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Hydrological Analysis and Statistical Modelling of Swat River Basin for Flood Risk Assessment

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Abstract

The climatic variations and anthropogenic activities in the river catchments worldwide are causing severe weather events and flooding. The narrowing down of natural floodplains/ channels, land-use changes, deforestation and mushroom urbanisation with unplanned infrastructure development are aggravating causes of severe storms and floods, especially in developing countries. Hydrological studies, flood modelling and statistical flood frequency analysis are considered imperative to assess the hazards/ risks of flooding and their mitigation measures. Estimating predicted storms/ floods for different return periods can give a reasonable idea about the frequency of storm events. This study analysed the Swat river basin to determine the predicted return periods with expected storm/ flood in its catchment and Swat river. The weather and rainfall in the Swat river basin remain unpredictable. Historically, it has seen peak precipitation of 150mm – 274mm and a super flood of 10050 m3/sec in 2010, more than its 200 years return period. Flood frequency and statistical analysis using Log Pearson 3 (LP3), Generalized Extreme Value (GEV) and Gumbel Maximum (Gumb-Max) on Easy Fit software and Log Pearson 3 equations have predicted weather instability in the Swat basin with the prediction of super flood like 2010 happening in 40 years return period. Construction of Swat expressway on elevated embankment will disturb the natural drainage pattern and likely result in inundation in flood plains due to inadequate capacity of cross drainage structures to withstand the spontaneous flash flooding. However, these have been designed on 100 years return period. However, probability density and hazard functions show a lesser probability of any mega hazard; therefore, cross drainage structures and crisscrossing channels in the river catchments may be planned on a minimum 100 years return period as an economic/ reasonable safe limit. Still, additional structural/ non-structural measures should augment these for efficient flood-fighting like plantation and maintenance of drainage structures, construction of small dams/ reservoirs for swift water management in case of a flash flood and placement of rescue/ relief resources at accessible points as per flood zoning.

Keywords : Historical flooding, Swat river basin, flood frequency analysis, statistical analysis, predicted return periods.

Introduction

Historical preview, climate changes and impact of flood and storm events

Water has a special place in the life of human beings as a necessity (Shirleyana & Anindya, 2012), and all civilisations were developed along the waterfront, which resulted in ecological modifications/ pollution, glaciers melting, extraordinary precipitation events, flooding, and damage to aqua life and wildlife (Worldwide Fund for Nature (WWF), 2012). Yangtze River in China has a history of devastating floods periodically, especially the floods in 1911, 1935 and 1954 were the worst floods which resulted in the deaths of millions of people and swapping of properties/ land in 6300 KM stretch, Yellow River in China, Indus in Pakistan, Ganges, Jumna and Brahma Putra in India and Bangladesh are the major flood causing rivers mainly arising from climatic changes and urbanisation/ modifications along natural rivers stretches (Kumar, 2017). The surge in 2011 in the Mississippi River was the worst of its kind in the USA, which impacted 31 states, including hundreds of casualties and destruction/ evacuation of millions of populations (HEITMEYER, 2008; Schleifstein, 2011; National Mississippi River Museum (NMRM), 2018; WIKI2, 2019). In the last few decades, there have been numerous causalities and loss of property because of heavy rain/ flood events due to climatic changes and human modifications/ pollution (Prevention Web, 2008). Elbe flooding in 2002 in central Europe, UK flood in 2007 (Flood site, 2009) and Copenhagen Denmark flooding in 2011 (Shandana, 2012) caused horrific impacts of multi-Billions USD on economy/ routine life.

Storm/ Flood Frequency Methods of Analysis

It is imperative to carry out storms/ floods frequency analysis to statistically predict their future occurrence for hazard assessment and mitigation (Benameur et al., 2017; Renard et al., 2013). It is generally common in the hydrology and construction industry to statistically evaluate the probability of flood events and the impacts of the construction of hydraulic structures (Saleh, 2011; Helsel & Hirsch, 2010; Stewart et al., 1999). The result's accuracy of such studies is based on selecting the best probability distribution function with the best ranking of Goodness of fit, suitability of long term past data and adoption of suitable estimation parameters (Saghafian et al., 2014; Kamal et al., 2018; Millington et al., 2011). The researchers like Rahman et al. (2013) and Millington et al. (2011), in their studies about discharge in River Thames, have described Log Pearson 3 (LP3), Generalized Extreme Value (GEV) and Gumbel Maximum (Gum Max) as better fitting probabilistic approaches with better Goodness of Fit ranking on Kolmogorov Smirnov, Anderson Darling and Chi-Squared methods (Millington et al., 2011; Rahman et al., 2013). The exact probability distribution functions and goodness of Fit methods will be used in this study to determine the predicted rainfall in the Swat river basin and discharge in the Swat river.

