Original Research Article

Long-Term Rainfall Data Analysis for Contingency Crop Planning for Indore Region of Madhya Pradesh

ABSTRACT

In order to weatherproof the region and prepare befitting contingent crop planning, the rainfall patterns, magnitudes, probabilities of Indore region of Malwa plateau of Madhya Pradesh were assessed systematically. The study revealed that probability of receiving annual rainfall of 663.9, 799, 969, 1163 and 1357 mm was computed to be 90, 75, 50, 25 and 10 % respectively in the region. The numbers of rainy days revealed a decreasing trend with time. The probability of occurrence of weekly rainfall of 0-9; 0-22; 1.1 – 51.7; 1.6-101.7 and 2.0- 175.9 mm was estimated to be 90, 75, 50, 25 and 10 percent, respectively. The initial and conditional probabilities of rainfall (Markov chain probability) of this region of Malwa plateau, for the 8 decades i.e. from 1930 to 2010 with a limit of 25 mm have been worked out. The gamma distribution function was found to be the best fit function for 2, 3 and 5 days' consecutive rainfall. The maximum rainfall for 2, 3 and 5 days with a recurring period of one year was 167.3, 223.7 and 266.7 mm, respectively. Similarly, for 2 and 5 year recurring period the maximum rainfall was estimated to be 206.7, 241.5, 298.5; and 266.2, 312.6, 315.9 mm in 2, 3 and 5 days, respectively. Thus, long-term rainfall data analysis for the region would provide a useful information for necessary weatherproofing of agricultural crops and crop planning, in terms of selection of crops/cultivars, efficient water and nutrient management.

Key Words: ***Annual Rainfall, Incomplete Gamma Distribution of precipitation, Frequency analysis***

INTRODUCTION

Indian Agriculture is largely characterized by rainfed farming, with more than 60% of the cropped area being dependent on rainfall. Uncertainties of weather pose a major threat to food security of the country. Extreme weather events like high intensity rains, cyclones, hail storms, prolonged dry spells, droughts, heat and cold waves and frost injury cause considerable damage to crop production every year. Also, an erratic distribution of rains often affects the crop yields.

The Malwa region of Central India represents the similar weather phenomenon. Rainfed nature of agriculture in the Malwa Plateau of MP has made the agriculture highly susceptible to the variations in distribution and patterns of rainfall. On the other hand extreme events like high temperature, excess rains and frost, have resulted in huge loss in productivity(Anonymous,2013a). Natural calamities like drought flood and hailstorms are the common features of the region. Under such situation an efficient use of available climatic resources, besides soil and water resource conservation may help in minimizing the adverse effect of weather extremes and provides an opportunity to benefit from favorable weather. Also the Weather forecast may provide a very useful input to the farmers as advisories that assist in planning to boost the agricultural production and minimize the adverse impact of it.

Therefore, short and long term agro-climatic analysis is crucial for planning of inputs and their management. Also, a clear understanding of the rainfall characteristics of a region is essential for efficient crop planning of that particular region. The information about rainfall amount, probability of occurrence of weekly rainfall events, probability of occurrence of dry spells, etc. would be of great use for planning better water management, since cropping pattern of any region is governed by rainfall distributions and pattern. Frequency analysis of rainfall data has been attempted for different places in India by many workers such as Jeevrathnam and Jaykumar, (1979), Singh (2001), Rizvi *et al.* (2001), Yadav and Saxena, (2014) and Pawar *et al.* (2015) Rana and Thakur (1998) and Jat *et al.* (2010) used incomplete gamma distribution for analysis of weekly rainfall in Himachal Pradesh and Udaipur (Rajasthan) region. Dhekale *et al.* (2014) utilized the rainfall and meteorological data for yield forecast of groundnut in Kolhapur. Similarly, Agnihotry and Sridhara (2014) analysed the weather data for rice yield forecast by statistical model in Karnataka. Anandakumar *et al.* (2008) analysed the spatial variability and seasonal behavior of rainfall pattern of Tamil Nadu to assess the impact of weather aberrations on crop yields. Many regions have reported the rainfall patterns and probabilities for crop planning at different scales (Chakraborty and Mandal, 2008, Chand *et al*, 2011 and Jakhar *et al.*, 2011). Probability analysis of rainfall is necessary for solving various water management problems and to access the crop failure due to deficit or excess rainfall. Scientific predictions of rains and crop planning done analytically may prove a significant tool in the hands of farmers for better economic returns (Bhakar *et al.*, 2008). Generally, the cropping pattern is suggested considering the rainfall probabilities at different levels (Mahale and Dhane, 2003). Probabilty and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances. Studies on rainfall probability in India have also been carried out earlier by many workers (Victor *et al.,* 1991). Rainfall at 80 percent probability can be safely taken as assured rainfall, while 50 percent chance can be considered as the maximum limit for taking any risk (Bhakar *et al.,* 2008). Since, there is a limited information on rainfall analysis and changes in rainfall pattern in Malwa Plateau of Madhya Pradesh, the present study was aimed to analyze the long term rainfall data of the region to assess the probabilities of rainfall and also efficient contingent crop planning for the region.

MATERIAL AND METHODS

The study region

The Indore district lies in the heart of Malwa plateau and is spread in an area of 3831 sq km between 22°31' and 23°05' N latitudes and 75°25' and 76°15' E longitudes at an altitude of 618 m above MSL (Fig. 1). It is bounded by *Ujjain, Khandwa, Dewas* and *Dhar* districts in the north, south, east and west respectively. The district lies partly in the Chambal sub basin of the Ganga basin (75%) and partly (25%) in the Narmada basin (Anonymous, 2013_b). It is bounded by *Vindhyan* ranges in the North-West. The average annual rainfall in the Madhya Pradesh state is 1160 mm, while it is 961 mm for Indore district, in which 91.2 % is received during the south-west monsoon season.

