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Research Article

A Methodological Comparison of Rainfall Frequency Distribution Derived from Disaggregated Rainfall Records

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Abstract

Rainfall is essential in hydrologic and hydraulic analyses, serving as critical parameter in water resource studies. Hydraulic structures are designed to manage flooding triggered by extreme rainfall events. One common approach to analyze these extreme occurrences is through probability distribution or frequency analysis. This study evaluates various methods of rainfall frequency analysis. Rainfall data was sourced from the Ethiopian Meteorological Agency (EMA), specifically the Addis Ababa Observatory. Before conducting frequency analyses, data quality was assessed for outliers, with findings within acceptable limits. The frequency analysis utilizes four different distribution methods: Gumbel Extreme Value I, Lognormal, Pearson II and Log-Pearson III. Moreover, these distribution methods were fitted using RMC BestFit software to select a method that fits best for the dataset. The fitted distribution methods were also calibrated with non-probability Intensity-Duration-Frequency (IDF) models. Results indicated that while all methods performed satisfactorily, the Gumbel EVI displayed the best balance between model fit and error reduction in this IDF analysis. The study underscores the importance of selecting appropriate statistical methods for accurate rainfall modeling, which is vital for the design and operation of hydraulic structures. Future research could investigate the applicability of these findings in other regions or integrate climate change variables into rainfall frequency analysis for enhanced flood risk management. Additionally, employing advanced techniques, like machine learning algorithms, may improve prediction accuracy and provide deeper understanding of rainfall variability and trends.

Keywords

Addis Ababa, Rainfall, Frequency Analysis, IDF, Gumbel EVI

1. Introduction

Any type of moisture that descends to the earth from the sky is called precipitation. Rainfall is the primary source of this precipitation in storm generated runoff [1, 2]. One of the most important inputs for groundwater recharge and surface water resources is rainfall [3-6]. A rain gauge in the gauge station is used to record this rainfall in depth format (mm or in). certain models require this rainfall data in an intensity format, such as mm/hr or in/hr [7]. Rainfall forecasting is also crucial since many catastrophes can result from heavy rainfall. In addition to being correct, the forecast encourages people to take preventive action [8]. Variations in precipitation events' intensity, length, and frequency results from changes in the hydrologic cycle brought on by a rise in greenhouse gases [7]. Many extreme events in hydrology cannot be predicted with adequate skill and lead-time using deterministic knowledge. In these situation, a probabilistic approach is necessary to take these

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phenomena's consequences into account while making decisions [9]. A statistical method for determining and forecasting the frequency and severity of rainfall events in a certain area during a given time period is called rainfall frequency analysis [10]. Choosing the best form of the Intensity-Duration-Frequency (IDF) curve becomes a pertinent concern in the area of sub-hourly durations, particularly in urban hydrology [11]. The link between rainfall intensity, duration, and return period is shown by Intensity-Duration-Frequency (IDF) curves. They are frequently employed in the planning, design, and managements of water resource, hydraulic, and hydrologic systems [12]. Frequency analysis of rainfall observations is used to determine the IDF connection [12]. A mathematical relationship between rainfall intensity, duration and return period is established via the IDF relationship [1, 13-17]. It is one of the most popular tools for developing rain intensity calculations for urban stormwater drainage system design [18]. In hydrological, hydraulic, and water resource systems projects, as well as in their analysis and validation, intensity-duration-frequency (IDF) or (depth-duration-frequency, DDF) curves are frequently used to estimate the frequency (or the return period) of observed rainfall events and to design synthetic rainfall events with a given frequency [11]. It was also used to calculate design rainfall [19]. Engineers rely on Intensity–Duration–Frequency (IDF) curves for the design and analysis of hydraulic and water-related infrastructure. However, a major source of uncertainty in IDF development lies in the selection of an appropriate rainfall frequency distribution, particularly in regions where high-resolution (sub-daily) rainfall records are scarce. In such cases, engineers are often forced to disaggregate daily rainfall data to shorter durations, a process that introduces additional uncertainty into extreme rainfall estimation. Consequently, this research focuses on identifying and evaluating the most suitable frequency distribution methods for constructing IDF curves using disaggregated rainfall data, with the aim of reducing uncertainty and improving the reliability of design rainfall estimates.

2. Methodology

2.1. Study Area Description and Data Availability

For this specific research, daily basis rainfall data was collected from the National Metrological Agency (NMA) of Ethiopia. The station found at latitude 9°1′ and longitude 38°45′ with station name Addis Ababa Observatory with an altitude of 2386.00 meter above mean sea level.

Table 1. *Description of Addis Ababa bole observatory station.*

Location		Data period		Duration	Total record	Format	Unit
Easting = 38°45′	Northing = 9°1′	Start year = 1980	End year = 2018	24 hour (daily)	39 year	Table	mm

2.2. Data Preparation and Frequency Analysis

From the collected data annual maximum value was selected for each station to analyse frequency through different distribution methods as shown in Table 2.

