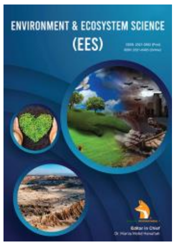
ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0882 (Print)
ISSN: 2521-0483 (Online)
CODEN: EESND2

Environment & Ecosystem Science (EES)

DOI: http://doi.org/10.26480/ees.01.2024.53.59



CrossMark

RESEARCH ARTICLE

BEST-FITTING AND RETURN PERIOD ANALYSIS AT KHULNA STATION DURING 1950-2022

Md. Bashirul Islam[a,*], Md. Nour Hossain[b], Md. Abul Hasan[b], Md. Mehedi Hassan Masum[a], Md. Ashraful Islam[c]

[a]Institute of River, Harbor and Environmental Science (IRHES), Chittagong University of Engineering & Technology, Chattogram, Bangladesh
[b]Department of Disaster Engineering and Management, Chittagong University of Engineering & Technology, Chattogram, Bangladesh
[c]Department of Water Resources Engineering, Chittagong University of Engineering & Technology, Chattogram, Bangladesh
[*]Corresponding E-mail Author: bashirul@cuet.ac.bd

ARTICLE DETAILS

Article History:

Received 20 April 2024
Revised 23 May 2024
Accepted 21 June 2024
Available online 26 June 2024

ABSTRACT

Rainfall and temperature are crucial weather parameters in addressing climate change. Understanding the magnitude and severity of extreme events is essential for mitigating the adverse effects of climate change. This study conducted a frequency analysis of monthly maximum rainfall and temperature data for Khulna station spanning 73 years (1950–2022) to identify the best-fit distribution models capable of predicting extreme events. Among the eight probability distribution models (Normal, Lognormal, Generalized Extreme Value (GEV), Extreme Value, Logistic, t Location-Scale, Gamma, and Weibull distribution) tested, GEV proved the best fit for rainfall data, while Extreme Value was the optimal choice for temperature data, as confirmed by statistical tests (AIC, K-S and A-D). Model parameters were calculated using the log-likelihood method. Furthermore, the study estimated extreme values of maximum rainfall and temperature for return periods of 5, 10, 25, 50, 100, and 500 years. These findings can offer valuable insights for developing plans and strategies to mitigate the risks and damages associated with extreme weather events.

KEYWORDS

Rainfall, Temperature, Return period, Statistical test, Climate change.

1. Introduction

Globally, temperature and rainfall profoundly impact climate, ecosystems, and human activities (Shen et al., 2023). Rising temperatures lead to melting ice caps and glaciers, increasing sea levels, and shifting weather patterns (Defrance et al., 2019). These changes also have significant consequences for agriculture, with heatwaves and frost harming crops, reducing yields, and affecting food production (Zhao et al., 2017). Conversely, insufficient rainfall results in droughts and water shortages, while heavy rainfall can lead to floods, waterlogging, soil erosion, and infrastructure damage. Both conditions can result in crop failures, decreased yields, and food shortages (Iderawumi et al., 2017). Sufficient and evenly distributed rainfall is essential for the availability of freshwater (Bedane et al., 2022). Regrettably, worldwide extreme events such as droughts, floods, and prolonged high temperatures continue to cause significant losses of lives and the economy (WMO, 2021).

The effects of temperature and rainfall can vary depending on the local geography, topography, and other factors (Lei et al., 2023). Researchers can comprehend and predict these effects using scientific research and climate models, which facilitates the formulation of adaptation and mitigation plans. In most developing countries, including Bangladesh, rain-fed agriculture continues to be the predominant method (Kashem et al., 2009). Limited and unpredictable precipitation as well as considerable variability in precipitation and temperature patterns are challenges for managing soil moisture in semi-arid and dry regions of the tropics (Matata et al., 2019). Finding the best-fit probability distribution to predict the extreme temperature and precipitation patterns can help a country forecast when a severe event occurs again.

Probability distributions are crucial for understanding uncertainty (Khudri and Sadia, 2016; Alam et al., 2018b). Distribution fitting involves selecting a statistical distribution that best fits a given dataset. Choosing the wrong distribution can lead to inaccurate results. In fields like hydrology, meteorology, and various sciences, there has been a continuous effort to identify the best probability distribution for modeling precipitation depth and temperature fluctuations on daily, monthly, and yearly timeframes. Some of the most commonly used and important probability distributions in rainfall and temperature models include Normal, Lognormal, GEV (Generalized Extreme Value), Extreme Value, Logistic, Loglogistic, Gamma, Weibull, and others (Ghosh et al., 2016; Hossain et al., 2018).

Khulna district, home to the third-largest city (Khulna city) in Bangladesh, covers a total area of 4,394.46 sq. km and has a population of 2,613,365, with 25.11% of its population engaged in the agricultural sector (KD, 2023). Like many regions in Bangladesh, this district faces a climate crisis driven by the impacts of rainfall and temperature. The district's agriculture, a vital contributor to the Bangladeshi economy, is increasingly vulnerable to catastrophic events such as droughts and floods (Rahman et

Quick Response Code	Access this article online	
	Website: www.environecosystem.com	**DOI:** 10.26480/ees.01.2024.53.59

Cite The Article: Md. Bashirul Islam, Md. Nour Hossain, Md. Abul Hasan, Md. Mehedi Hassan Masum, Md. Ashraful Islam (2024). Best-Fitting And Return Period Analysis At Khulna Station During 1950-2022. *Environment & Ecosystem Science, 8(1): 53-59.*

al., 2023). One potential solution is to predict these extreme events by utilizing the most suitable probability distribution model and determining the return period, which can enhance public awareness and mitigate losses.

