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Rainfall probability analysis for conservation of water resources for sustainable irrigation planning

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Abstract

Attempts were made to analyze trends of 44-years (1970-2013) of long-term rainfall using probability distribution functions, seasonal distribution, onset-withdrawal of monsoon, dry and wet spell(s) in 52 standard meteorological weeks (SMW) for Ludhiana (Punjab). Results revealed monsoon season rainfall (598.5 mm) in 39 rainy days delivers about 79.4 % of annual rainfall and its effective rainfall was 434.7 mm; pre-monsoon, post-monsoon and winter season contributes 8.2, 7.9 and 4.5 % of annual rainfall. This call for alternate cropping system with low water requiring crops to match with rainfall and distribution, less reliance on irrigation would arrest rapid declining of groundwater.

Key words: ***Irrigation planning, Ludhiana (Punjab), Markov chain model Analysis, Probability analysis, Rainfall analysis, Rice-wheat***

Introduction

India occupies 2.4 % of the world's land area and it supports about 15 % of the world's population. It receives annual precipitation of about 4000 km^3 (Kumar *et al.,* 2005); agriculture and allied farming in the country supports 65 % of the population and contributes about 13.9 % to the gross domestic product (DES, 2014; Prasanna, 2014). About 65.26 million ha (46.3 %) out of 140.80 million ha of net sown area in the country is irrigated (DES, 2014) and remaining area is rainfed (53.7 %). This rainfall occurs mostly (~75-80 %) during rainy season due to the influence of south-west monsoon; thus monsoon is often said to be the driver of Indian agriculture (Kumar *et al.,* 2004; Sharma *et al.,* 2010). The rainy season rainfall has direct impact on the agricultural production and is essential for the availability of freshwater for irrigation as well as drinking (Dash *et al.,* 2009; Jain and Kumar, 2012). The study on the climate change and trends in rainfall, its accurate forecasting and contingency planning receives high priority as uncertainty and variability of rainfall affects water resources management (Subash and Sikka, 2014; Subash *et al.,* 2011; Machiwal *et al.,* 2017), agricultural production (Bhale *et al.,* 2012; Prasanna, 2014) and overall economy of the country (Khan *et al.,* 2009; Jain and Kumar, 2012). Punjab is one of the north Indian states, which has witnessed the green revolution, rice-wheat cropping system was found as the most important for food self-security in the region (Timsina and Connor, 2001; Hobbs and Gupta, 2003; Gupta and Seth, 2007). In Punjab, rice is grown on 2.61 million ha during rainy season and wheat on 3.41 million ha during winter season, which shares about 40 % of the state gross domestic product and contributes food grains to the central pool (Chahal *et al.,* 2007; Singh and Kaur, 2012). The soils of the region are generally deep alluvium, sandy loam to loam, thus possess high fertility status. Groundwater is a major source of irrigation in the region; but its excessive extraction in Punjab and north Indian states has caused an alarming depletion at a rate of 54 ± 9 km^3 per year between April 2002 and June 2008 (Tiwari *et al.,* 2009), which is equivalent to a net loss of 109 km^3 of water during August 2002 to October 2008 (Rodell *et al.,* 2009). The problem of overexploitation of groundwater resources is most severe in central Punjab; the region is also dominated by rice crop during rainy season. While the average annual depletion in groundwater table in the central Punjab was about 17 cm during the

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1980s and about 25 cm during the 1990s, it was alarmingly high at 91 cm per annum during 2000-2005 (Singh , 2011). Out of 142 blocks in the state, water table is declining in 110 blocks due to over-extraction of water than the proportionate recharge. By the year 2023, the water table depth in central Punjab is projected to fall below 21 m in 66 % area, below 30 m in 34 % area and below 40 m in 7 % area (Sidhu *et al.*, 2010). Hence, a study on the rainfall pattern for optimal crop planning and management of rainwater is essential for the region.