Table 2. *Yearly peak rainfall of the station.*

year	Maximum rainfall record	year	Maximum rainfall record	year	Maximum rainfall record
1980	36.3	1993	53.5	2006	70.9
1981	58.0	1994	57.0	2007	64.0
1982	41.4	1995	85.3	2008	53.3
1983	50.1	1996	67.0	2009	54.7
1984	55.4	1997	46.3	2010	44.6
1985	43.2	1998	78.3	2011	55.8
1986	83.8	1999	37.4	2012	36.4
1987	56.8	2000	37.1	2013	47.2
1988	35.5	2001	42.5	2014	65.4

year	Maximum rainfall record	year	Maximum rainfall record	year	Maximum rainfall record
1989	49.2	2002	29.5	2015	33.1
1990	39.6	2003	46.2	2016	47.7
1991	47.3	2004	44.2	2017	50.8
1992	51.4	2005	58.6	2018	55.2

Before performing frequency analysis, data quality check was performed for outlier test (upper and lower). An outlier is an observation that deviates significantly from the bulk of the data, which may be due to errors in data collection, or recording, or due to natural causes. The presence of outliers in the data causes difficulties when fitting a distribution to the data.

Table 3. *Summary statistics of the raw data.*

Measure	Record Length	Mini-mum	Maxi-mum	Mean	Std Dev	Skew-ness	Kur-tosis	Mean (of log)	Std Dev (of log)	Skewness (of log)	Kurtosis (of log)
Value	39	30	85	52	13	0.8252	0.6051	1.6989	0.1081	0.1721	-0.1354

Low and high outliers are both possible and have different effects on the analysis. The retention or depletion of these outliers significantly affect the magnitude of statistical parameters computed from the data [20]. The test was performed depending on the skewness coefficient.

Table 4. *Outlier test skewness coefficient range.*

Skewness coefficient	>+0.4	<-0.4	Between ±0.4
Test for	Higher outliers	Lower outlier	Both high and low outliers

Source: [21]

The following equations can be used to detect higher and lower outliers:

$$y_h = \bar{y} + k_n S_y$$

$$y_l = \bar{y} - k_n S_y$$

Where: y_h and y_l are high and low outlier threshold in log units respectively, k_n = coefficient depends on sample size (for N = 39; k_n = 2.671) [21], $\bar{y}$ = mean of the data in log unit and S_y = standard deviation in log unit.

2.3. Estimation of Short Duration Rainfall

Since, in urban area most of the time flood is occurred for short period of duration and drainage facilities in urban areas were designed for design rainfall of shorter duration. Therefore, before directly proceeding into hydrological analysis it is necessary to determine storm events of shorter duration. [10] recommend the following formula to disaggregate daily rainfall data into shorter duration:

$$R_t = \frac{t(b+24)^n}{(24(b+t)^n}*R_{24}$$

Where: R_t = Rainfall of required duration, R_{24} = Rainfall of 24 hr (daily rainfall), t = Rainfall required duration, b = Coefficients (0.3), n = Coefficients (0.78 – 1.09).

2.4. Frequency Analysis Using Different Distribution Method

The objective of frequency analysis of rainfall data is to relate the magnitude of extreme events to their frequency of occurrence with probability distributions [21]. In this study, frequency analysis was performed for multiple return periods using different probability distribution methods. Annual maximum values for all the available durations have been statistically analyzed using four different probability distribution functions (PDF), namely: Gumbel Extreme Value Type-1 (Gumbel EVT-1), Pearson Type-3 (PT-3), Log-Pearson Type-3 (LPT-3) and Log-Normal (LN) distributions. [21] as gives the approximation of the magnitude of a random event such as rainfall intensity for all distribution methods:

$$X_T = \bar{X} + K_T S$$

$\bar{X} =$ mean, $S =$ standard deviation of the sample and $K_T =$ frequency factor and different for each distribution method. The last two parameters are functions of the return period, T, and the PDF type. The determination of the value of rainfall intensity requires the computation of the frequency factor for each PDF, the mean and standard deviation for the observed data is substituted into equation for evaluation.

2.4.1. Gumbel EVT-1 Distribution

For Gumbel EVT-1 distribution The K_T was calculated using:

$$K_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left[\left[\ln\frac{T}{T-1}\right]\right]\right]$$

The frequency factors for a return period of 2, 5, 10, 25, 50, and 100 year can be:

***Table 5**. General Extreme Value Type I frequency factor.*

T	2	5	10	25	50	100
K_T	-0.16436	0.719822	1.305225	2.044883	2.593603	3.138272

2.4.2. Pearson Type-3 (PT-3) Distribution

For Pearson distribution the frequency factor (KT) was obtained from [20, 21] for different return periods. In this method, the frequency factor depends on both the return period and the skewness coefficient.

