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Design Discharge Estimates from Frequency Analysis of Annual and Summer Maximum Flow Series

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Abstract

Floods, one of the most common and destructive natural disasters, have always been a significant part of Earth's history. Extreme flood occurrences can sometimes have a long-lasting effect on hydrologic systems. Therefore, planning, designing, and managing a variety of facilities require a hydrologic and hydraulic understanding of floods. Hydrologic flood frequency analysis is a method of forecasting future frequencies of floods by utilizing statistics and probability. In this study, the discharge data of River Jehlum in Kashmir-India, was analysed for annual & summer maximum flood peaks and flood frequency analysis was performed on nine gauging stations, using probability distributions. These included gamma distribution, Log Pearson Type-III distribution & Extreme Value Distribution (EV-I). The corresponding PDF, CDF, shape, scale & location parameters were obtained, fitting distributions, calculating flood quantiles and subsequently results were plotted. Corresponding confidence intervals at 95% were also constructed for flood quantiles from the best fitted distribution. The frequency curves obtained were compared with empirical estimates. The 100-year return period flood discharge was obtained at all the gauging stations which is useful in design of hydraulic structures. The delineation of River Jhelum watershed and sub basins was done in ArcGIS software using 30m SRTM Digital Elevation Model-DEM. The seasonality of discharge peaks and the corresponding extreme magnitude variations were studied to relate the seasonality of flood peaks with magnitudes. Rainfall and snowmelt contribute to the flood discharge, and the relative contribution of each changes with the season. The study has completed flood frequency analysis at each gauging station on River Jhelum and obtained the design discharge both for annual and summer data for comparison.

Keywords: Flood; Frequency Analysis; quantiles

Introduction

Floods are the most common and destructive natural calamities that have always played a significant role in Earth's geologic history. Flooding occurs when a river reaches an extra ordinary high level, commonly when the river bursts its banks and floods the region around it [Subramanya 2008]. Floods affected more than 178 million people in 2010, according to a detailed study by Jha et al. [2012]. Kashmir valley has faced widespread destruction due to floods in the past. Due to continuous rainfall and cloudbursts in September 2014, Jhelum River overflowed and breached at various places. This resulted in localized destruction of property, public infrastructure and severe impact on life, communities, and communication. The problem was magnified in the urban areas and cities. Extreme flood occurrences can sometimes have an impact on hydrologic systems. Therefore, the planning, construction, and management of many different types of hydrological systems within watershed, require the hydrologic and hydraulic study of floods.

Flood Frequency Analysis

Extreme flood events are inversely correlated with frequency, more seldom do very severe events occur than more mild ones, which occur regularly. Relating the size of extreme events to their frequency of occurrence-recurrence interval is the main goal of frequency analysis of hydrologic data. The term "recurrence interval," which is synonymous with "return period," can also be used to describe the average amount of time during which the size of a hydrologic event will typically be equaled or exceeded once. Hydrologic frequency analysis is a method for estimating frequencies (probabilities of hydrologic events occurring) based on data from hydrologic records utilizing probability and statistical analysis. In order to acquire an accurate frequency estimate and a standard for evaluating the reliability of this estimation, the observed data is analyzed using a variety of statistical approaches.

Hydrologic Statistics

In the application of statistical techniques to hydrologic frequency analysis, probability distributions are applied. The conclusions regarding the true population (all possible occurrences) for the theoretical distribution under examination are then formed from the hydrologic events that have already occurred, which are taken into account as a random sample (set of observed events).These conclusions are subject to uncertainty since a set of observed hydrologic occurrences only represents a sampling subset of the several sets of physical conditions that may represents the population denoted by the theoretical probability distribution. There are several frequency analysis techniques currently in use, as well as a wide range of ideas and points of view. Hydrologic frequency determination has previously employed a variety of probability distribution types.

