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RESEARCH

Rainfall intensity duration frequency curve statistical analysis and modeling for Patna, Bihar

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Using data from 41 years in Patna' India' the study's goal is to analyze the trends of how often it rains on a weekly, seasonal, and annual basis (1981–2020). First, utilizing the intensity-duration-frequency (IDF) curve and the relationship by statistically analyzing rainfall' the historical rainfall data set for Patna' India' during a 41 year period (1981–2020), was evaluated for its quality. Changes in the hydrologic cycle as a result of increased greenhouse gas emissions are expected to induce variations in the intensity, length, and frequency of precipitation events. One strategy to lessen vulnerability is to quantify probable changes and adapt to them. Techniques such as log-normal, normal, and Gumbel are used (EV-I). Distributions were created with durations of 1, 2, 3, 6, and 24 h and return times of 2, 5, 10, 25, and 100 years. There were also mathematical correlations discovered between rainfall and recurrence interval.

Findings: Based on findings, the Gumbel approach produced the highest intensity values, whereas the other approaches produced values that were close to each other. The data indicates that 461.9 mm of rain fell during the monsoon season's 301st week. However, it was found that the 29th week had the greatest average rainfall, 92.6 mm. With 952.6 mm on average, the monsoon season saw the highest rainfall. Calculations revealed that the yearly rainfall averaged 1171.1 mm. Using Weibull's method, the study was subsequently expanded to examine rainfall distribution at different recurrence intervals of 2, 5, 10, and 25 years. Rainfall and recurrence interval mathematical correlations were also developed. Further regression analysis revealed that short wave irrigation, wind direction, wind speed, pressure, relative humidity, and temperature all had a substantial influence on rainfall.

Originality and value: The results of the rainfall IDF curves can provide useful information to policymakers in making appropriate decisions in managing and minimizing floods in the study area.

Keywords: IDF, hydrologic, vulnerability, rainfall distribution, Gumbel techniques, Weibull's method

Introduction

Precipitation is a type of water that occurs when atmospheric vapor is converted to water on hydrologic occasions. It differs with existence. The information on total precipitation and its appropriation design around the time of a spot is critical for better harvest arranging, determining water system and waste prerequisites of yields, planning and development of hydrologic structures, and so on. References (1) and (2) have proposed the utilization of daily, weekly, monthly, occasional, and yearly precipitation disseminations for crop arranging.

We also supported the use of yearly precipitation conveyance for crop planning. Rajendra Nagar and Kankarbagh remain low for the eighth day on Friday PO, with the climate division issuing a warning for heavy rains in the coming days. The situation is probably going to deteriorate. Rajendra Nagar, one of the most severely affected areas, is under four feet of stale water, adding to the locals' despair. However, the organization said it has gotten substantial siphons to flush out water, but circumstances have not helped a lot.

There have also been reports of robberies in locked houses in the Kadam-kuan police headquarters region. The weighty downpours have guaranteed 73 lives up until now. Individuals who were taking refuge at the rooftop are presently leaving their homes.

A few groups have claimed that there was no game plan from the public authority to provide drinking water and food. Regardless, the organization has stated that authorities are on the streets and roads assisting the affected individuals. In the present, an endeavor has been made to assess the precipitation dispersion example of Patna, Bihar.

The forecast of precipitation dissemination at various repeat spans was done utilizing Weibull's strategy (3). On Monday, the state capital Patna remained among the most noticeably terrible influenced by four- to six-foot profound waterlogging in a few areas. The National Disaster Response Force (NDRF) must protect Vice President Minister Sushil Modi, who was abandoned at his Patna home.

Authorities say the state capital has not seen such waterlogging since the 1975 floods. The Bihar government has additionally requested two helicopters from the Air Force for lifting and airdropping food parcels and drugs. The Patna local organization has requested that all schools be closed until Tuesday. The NDRF and State Disaster Response Force (SDRF) are directing tasks in low-lying spaces of the state capital.

The waterlogging has seriously influenced one of Patna's leading government emergency clinics, Nalanda Medical College and Hospital (NMCH). A few trains and flights have been dropped, rescheduled, or redirected due to the circumstances. The investigation of precipitation information is one of the main occasions in the hydrological cycle.

It is an important part of the water cycle for collecting the vast amount of water in the universe. The normal precipitation in this nation is 1,200 mm per year. It varies from 339 to 2,250 mm per year. Ordinarily, 80—85% of the complete yearly precipitation in India is recorded from June to September.