Rainfall data analysis

The daily meteorological data recorded for the period 1930 to 2010 (81years) at observatory situated at 76° 54′ E longitude and 22°43′ N latitude in College of Agriculture, Indore, were used for analysis. There are several methods for rainfall analysis as suggested by Buishad (1977), Hills and Morgan (1981), Sivakumar, *et al.* (1979). In the present study, parameters developed at the International Crop Research Institute for Semi-Arid Tropics, (ICRISAT) (Virmani *et al*., 1982) were used for the analysis of rainfall.

Incomplete Gamma Distribution of precipitation (mm)

The Gamma distribution is one of the most appropriate models for interpreting rainfall data. Its function is expressed by;

$$g(x)= (x^{y-1} e^{-x/\beta}) / \{\beta^{y} T(y)\} \quad [y, \beta>0, x\geq 0] \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

$$E(x)= y\beta \text{ and } \sigma^2= y\beta^2, \quad \sigma^2= \text{variance}$$

Where'x' is a continuous random variable. 'β' is a scale parameter, 'y' is a shape parameter and T(y) is the ordinary gamma function of y. However, this formula gives a poor estimate of the parameters.

Adequate estimates are approximated by;

$$\hat{y}= \frac{1}{4A}\{1+\sqrt{1+\left(\frac{4}{3}\right)A}\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

and $\beta = x/y$, $\bar{X} = \frac{\sum X_i}{n}$

where A is given by

$$A= \ln(1/n \, \Sigma x_i) - 1/n \, \Sigma \ln (x_i)$$

The distribution function from which probabilities may be obtained is $G(x) = \int_0^x g(t)dt$.

To determine the amount of rainfall at any given probability it is put in the standard form t (F)=x/β. Incomplete Gamma Distribution (Precipitation (mm) were worked out for 90, 75, 50, 25 and 10% probabilities.

Initial and conditional probabilities of rainfall (Markov chain probability)

The estimation of the likely occurrence of rainfall is extremely useful for agricultural planning (Virmani *et al*., 1982). The probability of receiving a certain amount of rainfall in a given period, say a week, is termed the initial probability. The probability of that week being wet, P(W), would be the fraction of the number of years of record during which rain of the given amount or more was observed during that week. This concerns only the probability of having rain in any specific week. Another probability *i.e.* 'conditional probability' assumes that two events are often related in such a way that the probability of occurrence of the latter (B) depends upon whether the first (A) had occurred or not. By using such analyses, one can examine the probability of the occurrence of a rainy week, P(W), or the probability of having rain next week if it rains this week, P(w/w), and the probability of having rain next week if particular week is dry, P(W/D).

Therefore, initial probability for a given week having rain in excess of a specific amount is denoted by

P (W) = number of years which have rain more than specific amount of rainfall/ no. of years of data at any given week.

following formulae were used:

i) P(Wi)=n(Wi)/N …………………………….. (iii)

ii) P (Di) = n(Di)/N ……………………………. (iv)

Where, n= No of years getting wet week for a particular threshold level of rainfall.
n(Wi) = Number of occurrence of a wet week in the i^{th} period.
n(Di) = Number of occurrence of a dry week in the i^{th} period.
N=Total number of years [n(Wi) + n(Di)]

iii) Conditional probability of a given wet week to be followed by a wet week, P (W/W).

P (Wj/Wi) = n(Wj, Wi) / N(Wi) ………………….. (v)

Where n(Wj,Wi)= Number of occurrence of a wet week in i^{th} and j^{th} period.
n(Wi)= Number of occurrences of a wet week in i^{th} period.

iv) Conditional probability of a given dry week to be followed by a wet week, P(W/D).

P(Wj/Di) = n(Wj,Di)/N(Di) ………………………(vi)

Where n(Wj,Di) =Number of occurrences of a dry week in i^{th} period and a wet week in j^{th} period.

The above analyses were done considering long term data (1930-1996) of rainfall for 67 years. Further, rainfall data were randomly chosen from low rainfall (<700 mm), normal rainfall (951-981mm) and high rainfall (1292-1915 mm) and subjected to analyses so as to arrive at more accurate conclusions. The years 1952, 1957, 1965, 1966 and 1992 were having low annual rainfall of 627, 664, 553, 594 and 555 mm, respectively. Similarly, normal rainfall years included were 1937, 1960, 1964, 1980, 1981 receiving annual precipitation of 981, 942, 964, 973 and 951 mm, respectively. Ten high rainfall years 1933 (1311 mm), 1934 (1460 mm), 1938 (1292 mm), 1944 (1453 mm), 1954 (1359 mm), 1961 (1568 mm), 1973 (1915 mm), 1976 (1335 mm), 1994 (1445 mm) and 1996 (1299 mm) were also selected for computations. A more complete description of the conditional probability analysis is given by Robertson (1976), cited in Virmani (1982). The initial and conditional probabilities of rainfall

(Markov chain probability) of Indore district of Malwa Plateau was determined with a limit of 25 mm.