Objectives of the Study

In the current study, flood frequency analysis has been performed on River Jhelum in Kashmir at various Gauging & Discharge measuring stations to obtain the 100-year design discharge. Past records of yearly discharge data were obtained from the Jal-Shakti, Kashmir Irrigation & Flood Control Department. The seasonality of these annual maximum flood peaks, along with the magnitude and monthly variation was studied and plotted in the form of bar charts presented in Figure-3. Flood frequency analysis was performed on the data of annual maximum discharge series. Different Probability distributions were fitted to the data and the best fit was obtained with the help of certain statistical tests. In addition, flood frequency analysis was performed on the annual summer peaks, from the available annual discharge peak series. The summer data included annual discharge peaks observed in the months of June, July, August and September. The main objectives of the study include

1. Construction of Flood flow Frequency Curves at various locations of River Jhelum by fitting different probability distributions to the observed discharge data. The guidelines in USGS Bulletin 17C have also been adopted.
2. Flood Frequency Analysis using various empirical methods, comparison with the fitted curves and selection of best fitted distribution.
3. Reduce uncertainty in flood frequency estimation by achieving 95% Confidence Intervals and level of significance.
4. Calculation of flood discharges for 1, 2, 5, 10, 20, 50 and 100 year return period.
5. Delineation of River Jhelum watershed and sub basins done with the help of ArcGIS software using 30m SRTM Digital Elevation Model-DEM.
6. To study the seasonality of floods and comparison of peak magnitudes in different seasons.
7. Comparison of annual and summer Flood Frequency curves and the design discharge obtained thereof.

Study Area and Data Collection

River Jhelum is a part of the Indus River System which passes through Pakistan and India before joining the Chenab River and the Indus River, emptying into the Arabian Sea via the Indus delta. The river originates from a deep spring at Verinag, in J&K State's south-eastern region of Kashmir at the base of the massive Pir Panjal mountain range. The River flows from its source in southern Kashmir to the northwest at different speeds. It is the main drainage canal for Kashmir Valley, a low-lying bowl-shaped region bordered on all sides by mountains and hills. From Khanabal to Banayari -the inlet of Wular Lake, River Jhelum travels a distance of 125.17 kilometers. After emerging out from Wular lake, the river is known as Out Fall Channel and is joined by Ningli Nallah just downstream of Wular lake from left bank. River enters the Khadanyar gorge after covering a distance of 28.8 km from Wular Lake.

Catchment Area

The total catchment area of River Jhelum upto Wullar Lake is 8763 Km^2, whereas upto Pakistan border it is 12759 km^2. The catchment area upto Sangam is 4138 Km^2. The area above elevation of 3000m is mostly under permanent snow cover. The catchment between elevations of 2000 to 3000m is covered by flora and the lower elevations are mainly under dry and wet crop cultivation. Important tributaries of River Jhelum are listed in Table 1 & 2. It can be seen that Pohru Nala has largest catchment area whereas smallest catchment is drained by Vij-Dakil Nallah. Further smallest length tributary is Erin and longest tributary is Pohru Nallah.

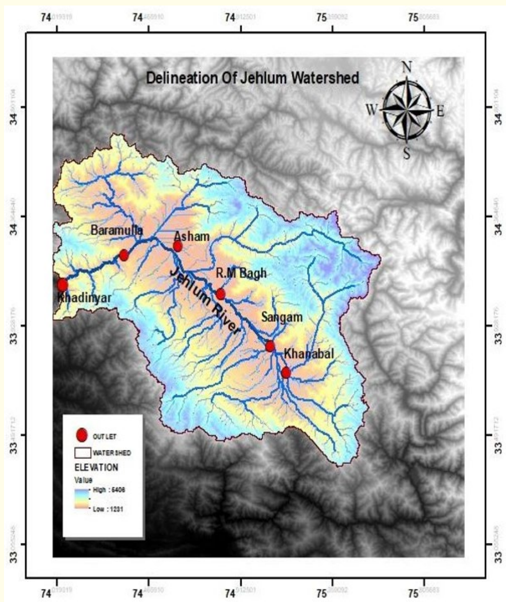


Figure 1: Delineation of Jhelum basin done in ArcGis using 30m SRTM DEM. The red dots depict gauging stations/ stream outlets. The variation in colours show elevation ranging from 6408 mts to 1231mts.The thickness of lines depicts the stream order. The brown coloured line demarcates the watershed boundary.

