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Research Article

STUDY ON RAINFALL PROBABILITY ANALYSIS OF INDIA

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Abstract- The present research included rainfall probability analysis of previous 114 years rainfall data (1901-2014) with a major object to forecast the yearly rainfall of India. The observed values were computed by Weibulls formula. The annual rainfall values were estimated by two prediction models using Gumbel and Log Normal distributions. The rainfall data in the Log Normal and Gumbel distribution and their equivalent rainfall events were estimated by Root Mean Square Deviation (RMSD) or Root Mean Square Error (RMSE) for goodness of fit. It clearly indicates that the Gumbel distribution was found to be the best model for forecasting yearly rainfall (mm). Whereas Log Normal distribution is fairly close to the observed annual rainfall of previous 114 years (mm).

Keywords- Rainfall, Probability Analysis, Rainfall Prediction, Gumbel and Log Normal probability distributions, Root Mean Square Deviation (RMSD).

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Introduction

Rainfall is one of the important hydrological actions; it is a major component of the water cycle and is accountable for depositing largely of the fresh water on the Globe. It provides suitable conditions for many types of ecosystems, while provide water for hydroelectric power plants and crop irrigation. This plays a significant role in many of the agriculture operations as well as non-agricultural operations. The mean rainfall in our country is 1190 mm per annum and it ranges from 350 to 2,000 mm annually. Normally 80 percent of the total annual rainfall in India accounts from the months of June to September. Rainfall is a unique phenomenon that is highly diversified with respect to space and time. Promoting irregularity, it characteristically shows the variations from one place to another and also from former to upcoming years.

The rainfall is an important and principal factor in the planning and operation strategies of any agricultural program in any given area. Thus, having the standard and accurate details and facts about the rainfall distribution pattern of any area over a period of time is an ideal illustrative path for best possible planning of the competent irrigation system and cropping pattern and plan. The foremost share of water-need of the country during the entire calendar year is met by the rainfall, which occurs during the monsoon phase. In India, disastrous floods and thirstily droughts are the results of profligate extremities of the rainfall frequency [1].

Analysis of rainfall and determination of annual maximum daily rainfall would improve the management of water resources applications as well as the effective consumption of water [2]. Probability and frequency study of rainfall data enables us to determine the expected rainfall at various chances [3]. Such information can also be used to prevent floods and droughts, and apply to development and designing of water resources associated to engineering such as reservoir design, flood control work and soil and water conservation setting up like dams.

Material and Methods

The rainfall data (1910-2014) was collected from IMD (Indian Meteorological Department), Pune. The present study was determined on variation of rainfall and a transformed distribution, Log Normal and an extreme distribution Gumbel was used for probability analysis and prediction of annual maximum rainfall of India. All the calculations were done via Microsoft Excel 2007.

Statistical Analysis of Data

The mean, standard deviation, coefficient of variation and coefficient of skewness, which describe the variability of rainfall, were estimated.

The mean rainfall was calculated by the following formula:

$$\overline{X} = \frac{\Sigma X}{N} \qquad \text{[Eq-1]}$$

Where, = Mean, ΣX = Sum of rainfall, N = Total number of observations.

The standard deviation (σ_n) which measures the variability of rainfall was computed by the following formula:

$$\sigma_n = \frac{\Sigma\left(\mathbf{x} - \overline{X}\right)^2}{N - 1} \qquad \text{[Eq-2]}$$

The Coefficient of Variation (C_V) was calculated by the following formula:

$$C_v = \frac{\sigma_n}{\overline{X}} \qquad \text{[Eq-3]}$$

The Coefficient of skewness (C_S) was calculated by the following formula:

$$C_s = \frac{N\sum(z-\overline{z})^3}{(N-1)(N-2)\sigma_n} \quad \text{[Eq-4]}$$

Where,
z = Log value of rainfall data.
$\overline{z}$ = Mean value of the rainfall data.
N = Sample size.
σ_n= Standard deviation.
Annual maximum rainfall data were fitted to various probability distributions.

Frequency Analysis by using Frequency Factors
Gumbel Distribution

$$X_T = X + K \cdot \sigma_n \quad \text{[Eq-5]}$$

$$K = \frac{Y_t - Y_n}{S_n} \quad \text{[Eq-6]}$$

Where, X_T = Predicted rainfall amount for a return period of T years, the K = Frequency factor of Gumbel distribution.

