low as -6°C, low humidity and high evaporation which is many times the rainfall are some of the noteworthy climatic features of this desert or arid region. Characteristics of the Rajasthan desert have been discussed by many scholars.¹⁻⁷ Compared to other desert regions of the world, West Rajasthan desert is unique in the sense that it comes under the influence of the Indian Southwest monsoon (or summer monsoon) during July and August and occasionally rain producing weather systems like 'lows' and 'depressions' from the Bay of Bengal and the Arabian sea permeate up to parts of Rajasthan and produce heavy rainfall in the desert region. For example, in August, 1973, a severe rainstorm associated with a low pressure area occurred over Rajasthan which caused widespread heavy rainfall over entire Rajasthan during 13 - 19 August. The districts of Jaisalmer, Barmer, Pali & Jalore in West Rajasthan were marooned for days together. Some stations received in one day rain amounts exceeding their respective mean annual rainfalls. Jaisalmer and Barmer recorded 20cm and 23cm of rain on 16 and 18 August, 1973 respectively while their annual rainfalls are about 18cm. and 31cm respectively. The total volume of water generated by the storm was estimated at 32293 million

cubic meters.⁸ The Meli bund dam was overtopped and breached on 20th August resulting in large loss of life and damage to property. Such instances of heavy rainfall in the desert area are of great importance to formulate new hydrological insights to utilize water in the desert area of West Rajasthan. The main purpose of this paper is to present some aspects of hydrometeorology of the Rajasthan desert rainfall useful for improving plant and human life and agriculture.



Figure 1 Map of Rajasthan showing the 10 arid districts of West Rajasthan.

Seasonal features of climate of West Rajasthan

The dry cold winter and hot summer are the two principal seasons of the West Rajasthan desert when the weather conditions are exactly opposite to one another. Between these two seasons are two transitional periods: the southwest monsoon or rainy period and the post monsoon period. Thus, the year may be divided into four seasons:

cold winter season (December- February), hot summer season (March- May), southwest monsoon or rainy season (June- September) and Post monsoon season (October- November). The winter season starts from December and continues up to February. It is a season of low temperature and January is the coldest month when at some places the temperature falls below freezing point. Jaisalmer (Figure 1) recorded the lowest temperature of -5.9°C on 12 January 1967. A few rain spells of light to moderate rain occur in winter when extra tropical disturbances called 'Western Disturbances' in meteorological parlance pass over the area through Punjab. The month of March marks the beginning of the hot summer season and continues up to the date of onset of monsoon. Temperatures start rising progressively from March onwards and May and June are the hottest months with the average daily maximum temperatures ranging between 40°C and 45°C and minimum temperatures between 24°C and 29°C . The heat during the summer is intense and scorching making West Rajasthan the hottest region in India. The station Ganganagar had recorded a temperature as high as 50°C in June 1934. This is also the period of strong dust raising winds and a blanket of suspended dust covers the whole area and extends to heights of 3 km or more. Summer season stays for a longer duration than other seasons. Technically monsoon season is the period between the date of onset and date of its withdrawal. The normal date of onset of monsoon over West Rajasthan is about 15 July and starts to withdraw during the first week of September. It stays over West Rajasthan for about 2 months. West Rajasthan receives 90% of the normal annual rainfall during monsoon season which not only

nourishes the rain fed kharif crops but meets the demands of water by the people. The annual rainfall over the West Rajasthan is least in the country. A record of 124 years of annual rainfall for West Rajasthan is presented in Table 1.

Area and population of different districts

In India a population survey is conducted at an interval of 10 years and is known as decennial survey. Last decennial survey was conducted in 2011. The area, population and the population density of different districts of West Rajasthan based on 2011 survey are given in Table 1. Population density varies from district to district. The population density of West Rajasthan is much less than India's average of 324 persons/km². This is mainly due to a number of factors such as climatic conditions, fertility of soils, availability of water, means of transportation and communication, growth of trade and infrastructural facilities. The Jaisalmer district occupying 20% of the area of West Rajasthan has only 3% of population which is typical of the desert environment. The areas and population are more or less proportionate in other districts. However, it is interesting to note that the West Rajasthan is the most densely populated desert region in the world with a population density of 114 people per km². About 33% of the total human population of Rajasthan lives in the arid environment of West Rajasthan. The main occupation of the people is agriculture and animal husbandry. The information is useful to determine the total requirement of water for population in each district.