S. No	***Sub Basin***	***Catchment Area (sq km)***	***Length (km)***	***S. No***	***Sub Basin***	***Catch Area (sq km)***	***Length (km)***
Left Bank Tributaries				***Right Bank Tributaries***			
1	Lidder	1229	110	12	Aripath	291	30
2	Vishaw	994	72	13	Bringi	676	49
3	Rambiara	702	66	14	Sandran	473	53
4	Romshi	338	52	15	Aripal	618	24
5	Vij-Dakil nallah	103	30	16	Sindh	1560	138
6	Dodhganga	756	49	17	Pohru	1837	177
7	Sukhnag	433	57	18	Erin	251	13

8	Ferozpura	446	52	19	Mahumati	420	39
9	Ningal Nallah	200	31	20	Dachigam	336	37
10	Gundar	164	16				
11	Lower Jhelum	1061	60				

Source: https://sandrp.files.wordpress.com/2017/06/jammu-kashmir-rivers-profile.pdf

Table 1: Important Tributaries of River Jhelum.

S. No	*Station*	*Latitude*	*Longitude*	*District*
1.	Khanabal	33°44’21.92”	75°08’3.61”	Anantnag
2.	Sangam	33°50’39.98”	75°03’22.47”	Anantnag
3.	Awantipora	33°55’27.01”	75°00’36.23”	Pulwama
4.	Pampore	34°00’41.22”	74°54’37.59”	Pulwama
5.	Padshahi Bagh	34°04’19.54”	74°50’03.69”	Srinagar
6.	Ram Munshi bagh	34°04’19.54”	74°50’03.69”	Srinagar
7.	Shadipora	34°11’06.05”	74°40’27.76”	Baramulla
8.	Asham	34°14’48.18”	74°37’26.38”	Baramulla
9.	Baramulla	34°12’31.68”	74°20’47.09”	Baramulla

Table 2: Location of Gauging & Discharge stations on River Jhelum.

Annual Peak Flood Data of River Jhelum

Annual peak flood data at G & D sites maintained by Central Water Commission / Irrigation & Flood Control Department for a period of at least recent 30 years are desirable for carrying out the analysis to derive design flood. In the present scenario the data for more than 60 years (1957 to 2021) at Khanbal, Sangam, Awantipora, Ram Munshi Bagh, Padshahi Bagh, Asham & Baramulla, 56 years at Shadipora (1957 to 2020) and 38 years of data at Pampore were available, with some missing data years.

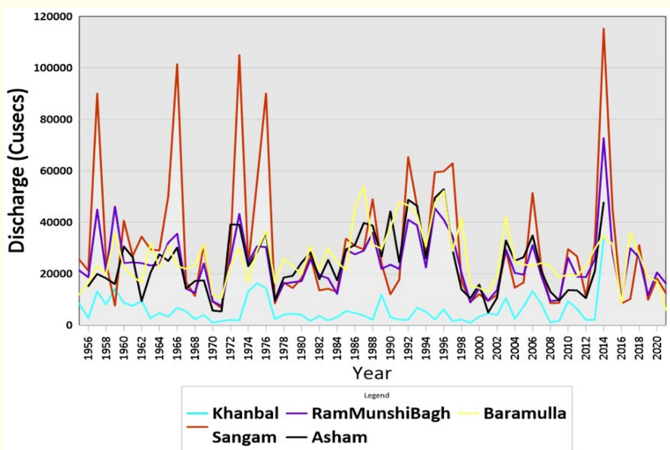


Figure 2: Annual Maximum Observed Discharge of Important G&D Stations located on Jhelum.

The annual maximum discharge recorded from the year (1955-2021) on important gauging stations located on River Jhelum is shown in Figure-2. Sangam is the confluence of two important tributaries of River Jhelum ie. Vishow and Rambiara, with the discharge of Lidder nallah as well, and hence records the maximum discharge. This is followed by RamMunshiBagh station in Srinagar and Asham in Baramulla.

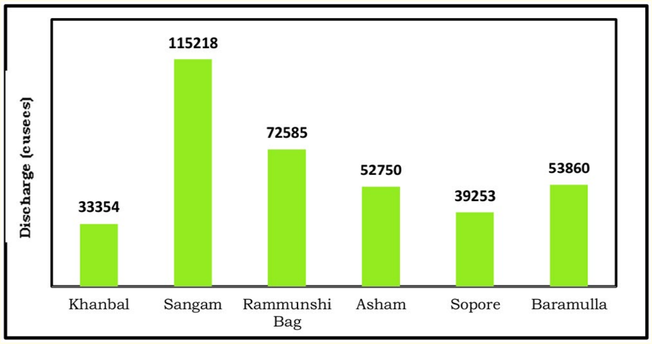


Figure 3: Maximum observed discharge in Jhelum Basin (cusecs). The maximum ever discharge located on important gauging stations.