The probability analysis on long-term rainfall data is useful for agricultural scientists, decision makers, policy planners and researchers for agricultural crop planning and construction of water harvesting structures, irrigation and/ or drainage systems (Singh *et al.*, 2012). Of course, it is essentially required for crop planning and water management under rainfed areas (Sharma *et al.*, 2010; Admasu *et al.*, 2014; Bhelawe *et al.*, 2015). Previously, our attempts were made to analyzing rainfall data of several years for Daspalla region in Odisha, eastern India using probability distribution functions and Markov chain model (Mandal *et al.*, 2015). The same technique was used for analysis of weekly rainfall at Dhera, central rift valley region in Ethiopia (Admasu *et al.*, 2014) and north Lakhimpur, Assam in India (Dabral *et al.*, 2014). It has been evident that probability analyses are more reliable and useful as it delves into more information than a single deterministic forecast (Fritsch, 1998). Information on probability of occurrence of maximum daily rainfall would be useful in devising risk management for sustaining rainfed crop production systems (Mandal and Choudhury, 2015). Long-term weekly, monthly, seasonal and annual rainfall probability helps in better decision making in crop planning, soil and water conservation programme and the optimum utilization of water resources in various production systems (Solanki and Singh, 2009). Markov chain model is used to evaluate the sequence of dry and wet spell(s) for agricultural planning (Pandarinath, 1991; Banik *et al.*, 2002; Panigrahi and Panda, 2002; Srinivasareddy *et al.*, 2008; Fischer *et al.*, 2013). The model output shows the drought proneness of a region and availability of surplus water required for rainwater management (Banik *et al.*, 2002, Kothari *et al.*, 2009; Nema *et al.*, 2013). The Markov model has been proven successful in predicting the average length of wet spells on monthly basis and also used to calculate the return period of wet and dry spells and better suited for paddy cultivation (Sonnadara and Jayewardene, 2015). In our present study, the region belongs to the trans-Gangetic plain in north India; the region is experiencing declining ground water level. Hence, it is hypothesized that the rainfall trend analyses may help in managing rainwater in a systematic way, which can enhance the crop production system in the long run. Rainfall trend analysis showed no significant trend in annual, seasonal and monthly rainfall in most of India (Kumar *et al.*, 2010). Less information is available on the probability analyses and fair idea on the probability of dry and/ or wet spells for Ludhiana, Punjab. Therefore, attempts were made: (1) to study the trends of long-term rainfall of Ludhiana on annual, monthly and weekly basis, and prediction of rainfall at different probability levels, (2) to find out the best-fit probability distribution function for prediction of annual and monsoon season rainfall, (3) for forecasting the onset and withdrawal of monsoon season, (4) for analyzing initial, conditional and consecutive dry and wet spell (s) by using Markov chain model, and (5) for appropriate water and crop management planning for the study region.

Materials and Method

Study area and the data

The study area is the Ludhiana district of Punjab in India. Geographical area of the district is 3790 km^2. The soil texture is mostly loamy sand with average sand fraction 78.5 %, silt 12.66 % and clay 8.80 % in 0-30 cm soil depth with average bulk density of 1.44 Mg m^{-3}. Long-term rainfall data were collected for the period of 1970-2013 (44 years) from meteorological station of Punjab Agricultural University, Ludhiana and Punjab. The rainfall data were categorized into four seasons according to Indian Meteorological Department (IMD) such as monsoon (June-September), pre-monsoon (March-May), post-monsoon (October-December) and winter (January-February) seasons. Monthly effective rainfall was estimated using FAO-CROPWAT 8.0 with the USDA soil conservation service method as stated in Eqs 1 and 2. This method has been used in India by previous researchers (Sharma *et al.,* 2010; Mandal *et al.,* 2015).

$$P_{eff} = \frac{P\,(125-0.2\,P)}{125} \quad \text{for } P < 250 \text{ mm} \qquad (1)$$

$$P_{eff} = 125 + 0.1\,P \quad \text{for } P \geq 250 \text{ mm} \qquad (2)$$

where, P_{eff} = monthly effective rainfall (mm), and P = monthly total rainfall (mm)

Calculation of probability distribution functions

Rainfall probability was analyzed using six probability distribution functions such as normal, two-parameter log normal, three-parameter log normal, Pearson type III, log Pearson type III and Gumbel (maximum and minimum). Different probability distribution functions were estimated as per Mandal et al, 2015. Then Chi-square test as per Kolmogrov-Smirnov (K-S) and Anderson-Darling (A-D) Test were carried out for goodness of fit (Aksoy, 2000; Mohanty *et al.,* 2000; Ebert, 2001; Sharda and Das, 2005; Moore, 2009; Sharma *et al.,* 2010; Singh *et al.,* 2012; Mishra *et al.,* 2013; Bhelawe *et al.,* 2015).

