IJAIR
International Journal of Agriculture Innovations and Research
Volume 6, Issue 5, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy):
Received: 06/10/2015 | Accepted on: 10/10/2015 | Published: 09/03/2018

Evaluation of Markov Chain Model for Forecasting Precipitation of Uttarakhand Districts

G. Pranuthi[1] & S.K. Tripathi[2]*
[2]Professor & [1]Research Scholar, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India.
[1]Corresponding author email id: pranuthiphd@gmail.com

***Abstract* – This paper intends to evaluate the Markov Chain model for forecasting rainfall of Uttarakhand state for each district separately. District wise interpolated daily rainfall data for the period 1971 – 2011 was collected from the NICRA (National Initiative on Climate Resilient Agriculture) website http://www.nicra-icar.in/nicrarevised/index.php/tools services. Instat climatic software version 3.37 is used to calculate the Markov chain probability of rainy day, rainy day preceded by a rainy day, rainy day preceded by a rainy day and rainy day preceded by a dry day. It is also used to study the probability of getting dry spells of duration 5 and 7 days during the monsoon period. This probability is used to model the 75% probable amount of rainfall that can occur on a given day using the Markov chain model. The model is validated for the period 2002 – 2011 by using various evaluation methods like skill scores, NMSE and MBE. Evaluation tests showed that the average skill score of the forecast is 76% while highest skill score is calculated for Udham Singh Nagar (88%) and lowest for Tehri Garhwal (63%) district. The rainfall event forecast during the months July and August was better compared to June and September months. The deviation percent is more than 20% for Bageshwar, Dehradun, Nainital, Rudraprayag, Tehri and US Nagar districts. It can be concluded that the Markov Chain model can be used for forecasting precipitation but the forecast accuracy depends on solely the reliability of the past rainfall data provided to the model.**

***Keywords* – Markov Chain Model, SW Monsoon, Precipitation, Uttarakhand, Probability.**

I. INTRODUCTION

Time series of daily rainfall can be modeled using traditional approaches such as moving averaging techniques (MA), autoregressive models (AR), combined autoregressive moving average models (ARMA) [1], [2] and autoregressive - integrated - moving average models (ARIMA). But rainfall in India is such a variable element which varies both spatially and temporally [3]. It shows long dry periods, intermittent dry days, heavy rainfall events storms etc., so to predict such parameter we need higher models. Especially daily and weekly rainfall data as such does not fit into Gaussian model so a transformation has to be applied before modelling it [4].

Rainfall variable is stochastic in nature and therefore they require stochastic models to describe them [5]. Markov Chain is one of the stochastic models that have gained popularity in describing rainfall characteristics since its introduction by Gabriel and Neumann [6]. They found that the daily rainfall occurrence for the Tel Aviv data successfully fitted using the first-order Markov chain model. Kottegoda [7] also reported that the first order Markov chain model found to fit the observed data in Italy successfully. However, Wilks [8], [9] reported that there are cases where first order Markov chain model failed to fit the observed data and therefore higher order Markov chain model was an alternative to improve these inadequacies.

Although a number of powerful statistical packages have the capability to analyze rainfall data using Markov chain models, most of them do not have specialized routines for doing this. INSTAT was introduced in the early 1980s as a simple statistical package to help in the teaching of statistics. It was later improved by adding more components with particular interest for processing climatic data [10]. Today it is the only available package with a specialized routine accessible for analyzing rainfall data using Markov chain models.

II. STUDY AREA

Uttarakhand is situated on the southern slope of the Himalayas. The climate and vegetation of different cities of this state vary with the height of its location. Glaciers are located at the highest elevations. However, there are dense forests at the lower elevations. It has 13 Districts and Dehradun is the capital city. Uttaranchal consists of 13 districts i.e., Almora, Pauri Garhwal, Tehri Garhwal, Bageshwar, Chamoli, Haridwar, Champawat, Nainital, Dehradun, Udham Singh Nagar, Uttarkashi, Pithoragarh, Rudraprayag. The state has two distinct climatic regions: mainly the hills and the relatively smaller plain region. The climatic condition of the plain region is very similar to plains. The hilly region has cold winters with snowfall for quite a long time, good rainfall in the monsoon, and mild summers. The State is bestowed with a relatively high average annual rainfall of 1229mm.

Normally rain starts in the State in late April and continues up to September. However, the intensity of rainfall increases during the months of June to September, higher rainfall occurring during first week of July. Rain continues through August until the first week of September.

Water, agriculture, forestry and energy, among other issues, are central to the State's inclusive strategy for future growth. Most of the people of Uttarakhand state are dependent on their natural environment, with over three fourths of the total population dependent on agriculture for their livelihood. When drought like conditions prevails most of the remotely located springs start drying up or the discharge is reduced to such a level that they are unable to fulfill the basic requirement of the residents.

District wise daily rainfall data for the period 1971 – 2011 (Venkateswarlu et al., 2011) was collected from the NICRA (National Initiative on Climate Resilient Agriculture) websitehttp://www.nicraicar.in/nicrarevised/index.php/tool s-services. The rainfall data utilized in the present study is available with Agromet Databank, CRIDA and the summary of the data are presented in Table 1. There is some parity between the IMD rainfall data and the data used. But the error is below the permissible limits. It is observed that state average rainfall is 1388 mm; Pithoragarh district (2013 mm) receives more rainfall and Haridwar district (1115 mm) receives less rainfall compared to other districts of the state. Data during the period 1971 – 2002 is used to calibrate the Markov Chain model while rainfall data during 2002 – 2011 is used to validate the Markov Chain model for rainfall prediction.

Table 1. Latitude, Longitude, Altitude and Annual average rainfall of districts of Uttarakhand.

S. No.	District	Lat (deg)	Long (deg)	Alt (m)	Average
1	Almora	28.9	79.1	1550	1305.2
2	Bageshwar	29.8	79.7	1600	1397.3
3	Chamoli	29.9	31.0	1960	1157.2
4	Champawat	29.5	79.5	1615	1811.8
5	Dehradun	30.2	78.1	960	1837.0
6	Garhwal	29.4	78.2	1500	1297.2
7	Haridwar	29.5	78.1	230	1115.1
8	Nainital	29.0	80.4	1938	1292.4
9	Pithoragarh	29.7	80.2	1650	2013.2
10	Rudraprayag	30.0	78.0	2100	1274.0
11	Tehri	30.3	77.5	1550	1532.2
12	US Nagar	28.4	80.4	217	1174.3
13	Uttarkashi	30.7	78.4	1140	1235.6
Average		-	-	-	**1387.9**

I. *The Markov Chain of First Order*

In the first-order Markov chain, the current state is dependent solely on the state of the immediate previous period and the chance that a process is in state-j at time τ given that it was in state-i at time τ-1 is represented by transitional probability which is expressed as follows

$$P_{ij,\tau} = P_r(X_\tau = j | X_{\tau-1} = 1) \quad (1)$$

The first order model assumes that the probability of rain occurring on any day depends only on whether it did or did not rain on the previous day. To fit this model, the parameter for transition probability $p_{i,\tau}$ is estimated over the year [11]. The $p_{i,\tau}$ the probability of rain in day τ given state i for $i = 1,0$ in day τ -1. The estimate of $p_{i,\tau}$ is given by $r_{i,\tau}$ [12] which is the proportion of years with state-i in their day τ- 1 that had rain in the day τ. The $r_{i,\tau}$ is expressed as shown below.

$$r_{i,\tau} = (n_{i_1,\tau}) / (n_{i\ ,\tau} + n_{i_0,\tau}) \quad (2)$$

Where $n_{i_1,\tau}$ is the number of years with rain on day τ and $n_{i_0,\tau}$ is the number of years with no rain on day τ. A function, in this case, using Fourier analysis is fitted to the estimated probabilities. Best fit is determined by *F*-test of added harmonics to the function.