Methodology

Fitting of a Probability Distribution

An illustration of the possibility that a random variable will occur is called a probability distribution. By fitting a distribution to a set of hydrologic data, a significant portion of the sample's probabilistic information can be condensedly expressed in the function and its related parameters. The maximum likelihood approach and the moments method can both be used to fit distributions.

A probability density function (PDF) is a continuous mathematical expression that determines the probability of an event. The best estimates, which are frequently extrapolations of the chance of an event occurring, should be provided by the distribution that best matches the collection of hydrologic data. Gamma distribution, Extreme value type I (EV- I), or Gumbell distribution, and Log Pearson Type III distributions are the probability distributions chosen for this investigation. Their essential properties are given below.

Log Pearson Type-III distribution

Probability Density function $f(x)$

$$f(x)=\frac{\lambda^{\beta}(x-\epsilon)^{\beta-1}\, e^{-\lambda(y-\epsilon)}}{x\Gamma(\beta)}$$

where $y = \log x$

Gamma Distribution

The sum of independent, identical random variables with exponential distributions is represented by the gamma distribution, which also has shape and scale parameters. The gamma distribution is an eclusive case of the exponential distribution, Erlang distribution, and chi-square distribution.

The corresponding probability density function with the shape & scale parameters is

$$f(x) = \frac{x^{\alpha-1}}{\beta^{\alpha}} \frac{e^{-x/\beta}}{\Gamma(\alpha)}$$

Where Γ is the gamma function.

In this study, the gamma distribution was fit to the set of annual maximum discharge readings in all the G&D stations of river Jhelum using fit distribution plus package in R-studio. This provided the shape α and scale parameters β of the distribution and generated the respective density plots, Q-Q plots, P-P plots, CDF's of the theoretical versus empirical probabilities, for each station. The shape parameter affects the shape of distribution & the larger the Scale parameter β, the more spread out is the distribution.

Probability Plots

A probability plot, often known as a Q-Q (quantile-quantile) plot, is a graphical tool for contrasting two probability distributions by showing their quantiles in opposition to one another Figure-4. In order to compare the data set to the theoretical interpretation, the corresponding Q-Q plots acquired for the G&D stations were evaluated. This analysis gave a graphical assessment of "goodness of fit" as compared to a numerical summary.

A P-P plot works by plotting the two cumulative distribution functions against each other; if they are similar, the data will appear to be a straight line. A P-P plot can be used as a graphical test of the fit of probability distributions.

Estimation of quantiles

The fitting of distribution was followed with the estimation of quantiles of Gamma distribution, and additionally constructing 95% confidence intervals(upper and lower) for the quantiles. The Discharge quantiles obtained were thus plotted against the return period, to perform flood frequency analysis and obtain 1,2,5,10,20,50 and 100 year return period discharge.

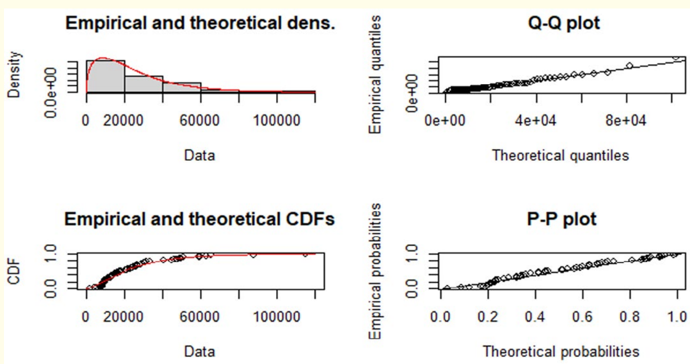


Figure 4: Gamma distribution fit- Density plots, Q-Q plots, P-P plots & CDF's of the theoretical versus empirical probabilities- G&D Station Sangam. The plot at top left depicts the comparison of theoretical (red line) versus empirical PDF's, Bottom right compares corresponding CDF's. The Q-Q and P-P plots are the respective Quantile Quantile & probability plots, for comparing the probability distributions.