Markov chain model Analysis

The dry and wet period was decided by the nature of weekly rainfall received. According to the classification by IMD, one whole year was divided into 52 standard meteorological weeks (SMW) and a year started with first SMW (1^{st}-7^{th} Jan) to 52^{nd} SMW (24^{th} -31^{st} Dec). The onset and withdrawal and the length of monsoon were the basic parameters for determining crop planning (Punyawardena 2002). Forward accumulation of 75 mm of rainfall was considered as the onset of monsoon which provides a favourable condition for land preparation and sowing/ planting of rainy season crops and a 20 mm of accumulated rainfall was considered as withdrawal of monsoon. The withdrawal of monsoon rainfall was determined by the backward summation at the end of monsoon period (Dash and Senapati, 1992; Babu and Lakshminarayana, 1997; Panigrahi and Panda, 2002; Srinivasareddy *et al.,* 2008). The probability of occurrences of rainfall (*p*) was calculated by using Weibull's method. In this method, the rainfall was arranged in descending order of magnitude, and was given rank 1; next magnitude was given rank 2 and so on. The probability '*p*' of a week having rainfall exceeding or equal to normal was calculated using Weibull's formula as follows.

$$P = \frac{m}{n+1} \times 100 \qquad (3)$$

where, *P* = probability of occurrence (%), *m* = rank number and *n* = number of years of data used

Markov chain model analysis for computation of probability of occurrences of dry and wet spell

Markov chain model was used for computing probability levels for occurrences of the sequence of dry and wet spell; it was conducted on weekly rainfall data. Less than 20 mm rainfall in a week was considered as dry week and 20 mm or more rainfall as wet week (Pandarinath, 1991). The analysis was worked out for initial probabilities, conditional probabilities and consecutive dry and wet week probabilities as per the method described in Mandal *et al.,* 2015.

Results and Discussion

Monthly and seasonal rainfall trends

Annual rainfall in Ludhiana varies from 379.6 mm to 1334.0 mm with an average of 754 mm. Monthly average and effective rainfall showed that highest amount occurred in the month of July (220.2 mm) and it contributes 29.2 % to the annual rainfall; August and September ranked second and third with rainfall of 189.1 mm and 105.2 mm, respectively and contributes about 25.1 % and 14.0 % to annual rainfall, respectively. The seasonal rainfall distribution during monsoon, post monsoon, pre-monsoon and winter season showed considerable variation (Table 1). The southwest monsoon which delivers about 79.4 % of annual rainfall i.e., an amount of about 598.5 mm was received during rainy season; and the effective rainfall was 434.7 mm. The monsoon rainfall was predominant in the region. Winter and post-monsoon contributes about 4.5 % and 7.9 %, respectively. Whereas pre-monsoon rainfall contributes 8.2 % to annual rainfall with an average of 61.5 mm and effective rainfall of 59.5 mm which was meant for land preparation for rainy season crops. The effective rainfall distribution in the study area was effectively used by the rice-wheat cropping system.

Prediction of rainfall using probability distribution functions

Probability of occurrences of monthly rainfall in January through May and October through December was very less even at 50 % level, whereas it was higher in the months, June through September than other months (Table 2). In general, rainfall amount decreases in higher probability levels in every month. Probability of occurrences of seasonal rainfall showed at higher magnitude in monsoon season than post-monsoon, winter and pre-monsoon seasons (Table 3). As the post-monsoon rainfall was very less, its probability was near zero; however during winter and pre-monsoon season, probability of occurrence was also very low in the higher level. Probable annual rainfall was 504.7 mm at 50 % probability and 107.8 mm at 90 % probability.

Six different probability distribution functions viz. normal, two-parameter log normal, three-parameter log normal, Pearson type III, log Pearson type III and Gumbel (maximum and minimum) were fitted for annual rainfall (Fig. 1) and for monsoon rainfall (Fig. 2). The statistic and rank values of different probabilities under Chi-square, K-S and A-D test for annual and monsoon rainfall revealed that Chi-square test showed good statistic than K-S and A-D test for annual and monsoon rainfall (Table 4). Results and trends showed that log Pearson type III is the best-fit probability distribution functions to predict annual rainfall with the rank value of 1. Similarly, for monsoon rainfall probability distribution function, Chi-square test performed better than the other two tests with its statistic ranged value between 0.78 and 3.51. But in both Chi-square and K-S test, normal distribution function ranked first and is found best-fit function for predicting monsoon rainfall.

Analyses of rainfall for onset and withdrawal of monsoon season

The results on onset, withdrawal, longest monsoon period and shortest monsoon period, based on weekly (SMWs) analyses, reveal that onset of monsoon mostly happens in 28th SMW (9th – 15th July) and remains active up to 38th SMW (17th -23th September) (Table 5). Hence, mean length of rainy season was found to be of 11 weeks. It is also clear that the longest and shortest monsoon period was the 27th SMW (2nd-8th July) in the year 1986, and the 30th SMW (23rd – 29th July) in the year 1981, respectively. In one year i.e., in 1986, the earliest week of onset of monsoon happened in 25th SMW (18th -24th June) and also the earliest withdrawal in 33rd SMW (13th -19th August); that was the longest monsoon period of 17 weeks (119 days). Similarly, the shortest monsoon period of 4 weeks (28 days) occurred in 1981 between the SMW 30th and 33rd (13th – 19th August). The most delayed onset and withdrawal occurred in 31st SMW (30th July- 5th August) and 43rd SMW (22nd – 28th October), respectively. In terms of probability, 24th through 30th weeks have 29.3 through 92.3 % probability (Table 6); similarly monsoon withdrawal event occurs in 35th SMW (27th August – 02nd September) with 24.5 % probability through 42nd SMW (15th – 21st October) with 97.7 % probability.