III. Probability of Dry Spell Occurrence

For this application, a 'dry' day is defined as a day with <0.25 mm rainfall and a 'dry spell' as any consecutive number of days defined as 'dry'. Rainfall characteristics and dry spell occurrences were obtained by statistical evaluation of data using a first-order Markov chain process to estimate probability of occurrence of rainfall. It is assumed that rainfall at any given day is a stochastic event which is only dependent on the probability of the previous day being dry (*P*(d)) or rainy (*P*(r)), therefore, it is a first-order process. Each year (Q_i) of the dataset can be described as a sequence of dry ($xj = 0$) or wet ($xj = 1$) days as:

$$Q_i = \{X_1, X_2, ..., X_{j-1}, X_j\} \text{ for}$$
$$Q_i = \{1, 2, 3..............., i-1, i\}$$

where *i* is the number of years and *j* the day of year (DOY). The probability for a day being rainy after a dry day can be estimated as:

$$P(rd) = prob(x_j = 1, x_{j-1} = 0) = \frac{\left(\sum_{q=1}^{q=i}(x_j = 1, x_{j-1} = 0)\right)}{\sum_{q=1}^{q=i}(x_{j-1} = 0)} \quad (3)$$

Similarly, a rainy day following a rainy day can be described with:

$$P(rr) = prob(x_j = 1, x_{j-1} = 1) = \frac{\left(\sum_{q=1}^{q=i}(x_j = 1, x_{j-1} = 1)\right)}{\sum_{q=1}^{q=i}(x_{j-1} = 1)} \quad (4)$$

The determined functions of probable occurrence of rainfall on any given day is then used to determine probabilities of dry spell occurrence of stated lengths within the next 5 or 7 days. For the estimation of probabilities of rainfall and dry spell occurrences, the software INSTAT version 6.5 was used (Statistical Service Centre, University of Reading, UK) [13].

Daily and weekly rainfall data of Roorkee station is directly used to assess dry spell trends. The direct method of analyzing climate data is applicable if the data record is at least 30 years long [11]. The daily rainfall data were fitted to the simple Markov chain model as outlined in INSTAT Climatic guide [13]. The Markov chain model was run so that it gave the probability of getting 5 and 7 day dry spells within 30 days following a wet day for monsoon season consisting of four months (June-Sep). Five and seven day dry spell was chosen because rainfall forecasts are currently being issued for 5 and 7 day periods in India. The analyses were performed.

IV. Forecast Evaluation

The rainfall being discrete variable, a daily contingency table (Table 2) was prepared for further analysis of rainfall data (bias corrected and observed) using [14] methodology as described below:

Table 2: Rainfall contingency table

Bias Corrected		Observed	
		Yes	No
	Yes	A (YY) (Hits)	B (YN) (False alarms)
	No	C (NY) (Misses)	D (NN) (Correct ejects)

Where,
A (YY) = No. of Hits (predicted and observed).
B (YN) = No. of False Alarms (predicted but not observed).
C (NY) = No. of misses (observed but not predicted), and
D (NN) = No. of correct rejects.

a) Forecast Accuracy or Ratio Score

It is the ratio of the number of correct forecasts to the total number of forecasts. The score is expressed in percentage indicating that higher the best.

$$ACC = \left(\frac{A + D}{A + B + C + D} \right) * 100 \quad (5)$$

It varies from 0 to 1. Perfect forecast is indicated as 1.

b) Probability of Detection (POD)

It is also known as Hit Rate and widely used to evaluate probabilistic forecasts. It is sensitive to hits, but ignores false alarms, very sensitive to the climatological frequency of the event. Good for rarely occurring events such as floods, cyclones, tornadoes, etc.

$$POD = \frac{A}{(A + C)} \quad (6)$$

It ranges between 0 to 1 and POD value of 1 is considered to be the best forecast.

c) False Alarm Ratio

It is sensitive to false alarms, but ignores misses, very sensitive to the climatological frequency of the event. It should always be used in conjunction with the probability of detection (above).

$$FAR = \frac{A}{(A + B)} \quad (7)$$

It varies from 0 to 1. Perfect forecast is indicated as 0.

d) Critical Succession Index

It is also known as Threat Score which measures the fraction of observed and/or forecast events that were correctly predicted. It is the accuracy score when correct negatives have been removed from consideration, that is, TS is only concerned with forecasts that count. Sensitive to hits, penalizes both misses and false alarms. It's incapability is that it does not distinguish source of forecast error. Depends on climatological frequency of events (poorer scores for rarer events) since some hits can occur purely due to random chance.

$$CSI = \frac{A}{(A + B + C)} \quad (8)$$

It ranges from 0 to 1, 0 indicates no skill and 1 indicates a perfect forecast.

e) Normalized Root Mean Square Error (NMSE)

The Normalized Root Mean Square Error (Kumar, 2000) is concerned with the deviations from the true value whereas SD is concerned with deviations from the mean. The Normalized Root Mean Square Error is dimensionless and calculated using the following formula.

$$ACC = \left(\frac{A + D}{A + B + C + D} \right) * 100 \quad (5)$$

Where,
N = number of observations.
SD = Standard Deviation.
P_{corr} = Bias corrected value.
P_{obs} = Observed value.

f) Mean Bias Error (MBE)

The Mean Bias Error [15] is simply the difference between the average forecast and average observation, and therefore expresses the bias of the forecasts. Forecasts that are, on average, too high will exhibit MBE >0 and forecasts that are, on average, too low will exhibit MBE < 0.

$$MBE = \frac{1}{N} * \left(\sum \left(P_{corr} - P_{obs} \right) \right) \quad (10)$$

V. Probability Plots

The probability plots (Fig.1) of a rainy day during the month of June on an average for all the districts ranges from 30 to 70 % and median lies at 50% which suggests that the rainy probability is unpredictable. The monthly average probability of having a rainy day for the month of June is highest (62%) for Champawat and Pithoragarh districts while it is least for Chamoli district with just 40% probability. Probability of having a rainy day is highly variable for Udham Singh Nagar probability ranging from 25 to 82% and it less variable for Almora district with probability ranging from 30 - 66%. July and August months mean probability of having rainy day is 77% and 80% respectively. Bageshwar, Champawat and Pithoragarh have been observed to have highest probability as 87% and 89%, lowest probability is observed for Tehri (67%) and Almora (69%) districts for July and August months respectively. Occurrence of a rain day is very much uncertain for Tehri district as the probability ranges from 44 – 83% during July month and Almora district during August month as the probability ranges from 46 – 85%. However September has less probability of a rainy day with only 53%. First and second week probability is between 60-70% and keeps on decreasing until it becomes 20-30% by the fourth week. Therefore the variability is highest for June and September months corresponding to time of onset and with drawl of monsoon season.

