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## **Original Research Article**

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

#### ABSTRACT

7 In order to weatherproof the region and prepare befitting contingent crop planning, the rainfall 8 patterns, magnitudes, probabilities of Indore region of Malwa plateau of Madhya Pradesh were assessed 9 systematically. The study revealed that probability of receiving annual rainfall of 663.9, 799, 969, 1163 10 and 1357 mm was computed to be 90, 75, 50, 25 and 10 % respectively in the region. The numbers of 11 rainy days revealed a decreasing trend with time. The probability of occurrence of weekly rainfall of 0-9; 12 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, 13 respectively. The initial and conditional probabilities of rainfall (Markov chain probability) of this region 14 of Malwa plateau, for the 8 decades i.e. from 1930 to 2010 with a limit of 25 mm have been worked out. 15 The gamma distribution function was found to be the best fit function for 2, 3 and 5 days' consecutive 16 rainfall. The maximum rainfall for 2, 3 and 5 days with a recurring period of one year was 167.3, 223.7 17 and 266.7 mm, respectively. Similarly, for 2 and 5 year recurring period the maximum rainfall was 18 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-19 term rainfall data analysis for the region would provide a useful information for necessary 20 weatherproofing of agricultural crops and crop planning, in terms of selection of crops/cultivars, efficient 21 water and nutrient management.

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

#### 23 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.

30 The Malwa region of Central India represents the similar weather phenomenon. 31 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 32 33 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 34 35 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 36 37 effect of weather extremes and provides an opportunity to benefit from favorable weather. 38 Also the Weather forecast may provide a very useful input to the farmers as advisories that 39 assist in planning to boost the agricultural production and minimize the adverse impact of it.

40 Therefore, short and long term agro-climatic analysis is crucial for planning of inputs 41 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 42 43 amount, probability of occurrence of weekly rainfall events, probability of occurrence of dry 44 spells, etc. would be of great use for planning better water management, since cropping 45 pattern of any region is governed by rainfall distributions and pattern. Frequency analysis of 46 rainfall data has been attempted for different places in India by many workers such as 47 Jeevrathnam and Jaykumar, (1979), Singh (2001), Rizvi et al. (2001), Yadav and Saxena, 48 (2014) and Pawar et al. (2015) Rana and Thakur (1998) and Jat et al. (2010) used incomplete 49 gamma distribution for analysis of weekly rainfall in Himachal Pradesh and Udaipur 50 (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 51 52 the weather data for rice yield forecast by statistical model in Karnataka. Anandakumar et al. 53 (2008) analysed the spatial variability and seasonal behavior of rainfall pattern of Tamil Nadu 54 to assess the impact of weather aberrations on crop yields. Many regions have reported the 55 rainfall patterns and probabilities for crop planning at different scales (Chakraborty and 56 Mandal, 2008, Chand et al, 2011 and Jakhar et al., 2011). Probability analysis of rainfall is 57 necessary for solving various water management problems and to access the crop failure due 58 to deficit or excess rainfall. Scientific predictions of rains and crop planning done analytically 59 may prove a significant tool in the hands of farmers for better economic returns (Bhakar et 60 al., 2008). Generally, the cropping pattern is suggested considering the rainfall probabilities 61 at different levels (Mahale and Dhane, 2003). Probability and frequency analysis of rainfall 62 data enables us to determine the expected rainfall at various chances. Studies on rainfall 63 probability in India have also been carried out earlier by many workers (Victor et al., 1991). 64 Rainfall at 80 percent probability can be safely taken as assured rainfall, while 50 percent 65 chance can be considered as the maximum limit for taking any risk (Bhakar et al., 2008). 66 Since, there is a limited information on rainfall analysis and changes in rainfall pattern in 67 Malwa Plateau of Madhya Pradesh,

68 The present study was aimed to analyze the long term rainfall data of the region to 69 assess the probabilities of rainfall and also efficient contingent crop planning for the region.