Table 1 Area and population of different districts of west Rajasthan⁹

No.	Districts	Area (km ²)	% of total area of arid west Rajasthan	Population (2011 census)	% of total population	Density (persons/km ²)
1	Barmer	28387	15	26,04,453	12	92
2	Bikaner	27244	14	23,67,745	11	87
3	Churu	16830	9	20,41,172	9	121
4	Ganganagar	7944	4	19,69,520	9	248
5	Hanumangarh	12690	7	17,79,650	8	140
6	Jalore	10640	5	18,30,151	8	172
7	Jodhpur	22850	12	36,85,681	16	161
8	Jaisalmer	38401	20	6,72,008	3	17
9	Nagaur	17718	9	33,09,234	15	187
10	Pali	12387	6	20,38,533	9	165
total	10	195091	100	222,98,144	100	114

Causes of low rainfall in the arid region of west Rajasthan

A heat low over Pakistan and West Rajasthan region develops from April onwards and becomes intense in June- July and persists there till about September end. Under its influence southwesterly moist winds generally prevail over Rajasthan during the monsoon months. But compared to other parts of the country the rainfall of West Rajasthan is the lowest. The main reason for this is that the depth of monsoon current is quite shallow limited to a kilometer or so. This is over run by dry air from the north circulating anti-cyclonically between 1.5 and 4 km and inhibiting formation of precipitation.¹ The rainfall in the monsoon months over West Rajasthan mostly occurs in association with the monsoon depressions and low pressure areas which move

up to parts of Rajasthan from the Bay of Bengal and the Arabian sea. According to,⁸ the number of depressions which moved across Rajasthan during the period 1891-1970 was of the order of 145 of which about 129 occurred during the month of July to September. Of the 145 disturbances, 114 had their origin from the Bay of Bengal, 9 moved from the Arabian Sea and the remaining were lows. The activity of the monsoon therefore is not felt over Rajasthan unless a low pressure area or depression moves towards it from east. In most cases, it was observed that when a monsoon depression/low is near northwest Madhya Pradesh, Rajasthan starts getting rainfall which increases in intensity as it approaches Rajasthan. When a low or depression moves west- north-westwards through Rajasthan, well distributed rain occurs over a large part of Rajasthan including West Rajasthan.

Rainfall over west Rajasthan

Rainfall over different districts of west Rajasthan

Like other parts of the country, the southwest monsoon is the main feature in the hydrometeorology of West Rajasthan. Table 2 gives the averages of seasonal and annual rainfall and rainy days for the 10 districts of West Rajasthan. In West Rajasthan the average annual rainfall ranges from 16.5cm in Jaisalmer district to 49.2cm in Pali district. As a matter of fact Jaisalmer which is a sandy desert area is the district with the lowest rainfall in the whole of India. The annual rainfall is higher in the districts of Jalore, Pali and Nagaur with 49.2cm in Pali. The number of rainy days during the monsoon period from June to September over West Rajasthan varies from 8 in Jaisalmer district to 23 in Pali district. About 90 % of the rain occurs during the monsoon season and the balance of 10 % occurring due to western disturbances and thunderstorms. A vast area extending from Barmer in the southwest to Ganganagar in the northeast has annual rainfall of less than 30cm. This region is not normally exposed to moist air masses for extended period and rainfall is irregular averaging only 2 or 3 days per month. However, in favorable synoptic situations, which infrequently occur over extensive part of the region, up to 40cm of rain may fall within a few days resulting in flooding.

Rainfall over West Rajasthan as a whole

The average monthly and annual rainfall, the number of rainy days and the coefficient of variability worked out on the basis of rainfall data for the 124 year period (1871-1994) of West Rajasthan as a whole are given in Table 3. This table shows that the average annual rainfall of West Rajasthan as a whole is about 29.5cm with a coefficient of variability of 37%. The region receives about 87% of the annual rainfall during the southwest monsoon season within 14 rainy days which not only nourishes the kharif crops but enriches all sources of water bodies. The bulk of the remaining 13% occurs mostly in the winter months (December- February) in association with western disturbances. Most of the annual rainfall is concentrated in the two months of July and August within 10 rainy days. Table 3 also gives the monthly variability of rainfall. The coefficient of variation for West Rajasthan during the monsoon months varies from 53 to 90%. Variability during the non monsoon months is very high indicating the erratic nature of the rainfall during these months. Among the four monsoon months, the lowest variability of rainfall of 53% is in July, when the monsoon is at its peak. The annual rainfall map of Rajasthan is given in Figure 2. The annual rainfall in West Rajasthan varies significantly and ranges from 40cm in the southeast extremity to less than 15cm in the northwest part of Jaisalmer.