2.4.3. Log-Pearson Type-3 (LPT-3) Distribution

The change from Pearson III distribution method in Log-Pearson was application of statistical parameters (mean, standard deviation, and skewness) from logarithmically converted data.

2.4.4. Log-Normal Distribution

In this distribution, the only difference is usage of statistical parameters (mean and standard deviation) from logarithmically transformed data and all the procedures are the same to Normal distribution. Therefore, by substituting the logarithmically changed data the maximum rainfall intensities.

2.5. Fitting Probability Distribution Methods

To fit multiple distributions to the given input data, the maximum likelihood estimation (MLE) method is employed, in accordance with the [22] recommendations. Also applied in [23]. Comparing each distribution's Akaike (AIC), Bayesian information criteria (BIC), or Root Mean Square Error (RMSE) can help in model selection. A smaller value denotes a better fit between the distribution and the input data, according to these metrics. For this purpose, probability fitting software (RMC-BestFit) was applied. RMC-BestFit is a menu-driven software package, which performs distribution fitting and Bayesian estimation for different probability distributions. The software features a fully integrated modeling platform, including a modern graphical user interface, data entry capabilities, distribution fitting analysis, Bayesian estimation analysis, and report quality charts.

The distribution method were also calibrated using Sherman modified quotient-power equation given by [21, 24] adopted for the derivation of the IDF model.

$$\mathrm{I} = \frac{C{T_r}^m}{{T_d}^a}$$

Where I=rainfall Intensity (mm/hr.), T_r = duration (minutes), and T_d=return period (years); c, m, and a and are model parameters. The equation is non-linear quotient power law that was calibrated for c, m, and parameters using intensity, duration, and return period values and Excel Optimization Solver. The Generalized Reduced Gradient (GRG) solver is an optimization tool embedded in Microsoft excel. It can be used to obtain the optimum values of parameters of linear or nonlinear equations. There are two solver methods namely linear programming solver (LP) for linear equations; GRG and Evolutionary solver for nonlinear Equations [24]. To obtain the values of optimum IDF parameters, Mean Square Error (MSE) is calculated using the sum of the square of deviation/ error between observed intensity and predicted intensity which was set to minimization using Generalized Reduced Gradient (GRG) solver as:

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(I_{obs} - I_{pred})^2$$

The coefficient of determination (R^2) is computed from:

$$R^2 = (\frac{(I_{obs} - I_{obsavg})(I_{pred} - I_{predavg}}{\sqrt{(I_{obs} - I_{obsavg})^2}\sqrt{(I_{pred} - I_{predavg})^2}}$$

Where: I_{avg}= average of observed or computed PDF rainfall intensity, I_{obs}, I_{obsavg} = observed and observed average PDF rainfall intensity, I_{pred}, $I_{predavg}$ = predicted or compute and predicted or computed average PDF rainfall intensity.

Rainfall intensities obtained from each distribution are tested against the rainfall intensities calculated using General Rainfall IDF Models developed for each PDF formulas derived from the data.

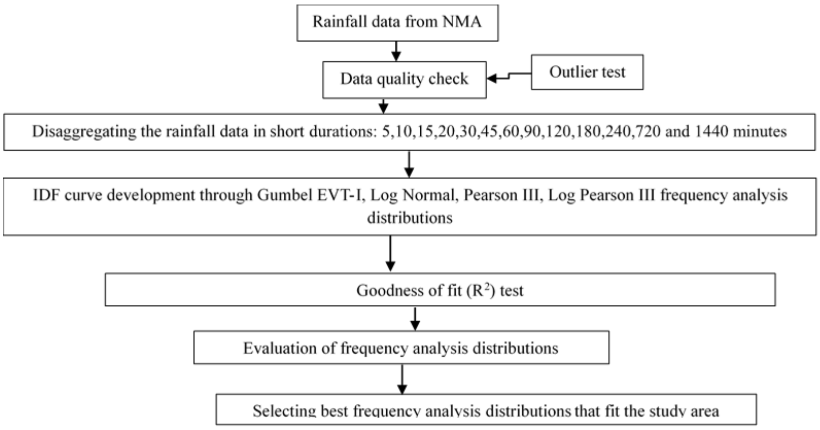

***Figure 1**. Graphical representation of IDF model development.*

3. Results

3.1. Data Quality Result

The raw data was assessed for adequacy and outlier test to determine effectiveness of the length of record and values that outlie from the raw data and the result become:

***Table 6**. Adequacy and outlier test results of the data.*

Test method	Value		Remark
Outlier	Higher from test	97.3	Ok
	Upper limit from the data	85.3	
	Lower from test	25.7	Ok
	Lower limit from the data	29.5	

3.2. Rainfall Disaggregation

After data quality check for the selected maximum rainfall values; calculation of conversion factors to estimate each shorter duration values were conducted and shown in table below.