Precipitation is an interesting phenomenon that is profoundly enhanced by space and time. So rainfall investigation and daily rainfall calculation should be carried out in order to work on the administration of water asset application and the compelling usage of water. This data is additionally utilized for some water in the executive's application, including the plan of major and minor storm water, the board framework, sanitary sewer, confinement lakes, course, span, dams, siphoning station, and street, among others.

Predictions of precipitation are also an important and controlling factor in the planning and activity methodologies of any farming system in any random region. In this way, accurate and unambiguous information about the pattern of precipitation throughout time for a specific location has ceased to be needed for proper and perfect planning of the most important irrigation system and trimming design. The precipitation that occurs during the storm season provides a sizable amount of the country's total annual conjunctive water needs.

Precipitation circulation varies greatly from year to year. Gulping flooding and hungrily dry times are the products of our nation's astoundingly far-reaching precipitation conveyance sites. Data of outrageous precipitation trademark is needed in hydrological plans of designs that control spillover; such data is frequently communicated as a connection between power length and frequency bend.

An intensity-term recurrence bend is a numerical function that relates the precipitation force with the span and frequency of the event, i.e., the return period (4). IDF frequency bend for precipitation in Vietnam's storm area; they deduced a summarized IDF formula using precipitation depth. Reference (5) developed a precise formula to assess the precipitation force for the Riyadh region in Saudi Arabia, and the results showed that the Gumbel method and other logical approaches worked well together.

Based on an examination of rainfall data, inferred precipitation profundity range, and frequency connection for two Saudi Arabian locations, it was discovered that the results obtained utilizing the Gumbel conveyance technique were superior to the outcomes obtained utilizing appropriation, for example, IPT III circulation (6). Reference (6) had set up a precipitation IDF relationship for Basrah City, Iran, utilizing the Gumbel technique; their outcome showed the greatest forces happen over a short term with high variety. Various specialists were directed to determine and set up experimental precipitation assessment condition, and IDF curves for various areas worldwide, particularly in nonindustrial nations (7).

Battered by heavy precipitation for the past 48 h in 3 areas of Bihar, something like 29 individuals have kicked the bucket in the state because of accidents brought about by the storm, as indicated by the news agency ANI. Patna, the state capital, remained among the most noticeably bad, influenced by four- to six-foot-deep waterlogging in a few areas Monday. The Bihar authorities say the state capital has not seen such waterlogging since the 1975 floods.

The Bihar government has likewise requested two helicopters from the Air Force for lifting and airdropping food parcels and medications. When Bihar experiences a waterlogging problem, the NDRF and SDRF lead relief efforts in the state capital's low-lying areas. The waterlogging has seriously influenced one of Patna's leading government clinics, NMCH.

In this problem, the investigation of precipitation information is one of the main occasions in the hydrological cycle. It is an important part of the water cycle for collecting the vast amount of water in the universe. The normal precipitation in this nation is 1200 mm per year. It varies from 339 to 2250 mm per year.

From June to September, India receives 80—85% of its total annual precipitation. Precipitation is a special phenomenon that is exceptionally expanded in both space and time. So rainfall examination and calculation should be done to work on the administration of water asset application and the compelling usage of water.

This data is likewise utilized for some water in the executive's application, including the plan of major and minor storm water, the board framework, sanitary sewer, confinement lakes, courses, spans, dams, siphoning stations, and streets among others. Predictions of precipitation are also an important and controlling factor in the planning and activity methodologies of any farming project in any random region.

All things considered, accurate and plain information about the precipitation appropriation design throughout time for a specific location is crucial for the right and ideal planning of the necessary irrigation framework and editing design. Precipitation that occurs during a storm period contributes significantly to the nation's overall conjunctive water needs throughout the calendar year. There is huge variety in the conveyance of precipitation from one year to another.

The incredible limits of precipitation conveyance in our country cause gushing floods and eagerly dry seasons. Extreme precipitation data is required in hydrological plans of designs that control storm overflow; such data is frequently communicated as a link between force length and frequency bend. An intensity span recurrence bend is a numerical function that relates the precipitation force with the length and frequency of events, i.e., the return period; it is an intriguing factual strategy for assessing precipitation force and advancing the IDF relationship utilizing outrageous precipitation data.

The connection between precipitation information and force and span for a bowl in Jordan; he guaranteed that the outcome acquired from Gumbel's strategy is comparable with different techniques. The IDF frequency bent for precipitation in the rainy area of Vietnam; they deduced a condensed IDF formula using precipitation depth. The following experimental formula was developed to evaluate the precipitation force at the Riyadh location in Saudi Arabia: he expressed a good match as an accomplishment between Gumbel's strategy and other insightful techniques.