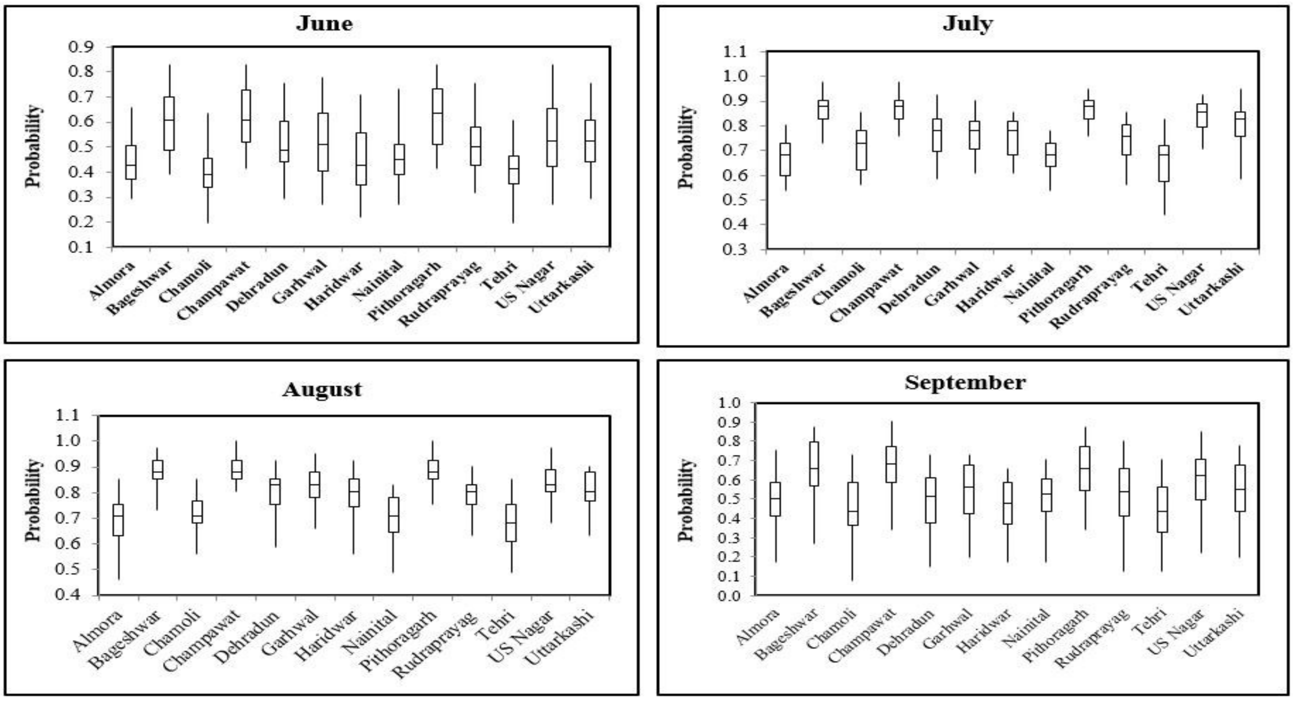
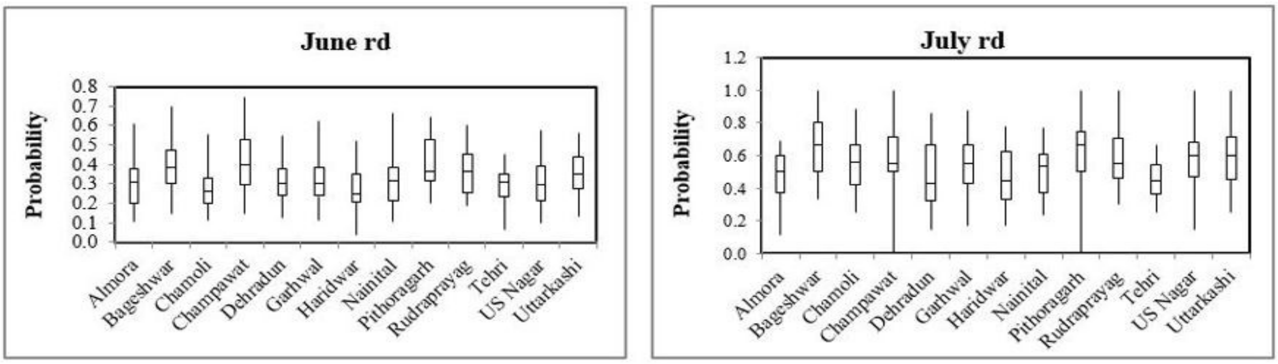


Fig. 1. District wise Error Charts showing the Markov Chain probability of getting a rainy day for June, July, August and September months.

The probability plot of a rainy day followed by a dry day (Fig.2) during the monsoon season on an average for all the districts ranges from 40 to 90 % and median lies at 80%. The monthly average probability of having a rainy day for the month of June is highest (73%) for Pithoragarh district while it is least for Chamoli district with 63% probability. The p_rr is highly variable for Tehri Garhwal district with probability ranging from 27 to 88%. The probability for July and August months is almost similar with an average of 85%. Champawat district has been observed to have highest probability as 92% lowest probability is observed for Nainital (75%) during July month. P_rr during the August month is highest for Bageshwar and Champawat districts (92%) and least for Almora (77%) district. The mean probability of rr during the September for all districts is as high as 80% and as less as 63% for Bageshwar and Tehri districts respectively. Occurrence of a rainy day followed by a rainy is very much uncertain for Tehri and Chamoli districts as the probability ranges from 57 – 96% during July month and Almora district during August month as the probability ranges from 46 – 85%. The first and second weeks of June has less probability compared to third and fourth week which indicates the onset of monsoon and it has its complete intensity during July and August months, First and second week probability of September months is between 80-90% and keeps on decreasing until it becomes 40-50% by the fourth week.

The probability of a rainy day followed by a rainy day (Fig. 3) during the monsoon season on an average for all the districts ranges from 40 to 90% and median at 80%. The monthly average probability of having a rainy day for the month of June is highest (73%) for Pithoragarh district while it is least for Chamoli district with 63% probability. The p_rr is highly variable for Tehri Garhwal district with probability ranging from 27 to 88%. The probability for July and August months is almost similar with an average of 85%. Champawat district has been observed to have highest probability as 92 % lowest probability is observed for Nainital (75%) during July month. P_rr during the August month is highest for Bageshwar and Champawat districts (92%) and least for Almora (77%) district. The mean probability of rr during the September for all districts is as high as 80% and as less as 63% for Bageshwar and Tehri districts respectively.



