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Full Length Research Paper

Flood frequency analysis of homogeneous regions of Jhelum River Basin

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Jhelum River is one of the major tributary of the Indus Basin River system. It drains the Northeast part of the Pakistan which includes the territory of occupied Kashmir, Azad Jammu and Kashmir, Northwest Frontier Province (NWFP) and Punjab. The major problem in the Jhelum River Basin is the scarcity of flow data. Therefore, under the circumstances of the lack of sufficient hydrological data, a regionalization technique was used to provide the estimate of the flow characteristics for unguaged catchments. The present study covers the Northeast part of the Pakistan up to the Mangla Dam. Maximum annual flow data for the selected fifteen gauging stations were assembled. Design flood for window (DFW) software for flood frequency analysis and MINITAB-11 were used for multiple linear regression analysis. The Gumbel distribution was found best fit by applying Chi-square test.

Key words: Flood frequency analysis, homogeneity test, Jhelum River Basin.

INTRODUCTION

A flood is commonly considered to be an unusually high stage of river flow. It is often the stage at which the stream channel becomes filled and starts overflowing its banks. When the flood rises above the banks, it overflows and causes damage to life and property in the adjoining areas.

The northern part of Pakistan is rich in surface water resources. The large river systems like the Indus and the Jhelum originate in this part, which makes it an attractive place for the exploitation of these precious resources. Jhelum River is one of the major rivers of the Indus Basin and contributes a good part of water supply to the system. The Jhelum River is an eastern tributary of the mighty Indus River. The catchment area of the Jhelum River is 33,000 km^2 and its length is about 500 km up to the Mangla Dam (Ahmad, 1993). A lot of hydropower potential is available on the tributaries of Jhelum Rivers. This potential needs to be exploited to a large extent. It is important to fulfill this basic need of life so as to improve the socio-economic conditions of the people there.

"Regional flood frequency analysis is used for the estimation of floods at sites where little or no data is available. It involves the identification of group (or regions) of hydrologically homogeneous catchments and the application of a regional estimation method in the identified homogeneous region" (Grehys, 1996). The flood frequency analysis procedures are based on general statistical and probability concepts and the data used in such analysis has to satisfy the criteria of homogeneity, independence, randomness and time invariance. Regional flood frequency analysis involves two major steps:

1) Grouping of sites into homogeneous regions.
2) Regional estimation of flood at the site of interest.

Flood frequency analysis for a station with a long record can be based almost exclusively on the record alone. However, when only short records are available, it is desirable to use a regional approach, which can also provide estimates of floods for sites (with no hydrologic

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and flow record available) through appropriate relationship of floods and catchment characteristics. The achievement of procedures recommended for regional frequency analysis mainly consists of correlating statistical parameters like mean, standard deviation, etc. of the annual flood peak series with catchment characteristics by use of multiple correlation procedures.

The catchment of the Jhelum River upstream of the Mangla Dam project consists of mountainous area. Many dams and rivers work for irrigation, and hydropower development have been proposed. Therefore, the conservation, control and regulation of the Jhelum River and its tributary have a strong direct bearing on the economic development in this area. There are number of rivers, tributaries and nullahs which are joining Jehlum River. For proper water resources management, sufficient amounts of hydrological data are required. But sufficient hydrological data on these rivers, tributaries and nullahs are not available. Some of the reasons behind the lack of the data are:

1) The area is mountainous with some of the world's highest mountains situated in it.
2) The accessibility of many places is very difficult, especially in the winter season.
3) The lack of revenue.

Moreover, the available stream flow records in some stations are too short to provide a reliable estimate for parameters of interest, such as flood events corresponding to a predetermined frequency interval, the seasonal flow characteristics at specified location etc. The objectives of flood frequency analysis of hydrological data are to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distribution (Haan, 1979). This information regarding the magnitude and frequency relationship is used in the design of flood control structures, dams, barrages and hydroelectric power plants.

