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Flood Frequency Analysis Along Bagmati River Basin in Khagaria District, Bihar Using Gumbel's Method and Log Pearson Type lll Distribution

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ABSTRACT

Flood frequency analysis is an essential hydrological method for determining the size and recurrence intervals of flood events, especially in areas vulnerable to flooding. One such area where frequent flooding has a major effect on the environment, the economy, and local inhabitants is Khagaria in Bihar, India. This study uses the Log-Pearson Type III Distribution and the Gumbel Extreme Value Distribution to analyze historical discharge data spanning 40 years (1985–2024) from the Bagmati River Basin in Khagaria District. Important statistical measures, including the mean, standard deviation, and skewness, are used to predict catastrophic hydrological events and to assess flood magnitudes for various return periods. The findings show that while both methods effectively model catastrophic floods, the Log-Pearson Type III Distribution more accurately captures variability at longer return periods. The results indicate the highest recorded flood discharge of 30734.001 m^3/s in 2023 and the lowest discharge of 884.77 m^3/s in 2011. The analysis calculates the anticipated inundation for the return periods of 2, 10, 25, 50, 100, and 1000 years. The expected flood for the two-year return period is 2833.731 cumecs according to the Gumbel distribution, while the Log-Pearson III distribution predicts a flood of 1169.9 cumecs. It has been noted that Gumbel estimated higher values for all of the aforementioned return periods, except for 1000 years, where Log Pearson III predicted significantly higher values. The 2-year flood event has a 50% possibility of occurrence in any year with average impacts, while severe flooding events are predicted at longer return periods, with discharge values exceeding the river's carrying capacity. The results highlight the urgent need for proactive floodplain management, infrastructure planning, and risk reduction strategies by illustrating the region's increasing flood frequency and severity. This study provides valuable information for sustainable flood management, hydrological modelling, and infrastructure design in the area under study.

Keywords: Flood Frequency Analysis; Gumbel's Method; Log Pearson Type lll Distribution; Peak Discharge; River Bagmati.

Análisis de Frecuencia de Inundaciones a lo largo de la Cuenca del Río Bagmati en el Distrito de Khagaria, Bihar, utilizando el Método de Gumbel y la Distribución Log Pearson Tipo III

RESUMEN

El análisis de frecuencia de inundaciones es un método hidrológico fundamental para determinar el tamaño y los intervalos de recurrencia de los eventos de inundación, especialmente en áreas vulnerables a estos fenómenos. Una de esas áreas donde las inundaciones frecuentes tienen un impacto considerable en el medio ambiente, la economía y los habitantes locales es Khagaria, en Bihar, India. Este estudio utiliza la Distribución Log Pearson Tipo III y la Distribución de Valores Extremos de Gumbel para analizar datos históricos de caudales durante un periodo de 40 años (1985–2024) de la cuenca del río Bagmati en el distrito de Khagaria. Se emplean importantes medidas estadísticas, como la media, la desviación estándar y la asimetría, para predecir eventos hidrológicos catastróficos y evaluar las magnitudes de las inundaciones para diferentes periodos de retorno. Los resultados muestran que, si bien ambos métodos modelan eficazmente las inundaciones catastróficas, la Distribución Log Pearson Tipo III capta con mayor precisión la variabilidad en periodos de retorno más largos. Los resultados indican el mayor caudal registrado de inundación de 30,734.001 m^3/s en 2023 y el caudal más bajo de 884.77 m^3/s en 2011. El análisis calcula la inundación anticipada para periodos de retorno de 2, 10, 25, 50, 100 y 1000 años. La inundación esperada para el periodo de retorno de dos años es de 2,833.731 m^3/s según la distribución de Gumbel, mientras que la distribución Log Pearson III predice una inundación de 1,169.9 m^3/s. Se ha observado que Gumbel estimó valores más altos para todos los periodos de retorno mencionados, excepto para el de 1000 años, donde Log Pearson III predijo valores significativamente más altos. El evento de inundación de 2 años tiene una probabilidad del 50% de ocurrir en cualquier año con impactos promedio, mientras que se prevén eventos de inundación severos en periodos de retorno más largos, con valores de descarga que superan la capacidad del río. Los resultados subrayan la necesidad urgente de una gestión proactiva de las llanuras de inundación, la planificación de infraestructuras y la implementación de estrategias de reducción de riesgos, ilustrando el aumento de la frecuencia y gravedad de las inundaciones en la región. Este estudio proporciona información valiosa para la gestión sostenible de inundaciones, la modelización hidrológica y el diseño de infraestructuras en el área de estudio.

Palabras clave: Análisis de Frecuencia de Inundaciones; Método de Gumbel; Distribución Log Pearson Tipo III; Caudal Máximo; Río Bagmati

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1. Introduction

Flooding happens when a river's water level suddenly rises as a result of heavy rainfall or when a large amount of water is released from up catchment areas that exceeds the river's carrying capacity. This causes the water to overflow and flood the nearby areas by breaching an embankment or road (Chakravartty, 2018). Floods are known to be extremely devastating on a global scale, and engineers utilize meteorological and hydrological data, including flow rate and rainfall, to build hydraulic structures that reduce floods (Ibrahim and Isiguzo, 2009). Flood frequency analysis is the process of estimating the frequency of a given event and the stream flow data that is crucial before estimation is done in order to determine the probability distribution of floods (Ahmad et al., 2011). Thus, flood frequency analysis fits a probability model to a sample of a region's catchment's annual flood maxima across time (Martin, 2019). After computing river location statistics data, a frequency distribution may be produced (Khan et al., 2015). This dimensionless technique links extreme occurrence magnitude to frequency (return time) using probability distributions generated from historical peak discharge data at numerous gauge stations along a river (Bhat et al., 2024). Accurate flood frequency forecasts are needed to protect the public, reduce flood costs for public and private organizations, design and site hydraulic infrastructure, and assess flood plain development dangers. (Tumbare, 2000).