Log Pearson Type III Distribution-Empirical:

By arranging the data in descending order of magnitude, with a rank assigned and then to transfer the original series of peak flow data into log domain, we could fit the log Pearson Type III distribution to the observed data. Using the Cunnane Plotting Position formula, the probability of non-exceedance corresponding to the T-yr recurrence interval was assigned to each variate. For the log converted series, the mean, coefficient of skewness (CS) and standard deviation were calculated. The frequency factor was calculated. The frequency factor depends on the return period and the coefficient of skewness (CS) = 0. It is equivalent to the standard normal variable (z) and was approximated using the equation:

$$KT = Z + (Z_2 + 1)K + 12(Z_2 - 6Z)K_2 - (Z_2 - 1)K_3 + ZK_4 + 13K_5$$

where $K = C_s/6$

While KT was produced using the aforementioned equation, the value of z for a specific return period was calculated using the same method as was used with the log normal case. and

$$Y_T = \bar{Y} + K_T S_y \text{ and } K_T = 10Y_T$$

The Logpearson Type-III distribution was fitted to the annual maximum discharge series on various G&D Stations to perform flood frequency estimation using R-Studio Programming. The three parameters of distribution-shape, scale and location were obtained for the data at each station. LP-III distribution was fit to the data using Method of Maximum likelihood.

The qpIII function gives the discharge quantiles which are plotted against the Return Period (1/p) to obtain flood frequency curve.

Testing the goodness of fit

A statistical hypothesis test called "Goodness-of-Fit" evaluates how well observed data and expected data fit one other. Which type of distribution the sample follows can be determined with the aid of goodness-of-fit tests. A probability distribution's quality of fit can be evaluated by contrasting its theoretical and sample probabilities. It allows one to assess the degree to which a sample group actually reflects the total population.

Chi Square Test

The chi-square goodness of fit test is used to compare expected probabilities to multiple observed distributions. The R function chisq.test() is used to perform chi square test in R-Programming.

- The Chi square test was performed for the data sets at various G&D Stations of River Jhelum, for given observed values against expected probabilities.
- The level of significance: 0.05
- Null hypothesis: There is no significant difference between the observed and the expected value.
- The function returned the value of chi-square test statistic ("X-squared") and a p-value.
- P value =0.238 >0.05 was returned for G&D Stations Sangam and Khanabal.
- P value of 0.242>0.05 was returned for G&D Station Ram Munshi Bagh & Padshahibagh.
- P value of 0.2403>0.05 was returned for G&D Station Baramulla.
- P value of 0.2384>0.05 was returned for G&D Station Shadipora.
- P value of 0.2386>0.05 was returned for G&D Station Asham.
- P value of 0.240>0.05 was returned for G&D Station Pampore.

Null hypothesis cannot be rejected.

However, for G&D Station Awantipora, pvalue=5.932e-14<<0.05 significance level.

Hence Null hypothesis is rejected for Awantipora. The best fit distribution for this station being Log Pearson Type-III.

Flood Seasonality and Magnitude

Seasonality of Annual Maximum Peaks

The Annual maximum discharge peaks at each G&D station on river Jhelum were analyzed and arranged in descending order. It was observed that maximum discharge peaks occur mostly between the months of March and September every year on all the G&D Stations, although maximum peaks have also rarely been observed in the month of October. The yearly discharge peaks were arranged as per their month for each data year. The frequency of discharge peaks for each month in the data period was then plotted in the form of bar charts, Figure-5, where N represents the number of years for which annual maximum discharge data is available for the respective station.

The frequency bar of maximum annual discharges on river Jhelum, indicate strong flood seasonality in the month of May for all the G&D stations, except Awantipora. The spring floods indicate the presence of early snowmelt in the discharge. Together with rainfall of even a shorter duration results in considerable discharge magnitudes. As per studies, the contribution of snowmelt has been found at approx.70% in the month of May, followed by June with 64%.

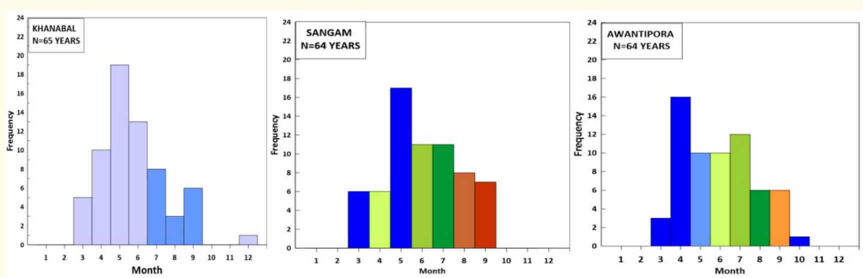
Magnitude

The Color in the caption depicts the average Magnitude of these discharge peaks recorded for a particular month in the annual series. Red color indicates highest average magnitude of (45000-50000) cusecs and above for that month. Green indicates the average magnitude variation between 15000-30000 cusecs. Whereas, light blue indicates the minimum average magnitude, for that month ranging between (0-5000) cusecs.

