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Probability analysis of 5-day antecedent rainfall at different return periods and seasons for Doimukh (Itanagar), Arunachal Pradesh

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ABSTRACT

Daily rainfall data recorded at Doimukh station for a period of 26 years (1988-2013) were used in this analysis. The 5 days total antecedent rainfall prior to the storm was calculated under three different seasons, *i.e.* pre-monsoon (March to May), monsoon (June to October) and post- monsoon (November to February). The 5 days antecedent rainfall was classified into AMC-I, AMC-II and AMC-III groups for all the seasons. Four probability distributions were fitted to 5 days antecedent rainfall data for different groups and 5 days antecedent rainfall at 1 to 100 years return period were calculated for the study site.

1. INTRODUCTION

Soil type, antecedent moisture, topographic factor and land cover are important variables deciding the process of runoff from a watershed. Abstraction such as interception, depression storage and soil moisture storage cause direct runoff to be less than storm rainfall. A common scheme to account for the dependence of abstraction on initial watershed moisture is to define a number of discrete antecedent rainfall condition based on total rainfall during a specified length of time preceding the storm of interest (Kumar, 1995). Dependence of abstractions on initial watershed moisture is defined by Antecedent Moisture Condition (AMC) groups. AMC is used as an index of watershed wetness. Three levels of AMC are used: AMC I: Lowest runoff potential: The watershed soils are dry enough for satisfactory cultivation to take place; AMC II: Average Condition; and AMC III: Highest runoff potential in this watershed is practically saturated from antecedent rains. The AMC group is determined by using the 5 days antecedent rainfall. For determining AMC I group, 5 days antecedent rainfall for dormant and growing seasons are taken less than 1.25 and 3.5 cm, respectively. For determining AMC II group, 5 days antecedent rainfall for dormant and growing seasons are taken less than 1.25 to 2.75 cm and 3.5 to 5.25 cm, respectively. For determining AMC-III group, 5 days antecedent rainfall for dormant and growing seasons are taken more than 2.75 and 5.25 cm, respectively (Murty and Jha, 2009). If the appropriate antecedent rainfall data are available, that may be used in prediction of runoff.

Hydrological frequency analysis can be used for predicting occurrence of future antecedent rainfall with the help of a probability distribution function. Several workers [Kumar and Kumar (1989); Kumar (1995); Nagarajan (2006); Ravi Babu *et al.* (2006); Dabral *et al.* (2006); Pilare *et al.* (2007); Dabral and Pandey (2008); Dabral *et al.* (2009); Subudhi *et al.* (2012); Subbaiah (2013); Singh *et al.* (2014); Kumar *et al.* (2007) and Pattanaaik *et al.* (2016)] used probability distribution function for predicting the value of hydrological parameter under different probability levels or return periods. The study area (Doimukh) comes under humid tropical climate of northeast India. The average annual rainfall of the study area is 3528 mm out of which 72 and 24% is concentrated during monsoon (June to October) and pre-monsoon (March to May) seasons, respectively. The objective of the present study is to determine 5 days antecedent rainfall at different return periods and seasons under different AMC groups for Doimukh. The outcome of the study would be helpful for predicting runoff for the study site.

2. MATERIALS AND METHODS

Study Area and Data Collection

Daily rainfall data recorded at Doimukh station ($27^0$08'39" N Latitude, $93^0$45'05" E Longitude and 118 m above msl) by the Rural Works Department, Itanagar for a period of 26 years (1988-2013) were used in this analysis. Data were grouped in seasonal rainfall of pre–monsoon (March to May), monsoon (June to October) and post-

monsoon (November to February). The 5 days total antecedent rainfall prior to the storm was calculated under three different seasons, *i.e.* pre-monsoon (March to May), monsoon (June to October) and post-monsoon (November to February). If there was a dry day (or two dry days) within 5 days prior to the storm, the rainfall of remaining four days (or three days) were added to obtain 5 days antecedent rainfall. The 5 days antecedent rainfall was classified into AMC-I, AMC-II and AMC-III groups for all seasons. Numbers of 5 days antecedent rainfall under different AMC groups and seasons were also worked out.

