Kashf Journal of Multidisciplinary Research
Vol: 02 - Issue 09 (2025)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

HYDROLOGICAL DROUGHT AND FLOOD FREQUENCY ANALYSIS OF NARAN DAM SITE

Khawaja Talha Iqbal*
Water & Agriculture Division, National Engineering Services Pakistan PVT LTD

Aqib Javed
Transmission & Distribution, DAR Engineering

Jawad Ahmad
Erasmus Mundus Student at Universidad de Cantabria in Coastal Hazards, Risks, Climate change impacts and Adaptation

Mudasir Bashir
Water & Agriculture Division, National Engineering Services Pakistan PVT LTD

*****Corresponding Author:*** engineertalhaiqbal@gmail.com

Article Info

Abstract

This study investigates the hydrological drought and flood frequency at the Naran Dam site on the Kunhar River. The research aims to support hydro energy generation while addressing the water resource management challenges posed by extreme hydrological events. Drought analysis using the Mean Annual Flow (MAF) method, low-frequency analysis, and Streamflow Drought Index (SDI) from 1990 to 2020 revealed fluctuations in wet and drought years, with four severe drought years recorded between 2010 and 2020. Monthly SDI analysis showed 10 extremely wet, 144 normal, 53 mild droughts, and 4 extremely drought months. Low-frequency analysis indicated a 32% occurrence of low flows (3.1–6 m^3/s), with minimum flows progressively decreasing in recent years, and for a return period of 2 to 1000 years, low flows ranged from 4.39 to 84.02 m^3/s. Flood frequency analysis using the Log-Pearson Type III method estimated flood discharges of 193 to 1260 m^3/s for return periods of 2 to 1000 years, making it the best-fitted model among the probability distribution methods analyzed.

Keywords:

Hydrological Drought, Flood Frequency Analysis, Naran Dam, Water Resource Management

1. INTRODUCTION

Water is essential for the existence and continuation of life since it produces food for people and satisfies their desire to drink. Water sources are crucial for agriculture and hydropower generation for countries across the world. To accomplish the aforementioned tasks, surface water flow must be maintained and stored. Worldwide, dam construction is the primary method used to reserve water storage, and in recent years, the number of dams built across all continents has increased. Droughts and floods are severe natural calamities that can lead to substantial economic, social, and environmental consequences [1].

In Pakistan, the shortage of water is becoming a natural calamity that needs to be addressed seriously. A lack of precipitation, whether it be rain or snow, can cause crops to suffer, stream flow to decrease, soil moisture or groundwater levels to drop, and there will be a general water shortage. On the other side, floods, one of nature's most devastating calamities, have devastated humanity and infrastructure worldwide, including in Pakistan. Floods were the natural catastrophes that affected people the most in Asia in 2015, following a worldwide trend [2]. The catastrophe by hydrological events and its consequences poses an immediate danger to Pakistan's chances of fulfilling the Sustainable Development Goals (SDGs).

Water storage is the only way to economically utilize this natural resource in developing nations. Water reservoirs mainly reduce the negative effects of floods and ensure a supply of water for domestic, industrial, and agricultural usage during droughts. Dam construction is the primary method for storing water globally, and the number of dams has recently expanded across all continents. A flood occurs when a river reaches an abnormally high level, usually when it breaches its banks and submerges the surrounding area [3].

6.8 million people died from floods in the 20th century, making them the world's most common natural disaster [4]. The effects of flooding are anticipated to worsen as a result of population growth, economic expansion, and climate change [5]. The most commonly used tactics for lowering flood-related losses are structural ones, yet hydraulic structure design heavily depends on river flow characteristics [6]. Floods cause a lot of losses, such as life, and properties, washing away of roads, culverts, crops, traffic difficulties, socioeconomic losses due to delays, etc. Figure 1 shows the geographical distribution of the indirect damages of Pakistan’s 2010 floods. The most affected provinces were Southern Punjab and Sindh [7].

The appropriate use of river runoff is restricted by seasonal variations and climatic flow abnormalities, with flooding and drought having catastrophic effects. Dams have been used for about 5,000 years to guarantee a sufficient supply of water by holding onto water during periods of abundance and releasing it during periods of scarcity, so averting or lessening floods [7]. The design of numerous hydraulic structures, including culverts, dams, and urban drainage systems, heavily relies on flood frequency analysis [8]. When designing [7][8]hydraulic infrastructure and managing fisheries and aquatic resources, flood frequency is crucial [9].

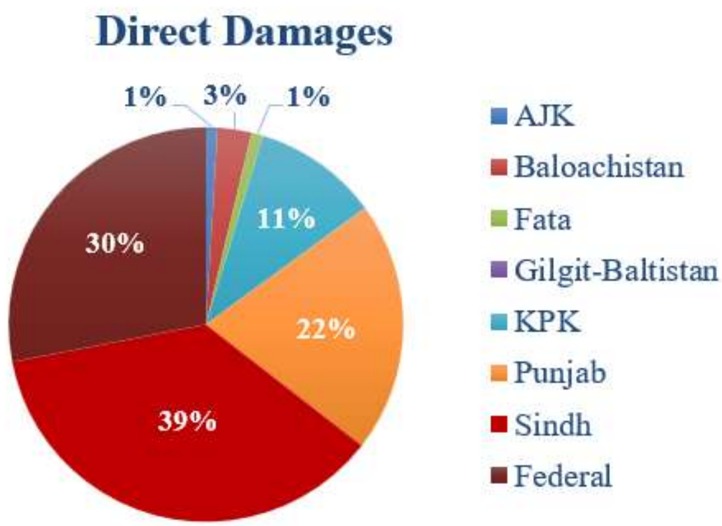

Figure 1: Pakistan floods 2010 preliminary damage and needs assessment (Asian Development Bank, 2010)

The climate of much of Pakistan is arid to semi-arid, with considerable regional and temporal variability. The monsoon season is the most significant hydrometeorological resource in Pakistan, contributing almost 59% of the nation's yearly precipitation. According to the climate risk index, Pakistan was ranked fifth out of the ten nations most impacted by climate change between 1999 and 2018 [10]. The drought of 1998-2002 is regarded as the worst in 50 years. According to a report provided by Pakistan's Economic Survey, drought is one of the causes contributing to poor growth performance. Table 1 indicates the production and financial losses of different crops by the 1998-2202 drought in Balochistan.

Table 1: Damages Caused by 1998-2002 Drought in Baluchistan, Pakistan

Crop	Production (Million tons)	Loss Billion Rs.
1999-2000	2000-2001	
Wheat	21.1	18.53
Gram	0.565	0.54
Cotton	10.6	9.7
Rice	4.8	33.9
Sugarcane	44	35
Total	81.07	66.64

This study aims to analyze the patterns of river flow and evaluate the frequency of floods in Pakistan to support the sustainable planning and design of hydraulic structures. By examining historical hydrological data and identifying trends influenced by climatic variability, this research seeks to improve flood forecasting and risk assessment. The findings will contribute to the development of effective water storage strategies, ensuring a reliable water supply during droughts while minimizing the destructive impacts of floods. Ultimately, the outcomes of this study are intended to aid policymakers, engineers, and water resource managers in enhancing the resilience of Pakistan's water infrastructure and safeguarding its socioeconomic development.