Flood frequency analysis has been employed both to make the maximum use of short period records and to provide a means of estimating flood frequencies in engaged catchments. Despite the large number of stream gauging stations now in existence, these represent only a fraction of the sites from which flood data are needed for design purposes. In this way, data from homogenous regions, which need not be contiguous, are combined to increase the size of the data sample and this improve the statistical quality of the derived frequency distribution, assuming that the flood frequency curve based on the combined experience of a group of stations has firmer support than one based on the data at a single station (Roy, 1978).

There are several types of theoretical probability distributions (or frequency distribution functions) that have been successfully applied to hydrologic data (Mays, 2004). Some of the probability distributions commonly used for hydrologic variables were normal distribution, lognormal distribution, exponential distribution, gamma distribution, Pearson Type III distribution, Log-Pearson Type III distribution and extreme value distribution. Extreme value distribution is further subdivided into three form - EVI (Gumbel distribution), EVII (Frechet distribution) and EVIII (Weibull distribution).

The essence of cluster analysis is to identify clusters (groups) of gauging stations such that the stations within a cluster are similar while there is dissimilarity between the clusters. Many algorithms are available for performing cluster analysis (Everitt, 1980) because different types of variable (for example, catchment characteristics or flood statistics) can be used to define the similarity measure required to generate clusters; the variables used have to be carefully selected and weighted according to their importance for the actual problem (Burn,1989). The main objective of the present study was the identification of homogeneous regions for flood frequency analysis and to carry out the flood frequency analysis using multiple regression analysis for homogeneous catchments.

METHODOLOGY

The study was conducted on the gauging stations of the Jhelum River. A total of fifteen gauging stations on the Jhelum River were selected. The description of these stations is shown in Table 1.

The mean daily flow and catchment characteristics data (Table 2) of selected gauging stations were collected from Surface Water Hydrology of Pakistan (SWHP), WAPDA. The Gumbel curve method for identification of the homogeneous gauging stations and design flood for window (DFW) software for flood frequency was used. Four probability distributions (Gumbel/EV-1, P-III, LP-III and LN) were analyzed and maximum likely hood method was used to estimate the parameters of probability distributions. The Chi-square test was used for evaluation of these distributions, the Chi-square or Goodness of Fit test equation is as follows:

$$\chi^2 = \sum \frac{(\text{Observed Value - Expected Value})^2}{(\text{Expected Value})}$$

RESULTS AND DISCUSSION

Homogeneity test

The Gumbel curve method was used to identify the homogenous and non-homogeneous gauging stations. The detail of all these stations is shown in Table 2 and graphically shown in Figure 1.

Flood frequency analysis

Four probability distributions (Gumbel EV-1, Pearson Type III, Log Pearson Type III and Log Normal distribution) were used for the flood frequency analysis and maximum Likelihood method was adopted to estimate the parameter of probability distributions and for

Table 1. Catchment characteristics of selected gauging stations.

S/No.	Gauging station	Location	Catchment area (km^2)	Slope (%)	Length of channel (Km)	Mean elevation (m.a.s.l)	Mean annual rainfall (mm)
1	Azadpattan	Jhelum	26485	0.51	409	485	1367.79
2	Chinari	Jhelum	13598	0.55	275	1070	1624.18
3	Dollai	Jhelum	24406	0.53	405	606	1406.97
4	Domel	Jhelum	14504	0.58	300	701	1377.40
5	Dudhnial	Neelum	4905	0.38	150	1823	1168.44
6	G.H.Ullah	Kunhar	2382	2.25	140	820	1398.16
7	Karoli	Jhelum	14292	0.70	248	788	1335.70
8	Kotli	Poonch	3238	0.88	105	530	1340.61
9	Kohala	Jhelum	24890	0.57	359	560	1436.54
10	Mangla	Jhelum	33411	0.46	507	267	1001.96
11	M.Abad	Neelum	7278	0.55	250	670	1348.00
12	Naran	kunhar	1036	2.6	60	2400	1596.17
13	Nosheri	Neelum	6809	0.47	200	1030	1272.92
14	Palote	Kanshi	1111	0.6	50	400	875.00
15	Sopor	Jhelum	6500	0.57	305	1550	1200.56

Table 2. Homogeneous and non-homogeneous catchments.