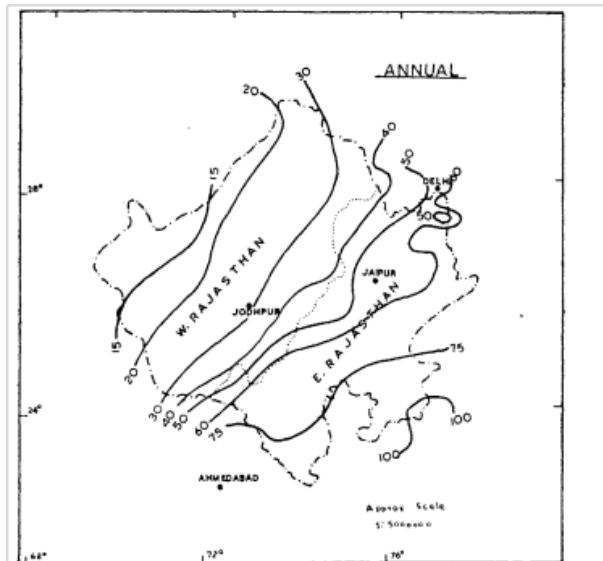
Table 2 Average seasonal and annual rainfall (cm) & rainy days in the districts of west Rajasthan

Sr.no	District		Winter (Dec-Feb)	Summer (Mar-May)	Monsoon (June-Sept)	Post monsoon (Oct-Nov)	Annual
1	Barmer	RF	0.8	1.2	25.4	0.4	27.8
		RD	0.6	0.8	11.1	0.2	12.7
2	Bikaner	RF	1.4	1.8	22.6	0.63	26.4
		RD	1.4	1.8	13.1	0.3	16.5
3	Churu	RF	1.8	2	28.1	0.7	32.6
		RD	1.9	2	15.1	0.4	19.4
4	Ganganagar	RF	2.3	1.6	18.2	0.2	22.3
		RD	2.4	1.7	10.1	0.2	14.4
5	Hanumangarh	RF	2.5	2.1	25.1	0.6	30.3
		RD	2.4	2.2	13	0.3	17.9
6	Jaisalmer	RF	0.7	0.7	15	0.1	16.5
		RD	0.5	0.6	6.6	0	7.7
7	Jalore	RF	0.9	0.9	39.7	0.7	42.2
		RD	0.7	0.7	16.9	0.4	18.7
8	Jodhpur	RF	1.1	1.4	28.9	0.5	31.9
		RD	1.1	1.4	14.7	0.4	17.6
9	Nagaur	RF	1.7	2.1	34.5	0.7	39
		RD	1.5	2	18.1	0.5	22.1
10	Pali	RF	1.1	1.5	45.9	0.7	49.2
		RD	1	1.3	19.7	0.6	22.6

RF- Rainfall in cm and RD- Rainy days (rainfall of 2.5mm or more)

Table 3 Average monthly and annual rainfall (cm) of west Rajasthan (1871-1994)

Months	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Rainfall (cm)	0.5	0.6	0.4	0.3	1.1	2.9	9.2	9.5	4	0.5	0.2	0.3	29.5
% of annual	1.7	2	1.4	1	3.7	9.8	31.2	32.2	13.6	1.7	0.7	1	100
CV (%)	135	155	195	211	114	90	53	70	99	205	261	199	37
Rainy days	0.5	0.6	0.4	0.3	0.7	1.8	4.9	4.9	2.1	0.3	0.1	0.2	16.8

**Figure 2** Annual rainfall (cm) map.

Inter annual variation of rainfall

Being located in the western most part of India, West Rajasthan comes under the influence of monsoon currents after the monsoon has advanced over the rest of the country. The normal dates of the advance of the monsoon over West Rajasthan are 2 July in the southern parts and 8 July in the extreme western parts. The monsoon begins to withdraw by the first week of September and the withdrawal is normally completed by the middle of September. The late commencement of monsoon, breaks in monsoon and its early withdrawal cause variability in rainfall from year to year. This variability is present in the records of annual and seasonal rainfall totals of West Rajasthan. In order to show the variation of rainfall over West Rajasthan as a whole, average annual rainfalls for the 124-year period (1871-1994) are given in Table 4. From this table, it can be seen that rainfall is not the same every year over West Rajasthan. The total annual rainfall varies significantly from year to year. The highest and lowest annual rainfalls over the period 1871-1994 were 72.3cm in 1917 and 3.7cm in 1918 the next year and the 75% dependable rainfall is 22.5cm. Moreover, in the 8, 17 & 54 years in the 124 years, the total annual rainfall exceeded 50.0cm, 40.0cm & 30.0cm respectively. There were years during which heavy rainfall resulted in the formation of runoff water in the rivers.