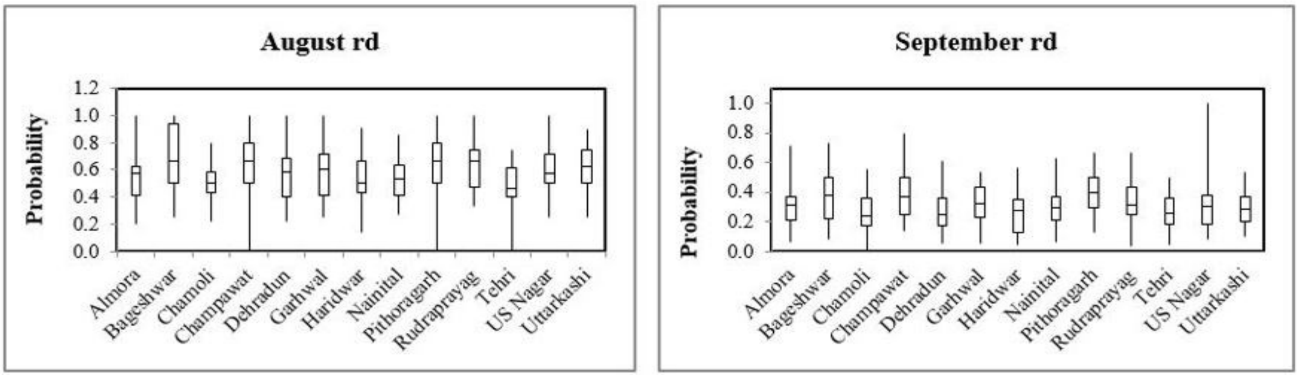


Fig. 2. District wise Error Charts showing the Markov Chain probability of getting a rainy day preceded by dry day for June, July, August and September months.

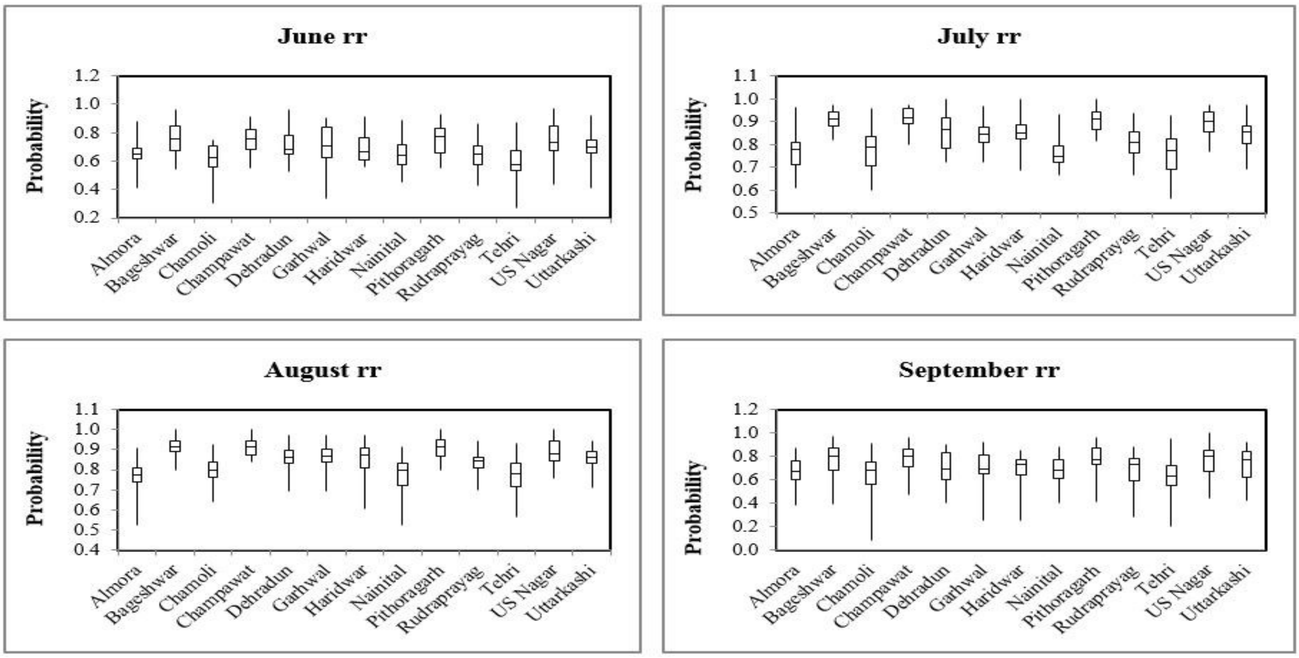


Fig. 3. District wise Error Charts showing the Markov Chain probability of getting a rainy day preceded by a rainy day for June, July, August and September months.

Occurrence of a rainy day followed by a rainy is very much uncertain for Tehri and Chamoli districts as the probability ranges from 57 – 96% during July month and Almora district during August month as the probability ranges from 46 – 85%. The first and second weeks of June has less probability compared to third and fourth week which indicates the onset of monsoon and it has its complete intensity during July and August months, First and second week probability of September months is between 80-90% and keeps on decreasing until it becomes 40-50% by the fourth week.

VI. Mean Amount of Rainfall Modeled

Using the above estimated daily probabilities for a rainy day, rainy day followed by rainy day and dry day the amount for each day is modeled and even the rainfall amounts are fitted using a normal distribution curve. These graphs give the most probable amount of rainfall that is likely (75%) to occur on each day (Fig. 4). The modeled rainfall shows that the heavy rainfall event (> 20 mm) can very much occur on 10th June, 17th August, 13th and 24th September. In case of Bageshwar the rainfall is rather steady and continuous with no heavy rainfall events and for Chamoli there are no heavy rainfall events but the rainfall is also less. According to the modeled rainfall a heavy rainfall event may possibly occur on 17th August in Champawat district.

The probability of getting 5 and 7 day dry spells during the monsoon period is given in Fig 5. Based on the data set reviewed, Tehri Garhwal had the highest probability of getting 5 and 7 day dry spells compared to the other stations which would require frequent irrigations are required during the crop period. The districts Bageshwar, Champawat and Pithoragarh had the least probability of getting dry spell for 5 and 7 days suggesting that the irrigation scheduling in these districts can be minimized or the irrigation water can be diverted to places of necessity. However, irrigation management not only depends on the rainfall but it also depends on slope and water retentive capacity of soils.