Forecasts of hydrologic events, such as rainfall depth, flow depth, discharge, and gauge level, must be incorporated into flood control planning and management for water resources projects. (Real-Time Flood Forecasting System, 2019; FLASH Project, 2017). Surface water hydrology studies the movement of water along watersheds due to precipitation (Arora, 2004). Recurrence intervals, on the other hand, are important for flood mitigation, land use regulation, disaster preparedness, and insurance since they indicate the time frame during which a flood event or magnitude will occur. (USGS, 1982). Road and bridge construction, floodplain identification and management, and water-use and water-control projects all depend on the ability to predict the size and frequency of flood flows. (Stedinger & colleagues, 2008).

A river's discharge is minimal in its high reaches and grows as the channel size decreases in its lower reaches (Morris, 2018). Direct measurement of discharge is challenging, and it is correlated with stage (water level), which is recorded in meters at a specific gauge station (Charlton, 2008). It was and still is one of the most often used statistical distributions in the frequency study of extreme events in hydrology, mostly because of its straightforward quantile function (inverse function) construction and parameters (Chow et al., 1988).

The Log-Pearson is a statistical approach for fitting frequency distribution values to predict floods at several river sites after obtaining river site statistics (Samantaray et al., 2020). The Federal Agencies in the United States typically employ this method for flood frequency analysis (U.S. Army Corps of Engineers, 2016; Sathe et al. 2012). Since the United States Water Resources Council (1967, 1982) recommended using the log-Pearson type III distribution as the foundational approach, it has become one of the most often utilized distributions for hydrologic frequency assessments. Ouarda and Ashkar (1998) assessed the impact of trimming on log-Pearson type III distribution flood quantile estimations using simulation. They studied how different ratios of symmetric trimming affected quantiles, distribution parameters, and moment estimation. For a number of return times and three fitting techniques, the impact of sample size and parent distribution characteristics on the estimation performance was also examined. Karl Pearson created this distribution, which is frequently employed in hydrologic research and was made famous by the US Water Resources Council (Sinam, 2019). Based on the historical data currently available, this distribution displays the anticipated values of discharges to be expected in the river at different recurrence intervals (Stedinger et al., 1993). After calculating the statistical data for the river location, a frequency distribution may be produced. It is possible to determine the probability of floods of different magnitude from the curve drawn (Izinyon et al., 2011). This method is taken into consideration when developing buildings in or close to rivers that might be impacted by flooding, this is useful (U.S. Water Resources Council, 1981) and when building structures to withstand the biggest anticipated event, it is also beneficial (Chow et al., 1988). Because of this, it is common practice to use the instantaneous peak discharge data to do the flood frequency analysis (Haan, 1979). However, the maximum values for mean daily discharge data may be used to create the Log-Pearson Type III distribution. (Patel, 2020; McCuen, 2005).

This study's primary goal is to use the Bagmati river's discharge data to do a flood frequency analysis of the Bagmati river basin in Khagaria District, Bihar using Gumbel's Extreme Value Distribution and log-Pearson type III distribution. These methods reduce significant bias and error in flood estimation design, particularly at large return periods, leading to potential overestimation or underestimation that could result in serious practical consequences. Furthermore, probabilistic models are the most suitable frameworks for delineating the joint distribution of flood volumes, peaks, and durations (Sahoo and Ghose, 2021). Based on the observed data, the research's outcome will offer detailed information on potential flow discharge that may be anticipated in the watershed during different return times. When developing hydraulic structures to stop anticipated flood occurrences, the results might be helpful one.

Anghel et al. (2025) seeks to provide a complete distribution guide for Flood Frequency Analysis. Five parameter estimation approaches are presented, including exact and newly derived approximate connections for distribution parameters and frequency factors. The analysis uses data from four rivers with different morphometrics and record lengths. The Pearson III distribution, when used with the L-moments method, provides the most accurate quantile estimates with the lowest biases (31% for the Nicolina River and 5% for the Siret and Ialomita Rivers) and the highest confidence in predicting rare events. These findings suggest using L-moments for flood frequency analysis to improve extreme flow forecasts.

2. Study Area

Khagaria and Gogari are the two subdivisions that make up Khagaria district. The district consists of the following seven blocks: Alauli, Beldaur, Chautham, Gogari, Khagaria, Parbatta, and Mansi and its total area is 1,485 square kilometres. The Ganga, Burhi Gandak, Bagmati, Kamla, and Ghaghri (the mainstream of the Koshi River) are the district's major rivers (Ramasastri, 2015). The Bagmati river is a significant watercourse in Khagaria district, Bihar (Kumar, 2020). Originating from the Shivpuri range in Nepal, it traverses several districts in Bihar, including Khagaria. Within Khagaria, the Bagmati flows in a generally easterly direction, eventually merging with the Kamla River near Chautham (Singh et al., 2019). The combined stream continues its course, contributing to the region's intricate river system. Bagmati, along with other rivers in the region, significantly influences the district's hydrology (Bhattacharya et al., 2022). During the monsoon season, these rivers are prone to flooding, impacting local agriculture and settlements (Jha et al., 2023).

Figure 1 represents is the study area map of Bagmati basin in Khagaria which is created using SRTM DEM data in Arc-GIS software. The area has elevation ranging between 0-91 meters.

The flood history of Khagaria has been devastating, with around 74% of the district's total area being vulnerable to floods (Flood Hazard Atlas Bihar, 2020). Notable floods occurred in 1954, 1957, 1974, 1987, 2004, 2007, and 2017, severely impacting people's lives, properties, and the district's agriculture sector. Floodwaters have often submerged agricultural land, causing widespread damage to standing crops. Every year, approximately one lakh hectares of standing crops are destroyed by floods, leading to significant losses, including loss of human lives (Kumar, 2019). The flood frequency analysis would be useful in flood forecasting and management studies in Khagaria district along Bagmati river basin.