Log Normal distribution

$$XT = X + K \times \sigma_n \quad \text{[Eq-7]}$$

Predicted rainfall was calculated as

$$\mathbf{XT} = \text{antilog}\,(XT) \quad \text{[Eq-8]}$$

Testing the Goodness of Fit

The Root Mean Square Deviation (RMSD) or Root Mean Square Error (RMSE) is a frequently used measure of the differences between values predicted by a model and the values observed. The RMSD represents the sample standard deviation of the differences between predicted values and observed values. The RMSE is the square root of the variance of the differences. It shows the absolute fit of the model to the data, how close the observed data are to the model's predicted values. While R-squared is a relative measure of fit, RMSE is an absolute measure of fit. Being the square root of a variance, RMSE can be interpreted as the standard deviation of the unexplained variance, and has the helpful property of being in the same units as the response variable. Lower values of RMSE indicate better fit of distribution models. RMSE is a fine measure of how precisely the model predicts the response, and is the best decisive factor for fit if the major objective of the model is prediction.
It is calculated as

$$\text{RMSE} = \left\{\sqrt{\sum(O-P)^2}\right\} \quad \text{[Eq-9]}$$

Where,
O = Observed values of the return period.
P = Predicted values for the return period.

Results And Discussion

The predictions of annual maximum rainfall of 114 years were estimated by two most widely used probability distribution method by Gumbel and Log Normal Distribution model.

For analysing of results, the maximum rainfall recorded from last 114 years data were taken down in descending order scale. These were marked as input in log normal distribution model. Other to this recurrence interval, C_S and C_V values, the frequency factor values were achieved from Chow's Table. In Gumbel distribution 114 years of data used were given as input and the annual maximum rainfall were arranged in descending order of magnitude. Recurrence intervals were computed for the Gumbel distribution as shown in [Table-1].

The predicted annual maximum rainfalls at the different probability levels are tabulated in [Table-1] for Gumbel and Log Normal distribution models. On the basis of calculation the graphs plotted [Fig-1 and Fig-2] showed similarity between observed and predicted values points next to precise, except variations at highest rainfall during both the probability distribution models.

The evaluation of Gumbel and Log Normal distribution models were conducted using statistical factor RMSD and RMSE for goodness of fit. The minimum value of the RMSE value is taken as the best. The result of annual maximum rainfall is tabulated in [Table-1]. It shows that the value of RMSE for Gumbel and Log normal distributions comes out to be is 108.2 mm and 110.0 mm respectively [Table-2]. Since the Gumbel distribution has the smallest value of RMSE as compared to the Log normal distribution. So the Gumbel distribution gave the best fit for yearly rainfall data. Therefore, it may be concluded that the Gumbel distribution was found to be the best model for predicting the annual maximum rainfall of India, which reveals the overall accuracy of the model for predicting rainfall. The graphical representation showed that the Gumbel distribution is predicting the rainfall very near to the observed rainfall [Fig-1].

The observed data were much successfully described using the predicted values, which were taken on basis of recorded data from natural process. Every predicted value are not precisely standard values but proved approximate to principal phenomenon.

Agricultural production can be significantly expanded with proficient application of rainfall. Though the nature of rainfall is erratic and varies with time and space, however it is possible to predict design rainfall quite accurately for certain return periods using various probability distributions functions [4]. Frequency analysis rainfall data has been attempted for different places in India [4-10]. Frequency analysis of rainfall is an important tool for solving various water management problems and is used to assess the extent of crop failure due to deficiency or excess of rainfall. Probability analysis of annual maximum daily rainfall for different returns periods has been suggested for the design of small and medium hydraulic structure [7]. The rainfall distribution pattern of any area strongly effects analysis of rainfall data. Establishing probability distribution for knowing daily rainfall activities has always been the matter of research in meteorological field. Various successful rainfall analysis and probability distribution models such as Normal, Log-Normal, Gumbel, Weibulls and Pearson type distribution were identified after wide and efficient studies conducted within India and international levels [11]. Influence of rainfall on the yield of wheat and distribution of rainfall during a season rather than the total amount of rainfall which influence the crop yield [12]**.** Rainfall distribution transformed the skew frequency of rainfall to approximate directly to the theoretical normal distribution. [13]

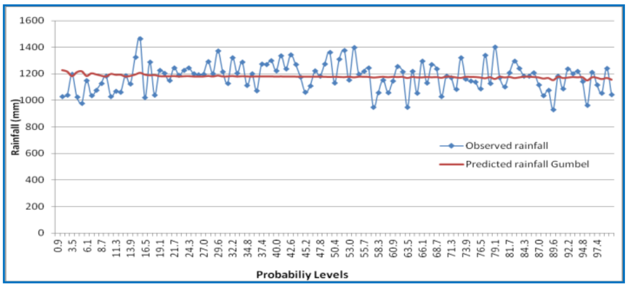

Fig-1 Comparison of observed and predicted rainfall Gumbel at various distribution levels