## 70 MATERIAL AND METHODS

## 71 The study region

72 The Indore district lies in the heart of Malwa plateau and is spread in an area of 3831 73 sq km between 22°31' and 23°05' N latitudes and 75°25' and 76°15' E longitudes at an 74 altitude of 618 m above MSL (Fig. 1). It is bounded by Ujjain, Khandwa, Dewas and Dhar 75 districts in the north, south, east and west respectively. The district lies partly in the Chambal 76 sub basin of the Ganga basin (75%) and partly (25%) in the Narmada basin (Anonymous, 77  $2013_{\rm b}$ ). It is bounded by *Vindhyan* ranges in the North-West. The average annual rainfall in 78 the Madhya Pradesh state is 1160 mm, while it is 961 mm for Indore district, in which 91.2 %79 is received during the south-west monsoon season.

## 80 Rainfall data analysis

81 The daily meteorological data recorded for the period 1930 to 2010 (81 years) at observatory 82 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 83 84 (1977), Hills and Morgan (1981), Sivakumar, et al. (1979). In the present study, parameters 85 developed at the International Crop Research Institute for Semi-Arid Tropics, (ICRISAT) 86 (Virmani et al., 1982) were used for the analysis of rainfall.

#### 87 Incomplete Gamma Distribution of precipitation (mm)

The Gamma distribution is one of the most appropriate models for interpreting rainfall data. 88 89 Its function is expressed by;

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- $g(x) = (x^{y-1} e^{-x/\beta}) / \{\beta^y T(y)\} [y, \beta > 0, x \ge 0]$  .....(i)  $E(x) = y\beta$  and  $\sigma^2 = y\beta^2$ ,  $\sigma^2 = variance$ 92
- 93

Where 'x' is a continuous random variable. ' $\beta$ ' is a scale parameter, 'y' is a shape parameter 94 and T(y) is the ordinary gamma function of y. However, this formula gives a poor estimate of 95 96 the parameters.

97 98 Adequate estimates are approximated by;

99 
$$\hat{Y} = \frac{1}{4A} \{ 1 + \sqrt{1 + \left(\frac{4}{3}\right)A} \}$$
 .....(ii)  
100 and  $\beta = \frac{N}{V}$ 

101

102 where A is given by

103 A= ln x { $(\Sigma lnx)/n$ } or  $\Sigma lnxi-lnx$ 

The distribution function from which probabilities may be obtained is  $G(x) = \int_{a}^{x} g(t) dt$ . 104 To determine the amount of rainfall at any given probability it is put in the standard form t 105

106  $(F)=x/\beta$ . Incomplete Gamma Distribution (Precipitation (mm) were worked out for 90, 75, 107 50, 25 and 10% probabilities.

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#### 109 Initial and conditional probabilities of rainfall (Markov chain probability)

110 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 111 112 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 113 114 given amount or more was observed during that week. This concerns only the probability of 115 having rain in any specific week. Another probability *i.e.* 'conditional probability' assumes 116 that two events are often related in such a way that the probability of occurrence of the latter 117 (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 118 rain next week if it rains this week, P(w/w), and the probability of having rain next week if 119 120 particular week is dry, P(W/D).