2. Study Area:

The Naran Basin was chosen as a hydrological flood and drought analysis case with a relatively high specific water output, which is potentially sensitive to changing climate. Naran is located in the mountainous area of KPK province, Pakistan. The study watershed is Upper Kunhar River Watershed. The watershed is situated in the foothills of southern Punjab Himalayan range as shown in Figure 2. It lies between latitude 34°54'30" N and longitude 73°39'5" E, has a catchment area of around 1,043 km2 and the elevation ranging from about 2364 to nearly over 4600 meters above mean sea level (AMSL). With an average annual temperature of 6.8°C and an annual precipitation total of 1,618 mm, the basin may soon be filled with melting snow water come spring.

Figure 2: Drainage Area of Proposed Naran Dam and its Location

3. Data Collection and Methodology:

3.1 Data Collection:

A minimum of 30 years of data were needed for the flood frequency analysis. Consequently, the surface water hydrology project office of WAPDA provided thirty-year flow data for the Naran Station, which is situated on the Kunhar River in Khyber Pakhtunkhwa. The information contained the station's maximum instantaneous flows, mean monthly flows, mean annual flows, and daily flows. The Surface Water Hydrology Project (SWHP) provided the data, which included the daily river Kunhar discharges at the Naran stream gauging station between 1990 and 2020.

3.2 Data Analysis:

The data was analyzed and for flood frequency analysis, max. instantaneous discharge/flows were selected. Similarly, low flows from data from each year were selected for drought severity analysis. Figure

3 represents the maximum instantaneous discharge data for each year from year 1990 to 2020. It also shows that during this period of 31 years, the maximum of all the maximum instantaneous discharges was 648.1 m^3/s, the average flow was 225.6 m^3/s, and the lowest of the maximum instantaneous discharges was 107.6 m^3/s. Figure 4, which shows the mean of mean discharge over the months of the year and was based on 31 years of data, provides useful insights into the region's hydrological trends. By averaging the mean values for each month over such a long period, the graph successfully smooths out annual anomalies and provides a clear depiction of long-term trends.

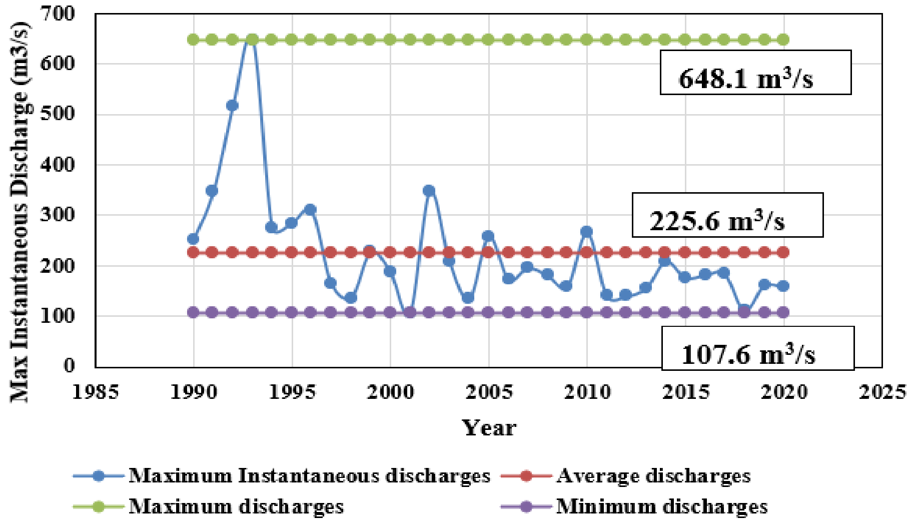

Figure 3: Max. Instantaneous Discharge Data from 1990 to 2020

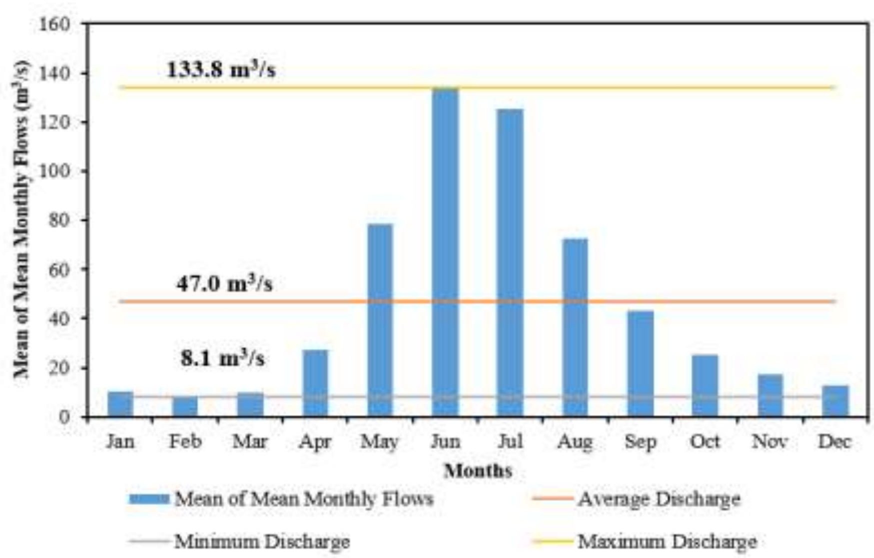

Figure 4: Represents Mean of mean monthly flows

The minimal discharge value of 8.065 m^3/s represents the lowest average flow recorded in any month throughout the 31 years. This predicts periods of severe water shortage or extremely dry circumstances, which could have serious ecological and socioeconomic consequences, especially in areas that rely on constant water supplies for agriculture, industry, or domestic use. On the other side, the maximum discharge value of 133.798 m^3/s indicates peak flow times, which could be related to extreme weather events such as heavy rains or snowmelt. These peaks are crucial for assessing flood danger and managing water supplies [11]. The average discharge value of 47.024 m^3/s was used as a benchmark to evaluate typical water flow conditions. This mean value serves as a reference point for determining how specific months vary from the average.

Figure 5 depicting mean yearly flows over 31 years reveals major hydrological trends. The lowest score of 30.3 m^3/s represents the driest year, which poses a difficulty for water availability. The average flow of 47.235 m^3/s serves as a reference point for normal conditions, assisting in the identification of anomalies. The peak flow of 80.42 m^3/s marks the wettest year, emphasizing the significance of flood management. This information is critical for understanding water resource variability and planning for both drought and flood events.