Statistical Analysis of Data

Mean, standard deviation, coefficient of variation, coefficient of skewness were calculated for 5 days antecedent rainfall for different AMC groups.

Fitting of Continious Probability Distribution Functions

The five continuous probability distribution functions were fitted to 5 days antecedent rainfall of different seasons under different AMC groups for the study site. They are: i) Normal distribution; ii) Log-Normal distribution; iii) Gamma distribution; iv) Log Pearson Type III and v) Extreme value Type-I.

Testing the Goodness of fit

The Kolmogorov- SmirnovTest

Let X_1, X_2, …… X_m….., X_n be the ordered values of the random variable in a sample of size n arranged in descending order of magnitude. Cumulative probability $P(X_m)$ for each of the observations X_m is computed for each of the observations X_m using the Weibull's formula. The theoretical cumulative probability $F(X_m)$ for each ordered observation X_m is obtained using the best fit distribution function. The absolute difference of $P(X_m)$ and $F(X_m)$, that is $P(X_m) - F(X_m)$ is computed for each X_m. The Smirnov-Kolmogorov statistics Δ is the largest value of these differences. That is,

$$\Delta = \text{maximum of } |P(X_m) - F(X_m)| \quad ...(1)$$

If $\Delta < \Delta_0$ (tabular value) at α = 1% or 5% significance level, the hypothesis that the distribution is a good fit, otherwise reject the hypothesis. If more than one distribution pass the test, then the distribution which gives the least value of Δ is taken to be the most appropriate choice.

Frequency Analysis Using Frequency Factors

Chow (1951) has shown that many frequency analysis can be reduced to form.

$$X_T = \overline{X}(1 + CV.K_T) \quad ...(2)$$

Where, CV = coefficient of variation, K_T = frequency factor, $\overline{X}$ = mean value of X and the X_T = magnitude of the event having a return period T.

For Normal and Lognormal distribution, the frequency factor can be expressed by the following equation:

$$K_T = \frac{(X_T - \mu)}{\sigma} \quad ...(3)$$

Where, X_T = magnitude of the hydrological event, K_T = frequency factor , μ = mean of the sample and σ = standard deviation of the sample. This is the same as the standard normal variable z. The value of z corresponding to an exceeding probability of p (p = 1/T) can be calculated by finding the value of an intermediate variable 'w';

$$\text{Where, } w = \left[ln\left(\frac{1}{P^2}\right)\right]^{1/2} \quad (0 < p \leq 0.5) \quad ...(4)$$

Then calculating z using the equation:

$$z = w - \left[\frac{(2.515517 + 0.802853w + 0.010328w^2)}{(1 + 1.432788w + 0.189269w^2 + 0.001308w^3)}\right] ...(5)$$

When p > 0.5, 1 – p is substituted for p in equation (9) and the value of z is computed by equation (10) is given a negative sign.

For Log-Pearson distribution, firstly logarithms of the hydrologic data ($y = \log_{10} x$) was taken. The mean y, standard deviation Sy and Coefficient of skewness Cs were calculated for the logarithms of the data. When Cs = 0, the frequency factor is equal to the standard normal variable z as given in equation 3 and 5. When $Cs \neq 0$, K_T is approximated by equation 6.

$$K_T = z + (z^2 - 1)\, k + \frac{1}{3}(z^3 - 6z)\, k^2 - (z^2 - 1)\, k^3 + zk^4 + \frac{1}{3}k^5 ...(6)$$

Where, $k = \frac{c_s}{6}$, For the Extreme Value Type I distribution, K_T is calculated from the below written expression:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\text{In}\left(\frac{T}{T-1}\right)\right]\right\} \quad ...(7)$$

In case of Gamma probability distribution function, values of λ (= mean/(S.D.)^2), β (= (mean)^2/(S.D.)^2) and v (= 2 x β) were calculated for the fitted weeks. For a particular probability level, χ^2 was calculated from the table for a certain v value. The expected value of the rainfall at certain probability was calculated from the following relationship:

$$Xp = \frac{\chi^2}{(2\lambda)} \quad ...(8)$$

Frequency analysis was carried out for the following return periods as given in Table 3.