Precipitation profundity length-frequency relationship for two areas in Saudi Arabia through rainfall data examination; discovered that the outcomes obtained utilizing Gumbel appropriation strategy were superior to the outcomes obtained utilizing dispersion, for example, IPT III conveyance. Numerous technical articles using previous and forthcoming rainfall forecast data to create IDF curves have been published at the scientific level. For our study, we have used numerous of these works as references. The papers are listed in the section titled, "References."

Materials and methods

The objective of the present study is to determine the IDF curve and the statistical analysis of rainfall data for a record of 41 years using log-normal, normal, and Gumbel (EV-I) distribution methods.

Study area

Patna has been chosen as the study location. It is the capital and largest city of the Indian state of Bihar. The daily rainfall data for 31 years (from 1965 to 1995) were collected from the meteorological observatory, located at the Agricultural Research Institute, Patna (25° 30′ N latitude, 85° 15′ E longitude, and 57.8°m above mean sea level), for evaluation of the rainfall distribution pattern.

According to the 2018 United Nations Population Report, Patna has a population of approximately 2.35 (8). Its urban agglomeration, the 18th biggest in India, spans 250 square kilometers (97 square miles) and has a population of nearly 2.5 million. Mostly on the Ganges River's southern bank is where you'll find the modern city of Patna.

Although earthquakes have not been common in recent history, Patna is located in seismic zone IV of India, demonstrating her vulnerability to severe tremors (9). Additionally, Patna moves toward the storm and flood zone. In **Figure 1**, the review area's guidance is visible and starts at this location in October and lasts until February.

The minimum temperature in Patna often fluctuates between 12 and 30 degrees throughout the colder months of the year and begins in March and ends in May. Due to its location in the sub-equatorial rainforest, Patna has

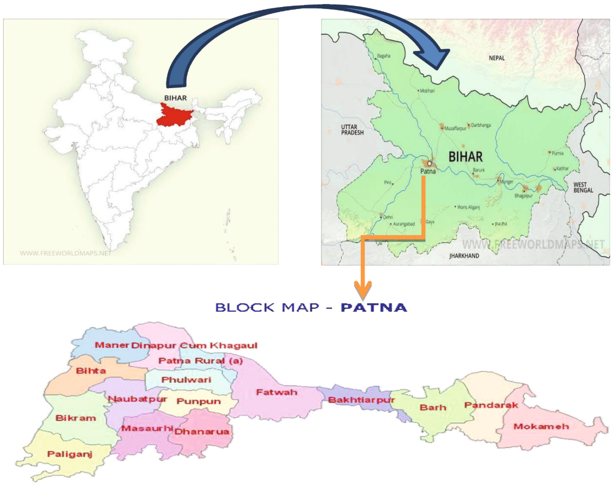

FIGURE 1 | Location map of the study area.

muggy, humid, late spring days. The base temperature is close to 26 degrees, while the typical maximum temperature is about 37 degrees.

The season runs from June to September. During the monsoon, the city experiences hefty amounts of rain, which can occasionally cause the city to flood. During these months, the temperature and humidity remain relatively high. The most precipitation ever recorded was 204.5 mm (8.05 inches) in 1997 (9).

Data collection

The Patna Metrological Department in Bihar collected rainfall data for the 40°year period 1981–2020 in order to create an intensity-duration-frequency (IDF) curve for the research region. After that, a maximum yearly rainfall is calculated using the data on annual rainfall depth that has been gathered using Eq. (1). **Table 1** displays the computed yearly maximum rainfall depth for periods of 1, 2, 3, 6, 12, and 24 h.

Methodology and discussion

Precipitation information was broken down to insulate the greatest precipitation profundity recorded in a day for a year. A yearly most extreme precipitation series was derived from precipitation profundity data. Eq. (1), a formula from the Indian Meteorological Office, is used to calculate the depth of precipitation across time periods of 60 min, 2, 3, 6, 12, and 24 h.

The IMD experimental decreasing recipe has been proven to provide the best evaluation of short-term precipitation in Chowdary:

$$p_t = p_{24}\sqrt{\frac{t}{24}} \qquad (1)$$

P is the computed depth of the precipitation, P_{24} is the yearly maximum precipitation lasting 24 h, and t can be used to signify the time for which P is being calculated. To calculate rainfall intensity, rainfall depth was divided by the corresponding time periods. Previous research publications have employed the IMD empirical formula (10).

TABLE 1 | Annual maximum rainfall depth, P (in mm) of different durations.