The general features of the frequency distribution of annual rainfall for the 124-year period (1871-1994) are shown in Figure 3. The shape of the frequency distribution is said to be skewed because frequencies are not symmetrically distributed about the mean. The distribution is skewed to the right or positively skewed which shows larger frequency of relatively low values and a few extremely high

values. In such a distribution the modal value is generally smaller than the median value which in turn is smaller than the mean value. The lack of symmetry of a distribution can best be studied by computing the coefficient of skewness (k) which is defined as follows:

$$\text{Skewness } (k) = (\text{mean} - \text{mode}) / \text{standard deviation} \quad (1)$$

For $k=0$, the distribution is symmetrical; for $k>0$ the distribution is skewed to the right; and for $k<0$ the distribution is skewed to the left. Based on the annual rainfall data of West Rajasthan the value of skewness is computed as $+0.18$.⁹

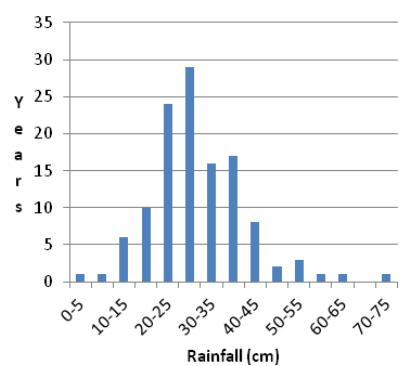
**Figure 3** Annual rainfall distribution.

Table 4 Yearly rainfalls (cm) over west Rajasthan (1871-1994),¹⁰ (average annual rainfall = 29.5cm)

Year	0	1	2	3	4	5	6	7	8	9
1870	-	33.4	30.6	34.6	25.4	33.8	36.7	17.4	35.2	36
1880	26.6	34.9	33.8	23.8	38.2	20.2	27.7	17.4	25.1	29.1
1890	24.9	20.9	43.5	54	37.4	22.5	26.6	35.2	25.4	5.4
1900	30.5	15.6	20	29.7	22.1	11	29.8	38.6	61	44.1
1910	30.4	14	27.6	22.1	29.3	15.2	41.9	72.3	3.7	28.9
1920	25.9	23	22	28.6	26.8	13.4	42.6	31.7	27.3	30.6
1930	20.9	37.5	26.4	36.6	31.1	24	24.9	29.1	19.3	12.6
1940	31.3	21.2	36.5	25.9	59.2	36.2	19.7	29.4	23.5	25
1950	31.1	21.8	23.3	37.2	28	40.9	40.5	25.6	28.7	36.6
1960	22.6	40.9	29	17.5	33.9	22.5	26.3	37.4	11.6	10.3
1970	34.9	23.2	21	42.4	18.5	51.6	45.6	36.9	39	38.1
1980	21.4	28.1	35.1	49.6	21.7	26.1	20.2	16	29.3	27.9
1990	53.1	17.8	54.1	32.5	36.9					

Incidence of heavy rainfall in the districts of west Rajasthan

Although the average annual rainfall of West Rajasthan is quite low there are some fascinating aspects of the heavy rains seen in the desert area of West Rajasthan. An examination of daily rainfall data of all stations in this region has shown that associated with certain meteorological situations like monsoon depressions or lows when rainfall of the order of 25 to 50cm in one day has occurred at individual stations in the past. Particularly intriguing are that at some stations more than their average annual amount was recorded in a single day (see Table 5 for more such surprises). Chotan recorded

35.6cm of rainfall on 26 August, 1944 as against the annual average rainfall of 23.9cm. Balotra recorded 33.7cm of rainfall on 26 July, 1995 as against the annual average rainfall of 29.4cm. Shergarh recorded 29.9cm on 2 September, 1908 against the annual average of 26.5cm. Bap received 26.7cm of rainfall on 8 August, 1933 as against the annual average of 18.4cm. Heavy falls of rain exceeding 25cm in one day are not therefore uncommon in this region. These are comparable with similar figures at some of the normally semi arid and sub humid stations in the country. Table 5 gives the heaviest one day rainfalls recorded at stations in the various desert districts of West Rajasthan during the period 1890 to 2007.