| 121 | Therefore, initial probability for a given week having rain in excess of a specific amount           |  |  |  |  |  |  |  |  |
|-----|--|--|--|--|--|--|--|--|--|
| 122 | is denoted by  |  |  |  |  |  |  |  |  |
| 123 | P(W) = number of years which have rain more than specific amount of rainfall/ no. of                 |  |  |  |  |  |  |  |  |
| 124 | years of data at any given week.   |  |  |  |  |  |  |  |  |
| 125 | following formulae were used:  |  |  |  |  |  |  |  |  |
| 126 |  |  |  |  |  |  |  |  |  |
| 127 | i) $P(Wi)=n(Wi)/N$   |  |  |  |  |  |  |  |  |
| 128 | ii) $P(Di) = n(Di)/N$ (iv)   |  |  |  |  |  |  |  |  |
| 129 |  |  |  |  |  |  |  |  |  |
| 130 | Where, n= No of years getting wet week for a particular threshold level of rainfall.                 |  |  |  |  |  |  |  |  |
| 131 | n(Wi) = Number of occurrence of a wet week in the i <sup>th</sup> period.                            |  |  |  |  |  |  |  |  |
| 132 | n(Di) = Number of occurrence of a dry week in the i <sup>th</sup> period.                            |  |  |  |  |  |  |  |  |
| 133 | N=Total number of years $[n(Wi) + n(Di)]$  |  |  |  |  |  |  |  |  |
| 134 |  |  |  |  |  |  |  |  |  |
| 135 | iii) Conditional probability of a given wet week to be followed by a wet week, P                     |  |  |  |  |  |  |  |  |
| 136 | (W/W).   |  |  |  |  |  |  |  |  |
| 137 |  |  |  |  |  |  |  |  |  |
| 138 | P(Wj/Wi) = n(Wj, Wi) / N(Wi)(v)  |  |  |  |  |  |  |  |  |
| 139 | Where $n(Wj,Wi)$ = Number of occurrence of a wet week in i <sup>th</sup> and j <sup>th</sup> period. |  |  |  |  |  |  |  |  |
| 140 | n(Wi) = Number of occurrences of a wet week in i <sup>th</sup> period.                               |  |  |  |  |  |  |  |  |
| 141 |  |  |  |  |  |  |  |  |  |
| 142 | iv) Conditional probability of a given dry week to be followed by a wet week,                        |  |  |  |  |  |  |  |  |
| 143 | P(W/D).  |  |  |  |  |  |  |  |  |
| 144 |  |  |  |  |  |  |  |  |  |
| 145 | $P(Wj/Di) = n(Wj,Di)/N(Di) \dots (vi)$   |  |  |  |  |  |  |  |  |
| 146 | Where n(Wj,Di) =Number of occurrences of a dry week in i <sup>th</sup> period and a wet week in      |  |  |  |  |  |  |  |  |
| 147 | j <sup>th</sup> period.  |  |  |  |  |  |  |  |  |
| 148 |  |  |  |  |  |  |  |  |  |
| 149 | The above analyses were done considering long term data (1930-1996) of rainfall for                  |  |  |  |  |  |  |  |  |
| 150 | 67 years. Further, rainfall data were randomly chosen from low rainfall (<700 mm), normal            |  |  |  |  |  |  |  |  |
| 151 | rainfall (951-981mm) and high rainfall (1292-1915 mm) and subjected to analyses so as to             |  |  |  |  |  |  |  |  |
| 152 | arrive at more accurate conclusions. The years 1952, 1957, 1965, 1966 and 1992 were having           |  |  |  |  |  |  |  |  |
| 153 | low annual rainfall of 627, 664, 553, 594 and 555 mm, respectively. Similarly, normal                |  |  |  |  |  |  |  |  |
| 154 | rainfall years included were 1937, 1960, 1964, 1980, 1981 receiving annual precipitation of          |  |  |  |  |  |  |  |  |
| 155 | 981, 942, 964, 973 and 951 mm, respectively. Ten high rainfall years 1933 (1311 mm), 1934            |  |  |  |  |  |  |  |  |
| 156 | (1460 mm), 1938 (1292 mm), 1944 (1453 mm), 1954 (1359 mm), 1961 (1568 mm), 1973                      |  |  |  |  |  |  |  |  |
| 157 | (1915 mm), 1976 (1335 mm), 1994 (1445 mm) and 1996 (1299 mm) were also selected for                  |  |  |  |  |  |  |  |  |
| 158 | computations. A more complete description of the conditional probability analysis is given by        |  |  |  |  |  |  |  |  |
| 159 | Robertson (1976), cited in Virmani (1982). The initial and conditional probabilities of rainfall     |  |  |  |  |  |  |  |  |
| 160 | (Markov chain probability) of Indore district of Malwa Plateau was determined with a limit           |  |  |  |  |  |  |  |  |
| 161 | of 25 mm.  |  |  |  |  |  |  |  |  |
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## 163 Frequency analysis for 2, 3 and 5 days of rainfall