Frequency analysis for 2, 3 and 5 days of rainfall

Daily long term data (81 years) of rainfall from 1930 -2010 was employed to estimate the frequency of rainfall. The daily data in a particular year was converted to 2 to 5 days' consecutive days' rainfall by summing up the rainfall of corresponding previous days. The probability or frequency of any event was calculated by the Weibull's equation:

$$P(\%) = \left(\left(\frac{m}{n}\right) + 1\right) * 100$$ or P(%)=((m/n)+1) .... (vii)

Where, m = descending order rank number given to the event, which is assigned after arranging the events in by their magnitude; n = total number of observations (no of years of data)

RESULTS AND DISCUSSION

Annual rainfall trends at Indore region of Malwa Plateau

The annual rainfall during 1930-2010 was ranged from 341.8 to 1898.5 mm. The lowest rainfall was recorded in the year 1975 and the maximum in the year 1973. The 81 years' average rainfall was 993.6 mm with a standard deviation of 270.62 mm which clearly indicated its erratic distribution pattern of rainfall in the region. The linear trend line fitted for annual rainfall data showed a decreasing trend in annual rainfall over the years. The decade wise analysis of rainfall also showed a decreasing trend of average annual rainfall (Fig. 3). Similarly, the mean rainfall of every 20 years for the period 1930-1949, 1950-1969, 1970-1989 and 1990-2010 was 1076.5, 992.1, 975.2 and 933.6 mm, respectively. Yet again this pattern clearly indicates a gradual decrease in the annual rainfall of Indore region with time. A change detection study using monthly rainfall data for 306 stations distributed across India was attempted by Rupa Kumar et al. (1992). They also showed that areas of the northeast peninsula, northeast India and northwest peninsula experienced a decreasing trend in summer monsoon rainfall. Analysis of month wise rainfall data further revealed that only 7.17 percent of the total average rainfall is received during the months of January, October, November, and December. The months of February to May receive only a very meager fraction of total rainfall (2.21%). The months of June to September are the crucial months from agriculture productivity point of view as most of the rainfall occurs during this period. Also, this is the period to harvest and conserve the rainwater for rabi season crops. However, no specific trend was observed with respect to change in month wise rainfall on a decadal scale.

Similar to rainfall, the number of rainy days per year showed a decreasing trend since 1930 to 2010 and found erratic with a high degree of coefficient of variation (21.05%). The average numbers of rainy days recorded were 48.12 ±10.13. The highest number of rainy days (69) were recorded in the year 1963 and the lowest number of rainy days (23) were recorded in the year 1975 (Fig. 4). The last five decades showed less number of rainy days as compared to the initial period of the study which again indicate that the number of rainy days at Indore region of Malwa Plateau of Central India is decreasing over time. Goswami et al. (2006) used daily rainfall data to show the significant rising trends in the frequency and magnitude of extreme rain events, and a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000. Similar decrease in rainy days has also been reported by Vijay Kumar et al. (2010) from the analysis of long term rainfall trends in India. Mean week wise rainfall of area shows that monsoon in the region sets in after 20th standard meteorological weeks (SMW) and continues till 41st SWM (Fig. 5). These are the normal periods of onset and withdrawal of monsoon in Malwa plateau.

Incomplete Gamma distribution probabilities

The Gamma distribution is one of the most appropriate models for interpreting rainfall data. The precipitation with a probability of 90, 75, 50, 25 and 10 per cent calculated by incomplete gamma distribution for 52 SMW is given in the Table 1. Analysis of 81 years' data revealed that there was 90, 75, 50, 25 and 10% probability of receiving annual rainfall of 663.9, 799.0, 969.7, and 1163.2 and 1357.7 mm respectively. The data further revealed that probability of occurring rainfall between 0-9, 0-22 and 1-51.7 mm in a week was 90, 75 and 50% respectively. However, there was probability of only 25 and 10% for receiving rainfall amount of 1.6 - 101.7 and 2.0 - 175.9 mm, respectively.

The mean precipitation for each SMW revealed that the highest weekly rainfall of 5.6, 17.7, 47.4, 101.7, 175.9 mm was observed in 17th SMW and the least of 0.6, 0.8, 1.1, 1.6, 2.0 mm in 1st SMW. Probability analysis of long term data is useful for effective planning of farm operations and crop management under both rainfed and irrigated agro-ecosystems Virmani *et al*. (1982) and Sharma *et al*. (1999). In *Malwa* region, soybean is a major crop during rainy season and is highly susceptible to both the water logging and prolonged water stress conditions. The probabilities for different amount of rainfall for each week would be of immense use for managing favorable moisture regime during crop growing period.

Initial and conditional probabilities of rainfall

Initial and conditional probabilities of rainfall (Markov chain probability) of Indore region of Malwa Plateau, for the period from 1930 to 2010 with a limit of 25 mm are presented in Table 2. The data revealed that there is probability of wet week, for SMW 6 to 39, 41, and 43 to 46. All the other SMW showed zero percent probability of getting a wet week.

The conditional probability analysis revealed zero probability of wet week followed by wet week, P(w/w), for SMW 1 to 7, 30 to 32 and 36 to 52. Remaining SMWs have some probability of wet week followed by wet week (Table 2). The highest probability of 0.80% was observed for 17th SMW. The probability of dry week, P(d/w), followed by dry week showed a reverse trend. The probability of wet week followed by a dry week was higher for SMW 11 to 26 which, ranged from 0.26 to 0.76 per cent. The SMW 1, 2, 3, 5, 42, 48, 49, 50, 51 and 52 showed zero probability of wet week followed by a dry week. The opposite trend was obtained in case of dry week followed by wet week. Sharma *et al*., (1999) concluded from 67 years rainfall analysis translated into an extremely useful information for agriculture planning specifically for water and nutrient management for rainfed crops. Prakash and Rao (1986) also highlighted use of probability and frequency analysis of rainfall data to determine the expected rainfall at various probabilities. Rainfall at 80 per cent probability can be safely taken as assured rainfall, while 50 per cent chance can be considered as the maximum limit for taking any risk and further indicated usefulness of weekly rainfall analysis for crop planning in the Kota region. In a similar line, Jat *et al.* (2010) also reported similar observation for crop planning through analysis of weekly, monthly and seasonal probability analysis of rainfall. It is worth mentioning here that the weekly distribution of rainfall and its probability is helpful in crop planning by identifying the periods of drought, normal and excess rainfall (Ray *et al.,* 1980). In most of studies the workers have suggested the cropping pattern considering the rainfall amount at different probability levels (Ravindrababu *et al.,* 2010). Kulandaivelu (1984) analyzed the daily precipitation data of Coimbatore for a period of 70 years for weekly totals by fitting incomplete Gamma distribution model. The data indicate the likely commencement of rains, periods of drought length of growing season and end of growing season. Based on the assured rainfall at (50%) probability level, suitable cropping system was suggested for Coimbatore.

