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Estimation of One to Two Consecutive Days Maximum Annual Rainfall Using Probability Distributions: The Case of Bedele Town, Oromia, Ethiopia

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Abstract: Probability distribution and frequency analysis of rainfall data enable future extreme events. Rainfall is an infrequent and important hydrological parameter on the earth. When designing irrigation and other hydraulic systems, assessing the size of an extreme rainfall event for a specific probability level is extremely important. For the present study daily rainfall data from 2000-2022 for Bedele Town is collected from the Ethiopian Meteorological Institute (EMI) and analyzed for One to two consecutive days maximum annual rainfall using various three commonly used probability distribution viz., Gumbel's, Log-normal, and Log-pearson type III distributions to determine the best-fit probability distribution. The expected values were compared with the observed values using the goodness of fit and were determined by the chi-square ($\chi 2$) test. The chi-square values of 1day maximum annual rainfall for Gumbel's, Log-normal, and Log-pearson type-III distributions were 3.276, 1.548, and 3.777 respectively which shows that the Log-normal distribution was the best-fit probability distribution to forecast annual 1day maximum rainfall for different return periods. Also, predictable One day maximum annual Rainfall using Log-normal distribution for a return period of 2, 10, 25, 50, 100, and 200 were 63.1mm, 85.1mm, 95.5mm, 102.3mm, 107.2mm, and 120.2mm respectively. The chi-square values of 2days maximum annual rainfall for Gumbel's, Log-normal, and Log-pearson type-III distributions were 3.023, 12.171, and 10.395 respectively which shows that the Gumbel's distribution was the best-fit probability distribution to forecast 2days maximum annual rainfall for different return periods. Also, predictable 2Days maximum annual Rainfall using Gumbel's distribution for return periods of 2, 10, 25, 50, 100, and 200 were 87.8mm, 112.8mm, 125.3mm, 134.7mm, 143.9mm and 153.2mm respectively. The comparisons between the observed and predicted maximum value of annual rainfall clearly show that the developed model can be efficiently used for the prediction of rainfall. The results of this study would be useful for agricultural scientists, decision-makers, policy planners, and researchers for agricultural development and construction of small soil and water conservation structures, irrigation, and drainage systems in Bedele Town, Ethiopia.

Keywords: Bedele Town, Chi-Square, Consecutive, Rainfall, Probability Distributions

1. Introduction

One of the most significant hydrological events is rainfall, which has a significant impact on many types of farming and non-farm activities [1]. Even though the characteristics of the rainfall are unpredictable and change over time and space, different probability distribution functions can be used to forecast return periods [2–7]. Frequency analysis is the process of determining the constant circumstance of a hydrological event [8]. Analysis of consecutive days return periods is a basic tool for safe and economic planning and design of structural and non-structural measures, small and medium hydraulic structures such as small dams, bridges, culverts, spillways, check dams, ponds, irrigation mid-drainage work in watershed management and command area development programmer and plant protection activities in a more scientific basis through the application of climatological information [9]. Using probability and frequency analysis of the rainfall data, we can predict the expected rainfall at different chances [4]. This data can be applied to the planning and design of water-related engineering projects, such as water management, flood control projects, and planning for soil and water conservation, to prevent floods and droughts [10]. By using probability and frequency analysis to examine rainfall data, we can calculate the likelihood of experiencing extreme rainfall at different times [3]. The Gumbel, log-normal, and log-pearson type-III distributions are the probability distribution functions that are most frequently used to estimate the frequency of rainfall [2–7, 10–13]. The goal of the current study was to identify the optimal probability distribution system and determine the statistical parameters and annual maximum rainfall for one day, and two consecutive days using different probability levels and three probability distribution functions: Gumbel, log-normal, and log-pearson type-III distribution.

2. Materials and Methods

2.1. Location and Description of the Study Area

Bedele Town is located Western part of Ethiopia in the Buno Bedele Zone at 480 km from Addis Ababa on the main road to Gambella. Bedele Town has latitude and longitude of 8°25′30"N to 8°28′30"N and 36°19′30"E to 36°22′30"E an elevation range between 1800m at lowest to 2100m above mean sea level at the highest and receives an annual average rainfall of 1800mm.