While some studies have focused on identifying the best-fit probability distributions for rainfall data (Ghosh et al. 2016; Alam et al. 2018a) and temperature data (Hossain et al. 2018; Hasan 2021) in Bangladesh, the simultaneous analysis of temperature and rainfall data for the best-fit distribution, along with the return period, remains unexplored at the Khulna station. Consequently, this study has two primary objectives: firstly, to compare the Normal, Lognormal, GEV, Extreme Value, Logistic, t Location-Scale, Gamma, and Weibull distributions and identify the best-fit distribution for monthly maximum temperatures and rainfall at the station; and secondly, to estimate extreme values of maximum temperatures and rainfall for the return period of 5, 10, 25, 50, 100, and 500 years. The suitability of the best-fit probability distribution was assessed using various goodness-of-fit tests.

2. Materials And Methods

The selection of probability distribution models is crucial when determining the most suitable fit for a particular dataset at a specific location. In this section, commonly utilized distribution models for the analysis of monthly maximum rainfall and temperatures in Khulna station are presented. The method of parameter estimation, as well as the numerical and graphical goodness-of-fit tests employed for model selection, are discussed. Furthermore, the procedure for estimating return periods is explained. The overall methodological flowchart of this study is given in **Figure 1.**

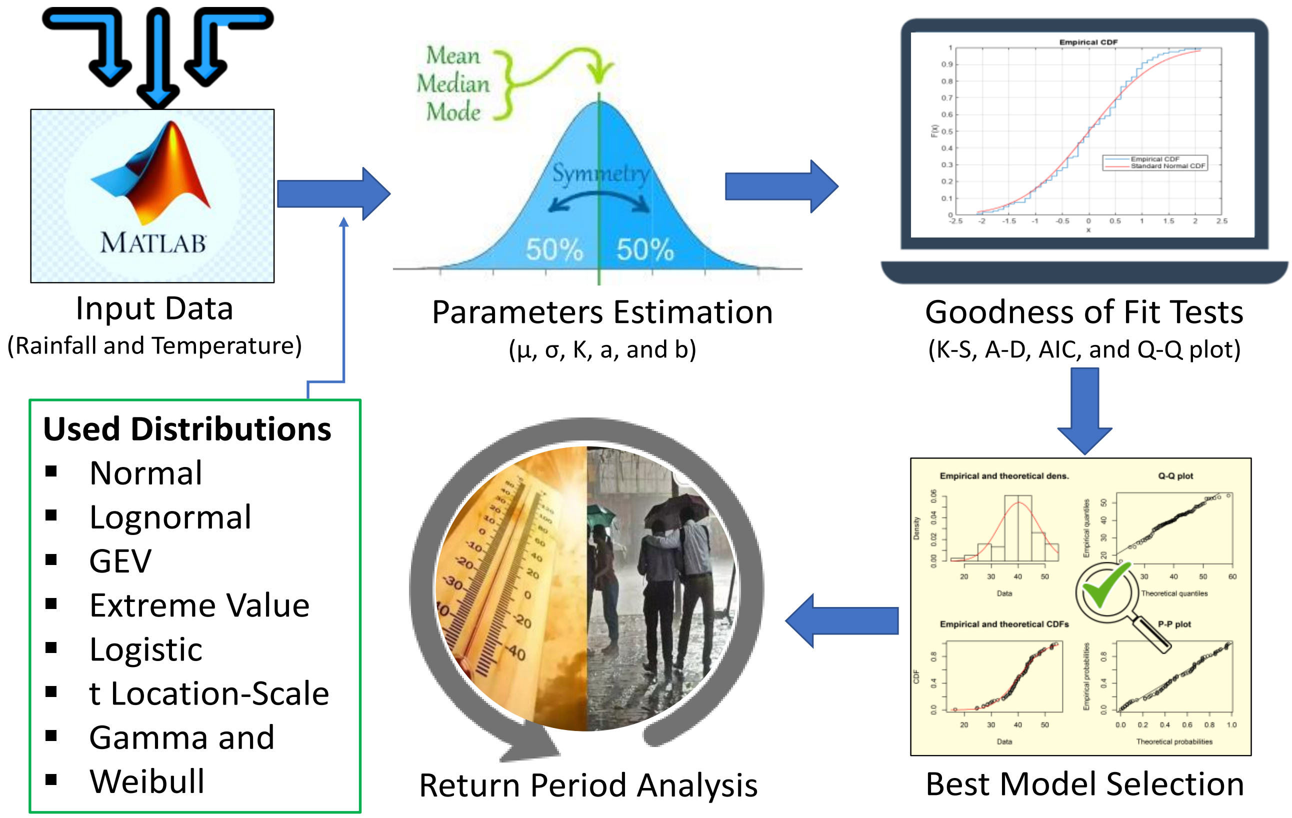


Figure 1: Methodological flowchart used in this study

2.1 Data collection

This study utilized weather station data from the Khulna District, located at 22° 47' North latitude and 89° 32' East longitude. The dataset comprised monthly rainfall and maximum temperature time series, collected for 73 years (January 1950 to December 2022) from the Bangladesh Meteorological Department (BMD) through the link http://barcapps.gov.bd/climate/. The simplest arithmetic average method was used to calculate missing values in the monthly time series data.

2.2 Probability distribution function

In the recent past, various probability distribution functions have been proposed to fit the maximum rainfall and temperature data best. However, in the present study, Normal, Lognormal, General Extreme Value (GEV), Extreme Value, Logistics, t Location-Scale, Weibull, and Gamma distributions are considered for testing the goodness of fit.

The normal distribution is the most valuable continuous distribution among all distributions due to its characteristic of symmetrically distributing the values of a random variable (Omer et al. 2020). Conversely, the Lognormal distribution describes the probability distribution of a variable whose logarithm follows a normal distribution. In the context of flood data, the GEV distribution, a well-known three-parameter distribution for maxima, is recommended as the optimal choice to achieve the best fit (Ng et al., 2020). Furthermore, extreme value distributions frequently apply to modeling the smallest or largest values within a large set of independent and identically distributed random values. The Logistic distribution is employed for growth modeling as well as logistic regression.