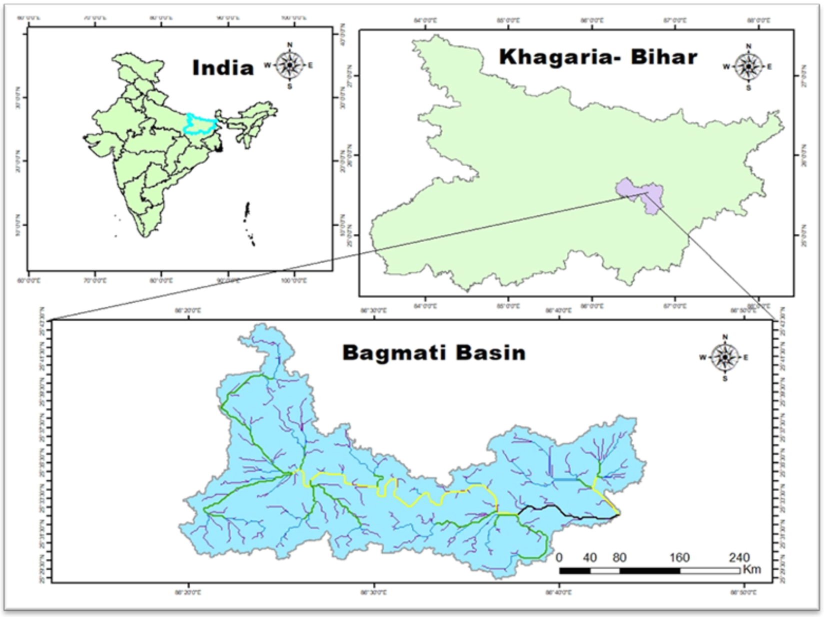

Figure 1. Study Area

3. Material

Table 1 contains all the data that has been used in this study. The river discharge data from 2008 to 2024 of Bagmati basin in Khagaria district has been considered for finding the flood frequency. The discharge data has been collected from Flood Management Improvement Support Centre, Water Resource Department, Government of Bihar. The origin of the Flood Management Information System, Bihar can be traced back to a brainstorming session held on January 18, 2006, where the World Bank and the Government of Bihar decided on an action plan and cooperation matrix for the water sector over three-time horizons. By introducing the widespread use of contemporary information technology and creating and executing a comprehensive flood control Information System (FMIS) in priority regions, it was suggested that the State of Bihar's technical and institutional capability for flood control be improved in the near future. Shuttle Radar Topography Mission (SRTM) data with a 30-meter resolution is used to construct the research area map. NASA and the U.S. National Geospatial-Intelligence Agency are partners in the global SRTM project. It collects elevation data on a virtually global scale to build the most complete high-resolution digital topographic record of Earth. The 30-meter resolution SRTM data were transformed into point data using ArcGIS 10.8.2 software. The USGS website provided the SRTM data for free download.

Table 1. Data Types and Sources

Sno.	Data Types	Sources
1.	Bagmati River Discharge (m^3/s) Data for 40 Years, (1985-2024)	Flood Management Improvement Support Centre, Water Resource Department, Government of Bihar
2.	SRTM DEM (30m resolution)	USGS Earth Explorer https://earthexplorer.usgs.gov/

4. Methods

Flood frequency analysis is a statistical method employed to forecast and quantify anticipated river flow (Shahid et al., 2023) and may be conducted at any river gauge location. Effective flood frequency analysis requires the elimination of outliers to improve result precision (Griffis et al., 2004). The sample time series data is used to calculate several statistical parameters (mean, standard deviation, and skewness) for flood frequency analysis. Long-term series data reduces sampling error and yields precise and trustworthy predictions. Roy et al. (2024). Figure 2 shows the step-wise methods that has been followed in this research.