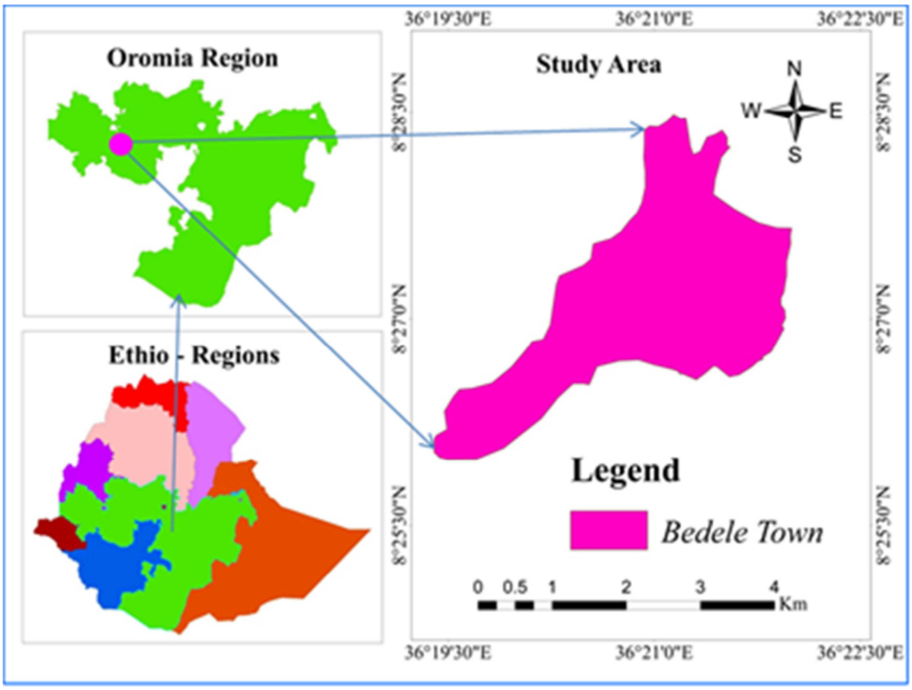

Figure 1. *Location map of the study.*

2.2. Data Collection

The daily rainfall data was collected from the Ethiopia Meteorological Institute (EMI) for Bedele station. The daily rainfall data covers 23 years (2000-2022) as shown in Figure 2 below.

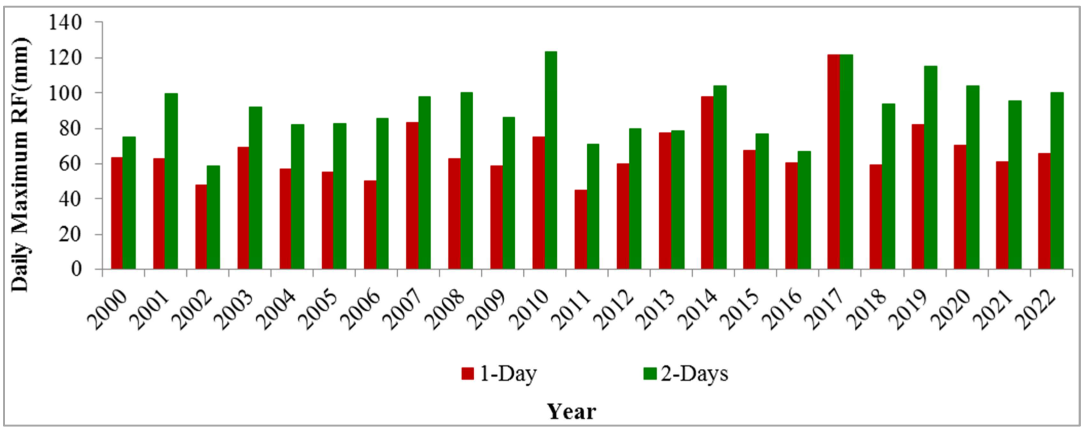

Figure 2. *Collected data from 2000-2022 years for one to two consecutive days' maximum annual rainfall for Bedele Town.*

2.3. Frequency Analysis Using Frequency Factors

2.3.1. Gumbel Distribution

Gumbel probability distribution is widely used for extreme value analysis of hydrologic and meteorological data such as floods, maximum rainfalls, and other events determined by equation 1 cited by [1, 2, 9–12].

$$X_T = \bar{X} + K_T * \sigma x \quad (1)$$

Where $\bar{X}$ is the mean of the observed rainfall, σx is the standard deviation for x; K_T - frequency factor which is calculated by the formula given by Gumbel (1958) and recommended by [7, 9, 10, 14–17].