***Table 7**. Rainfall ratio (R_{Rt}) computation sheet.*

Duration (min)	5	10	15	20	30	45	60	90	120	180	240	720	1440
t(hr)	0.08	0.17	0.25	0.33	0.50	0.75	1.00	1.50	2.00	3.00	4.00	12.00	24.00
b+24	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30
$(b+24)^n$	19.75	19.75	19.75	19.75	19.75	19.75	19.75	19.75	19.75	19.75	19.75	19.75	19.75
b+t	0.38	0.47	0.55	0.63	0.80	1.05	1.30	1.80	2.30	3.30	4.30	12.30	24.30

Duration (min)	5	10	15	20	30	45	60	90	120	180	240	720	1440
$(b+t)^n$	0.41	0.49	0.57	0.65	0.81	1.05	1.28	1.73	2.18	3.05	3.91	10.45	19.75
R_{Rt}	0.17	0.28	0.36	0.42	0.51	0.59	0.64	0.71	0.76	0.81	0.84	0.95	1.00

3.3. Frequency Analysis

Then frequency factor for each distribution method was determined; since, it is the only parameter different for each distribution method. These frequency factor mainly depends on return period and skewness coefficients of the data [21].

Table 8. *Summary of Probability distribution frequency factors, K_T values.*

Probability distribution	Frequency factor, K_T for different return periods					
	2	5	10	25	50	100
Gumbel EVT-I	-0.164	0.7195	1.304563	2.0438	2.5923	3.137
Log Normal	-1.01E-07	0.8415	1.281729	1.7511	2.0542	2.327
Pearson III	-0.135	0.7743	1.333730	1.9981	2.4663	2.915
Log Pearson III	-0.029	0.8319	1.298620	1.8089	2.1455	2.453

The following Intensity-Duration-Frequency (IDF) curves for each distribution methods are produced by estimating rainfall intensity values using this frequency factor, which are found in the appendix:

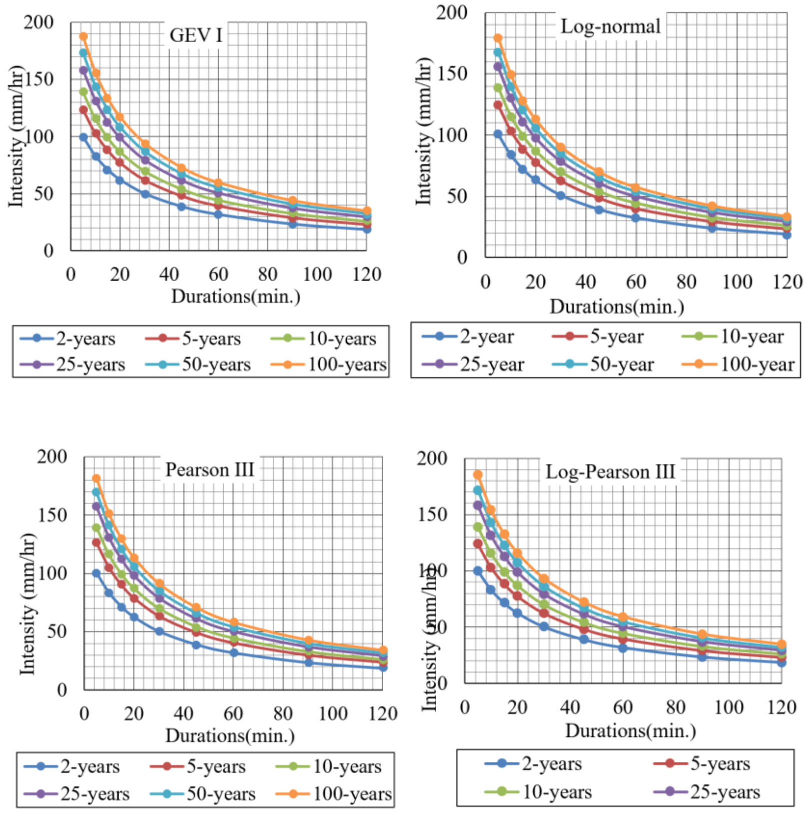

Figure 2. *Intensity Distribution Frequency Curves of different distribution method.*

3.4. Goodness of Fit Test

The model selection can be assisted by comparing the Akaike (AIC) and Bayesian Information Criteria (BIC) for each distribution method.

Table 9. Performance metrics from Goodness of Fit.