Additionally, the t location-scale distribution is beneficial for statistical modeling and hypothesis testing, especially when the data is believed to have heavier tails than the normal distribution. The widely used two-parameter Weibull distribution is extensively applied in analyzing diverse hydrological and meteorological datasets. Finally, the Gamma distribution involves the concept of the gamma function, which finds extensive use in hydrologic analysis, particularly in modeling rainfall and temperature amounts within a specific region (Poonia and Azad, 2022).

The probability density function, parameters, and range of the selected distributions mentioned above are given in **Table 1.** The parameters defining each distribution function were estimated using the maximum likelihood method. MATLAB software was employed to obtain these parameters for the distribution functions.

Table 1: Probability density function with parameters description of the selected distributions

Distribution	Probability density function (PDF)	Parameters Description
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$ for $x \in \mathbb{R}$.	μ = Mean (−∞<μ<∞) σ = Standard deviation (σ≥0)
Lognormal	$f(x) = \frac{1}{x\sqrt{2\pi\sigma^2}} e^{\frac{-(logx-\mu^2)}{2\sigma^2}}$ for $x>0$.	μ = Mean of logarithmic values (−∞<μ<∞) σ = Standard deviation of logarithmic values (σ≥0)
GEV	$f(x) = \frac{1}{\sigma} e^{(-(1+\frac{k(x-\mu)}{\sigma})^{\frac{-1}{k}})} \left(1+\frac{k(x-\mu)}{\sigma}\right)^{-1-\frac{1}{k}}$ for $1 + \frac{k(x-\mu)}{\sigma} > 0$	k = Shape parameter (−∞≤k≤∞) σ = Scale parameter (σ≥0) μ = Location parameter (−∞≤μ≤∞)
Extreme value	$f(x) = \sigma^{-1} e^{(\frac{x-\mu}{\sigma})} e^{(-e^{(\frac{x-\mu}{\sigma})})}$	μ = Location parameter (−∞<μ<∞) σ = Scale parameter (σ≥0)
Logistic	$f(x) = \frac{e^{\frac{x-\mu}{\sigma}}}{\sigma((1+e^{\left(\frac{x-\mu}{\sigma}\right)})^2}$ for $-\infty<x<\infty$	μ = Mean (−∞<μ<∞) σ = Scale Parameter (σ≥0)
t location-scale	$f(x) = \frac{\Gamma(\frac{\nu+1}{2})}{\sigma\sqrt{\nu\pi}\,\Gamma(\frac{\nu}{2})} [\frac{\nu+(\frac{x-\mu}{\sigma})^2}{\nu}]^{-(\frac{\nu+1}{2})}$	μ = Location parameter ($-\infty < \mu < \infty$) ν = Shape parameter (ν>0) σ = Scale parameter (σ>0)
Gamma	$f(x) = \frac{1}{b^a\Gamma(a)} x^{a-1} e^{\frac{-x}{b}}$ where Γ is the gamma function	a = Shape (a > 0) b = Scale (b > 0)
Weibull	$f(x) = \begin{cases} \frac{b}{a}(\frac{x}{a})^{b-1} e^{-(xla)^b} \\ 0 \end{cases}$ if x≥0, if x<0.	a = Scale (a > 0) b = Shape (b > 0)

2.3 Goodness-of-fit Tests

Goodness-of-fit tests were conducted to determine the most suitable distribution model that accurately fits the data. These tests evaluate how well the chosen distribution aligns with the observed data. The goodness-of-fit test measures the disparity between the observed values and the predicted values of the statistical model. In this study, several tests were employed, including the nonparametric Kolmogorov-Smirnov (K-S) test, Anderson-Darling (A-D) test, the information-criterion test known as Akaike Information Criterion (AIC), and the graphical assessment using Quantile-Quantile (Q-Q) plots.

2.3.1 Quantile-Quantile (Q-Q) Plot Test

A Quantile-Quantile (Q-Q) plot is a powerful and straightforward graphical technique often used to choose the best-fit model (Ghosh et al., 2016). It serves as a visual assessment tool to determine if sample data conforms to a particular theoretical distribution. To create a Q-Q plot, the sample data values are first arranged in ascending order and then plotted against the expected values for the chosen distribution at each quantile within the sample data. The y-axis represents the quantile values derived from the input sample, while the x-axis displays the corresponding theoretical values of the specified distribution. When the resulting plot closely resembles a straight line, it indicates that the sample data is likely consistent with the chosen distribution (Pandit and Infield 2018).

2.3.2 Kolmogorov-Smirnov (K-S) Test

The Kolmogorov-Smirnov (K-S) test is a commonly used nonparametric test to assess whether a given data set significantly deviates from a hypothesized continuous distribution. It serves as a substitute for the chi-squared goodness of fit test. The test statistic (D*) represents the highest absolute variance between the empirical cumulative distribution function (CDF) computed from the dataset and the hypothesized CDF, as shown in Equation (1). A larger value of D* indicates a greater discrepancy between the observed data and the statistical distribution model (Sukrutha et al. 2018).

$$D *= \max_x(|\hat{F}(x) - G(x)|) \tag{1}$$

Here, $\hat{F}(x)$ refers to the empirical CDF calculated from the data, and $G(x)$ represents the CDF of the hypothesized distribution.

2.3.3 Anderson-Darling (A-D) Test

The Anderson-Darling (A-D) test is used to determine if a data sample originates from a specific distribution. It is a modification of the K-S test and is more sensitive to outliers, placing greater emphasis on the tails of the distribution. This test can be applied to any hypothesized distribution as it does not require specifying distribution parameters, and its critical values are independent of the distribution being tested (Sukrutha et al., 2018). The A-D test statistic, which falls under quadratic empirical distribution function statistics, is defined as follows:

$$A_n^2 = -n - \sum_{i=1}^{n} \frac{2i-1}{n} [\ln(F(X_i)) + \ln(1 - F(X_{n+1-i}))] \tag{2}$$

Where $\{X_1<...<X_n\}$ are the ordered sample data points and n is the sample size.