Markov chain model

Result of initial and conditional probabilities for dry and wet weeks were presented in Table 7 for 52 standard meteorological weeks. The result revealed that the probabilities of occurrence of dry spell of one week, *P(D)* was higher (68.18- 90.91 %) up to 25th SMW. Again the probability of occurrences of a dry week followed by another dry week $P(DD)$ and the dry week followed by a wet week $P(DW)$ varies from 57 to 95 % and 71 to 100 %, respectively during the duration of 1st to 25th SMW. From 26th SMW the greater probabilities (>50 %) of occurrence of wet week were observed up to 34th SMW and the percentage probabilities of getting wet period was about 52 to 80 %. Hence the probabilities of getting dry week decreases, and $P(D)$ and $P(DD)$ values get lower during the monsoon period. Again, *P(D)* values were higher that 50 % from 35th SMW onwards, and obviously the *P(W)* and *P(WW)* values were lower, even zero in several weeks. The probability of getting wet week preceded by another wet week varied between 49 to 80 %. Further the probability of getting dry spell increases after the 42nd SMW to the end of the year (52nd SMW) with the percentage varied from 61 to 100 %. The analyses of consecutive dry and wet spells showed that the possibility of occurrences of two consecutive weeks dry i.e., *P(2D)* during 1st to 25th SMW was higher with percentage ranging from 39 to 93 % (Table 8). But the chances of getting three consecutive weeks dry i.e., *P(3D)* was less and the probability varied from between 7 and 30 % in first 25 weeks of the year; chances of occurrence of consecutive wet weeks

Table 1. Rainfall distribution in different seasons in Ludhiana based on 44-years long-term rainfall (1970-2013)

Seasons	Average rainfall (mm)	Effective rainfall (mm)	% of annual rainfall
Pre-monsoon (March-May)	61.5	59.5	8.2
Monsoon (June-September)	598.5	434.7	79.4
Post-monsoon (October-December)	33.7	33.0	4.5
Winter (January-February)	59.7	56.8	7.9

Table 2. Probability of occurrences of monthly rainfall at different levels

Probability levels (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
50	15.9	20.0	13.4	7.4	9.7	49.5	178.0	149.2	54.9	0.6	0.1	5.8
60	9.0	16.4	9.8	5.4	4.7	43.7	145.9	123.2	41.2	0.0	0.0	2.3
70	4.8	10.8	4.1	2.9	1.6	37.0	112.9	104.5	27.5	0.0	0.0	0.1
80	2.3	3.3	1.0	1.1	0.1	30.4	89.4	71.5	19.3	0.0	0.0	0.0
90	0.1	0.1	0.1	0.0	0.0	18.4	38.7	48.4	1.7	0.0	0.0	0.0

Table 3. Probability of occurrences of seasonal rainfall at different levels

Probability levels (%)	Monsoon (Jun-Sep) mm	Post- monsoon (Oct-Dec) mm	Winter (Dec-Feb) mm	Pre-monsoon (Mar-May) mm	Annual rainfall mm
50	431.7	0.6	41.8	30.5	504.7
60	354.0	0.0	27.8	20.0	401.9
70	282.0	0.0	15.8	8.7	306.6
80	210.8	0.0	5.6	2.3	218.8
90	107.3	0.0	0.2	0.1	107.8

i.e., *P(2W)* and *P(3W)* are very less in the corresponding weeks. As the arrival of the monsoon from 26th SMW probability of getting two and three consecutive weeks wet increased; and *P(2W)* and *P(3W)* values were very less or zero in the weeks, 39th SMW through 52nd SMW.