3. RESULTS AND DISCUSSION

Numbers of 5 days Antecedent Rainfall alongwith the Values of Statistical Parameters Under Different Seasons and AMC groups

The detail breakup of the total number of 5 days antecedent rainfall values analysed under different seasons

and AMC groups are shown in Table 1. It is interesting to note that only 10.61% of the total number of values fall under AMC group II. Kumar and Kumar (1989) for similar type of analysis for Pantnagar (Uttarakhand) also reported that only 10.96% of the total number of values fall under AMC group II. Thus, it is necessary to convert the curve number from the AMC-II to AMC-I in 38.33% cases and to AMC-III in 51.06% cases (Table 1). In standard text book, tables are available for factors to convert the curve numbers from the AMC-II to AMCs I and III.

Statistical parameters of 5 days antecedent rainfall under different AMC groups are shown in Table 2. During pre-monsoon season, mean, standard deviation, coefficient of variation and coefficient of skewness under AMC I, II and III groups were found in the range of 15.21-107.3 mm, 5.45-68.10 mm, 12.8-65.32 and 0.25-2.32, respectively. During monsoon season mean, standard deviation, coefficient of variation and coefficient of skewness under AMC-I, II and III groups were found in the range of 43.80-311 mm, 5.19-7659.04 mm, 12-83.67 and 0.12-41.53 respectively. Similarly, during post-monsoon season mean, standard deviation, coefficient of variation, coefficient of skewness under AMC-I, II and III groups were found in the range of 5.34-86 mm, 72, 5.5-68.10 mm, 26-80 and 0.75-2.58, respectively (Table 2).

Fitting of Various Probability Distribution Functions

For 5 days antecedent rainfall values (mm) of all seasons and AMC groups, data of original form were used for probability distribution fitting except for monsoon season (under AMC-III group) in which use of square root of the original data were done. Calculated Smirnov-Kolmogorov statistics were compared with tabular values at the 1% and 5% level of significance. It was observed that all probability functions were fitted significantly. As per minimum Smirnov-Kolmogorov statistics values, Log-Pearson-III probability distribution function was found the best fit for the values of 5 days antecedent rainfall of pre monsoon season under AMC-I group and also for post monsoon season under AMC-II and III groups. Kumar and Kumar (1989) for similar type of analysis for Pantnagar (Uttarakhand) also found the fitting of Pearson type I probability distribution as the best fit in all cases except AMC II group of summer and post monsoon season in which Log-Pearson type III distribution fitted well. Extreme value-I probability distribution was found the best fit for 5 days antecedent rainfall values of pre monsoon season for AMC-II and III groups, for monsoon season for AMC-I, II and III groups and for post-monsoon season for AMC-I group (Table 3).

Estimation of 5 days Antecedent Rainfall (mm) at Different Recurrence Intervals Under Different Seasons and AMC groups

Using the best fit probability distribution functions, 5 days antecedent rainfall (mm) at different recurrence intervals under different seasons and AMC groups were estimated and presented in Table 4. 5 days antecedent rainfall values in pre-monsoon, monsoon and post- monsoon seasons under all AMCs, were found in increasing order with the increase in the recurrence interval. The lowest 5 days antecedent rainfall value of 3.1 mm was observed at 1.053 years of recurrence interval under AMC-I group during the pre-monsoon season. The highest 5 days antecedent rainfall value of 2905.1 mm was observed at 100 years of recurrence interval under AMC-III group during monsoon season.

During the pre-monsoon season, the lowest 5 days antecedent rainfall value of 3.1 mm was observed at 1.053 years of recurrence interval under AMC-I group and the highest 5 days antecedent rainfall value of 321 mm was observe at 100 years of recurrence interval under AMC-III group.

During monsoon season, 5 days antecedent rainfall value was observed nil at 1.053 and 1.25 years of recurrence interval under AMC-III group. The lowest 5 days antecedent rainfall value of 3.8 mm was observed in 1.053 years of recurrence interval under AMC-I group and the highest 5 days antecedent rainfall value of 2905.1 mm was observed in 100 years of recurrence interval under AMC-III group.