Conclusions

Although, May is the month of Maximum discharge peaks in terms of frequency of occurrence, but the average magnitude strongly indicates that extreme floods have been witnessed in the month of September. The months of June and July have also witnessed floods with a considerable magnitude.

- The maximum number of annual discharge peaks in the month of May, strongly indicate the presence of high snowmelt, attributing to the fact that snowmelt is an important process indicator for floods in River Jhelum.
- Extreme floods witnessed in the month of September, when snowmelt contribution is less and corresponding precipitation has been high, clarifies that long duration rainfall is the main causative factor for causing extreme floods in the past
- The presence of antecedent soil moisture is also in an important catchment characteristic, which however is beyond the scope of this study.



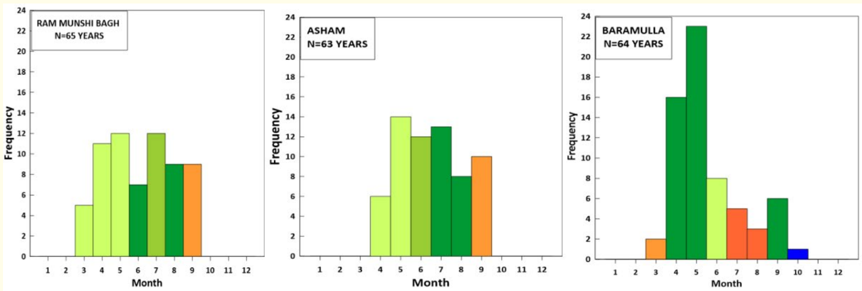
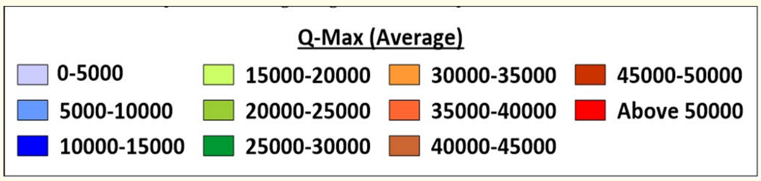


Figure 5: Seasonality of Maximum Annual discharge peaks (Q-Max) for G&D stations on River Jhelum. The Color bar depicts the Average Magnitude of these peaks (Cusecs) recorded in each month of the year.



Design Discharge Estimates

The design discharge for various gauging stations was calculated for return periods of 2, 5, 10, 20, 50 and 100 year using empirical methods as well as from frequency curves. The discharge estimation was done for both the annual maximum series and the summer maximum flow series. The results have been presented in Table 3. The summer months being June, July, August and September.

Comparison of Annual and Summer Discharge estimates

The comparison of annual and summer discharge estimates for a particular return period, indicates that extreme flood events can be expected more frequently if summer analysis is considered (partial duration series).

STATION		***Discharge (Cusecs)***					
Return Period		***2Yr***	***5Yr***	***10yr***	***20yr***	***50Yr***	***100Yr***
Khanabal	Gamma Dist.	2000	7000	11500	17000	19000	22500
	Log Pearson III	2732	5723	8738	14000	19397	26189
	QMAX-JJAS	3979	9233	14392	23127	31463	41539
Sangam	Gamma Dist.	20000	40000	53000	67000	83000	97000
	Log Pearson III	19351	36838	51502	73605	92514	100000
	QMAX-JJAS	27494	52035	70321	94212	132000	133000
Awantipora	Gamma Dist.	19000	40000	52100	66000	82500	92500
	Log Pearson III	13709	24269	33667	48778	62767	79403
	QMAX-JJAS	19869	35325	47698	65736	80819	97240