2.3.4 Akaike Information Criterion (AIC) Test

The Akaike information criterion (AIC) is often used in statistics to select the most appropriate model from a given set of models. It is based on information theory and aims to find a model that closely matches the true underlying data distribution while using a minimal number of parameters. The AIC is calculated using the Equation:

$$AIC = 2K - 2\log(L) \tag{3}$$

Where K represents the number of estimated parameters in the model and $\log(L)$ refers to the log-likelihood function of the model. The model with the lowest AIC score best fits the data (Mohd Supian and Hasan, 2021).

2.3.5 Return period (T) analysis

One of the main objectives of frequency analysis is to determine the recurrence interval or return period. The return period (T) provides an estimate of the likelihood of a specific event, such as a flood or intense rainfall, occurring within a given timeframe. It is a statistical concept to express the exceedance probability (Yuan et al., 2018).

T represents the average time interval between the occurrences of a given event of a certain magnitude or higher. If a hydrometeorological variable (X) with a magnitude equal to or greater than x occurs, on average, once every T years, then the probability of such an event occurring, denoted as P(X ≥ x), can be calculated using the following equations (Alam et al., 2018a):

$$P(X \geq x) = \frac{1}{T} \tag{4}$$

$$T = \frac{1}{1-P(X \leq x)} \tag{5}$$

3. Results And Discussion

3.1 Description of rainfall and temperature data

Statistical analysis was conducted on a dataset spanning 73 years (1950–2022) of monthly maximum rainfall and temperature data for the Khulna region. **Table 2** comprehensively summarizes statistical characteristics, including the arithmetic mean, median, standard error, standard deviation, sample variation, skewness, kurtosis, maximum, minimum, 95th percentile value, and range for both monthly rainfall and temperature. The analysis reveals that the kurtosis and skewness values (>1.0) of monthly rainfall are positive, while for temperature, they are negative (-0.63-0). This signifies that the dataset for rainfall exhibits a higher proportion of values in the right tails, indicating significant deviations from the mean compared to the temperature dataset. Over the study period, the dry season (November to March) mostly observed minimum monthly rainfall values (5–38 mm). Conversely, the hot season (March to June), characterized by high humidity levels, experienced maximum monthly temperatures (32.2–34.8 °C) (**Figure 2**).

Table 2: Statistical characteristics for the Khulna station

Statistical Parameters	Rainfall	Temperature
Data Collection years	1950- 2022	1950- 2022
Data collection periods	73	73
Mean	146.32	31.260
Median	97.0	31.905
Standard Error	5.397	0.099
Standard Deviation	159.722	2.947
Sample Variance	25511.232	8.683
Kurtosis	1.455	-0.405
Skewness	1.247	-0.630
Minimum	0	23.28
Maximum	922	37.68
95^{th} Percentile	449.0	35.3
Range	922	14.4

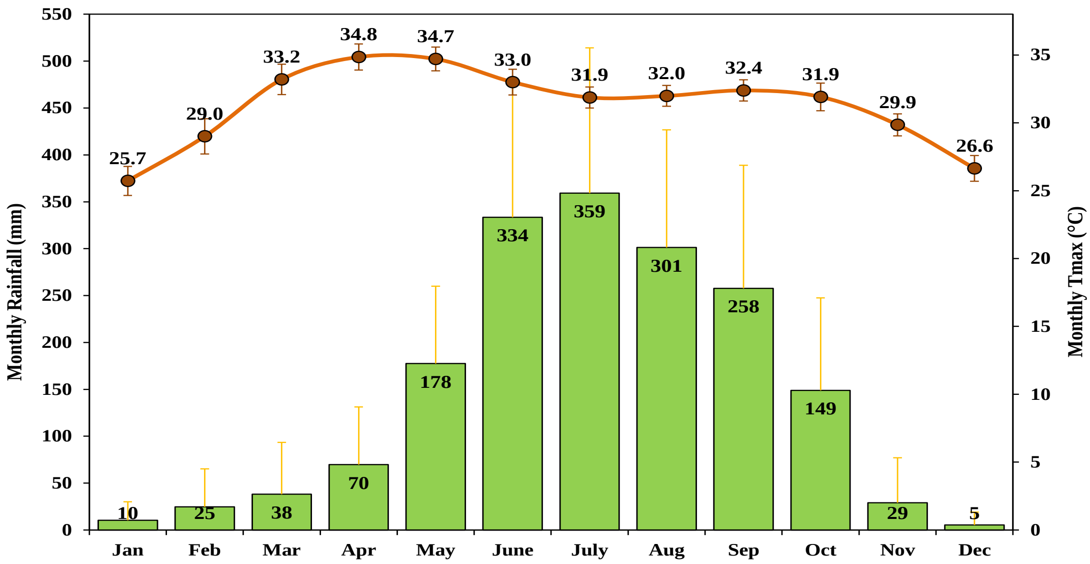


Figure 2: Month-wise rainfall and maximum temperature variation during 1950-2022

3.2 Best-fit distribution selection

The selection of the best-fit probability model for the climatic factors of a given area is of utmost importance for understanding local climate dynamics, predicting future climate trends, making well-informed decisions, and ensuring sustainable long-term development. As this study considers, the graphical comparisons of different probability distributions are presented in **Figure 3**. Normally, the graphical comparison is a valuable initial approach to selecting the optimal distribution. In **Figure 3(a)–(b),** it is observed that the PDF and CDF of the Generalized Extreme Value (GEV) distribution closely match the shape of the observed rainfall data. Conversely, in **Figure 3(c)–(d),** it is found that the PDF and CDF of the Extreme Value distribution best fit the shape of the observed temperature data. These preferences for rainfall and temperature models arise from the distinct nature and statistical properties of the dataset, as outlined in **Table 1**.