The major cropping system, rice-wheat is followed by the farmers over several years in the study region i.e., within the trans-Gangetic plains of the country, rice during rainy season and wheat in winter. The water requirement of rice in the study area is about 965-1371 mm depending upon the growing period and varieties (Kaur *et al.,* 2011). Average annual rainfall of the study area i.e., Ludhiana is about 750 mm which is not sufficient to meet water requirement of rice-wheat cropping system; that is why farmers provide irrigation to rice through extraction of groundwater; over-drafting of ground water resulted in declining of water table, which has become a serious concern. Our analyses indicate that the rainfall received during monsoon season is about 600 mm i.e., ~80 % of average annual rainfall. Long term rainfall analysis showed that monsoon and annual rainfall is in decreasing trend where as pre, post and winter rainfall is in increasing trend in India (Kumar *et al.,* 2010). This indicates that rainwater management is very crucial and should get the top priority for the area. For Ludhiana, post-monsoon season and winter season rainfall, if combined, it amounts to 93.4 mm (Table 1), though almost the total amount is effective rainfall, is not enough to meet the demand. Supplemental irrigation is provided from groundwater source to wheat crop. Further, there is a scope for storage of excess rainfall i.e., 163.8 mm which occurs during monsoon period in addition to the effective rainfall of 434.7. Of course, there is a possibility of year-to-year variation of this mean rainfall. Another concern is that crops, rice and wheat are high water demanding.

The nature of rainfall amount and distribution call for firstly, the choice of crops and appropriate cropping pattern to fitting the rainfall as well as to arresting groundwater depletion, secondly the use of improved soil-water-crop management technologies as well as water saving irrigation methods. There has been a felt need that water saving technologies be promoted to check groundwater depletion, which may improve also the access of the smallholders to groundwater (Kaur and Vatta, 2015). Now, it is the high time when the farmers of Ludhiana should plan for water-wise methods of rice cultivation which would reduce amount of water inputs. In eastern India, it has been reported that water input for wet land preparation for transplanting of rice was 362-401 mm, whereas for aerobic rice a pre-sowing irrigation was only 54-62 mm (Mandal *et al.*, 2013b); hence, by adopting aerobic method of rice cultivation irrigation requirement may be reduced considerably. Crop diversification is another strategic option for optimal use of water resources. In this rice-wheat growing region, indiscriminate use of groundwater for irrigation would be arrested if low water requiring crops are grown. In a study in eastern India, rice-based diversified systems involving cowpea, sunflower, short duration maize would increase crop water use efficiency with concomitant increase in total system productivity, production efficiency while maintaining soil organic carbon (Mandal *et al.*, 2014). By adopting water conservation techniques like controlled irrigation method, direct-seeded rice and adjustment of sowing and harvesting period would effectively utilize the excess rainwater in the study area during the monsoon season.

It has been tested statistically in our study that the log Pearson type III is the best-fit probability distribution function to predict annual rainfall in Ludhiana. The higher degree of accuracy has been obtained with this prediction function; and it has comparatively better strength to describe the 44 years of rainfall data with least departure of estimated values from the observed and actual rainfall data. Further, our analyses indicate that normal distribution function is the best-fit prediction model for monsoon season rainfall in Ludhiana. The monsoon rainfall in Ludhiana did not vary significantly for 44 years (1970-2013). These have been emerged based on the goodness of fit tests using both parametric as well as non-parametric statistical tests. However, studies have been carried out elsewhere in India where Gumbel distribution was the best-fit prediction function for weekly and monthly maximum rainfall. Bhakar *et al.,* (2008) conducted a statistical analysis on monthly and weekly rainfall for Kota using 35 years daily rainfall data, and they have found the pattern of rainfall consistent during monsoon period. The probability model, thus emerged out

Table 4. Chi-square, Kolmogorov-Smirnov (K-S) and Anderson-Darling (A-D) test statistics for each probability distribution function for annual and monsoon season rainfall

Probability distribution functions	Annual			Monsoon		
	Chi-square test	K-S test	A-D test	Chi-square test	K-S test	A-D test
Normal	1.24	0.07	0.25	0.78	0.67	0.33
Two-Parameter log Normal distribution	0.86	0.06	0.26	3.14	0.11	0.43
Three-parameter log normal distribution	0.88	0.06	0.17	3.51	0.08	0.22
Pearson type III distribution	0.88	0.05	0.17	1.28	0.08	0.22
Log Pearson type III distribution	0.79	0.05	0.16	2.77	0.76	0.22
Gumbel (maximum)	1.12	0.07	0.47	2.75	0.10	0.45
Gumbel (minimum)	2.34	0.14	1.74	2.73	0.11	1.92

Table 5. Onset and withdrawal weeks (SMW) for monsoon season rainfall, based on long-term data (1970-2013)

Particulars	Onset week		Withdrawal week	
	Standard meteorological week (SMW)	Date/ period	Standard meteorological week (SMW)	Date/ period
Average	28	09-15 July	38	17-23 September
Longest	27	02-08 July	43	22-28 October
Shortest	30	23-29 July	33	13-19 August
Earliest	25	18-24 June	33	13-19 August
Delayed	31	30 July- 05 August	43	22-28 October