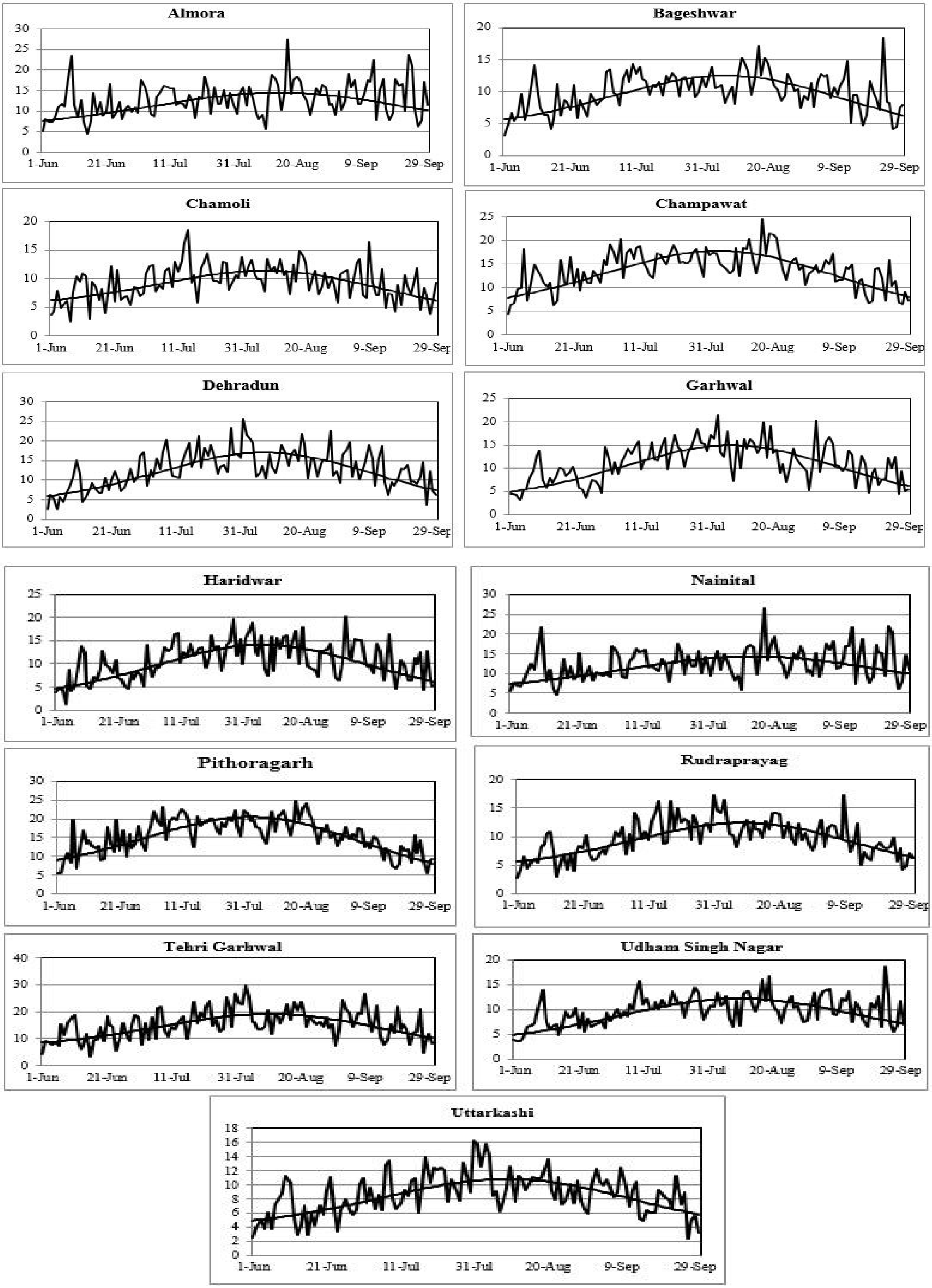
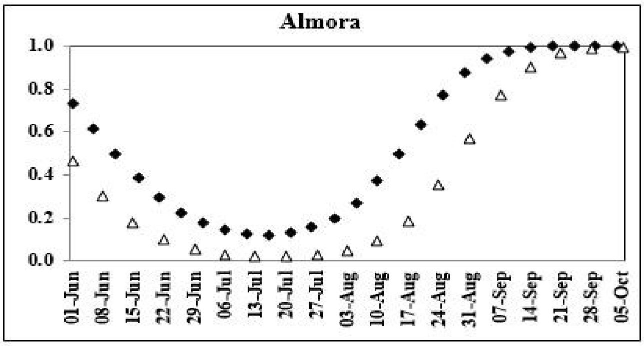
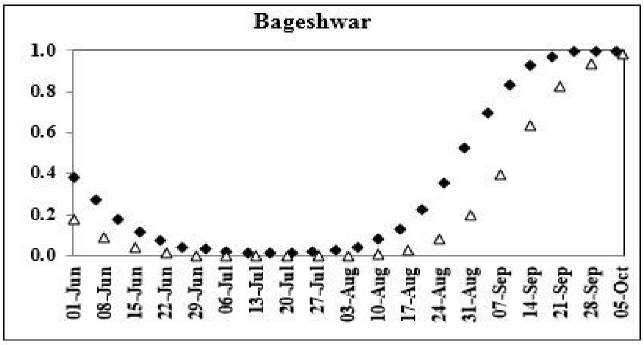
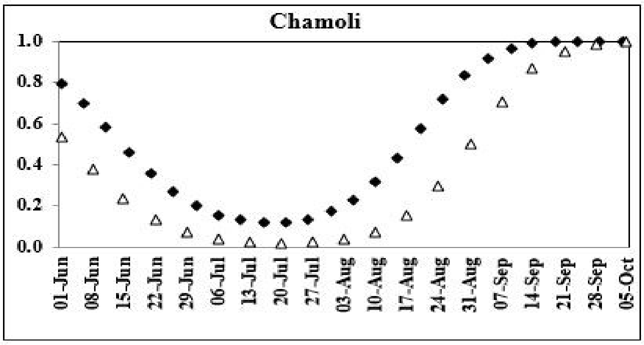
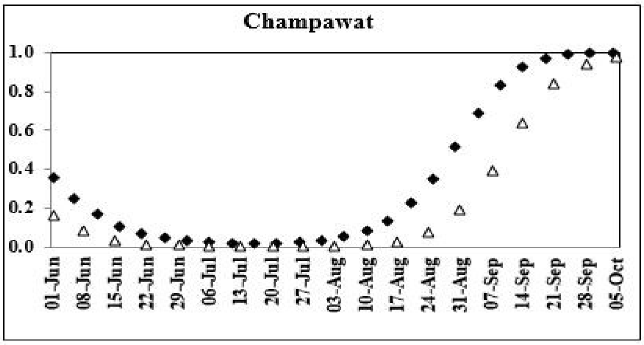


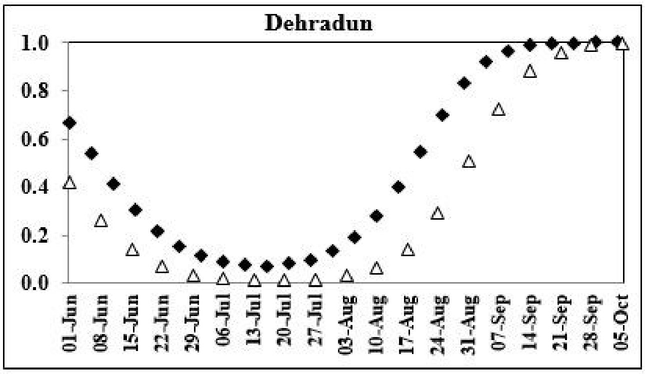
Fig. 4. Mean amount of SW monsoon rainfall modeled at 75% probability along with its trend line for the districts of Uttarakhand.