Q-Q plots are a graphical tool used to assess whether a given dataset follows a specific distribution visually and to aid in selecting the best-fit distribution model (Velez and Correa Morales 2015). **Figure 4** presents Q-Q plots of various distributions for both rainfall and temperature data. Notably, it is observed that no single distribution precisely fits the datasets for rainfall and temperature. All distributions exhibit a right-skewed pattern regarding rainfall data (**Figure 4(a)**). The logistic and t Location-Scale distributions come closest to approximating the data points and intriguingly align their right tail with the reference line. Conversely, for the temperature data (**Figure 4(b)**), the Lognormal and Gamma distributions closely follow the reference line compared to the other distributions. However, outliers across all distributions for rainfall and temperature data indicate a lack of normality in the datasets. This emphasizes the necessity for additional statistical tests.

Table 3 displays the estimated parameters and results of statistical tests (AIC, K-S, and A-D) for various probability distributions, providing a more quantitative approach compared to graphical inspection. The distribution model with the lowest AIC value, K-S, and A-D test statistics was selected as the optimal choice from all the models considered in this study. For rainfall data, the GEV distribution emerged as the best fit among the range of distributions, demonstrating the lowest values for AIC (10350.84), K-S statistic (0.1383), and A-D statistic (27.1091). Conversely, the Extreme Value distribution provided the best fit for temperature data, exhibiting lower values of AIC (4285.62), K-S statistic (0.0605), and A-D statistic (3.8215) compared to the other distributions.

The findings derived from the best-fit analysis gain support from previous studies conducted across diverse stations and geographical areas. For example, a group of researchers conducted a study on the best-fit probability distribution for monthly maximum rainfall in Bangladesh and found that the GEV distribution was suitable for 14 out of 35 stations (Alam et al., 2018a). The study also concluded that three-parameter distributions (such as GEV and LP3) with skewness exceeding 1.0 demonstrated greater flexibility than two-parameter distributions for fitting rainfall data. Similarly, another study focused on monthly rainfall data from Chittagong, Dhaka, Rajshahi, and Sylhet and empirically validated the GEV distribution as the most appropriate choice for modelling the monthly rainfall data (Ghosh et al., 2016). The common findings of the GEV distribution as the best fit for rainfall data are observed in different areas, including Malaysia, Saudi Arabia, Qatar, Brazil, and India (Ng et al., 2020; Alahmadi et al. 2014; Mamoon and Rahman 2017; Abreu et al. 2023; Sukrutha et al. 2018). The GEV distribution's capacity to effectively capture and model extreme events, such as heavy-tailed occurrences commonly observed in rainfall data, contributes to its recurrent preference.

Regarding monthly maximum temperature data, the Generalized Skew Logistic Distribution (GSL) identified as the optimal fit for the Patuakhali station among various probability distributions (Hossain et al., 2018). Similarly, another researcher found the Beta distribution to be the best-fitted option for the Sylhet station (Hasan, 2021). Furthermore, researchers in 2016 observed that the Generalized Skew Logistic Distribution (GSL) provided the most appropriate fit for Dhaka city (Hossain et al., 2016). Additionally, a study focused on the Northwest Himalayas of India found the Normal distribution to be the best-fit choice among five distributions (Normal, Lognormal, Gamma, Gumbel, and Weibull) (Poonia and Azad 2022). These variations in the best-fit distributions compared to the current study could be due to differences in dataset characteristics and the duration of the studies.

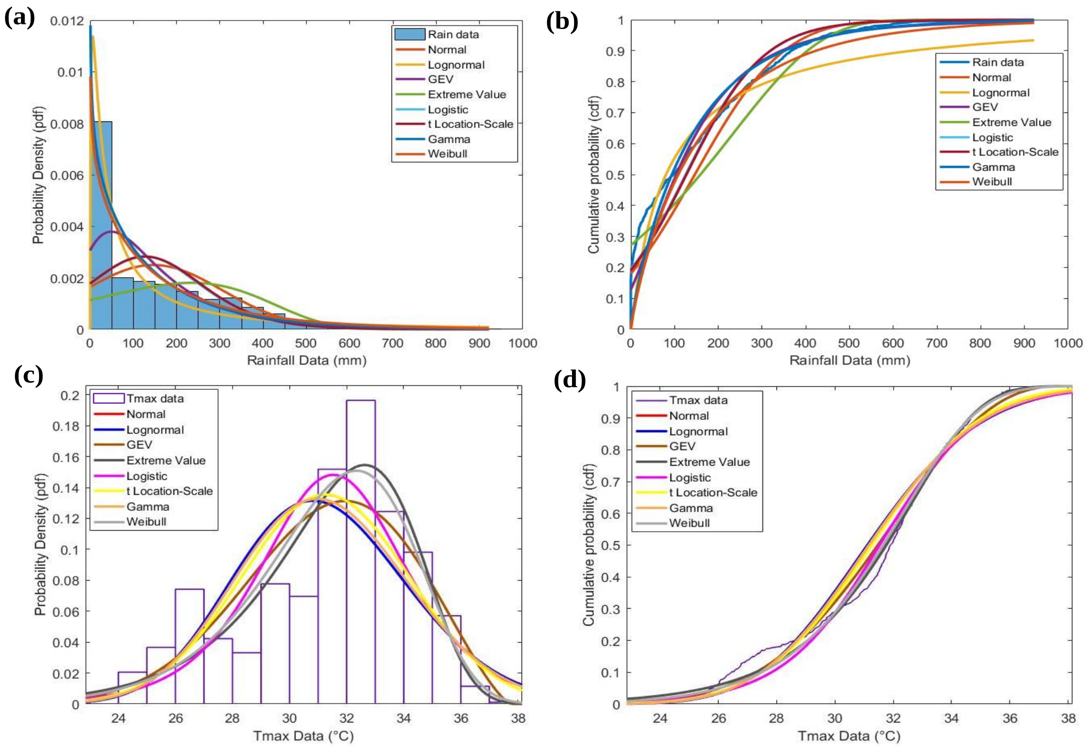


Figure 3: Probability distributions of (a) PDFs and (b) CDFs for the rainfall data, and (c) PDFs and (d) CDFs for the temperature data.