Frequency analysis for 2, 3 and 5 days' rainfall

Analysis of consecutive days' maximum rainfall of different return periods is a basic tool for safe and economic crop planning along with help in designing of small dams, bridges, culverts, irrigation and drainage network, etc. Though the nature of rainfall is erratic and varies with time and space, yet it is possible to predict rainfall fairly accurately for certain return periods using various probability distributions (Upadhaya and Singh, 1998). The 2, 3 and 5 days' consecutive maximum rainfall for different return periods are presented in Tables 3 and 4. The gamma distribution function was found to be the best fit function for 2, 3 and 5 consecutive day rainfall. The data presented revealed that a maximum annual rainfall of 167.38 mm in two days, 223.7 mm in three days and 266.7 mm in five days is expected to occur every year at Indore region of Malwa Plateau.

Similarly, a maximum rainfall of 206.7 mm in two days, 241.5 mm for 3 days and 298.5 mm for five days is expected to occur every alternate years. For 5 years return period the maximum amount of rainfall expected to occur at Indore is 266.2 mm in two days, 312.6 mm for 3 days and 315.7 mm in five days. On the basis of 20 and 40 years return period there is probability to receive a maximum of 276.6 and 314 mm rainfall in two consecutive days, respectively. However the recurrence interval of 10, 20, 40 years is more important for designing hydrologic structures and is of less use for agriculture planning. For "three days" consecutive maximum rainfall of 321.56 mm and 375.8 mm is expected in 13 and 27 years, respectively. With a return period of 8 and 16 years the maximum amount of rainfall which expected to occur in consecutive 5 days was estimated to be 325.9 mm and 399.5 mm respectively. Frequency analysis of rainfall data has been attempted for different places in India by Jeevrathnam and Jaykumar (1979), Sharda and Bhushan (1985) Prakash and Rao (1986), Aggarwal *et al.* (1988), Bhatt *et al.* (1996), Mohanty *et al.* (1999) and Rizvi *et al.* (2001).

The statistical parameters calculated for 1 day as well as consecutive 2, 3, and 5day maximum rainfall indicated occurrence of 250 mm, 314 mm, 375 mm and 399.5 mm maximum rainfall for consecutive 1, 2, 3, and 5 days, respectively, with mean respective values of 2.71, 5.43, 8.14 and 13.5 mm. The standard deviation was observed maximum in case of consecutive 5-days rainfall (34.55 mm) which was followed by 3 days (24.68 mm), 2 days (18.90 mm) and 1 day (11.56 mm) rainfall. The coefficient of variation was maximum in case of consecutive 3-day rainfall *i.e.* 33.02 followed by 2 days (28.75 mm), 5 days (25.66 mm) and minimum in case of 1-day rainfall (23.49 mm). Skewness and Kurtosis was higher in case of 1-day rainfall and decreased with the increase consecutive rainfall from 2 days to 5 days.

Contingency crop planning for better crop production in the region

Contingency crop planning (CCP) refers to mitigate any unexpected, unsual, unfavourable and hence unwanted accidental weather situations occurring at any time without prior knowledge at any time before the crops are sown or even after the crops are sown. Thus, CCP assumes greater significance in view of the erratic behavior of the rainfall in the Malwa plateau of Central India. It is very important to select crops for *kharif* and *rabi* season carefully since rainfed farming is practiced in the region especially during *kharif* season. There is good chance of occurring rain during July to August with some showers during September. The region is occupied with black soils and the opportunity to harvest water in farm ponds, is high which can be recycled during rabi season crops when the probability of rainfall is very meager (Somasundaram *et al.,* 2014). Since *kharif* cropping is a primary activity in the rainfed areas, where monsoon variability plays a crucial role in production, the contingency crop planning will require a greater attention in these areas. Longterm strategic approaches are also needed to efficiently conserve and utilize rain water on the one hand and in season tactical approaches to mitigate the adverse effects of weather aberrations.

Gram and mustard crops needs to be preferred in the region where ground water availability for *rabi* crops is limited. Over the period there is decline in the rainfall as well as number of rainy days in the year which is a matter of concern for future. Hence there would be need to develop short duration varieties of crops like maize, pigeonpea, adjustment in sowing and harvesting time of crops, intensive soil and water conservation practices to harvest and recycle the rainwater on watershed basis, digging of farm ponds wherever possible for enhanced ground water recharge etc. Further the information of rainfall behavior might be useful in predicting the incidence of insect pests and diseases in the region.

CONCLUSIONS

The present study has examined trends in the monthly, seasonal and annual rainfall at a regional scale, Indore district of Malwa Plateau of Madhya Pradesh based on “81 years” rainfall data. The rainfall analysis of Indore region indicated a decreasing trend with respect to total rainfall and number of rainy days. Analysis of “81 years” rainfall data revealed that there is 90% and 75% probability of occurrence of 664 mm and 799 mm annual rainfall, respectively. The pattern of occurrence of rainfall revealed that there is a great potential for rain water harvesting in the district for better (Rabi) season crops along with assured rainy season crop. Soybean is the prominent crop during (kharif) season in the region that requires low but assured rainfall. However, if the rain delayed for one or "two weeks" short duration varieties like maize, pigeonpea and cow pea may be opted for the region. It may be succeeded by crops like gram, mustard, safflower etc. Soybean-wheat and maize-wheat crops may be preferred in the areas having assured irrigation facilities. Thus, rainfall analysis for a particular region would provide a useful information for agriculture planning specifically for selection of crops, water and nutrient management in the rainfed region.