Years	1°H	2°H	3°H	6°H	12°H	24°H
1981	51.960	65.466	74.939	94.418	118.959	149.879
1982	17.276	21.767	24.917	31.393	39.553	49.834
1983	22.560	28.424	32.537	40.994	51.649	65.074
1984	33.900	42.711	48.892	61.600	77.611	97.784
1985	24.470	30.831	35.292	44.466	56.023	70.585
1986	41.989	52.903	60.558	76.299	96.130	121.116
1987	26.482	33.366	38.194	48.122	60.629	76.388
1988	25.314	31.894	36.509	45.999	57.955	73.018
1989	18.808	23.697	27.126	34.176	43.059	54.252
1990	16.3	20.611	23.594	29.727	37.453	47.188
1991	15.495	19.522	22.347	28.156	35.474	44.694
1992	13.994	17.631	20.183	25.429	32.038	40.365
1993	38.505	48.513	55.534	69.968	88.154	111.067
1994	33.168	41.789	47.836	60.270	75.935	95.672
1995	45.226	56.982	65.228	82.182	103.543	130.455
1996	19.286	24.299	27.816	35.046	44.155	55.632
1997	50.719	63.901	73.149	92.162	116.117	146.298
1998	32.298	40.692	46.581	58.689	73.943	93.163
1999	40.243	50.702	58.040	73.126	92.132	116.080
2000	31.407	39.571	45.297	57.071	71.904	90.594
2001	64.086	80.743	92.428	116.452	146.721	184.856
2002	27.552	34.714	39.737	50.066	63.079	79.475
2003	34.137	43.010	49.234	62.031	78.155	98.469
2004	21.781	27.442	31.414	39.579	49.866	62.827
2005	21.707	27.349	31.307	39.445	49.697	62.614
2006	38.285	48.236	55.217	69.569	87.651	110.433
2007	38.183	48.108	55.070	69.384	87.418	110.140
2008	18.229	22.967	26.291	33.125	41.734	52.582
2009	19.770	24.909	28.513	35.924	45.262	57.026
2010	16.103	20.288	23.224	29.260	36.866	46.448
2011	33.532	42.247	48.361	60.931	76.768	96.722
2012	20.472	25.794	29.526	37.201	46.870	59.052
2013	40.326	50.807	58.160	73.277	92.323	116.320
2014	32.682	41.176	47.135	59.387	74.823	94.271
2015	21.576	27.183	31.117	39.205	49.396	62.235
2016	27.020	34.044	38.970	49.099	61.861	77.940
2017	35.859	45.180	51.718	65.160	82.097	103.436
2018	22.538	28.397	32.506	40.955	51.600	65.012
2019	35.571	44.817	51.302	64.637	81.438	102.605

Regression analysis

Regression analysis was applied to examine the strength of relationship between Short Wave Irrigation, Wind Direction, Wind Speed, Pressure, Relative Humidity, Temperature (Predictor Variables) and Rainfall (Outcome Variable) by using IBM-SPSS 25.

Table 2 the correlation between predictor variables and outcome variables is 89.6 according to R-value. The adjusted R^2 is 0.802, indicating that short-wave irrigation, wind direction, wind speed, pressure, relative humidity, and temperature (an independent variable) explain 80.2% of the variance in rainfall (a dependent variable); the remaining 19.8% is influenced by other factors. Durbin- Watson is 1.839, which shows that there is no first-order linear autocorrelation in the data.

Overall, the regression model statistically substantially predicts the outcome variable, according to ANOVA

TABLE 2 |

Model summary[b]

Model	R	$R2$	Adjusted $R2$	Std. error of the estimate	Durbin-Watson
1	0.896[a]	0.802	0.802	112.6256853	1.839

[a] Predictors: (Constant), Short Wave Irrigation, Wind Direction, Wind Speed, Pressure, Relative Humidity, Temperature.
[b] Dependent Variable: Rainfall.

TABLE 3 |

ANOVA[a]

Models	Sum of squares	Df	Mean square	F	Sig.
1 Regression	754143768.949	6	125690628.158	9908.958	0.000[b]
Residual	185612946.902	14633	12684.545		
Total	939756715.852	14639			

[a] Dependent Variable: Rainfall.
[b] Predictors: (Constant), Short Wave Irrigation, Wind Direction, Wind Speed, Pressure, Relative Humidity, Temperature.

(Table 3), which shows $p = 0.000$, which is less than 0.05. (i.e., it is a good fit for the data).