164 Daily long term data (81 years) of rainfall from 1930 -2010 was employed to 165 estimate the frequency of rainfall. The daily data in a particular year was converted to 2 to 5 166 days' consecutive days' rainfall by summing up the rainfall of corresponding previous days. 167 The probability or frequency of any event was calculated by the Weibull's equation:

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169 Where, m = descending order rank number given to the event, which is assigned after 170 arranging the events in by their magnitude; n = total number of observations (no of years of 171 data)

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#### 173 **RESULTS AND DISCUSSION**

#### 174 Annual rainfall trends at Indore region of Malwa Plateau

175 The annual rainfall during 1930-2010 was ranged from 341.8 to 1898.5 mm. The 176 lowest rainfall was recorded in the year 1975 and the maximum in the year 1973. The 81 177 years' average rainfall was 993.6 mm with a standard deviation of 270.62 mm which clearly 178 indicated its erratic distribution pattern of rainfall in the region. The linear trend line fitted for 179 annual rainfall data showed a decreasing trend in annual rainfall over the years. The decade 180 wise analysis of rainfall also showed a decreasing trend of average annual rainfall (Fig. 3). 181 Similarly, the mean rainfall of every 20 years for the period 1930-1949, 1950-1969, 1970-182 1989 and 1990-2010 was 1076.5, 992.1, 975.2 and 933.6 mm, respectively. Yet again this 183 pattern clearly indicates a gradual decrease in the annual rainfall of Indore region with time. 184 A change detection study using monthly rainfall data for 306 stations distributed across India 185 was attempted by Rupa Kumar et al. (1992). They also showed that areas of the northeast 186 peninsula, northeast India and northwest peninsula experienced a decreasing trend in summer 187 monsoon rainfall. Analysis of month wise rainfall data further revealed that only 7.17 percent 188 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 189 190 rainfall (2.21%). The months of June to September are the crucial months from agriculture 191 productivity point of view as most of the rainfall occurs during this period. Also, this is the 192 period to harvest and conserve the rainwater for rabi season crops. However, no specific trend 193 was observed with respect to change in month wise rainfall on a decadal scale.

194 Similar to rainfall, the number of rainy days per year showed a decreasing trend since 195 1930 to 2010 and found erratic with a high degree of coefficient of variation (21.05%). The average numbers of rainy days recorded were  $48.12 \pm 10.13$ . The highest number of rainy 196 197 days (69) were recorded in the year 1963 and the lowest number of rainy days (23) were 198 recorded in the year 1975 (Fig. 4). The last five decades showed less number of rainy days as 199 compared to the initial period of the study which again indicate that the number of rainy days 200 at Indore region of Malwa Plateau of Central India is decreasing over time. Goswami et al. 201 (2006) used daily rainfall data to show the significant rising trends in the frequency and 202 magnitude of extreme rain events, and a significant decreasing trend in the frequency of 203 moderate events over central India during the monsoon seasons from 1951 to 2000 Similar 204 decrease in rainy days has also been reported by Vijay Kumar et al. (2010) from the analysis 205 of long term rainfall trends in India. Mean week wise rainfall of area shows that monsoon in

the region sets in after 20<sup>th</sup> standard meteorological weeks (SMW) and continues till 41<sup>st</sup>
SWM (Fig. 5). These are the normal periods of onset and withdrawal of monsoon in Malwa
plateau.

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## 210 Incomplete Gamma distribution probabilities

211 The Gamma distribution is one of the most appropriate models for interpreting rainfall 212 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' 213 214 data revealed that there was 90, 75, 50, 25 and 10% probability of receiving annual rainfall of 215 663.9, 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 216 217 50% respectively. However, there was probability of only 25 and 10% for receiving rainfall 218 amount of 1.6 - 101.7 and 2.0 - 175.9 mm, respectively.