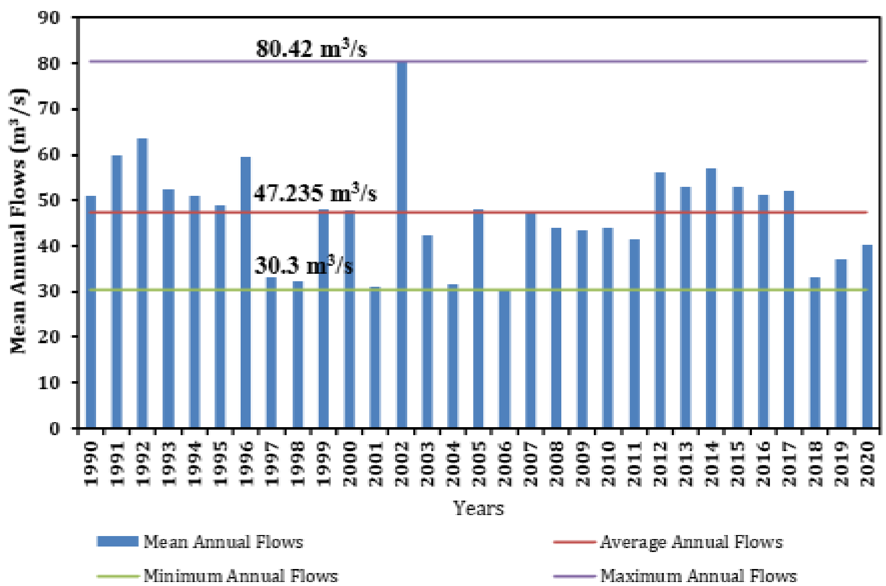

Figure 5: Represents Mean Annual Flows

3.3 Hydrological Drought Analysis:

The hydrological drought analysis is done to determine the frequency and severity of droughts. The methods used are:

- **i.** Drought severity analysis by Mean Annual Flow
- **ii.** Drought severity analysis by Streamflow Drought Index (SDI)
- **iii.** Drought frequency by Low-Frequency Analysis Method

3.3.1 Drought severity analysis by Mean Annual Flow

When conducting hydrological analyses, it is crucial to focus on periods of increased rainfall. This approach ensures that the data is appropriately represented, as considering the entire year may not capture the variations effectively [12]. The analysis of data is done by determining the deviation of Annual flow from the overall mean annual flow of the research span. Each year's deviation will illustrate the level of severity for each flow. The governing equation for this method is referred in the literature review. Table 2 shows the color-coding scheme for each level of drought severity.

Table 2: Color coding of each level of drought severity

Sr. No.	Drought Severity	Criteria
1	Wet Years	> 10
2	Normal Years	± 10
3	Slight Drought Years	-10 to -25
4	Moderate Drought Years	-25 to -50
5	Severe Drought Years	> -50

The drought severity using mean annual flow method, which divide years according to their level of departure from long-term average flows. These classes / were wet years (deviation >10%), normal years (within ± 10%); slight drought (-10 to -25), medium drought (-25 to -50) and pronounced or severe deficit from evaporation intensity. It lets water managers determine how much certainty they can have in the patterns of scarcity documented here, which feeds discussions around drying trends and long-term planning under continual drought management concern. The strategy allows for monitoring and remediation of low-flow effects in a structured manner. Table 3 represents the deviation of each year flow and classify all the years in their respective ranges of wet years, normal drought years, slight drought years and moderate drought years.

Table 3: Deviations by Mean Annual Flow Method

Sr. No.	Year	Annual Flow	Deviation
	Wet Years		
1	1991	59.89	27
2	1992	63.47	34
3	1993	52.5	11
4	1996	59.7	26
5	2002	80.42	70
6	2012	56.01	19
7	2013	53.09	12
8	2014	57.11	21
9	2015	52.87	12
	Normal Drought Years		
10	1990	50.92	8

11	1994	50.87	8
12	1995	49.05	4
13	1999	48.2	2
14	2000	47.86	1
15	2005	48.15	2
16	2007	47.47	0
17	2008	44.01	-7
18	2009	43.39	-8
19	2010	44.12	-7
20	2016	51.11	8
21	2017	52.05	10
Slight Drought Years			
22	2003	42.42	-10
23	2011	41.36	-12
24	2019	37.08	-21
25	2020	40.2	-15
Moderate Drought Years			
26	1997	32.95	-30
27	1998	32.09	-32
28	2001	30.94	-34
29	2004	31.63	-33
30	2006	30.3	-36
31	2018	33.07	-30

3.3.2 Streamflow Drought Index (SDI)

Table 4 illustrates the various stages of drought based on their Indices ranges. DrinC (Drought Indices Calculator) software was utilized to calculate the streamflow drought index. The goal of the DrinC software is to offer an intuitive interface for evaluating drought indices suitable for hydrological, agricultural, and meteorological drought research. A graphical user interface is used to carry out the calculation procedure, and the options were modified to meet the goals of this study's drought analysis. The positive value indicates no drought period and the negative value indicates the prevalence of a particular drought condition.

Table 4: Classification of drought [13]

Category	SDI Value
Extremely Wet	≥ 2
Severely Wet	1.5-1.99

Moderately Wet	1-1.49
Slightly Wet	0.5-0.99
Normal	-0.49 to +0.49
Mild Drought	-0.5 to -0.99
Moderately Drought	-1 to -1.49
Severely Drought	-1.5 to -1.99
Extremely Drought	≤ -2

3.3.3 Drought frequency by Low Frequency Analysis Method

Table 5 shows the low flow range, which determines the number of years and percentage frequency of return for each flow. The frequency of hydrological droughts is ascertained by low flow frequency analysis. This approach evaluates the return of low flow ranges over thirty years, from 1990 to 2020, and determines the frequency of occurrence for each flow range.

Table 5: Frequency of occurrence of each flow range

Low Flow	0-3	3.1-6	6.1-9	9.1-12	12.1-15	Total
Units					m^3/s	
N	8	10	8	2	3	31
Frequency %	26	32	26	6	10	100

3.4 Flood Frequency Analysis

A flood frequency study was a statistical analysis used to ascertain the likelihood and magnitude of flood episodes over time in a specific location. It includes investigating verifiable information on waterway streams and precipitation to decide the likelihood of surges of different sizes happening inside a given period. This study requires at least 30 years of historical data. If data was less than 30 years then this frequency study method was not suitable. In flood frequency analysis, there are two methods for the computation of return periods of various flood magnitudes.

I. Empirical Approach (for Short Extrapolations)
II. Analytical Approach (for Long Extrapolations)

3.4.1 Empirical Approach

To estimate return durations, empirical formulas rely on observed data and statistical methods. Instead of assuming an underlying theoretical distribution, they immediately infer associations from the historical data. Here, some empirical approaches are given:

i. California Method
ii. Allen Hazen Method
iii. Weibull Method
iv. Gumbel Method

3.4.2 Analytical Approach

Using analytical procedures, return periods are determined by fitting a probability distribution to past flood data and using the distribution's characteristics. The selected approaches for frequency study were as under:

i. Log Normal Distribution,
ii. Log Pearson Type-III
iii. Gumbel EV-I Method

General Equation of Hydrologic Frequency Analysis:

$$x_T = \bar{x} + k$$

x_T = Value of variate x of a random hydrologic series with a return period T, $\bar{x}$ = Mean value of Variate, σ = Standard Deviation of Variate, k = Frequency Factor

Log Normal Distribution

The discharges estimated by the Log-Normal Distribution for different return periods are presented in Table 6 and illustrated in Figure 6. The Log-Normal Distribution is a specific case of the Log Pearson Type-III distribution when the coefficient of skewness (Cs) is zero, and it plots as a straight line on logarithmic probability paper. This method tends to yield higher discharge values than the Log Pearson Type-III method when the coefficient of skewness is negative. The expected flow rates shown in Table 6 represent the probability of different flood magnitudes occurring over various return periods, where longer return periods indicate rarer flood events. These flow rates were calculated using frequency factors obtained from the Log-Normal Distribution, which modify the standard deviation of the logarithms of the measured flows.