Coefficients table shows the strength of the relationship, i.e., the significance of the variable in the model and magnitude with which it impacts the dependent variable. Table No - reveals

- The Sig. value indicates that the significant difference in rainfall caused by temperature is 0.028, which is less than the allowed limit of 0.05.
- The significant change in rainfall caused by relative humidity as a result of the Sig. value is 0.013, which is less than the 0.05 limit.
- The difference in rainfall caused by pressure is considered significant because the Sig. value of 0.030 is less than the 0.05 threshold.
- As a result of the Sig. value, the significant difference between rainfall and wind speed is 0.014, which is less than the permitted standard of 0.05.
- The significant variation in rainfall caused by wind direction, as determined by the Sig. value, is 0.000, which is below the permitted limit of 0.05.
- The Sig. value has caused a significant shift in rainfall that is less than the permitted value of 0.05 or 0.000. This is due to short-wave irrigation.
- Since VIF and tolerance are below the permissible range, there is no evidence of multiple collinearities among the variables, and as a result, the variance of beta is not inflated in any way.

A multiple regression was run to predict rainfall from short wave irrigation, wind direction, wind speed, pressure, relative humidity, and temperature. These variables predicted rainfall statistically significantly: F (6, 14633) = 9908.958, $p < 0.05$, and adjusted $R^2 = 0.802$. All six variables contributed statistically significantly ($p < 0.05$) to the prediction. Hence, linear regression established that there is a significant impact of short wave irrigation, wind direction, wind speed, pressure, relative humidity, and temperature on rainfall.

The regression equation:

$$\begin{aligned}\text{Rainfall} = 501.793 &+ (-0.892)\text{Temparature}\\ &+ 0.528(\text{Relative Humidity}) + (-0.029)\text{Pressure}\\ &+ 0.337(\text{Wind Speed}) + 0.140(\text{Wind Direction})\\ &+ 0.164(\text{Short Wave Irrigation})\end{aligned}$$

As previously discussed, force length recurrence bends are used to track down plan precipitation power as a component of the tempest term and return time of a specific period on which the tempest water framework is based. Power span recurrence bends are created for a series of tempest events rather than a single tempest event. The quantity of the mean and its takeoff from the mean may be used to describe the power of any tempestuous event.

TABLE 4 |

Coefficients

Models	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	501.793	416.660		1.204	0.028		
Temperature	−0.892	0.358	−0.023	−2.493	0.013	0.152	1.577
Relative Humidity	0.528	0.058	0.049	9.102	0.000	0.465	1.151
Pressure	−0.029	0.325	−0.001	−0.088	0.030	0.173	1.767
Wind speed	0.337	0.669	0.002	0.504	0.014	0.827	1.210
Wind direction	0.140	0.012	0.053	12.144	0.000	0.718	1.392
Short wave Irrigation	0.164	0.001	0.937	150.686	0.000	0.349	1.865

[a] Dependent Variable: Rainfall

TABLE 5 | Values of S and *P* for normal distribution.

Durations	1°H	2°H	3°H	6°H	12°H	24°H
P (in mm)	29.971	37.761	43.226	54.461	68.616	86.451
S (in mm)	11.451	14.427	16.515	20.808	26.217	33.031

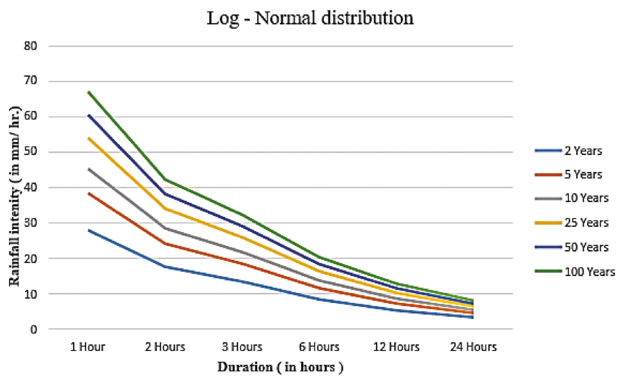

FIGURE 2 | Intensity-duration-frequency (IDF) curve by normal distribution.

The flight of the mean is interpreted as the product of the standard deviation and the recurrence factor K. As a result, “” is derived from Eq. (4). The return period is a function of both the departure and the frequency factor K.

Chow (11) provides the frequency factor equation, which may be used for a variety of hydrological probability assessments.

Procedure for developing the IDF curves:

1. The precipitation data is separated into the series of yearly most extreme precipitation for 1, 2, 3, 6, 12, and 24 h. Precipitation power is determined for all the precipitation profundities in millimeters per hour.
2. The mean and standard deviation were determined for the given information. For instance, the mean (average) utilizing Eq. (2) and the standard deviation (SD) utilizing Eq. (3) for the yearly greatest precipitation power series for 1°h length are determined. The same interaction is repeated every 2, 3, 6, 12, and 24 h.

TABLE 7 | Value of standard deviation (**S***) and avg. precipitation (**P** *).