Pampore	Gamma Dist.	20050	40000	51000	65100	85000	94000
	Log Pearson III	14572	27322	38545	56792	79394	93731
	QMAX-JJAS	19953	35512	48113	66517	82066	99188
Padshahi Bagh	Gamma Dist.	16200	29000	39000	46100	57000	65000
	Log Pearson III	16566	29117	38744	49000	63293	75001
	QMAX-JJAS	24170	40658	51977	66068	76254	86102
Ram Munshi Bagh	Gamma Dist.	20900	30000	40000	47000	56000	63000
	Log Pearson III	21038	34191	42530	51000	59075	65311
	QMAX-JJAS	26861	41549	50589	60984	67984	74385
Shadipora	Gamma Dist.	17000	26000	34000	39000	45300	51000
	Log Pearson III	16765	26745	33688	40683	49482	56300
	QMAX-JJAS	19108	30348	38335	48919	57055	65335
Asham	Gamma Dist.	18000	27000	34200	39600	46500	52200
	QMAX-JJAS	25429	38217	46147	55489	61982	68090
	Log Pearson III	22527	33515	40626	49332	55653	61752
Baramulla	Gamma Dist.	24900	33900	40000	46300	52000	57800
	Log Pearson III	22527	33515	40861	50150	57031	61593
	QMAX-JJAS	24645	38544	47630	58714	66624	74200

Table 3: Estimated discharges at various stations using different probability distributions (Annual & Summer peaks). The frequency analysis (Q-Max) for summer months June, July, August & September has been performed to get corresponding Q-Max for same return periods for comparison. The discharge for same return period is increasing considerably with summer analysis.

Results

The results were obtained after fitting various probability distributions to the data of annual maximum discharge series. The 100-year flood discharge has been calculated at each G&D station using various methods.

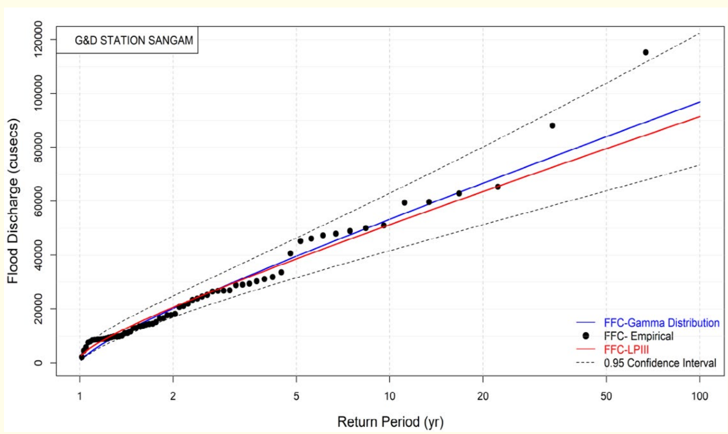


Figure 6: Flood Frequency Analysis at G&D Station Sangam by fitting gamma distribution and LP-III distribution with Confidence intervals at 95%, to the set of annual Q-Max data & comparison with the plot obtained by empirical calculations. (FFC-Flood Frequency Curve).

The data is first ranked from largest (m=1) to smallest m=65. Weibull's plotting formula is used $P={}^{m}/_{N+1}$. The observed data are plotted against the fitted curve. The frequency curve is generated by fitting Gamma distribution to the data, to linearize the plot, the log=X function is used as the horizontal axis.

The plot obtained for Sangam station (Figure-9) depicts that the fitted line is consistent with the observed data except for the outlier point, which departs significantly from the trend of the remaining data. The Water Resources council has recommended performing tests on outliers for keeping them or deleting, as the outlier points can significantly affect the distribution. Testing on outlier has not been performed in this study, which is beyond the scope of this study. The plot obtained for Ram Munshi Bagh (Figure-7) depicts that the fitted line is consistent with the observed data, except for outlier point; outlier testing is beyond the scope of this study. Both the distributions have a good fit, as is also depicted from chi square test.