Table 6: Predicted discharges by Log Normal Distribution

Return Period	Probability (p)	w	Z	Flow (m^3/s)
1000	0.001	3.717	3.091	736
500	0.002	3.526	2.879	674
100	0.01	3.035	2.327	537
50	0.02	2.797	2.054	480
25	0.04	2.537	1.751	423
20	0.05	2.448	1.645	405
10	0.1	2.146	1.282	349
5	0.2	1.794	0.841	291
2	0.5	1.177	0.000	206

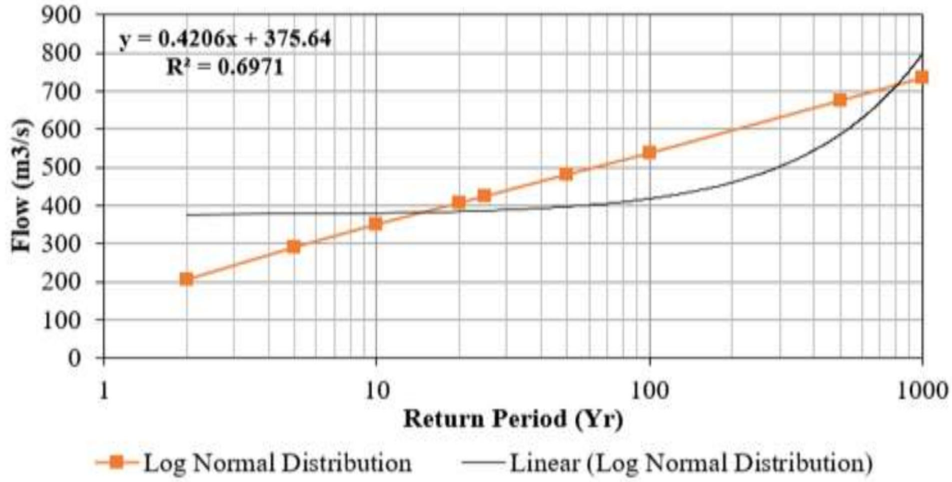

Figure 6: Discharges against different return periods by Log-Normal Method

Log Pearson Type-III

The three-parameter Gamma distribution, often known as the Log Pearson Type-III, is a member of the Pearson Type III distribution family [14]. Since the United States Water Resources Council's (1967, 1982) recommendation, the approach has been one of the most often used distributions for flood frequency analysis [15]. When developing buildings in or near rivers that could be impacted by flooding, it is useful. The series of Z fluctuates where X is the variate of random hydrological series;

$$Z = \log x$$

Are first obtained, for this Z series for any recurrence interval T, Eq gives

$$Z_T = \overline{z} + K_Z . \sigma_Z$$

Where, K_Z = a frequency factor which is a function of recurrence interval T and the coefficient of skew C_s, σ_z = standard deviation of the Z variate sample, Cs = Coefficient of Skewness, $\overline{z}$ = mean of Z values, N = Sample size = Number of Years of record

This method, known for its flexibility in handling skewed data, has provided a comprehensive statistical summary of potential flood events. Important metrics including the mean, standard deviation, and skewness of the logarithms of the yearly peak flows are included in the results. For each return period, these characteristics are essential for calculating the frequency factor and, in turn, the flow rate. Gumbel EV-I Approach. Using the Log-Pearson Type III method, the estimated discharges for 2–1000-year return periods ranged from 193 to 1260 m³/s shown in Table 7 and Figure 7.

Table 7: Predicted discharges by Log Pearson Type-III

Return Period	K	Z_t	Flow (m^3/s)
1000	4.395	3.10	1260
500	3.77	2.99	974
100	2.96	2.84	696

50	2.50	2.76	576
25	2.018	2.67	472
10	1.34	2.55	357
5	0.41	2.39	243.5
2	-0.15	2.29	193

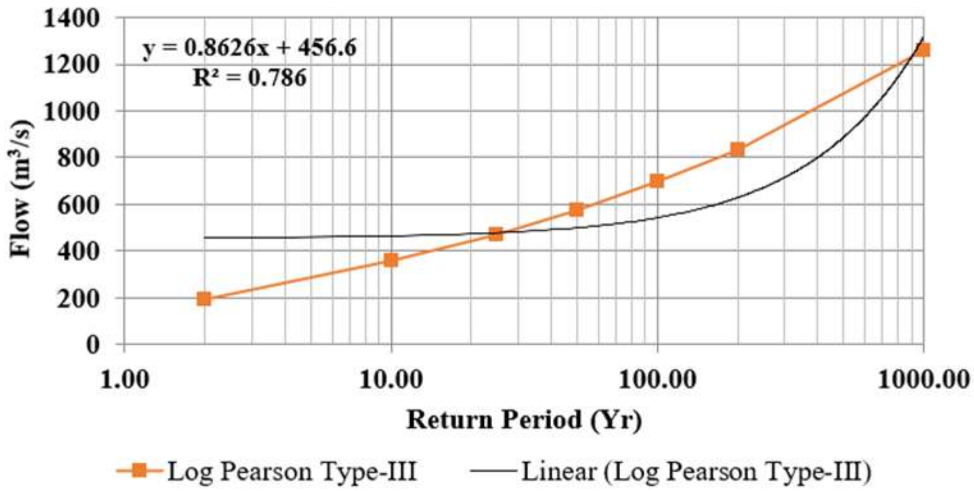

Figure 7: Discharges Against Different Return Periods by Log Pearson Type-III Distribution

Gumbel EV-I

This probability distribution has been found to be a reasonable method for predicting the flood recurrence interval and has been utilized as a general model of extreme occurrences, especially in the context of regionalization techniques [16]. In probability theory and statistics, the Gumbel distribution is a distribution model that shows the distribution of the maximum (or minimum) of multiple samples with various distributions.

The discharges estimated by the Gumbel EV-I method are presented in Table 8 and Figure 8. This distribution models the annual maximum values of a river and is commonly used to estimate the probability of extreme events such as floods. The predicted flow rates for different return periods represent the likelihood of various flood magnitudes occurring, calculated using the mean and standard deviation of the measured peak flows to determine the Gumbel frequency factor. This information is crucial for forecasting extreme floods and supports better flood risk management, infrastructure planning, and mitigation efforts.