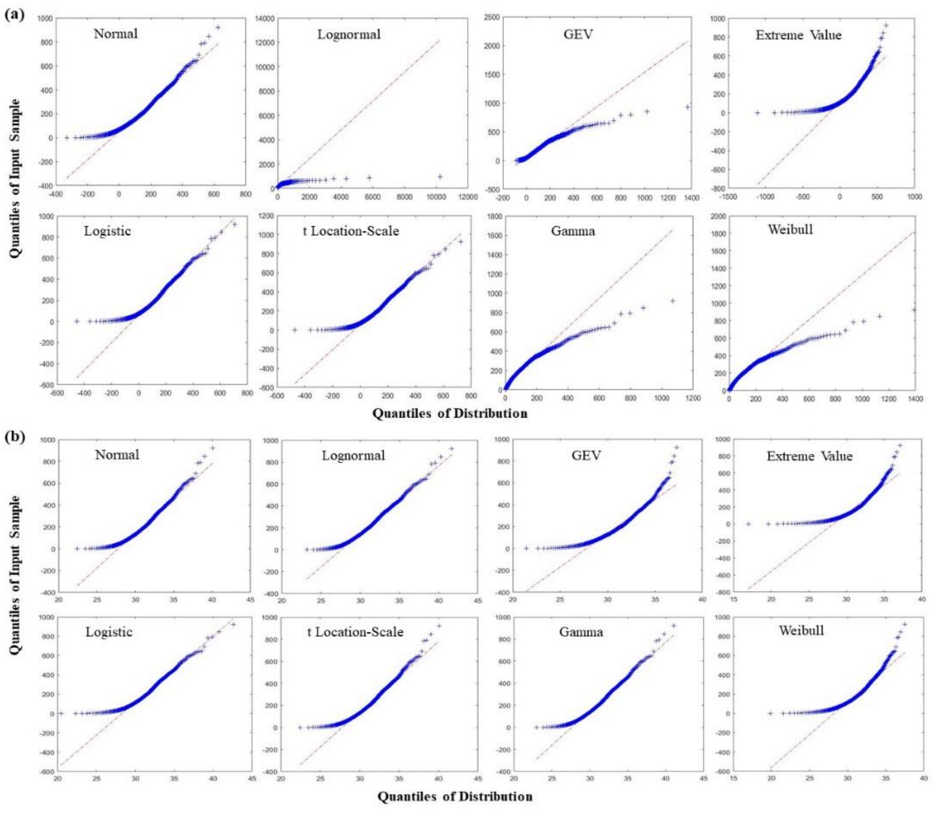


Figure 4: Q-Q plot of different distributions for (a) Rainfall and (b) Temperature data

3.3 Return Period Results

The concept of a return period proves invaluable for evaluating natural hazard risks and future planning. In this study, **Figure 5** illustrates the utilization of 5-year, 10-year, 25-year, 50-year, 100-year, and 500-year return periods for rainfall and temperature analysis across various probability distributions. Across all distribution models, an increasing trend in both rainfall and temperature values is evident as the return period increases. This implies that the likelihood of experiencing an event of rainfall or temperature at a magnitude equal to or exceeding a certain threshold decreases with longer return periods. For the rainfall data, the GEV distribution, which demonstrated the best fit, projected 238 mm, 344 mm, 503 mm, 640 mm, 796 mm, and 1248 mm of rainfall for return periods of 5, 10, 25, 50, 100, and 500 years, respectively. Correspondingly, concerning temperature data, the optimal-fitting Extreme Value distribution indicated temperatures of 33.8 °C, 34.6 °C, 35.4 °C, 35.9 °C, 36.3 °C, and 37.0 °C for the same return periods. A previous study (Alam et al. 2018a) reported a 100-year return period result of 1000 mm rainfall through the GEV distribution in Khulna station, which is comparably higher than the results of this study. This divergence can be attributed to disparities in periods and the approach to return period calculations for 50 and 100 years. However, the extreme values of rainfall and temperature associated with their respective return periods indicated that the area would be exposed to the risk of flood or waterlogging and heatwave events in the upcoming years.

Table 3: Estimated parameters and statistical test values of different distribution

PDF	Rainfall					Temperature				
	Parameters	Log-likelihood	AIC	K-S	A-D	Parameters	Log-likelihood	AIC	K-S	A-D
Normal	μ = 145.323 σ = 159.722	-5686.82	11377.64	0.1874	39.3062	μ = 31.260 σ = 2.947	-2189.16	4382.32	0.1229	16.9607
Log Normal	μ = 4.388 σ = 1.622	*	-	0.2098	266.69	μ = 3.438 σ = 0.098	-2219.08	4442.16	0.1407	23.1664
GEV	k = 0.192 σ = 98.745 μ = 10.095	-5172.42	10350.84	0.1383	27.1091	k = -0.425 σ = 3.119 μ = 30.410	-2150.82	4307.64	0.0947	8.7598
Extreme value	μ = 233.802 σ = 203.803	-5909.83	11823.66	0.2721	60.4837	μ = 32.633 σ = 2.380	-2140.81	4285.62	0.0605	3.8215
Logistic	μ = 125.507 σ = 88.295	-5674.02	11352.04	0.1944	34.7016	μ = 31.529 σ = 1.687	-2201.5	4407.00	0.0859	14.2136
t location-Scale	μ = 127.093 σ = 136.569 ν = 7.424	-5671.72	11349.44	0.1907	35.0109	μ = 31.260 σ = 2.945 ν = 2.034×10^6	-2189.16	4384.32	0.1229	16.9607
Gamma	a = 0.839 b= 174.35	*	-	0.1814	225.55	a = 107.236 b= 0.292	-2208.1	4420.20	0.1350	21.0056
Weibull	a = 164.38 b = 0.881	*	-	0.1905	248.37	a = 32.537 b = 13.306	-2141.01	4286.02	0.0687	5.6866

Note: *Maximum likelihood estimation did not converge. Iteration limit exceeded.