Homogeneous catchments	Non-homogeneous catchments
Domel	Kohala
Dollai	Karoli
Nosheri	Naran
Dudhnial	Sopore
Garri Habib Ullah	Muzaffarabad
Azadpattan	Chinari
Mangla	
Kotli	
Palote	

evaluation of these distributions Chi-square test was applied. The evaluation of these distributions on Chi-square basis is shown in Table 3.

It is clear from Table 3 that only Gunbel EV-1 distribution is one in which almost all values (except two) are under the Chi-square value and in case of other distributions, some values are much more than Chi-square. So on, the Chi-square test basis of the Gumbel EV-1 distribution is best fit for flood frequency analysis. DFW software was used for flood frequency analysis.

Regression analysis

To determine the correlation between the catchment characteristics, "MINITAB" software was used and the results are shown in Tables 4 and 5.

As shown in Table 4, it is clear that the highest correlation coefficient is 0.97 between the catchment area (A) and stream length (L) but Hack (1957) demonstrated the applicability of a power function relating length and area for streams of the Shenandoah Valley and adjacent mountains in Virginia and found the following equation:

$$L = 1.4A^{0.6}$$

Where L is the length of the longest stream in miles from the outlet to the divide and A is the corresponding area in square miles.

Hack (1957) also corroborated his equation through the measurements of Langbein (1947), who had measured L and A for nearly 400 sites in the northeastern United States. Later on, Gray (1961) refined the analysis and

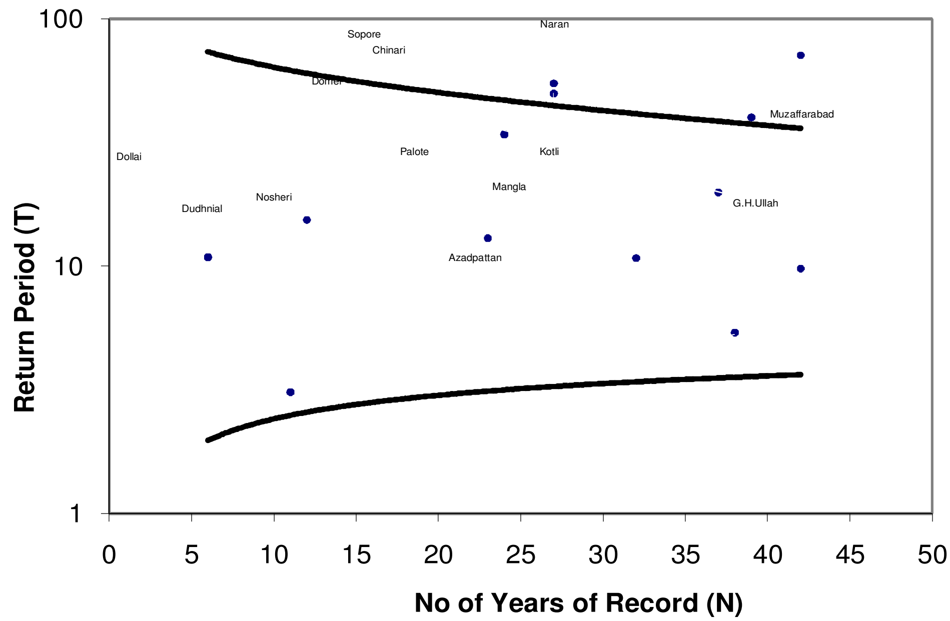

Figure 1. Homogeneity test by Gumbel curve method.

Table 3. Chi-square test for the best fit distribution of homogeneous regions.