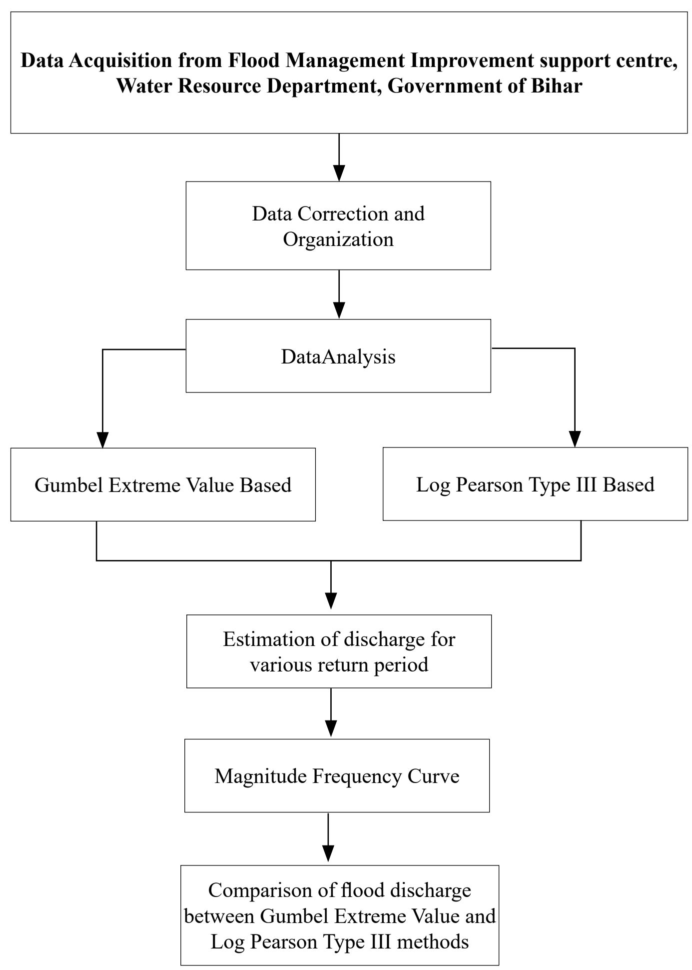

Figure 2. Flowchart of Methodology

Gumbel suggested using extreme value distribution to assess flood frequency in 1941 (Krishan and Roy, 2016; Bhagat, 2017). Gumbel characterised a flood as the maximum of the 365 daily flow measurements, and the yearly compilation of flood flows is a succession of these maximum flow values. This theory of extreme occurrences posits the likelihood of an event occurring that is equal to or above a value of x_0 (Sonowal & Thakuriah, 2019). Frequency distribution curves are created by measuring the mean, standard deviation, and skewness of the given peak flow data using river water discharge data. For flood frequency analysis, Gumbel, Log-normal, Normal, Log-Pearson, Pearson, Weibull, and exponential techniques are essential statistical measures (Al-anazi a et al., 2013). It is a well-known statistical distribution that is a particular instance of the Generalised Extreme Value distribution (Gumbel, 1958). However, in this study, the annual peak discharge data of the Bagmati river basin in Khagaria district from 1985–2024 for 40 years, as 15 years or above data is considered valid for flood frequency analysis, which were gathered from the Flood Management Improvement Support Centre, Water Resources Department, Government of Bihar—were analysed using this distribution. The sample time series data is used to calculate a number of statistical metrics for Flood frequency analysis including mean, standard deviation, and skewness. The observed Bagmati river water discharge data was used to predict the flood discharge for the return periods of 2 years, 5 years, 10 years, 25 years, 50 years yrs, 100 years, and 200 years. The plotting-position formula is shown in the Equation 1:

$$P = \frac{m}{N+1} \tag{1}$$

where;

P is the plot of position/exceedance probability.

N is the event/record's number of years.

m = the event's order number

Consequently, the return time, also known as the recurrence interval, is determined using Equation 2 and is the inverse of the chance of exceedance:

$$T = \frac{1}{p} \tag{2}$$

where, P is the Plotting position as calculated in equation (1)
Y_T is the reduced variate which has been calculated in equation (3):

$$Y_T = -\ln.\ln\frac{T}{T-1} \tag{3}$$

where, T is the return period or recurrence interval which is calculated in equation (2). Mean of the data series has been calculated as in equation (4):

$$\bar{x} = \frac{\sum x}{n} \tag{4}$$

where, n is the total n°. Of sample and $\sum x$ is the sum total discharge.
σ_n is the standard deviation which is calculated as in equation (5):

$$\sigma_n = \sqrt{\frac{n}{n-1}}\,(\bar{x}^{2} - \bar{x}^{2}) \tag{5}$$

where n is the n°. Of sample and $\bar{x}$ = Mean
K_T is the Frequency Factor, which is calculated as in equation (6):

$$K_T = \frac{Y_{T-Y_n}}{\sigma_n} \tag{6}$$

where Y_T is the reduced variate which has been calculated in equation (3). Using Gumbel's Extreme Value Distribution table, the parameters Yn and Sn are established according to the sample size.

Equation 7 provides the equation for Gumbel's Extreme Value Distribution and the process with a return period of T.

$$X_T = \bar{x} + K_{T.}\sigma_n \tag{7}$$

where, $\bar{x}$ is the mean of the series, K_T is the Frequency Factor, which is calculated as in equation (6) and σ_n is the standard deviation. For the flood frequency study using Gumbel's distribution, the maximum discharge data of Bagmati river from 1985 to 2024 (40 years of flood data) in Khagaria were taken into consideration. The following procedures can be used to estimate the design flood for any return period:

- Step I: From 2008 to 2024, annual peak flood data was compiled.
- Step II: The mean and standard deviation is calculated from the maximum discharge data for 40 years.
- Step III: The values Yn and Sn are determined to be 0.5181 and 1.0411, respectively, from the Gumbel's Extreme Value distribution that has been calculated in the calculation table.
- Step IV: Equation (3) is used to calculate the reduced variate Y_T from the specified return period T.
- Step V: Using Equation (6), the flood frequency factor K_T is calculated for Sn and Yn.
- Step VI: The flood's magnitude is calculated using Equation (7).

It is critical to confirm if the observed flood data collected in the watershed follows Gumbel's distribution. This is accomplished by assigning the return time for each flood and sorting the observed data in descending order (highest coming first); Equation (3) is then used to calculate the reduced variate corresponding to each flood. On regular graph paper, a plot of the flood's size and decreased variate is created and if the eye fit to the logarithmic plot, it shows a straight line, then it is reasonable to assume that this represents the Gumbel's distribution and it closely resembles the observed flood data (Temtime, 2024).

Another distribution is Log-Pearson Type III distribution, that has been widely employed in several studies for flood frequency analysis in India because it is very effective at recording the fluctuation of flood peaks. (Mangukiya et al., 2022; Zhang et al., 2021). It is one such popular distribution, which first converts the variable into base-10 logarithmic form before analyzing the converted data (Subramanya, K., 2013; Pearson, K. 1916; IACWD, 1982). Peak discharge for a given event at a certain return time is estimated using the mean logarithm (X), the standard deviation of the logarithm (σlog x), and the skewness co-efficient (CS) (Gogoi et al., 2023). The following formula has been used to determine the river Bagmati's return period using this frequency distribution technique:

If X is the variant of an arbitrary hydrologic sequence, followed by the Z variants, which is calculated using equation (8) where,

$$Z = \log x \tag{8}$$

are calculated first, then for this Z series, for any recurrence interval T gives Z_T as calculated in equation (9):

$$Z_T = Z + K_Z.\,\sigma_z \tag{9}$$

where σ_z is the series' standard deviation, Z is the log of the X series as determined by equation (10), and Kz is a frequency factor that depends on the recurrence interval T and the coefficient of skew Cs. The Log Pearson Type III distribution is the logarithmic variant of the Pearson Type III distribution, characterized by three parameters: skewness, location, and scale. The distribution relies on logarithmic transformations of the data and is frequently employed due to its capacity to effectively depict a broad spectrum of flood frequency distributions (National Institute of Hydrology, 2024).