$$\sigma_x = \sqrt{\frac{\Sigma(X-\bar{X})^2}{N-1}} \quad (2)$$

$$K_T = -\frac{\sqrt{6}}{\pi}\{0.5772+\ln(\ln(\frac{T}{T-1}))\} \quad (3)$$

2.3.2. Log-Normal Distribution

A log-normal distribution is a probability distribution of a random variable whose logarithm is normally distributed. The maximum rainfall for a particular return period is calculated using the following equation that recommended by [2, 3, 5, 9, 11-15, 18, 21, 22].

$$Y_T = \bar{Y} + K_T * \sigma y \quad (4)$$

$$\sigma_y = \sqrt{\frac{\Sigma(Y-\bar{Y})^2}{N-1}} \quad (5)$$

$$XT = \text{Antilog } Y_T \quad (6)$$

Where $\bar{Y}$ is the mean value, K_T is the frequency factor and the value of K_T is determined by considering the coefficient of skewness as zero and also σy is the standard deviation for y.

2.3.3. Log-Pearson Type III Distribution

In this type of probability distribution, the coefficient of skewness is calculated using the formula recommended by [22] cited by [4, 6, 14–16, 19–23].

$$Y_T = \bar{Y} + K_T * \sigma y \quad (7)$$

$$XT = \text{Antilog } Y_T \quad (8)$$

$$C_s = \frac{N\sum[Y-\bar{Y}]^3}{(N-1)(N-2)(\sigma_n)^3} \quad (9)$$

The frequency factor K_T is obtained from the theoretical table available for the Pearson type III distribution with a skew coefficient [13].

2.4. Goodness of Fit Criteria

2.4.1. Chi-Square Test

This test applies to various problems of hydro-meteorological nature. It is primarily used for testing the agreement of the observed data with those expected upon a given hypothesis [1, 2, 10, 11]. The Chi-Square values, $\chi 2$ can be calculated by [9, 10].

$$X^2 = \frac{(R_o - R_e)^2}{R_e} \quad (10)$$

Ro and Re are the observed and estimated rainfall magnitudes, respectively. The distribution with the least average of the Chi-Square values is adjudged to be the best [13]. The $\chi 2 = 0$ indicates the Ro and Re rainfall magnitudes agree exactly. The $\chi 2$ values for each distribution are shown in Tables 5 and 9.

3. Results & Discussion

3.1. Computation of Statistical Parameters of One to Two Consecutive Days Maximum Annual Rainfall

Table 1. *Value of estimated statistical parameters for one day and two consecutive days.*

S.No	Statistical parameters	Unit	One day	Two days
1	Total	mm	1553.7	2089.8
2	Maximum	mm	121.4	123.3
3	Minimum	mm	45	58.9
4	XMean	mm	67.6	90.6
5	Standard deviation of X	mm	17	17
6	YMean	mm	1.8	2
7	Standard deviation of Y	mm	0.1	0.1
8	Coefficient of variation	%	25	19
9	Coefficient of skewness	-	1.4	-0.1

3.2. One Day Maximum Annual Rainfall

Table 2. *Prediction of one day maximum annual rainfall using Gumbel distribution.*

Return period (T), in year	KT	Estimated rainfall (X_T) in mm
2	-0.164	64.8
10	1.305	89.8
25	2.044	102.3
50	2.592	111.7

Return period (T), in year	KT	Estimated rainfall (X_T) in mm
100	3.137	120.9
200	3.680	130.2

Table 3. *Prediction of one day maximum annual rainfall using Log-normal distribution.*

Return period (T) in year	K_T	Y_T	Estimated rainfall (X_T) *in mm*
2	0.000	1.80	63.1
10	1.282	1.93	85.1
25	1.751	1.98	95.5
50	2.054	2.01	102.3
100	2.326	2.03	107.2
200	2.760	2.08	120.2

Table 4. *Prediction of one-day maximum annual rainfall using Log-pearson type-III distribution.*

Return period (T), in year	K_T	Y_T	Estimated rainfall (X_T)
2	-0.225	1.78	60.3
10	1.337	1.93	85.1
25	2.128	2.01	102.3
50	2.706	2.07	117.5
100	3.271	2.13	134.9
200	3.828	2.18	151.4