Durations	1°H	2°H	3°H	6°H	12°H	24°H
P^*	3.331	3.562	3.698	3.929	4.160	4.391
s^*	0.376	0.376	0.376	0.376	0.376	0.376

3. The value of consistent KT for a specific time period is calculated using probability conveyance. The worth of KT is different for every likelihood appropriation (12):

$$P_{avg} = \frac{1}{n}\sum_{i=1}^{n} P_i \tag{2}$$

$$S = \left[\frac{1}{n}\sum_{i=1}^{n}(P_i - P_{avg})\right]^{0.5} \tag{3}$$

4. Next, rainfall intensity is determined using the K, mean, and standard deviation values from Eq. (2). A typical distribution and the most common approach in statistics is called the normal (Gaussian) distribution. Like all other approaches, this one also calculates the rainfall intensities in order to determine the rain intensities for a certain return time and every storm length. The formula to calculate precipitation P (in mm) using a given return period (T) and a given duration (t) is shown below (13):

$$P = \overline{P} + K_T^* S \tag{4}$$

Equations (5), (6), and (9) are used to get the frequency factor, KT, which is equal to “Z” for both the log-normal and normal distributions (7):

$$Z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3} \tag{5}$$

Here, “w” is calculated as

$$W = [1n(1n(1/P^2))]^{0.5} \tag{6}$$

In Eq. (3), “p” is the probability of occurrence in a specified return period “T” and its value calculated as

$$\text{P} = 1/\text{T} \tag{7}$$

TABLE 6 | Rainfall intensity (I) computed from normal distribution.

Return period (T)	Value of “Z” calculated by Eq. (5)	Durations					
		1 h	2 h	3 h	6 h	12 h	24 h
2°Years	−1.0E–07	29.971	18.881	14.409	9.077	5.718	3.602
5°Years	0.8414567	39.607	24.951	19.041	11.995	7.556	4.760
10°Years	1.2817288	44.648	28.127	21.465	13.522	8.518	5.366
25°Years	1.7510765	50.023	31.512	24.048	15.150	9.544	6.012
50°Years	2.0541886	53.494	33.699	25.717	16.201	10.206	6.429
100°Years	2.3267853	56.615	35.665	27.218	17.146	10.801	6.804

TABLE 8 | Rainfall intensity (I) computed from log-normal distribution.

Return periods (T)	Value of "Z" calculated by Eq. (5)	Durations					
		1 Hour	2 Hours	3 Hours	6 Hours	12 Hours	24 Hours
2° Years	−1.0E–07	27.978	17.625	13.451	8.473	5.338	3.363
5° Years	0.8414567	38.389	24.184	18.455	11.626	7.324	4.614
10° Years	1.2817288	45.299	28.537	21.777	13.719	8.642	5.444
25° Years	1.7510765	54.040	34.043	25.980	16.366	10.310	6.495
50° Years	2.0541886	60.563	38.152	29.116	18.342	11.555	7.279
100° Years	2.3267853	67.099	42.269	32.258	20.321	12.801	8.064

For the case of $p > 0.5$, "p" in Eq. (3) is substituted by (1 − p), and Z gives a negative value. Considering Eq. (1), for a single time, "P" is the arithmetic average of the rainfall records Moreover, "S" is the standard deviation, and the multiplication of "S" and "KT" gives the output as departure of a return period. Finally, to develop the IDF curve, the rainfall intensity I (in millimeters per hour) with respect to a specific return period "T" and storm duration "t" (in hours) is calculated by using Eq. (5):

$$I = \frac{PT}{t} \tag{8}$$

In our project, we use the previously mentioned as well as the following procedures to find the expected intensities for six different rainfall durations and six different return periods using the normal distribution (14).

Now, on the basis of recorded rainfall data, the values of standard deviation (SD) and average precipitation (P) are calculated by Eqs. (2) and (3) and mentioned in **Table 2**. After that, using the value of Z for six different return periods in Eq. (4), the corresponding value of expected rainfall depth (PT) is calculated and by using Eq. (8), corresponding value of expected intensities for six different rainfall durations and six different return periods is calculated, which are mentioned in **Table 3**.

Using **Table 6**, the IDF curve is finally shown with rainfall intensity on the y-axis and rainfall duration on the x-axis.

With the help of "Microsoft excel software," which is shown in [**Figure 2**;(15)].

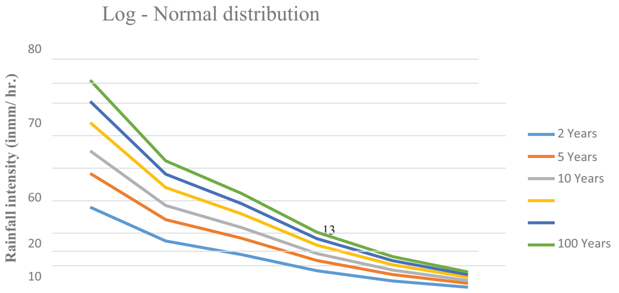

FIGURE 3 | Intensity-duration-frequency (IDF) curve by log-normal distribution.