Table 6. Probability of onset and withdrawal weeks for monsoon rainfall

Onset SMW	Probability of occurrences (%)	Withdrawal SMW	Probability of occurrences (%)
24	29.3	35	24.5
25	42.7	36	35.6
26	56.6	37	50.0
27	67.1	38	70.0
28	76.9	39	87.8
29	88.5	40	95.1
30	92.3	42	97.7

i.e., normal distribution function would be very useful for taking policy decision to go for conservation of excess rainfall in Ludhiana during the monsoon season. Similar model was also used for conservation of surplus rainfall through water harvesting structures during post-monsoon season in Koraput district of Odisha, an eastern Indian state (Panda *et al.*, 2009), they observed no significant difference between observed and predicted values with two-parameter and three-parameter Gamma distribution function. From our study, it is also revealed that only one single probability distribution would not be appropriately used for all the rainfall data sets over years; previous reports indicate different probability models for different regions and seasons (Kumar, 2000, Singh, 2001, Kumar *et al.,* 2007, Singh *et al.*, 2012). Similar inference was drawn by Sharda and Das (2005), that three-parameter distributions were not so significant over two-parameter distribution. As the Gamma distribution function contains more number of parameters than other functions, Sharma *et al.,* (2010), have found log normal distribution as the best-fit model for annual rainfall in Pantnagar, India. Our results are corroborated with the findings of Subudhi (2007), that normal distribution function was the best-fit model for prediction of monsoon rainfall in Chakapada block of Kandhamal district in Odisha. Our analyses reveal that the most probable occurrence and average onset week of monsoon in Ludhiana is in 28th SMW (9th – 15th July), and it remains active up to 38th SMW (17th - 23th September) (Table 5 and 6). This indicates that on an average monsoon rainfall is distributed over 11 weeks or about 80 days. Hence, the crop planning is suggested to match with this period. Land preparation should be completed before 28th SMW and the sowing and/ or planting operation is advisable to be completed by 9-15th July. In addition, the soil and water management technologies should be adopted for efficient utilization of rainwater as well as its conservation *in-situ* and *off-situ*. The strategic plan for adopting short duration high yielding variety, conservation agriculture technology with reduced or zero tillage, bed planting, direct-seeded in rice (and optimizing crop yield, better water management options can be explored (Abrol, 1999; Hobbs and Gupta, 2003; Gupta and Seth, 2007; Walia *et al.,* 2011; Singh *et al.,* 2013; Timsina and Connor, 2001). Similarly, mean withdrawal week is 38th SMW (17th -23th September), hence soil moisture conservation towards physiological maturity of crops and effective utilization of residual soil moisture through sowing of succeeding crops immediately after harvest of the first crop would be essential. Conservation tillage or crop residue management and use of no-till seed drill would be useful for the next crop i.e., for winter season crops. Evidences are available that use of appropriate land surface modification and choice of appropriate sole or intercrops utilize rainwater and residual soil moisture efficiently. In central India, broad-bed and furrow land configuration reduces runoff of water and soil loss compared to flat-bed during rainy season, and enhances yield of diversified crops viz. soybean, maize, pigeonpea as sole and as well as intercropping and succeeding chickpea by about 12.7-20.0% (Mandal *et al.*, 2013a).

The broad-bed and furrow method would avoid water congestion if heavy rainfall occurs, and facilitate soybean-chickpea or intercropping systems. By this way complete reliance on irrigation, as is being followed for rice-wheat cropping in Ludhiana, would be eliminated. Soybean-chickpea, maize-chickpea, soybean-lentil, maize-lentil or soybean-wheat may be effective cropping systems suiting to rainfall trends and pattern in different seasons, onset and withdrawal behaviour. In central Indian situation, which is having the similar rainfall pattern, based on a long-term field experiment on soybean-wheat system, it was concluded that no-tillage and/ or reduced tillage systems with crop residue retention would be a suitable practice for efficient management of rainwater and sustainable crop production (Hati *et al.,* 2014). The probability of occurrence of dry spells is found higher up to 25th SMW, that means soil moisture retention through mulching and light hoeing in inter-row spaces for standing winter crop would be beneficial. Other contingency measures, if required, need to be adopted if the dry spells continues for two weeks. Of course, the amount of excess rainwater (163.8 mm), which was stored or used to recharge groundwater, may be utilized for irrigation to winter crop(s) as life-saving irrigation in case of prolonged dry spells or during the most critical growth stage of the crop with respect to moisture stress. As the chances of getting three consecutive