REFERENCES

Aggarwal, M.C., Katiyar, V.S. and Ramu Babu, 1988. Probability analysis of annual maximum daily rainfall of U.P. Himalayas. *Indian J. of Soil Cons.* **16**(1): 35-42.

Agnihotri, G and Sridhara. 2014. Pre -harvest forecasting models for kharif rice yield in coastal Karnataka using weather indices. *Journal of agrometeorology* **16**(2):207-209.

Anandakumar, S., Subramani, T. and Elango, L. 2008. Spatial variation and seasonal behaviour of rainfall pattern in lower Bhavani river basin, Tamil Nadu, India. *The Ecoscan* 2 (1): 17-24.

Anonymous, 2013$_{a.}$ Madhya Pradesh State Action Plan on Climate Change. State knowledge mgt centre on climate change, Govt. of MP. pp. 185

Anonymous. 2013$_b$. District ground water information booklet. Ministry of Water Resources, Central Ground Water Board, North Central Region, pp. 8.

Bhatt, V.K., Tiwari, A.K. and Sharma, A.K. 1996. Probability models for prediction of annual maximum daily rainfall of Datia. *Indian J. of Soil Cons.* **24** (1): 25-27.

Bhakar, S.R.,Iqbal,M.,Devanda,Mukesh,Chhajed,Neeraj and Bansal,A.K. (2008). Probabilty analysis of rainfall at Kota. *Indian J. Agric. Res*. **42** : 201-206.

Buishand, T.A. 1977. Stochastic modeling of daily rainfall sequences, Wagenengin. The Netherlands, 54-56.

Chakarborty, P.B., and Mandal, A.P.N. 2008. Rainfall characteristics of Sagar island in Sunderban, West Bengal, Indian *J. Soil Cons.* **36** (3): 125-128.

Chand, M., Kumar, D., Singh, D., Roy, N. and Singh, D.K. 2011. Analysis of anuual rainfall for crop planning in Jhansi District of Bundelkhand zone of UP. *Indian J. Soil Cons.* **39** (1): 20-26.

Dhekale, B.S., Sheraz Mahdi, S., Dalvi, T.P. and Sawant, P.K. 2014. Forecast models for groundnut using meteorological variables in Kolhapur, Maharashtra. *Journal of Agrometeorology,* **16** (2): 238-239.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanam, M. S. and Xavier, P. K. 2006. Increasing trends of extreme rain events over India in a warming environment. *Science* **314**: 1442–1445

Hills, RC., and Morgan, H.T. 1981. Rainfall Statistics: An Interactive approach to the analysis of rainfall records for agricultural purposes. *Expl. Agric*. **17**: 1-16.

Jakhar, P., Hombe Gowda, H.C., Naik, B.S. and Barman, D. 2011. Probability analysis of rainfall characteristics of Semiliguda in Koraput, Orissa. *Indian J. Soil Cons*. **38**(2):69-74.

Jat, M.L., Sharma, K.L., Sammauria, R., Sharma, S.K., Balyan,J.K. and Sharma, R.K. 2010. Cropping pattern and crop diversification in response to climatic change in dry sub humid of South-East Rajasthan. *Indian.J. Dryland Agric. Res. & Dev.* **25**(2): 112-116.

Jat, M.L., Sumauria, R., Balyan, J.K. and Sharma, R.K. 2010. Crop planning in semi-arid tracks in Udaipur region based on analysis of weekly rainfall. *Indian J. of Soil Cons*. **38** (2): 69-74.

Jeevrathnam, K. and Jay Kumar, K .1979. Probability analysis of maximum daily rainfall for Ootacamud. *Indian J. of Soil Cons.* **7**(1): 10-16.

Kar, Amal and Joshi,N.L. 2009. Contingency crop planning for dryland areas in relation to climate change. *Indian Journal of Agronomy* **54**(2): 237-243.

Kulandaivelu, R.(1984). Probability analysis of rainfall and evolving cropping system for Coimbatore. *Mausam,* **5**(3):257-258.

Mahale, D. and Dhane, S.S. (2003). Rainfalll analysis in relation to paddy crop in coastal saline soils at panval. *J. Agrometerol.,* **5**(1): 89-92

Mohanty, S., Marathe, R.A. and Singh, S. 1999. Probability analysis of annual maximum daily rainfall for Amravati. *Indian J. of Soil Cons*. **43**(1): 15-17.

Pawar,P.B., Jadhav, J. D., Patil, S. R. and Amrutsagar, V. M. 2015. Weekly rainfall variability and probability analysis for Solapur in respect of crop planning. *The Ecoscan*, **9** (1 & 2): 117 – 122.

Prakash, C. and Rao, D.H.1986. Frequency analysis of rain data for crop planning, Kota. *Indian J. of Soil Cons.* **14**(2): 23-26.

Rana, R.S. and Thakur, D.R. 1998. Rainfall analysis for crop planning in Kullu Valley of Himachal Pradesh*. Indian J. of Soil Cons*. **26** (2): 144-146.

Ravindrababu, B.T., Rajegowda, M.B., Janardhanagowda, N.A. and Girish , J. (2010). Weekly, Monthly and Seasonal Rainfall at Bengaluru in Kranataka. *J. Agrometeorol*., **12**: 263-265.

Ray, C.R., Senapati, P.C. and Lai, R. (1987). Investigation of drought from rainfall data at Gopalpur (Orissa). *Indian J. Soil Conservat.,* **15**(1):15-19

Rizvi, R.H., Singh, R., Yadav, R.S., Tewari, R.K., Dadhwal, K.S. and Solanki, K.R. 2001. Probability analysis of annual maximum daily rainfall for bundelkhand region of Uttar Pradesh*. Indian J. of Soil Cons.* **29** (3): 259-262.