219 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 17<sup>th</sup> SMW and the least of 0.6, 0.8, 1.1, 1.6, 2.0 mm in 1<sup>st</sup> 220 SMW. Probability analysis of long term data is useful for effective planning of farm 221 222 operations and crop management under both rainfed and irrigated agro-ecosystems Virmani 223 et al. (1982) and Sharma et al. (1999). In Malwa region, soybean is a major crop during rainy 224 season and is highly susceptible to both the water logging and prolonged water stress 225 conditions. The probabilities for different amount of rainfall for each week would be of 226 immense use for managing favorable moisture regime during crop growing period.

## 227 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.

233 The conditional probability analysis revealed zero probability of wet week followed 234 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% 235 was observed for 17th SMW. The probability of dry week, P(d/w), followed by dry week 236 showed a reverse trend. The probability of wet week followed by a dry week was higher for 237 238 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 239 240 was obtained in case of dry week followed by wet week. Sharma et al., (1999) concluded 241 from 67 years rainfall analysis translated into an extremely useful information for agriculture 242 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 243 244 the expected rainfall at various probabilities. Rainfall at 80 per cent probability can be safely 245 taken as assured rainfall, while 50 per cent chance can be considered as the maximum limit 246 for taking any risk and further indicated usefulness of weekly rainfall analysis for crop

247 planning in the Kota region. In a similar line, Jat et al. (2010) also reported similar 248 observation for crop planning through analysis of weekly, monthly and seasonal probability 249 analysis of rainfall. It is worth mentioning here that the weekly distribution of rainfall and its 250 probability is helpful in crop planning by identifying the periods of drought, normal and 251 excess rainfall (Ray *et al.*, 1980). In most of studies the workers have suggested the cropping 252 pattern considering the rainfall amount at different probability levels (Ravindrababu et al., 253 2010). Kulandaivelu (1984) analyzed the daily precipitation data of Coimbatore for a period 254 of 70 years for weekly totals by fitting incomplete Gamma distribution model. The data 255 indicate the likely commencement of rains, periods of drought length of growing season and 256 end of growing season. Based on the assured rainfall at (50%) probability level, suitable 257 cropping system was suggested for Coimbatore.

#### 258 Frequency analysis for 2, 3 and 5 days' rainfall

259 Analysis of consecutive days' maximum rainfall of different return periods is a basic 260 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 261 262 and varies with time and space, yet it is possible to predict rainfall fairly accurately for 263 certain return periods using various probability distributions (Upadhaya and Singh, 1998). 264 The 2, 3 and 5 days' consecutive maximum rainfall for different return periods are presented 265 in Tables 3 and 4. The gamma distribution function was found to be the best fit function for 266 2, 3 and 5 consecutive day rainfall. The data presented revealed that a maximum annual 267 rainfall of 167.38 mm in two days, 223.7 mm in three days and 266.7 mm in five days is 268 expected to occur every year at Indore region of Malwa Plateau.

269 Similarly, a maximum rainfall of 206.7 mm in two days, 241.5 mm for 3 days and 270 298.5 mm for five days is expected to occur every alternate years. For 5 years return period 271 the maximum amount of rainfall expected to occur at Indore is 266.2 mm in two days, 312.6 272 mm for 3 days and 315.7 mm in five days. On the basis of 20 and 40 years return period there 273 is probability to receive a maximum of 276.6 and 314 mm rainfall in two consecutive days, 274 respectively. However the recurrence interval of 10,20,40 years is more important for 275 designing hydrologic structures and is of less use for agriculture planning. For three days' 276 consecutive maximum rainfall of 321.56 mm and 375.8 mm is expected in 13 and 27 years, 277 respectively. With a return period of 8 and 16 years the maximum amount of rainfall which 278 expected to occur in consecutive 5 days was estimated to be 325.9 mm and 399.5 mm 279 respectively. Frequency analysis of rainfall data has been attempted for different places in 280 India by Jeevrathnam and Jaykumar (1979), Sharda and Bhushan (1985) Prakash and Rao 281 (1986), Aggarwal et al. (1988), Bhatt et al. (1996), Mohanty et al. (1999) and Rizvi et al. 282 (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.