Station	Chi-square value			
	Gumbel EV-1	P-III	LP-III	LN
Domel	11.00	11.00	-	12.67
Dollai	14.00	16.00	-	-
Nosheri	18.41	23.18	33.54	32.46
Dudhnial	6.13	9.61	8.74	7.00
G. H. Ullah	8.32	-	4.63	9.89
Azadpattan	4.67	-	-	3.00
Mangla	5.00	-	-	-
Kotli	9.43	14.67	4.19	7.05
Palote	9.25	-	-	7.38

Total value of Chi-square = 12.02 (0.90, 7).

Table 4. Pearson correlation matrix.

	Q	A	L	E	P	S
Q	1.00	0.82	0.78	-0.41	0.13	-0.37
A	0.82	1.00	0.97	0.41	0.04	-0.38
L	0.78	0.97	1.00	-0.34	0.16	-0.35
E	-0.41	0.41	-0.34	1.00	0.23	-0.06
P	0.13	0.04	0.16	0.23	1.00	0.21
S	-0.37	-0.38	-0.35	-0.06	0.21	1.00

finding the relationship L α $A^{0.6}$, but Bras (1990) noted the fact that the length does not go and the square root of the area implies that the river basin is not fully geometrically similar that is, the ratio of the area to the square of the

Table 5. Results of regression analysis.

No. of variable	Name	Coefficient	T	P	R^2	R^2-Adj	S
1	Constt	514.00	1.94	0.09	0.86	0.84	525.90
	A	0.10	6.51	0.00			
2	Constt	997.30	1.49	0.19	0.87	0.83	540.60
	A	0.18	1.81	0.12			
	L	-5.81	-0.79	0.46			
3	Constt	994.30	1.31	0.25	0.87	0.80	592.20
	A	0.18	1.42	0.22			
	L	-5.87	-0.65	0.55			
	E	0.01	0.02	0.99			
4	Constt	999.90	1.08	0.34	0.87	0.74	662.00
	A	0.17	1.04	0.36			
	L	-5.78	-0.49	0.65			
	E	0.00	0.00	1.00			
	S	-8.20	-0.02	0.99			
5	Constt	-245.00	-0.15	0.89	0.90	0.73	676.90
	A	0.255	1.32	0.278			
	S	-118.5	-0.21	0.84			
	p	1.516	0.91	0.43			
	L	-12.26	-0.87	0.45			
	E	0.027	0.04	0.97			

Length is not constant for all basins.

Larger basins are more elongated than smaller ones since A/L^2 decreases as the area increases. Depending upon these conditions and standard error of estimation (s) from Table 5, the model with two parameters (L, A) is rejected. One parameter model has the lowest standard error of estimation and higher value of R^2-Adj as compared to other parameters model; so it is regarded as the best subset of the regression equation.

By regression analysis, the best equation for the homogeneous catchments is as follows:

$$Q_{mean} = 514 + 0.10*A$$

Where A = Catchment area (km^2); Q_{mean} = Mean annual flood (m^3/s).

Conclusions

1) Gumbel Ev-1 distribution is best for flood frequency analysis on the base of Chi-square test.
2) The best correlation is between the discharge (Q) and catchment area (A), and the equation developed for homogeneous catchments is:

$$Q_{mean} = 514 + 0.10*A$$

Where A = Catchment area (km^2); Q_{mean} = Mean annual flood (m^3/s)

RECOMMENDATIONS

1) The selected catchments were with in same geographical region; the study should expand to include catchments from other geographical regions which show already hydrological similarity with the catchment under study.
2) The other catchment characteristics which were not included in this study such as rainfall intensity, land use and temperature having strong effect especially the mean annual flood of Jhelum River catchment upstream of the Mangla dam where there is high intensity snowfall should be used in further studies.
3) Multiple linear regression method was used in this study. Other type of regression analysis like multiple nonlinear regression analysis may also be used for good results.

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