Robertson, G.W. (1976). Dry and wet spells. UNDP/FAO TunRazak Research Centre. Sungh: Tekam, Malayasia, Project Field Report, *Agrometerology*, **A-6**:25-27

Rupa Kumar, K., Pant, G. B., Parthasarathy, B. and Sontakke, N. A. (1992) Spatial and sub seasonal patterns of the long term trends of Indian summer monsoon rainfall. Int. J. Climatol. **12**: 257–268.

Sharda, V.N. and Bhushan, L.S. (1985). Probability analysis of annual maximum daily rainfall for Agra.*Indian J. of Soil Cons.,* **13**(1): 16-20.

Sharma, R.A., Gupta, R. and Verma, O.P.1999.Agroclimatology of Malwa region, Technical bulletin No. DRS/99/4, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur MP, India

Singh, R.K. (2001). Probability analysis for prediction of annual maximum daily rainfall of Eastern Himalaya (Sikkim Mid Hills). *Indian J. of Soil Cons*. **29**(3): 263-265.

Somasundaram, J, B. L. Lakaria, R. Saha, N.K. Sinha, P.Jha R. S. Chaudhary, R.K. Singh, D. Mandal, K.M.Hati, K. Ramesh, M. Vassanda Coumar, A.K. Biswas, P. Dey, K. Sammi Reddy and A. Subba Rao. (2014). Management of Stressed Soils of Dryland Agriculture in Semi-Arid Tropics-A Review. *Indian J. of Soil Cons*. **42** (2): 178-187.

Sivakumar, M.V.K., Virmani, S.M. and Reddy, S.J. 1979. Rainfall climatology of West Africa: Niger. Information Bulletin No.5, ICRISAT, Hyderabad, India. 66 pp.

Tomar, V.S., Gupta, G.P. and Kaushal, G.S.1995. Soil resources and agroclimatic zones of Madhya Pradesh, Deptt.of Soil science & Agril. Chemisttry, JNKVV, Jabalpur, M.P. Bulletin, PP. 132+

Upadhaya, A. and Singh, S.R.1998. Estimation of consecutive days' maximum rainfall by various methods and their comparison. *Indian J. of Soil Cons.*, **26**(3): 193-201.

Vijay Kumar, Jain, S.K. and Yatveer Singh .2010. Analysis of long-term rainfall trends in India. *Hydrological Sci. J.* **55** (4): 484-496.

Victor, U.S., Ramana, Rao B.V., Srivastava, N.N. and Vijaykumar, P. (1991). Rainy season and variability for planning in Andhra Pradesh. *Indian J. Dryland Agric. Res & Dev.*, **6**(1,2): 1-12

Virmani, S.M., Sivakumar, M.V.K. and Reddy, S.J. 1982. Rainfall probabilities estimates for selected locations of semiarid India. *ICRISAT Research Bulletin No.*1 ICRISAT, Patancheru, P.O. 50234, AP, India.

Yadav, R.C. and Saxena, S.C. (2014) Partial Duration Trend Analysis for Yearly Rainfall and its Sequential Distribution: a Conceptual Model. *The Open Hydrology Journal*, **8**: 1-7.

Fig. 1. Location map of the study Malwa region

Table 1. Incomplete Gamma Distribution (rainfall, mm) in standard meteorological weeks (SMW)

SMW	Probability (%)					SMW	Probability (%)				
	90	75	50	25	10		90	75	50	25	10
1	0.6	0.8	1.1	1.6	2.0	27	0.3	1.7	7.4	20.8	41.9
2	0.6	0.9	1.2	1.6	2.0	28	0.2	1.4	6.5	19.6	40.9
3	0.5	0.8	1.2	1.8	2.3	29	0.1	0.9	3.7	10.4	20.9
4	0.2	0.7	1.7	3.6	6.2	30	0.2	0.6	1.9	4.2	7.5
5	0.4	0.8	1.4	2.3	3.4	31	0.2	0.7	2.2	5.5	10.2
6	0.0	0.0	1.3	6.0	9.3	32	0.1	0.7	3.2	9.3	19.2
7	0.0	0.0	2.6	9.0	13.9	33	0.1	0.5	2.5	7.2.	14.7
8	0.0	0.0	4.1	10.6	15.5	34	0.2	0.7	1.9	4.2	7.2
9	0.2	1.1	4.7	13.6	27.7	35	0.1	0.6	2.2	5.8	11.2
10	0.2	1.6	7.4	21.6	44.2	36	0.2	0.7	1.6	3.3	5.5
11	1.3	5.5	18.3	44.8	83.5	37	0.1	0.6	1.7	4.1	7.5
12	1.4	6.2	20.9	51.7	96.9	38	0.3	0.7	1.6	3.0	4.8
13	2.6	10.1	31.5	74.0	134.9	39	0.3	0.7	1.3	2.2	3.3
14	5.3	16.5	44.0	93.9	162.0	40	0.3	0.7	1.7	3.4	5.6
15	5.1	15.1	38.7	80.6	136.9	41	0.3	0.8	2.2	4.6	8.0
16	5.8	17.3	44.9	94.0	160.4	42	0.3	0.7	1.7	3.3	5.5
17	5.6	17.7	47.4	101.7	175.9	43	0.3	0.7	1.5	2.7	4.3
18	7.3	20.2	49.4	99.7	166.4	44	0.2	0.7	2.0	4.5	8.1
19	9.0	22.8	51.7	99.4	161.3	45	0.3	0.7	1.6	3.0	4.9
20	5.3	14.8	36.4	73.6	123.0	46	0.2	0.6	1.7	3.9	6.9
21	2.7	11.0	35.2	84.0	154.7	47	0.4	0.8	1.3	2.1	3.0
22	2.6	10.5	34.2	82.3	152.1	48	0.4	0.7	1.3	2.0	2.9
23	3.2	12.3	38.5	90.8	165.6	49	0.4	0.7	1.4	2.3	3.4
24	1.8	7.8	26.3	64.5	120.5	50	0.4	0.7	1.5	2.5	3.9
25	1.1	5.6	20.6	53.4	102.7	51	0.5	0.8	1.2	1.7	2.3
26	0.5	3.3	15.3	45.7	94.8	52	0.5	0.8	1.6	3.0	4.6