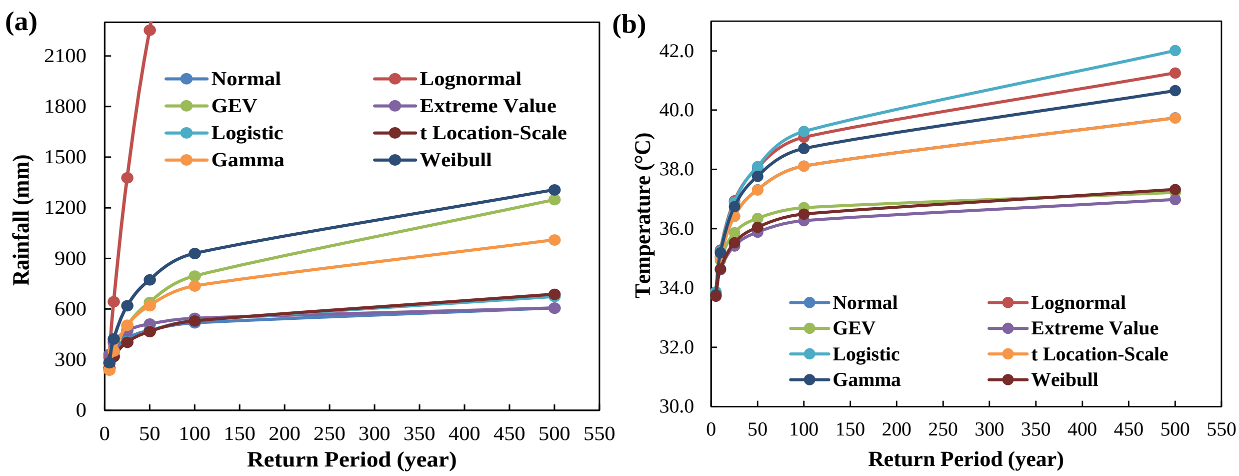


Figure 5: Return period results of different distributions for (a) Rainfall and (b) Temperature data

4. Conclusion

This study aimed to determine the best-fit probability distribution and return period for the monthly maximum rainfall and temperature dataset at the Khulna station. The analysis identified the GEV distribution as the best fit for rainfall data and the Extreme Value distribution as the best fit for temperature data. These findings were rigorously evaluated through goodness of fit tests, including the AIC value, K-S test, A-D test, and graphical Q-Q plot. The return period analysis for rainfall and temperature indicates that the area will experience more frequent and severe flooding (or waterlogging) and heatwave events in the coming years. These results can significantly affect various disciplines, including agriculture, construction, environmental management, and climate research. Engineers and policymakers can use this information to develop safer and more resilient models to protect lives and property. Nevertheless, it's worth noting that while this study provides valuable insights, further research is needed to develop a more reliable model that considers the variation in climate change over time to exhibit the actual real-world scenario better.

Acknowledgment

The authors extend their gratitude to the Bangladesh Meteorological Department (BMD) for providing the necessary data. Additionally, the authors express their appreciation to the Chittagong University of Engineering and Technology (CUET) for their valuable support and unwavering encouragement.

Credit Authorship Contribution Statement

Md. Bashirul Islam: Conceptualization, Methodology, Resources, Investigation, Data curation, Formal analysis, Software, Writing – original draft. Md. Nour Hossain: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing. Md. Abul Hasan: Methodology, Visualization, Writing – review & editing, Md. Mehedi Hassan Masum: Data curation, Resources, Formal analysis, Writing – review & editing. Md. Ashraful Islam: Investigation, Software, Formal analysis.

Declaration Of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

There is no funding information available for the work.

Data Availability

Data will be available on request.

References

Abreu, M.C., De Souza, A., Lyra, G.B., et al., 2023. Assessment and characterization of the monthly probabilities of rainfall in Midwest Brazil using different goodness-of-fit tests as probability density functions selection criteria. Theoretical and Applied Climatology, 151, Pp. 491–513. https://doi.org/10.1007/s00704-022-04286-z

Alahmadi, F., Rahman, N.A., Abdulrazzak, M., 2014. Evaluation of the best fit distribution for partial duration series of daily rainfall in Madinah, western Saudi Arabia. Proceedings International Association Hydrological Sciences, 364, Pp. 159–163. https://doi.org/10.5194/piahs-364-159-2014

Alam M, Emura K, Farnham C, and Yuan, J., 2018a. Best-Fit Probability Distributions and Return Periods for Maximum Monthly Rainfall in Bangladesh. Climate 6 (9). https://doi.org/10.3390/cli6010009

Alam, M., Farnham, C., and Emura, K., 2018b. Best-Fit Probability Models for Maximum Monthly Rainfall in Bangladesh Using Gaussian Mixture Distributions. Geosciences 8:138. https://doi.org/10.3390/geosciences8040138

Bedane, H. R., Beketie, K. T., Fantahun, E. E., Feyisa, G. L., and Anose, F.A., 2022. The impact of rainfall variability and crop production on vertisols in the central highlands of Ethiopia. Environmental Systems Research, 11, Pp. 26. https://doi.org/10.1186/s40068-022-00275-3

Defrance, D., Catry, T., Rajaud, A., Dessay, N., and Sultan, B., 2019. The Impact of Melting Ice Sheets on Future Global Climate. Physical Sciences and Mathematics

Ghosh, S., Roy, M.K., Biswas, S.C., 2016. Determination of the Best Fit Probability Distribution for Monthly Rainfall Data in Bangladesh. Am J Math Stat 6:170–174. https://doi.org/10.5923/j.ajms.20160604.05

Hasan, M.D.R, 2021. Estimating the Best-Fitted Probability Distribution for Monthly Maximum Temperature at the Sylhet Station in Bangladesh. Journal of Mathematics and Statistics studies. 2, Pp. 60–67. https://doi.org/10.32996/jmss.2021.2.2.7