5. Result and Discussion:

Gumbel's Distribution Method:

Gumbel's approach was used to analyse the flood frequency of the Bagmati river, and the findings are displayed in Table 2. According to the figures above, the lowest flood flow of 884.77 m^3/s was observed in 2011, while the highest flow of 30734.001 m^3/s was recorded in 2023. The average instantaneous flood flow over the last 40 years is 3638.3673 m^3/s. The floods with varying recurrence intervals were also calculated using Gumbel's distribution analysis; the outcomes are displayed in Table 3.

Table 2. Computation Table for Gumbel Method

Year	X (Maximum Discharge) (m^3/s)	Ranked X	Rank	P=m\n+1	Return Period (T)	YT	KT
1985	1058.29	30734.001	1	0.024	41	3.701	2.767
1986	1976.21	28974.977	2	0.049	20.5	2.996	2.148
1987	1148.22	27150.267	3	0.073	13.667	2.577	1.782
1988	1819.26	2893.55	4	0.098	10.25	2.276	1.518
1989	2573.39	2617.61	5	0.122	8.2	2.040	1.311
1990	1348.12	2573.39	6	0.146	6.833	1.844	1.139
1991	1170.46	2268.48	7	0.171	5.857	1.676	0.992
1992	2240.18	2240.18	8	0.195	5.125	1.528	0.862
1993	890	2173	9	0.220	4.556	1.395	0.746
1994	1084.66	2171.33	10	0.244	4.1	1.274	0.640
1995	2021.24	2021.24	11	0.268	3.727	1.164	0.543
1996	1584.66	1992.8	12	0.293	3.417	1.061	0.453
1997	1496.21	1976.21	13	0.317	3.154	0.964	0.368
1998	1048.5	1965.33	14	0.341	2.929	0.873	0.289
1999	1134.31	1938.24	15	0.366	2.733	0.786	0.213
2000	1240.28	1819.26	16	0.390	2.563	0.704	0.140
2001	1550.11	1713.4	17	0.415	2.412	0.625	0.071
2002	1938.24	1666.98	18	0.439	2.278	0.548	0.004
2003	1128.7	1584.66	19	0.463	2.158	0.474	-0.061
2004	1329.74	1550.11	20	0.488	2.05	0.402	-0.124
2005	2893.55	1496.21	21	0.512	1.952	0.332	-0.186
2006	1965.33	1469.35	22	0.537	1.864	0.262	-0.246
2007	1237.65	1348.12	23	0.561	1.783	0.195	-0.306
2008	1469.35	1341.05	24	0.585	1.708	0.127	-0.365
2009	1713.4	1329.74	25	0.610	1.64	0.061	-0.423
2010	1341.05	1314.22	26	0.634	1.577	-0.006	-0.481
2011	884.77	1240.28	27	0.659	1.519	-0.072	-0.539
2012	1102.97	1237.65	28	0.683	1.464	-0.139	-0.598
2013	1314.22	1170.46	29	0.707	1.414	-0.206	-0.657
2014	936.72	1148.22	30	0.732	1.367	-0.274	-0.717
2015	1666.98	1145.46	31	0.756	1.323	-0.344	-0.778
2016	2268.48	1134.31	32	0.780	1.281	-0.416	-0.841
2017	1145.46	1128.7	33	0.805	1.242	-0.491	-0.907
2018	2617.61	1102.97	34	0.829	1.206	-0.570	-0.975
2019	2173	1084.66	35	0.854	1.171	-0.653	-1.049
2020	1992.8	1058.29	36	0.878	1.139	-0.744	-1.128
2021	2171.33	1048.5	37	0.902	1.108	-0.845	-1.216
2022	28974.977	936.72	38	0.927	1.079	-0.961	-1.319
2023	30734.001	890	39	0.951	1.051	-1.105	-1.445
2024	27150.267	884.77	40	0.976	1.025	-1.312	-1.626

N=40 Mean = 3638.367 Standard Deviation (σ_n) = 10767.198. Skew= 3.343
Yn (Reduced mean which is a function of sample size 'N') = 0.5436 Sn (Reduced standard deviation which is a function of sample size 'N') = 1.1413

Table 3 illustrates how the frequency factor (KT) and decreased variate (YT) rise in tandem with the time frame for returns (T), indicating the growing extreme and rarity of flood episodes. Longer return periods are linked to more intense floods, as evidenced by the fact that the anticipated flood (XT) rises with the return duration. For instance, the estimated magnitude of a flood with a 2-year return time is 2833.731 (units), but a flood with a 200-year return period is 38961.197 (units), which is a substantially bigger size.

The values of the reduced mean (Yn) and reduced standard deviation (Sn), which are dependent on sample size "N," are 0.5436 and 1.1413, respectively. Figure 3 shows a graphical representation of the expected flood discharges of the study area for return periods of 2, 5, 10, 25, 50, 100, and 200 years. These discharges were estimated to be 2833.731 m^3/s, 11140.764 m^3/s, 16640.742 m^3/s, 23589.979 m^3/s, 28745.320 m^3/s, 33862.594 m^3/s, and 38961.97 m^3/s.