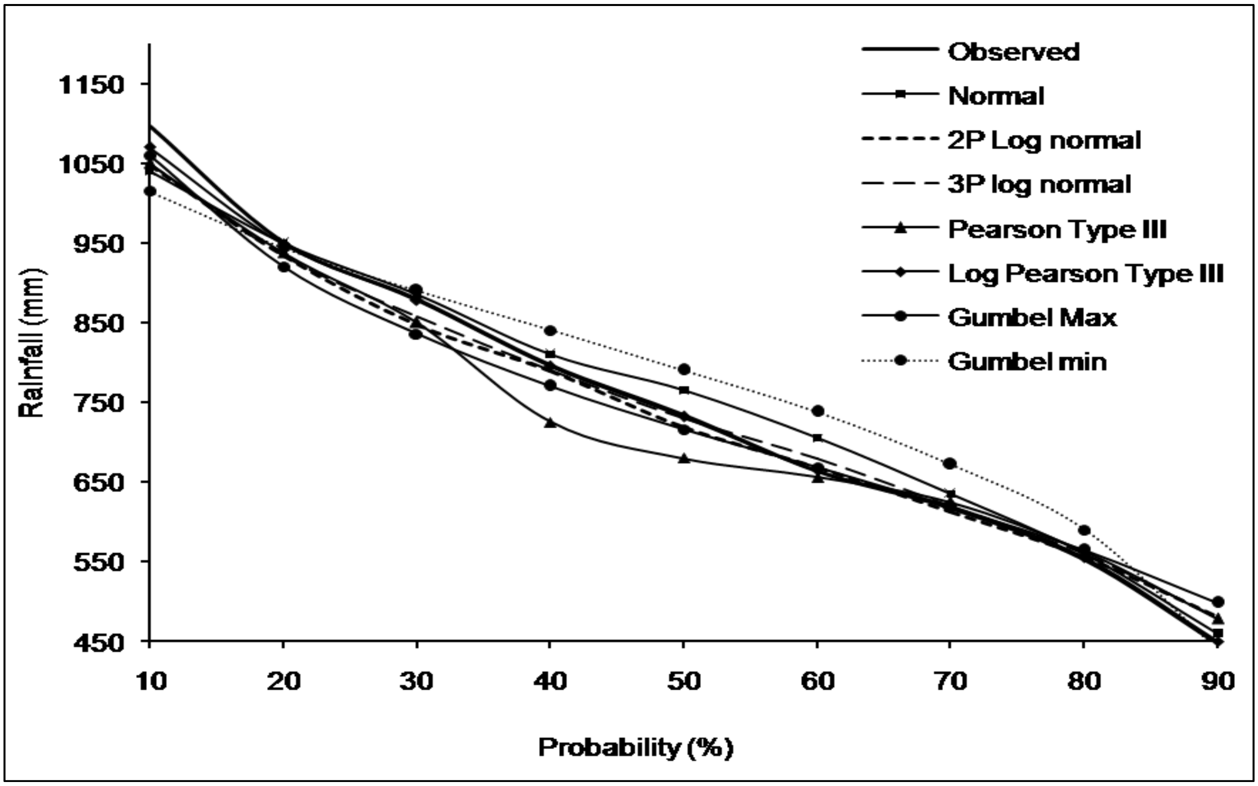

Fig. 1 Observed and predicted annual rainfall in Ludhiana, India using probability distribution functions