Table 5 Highest daily rainfalls (cm) in the arid districts of west Rajasthan¹¹

District	Station	Highest rainfall (cm)	Date & Year	Annual rainfall (cm)	District	Station	Highest rainfall (cm)	Date & year	Annual rainfall (cm)
Barmer	Chotan	35.6	26.8.1944	23.9	Jalore	Bhinmal	28.4	14.8.1941	47.8
	Barmer	25.6	13.8.1944	31.4		Jalore	26.8	5.7.1990	36.3
	Sheo	20.3	28.7.1929	20.8	Jodhpur	Shergarh	29.9	2.9.1908	26.5
	Pachpadra	37	12.8.1992	27		Phalodi	22.5	12.7.1964	23.6
	Balotra	33.7	26.7.1995	29.4		Jodhpur	21.6	12.9.1924	36.6
	Gudha	27	6.8.1990	26.6	Bilara		30	31.7.1999	43.5
	Siwana	20.5	18.8.1973	34.4		Nagaur	30.7	24.7.1929	38.9
Bikaner	Palana	26.6	7.8.1933	28.7	Nagore		24.2	28.8.1953	31
Churu	Sardarshar	22.6	9.7.196	28.1		Mertacity	27.9	16.7.1943	41.9
	Sujangarh	20.9	22.7.1957	37.2	Pali	Desuri	38.1	31.7.1952	62.6
Ganganagar	Ganganagar	25.2	31.8.1928	30.3		Bali	35	5.7.1990	56.4
Jaisalmer	Bap	26.7	8.8.1933	18.4	Jaitaran		22.6	17.7.1979	37.8
Jalore	Sanchor	51.2	16.9.1893	38.1		Sojat	30.5	6.7.1908	47.2
	Jaswantpura	32.5	6.8.1990	47.1	Pali		35.7	5.7.2007	41.1

Severe rainstorms over west Rajasthan

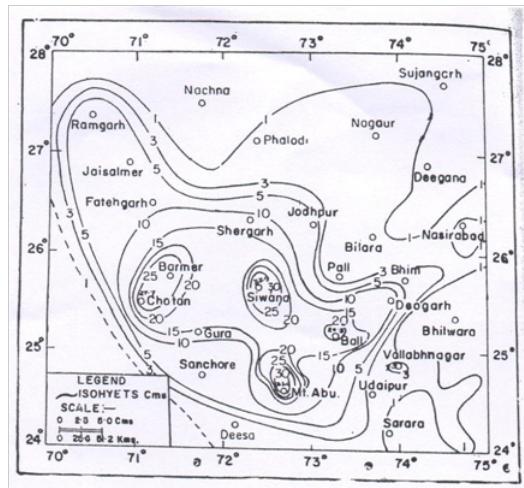
Flood producing rainstorms are rare due to poor rainfall in West Rajasthan but unusually high quantum of rain from severe rainstorms associated with lows or the cyclonic storms coming from the Bay of Bengal as discussed in section 4 can result in floods in West Rajasthan. Daily rainfalls for the period 1871-2010 were surveyed to determine the severe rainstorms that produced the greatest areal rainfalls over the West Rajasthan. This yielded the following list of severe rainstorms.

- 30-31 July 1952 with centre at Desuri (24° 46' N, 75° 53' E)
- 17-19 August 1973 with centre at Siwana (25° 39' N, 72° 25' E)
- 25-27 July 1995 with centre at Balotra

Of these, the August 17-19, 1973 rainstorm gave the greatest areal rainfalls over West Rajasthan. In a sense, this was considered for analysis.¹⁰