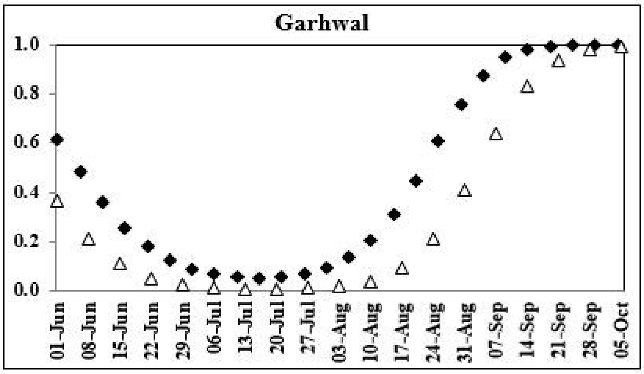

Almora
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct

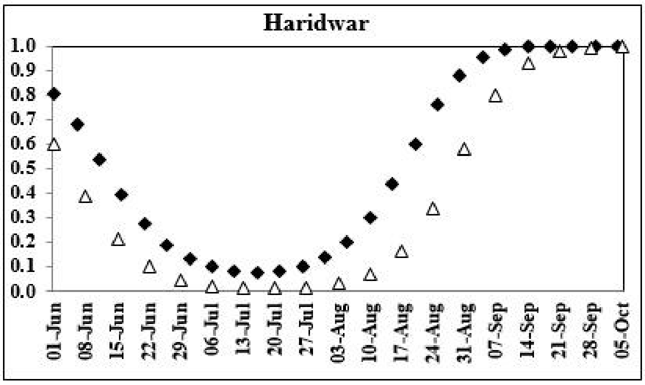

Bageshwar
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct

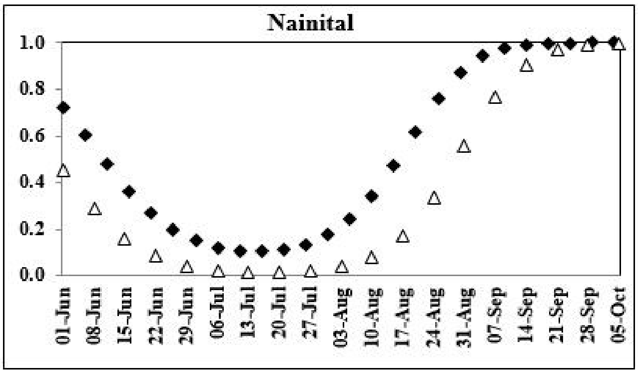

Chamoli
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct

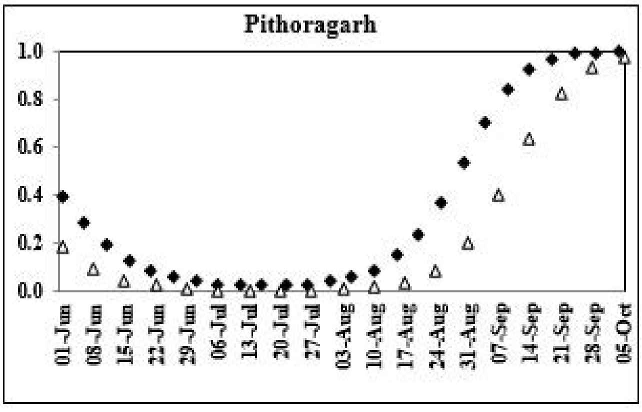

Champawat
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct

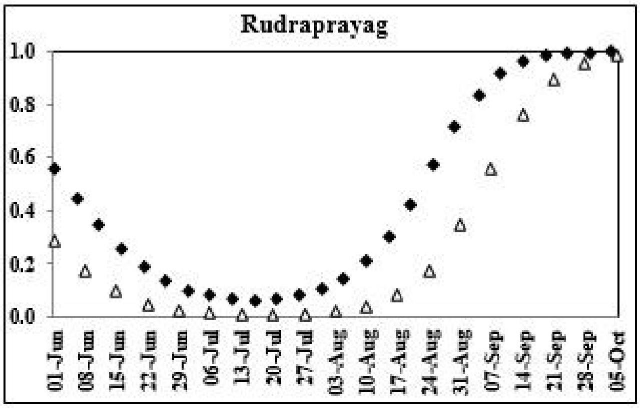

Dehradun
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct


Garhwal
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct


Haridwar
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct


Nainital
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct


Pithoragarh
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct


Rudraprayag
1.0
0.8
0.6
0.4
0.2
0.0
01-Jun 08-Jun 15-Jun 22-Jun 29-Jun 06-Jul 13-Jul 20-Jul 27-Jul 03-Aug 10-Aug 17-Aug 24-Aug 31-Aug 07-Sep 14-Sep 21-Sep 28-Sep 05-Oct