Table 3. Computation Expected Flood using Gumbel's Distribution Method

Return Period (T)	Reduced Variate (YT)	Frequency Factor (KT)	Expected Flood (XT)
2	0.367	-0.110	2833.731
5	1.500	1.024	11140.764
10	2.250	1.774	16640.742
25	3.199	2.722	23589.979
50	3.902	3.426	28745.320
100	4.600	4.124	33862.594
200	5.296	4.820	38961.197

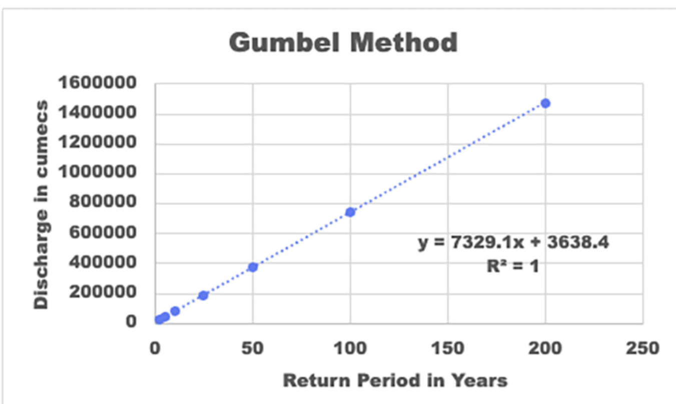

Figure 3. Flood frequency analysis using Gumbel's distribution

There is a pattern in the link between flood projections and their return periods; a Pearson correlation value (R^2) of 1 indicates a perfect positive association between these two variables. This indicates that their correlation with return periods accounts for about 100% of the variance in projected flood levels. As the return period gets longer, we typically see higher predicted flood levels. The statistical evidence is quite compelling, with a p-value of 0.01. To put this in perspective, this p-value is well below the commonly accepted threshold of 0.05, giving us strong confidence that this relationship is real and not just a coincidence. What makes this particularly meaningful for practical applications is how consistently these two factors move together. When we observe longer return periods, we can reliably anticipate higher flood levels. The strength of this relationship suggests that communities and planners can use return period data as a reliable indicator when preparing for potential flood events. It's like having a well-calibrated warning system - the longer the return period, the more seriously we should take the potential for significant flooding. This analysis gives us a clearer picture of how flood patterns behave over time, this is essential for creating plans for managing floods and safeguarding places that are susceptible.

Looking at our scatter plot (figure. 3), we can see how floods behave over time. Imagine a timeline of flood events - some happen frequently, while others are rare but more severe. This is exactly what our data reveals through the relationship between return periods and expected flood levels. As we look at longer return periods (think of these as the waiting time between major flood events), we see a natural increase in the expected flood intensity. This makes intuitive sense - the rarer an event is, the more extreme it tends to be. When we view this relationship on logarithmic scales, we notice something intriguing, the relationship follows what appears to be a power-law pattern, though it's gentler than what we might see in other flood-related measurements like discharge rates. Engineers and city planners can use this information like a roadmap. For instance, when designing a bridge or a flood barrier, they can look at this relationship and say, "We want this structure to withstand a flood that might occur once every 100 years." This kind of informed decision-making helps create safer, more resilient communities. The beauty of this analysis lies in its practical applications - it transforms complex data into actionable insights that help protect people and property from flood risks. It gives us a clearer picture of what to expect and how to prepare for different levels of flooding events.

Log-Pearson Type III distribution:

Table 4 displays the findings of the flood Frequency Analysis of the Bagmati river basin, which was conducted using the Log-Pearson Type III distribution technique. With mean values of 3.247, standard deviation of 0.3682, and coefficient of skewness of 1.8 at the Badlaghat gauging station, the statistical characteristics of this distribution with regard to its various parameters are described in Table 4. The figures above show that the highest flood flow of 30734.001 m^3/s was recorded in 2023, while the lowest flood flow of 884.77 m^3/s was recorded in 2011. It was also used to compute the floods with different recurrence intervals, and the results are shown in Table 5 as a scatter plot.

Table 5 illustrates that longer return times are associated with greater discharge values, indicating that the severity of severe occurrences increases with time. Skewness rises with return duration, indicating that longer return periods increase the likelihood of extremely high discharge values (such as floods). With longer return times, the frequency factor (K) rises, indicating a larger departure from the average discharge value over time. As predicted in flood studies, the discharge values (XT) for each return period are significantly greater for bigger return periods; fewer frequent occurrences (e.g., a flood that occurs once per 100 or 200 years) tend to have substantially higher discharge values. A graphical representation of the study area's expected flood discharges for return periods of two, five, ten, twenty-five, fifty, one hundred, and two hundred years is provided in Figure 4. The estimated flood discharges were 1169.9 m^3/s, 3038.6 m^3/s, 5389.3 m^3/s, 11335.0 m^3/s, 19729.4 m^3/s, 34228.3 m^3/s, and 59290 m^3/s.

With a Pearson correlation value (R^2) of 0.9918, the research demonstrates a strong positive link between the Return Period (T) and Expected Discharge. The incredibly small p-value of 0.002 suggests a virtually perfect linear correlation, which is statistically significant. The data shows that the predicted discharge increases approximately linearly with the length of the return time. The frequency and severity of floods in the area are shown visually in Tables 3 and 5 and Figures 3 and 4, which use Gumbel's and Log-Pearson Type III distributions.

The rising trend in peak discharges during extended return periods highlights the imperative for effective flood management techniques. The data underscores the risk of significant flooding occurrences, highlighting the necessity for infrastructural resilience and proactive planning in flood-prone areas such as the LBDR basin (Handique et al., 2024). As the return period increases, the projected discharge also rises, indicating that higher discharge levels are associated with more severe and less frequent flood events. When plotted on a logarithmic scale, the relationship between discharge and return period appears almost linear, suggesting an exponential or power-law connection. This trend is a common observation in hydrology, where rare events (with longer return periods) are linked to significantly higher flows. These extreme flows are critical considerations when designing flood defenses and dams. While the statistical values for each distribution are clearly outlined in the provided tables for both stations, the return period parameters for the Log Pearson Type III distribution show a distinct relationship when compared to those derived from Gumbel's distribution for the same gauging stations.