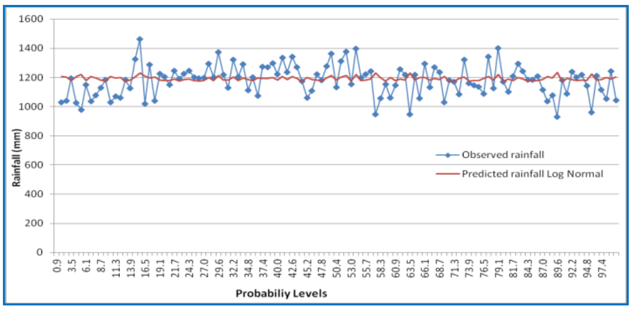

Fig-2 Comparison of observed and predicted rainfall Log Normal at various distribution levels

Table-1 *Annual maximum rainfalls at different return periods in years (1901-2014)*

Probability (%)	Recurrence interval (T) in years	Observed rainfall (O)#	Predicted rainfall (P)	
			Gumbel	Log Normal
0.9	115.0	1030.8	1225.6	1206.4
1.7	57.5	1038.4	1215.5	1204.5
2.6	38.3	1195.9	1182.1	1177.8
3.5	28.8	1025.1	1210.8	1207.9
4.3	23.0	977.5	1217.5	1220.6
5.2	19.2	1149.2	1182.9	1178.0
6.1	16.4	1034.8	1202.3	1205.4
7.0	14.4	1077.4	1193.9	1194.8
7.8	12.8	1128.5	1185.2	1182.7
8.7	11.5	1183.9	1178.6	1175.2
9.6	10.5	1028.9	1197.8	1206.9
10.4	9.6	1070.4	1191.5	1196.5
11.3	8.8	1061.8	1191.8	1198.6
12.2	8.2	1185.9	1178.6	1175.6
13.0	7.7	1124.4	1183.5	1183.7
13.9	7.2	1324.8	1193.0	1204.5
14.8	6.8	1463.9	1206.1	1231.2
15.7	6.4	1020.2	1192.6	1209.2
16.5	6.1	1287.9	1187.6	1197.1
17.4	5.8	1039.1	1189.5	1204.3
18.3	5.5	1225	1181.5	1184.0
19.1	5.2	1204.2	1179.7	1179.6
20.0	5.0	1148.6	1179.8	1178.2
20.9	4.8	1245.9	1182.4	1188.4
21.7	4.6	1189.5	1178.5	1176.4
22.6	4.4	1226.2	1180.7	1184.3
23.5	4.3	1244.6	1181.6	1188.2
24.3	4.1	1200.2	1178.9	1178.7
25.2	4.0	1193.2	1178.5	1177.2
26.1	3.8	1198.5	1178.7	1178.4
27.0	3.7	1292.8	1183.1	1198.1
27.8	3.6	1202.9	1178.8	1179.3
28.7	3.5	1372	1185.6	1213.8
29.6	3.4	1217.5	1179.2	1182.4
30.4	3.3	1127.9	1179.4	1182.9
31.3	3.2	1321.8	1182.4	1203.9
32.2	3.1	1204.4	1178.5	1179.6
33.0	3.0	1290.5	1180.8	1197.6
33.9	2.9	1111.6	1179.3	1186.6
34.8	2.9	1201.3	1178.2	1179.0
35.7	2.8	1073.9	1179.8	1195.7
36.5	2.7	1272.9	1179.4	1194.0
37.4	2.7	1269.2	1179.1	1193.3
38.3	2.6	1298.5	1179.3	1199.3
39.1	2.6	1222	1178.2	1183.4
40.0	2.5	1337.2	1179.1	1207.0
40.9	2.4	1236.3	1178.1	1186.4
41.7	2.4	1342.2	1178.4	1208.0
42.6	2.3	1269.6	1177.9	1193.4
43.5	2.3	1174.2	1177.7	1173.1
44.3	2.3	1060.6	1177.5	1198.9
45.2	2.2	1110.1	1177.4	1187.0
46.1	2.2	1222.1	1177.4	1183.4
47.0	2.1	1181.4	1177.7	1174.7
47.8	2.1	1275.4	1176.7	1194.5
48.7	2.1	1362.6	1175.4	1212.0
49.6	2.0	1131.9	1177.0	1181.9
50.4	2.0	1312.3	1175.5	1202.0
51.3	1.9	1376.9	1174.1	1214.8
52.2	1.9	1154.8	1177.2	1176.8
53.0	1.9	1399.2	1172.8	1219.1
53.9	1.9	1198	1177.2	1178.3
54.8	1.8	1220.9	1176.6	1183.2
55.7	1.8	1244.4	1175.9	1188.1
56.5	1.8	947.4	1170.9	1229.0
57.4	1.7	1058	1173.9	1199.6
58.3	1.7	1154	1176.9	1176.9
59.1	1.7	1059.3	1173.5	1199.2
60.0	1.7	1147.8	1176.6	1178.3
60.9	1.6	1255	1174.7	1190.3
61.7	1.6	1216.9	1176.1	1182.3
62.6	1.6	947.1	1167.9	1229.0
63.5	1.6	1219.5	1175.8	1182.9
64.3	1.6	1055.3	1172.0	1200.2
65.2	1.5	1294.8	1172.1	1198.5
66.1	1.5	1131.6	1175.4	1182.0
67.0	1.5	1269.7	1172.9	1193.4
67.8	1.5	1237.2	1174.5	1186.6
68.7	1.5	1030.2	1169.5	1206.6
69.6	1.4	1182.3	1177.4	1174.9
70.4	1.4	1170.7	1177.3	1173.2
71.3	1.4	1084.4	1172.0	1193.1
72.2	1.4	1320.9	1168.7	1203.8
73.0	1.4	1160.8	1176.6	1175.4
73.9	1.4	1144.9	1175.5	1179.0
74.8	1.3	1137.6	1174.9	1180.6
75.7	1.3	1088.9	1171.4	1192.0
76.5	1.3	1342.1	1165.8	1208.0
77.4	1.3	1127.4	1173.9	1183.0
78.3	1.3	1401.4	1160.5	1219.5
79.1	1.3	1170.2	1177.1	1173.4
80.0	1.3	1102.7	1171.6	1188.7
80.9	1.2	1207.8	1175.2	1180.4
81.7	1.2	1295.3	1167.7	1198.6
82.6	1.2	1242.4	1172.0	1187.7
83.5	1.2	1182.9	1177.2	1175.0
84.3	1.2	1183.1	1177.2	1175.0
85.2	1.2	1208.8	1174.8	1180.6
86.1	1.2	1116.6	1171.8	1185.5
87.0	1.2	1035.4	1163.6	1205.3
87.8	1.1	1076.2	1167.4	1195.1
88.7	1.1	930.1	1151.8	1233.9
89.6	1.1	1182.3	1177.2	1174.9
90.4	1.1	1086.2	1167.6	1192.7
91.3	1.1	1238.7	1170.8	1186.9
92.2	1.1	1202.4	1174.8	1179.2
93.0	1.1	1219.8	1172.6	1182.9
93.9	1.1	1144.1	1173.5	1179.2
94.8	1.1	961.8	1150.0	1224.9
95.7	1.0	1212.1	1173.1	1181.3
96.5	1.0	1116.3	1169.2	1185.5
97.4	1.0	1054.7	1159.9	1200.4
98.3	1.0	1242.6	1167.8	1187.7
99.1	1.0	1044.6	1155.7	1202.9