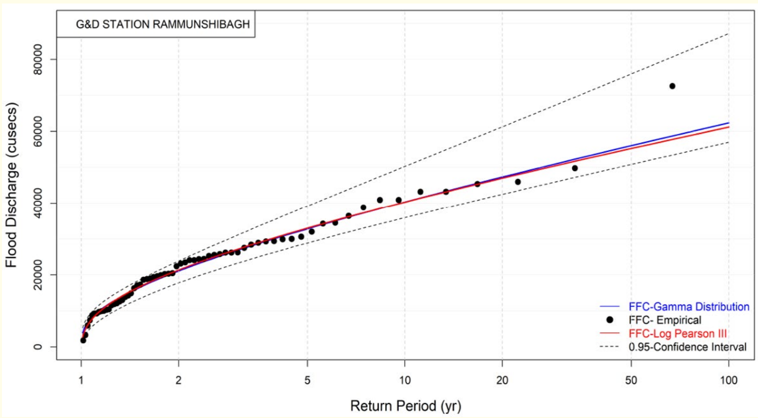


Figure 7: Flood Frequency Analysis at G&D Station Ram MunshiBagh by fitting gamma distribution and LP III distribution with 95% Confidence intervals, to the set of annual Q-Max data in "R" & comparison with the plot obtained by empirical calculations.

Comparison Flood Frequency Analysis Annual Data & Summer Data

A comparison was drawn by filtering the annual peaks for the summer months of June, July, August and September and flood frequency analysis was performed on summer peaks to obtain the peak discharge estimates for a return period. The results have been plotted for comparison on a single plot.

The analysis of flood frequency curves obtained from the data of annual peak discharges of summer months of June, July, August and September, depict a reduction in the return period for the same extreme flood event, when compared with the return period obtained from frequency analysis taking all the annual peaks. As for example, from Figure-8 (Sangam) the probability that a discharge of 1,00000 cusecs will be equalled or exceeded has a return period of 50 years with summer peak analysis, whereas for the same discharge, the return period is 100 years.

Also, the magnitude flood event of 2014 (115218 cusecs) has a return period of almost 100 years, against 150 years with annual peak flow analysis. Similar results have been obtained for other station; the return period is decreasing considerably for the same flood event.

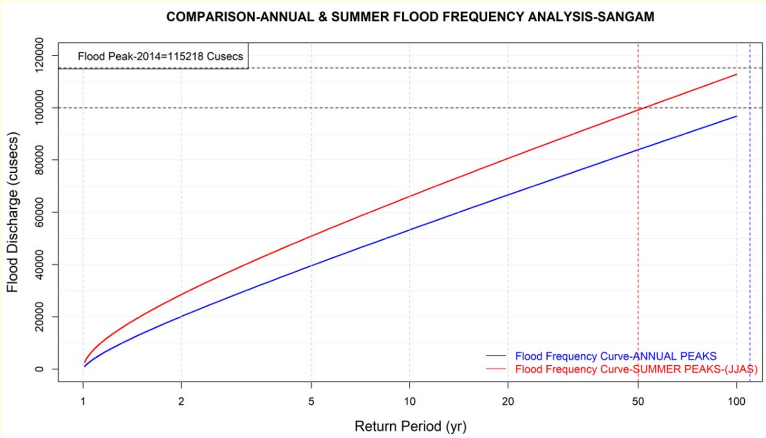


Figure 8: Flood Frequency Analysis at Sangam with discharge peaks from summer months (June, July, August, September) compared with annual discharge peaks (1956-2021).

Conclusions

After the completion of this research work, following conclusions have been arrived at, on the basis of the results obtained in the analysis completed so far.

1. In River Jhelum, May is the month of peak discharge in terms of frequency of occurrence, but the average seasonal magnitude strongly indicates that extreme floods in the past have been witnessed in the month of September. This indicates the possibility of peak discharges due to early snowmelt coupled with rainfall in the month of May. The September floods can be attributed to long duration rainfall.
2. The Gamma distribution has fitted better in most of the Gauging stations, as confirmed by the goodness of fit tests, though Log Pearson type-III distribution has also fitted well in G&D Station Awantipora.
3. The flood frequency analysis provided magnitude of 100year return period discharge, from the best fit distribution. The discharge calculations can be utilized for design of hydraulic structures.
4. After analyzing and comparing the flood frequency analysis performed with summer peaks, it can be concluded that 2014 flood can have a return period of 100 years for river Jhelum in Srinagar, which was earlier comprehended to be a 150 year return period flood, based on flood frequency analysis of annual discharge peaks.
5. Snowmelt contributes significantly to the spring and early summer peaks in river Jhelum, i.e May and June.
6. Extreme flood events can be expected to occur more frequently if frequency analysis is based on summer maximum flow series.
7. It is possible that because of lack of physical study of processes, the statistical distribution approach does not perform upto the expectations, when it comes to prediction of floods. Hence emphasis should be on understanding the physical basis.

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