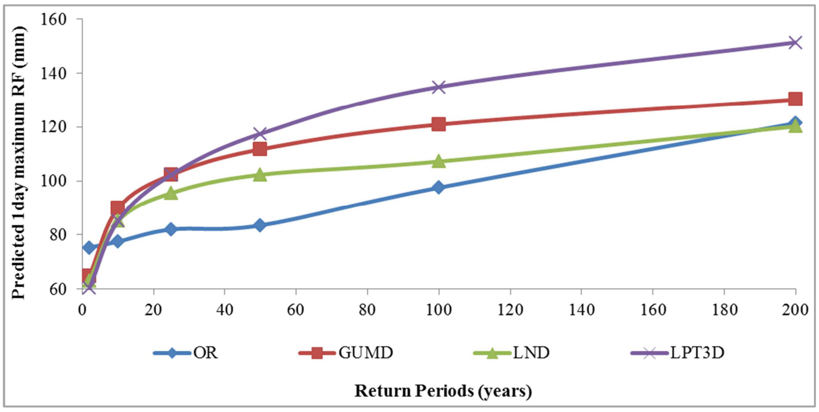

Figure 3. *Comparison of observed and predicted one-day maximum annual rainfall for various probability distributions.*

Table 5. *Chi-square value of predicted one day's maximum annual rainfall for different probability distributions for Bedele town.*

Return period (T)	Probability (P)	Ro	Expected rainfall (Re)			$X^2 = \frac{(R_o - R_e)^2}{R_e}$		
year	%	mm	GUMD	LND	LPT3D	GUMD	LND	LPT3D
2	50	75.3	64.8	63.1	61.7	1.701	2.359	3.731
10	10	77.5	89.8	85.1	85.1	1.685	0.679	0.679
25	4	82	102.3	95.5	100.0	4.028	1.908	4.028
50	2	83.5	111.7	102.3	112.2	7.119	3.455	9.838
100	1	97.5	120.9	107.2	125.9	4.529	0.878	10.369
200	0.5	121.4	130.2	120.2	138.0	0.595	0.012	5.945
Mean						3.276	1.548	5.765

Key: Ro – Observed rainfall, GUMD – Gumbel distribution, LND – Log-normal distribution, and LPT3D – Log-pearson type three distributions.

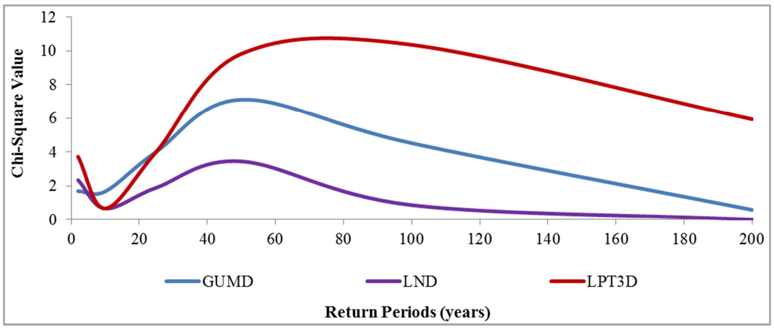

Figure 4. *Chi-square value of one day's maximum annual rainfall for different distributions for Bedele town.*

3.3. Two Consecutive Day's Maximum Annual Rainfall

Table 6. *Prediction of two day maximum annual rainfall using Gumbel distribution.*

Return period (T) in year	K_T	Estimated rainfall (X_T) in mm
2	-0.164	87.8
10	1.305	112.8
25	2.044	125.3
50	2.592	134.7
100	3.137	143.9
200	3.680	153.2

Table 7. *Prediction of two-day maximum annual rainfall using Log-normal distribution.*

Return period (T) in year	K_T	Y_T	Estimated rainfall (X_T) *in mm*
2	0.000	2.00	100.0
10	1.282	2.13	134.9
25	1.751	2.18	151.4
50	2.054	2.21	162.2
100	2.326	2.23	169.8
200	2.760	2.28	190.6

Table 8. *Prediction of two-day maximum annual rainfall using Log-pearson type-III distribution.*

Return period (T), in year	K_T	Y_T	Estimated rainfall (X_T)
2	0.017	2.00	100.0
10	1.270	2.13	134.9
25	1.716	2.17	147.9
50	2.000	2.20	158.5
100	2.252	2.23	169.8
200	2.482	2.25	177.8