Table 8: Predicted Discharges by Gumbel EV-1

Return Period	Probability (p)	Y_t	K	Flow (m^3/s)
1000	0.001	6.9073	4.9355	797
500	0.002	6.2136	4.3947	734

100	0.01	4.6001	3.1367	589
50	0.02	3.9019	2.5923	526
25	0.04	3.1985	2.0438	462
20	0.05	2.9702	1.8658	442
10	0.1	2.2504	1.3046	377
5	0.2	1.4999	0.7194	309
2	0.5	0.3665	-0.1643	207

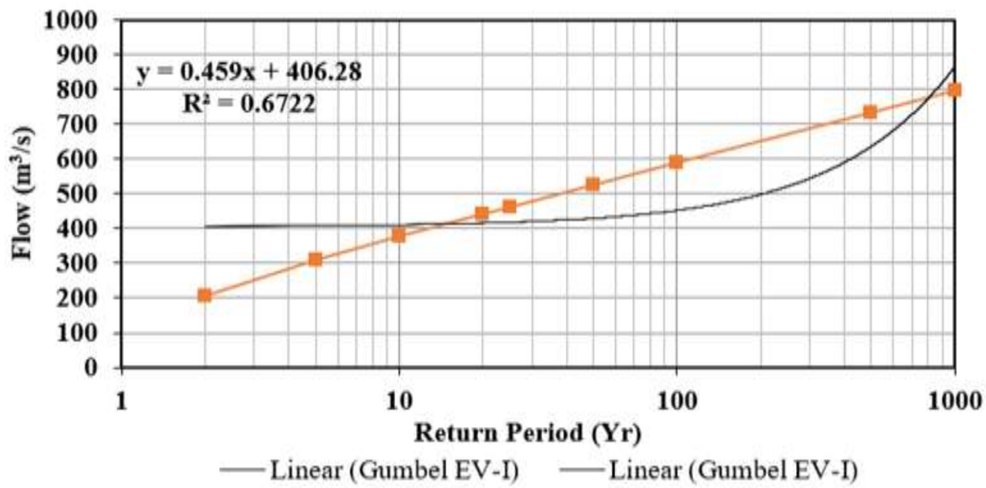

Figure 8: Discharges Against Different Return Periods by Gumbel EV-1 Method

4. Results and Discussion

4.1 Hydrological Drought Trends

In light of the frequency and severity analyses, a hydrological drought analysis was conducted. Over the course of 30 years, a variety of techniques were employed to evaluate the frequency and intensity of droughts. In order to examine the trends in drought characteristics, these findings are first carefully examined. Below is a discussion of the findings from the hydrological drought severity analysis. Using the deviation of mean annual flow (MAF) approach, these findings were ascertained.

4.1.1 Hydrological Drought Analysis by Mean Annual Flow Method

Annual hydrological drought analysis using the MAF method is shown in Figure 9. As move from the first to the second decade of the hydrological record, the number of wet years declined, while it increased again during the past ten years. This unusual pattern may be linked to global warming and climate change. Between 1990 and 2020, there were fewer normal years and more mild drought years, indicating a shift from typical conditions toward mild drought near the Naran Dam project [17]. Table 10 shows that over

31 years, there were 9 wet years, 12 normal years, 4 slight drought years, 6 moderate drought years, and no severe drought years.

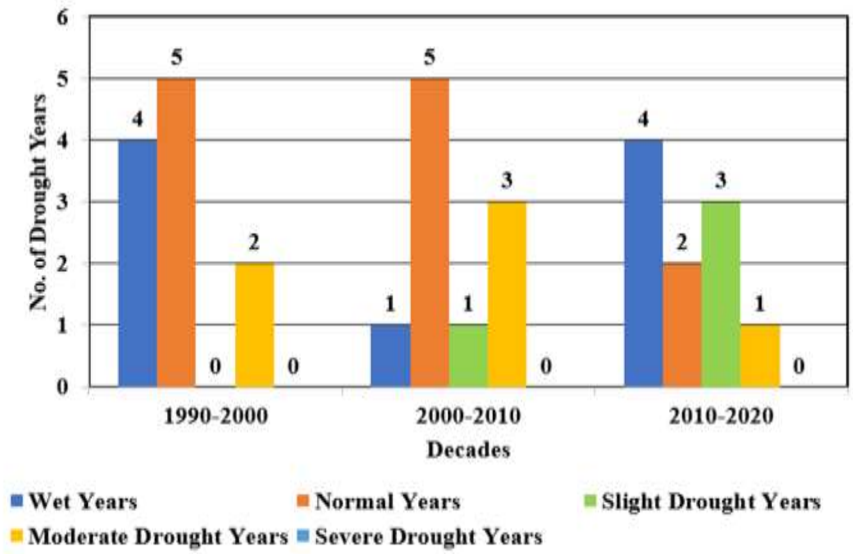

Figure 9: The numbers and type of drought years per decade

4.1.2 Streamflow Drought Index (SDI)

More precise severity analysis was made using the streamflow drought index considering the monthly analysis. The index value for each month during the thirty-one-year period is calculated and classified according to the drought severity range in which it falls. Based on the range of the stream flow drought index, Table 11 displays the number of months in each type of drought severity.

Table 11: Drought classification according to the SDI values [13]

Sr. No.	Description	Range	Months	%
1	Extremely Wet	≥ 2	10	2.69
2	Severely Wet	1.5-1.99	16	4.30
3	Moderately Wet	1-1.49	40	10.75
4	Slightly Wet	0.5-0.99	44	11.83
5	Normal	-0.49 to +0.49	144	38.71
6	Mild Drought	-0.5 to -0.99	53	14.25
7	Moderately Drought	-1 to -1.49	47	12.63
8	Severely Drought	-1.5 to -1.99	14	3.76
9	Extremely Drought	≤ -2	4	1.08
	Total		372	100

Ten extremely wet months, sixteen severely wet months, forty moderately wet months, forty-four slightly wet months, 144 normal months, fifty-three mild drought months, forty-seven moderately drought months, fourteen severely drought months, and four extremely drought months have been recorded over the course of thirty-one years. The percentages for extremely wet months and severely wet months are 2.69 and 4.3%, respectively, 10.75% and 10.83% for moderately wet months and slightly wet months, 38.71% for normal months, 14.25% for mild drought, 12.63% for moderately drought months, 3.76% for severely drought months, and 1.08% for extremely drought months.

Figure 10 presents monthly drought intensity for each decade from 1990 to 2020. In 1990-2000, there were 63 normal months, 18 moderately drought months, 14 mild drought months, and 9 severely wet months [18]. From 2001 to 2010, extremely wet months rose to 5, slight drought months increased by 44%, and normal months reduced by 32%. The second decade (2001-2010) is notable for its 4 extreme drought months. In the final decade (2011-2020), slightly wet months increased from 12 to 24, while moderately drought months slightly decreased from 15 to 14.