Distribution	AIC	BIC	RMSE
Gumbel (EVI)	310.49	313.48	1.85
Log-Normal	310.64	313.64	2.23
Log-Pearson Type III	312.77	317.07	1.98
Pearson Type III	312.52	316.82	1.98

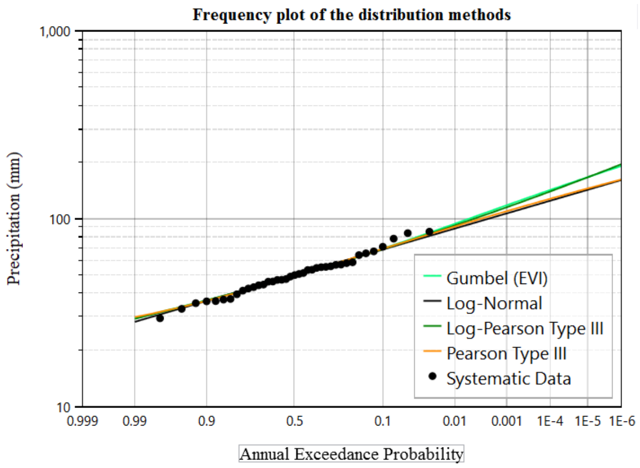

Figure 3. Different distribution method frequency plot in comparison with the station data.

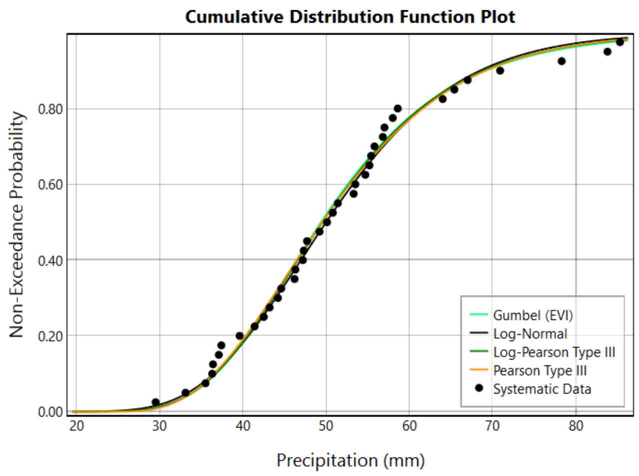

Figure 4. Cumulative distribution plot of different distribution methods.

The calibrated results of different distribution method become:

Table 10. Calibration summary of Sherman's general IDF models for each PDF.

No.	PDF	IDF models	R^2	MSE
1	Gumbel EVT-I	$I = \frac{228.931 T_r^{0.151}}{T_d^{0.489}}$	0.9705	71.88
3	Log Normal	$I = \frac{235.779 T_r^{0.137}}{T_d^{0.489}}$	0.9703	70.35
4	Pearson III	$I = \frac{235.159 T_r^{0.140}}{T_d^{0.489}}$	0.9702	71.77
5	Log Pearson III	$I = \frac{231.860 T_r^{0.147}}{T_d^{0.489}}$	0.9704	72.00

4. Discussion

4.1. Data Quality

The skewness coefficient was 0.172 which is found between -0.4 and 0.4, the statistical parameter skewness of the data directs to compute the outlier test for both higher and lower limits [21, 23]. The higher threshold value was 97.3 mm, which is higher than the 85.3 mm value of the raw data obtained. Also, lower threshold value was 25.7 mm, which is lower than the 29.5 mm value of the raw data obtained. Based on the test result, both the lower and higher limits of the data were found in the required threshold.

4.2. Disaggregation

For urban scale applications where impermeable layers and short times of concentration cause catchments to react nearly quickly to high intensity events, rainfall disaggregation to break down coarse daily rainfall into minutes is a technical need [25]. As showed table 7 an effort to break down a 24-hour rainfall depth into amounts of rainfall that last shorter periods. The original 24-hour rainfall used as reference reflected in the constant values for b + 24 and $(b + 24)^n$. The relevant rainfall depths for shorter periods are represented by the values b + t and $(b + t)^n$ as the duration drops from 24 hours to a few minutes [26]. The R_{Rt} rises from 0.17 to 1.00, indicating the portion of the 24-hour rainfall that occurs during each shorter period. Smaller durations receive proportionately less rainfall, according to this pattern, but the cumulative fraction increases steadily until it reaches the entire 24-hour total. In general, the table shows scaling techniques that supports hydrologic modeling or Intensity-Duration-Frequency (IDF) analysis by redistributing the 24-hour rainfall among different durations [19].

4.3. Frequency Analysis

Frequency factors (K_T) for a number of popular probability distributions [19, 21, 23], including Gumbel (EVT-I), Lognormal, Pearson III, and Log Pearson III, are shown in the table 7 for return periods between 2 and 100 years. Because they enable the estimate of rainfall or flood magnitudes associated with various return periods once the mean and standard deviation (or log-transformed equivalents) are known, these frequency factors are crucial to hydrologic frequency analysis [19]. Different K_T values are produced by each distribution method, particularly at greater return periods, which reflect variations in the behavior of the distributions' tails. Because of its greater tail, the Gumbel distribution consistently yields higher frequency factors for lengthy return periods, whereas the Normal and Lognormal distributions yield smaller values. Pearson and Log Pearson falls between these two extremes and provide greater versatility, because they consider skewness. Overall, the table shows how the choice of probability distribution as a substantial impact on the final design values in hydrological studies with rare, high return period events.