Source: #Observed rainfall data obtain from IMD, Pune Website(www.imdpune.gov.in)

Table-2 *RMSE value for goodness of fit*

Distribution Models	RMSE Value
Gumbel	108.2
Log Normal	110.0

Conclusion

The present study concluded that data of one hundred fourteen years (1910-2014) is sufficient to obtain annual maximum rainfall (mm) distribution of India. The selection of probability distribution function to be used for representing the observed data influentially depends on rainfall pattern of the place. As rainfall pattern varies from place to place. The annual maximum rainfall was 1463.9 mm in the year 1917 and minimum of 930.1 mm in the year 2002 respectively was observed for analysis. The Root Mean Square Deviation (RMSD) or Root Mean Square Error (RMSE) for goodness of fit was conducted Gumbel and Log Normal distribution method. The minimum value of the RMSE value is taken as the best for goodness of fit. The predicted rainfalls are fairly close to the observed rainfall according to the analysis. It shows that the Gumbel distribution has the least value as compared to the Log Normal distribution method according to RMSE. Therefore, prediction by Gumbel distribution method was found to be the best model for India.

Having precise and standard information of rainfall pattern proves useful for preparing crop calendar, designing of different storage structures and also managing and executing up of irrigation strategies during drought spells. Well knowledge of consecutive days of return periods proves a fundamental parameter of safe, sound and effective economic planning and in designing of different structural and non-structural measures, small and medium hydraulic structure such as small dams, bridges, culverts, spillways, check dam, ponds, irrigation and drainage work in watershed management and command area development programs and plant protection activities in a more scientific way through the application of climatologically information.

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Conflict of Interest: None declared

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