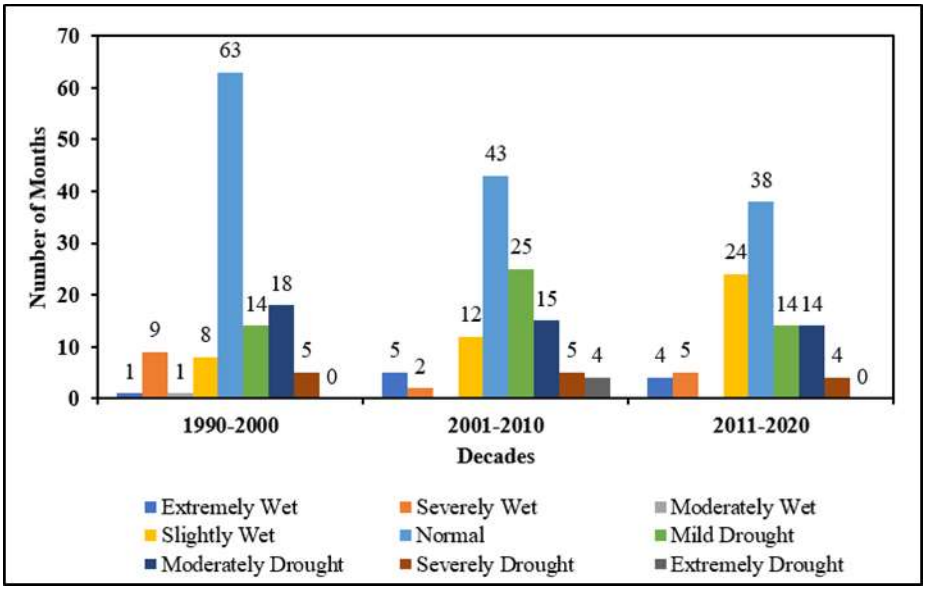

Figure 10: Number of months for each drought severity levels for 31 years

4.1.3 Drought frequency using Low Flow Frequency Analysis Method

Figure 11 presents the minimum annual flows of the Kunhar River from 1990 to 2020, illustrating the variation and overall trend of low flows over the 31-year period. The chart indicates that the lowest recorded minimum flow was 1.09 m^3/s, the highest was 13.87 m^3/s, and the overall average of the annual minimum flows was 5.84 m^3/s. These fluctuations reflect periods of significantly reduced water availability, which could be linked to changing climatic conditions or variations in seasonal precipitation. Such information is crucial for understanding the hydrological behavior of the river, especially during dry periods, as it supports the assessment of water resource reliability for ecological, agricultural, and domestic uses [19], [20].

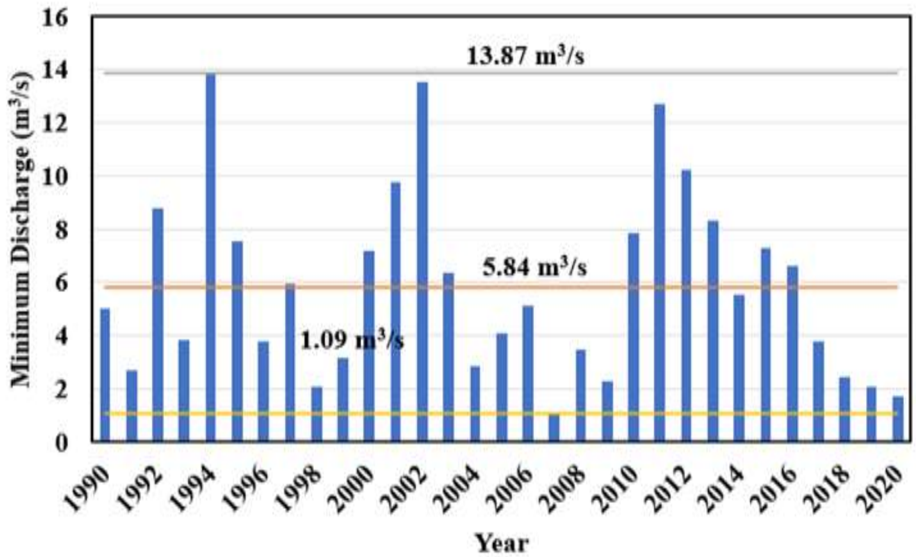

Figure 11: Minimum flow of each year

Figure 12 shows the frequency distribution of these low flows, grouped into five ranges: 0–3 m³/s, 3.1–6 m³/s, 6.1–9 m³/s, 9.1–12 m³/s, and 12.1–15 m³/s. The analysis indicates that flows between 3.1–6 m³/s occurred most frequently, representing 32% of the observations, followed by 0–3 m³/s and 6.1–9 m³/s, each contributing 26%. Flows within 9.1–12 m³/s and 12.1–15 m³/s were much less frequent, accounting for 6% and 10%, respectively. This frequency analysis highlights the predominance of low to moderate flows in the river, which are critical to consider when planning water management strategies, ensuring ecological sustainability, and preparing for potential drought conditions.

Table 12 further supports this analysis by showing the predicted low-flow discharges for different return periods using three statistical methods: Log-Normal, Log Pearson Type-III, and Gumbel EV-I. It can be observed that as the return period increases, the estimated

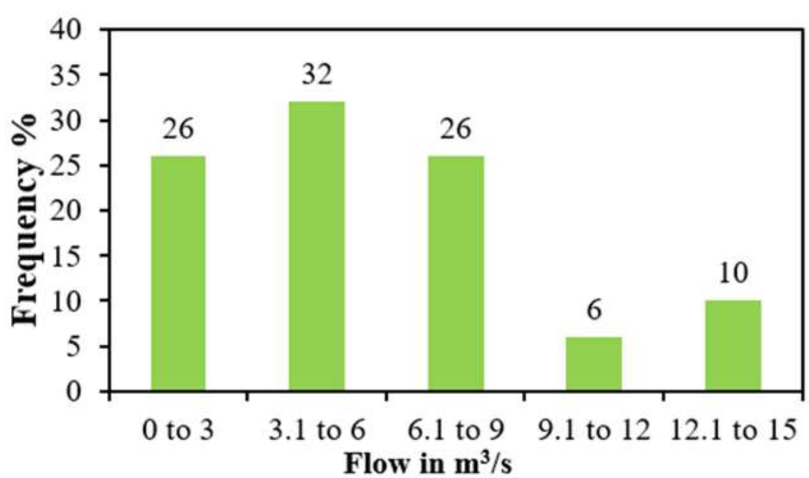

Figure 12: Frequency trend of low flow returns

low flows also increase across all methods. For example, for a 2-year return period, the predicted flows range from 23 m³/s (Gumbel) to 84 m³/s (Log Pearson Type-III), while for a 1000-year return period, they range between 4 m³/s and 5 m³/s. These results help estimate the likelihood of extreme low-flow events over different time scales, which is crucial for long-term water resource planning and drought risk management.

Table 12: Low flow discharges for various return periods

Return Periods	Log-Normal	Log Pearson Type-III	Gumbel EV-I
		Flow (m^3/s)	
1000	5	4	5
500	8	12	8
200	11	18	10
100	15	24	12
50	18	33	13
25	22	44	17
10	31	56	21
2	36	84	23

4.2 Flood Frequency Analysis Results

To determine which probability distribution best fits our sample data, the discharges produced for different return times using the log-normal method, log Pearson type-III method, and Gumbel EV-I method were tested using the method of confidence limits.