The Intensity-Duration-Frequency (IDF) plot illustrates how rainfall intensity decreased with increasing storm duration for various return periods ranging from 2 to 100 years. For every return period, the curves exhibit a typical IDF pattern; very high intensities at shorter durations followed by a rapid decline as the duration increases [10]. Higher return periods consistently produce greater intensities, reflecting the increased severity of rarer storms [10, 19, 21, 23]. The 100-year curve lies at the upper envelope, while the 2-year curve forms the lower bound. Beyond approximately 60 minutes, the curves begin to converge, showing smaller differences between return periods at longer durations. This is basic and helpful in design of urban water related structures because they are sensitive and designed to handle shorter duration rainfalls especially in flood controlling structures [4, 5, 18].

4.4. Goodness of Fit Test and Method Selection

The choice of probability distribution to represent data has significant cost and safety implications from an engineering standpoint because these models determine the design capacity of vital infrastructure [27]. Flood risk is dangerously underestimated if the distribution choice or disaggregation approach is unable to catch the heavy tails of extreme weather, which could lead to catastrophic structure failure and urban inundation. On the other hand, overestimating can lead to precious infrastructure, wherein extra municipal funds are allocated to drainage systems that are not necessary [27]. Based on the statistical metrics provided, the Gumbel (EVI) distribution is the most suitable model for this dataset. In statistical model selection, lower values for the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Root Mean Square Error (RMSE) indicate a superior fit. The Gumbel distribution achieves the lowest scores across all three categories, specifically boasting an AIC of 310.49 and an RMSE of 1.85. While the Log-Normal distribution is a very close competitor regarding information criteria (AIC of 310.64), its significantly higher RMSE of 2.23 suggests it is less accurate at capturing the actual variance within the data compared to the Gumbel model. Furthermore, the Pearson Type III and Log-Pearson Type III distributions perform the poorest in this comparison. They not only have higher overall error rates but also show a larger gap between their AIC and BIC values, which often penalizes models for unnecessary complexity without a proportional gain in accuracy. Because the Gumbel distribution excels at both minimizing information loss and reducing predictive error, it should be prioritized for any subsequent risk analysis or forecasting.

5. Conclusion

The availability and integrity of raw data are equally important in hydrologic analysis. Before moving on to modeling and application, it is crucial to comprehend and assess the quality of this data. Accurate rainfall intensity estimates over shorter periods are crucial for urban drainage models, which are especially vulnerable to short-duration rainfall events because of the quick start of urban flooding. The Ethiopia Road Authority (ERA) created a system to divide 24-hour rainfall totals into smaller time intervals in order to accomplish this. In urban settings, where heavy rainfall can cause floods in a matter of minutes, this method enables a more accurate estimate of rainfall intensity. Based on the Goodness of Fit test result of AIC, BIC and RMSE the Gumbel EVI distribution was found to be the most appropriate fit for the rainfall data from the chosen observation site. This result suggests that the Gumbel EVI can be used to adequately simulate the behavior of rainfall intensity over shorter timeframes. The rainfall intensity values produced by this Gumbel EVI distribution also show a favorable association with those obtained from a non-probability intensity-duration-frequency (IDF) model. The validity of the Gumbel EVI distribution approach for forecasting rainfall intensities in hydraulic structure design and urban drainage planning is supported by this association. This work has implications that go beyond the current investigation. It shows how researchers and practitioners can use the established distribution mechanism to create hydrologic models customized to particular locations or areas, improving the precision and dependability of urban water management systems.

Abbreviations

AACRA	Addis Ababa City Road Authority
AIC	Akaike Information Criteria
BIC	Bayesian Information Criteria
DDF	Depth Duration Frequency
EMA	Ethiopian Meteorological Agency
ERA	Ethiopia Road Authority
EVI	Extreme Value I
GRG	Generalized Reduced Gradient
IIDF	Intensity-Duration-Frequency
LP	Linear Programming
MLE	Maximum Likelihood Estimation
PDF	Probability Density Function
RMC	Risk Management Center
RMSE	Root Mean Square Error

Author Contributions

Mezen Desse Agza: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Conflicts of 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.