Table 4. Computation Table for Log-Pearson Type III distribution

Year	X (Maximum Discharge) (m^3/s)	Z= log (X)	(Z- z̄)	(Z- z̄)2	(Z- z̄)3
1985	1058.29	3.025	3.025	9.148	27.670
1986	1976.21	3.296	3.296	10.863	35.801
1987	1148.22	3.060	3.060	9.364	28.653
1988	1819.26	3.260	3.260	10.627	34.643
1989	2573.39	3.411	3.411	11.632	39.669
1990	1348.12	3.130	3.130	9.795	30.656
1991	1170.46	3.068	3.068	9.415	28.888
1992	2240.18	3.350	3.350	11.224	37.605
1993	890	2.949	2.949	8.699	25.656
1994	1084.66	3.035	3.035	9.213	27.964
1995	2021.24	3.306	3.306	10.927	36.121
1996	1584.66	3.200	3.200	10.240	32.766
1997	1496.21	3.175	3.175	10.081	32.006
1998	1048.5	3.021	3.021	9.124	27.559
1999	1134.31	3.055	3.055	9.331	28.505
2000	1240.28	3.094	3.094	9.570	29.605
2001	1550.11	3.190	3.190	10.178	32.473
2002	1938.24	3.287	3.287	10.807	35.527
2003	1128.7	3.053	3.053	9.318	28.445
2004	1329.74	3.124	3.124	9.758	30.481
2005	2893.55	3.461	3.461	11.982	41.473
2006	1965.33	3.293	3.293	10.847	35.723
2007	1237.65	3.093	3.093	9.564	29.578
2008	1469.35	3.167	3.167	10.031	31.768
2009	1713.4	3.234	3.234	10.458	33.819
2010	1341.05	3.127	3.127	9.781	30.589
2011	884.77	2.947	2.947	8.684	25.590
2012	1102.97	3.043	3.043	9.257	28.166
2013	1314.22	3.119	3.119	9.726	30.332
2014	936.72	2.972	2.972	8.830	26.241
2015	1666.98	3.222	3.222	10.381	33.446
2016	2268.48	3.356	3.356	11.261	37.789
2017	1145.46	3.059	3.059	9.357	28.624
2018	2617.61	3.418	3.418	11.682	39.928
2019	2173	3.337	3.337	11.136	37.161
2020	1992.8	3.299	3.299	10.886	35.919
2021	2171.33	3.337	3.337	11.134	37.150
2022	28974.977	4.462	4.462	19.910	88.837
2023	30734.001	4.488	4.488	20.139	90.375
2024	27150.267	4.434	4.434	19.658	87.161

No. Of Sample (N) = 40   Mean (z̄) = 3.247   Standard Deviation (σ) = 0.3682   Co-efficient of skewness (Cs) = 1.8

Table 5. Computation of Expected Flood using Log-Pearson Type III distribution

Return Period (TR)	Probability Percent	Cs	Frequency factor (K)	σ	Kσ	XT= X̄ + Kσ	Antilog (Discharge m3 /s)
2	50		-0.282		-0.179	3.068	1169.9
5	20		0.643		0.236	3.483	3038.6
10	10	1.8	1.318	0.368	0.485	3.732	5389.3
25	4		2.193		0.807	4.054	11335.0
50	2		2.848		1.048	4.295	19729.4
100	1		3.499		1.287	4.534	34228.3
200	0.5		4.147		1.526	4.773	59290

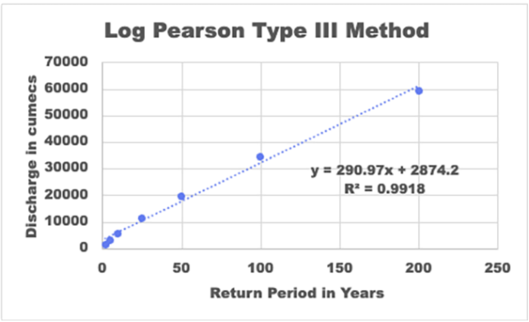

Figure 4. Flood frequency analysis using Log-Pearson Type III distribution

Comparing Gumbel's Method and Log Pearson Type lll Distribution

Both datasets cover the same return periods: 2, 5, 10, 25, 50, 100, and 200 years. This alignment allows for a straightforward comparison of expected flood levels and discharge values.

Trends and Growth Patterns:

- **Gumbel's Distribution:** The expected discharge values show a more gradual increase compared to the expected flood levels. While higher return periods still exhibit growth, the rate of increase is not as steep as observed in Table 3.
- **Log Pearson Type III Distribution:** As the return period extends, the expected flood levels rise significantly, following a trend that resembles exponential growth. This is particularly evident in higher return periods, such as 50 and 100, 200 years, where the increase is much more pronounced compared to shorter return periods

Dataset Fitting and Graphical Representation:

When plotting return periods against expected flood and discharge values:

- **Flood Values (Log Pearson Type III Distribution)**: These are likely to form a steeper curve, indicating an exponential or power-law relationship.
- **Discharge Values (Gumbel's Distribution):** These are expected to follow a less steep curve, potentially fitting a logarithmic or linear relationship. This suggests a more gradual increase in discharge over time.

Goodness of fit Analysis (GOF):

The application of GoF test is the most central step to find out the best-fit flood probability model at a gauging site in a basin. Rank 1 shows best fit while rank 2 shows non-significant level of test (Kumar et al., 2023). The table compares the efficacy of two flood-frequency distribution models: Gumbel and Log Pearson Type III. Three statistical tests—Kolmogorov–Smirnov (KS), Anderson–Darling (AD), and Chi-Squared—were employed using to assess the adequacy of each distribution in fitting the observed flood data. The analysis of the test is done using a software called EasyFit 5.6 Professional developed by MathWave Technologies. Reduced statistical values and improved rankings (1 = optimal fit) signify enhanced performance. The Log Pearson Type III approach exhibits lower KS (0.088) and AD (0.129) values, securing the top rank in both tests, indicating superior fit to the data in the distribution tails. The Gumbel technique exhibits marginally superior performance alone in the Chi-Squared test. In summary, Log Pearson Type III offers the most optimal match.