4.2.1 Confidence Limit for Log Normal Distribution

Figure 13 summarizes discharge data for various return periods, with uncertainty and confidence ranges at 80% and 90%. It displays the expected discharges (m^3/s), the probable error (b) in terms of uncertainty, and the standard error (Se) for precision.

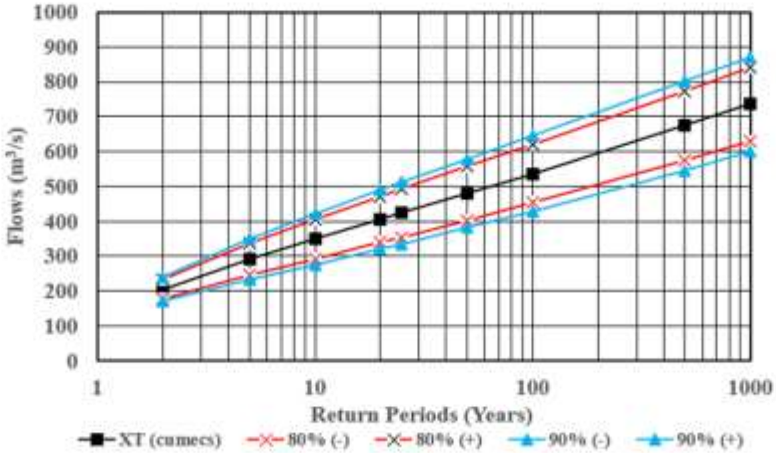

Figure 13: Graphical representation of the confidence limits for discharge data for Log Normal Distribution

4.2.2 Confidence Limit for Log Pearson Type-III

Figure 14 displays the discharge data for various return periods, with uncertainty and confidence ranges at 80% and 90%. It displays the projected flow in m^3/s, the probable error (b) in terms of uncertainty, and the standard error (Se) for precision.

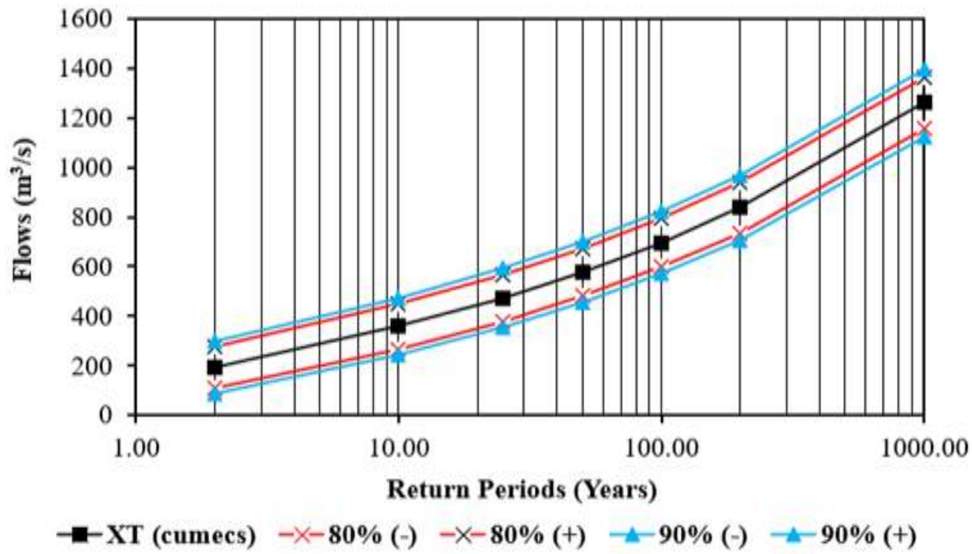

Figure 14: Graphical representation of the confidence limits for discharge data for Log Pearson Distribution

4.2.3 Confidence Limit for Gumbel EV-I

Figure 15 shows discharge data for various return periods, with uncertainty and confidence ranges at 80% and 90%. The probable error (b) represents uncertainty, whereas the standard error (Se) represents precision.

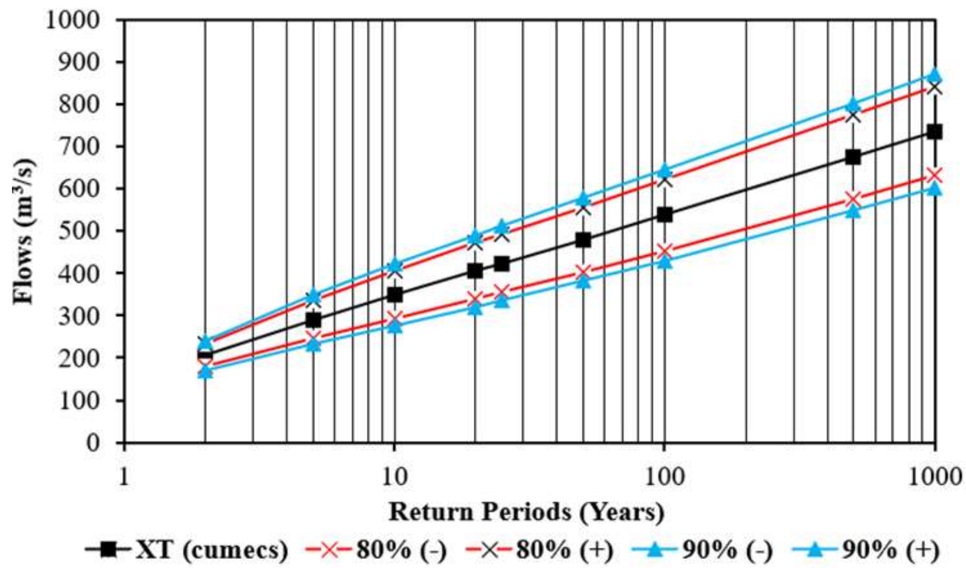

Figure 15: Graphical representation of the confidence limits for discharge data obtained by the Gumbel Method

4.3 Comparison of Flood Frequency Analysis Results

Three statistical methods—Gumbel Extreme Value Type-1, Log-Normal, and Log Pearson Type-III—for estimating flow magnitude over different return periods are contrasted in Table 13. These techniques yield a range of flow estimates, enabling decision-makers to select the best one. This comparison aids in evaluating how well each method estimates extreme flow events. Because it fits the best on a confidence limit chart with no outliers, Log Pearson Type-III is the best-fitting of the three statistical techniques.

Table 13: Comparison of flood frequency analysis results

Serial Sr. No.	Return Period (Years)	Gumbel EV-I (m^3/s)	Log Pearson Type-III (m^3/s)	Log Normal (m^3/s)
1	1000	797	1260	736
2	500	734	973	674
2	100	589	696	537
3	50	526	576	480
4	25	462	473	423
5	10	377	357	349
6	2	207	193	206

Table 14 represents the flow against different return periods of 2, 10, 25, 50, 100, 500 and 1000 years.