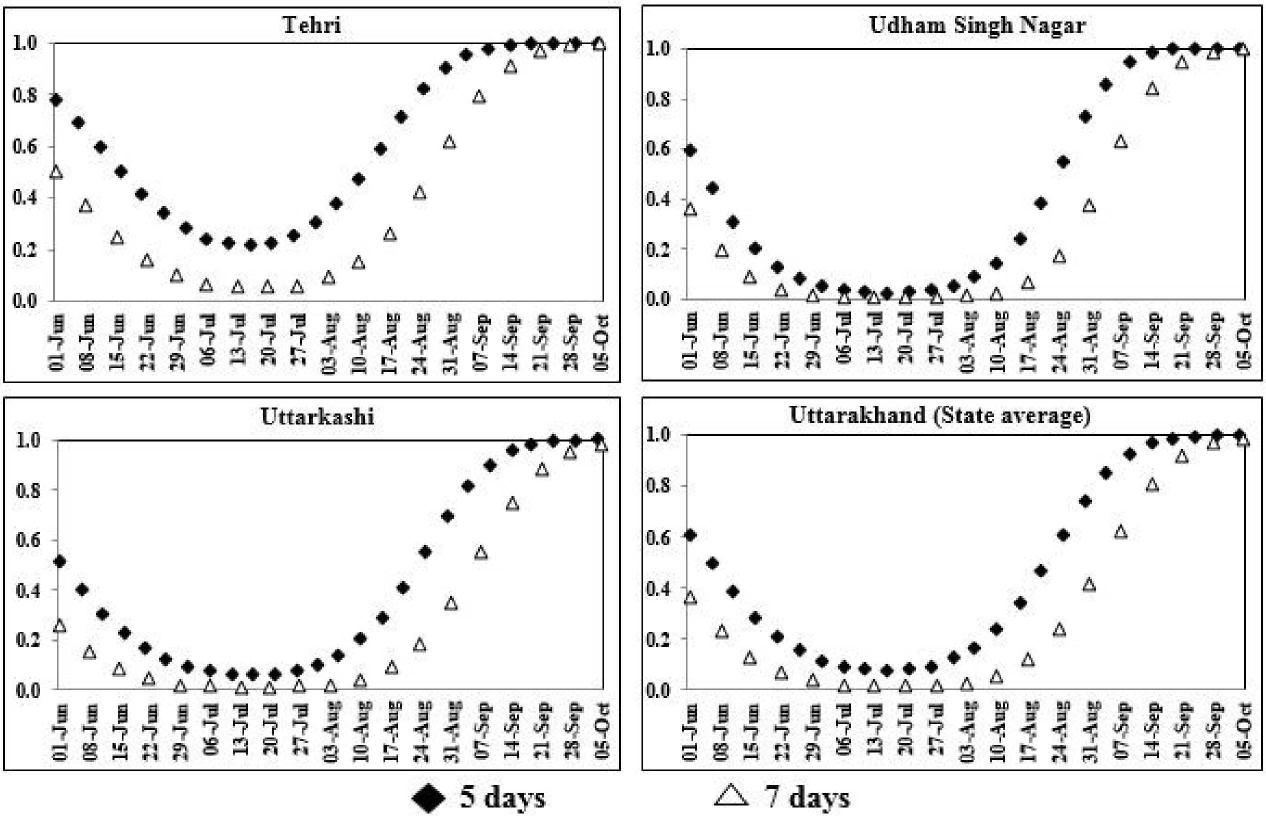


Fig. 5. Markov Chain Probability of getting 5 and 7 days duration dry spells during the SW monsoon season for the districts of Uttarakhand.

VII. Evaluation of Markov Chain Model

Various skill scores and error measures were used to evaluate the rainfall simulated during the calibration period (2002 – 2011) (Table.3). The FC and CSI during the August month (0.81) was higher compared to other months during the monsoon. POD (0.87) and FAR (0.11) showed that the rainfall simulation is better during the month of July. FC is highest for Udham Singh Nagar during June (0.66), July (0.89) and August (0.9) and for Bageshwar during September month (0.65). While it is least for Rudraprayag (0.51), Nainital (0.68), Tehri Garhwal (0.69) and Almora (0.48) districts during June, July, August and September months respectively. POD is highest for Bageshwar during June (0.8) and September (0.74) and for Udham Singh Nagar during July (0.93) and August (0.94) month; while it is lowest for Tehri Garhwal district during June (0.5), July (0.8) and August (0.75); for Almora district during September (0.47) month. The higher values of FAR indicate a wrong forecasts for Almora district during June (0.34), August (0.13) and September (0.31) months and for July (0.15) month it is higher for Tehri Garhwal district. Lower values of FAR indicate higher number of correct forecasts which is estimated for Pauri Garhwal and US Nagar for June (0.21); US Nagar for July (0.05); Dehradun, Pauri Garhwal Haridwar and Uttarkashi for August (0.03) and Pauri Garhwal for September (0.19) month. CSI is used to measure the accuracy of the forecast only during rainy days. It is highest for Bageshwar during June (0.64) and September (0.62) months; US Nagar during July (0.89) and August (0.9) months. Poor rain forecasts are observed for Tehri during June (0.4) and August (0.69) months; Nainital and Almora for July (0.68) and September (0.38) months respectively. The skill scores FC, POD, CSI and FAR only indicate whether the rain event is forecasted correctly or not but NMSE and MBE indicate the deviation of rainfall amount forecasted from that of the observed. Higher values of NMSE and MBE indicate more deviation of rainfall amount forecasted from the observed values, while lower values indicate a better forecast. According to NMSE values rainfall forecast for Chamoli district is found to deviate less from the observed during June (0.24), July (0.19) and August (0.10); September (0.13) forecast was better for Champawat district. NMSE is highest for Haridwar, Rudraprayag and US Nagar districts during June (0.49); US Nagar during July (0.68) and Tehri during August (0.98) and September (0.87) months. MBE is highest for Pithoragarh, Tehri, Dehradun and Almora districts during June (2.96), July (2.62), August (-5.06) and September (-5.42) months. It is lower for US Nagar during June (0.01) and September (-3.04) months; Bageshwar (-0.18) and Champawat (0.41) during July (0.89) and August (0.9) months. The percent deviation of forecasted rainfall from the normal rainfall of respective districts is calculated (Fig. 6). The deviation percent is more than 20% for Bageshwar, Dehradun, Nainital, Rudraprayag, Tehri and US Nagar districts.

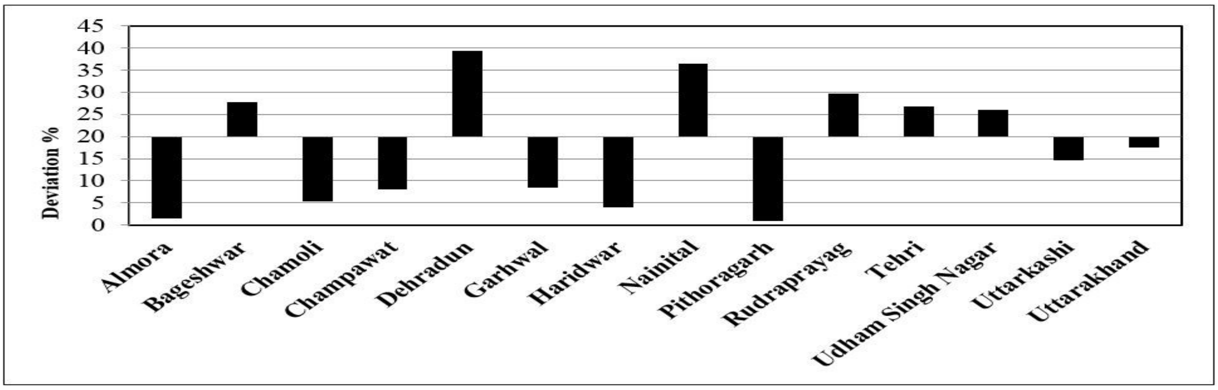


Fig. 6. District wise Deviation % estimated for Forecasted Rainfall (2002 – 2011) from that of the Normal rainfall.