## 293 Contingency crop planning for better crop production in the region

294 Contingency crop planning (CCP) refers to mitigate any unexpected, unsual, 295 unfavourable and hence unwanted accidental weather situations occurring at any time without 296 prior knowledge at any time before the crops are sown or even after the crops are sown. Thus, 297 CCP assumes greater significance in view of the erratic behavior of the rainfall in the Malwa 298 plateau of Central India. It is very important to select crops for kharif and rabi season 299 carefully since rainfed farming is practiced in the region especially during *kharif* season. 300 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 301 302 farm ponds, is high which can be recycled during rabi season crops when the probability of 303 rainfall is very meager (Somasundaram et al., 2014). Since kharif cropping is a primary 304 activity in the rainfed areas, where monsoon variability plays a crucial role in production, the 305 contingency crop planning will require a greater attention in these areas. Longterm strategic 306 approaches are also needed to efficiently conserve and utilize rain water on the one hand and 307 in season tactical approaches to mitigate the adverse effects of weather aberrations.

308 Gram and mustard crops needs to be preferred in the region where ground water 309 availability for *rabi* crops is limited. Over the period there is decline in the rainfall as well as 310 number of rainy days in the year which is a matter of concern for future. Hence there would 311 be need to develop short duration varieties of crops like maize, pigeonpea, adjustment in 312 sowing and harvesting time of crops, intensive soil and water conservation practices to 313 harvest and recycle the rainwater on watershed basis, digging of farm ponds wherever 314 possible for enhanced ground water recharge etc. Further the information of rainfall behavior 315 might be useful in predicting the incidence of insect pests and diseases in the region.

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#### 317 CONCLUSIONS

318 The present study has examined trends in the monthly, seasonal and annual rainfall at 319 a regional scale, Indore district of Malwa plateau of Madhya Pradesh based on 81 years' 320 rainfall data. The rainfall analysis of Indore region indicated a decreasing trend with respect 321 to total rainfall and number of rainy days. Analysis of 81 years' rainfall data revealed that 322 there is 90% and 75% probability of occurrence of 664 mm and 799 mm annual rainfall, 323 respectively. The pattern of occurrence of rainfall revealed that there is a great potential for 324 rain water harvesting in the district for better *rabi* season crops along with assured rainy 325 season crop. Soybean is the prominent crop during *kharif* season in the region that requires 326 low but assured rainfall. However, if the rain delayed for one or two weeks' short duration 327 varieties like maize, pigeonpea and cow pea may be opted for the region. It may be 328 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.

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#### Fig. 1. Location map of the study Malwa region

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

| SMW |     | P    | robabilit | y (%) | 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  |

| SMW | <b>AW</b> Initial Probabilities |      | <b>Conditional Probabilities</b> |      |      | SMW  | Initial Probabilities |      |      | <b>Conditional Probabilities</b> |      |      |      |
|-----|---------------------------------|------|----------------------------------|------|------|------|-----------------------|------|------|----------------------------------|------|------|------|
|     | P(W)                            | P(D) | <b>P(W/W)</b>                    | P(W) | P(D) | P(W) |                       | P(W) | P(D) | <b>P(W/W)</b>                    | 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 |
| 442 |                                 |      | •                                | •    |      |      |                       |      |      | •                                | •    |      |      |

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

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

| Return<br>Period | 2 days<br>maximum rainfall | Return<br>Period | 3 days<br>maximum<br>rainfall | Return<br>Period | 5 days<br>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                         | -                | -                          |

# Statistical parameters for 1, 2, 3, and 5-day consecutive maximum rainfall Statistical parameter 1 day 2 day 3 day Minimum, mm 0.00 0.00 0.00 Maximum, mm 250.44 314.45 375.80

| 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  |



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





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

5 day