Table: 1
Numbers of 5 days antecedent rainfall under different seasons and AMC groups

Season	AMC-I	AMC-II	AMC-III	Total
Pre-monsoon (March to May)	657	62	817	1536 (35.04%)
Monsoon (June to October)	741	228	1726	2695 (61.15%)
Post-monsoon (November to February)	282	115	195	592 (13.51%)
Total numbers	1680 (38.33%)	465 (10.61%)	2238 (51.06%)	4383

Table: 2
Statistical parameters of 5 days antecedent rainfall under different seasons and AMC groups

S.No.	Parameters	Pre monsoon			Monsoon			Post monsoon		
		AMC-I	AMC-II	AMC-III	AMC-I	AMC-II	AMC-III	AMC-I	AMC-II	AMC-III
1	Mean (mm)	15.21	42.86	107.3	16.85	43.80	311.00	5.34	19.85	86.72
2	Standard Deviation (mm)	9.93	5.45	68.10	10.04	5.19	7659.04	9.93	5.5	68.10
3	Coefficient of Variation (%)	65.32	12.8	63.49	60	12	83.67	80	26	73
4	Coefficient of Skewness	0.284	0.25	2.32	0.12	0.25	41.53	2.58	0.75	1.70

Table: 3
The values of Smirnov- Kolmogorov statistics (Δ) under different probability distribution functions

Seasons	Group	Normal	Log-normal	Gamma	Log-Pearson -III	Extreme value-I
Pre-Monsoon	AMC-I	0.08063	0.12899	0.08934	0.0529**#	0.05581**
	AMC-II	0.09782*	0.07885*	0.08406*	0.07703*	0.0693*#
	AMC-III	0.20499	0.108941	0.21161	0.06392*	0.06256*#
Monsoon	AMC-I	0.07108*	0.12305*	0.09546*	0.07971*	0.05846 **#
	AMC-II	0.06409*	0.07654 *	0.07226*	0.07470*	0.06028*#
	AMC-III	0.37736	0.05728	0.52406	0.19836	0.03782 **#
Post-Monsoon	AMC-I	0.14071	0.12717	0.06173*	0.05808*	0.04215*#
	AMC-II	0.07436*	0.08192*	0.06071*	0.012196*#	0.05734*
	AMC-III	0.20673	0.0851*	0.14291	0.05785*#	0.06311*

*= Significant at the 1% level , **= significant at the 5 % level and # = the best fit probability distribution function

Table: 4
5 days antecedent rainfall (mm) at different recurrence intervals under different seasons and AMC groups

Season	Group	Recurrence interval(years) / 5 days antecedent rainfall (mm)							
		1.053	1.25	2	10	20	25	50	100
Pre-Monsoon	AMC I	3.1	4.4	13.5	31.3	35.5	36.6	39.4	41.2
	AMC II	35.7	38.3	42.0	50.0	53.1	54.1	57.1	60.1
	AMC III	18.4	51.3	96.1	196.1	234.4	246.5	283.9	321.0
Monsoon	AMC I	3.8	8.6	15.2	30.0	35.6	37.4	42.9	48.4
	AMC II	37.0	39.5	42.9	50.6	53.5	54.4	57.3	60.1
	AMC III	0	0	81.3	840.3	1341.0	1524.0	2162.0	2905.1
Post-Monsoon	AMC I	0	1.8	4.6	10.9	13.3	14.1	16.4	18.8
	AMC II	14.0	15.1	20.4	25.2	26.0	26.2	26.6	26.8
	AMC III	23.7	44.1	67.0	159.3	211.5	230.4	297.0	377.0

During the post monsoon season 5 days antecedent rainfall value was observed at 1.053 years of recurrence interval under AMC-I group. The lowest 5 days antecedent rainfall value of 1.8 mm was observed at 1.25 years of recurrence interval under AMC-I group. The highest 5 days antecedent rainfall value of 377 mm was observed in 100 years of recurrence interval under AMC-III group.

4. CONCLUSIONS

Only 10.61% of the total number of 5 days antecedent rainfall values of all seasons fall under AMC–II group. It was observed that all probability distribution functions were fitted significantly. As per minimum Smirnov-Kolmogorov statistics values, the best fit probability distribution was selected for estimating the 5 days antecedent rainfall at different recuurence intervals under different seasons and AMC groups. The predicted 5 days antecedent rainfall values may be helpful for predicting runoff for the study site.

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