- **Flood Frequency Analysis:** The Log Pearson Type III distribution aligns well with typical flood frequency patterns, where extreme events become significantly more frequent as return periods increase.
- **Discharge Analysis:** Gumbel's distribution appears to better represent discharge trends, with its linear or logarithmic growth reflecting a more gradual increase over time.

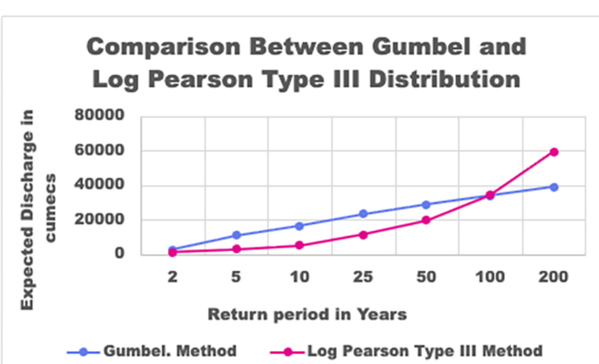

Figure 5. Comparison graph for Gumbel and Log Pearson Type III Distribution

Table 6. Goodness of Fit Test

Method	Gumbel Method		Log Pearson Type III Method	
	Statistics	Rank	Statistics	Rank
Kolmogorov Smirnov	0.108	2	0.088	1
Anderson Darling	0.196	2	0.129	1
Chi-Squared	0.628	1	0.794	2

The peak flood for the return period of 2, 5, 10, 20, 50, 100, and 200 years is on the rise, as evidenced by the flood frequency analysis computed using Gumbel's distribution and Log Pearson Type III distribution. The Bagmati basin experiences flood events annually. The anticipated flood peak discharge and flood magnitude increase as the return period increases (10, 50, 100, 500, and 1000 years), suggesting that flood events are more severe. The flood event is exceedingly rare and severe, as evidenced by the highest flood peak discharge (59290 m^3/s) and flood magnitude (5.4567) occurring at a return period of 1000 years. The settlements along the Bagmati River are particularly vulnerable due to the high likelihood of floods and its catastrophic impact on public safety, essential infrastructure, and economic viability. Flooding may result in the loss of access to essential services, the destruction of residences and agricultural land, and displacement. The Gumbel's Distribution and Log Pearson Type III distribution methodologies have shown effective in forecasting floods in the Bagmati river basin, demonstrating a dependable capacity to predict high flooding and enhance early warning and risk management strategies. For both Gumbel's and Log Pearson Type III distributions, the likelihood of exceedance decreases with longer return periods. This illustrates how the likelihood of extreme occurrences declines with time. However, the data highlights the importance of putting in place robust flood control mechanisms, especially in regions such as the Bagmati river basin zone. As seen by the increasing tendency in peak flows over longer return periods, early planning and strong infrastructure are crucial to lowering the risks of catastrophic floods. The findings of this study are significant for flood mitigation, including levee building, enhancement of drainage systems, and implementation of prompt warning mechanisms. Moreover, community engagement and disaster mitigation are essential for minimizing flood effects and ensuring a coordinated response to such calamities. The settlements along the Bagmati River are particularly vulnerable due to the high likelihood of floods and its catastrophic impact on public safety, essential infrastructure, and economic viability. Flooding may result in the loss of access to essential services, the destruction of residences and agricultural land, and displacement. The Gumbel and Log Pearson Type III methodologies have shown effective in forecasting floods in the Bagmati river basin due to their reliable capacity to predict high flooding, hence enhancing early warning systems and risk management. Nonetheless, the limited availability of hydrological data, particularly discharge and wet water level in Indian river basins, constrains the applicability of the flood frequency analysis. Furthermore, since the Bagmati river system is classified as an international river, real-time data for flood assessment is not accessible in the public domain. The findings of this study are significant for flood mitigation, including levee building, enhancement of drainage systems, and implementation of prompt warning mechanisms. Moreover, community engagement and disaster mitigation are essential for diminishing flood effects and ensuring a coordinated response during such calamities.

Conclusion

- The study used two different statistical techniques, the thorough examination of flood patterns in the Bagmati river basin of Khagaria District, Bihar to produce important new information on flood frequency analysis.
- The comparison of the Log-Pearson Type III Distribution and Gumbel's Extreme Value Distribution demonstrated complementary viewpoints on flood risk assessment. The study used 40 years (1985–2024) river discharge data of Bagmati river and applied techniques to it.
- The Log-Pearson Type III Distribution better captures catastrophic floods' non-linear nature, while Gumbel's method exhibits a linear pattern in flood magnitudes over return periods, making it reliable

for ordinary flood forecasts. For regional planning, this divergence is crucial since it highlights catastrophic floods that linear models would miss.

- There is a high correlation between expected flood magnitudes and return periods for 2 5 10 25 50 100 200 years, according to statistical evidence. This association highlights an important fact: there is a growing probability of major flooding occurrences in the Bagmati river basin, which needs quick action.
- A strong case for improved flood resilience measures is made by the exponential increase in flood size estimates, which is especially noticeable in the Log-Pearson Type III analysis.
- These discoveries have important ramifications for engineers and policymakers. The region's infrastructure construction must take into consideration both frequent flood patterns and severe occurrences, indicating a two-pronged strategy to flood control.
- The Log-Pearson Type III analysis gives vital insights for developing infrastructure that can endure extreme flood occurrences, even if Gumbel's technique offers a strong basis for normal flood protection measures. Both analytical methodologies must be included into flood control schemes along the Bagmati river basin.
- Better decisions on infrastructure development and catastrophe preparedness are made possible by this dual technique, which guarantees a more thorough and solid assessment of flood threats.
- The actual use of these statistical insights in the creation of flexible and sustainable flood control strategies will determine the future resilience of this flood-prone area.

Statements & Declarations

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Conflict of Interest

Author proclaimed no conflict of interest.

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