Appendix

Appendix I: Disaggregated Rainfall Intensity Values

Table A1. *Disaggregated rainfall intensity values for different durations.*

Rainfall intensity (mm/hr)												
5 min	**10 min**	**15 min**	**20 min**	**30 min**	**45 min**	**60 min**	**90 min**	**120 min**	**180 min**	**240 min**	**720 min**	**1440 min**
14.34	23.86	30.69	35.86	43.24	50.30	54.92	60.77	64.43	68.96	71.79	80.61	85.30
14.08	23.44	30.15	35.23	42.48	49.41	53.96	59.70	63.30	67.75	70.52	79.19	83.80
13.16	21.90	28.17	32.92	39.69	46.17	50.41	55.78	59.14	63.30	65.90	74.00	78.30
11.92	19.83	25.51	29.81	35.94	41.80	45.65	50.51	53.55	57.32	59.67	67.00	70.90
11.26	18.74	24.10	28.17	33.96	39.51	43.14	47.73	50.61	54.16	56.39	63.32	67.00
10.99	18.29	23.53	27.50	33.15	38.56	42.11	46.59	49.40	52.87	55.04	61.81	65.40
10.76	17.90	23.03	26.91	32.44	37.74	41.21	45.60	48.34	51.74	53.86	60.48	64.00

Rainfall intensity (mm/hr)												
5 min	**10 min**	**15 min**	**20 min**	**30 min**	**45 min**	**60 min**	**90 min**	**120 min**	**180 min**	**240 min**	**720 min**	**1440 min**
9.85	16.39	21.08	24.64	29.70	34.55	37.73	41.75	44.26	47.37	49.32	55.38	58.60
9.75	16.22	20.87	24.38	29.40	34.20	37.34	41.32	43.81	46.89	48.81	54.81	58.00
9.58	15.94	20.51	23.96	28.89	33.61	36.70	40.61	43.05	46.08	47.97	53.87	57.00
9.55	15.89	20.44	23.88	28.79	33.49	36.57	40.47	42.90	45.92	47.80	53.68	56.80
9.38	15.61	20.08	23.46	28.28	32.90	35.93	39.75	42.15	45.11	46.96	52.73	55.80
9.31	15.49	19.93	23.29	28.08	32.67	35.67	39.47	41.85	44.79	46.62	52.36	55.40
9.28	15.44	19.86	23.21	27.98	32.55	35.54	39.33	41.70	44.63	46.46	52.17	55.20
9.19	15.30	19.68	23.00	27.73	32.25	35.22	38.97	41.32	44.22	46.03	51.69	54.70
8.99	14.96	19.25	22.49	27.12	31.55	34.45	38.11	40.41	43.25	45.02	50.56	53.50
8.96	14.91	19.18	22.41	27.02	31.43	34.32	37.97	40.26	43.09	44.86	50.37	53.30
8.64	14.38	18.49	21.61	26.05	30.31	33.09	36.62	38.82	41.55	43.26	48.58	51.40
8.54	14.21	18.28	21.36	25.75	29.95	32.71	36.19	38.37	41.07	42.75	48.01	50.80
8.42	14.01	18.02	21.06	25.40	29.54	32.26	35.69	37.84	40.50	42.16	47.35	50.10
8.27	13.76	17.70	20.68	24.94	29.01	31.68	35.05	37.16	39.77	41.41	46.50	49.20
8.02	13.34	17.16	20.05	24.18	28.13	30.71	33.98	36.03	38.56	40.14	45.08	47.70
7.95	13.23	17.02	19.89	23.98	27.89	30.45	33.70	35.73	38.24	39.81	44.70	47.30
7.93	13.20	16.98	19.84	23.93	27.83	30.39	33.63	35.65	38.16	39.72	44.61	47.20
7.78	12.95	16.66	19.47	23.47	27.30	29.81	32.99	34.97	37.43	38.97	43.76	46.30
7.77	12.92	16.62	19.42	23.42	27.24	29.75	32.91	34.90	37.35	38.88	43.66	46.20
7.50	12.47	16.05	18.75	22.61	26.30	28.72	31.77	33.69	36.06	37.53	42.15	44.60
7.43	12.36	15.90	18.58	22.40	26.06	28.46	31.49	33.39	35.73	37.20	41.77	44.20
7.26	12.08	15.54	18.16	21.90	25.47	27.81	30.78	32.63	34.92	36.36	40.83	43.20
7.14	11.89	15.29	17.87	21.54	25.06	27.36	30.28	32.10	34.36	35.77	40.16	42.50
6.96	11.58	14.89	17.41	20.99	24.41	26.66	29.49	31.27	33.47	34.84	39.12	41.40
6.66	11.08	14.25	16.65	20.07	23.35	25.50	28.21	29.91	32.01	33.33	37.42	39.60
6.29	10.46	13.46	15.72	18.96	22.05	24.08	26.64	28.25	30.24	31.48	35.34	37.40
6.24	10.38	13.35	15.60	18.81	21.88	23.89	26.43	28.02	29.99	31.22	35.06	37.10
6.12	10.18	13.10	15.30	18.45	21.46	23.44	25.93	27.49	29.43	30.63	34.40	36.40
6.10	10.15	13.06	15.26	18.40	21.40	23.37	25.86	27.42	29.35	30.55	34.30	36.30
5.97	9.93	12.77	14.92	17.99	20.93	22.86	25.29	26.81	28.70	29.88	33.55	35.50
5.56	9.26	11.91	13.92	16.78	19.52	21.31	23.58	25.00	26.76	27.86	31.28	33.10
4.96	8.25	10.61	12.40	14.95	17.39	18.99	21.02	22.28	23.85	24.83	27.88	29.50