Table 14: Coefficient of determination (R2) values for different distributions

Methods	Log-Normal (m^3/s)	Log Pearson Type-III (m^3/s)	Gumbel EV-I (m^3/s)
R^2 value	0.6971	0.786	0.528

The Gumbel, Log Pearson Type III (LP-III), and Log Normal methods were used to estimate the flood flows for different return times. The flows were roughly 207, 193, and 206 m^3/s throughout a two-year return period. 589, 696, and 537 m^3/s were the flows over a 100-year return period. The LP-III method consistently provided higher values, especially for extreme return periods like 500 and 1000 years, where the flows reached 973 and 1260 m^3/s. Based on R^2 values, the LP-III distribution best fits the data, indicating more accurate flood prediction for larger return periods.

5. Conclusions:

- Hydrological drought analysis by using the mean annual flow approach found that from 1990 to 2000, there were 4, 5, and 2 wet years, normal years, and moderate drought years respectively. From 2000 to 2010, there were 1, 5, 1, and 3 wet years, normal years, slight drought years, and moderate drought years respectively. Also, from year 2010 to 2020, there were 4 wet years, 2 normal years, 3 slight drought years, and 0 severe drought years.

- Hydrological drought analysis monthly from the year 1990 to the year 2020 using the streamflow drought index (SDI) revealed that there were 10 extremely wet months, 16 severely wet months, 40 moderately wet months, 44 slightly wet months, 144 normal months, 53 mild drought months, 47 moderately drought months, 14 severely drought months, and 4 extremely drought months in this period.
- The low-frequency analysis method shows that low flow frequency has grown in recent years, resulting in lower minimum flow values in recent years as compared to the earlier years. The overall frequency of low flow range 3.1 to 6 m^3/s is the highest and is about 32%. For return periods of 2, 10, 25, 50, 100, 500, and 1000 years, low flows of magnitude 4.39, 11.54, 17.93, 24.50, 33.01, 44.04, 55.98 and 84.02 m^3/s are found respectively.
- Of the three, the Log-Pearson Type III probability distribution fit the flood frequency analysis the best. This approach yielded discharges of 193, 357, 473, 576, 696, and 1260 m^3/s for return times of 2, 10, 25, 50, 100, 500, and 1000 years, respectively.

6. Recommendations:

Based on the findings of this research, the recommendations for the researchers which can be explored are given below;

- The study's findings should be helpful in determining the dimensions of hydraulic and civil structures, such as dams and bridges, during a design life of more than a century.
- Climate change impacts and changes in land use over different years can provide a more comprehensive understanding of the study area. This could involve analyzing historical climate data and using remote sensing techniques to compare land use maps from different periods.
- The Outcomes from this study and its findings may aid the water resource managers to develop measures for reducing the risk of future floods and droughts.

References

[1] M. A. Pasha, "Sindh drought 2014 – Pakistan: Was it a natural or a man-made disaster.," Amer. J. Soc. Sci, pp. 16–20, 2015.

[2] D. Guha-Sapir, F. Vos, R. Below, and S. Ponserre, "Annual disaster statistical review 2010," Centre for Research on the Epidemiology of Disasters, pp. 1–80, 2011.

[3] K. Subramanya, Engineering Hydrology, 4th ed. Tata McGraw-Hill Education Pvt. Ltd., 2013.

[4] S. Doocy, A. Daniels, S. Murray, and T. Kirsch, "The Human Impact of Floods: A Historical Review of Events 1980-2009 and Systematic Literature Review," PLoS Curr, vol. 5, Apr. 2013, doi: 10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a.

[5] M. Tanoue, Y. Hirabayashi, and H. Ikeuchi, "Global-scale River flood vulnerability in the last 50 years," Sci Rep, vol. 6, Oct. 2016, doi: 10.1038/srep36021.

[6] V. T. Chow et al., "Streamflow evaluation for watershed restoration planning and design: an interactive guide for Oregon streams," Oregon, U.S, 1991.

[7] "International Commission on Large Dams."

[8] S. Afreen and F. Muhammad, "Flood frequency analysis of various dams and barrages in Pakistan," Irrigation and Drainage, vol. 61, Feb. 2012.

[9] D. Caissie, G. Goguen, N. El-Jabi, and W. Chouaib, "Fitting flood frequency distributions using the annual maximum series and the peak over threshold approaches," Canadian Water Resources Journal , vol. 47, pp. 1–15, Mar. 2022.

[10] D. Eckstein, V. Künzel, L. Schäfer, and M. Winges, "Global climate risk index 2020," Berlin, Dec. 2018.

[11] S. Barbetta et al., "Assessment of Flooding Impact on Water Supply Systems: A Comprehensive Approach Based on DSS," Water Resources Management, vol. 36, no. 14, 2022, doi: 10.1007/s11269-022-03306-x.

[12] P. Klingemann, "Streamflow Evaluation for Watershed Restoration Planning and Design: An Interactive Guide for Oregon Streams," Oregon, U.S, 2005.

[13] I. Nalbantis and G. Tsakiris, "Assessment of hydrological drought revisited," Water Resource Management, vol. 23, pp. 881–897, Jul. 2009.

[14] N. Millington, S. Das, and S. Simonovic, The Comparison of GEV, Log-Pearson Type 3 and Gumbel Distributions in the Upper Thames River Watershed under Global Climate Models. 2011.

[15] V. P. Singh, "Log-Pearson Type III Distribution," in Entropy-Based Parameter Estimation in Hydrology, V. P. Singh, Ed., Dordrecht: Springer Netherlands, 1998, pp. 252–274. doi: 10.1007/978-94-017-1431-0_15.

[16] G. AL-MASHIDANI, P. B. B. LAL, and M. F. MUJDA, "A simple version of Gumbel's method for flood estimation" Hydrological Sciences Bulletin, vol. 23, no. 3, pp. 373–380, Sep. 1978, doi: 10.1080/02626667809491810.

[17] M. H. I. Dore, "Climate change and changes in global precipitation patterns: What do we know?" 2005. doi: 10.1016/j.envint.2005.03.004.

[18] M. F. Ul Moazzam, G. Rahman, S. Munawar, A. Tariq, Q. Safdar, and B. G. Lee, "Trends of Rainfall Variability and Drought Monitoring Using Standardized Precipitation Index in a Scarcely Gauged Basin of Northern Pakistan," Water (Switzerland), vol. 14, no. 7, 2022, doi: 10.3390/w14071132.

[19] T. Zhu and C. Ringler, "Climate change impacts on water availability and use in the Limpopo River Basin," Water (Switzerland), vol. 4, no. 1, 2012, doi: 10.3390/w4010063.

[20] M. D. Peña-Guerrero, A. Nauditt, C. Muñoz-Robles, L. Ribbe, and F. Meza, "Drought impacts on water quality and potential implications for agricultural production in the Maipo River Basin, Central Chile," Hydrological Sciences Journal, vol. 65, no. 6, 2020, doi: 10.1080/02626667.2020.1711911.