Rainstorm of august 1973 over west Rajasthan

The 1973 rainstorm was associated with the movement of a low pressure area from the central Uttar Pradesh which strengthened and became well marked on 14th and 15th August during its movement over central Rajasthan. It concentrated into a depression near Jaisalmer on 17th August and after recurring in a south-easterly direction, deepened on 18th August but weakened again into low pressure area over east Rajasthan on 19th August and finally merged with the seasonal trough. During this period a western disturbance also moved across the extreme north of the country between 16-18 August. In association with both these systems, vigorous monsoon conditions prevailed all over Rajasthan. This rainstorm was quite unique as it caused widespread heavy rainfall over entire Rajasthan between 13-19 August. It was found that the storm gave the greatest areal depths of rainfall over east Rajasthan from 13 to 15 August and West Rajasthan recorded the greatest rain depths from 17-19 August. Some stations in West Rajasthan recorded in one day rainfall amounts exceeding their respective mean annual rainfall. Jaisalmer which is situated in the heart of the desert recorded 20cm of rainfall on 16 August while its mean annual rainfall is about 18cm. Other stations like Jalore and Barmer recorded 17 and 23cms respectively on 17 and 18 August. The isohyetal map of this rainstorm for the period 17-19 August is shown in Figure 4. The water potential generated by this rainstorm for each day of the rainspell over West Rajasthan is given in Table 6.¹¹



Rajasthan and caused loss of life and property. It is more important in the context of desert hydrology to study the occurrence of flood rainfall in West Rajasthan in terms of rainfall. The¹² has defined flood as a situation occurring over an area in a year when the rainfall is more than 125% of the normal rainfall. If the rainfall is more than 125-150% of normal, it is called moderate flood rainfall and if rainfall is more than 150% of the normal, it is called severe flood rainfall. On the basis of this criterion, the rainfall of each year in West Rajasthan was classified as moderate or severe flood rainfall during the period 1871-1994. The years of moderate and severe flood rainfall are listed in Table 7. This table shows that 27 flood rainfall years have occurred during the 124 years and during these years the annual rainfall was in excess of 125 to 245% of normal rainfall. As such on an average one flood rainfall year can be expected to occur in 4 or 5 years. It is more interesting to see that 2, 2 and 1 times 2 (1916-1917; 1955-1956), 3 (1892-1894; 1907-1909), and 5 (1975-1979) consecutive flood rainfall years respectively with high amount of rainfalls have also occurred. Flood rains however, occur at irregular intervals in West Rajasthan.

Probable maximum precipitation (PMP)

It has been seen in section 7 that the maximum rainfall as high as 51cm has been recorded in one day at a station in West Rajasthan. This magnitude of rainfall however, varies from place to place. It is of great importance to know the highest rainfall that is physically possible over a given station or an area. This is called the Probable maximum Precipitation (PMP) and according to¹³ is defined as the greatest depth of rainfall for a given duration that is physically possible for a given station or specified area. The main use of PMP is for the safe design of a variety of hydrological structures as also has a key role in flood plain management. The one-day PMP for stations in West Rajasthan were estimated from the frequency analysis of the annual maximum rainfall data of stations in West Rajasthan.¹⁴ Figure 5 shows the one-day PMP for West Rajasthan. This figure shows that one-day PMP estimates vary from 30cm to 90cm.

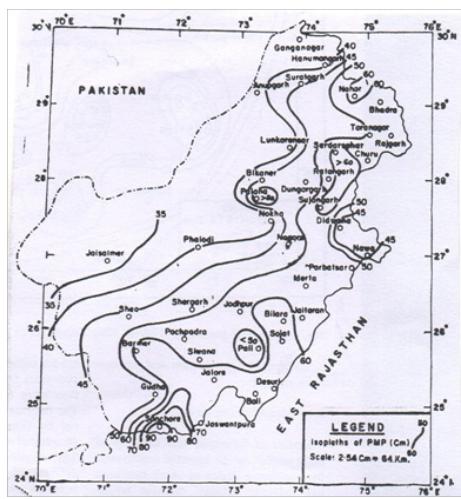


Figure 5 PMP (cm) for one-day over west Rajasthan.

Conclusions

Low rainfall and high temperature are the most visible characteristics of the desert climate. Despite harsh conditions, it is

interesting to note that West Rajasthan is the most densely populated region in the world with a population density of 114 persons/km². Also, as compared to other desert regions of the world, West Rajasthan desert in India receives considerable amount of rainwater. There is a long felt realization that if we could reclaim this desert and make it more suitable for water availability for agriculture then there would be economic benefits for all concerned. An attractive feature of this paper is that it provides interesting information on climate and rainwater resources in West Rajasthan that is useful for sustainable availability of water and the alleviation of water scarcity.

Acknowledgments

None.

Conflicts of interest

The author declares that there are no conflicts of interest.

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