Appendix II: Rainfall Intensity of Different Distribution Method

Table A2. *Rainfall intensity computed from GEV 1 distribution.*

Return Period	**2**	**5**	**10**	**25**	**50**	**100**
Duration (min.)	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**
5	99.57	123.13	138.72	158.43	173.05	187.56
10	82.84	102.44	115.42	131.81	143.98	156.05
15	71.04	87.85	98.98	113.04	123.47	133.83
20	62.27	77.00	86.75	99.07	108.21	117.29
30	50.05	61.89	69.73	79.63	86.98	94.27
45	38.81	47.99	54.07	61.75	67.45	73.11
60	31.79	39.31	44.28	50.58	55.24	59.88
90	23.45	28.99	32.67	37.31	40.75	44.17
120	18.64	23.06	25.98	29.67	32.40	35.12
180	13.30	16.45	18.53	21.17	23.12	25.06
240	10.39	12.84	14.47	16.53	18.05	19.57
720	3.89	4.81	5.42	6.19	6.76	7.32
1440	2.06	2.54	2.87	3.27	3.57	3.87

Table A3. *Rainfall intensity computed from log-normal distribution.*

Return Period	**2**	**5**	**10**	**25**	**50**	**100**
Duration (min.)	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**
5	100.82	124.31	138.71	155.90	168.11	179.92
10	83.88	103.43	115.41	129.71	139.87	149.69
15	71.94	88.70	98.97	111.24	119.95	128.37
20	63.05	77.74	86.74	97.49	105.13	112.51
30	50.68	62.48	69.72	78.36	84.50	90.43
45	39.30	48.46	54.07	60.77	65.53	70.13
60	32.19	39.68	44.28	49.77	53.67	57.44
90	23.74	29.27	32.66	36.71	39.59	42.37
120	18.88	23.28	25.97	29.19	31.48	33.69
180	13.47	16.61	18.53	20.83	22.46	24.04
240	10.52	12.97	14.47	16.26	17.54	18.77
720	3.94	4.85	5.42	6.09	6.56	7.03
1440	2.08	2.57	2.87	3.22	3.47	3.72

Table A4. *Rainfall intensity computed from Pearson III distribution.*

Return Period	**2**	**5**	**10**	**25**	**50**	**100**
Duration (min.)	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**
5	100.35	124.59	139.50	157.21	169.69	181.64
10	83.49	103.66	116.06	130.80	141.18	151.13
15	71.60	88.90	99.54	112.17	121.08	129.60
20	62.75	77.91	87.24	98.31	106.12	113.59
30	50.44	62.62	70.12	79.02	85.29	91.30
45	39.12	48.56	54.38	61.28	66.14	70.80
60	32.04	39.77	44.53	50.19	54.17	57.99
90	23.63	29.34	32.85	37.02	39.96	42.77
120	18.79	23.33	26.12	29.44	31.78	34.01
180	13.41	16.65	18.64	21.00	22.67	24.27
240	10.47	13.00	14.55	16.40	17.70	18.95
720	3.92	4.86	5.45	6.14	6.63	7.09
1440	2.07	2.57	2.88	3.25	3.51	3.75

Table A5. *Rainfall intensity computed from log Pearson III distribution.*

Return Period	**2**	**5**	**10**	**25**	**50**	**100**
Duration (min.)	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**	**Rainfall Intensity (mm/hr)**
5	100.10	124.02	139.29	158.16	171.98	185.65
10	83.29	103.18	115.89	131.59	143.08	154.46
15	71.43	88.49	99.39	112.85	122.71	132.47
20	62.60	77.55	87.11	98.90	107.54	116.10
30	50.32	62.33	70.01	79.50	86.44	93.32
45	39.02	48.34	54.30	61.65	67.03	72.37
60	31.96	39.59	44.47	50.49	54.90	59.27
90	23.57	29.20	32.80	37.24	40.50	43.72
120	18.74	23.22	26.08	29.62	32.20	34.76
180	13.37	16.57	18.61	21.13	22.98	24.80
240	10.44	12.94	14.53	16.50	17.94	19.37
720	3.91	4.84	5.44	6.18	6.72	7.25
1440	2.07	2.56	2.88	3.27	3.55	3.84

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