Log-normal distribution

By means of the log-normal distribution with the interference of logarithm variables, the frequency of precipitation can be calculated, which is like the normal distribution. Calculations for average precipitation and standard deviations are done through logarithmically transformed data (16):

$$P^* = \log(Pi) \tag{9}$$

$$\overline{\overline{P}}^* = \frac{1}{n}\sum_{i=1} nP^* \tag{10}$$

$$S^* = \frac{1}{n}\sum_{i=1}^{i} n(P^* - \overline{P}^*)^2 \tag{11}$$

The frequency precipitation is calculated as

$$PT^* = \overline{\overline{P}}^* + KT^*S^* \tag{12}$$

The intensity can be calculated by

$$I = PT/t \tag{13}$$

where PT is the antilogarithm of PT and KT is the frequency factor with the same value as "Z" in the normal distribution. In our project, the earlier discussed as well as the following procedures are utilized to find the expected intensities for six different rainfall durations and six different return periods by log-normal distribution (17). Now, on the basis of recorded rainfall data, the first values of P^* for different durations are calculated using Eq. (9) and **Table 1** and mentioned in **Table 4**. After that, the values of standard deviation (S^*) and average precipitation

TABLE 9 | Values of standard deviation (S) and average precipitation (X).

Durations	1°H	2°H	3°H	6°H	12°H	24°H
X	29.971	18.881	14.409	9.077	5.718	3.602
S	11.451	7.214	5.505	3.468	2.185	1.376

TABLE 10 | Rainfall intensity (I) computed from Gumbel distribution EV1.

Return periods (T)	Value of "K_T" calculated by Eq. (14)	Durations					
		1 Hour	2 Hours	3 Hours	6 Hours	12 Hours	24 Hours
2° Years	−0.164	28.090	17.696	13.504	8.507	5.359	3.376
5° Years	0.719	38.210	24.071	18.369	11.572	7.290	4.592
10° Years	1.305	44.910	28.291	21.590	13.601	8.568	5.398
25° Years	2.044	53.375	33.624	25.660	16.165	10.183	6.415
50° Years	2.592	59.656	37.581	28.679	18.067	11.381	7.170
100° Years	3.137	65.889	41.508	31.676	19.955	12.571	7.919

TABLE 11 | Chi-square goodness of fit test for various yearly rainfall patterns in years 1981–2019.

Probability of occurrences P (%)	Return period (T)	Observed rainfall depth (in mm) for 24° H duration	Expected rainfall depth (in mm) for 24° H duration calculated by using probability distribution			Chi-square test values for different probability distribution		
			Normal	Log-normal	Gumbel	Normal	Log-normal	Gumbel
50	2	76.7	86.5	80.7	81.0	1.093	0.195	0.227
20	5	110.8	114.2	110.7	110.2	0.105	0.000	0.003
10	10	136.5	128.8	130.7	129.5	0.465	0.263	0.377
4	25	170.6	144.3	155.9	154.0	4.787	1.385	1.792
2	50	196.3	154.3	174.7	172.1	11.443	2.678	3.417
1	100	222.1	163.3	193.5	190.1	21.149	4.206	5.394
					Total	39.042	8.727	11.209

($\overline{P}^*$) are calculated by Eqs. (10, 11), respectively, and mentioned in **Table 5**. After that, by using the value of Z for six different return periods in Eq. (12), corresponding values of expected rainfall depth (PT^*) are calculated, and again by using Eq. (13), corresponding values of expected intensities for six different rainfall durations and six different return periods are calculated, which are mentioned in **Table 6**.

Finally, using **Table 8**, the IDF curve is displayed with rainfall intensity on the y-axis and rainfall duration on the x-axis, with the help of "Microsoft Excel software," which is shown in **Figure 3**.

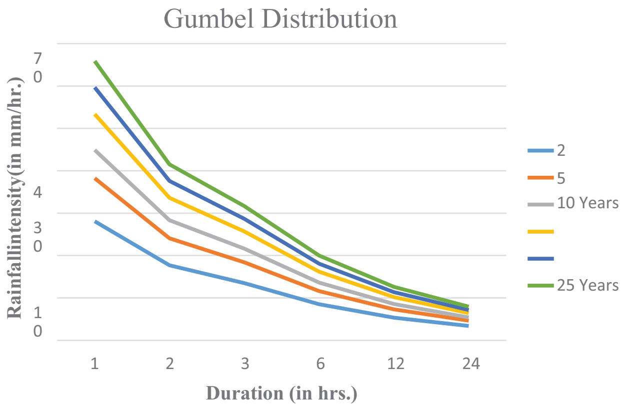

FIGURE 4 | Intensity-duration-frequency (IDF) curve by Gumbel distribution.