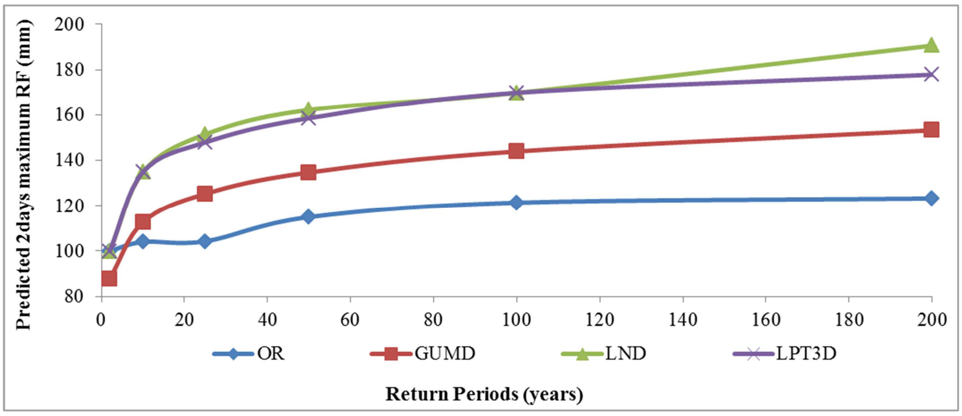

Figure 5. *Comparison of observed and predicted two days maximum annual rainfall for various Probability Distributions.*

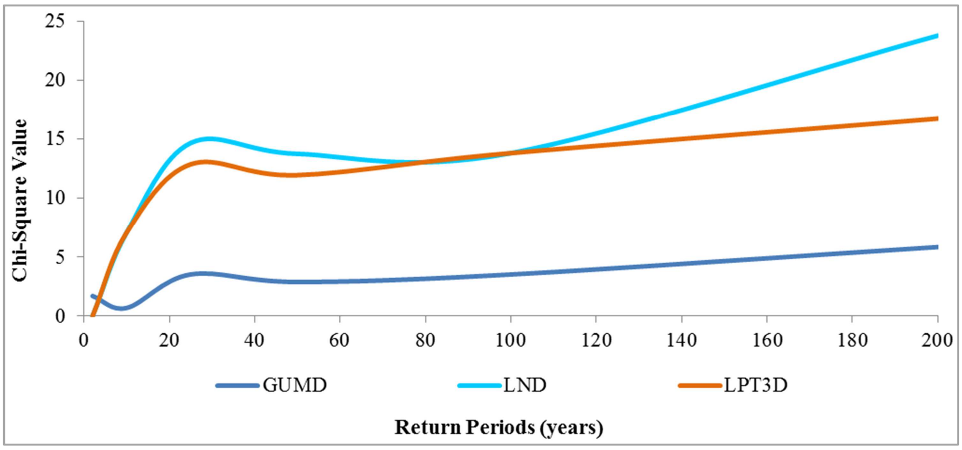

Figure 6. *Chi-square value of two days' maximum annual rainfall for different distributions for Bedele town.*

Table 9. *Chi-square value of predicted two days maximum annual rainfall for different distribution for Bedele town.*

Return period (T)	Probability (P)	Ro	Expected rainfall (Re)			$X^2 = \frac{(R_o - R_e)^2}{R_e}$		
year	%	mm	GUMD	LND	LPT3D	GUMD	LND	LPT3D
2	50	100	87.8	100	100	1.695	0.000	0.000
10	10	104	112.8	134.9	134.9	0.687	7.078	7.078
25	4	104.3	125.3	151.4	147.9	3.520	14.653	12.853
50	2	115	134.7	162.2	158.5	2.881	13.735	11.938
100	1	121.4	143.9	169.8	169.8	3.518	13.796	13.796
200	0.5	123.3	153.2	190.6	177.8	5.836	23.763	16.706
Mean						3.023	12.171	10.395

4. Conclusion

Rainfall is a renewable resource, highly variable in space and time, and subject to depletion or enhancement due to both natural and anthropogenic causes. The frequency analysis of one-day and two-day maximum annual rainfall for identifying the best-fit probability distributions can be studied for three probability distributions such as Gumbel's, Log-normal, and Log-pearson Type-III by using the Chi-square goodness of fit test. The results of the study were the mean, standard deviation, and coefficients of skewness were 67.6mm, 17, and 1.4 for one-day maximum annual rainfall respectively. Also, the mean, standard deviation, and coefficient of skewness were 90.6mm, 17, and -0.1 for two days of maximum annual rainfall respectively. This study gives an idea about the prediction of one to two consecutive days' maximum annual rainfall to design small and medium hydraulic structures, soil and water conservation structures, irrigation structures, and drainage works.

Data Availability

All information provided to this publication is presented in the full document.

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Conflicts of Interest

The author declares that they have no conflicts of interest.

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