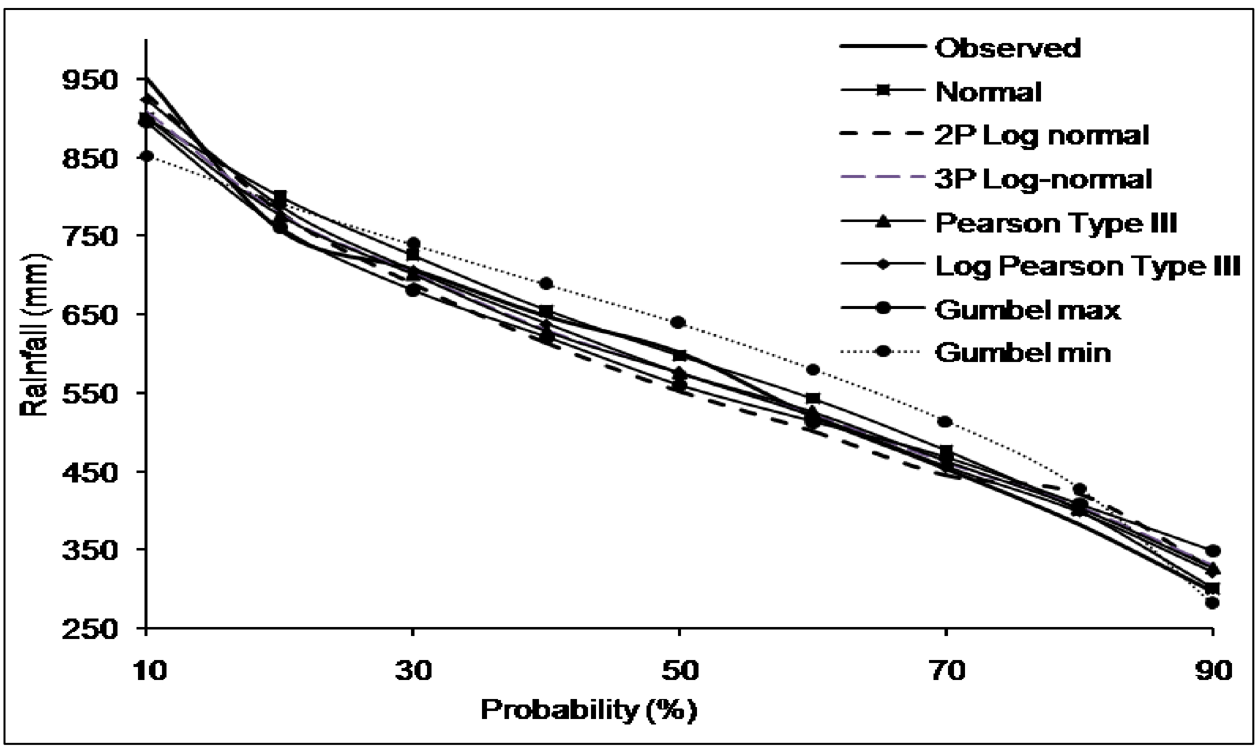

Fig. 2 Observed and predicted monsoon rainfall in Ludhiana, India using probability distribution functions

weeks dry during monsoon session was less due to some pre-monsoon rainfall and the probability varied from between 7 and 30 % in first 25 weeks of the year; chances of occurrence of consecutive wet weeks are very less in the corresponding weeks. The Markov chain analyses would help in adopting appropriate soil and crop management measures during the dry spells.

Conclusion

Probability analyses of long-term rainfall, seasonal distribution, onset and withdrawal of monsoon would form the guidelines for suitable crop planning and soil water conservation in Ludhiana, Punjab. Rainfall has been quantified with probability of occurrences; it has been shown that there is scope for storage of excess rainfall (163.8 mm) into on-farm reservoir which otherwise is getting lost due to runoff, deep percolation and evaporation. A guideline for systematic recharge of groundwater would be possible tapping this excess rainfall during monsoon months. It is clear that the most important is the monsoon season rainfall; hence our analyses have indicated its most probable onset and withdrawal of effective monsoon. Now, appropriate cropping pattern, land preparation and all agricultural operations could be planned in advance. It is concluded from our analyses that the log Pearson type III and normal distribution would be useful for prediction of annual rainfall and monsoon rainfall, respectively. Rice-wheat is the cropping system, which is mostly followed by Ludhiana farmers; but this system is not suggested for long-term sustainability; rather alternate cropping systems viz. soybean-chickpea, maize-chickpea, soybean-lentil, maize-lentil or other systems which would require less amount of water in addition to rainfall received. Since, post-monsoon rainfall is more uncertain and erratic than monsoon rainfall, growing of high value post-monsoon crops without supplementary irrigation would be risky. By this way, irrigation requirement will be decreased; a balance of groundwater resources with its minimal extraction during monsoon season and promoting the groundwater recharge could be maintained. If rice is grown, then short duration, high yielding and moisture stress tolerant cultivars may be chosen than long duration; the cultivation techniques like aerobic method or the direct dry-seeding is suggested to reduce the water required for puddling. Dry-seeding of rice or sowing/ planting or other crop is advisable to be completed by 28^{th} SMW ($9-15^{th}$ July). The soil and crop management technologies like broad-bed and furrow method, mulching during the terminal drought, if occurs, crop residue retention and conservation tillage for soil moisture conservation may be adopted. Markov chain model analyses has highlighted the knowledge on probability of dry and wet spells; it has helped to find out the possibilities of getting dry spells during the crop period in Ludhiana. It would be easier for growers to take appropriate contingency measures, if dry spells occur during early part of the year which coincide with winter cropping period. Overall, rainfed cropping system could be planned based on this rainfall analyses so that effective utilization of rainwater is achieved, and indiscriminate use of groundwater is reduced. A better soil-water-crop management would be possible for sustainable agriculture in the region.

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