Hossain, M., Abdulla., F., Alam, G., 2018. On Identifying the Probability Distribution of Monthly Maximum Temperature of Two Coastal Stations in Bangladesh. Journal of Environmental Statistics, 8, Pp. 1–12

Hossain, M., Abdulla, F., Rahman M.d.H., 2016. Selecting the Probability Distribution of Monthly Maximum Temperature of Dhaka (Capital City) in Bangladesh. Jahangirnagar Journal of Statistical Planning and Inference, 33, Pp. 33–45

Iderawumi, A, Charles, E., Owoade, O., Onifade, A., 2017. An Investigation into the Effect of Rainfall Variability on Farming Activities in Rural Area. Asian Journal of the Advances in Agricultural Research, 4, Pp. 1–7. https://doi.org/10.9734/AJAAR/2017/37872

Kashem M, Hossain M, Faroque M.A.A., 2009. Rainfed Agriculture: On Going And Future Researchable Issues In Bangladesh. Bangladesh Sci Fund 7 (1), Pp. 1–8

KD, 2023. An overview of the Khulna district. https://www.khulna.gov.bd/en/site/page/N3Rh-%E0%A6%8F%E0%A6%95-%E0%A6%A8%E0%A6%9C%E0%A6%B0%E0%A7%87-%E0%A6%9C%E0%A7%87%E0%A6%B2%E0%A6%BE%E0%A6%B0-%E0%A6%AA%E0%A6%B0%E0%A6%BF%E0%A6%9A%E0%A6%BF%E0%A6%A4%E0%A6%BF. Accessed 2 Sep 2023

Khudri, M., Sadia, F., 2016. Determination of the Best Fit Probability Distribution for Annual Extreme Precipitation in Bangladesh. European Journal of Scientific Research 103, Pp. 391–404

Lei, Y., Liao, R., Su, Y., Zhang, X., Liu, D., and Zhang, L., 2023. Variation Characteristics of Temperature and Rainfall and Their Relationship with Geographical Factors in the Qinling Mountains. Atmosphere 14, Pp. 696. https://doi.org/10.3390/atmos14040696

Mamoon, A.A., and Rahman, A., 2017. Selection of the best fit probability distribution in rainfall frequency analysis for Qatar. Nat Hazards 86, Pp. 281–296. https://doi.org/10.1007/s11069-016-2687-0

Matata, P., Bushesha, M., and Msindai, J., 2019. Assessing Rainfall and Temperature Changes in Semi-Arid Areas of Tanzania. American Journal of Climate Change, 8, Pp. 173–189. https://doi.org/10.4236/ajcc.2019.82010

Mohd, Supian, N., and Hasan, H., 2021. Selecting the probability distribution of annual maximum temperature in Malaysia. ITM Web Conferences, 36, Pp. 01010. https://doi.org/10.1051/itmconf/20213601010

Ng, J.L., Yap, S.Y., and Huang, Y.F., Noh, N.M., Al-Mansob, R.A., and Razman, R., 2020. Investigation of the best fit probability distribution for annual maximum rainfall in Kelantan River Basin. IOP Conference Series: Earth and Environmental Science, 476, Pp. 012118. https://doi.org/10.1088/1755-1315/476/1/012118

Omer, M. akram, Salh, S.M., Ahmed, S.A., 2020. Statistical Distribution of Rainfall in Kurdistan-Iraq Region. Al-Mustansiriyah Journal of Science, 30, Pp. 18–28. https://doi.org/10.23851/mjs.v30i4.662

Pandit, R.K., and Infield, D., 2018. QQ plot for assessment of Gaussian Process wind turbine power curve error distribution function. Manchester, UK

Poonia, N., and Azad, S., 2022. Projection of annual maximum temperature over Northwest Himalayas using probability distribution models. Theoretical and Applied Climatology, 149, Pp. 1599–1627. https://doi.org/10.1007/s00704-022-04121-5

Rahman, M.C., Rahaman, M.S., Biswas, J.C., Rahman, N.M.F., Islam, M.A., Sarkar, M.A.R., and Maniruzzaman, M., 2023. Climate change and risk scenario in Bangladesh. Asia-Pacific Journal of Regional Science, 7, Pp. 381–404. https://doi.org/10.1007/s41685-022-00252-9

Shen., W., Li, Y, Qin, Y., and Cheng J., 2023. Influencing mechanism of climate and human activities on ecosystem health in the middle reaches of the Yellow River of China. Ecological indicators, 150, Pp. 110191. https://doi.org/10.1016/j.ecolind.2023.110191

Sukrutha, A., Dyuthi, S.R., Desai, S., 2018. Multimodel response assessment for monthly rainfall distribution in some selected Indian cities using best-fit probability as a tool. Applied Water Science, 8, Pp. 145. https://doi.org/10.1007/s13201-018-0789-4

Velez, J.I., and Correa, Morales, J.C., 2015. A modified Q-Q plot for large sample sizes. Comun En Estad, 8, Pp. 163. https://doi.org/10.15332/s2027-3355.2015.0002.02

WMO, 2021. Weather-related disasters increase over past 50 years, causing more damage but fewer deaths. In: World Meteorol. Organ. WMO. https://public.wmo.int/en/media/press-release/weather-related-disasters-increase-over-past-50-years-causing-more-damage-fewer. Accessed 2 Sep 2023

Yuan, J., Emura, K., Farnham, C., and Alam, M.A., 2018. Frequency analysis of annual maximum hourly precipitation and determination of best fit probability distribution for regions in Japan. Urban Clim 24:276–286. https://doi.org/10.1016/j.uclim.2017.07.008

Zhao C, Liu B, Piao S, et al (2017) Temperature increase reduces global yields of major crops in four independent estimates. Proceedings of the National Academy of Sciences of the United States of America, 114, Pp. 9326–9331. https://doi.org/10.1073/pnas.1701762114