Table 2. Initial and Conditional Probabilities of Rainfall (Markov chain probability) in different standard meteorological weeks (SMW) for a limit of 25 mm

SMW	Initial Probabilities			Conditional Probabilities			SMW	Initial Probabilities			Conditional Probabilities		
	P(W)	P(D)	P(W/W)	P(W)	P(D)	P(W)		P(W)	P(D)	P(W/W)	P(W)	P(D)	P(W)
1	0.00	1.00	0.00	0.00	1.00	0.00	27	0.16	0.84	0.35	0.63	0.93	0.07
2	0.00	1.00	0.00	0.00	1.00	0.00	28	0.16	0.84	0.31	0.69	0.87	0.13
3	0.00	1.00	0.00	0.00	1.00	0.00	29	0.10	0.90	0.08	0.92	0.90	0.10
4	0.01	0.99	0.00	0.00	0.99	0.01	30	0.02	0.98	0.00	1.00	0.97	0.03
5	0.00	1.00	0.00	1.00	1.00	0.00	31	0.04	0.96	0.00	1.00	0.96	0.04
6	0.02	0.98	0.00	0.00	0.98	0.02	32	0.09	0.91	0.00	1.00	0.91	0.09
7	0.06	0.94	0.00	1.00	0.94	0.06	33	0.05	0.95	0.14	0.86	0.96	0.04
8	0.05	0.95	0.20	0.80	0.96	0.04	34	0.02	0.98	0.25	0.75	0.99	0.01
9	0.14	0.86	0.25	0.75	0.87	0.13	35	0.05	0.95	0.50	0.50	0.96	0.04
10	0.15	0.85	0.36	0.64	0.89	0.11	36	0.01	0.99	0.00	1.00	0.99	0.01
11	0.41	0.59	0.58	0.42	0.62	0.38	37	0.02	0.98	0.00	1.00	0.98	0.03
12	0.51	0.49	0.58	0.42	0.54	0.46	38	0.01	0.99	0.00	1.00	0.99	0.01
13	0.58	0.42	0.61	0.39	0.45	0.55	39	0.01	0.99	0.00	1.00	0.99	0.01
14	0.70	0.30	0.74	0.26	0.35	0.65	40	0.00	1.00	0.00	1.00	1.00	0.00
15	0.65	0.35	0.70	0.30	0.46	0.55	41	0.04	0.99	0.00	0.00	0.96	0.04
16	0.68	0.32	0.70	0.30	0.36	0.64	42	0.00	0.98	0.00	1.00	1.00	0.00
17	0.72	0.28	0.80	0.20	0.46	0.54	43	0.01	0.99	0.00	0.00	0.99	0.01
18	0.69	0.31	0.69	0.31	0.30	0.70	44	0.02	0.98	0.00	1.00	0.98	0.03
19	0.70	0.30	0.68	0.32	0.24	0.76	45	0.01	0.99	0.00	1.00	0.99	0.01
20	0.63	0.37	0.70	0.30	0.54	0.46	46	0.02	0.98	0.00	1.00	0.98	0.03
21	0.56	0.44	0.59	0.41	0.50	0.50	47	0.00	1.00	0.00	1.00	1.00	0.00
22	0.54	0.46	0.53	0.47	0.44	0.56	48	0.00	1.00	0.00	0.00	1.00	0.00
23	0.57	0.43	0.70	0.30	0.59	0.41	49	0.00	1.00	0.00	0.00	1.00	0.00
24	0.51	0.49	0.54	0.46	0.54	0.46	50	0.00	1.00	0.00	0.00	1.00	0.00
25	0.43	0.57	0.51	0.49	0.65	0.35	51	0.00	1.00	0.00	0.00	1.00	0.00
26	0.32	0.68	0.40	0.60	0.74	0.26	52	0.00	1.00	0.00	0.00	1.00	0.00

Table 3. Consecutive 2, 3 and 5 days' maximum rainfall (mm) in for various return periods

Return Period	2 days maximum rainfall	Return Period	3 days maximum rainfall	Return Period	5 days maximum rainfall
1	167.4	1	223.7	1	266.7
2	206.8	2	241.6	2	298.5
5	247.1	5	298.5	5	316.0
10	266.2	9	312.6	8	325.9
20	276.6	13	321.6	16	399.5
40	314.5	27	375.8	-	-

Table 4. Statistical parameters for 1, 2, 3, and 5-day consecutive maximum rainfall

Statistical parameter	1 day	2 day	3 day	5 day
Minimum, mm	0.00	0.00	0.00	0.00
Maximum, mm	250.44	314.45	375.80	399.50
Mean, mm	2.71	5.43	8.14	13.46
Standard deviation, mm	11.56	18.90	24.68	34.55
Coefficient of variation,%	23.49	28.75	33.02	25.66
Skewness	8.15	6.44	5.23	4.10
kurtosis	94.23	56.71	39.96	21.52