Dry spells of more than 7 days is not a common phenomenon in Uttarakhand districts but due to undulating topography the water retention within the soil is less. Therefore 5 and 7 days dry spells adversely affect the crop growth. The frequency of dry spells during the first fortnight of June, second fortnight of August and September months is more which indicate the necessity for irrigation during these periods depending on the crop and the stage of the crop. A study on dry spell analysis by Markov chain approach for Nigeria was found reliable for Maize crop planning [16]. Forecast is found reliable for districts with majority of plain area and also for districts with proper distributed rain gauges from whose regular and correct data is being collected distribution. Forecasts with much reliability can be issued using Markov Chain for districts like US Nagar, Bageshwar, Garhwal and Haridwar districts. Two state first order Markov Chain model simulated rainfall for the period 2002-2011 proved to be reliable with less bias for all the districts of Uttarakhand. Therefore it can be concluded that the dry spell analysis and rainfall forecast can be done using Markov Chain model. Similar report has also been generated by [17] in which Markov Chain model was used to simulate rainfall for Italy and Switzerland.

References

[1] P. Burlando, R. Rosso, L.G. Cadavid, and J.D. Salas, "Forecasting of short-term rainfall using ARMA models," J. Hydrol., vol. 144, no. 1–4, pp. 193–211, 1993.

[2] E. Toth, A. Brath, and A. Montanari, "Comparison of short-term rainfall prediction models for real-time flood forecasting," J. Hydrol., vol. 239, no. 1–4, pp. 132–147, 2000.

[3] V. Krishnamurthy and J. Shukla, "Intraseasonal and interannual variability of rainfall over India," J. Clim., vol. 13, no. 24, pp. 4366–4377, 2000.

[4] V. Gowariker, V. Thapliyal, R. P. Sarkar, G. S. Mandal, and D. R. Sikka, "Parameteric and power regression models: new approach to long range forecasting of monsoon rainfall in India," Mausam, vol. 40, pp. 115–122, 1989.

[5] M. Mimikdu, "Daily precipitation occurrences modelling with Markov chain of seasonal order," Hydrol. Sci. J., vol. 28, no. 2, pp. 221–232, 1983.

[6] K. R. Gabriel and J. Neumann, "A Markov chain model for daily rainfall occurrence at Tel Aviv," Q. J. R. Meteorol. Soc., vol. 88, no. 375, pp. 90–95, 1962.

[7] N. T. Kottegoda, L. Natale, and E. Raiteri, "Some considerations of periodicity and persistence in daily rainfalls," J. Hydrol., vol. 296, no. 1–4, pp. 23–37, 2004.

[8] D. S. Wilks, "Interannual variability and extreme-value characteristics of several stochastic daily precipitation models," Agric. For. Meteorol., vol. 93, no. 3, pp. 153–169, 1999.

[9] D. S. Wilks and R. L. Wilby, "The weather generation game: a review of stochastic weather models," Prog. Phys. Geogr., vol. 23, no. 3, pp. 329–357, 1999.

[10] N. Stern, "Stern review report on the economics of climate change," 2006.

[11] R. Coe and R. D. Stern, "Fitting models to daily rainfall data," J. Appl. Meteorol., vol. 21, no. 7, pp. 1024–1031, 1982.

[12] R. D. Stern and R. Coe, "A model fitting analysis of daily rainfall data," J. R. Stat. Soc. Ser. A, pp. 1–34, 1984.

[13] R. Stern, D. Rijks, I. Dale, and J. Knock, "INSTAT climatic guide," Univ. Read., 2006.

[14] D. S. Wilks, Statistical methods in the atmospheric sciences, vol. 100. Academic press, 2011.

[15] T. M. Addiscott and A. P. Whitmore, "Computer simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter and spring," J. Agric. Sci., vol. 109, no. 1, pp. 141–157, 1987.

[16] M. G. Barron and L. Ka'aihue, "Critical evaluation of CROSERF test methods for oil dispersant toxicity testing under subarctic conditions," Mar. Pollut. Bull., vol. 46, no. 9, pp. 1191–1199, 2003.

[17] N. T. Kottegoda, L. Natale, and E. Raiteri, "Simulation of climatic series with non-stationary trends and periodicities," J. Hydrol., vol. 398, no. 1–2, pp. 33–43, 2011.

Authors' Profiles

First Author – Dr. G. Pranuthi was born in Hyderabad in the year 1984, 9th August. Pranuthi has done her bachelors in Agriculture from the Acharya N.G. Ranga Agricultural University, Hyderabad during the period 2002 – 2006. Pranuthi has pursued her Masters in Satellite Meteorology & Weather Informatics from the Jawaharlal Nehru Technological University Hyderabad during the period 2006 – 2008. She has completed her Ph.D (2011 – 2016) under the guidance of Prof. S.K. Tripathi in Irrigation Water Management from the Water Resources Development & Management, Indian Institute of Technology Roorkee, Roorkee. Presently Pranuthi is doing her Post Doctoral Fellow under Dr. Yafit Cohen, Agricultural Research Organization Volcani Centre, Israel. She has worked in Agromet-Cell, ANGRAU as Senior Research Fellow during the period 2008 – 2010. She is a mother of two wonderful kids and home maker too. She has been awarded the best paper award at Agromet Conference, Coimbatore, India.

Second Author – Dr. S.K. Tripathi was born on August 15, 1951 at his ancestral village in Pratapgarh District of Uttar Pradesh. Dr Tripathi completed his primary schooling and secondary education in his village. He took admission in Allahabad Agricultural Institute (Allahabad University) in 1968 to pursue his higher studies in Agriculture. He obtained his B.Sc. (Ag.) in 1968, M.Sc. (Ag.) Agronomy in 1973 and Ph.D. in 1980. Dr. Tripathi started his career as a Subject Matter Specialist (Agronomy) in 1977 and worked for about two years at Allahabad Agricultural Institute. Dr Tripathi as a team leader was responsible for organizing Field Demonstrations in Intensive Agronomic Practices on farmers fields, organizing field days and other

International Journal of Agriculture Innovations and Research
Volume 6, Issue 5, ISSN (Online) 2319-1473

extension activities of the farmers interest. Dr. Tripathi joined as Agronomist in 1979 in the Department of Water Resources Development Training Centre, University of Roorkee. Dr. Tripathi was responsible for the development of Academic Programme for Master of Engineering in Water Use Management which was subsequently renamed as Irrigation Water Management Programme. Dr. Tripathi was also made responsible for the establishment of Demonstration Farm and Irrigation Water Management Laboratory. He completed this task single handedly and successfully. He was promoted as Reader in 1983 and then Professor (Agronomy) in 1995. Dr. Tripathi was appointed as Head of the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee in 2005 for a period of three years. During his tenure as Head, he transformed the working and academic environment of the Department that resulted into tremendous infrastructure development, influx of research and consultancy activities. Dr. Tripathi as a faculty has taught various subjects like agronomy, soil science, principles of irrigation, irrigation practices, land reclamation, on farm development, organizational management, evaluation of irrigation projects, cropping system modeling etc. He guided action oriented field research and organized field oriented diagnostic analysis for M.Tech. Programme in Irrigation Water Management. His interactive teaching methodology is very much appreciated by his students. Dr. Tripathi has published 83 research papers in various national and international journals, symposium and conferences as well as 33 popular articles covering different aspects of Agriculture and Water Management.