Gumbel distribution (EV1)

After the name of the developer, Gumbel, the functionality is termed, and it is also called "type 1 distribution of maxima." Utilizing the Gumbel distribution, the IDF curves are studied and assessed as fitting maxima for attaining appropriateness. Utilization of the maximum rainfall values and extreme data with ease is done by the Gumbel method. When using the "likely to normal" function approach to estimate precipitation frequency, a different occurrence factor K is used, which is supplied by:

$$k_t = \frac{\sqrt{6}}{\pi}\left(0.5772 + \ln\left(\ln\frac{\overline{T}}{T-1}\right)\right) \qquad (14)$$

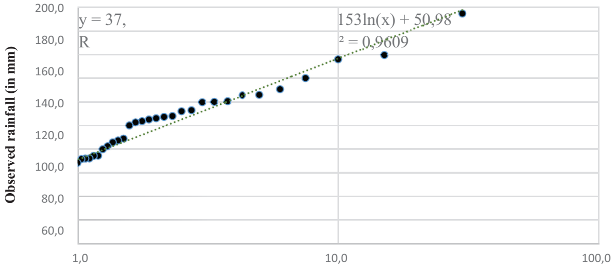

FIGURE 5 | Graph between observed rainfall (in mm) in 24 h and their return period.

The Gumbel distribution uses the following equation proposed by Chow:

$$X_T = X_{avg} + K_T^* S \tag{15}$$

where X_T is the intensity in millimeters per hour, X_{avg} is the mean, S is the standard deviation, and K_T is the frequency factor.

$$X = \frac{1}{m}\sum_{i}^{m} x_i \tag{16}$$

In the present study, the earlier discussed as well as the following procedures are utilized to find the probable rainfall intensities for six dissimilar rainfall durations and six different return periods by Gumbel distribution.

Firstly, on the basis of recorded rainfall data series, rainfall intensity (X) data series for different durations are calculated from **Table 1** by simply dividing the value of rainfall depth by their duration, as mentioned in **Table 9**. After that, the values of the standard deviation (S) and average precipitation ($\overline{\mathrm{X}}$) are calculated by Eq. (16), and mentioned in **Table 9**. Further, by using Eq. (14), the frequency factor for different return periods is calculated, and finally, corresponding values of expected rainfall intensity are calculated by using Eq. (15) for six different rainfall durations and six different return periods, which are mentioned in **Table 10**.

Finally, the IDF curve is designed with rainfall period on the x-axis and rainfall intensity on the y-axis by using **Table 10** with the help of "Microsoft Excel software," which is shown in **Figure 4**.

Goodness of fit

The chi-square test is typically used to see how closely the values anticipated by the theoretical distribution fitted to the data and the values actually observed during the return period, T, match up.

The chi-square values with the lowest values provided the best match.

Now, before carrying out a chi-square test, difference in observed rainfall depth (in millimeters) between 39 years of 24 h duration and their return period is plotted on a log scale, which is shown in **Figure 5**, and its variation is analyzed.

The aforementioned chi-square test of goodness of fit was conducted for various distributions of the maximum annual rainfall in the years 1981—2019, and its value for various probability distributions was computed using Eq. (18) and mentioned in **Table 11**.

Results

The relationship between rainfall intensity and time durations, also known as the return period, can be generated using the normal distribution, log-normal distribution, and Gumbel distribution (EV1). In this paper, we calculated the intensity, and the result shows that with the increase in rainfall, the intensity of the return periods also increases. This is shown in **Tables 3**, **4**, **10**. The intensity was calculated with the help of return periods with respect to probability distributions.

Conclusions

The observed rainfall data were used to formulate the probability distribution function, and it represents the suitable probability distribution. The rainfall pattern depends upon the observed rainfall data. It was discovered that rainfall patterns vary by location.

Data on rainfall were compared statistically at 1, 2, 4, 10, 20, and 50 percent probability using the chi-square test for goodness of fit. It demonstrates that when compared to the normal distribution and the Gumbel distribution technique, the log-normal distribution has the lowest value. Prediction using the log-normal distribution approach was therefore determined to be the best model for the Patna city region.

Conflict of interest

During the study, there were no financial or commercial ties that could be interpreted as potential conflicts of interest.

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