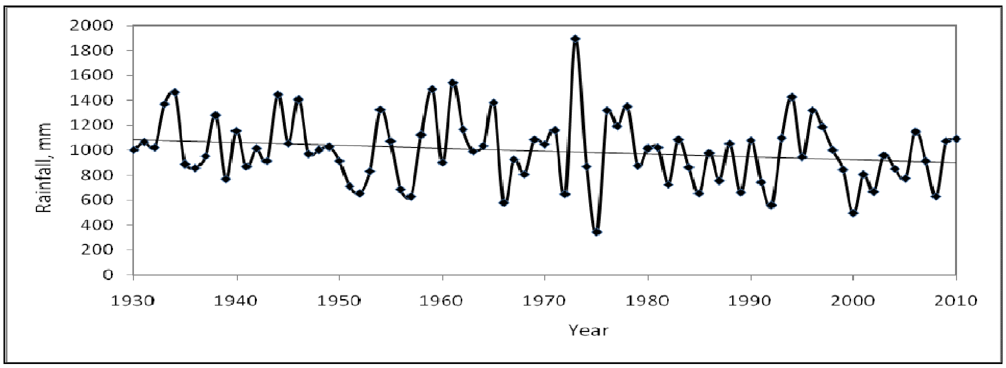

Fig. 2. Annual rainfall spread over 81 years (1930-2010).

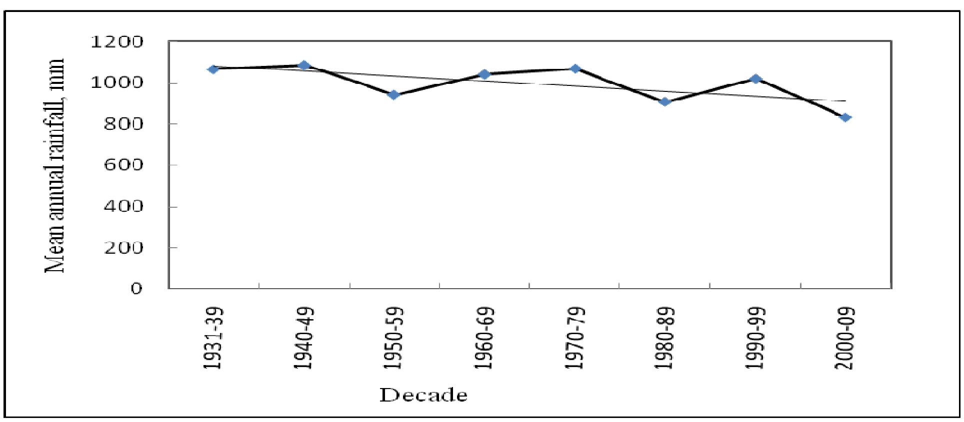

Fig. 3. Decade-wise mean annual rainfall in Indore region

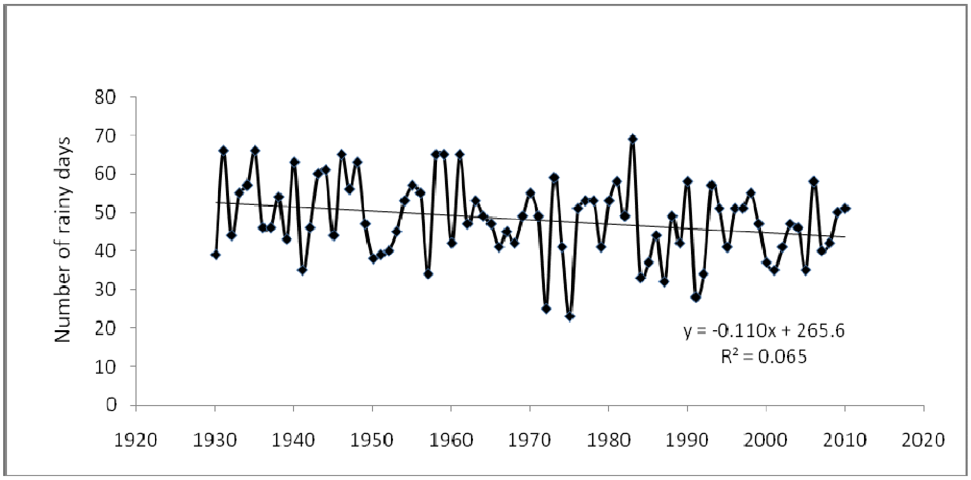

Fig. 4. Number of rainy days over the years

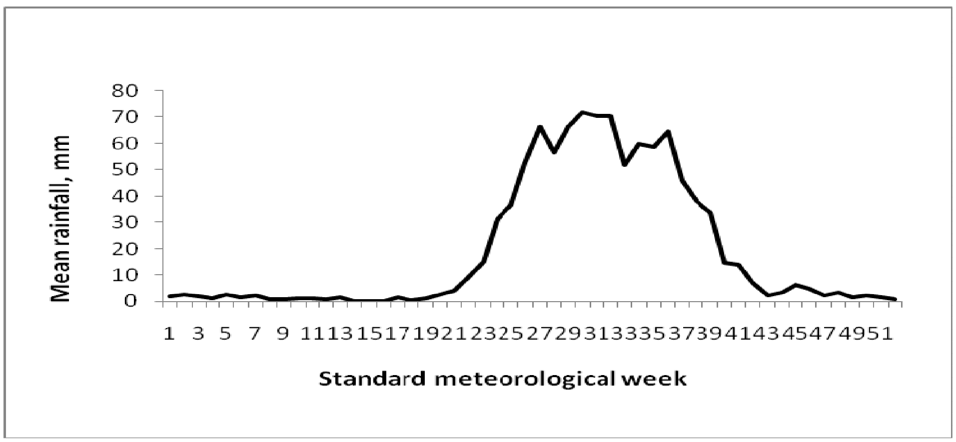

Fig. 5. Mean weekly rainfall in Indore region