Swat River Basin Geography, hydrology and climate

As per the World Bank feasibility report for Munda Dam (2005), the Swat river drains water from more than 14800 Km2 catchment areas originating from Kalam in Kohistan and terminating in Kabul river after passing through Munda headworks as shown in Figure 1. Swat valley is situated in Khyber Pukhtun Khawah (KPK), the Northern province of Pakistan, ranging from 900 m elevation above sea level to around 4000 m in the mountains of the Hindukush range (World Bank Report (WBR, 2005; Farooq et al., 2018; Cohen, 2004). The area is crisscrossed by hundreds of draining channels passing through narrow mountainous paths in upper parts and comparatively flat/ clay fields in lower regions. The valley receives more than 780 mm average annual rainfall having a population of 2.3 Million, with Saido Sharif as its capital, Mingora as the biggest city and Malam Jabba as one of its highest ski resorts. 68.5 % area is under agricultural use, 26 % area is covered by wild vegetation/ bushes, forests, water streams and 4 % area comprises built-up area (Pakistan Bureau of Statistics (PBS), 2018). Swat has the hottest weather in June, coolest in January, receives maximum rain in July-August from monsoon spells and winter rains in January from Westerly disturbances (Malik & Ahmad, 2014). Pakistan Meteorological Department (PMD) has seven rain observatories in Swat and surrounding northern areas, which include Malam Jabba, Kalam, Saido Sharif, Dir, Chitral, Drosh and Timergara, all fall under an accumulated annual rainfall range of 300-520 mm areas in monsoon season shown with dark blue Colour as shown in Figure 2. There are four flood gauging stations in Punjkora River and three in Swat River at Khawaza Khela, Chakdara and Munda Headworks, as shown in Figure 3 (PMD, 2019).

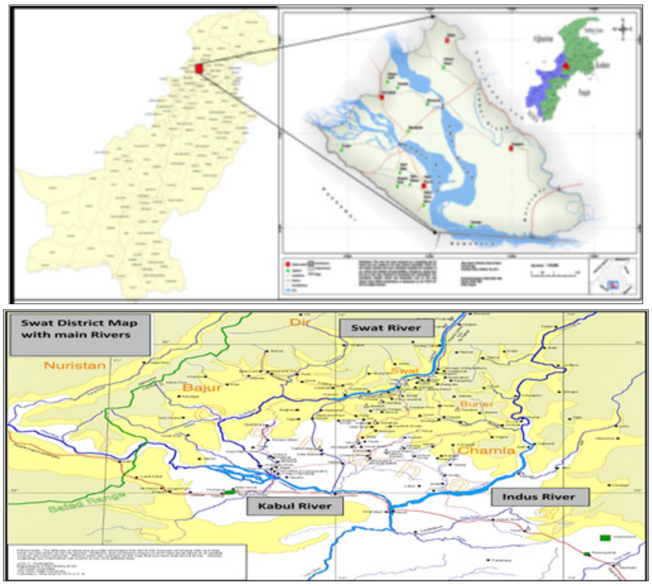

Figure 1: Swat District Maps showing River Catchment and other Rivers in the area (Kaladarshan, 2006; Bibi et al., 2018)

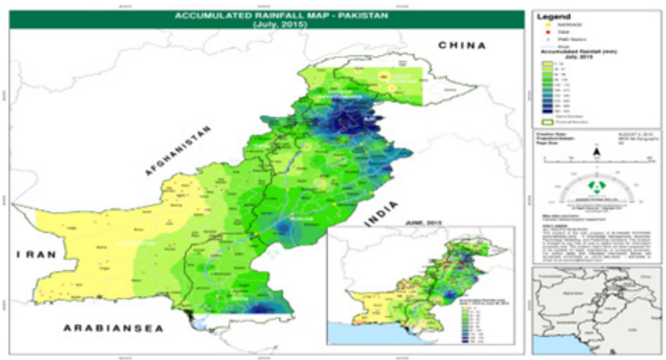

Figure 2: Accumulated Rainfall Range and PMD Observatories Location Map (Relief Web, 2015)

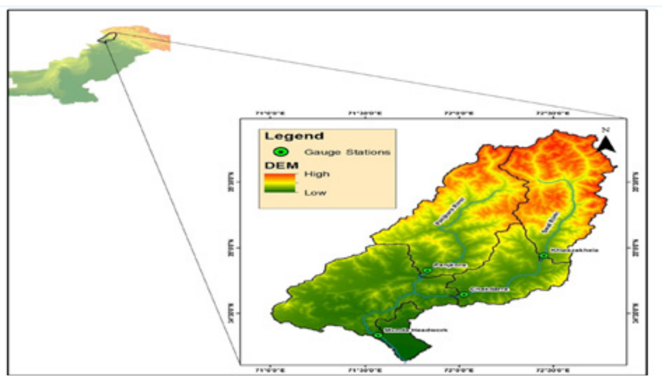

Figure 3: Swat Map and Location of River Gauging Stations (Farooq et al., 2018)

Methodology

Data Collection

The rainfall data of 24 hours of maximum rainfall per annum from 3 observatories of the Pakistan Meteorological Department PMD has been collected from Peshawar and Saido Sharif for the last 25 Years (1994-2018) and Malam Jabba for the previous 15 Years (2004-2018, Established in 2004) as shown in Table 1. The annual peak discharge data of River Swat has been taken for the last 20 years from Munda Headworks Gauging stations of PMD/ KPK Irrigation Department, as shown in Table 1. This data will be used/ correlated with analysis on a statistical tool like Mathwave's Easyfit to give probability distributions. They will be fitted on Log Pearson 3 equations to calculate predicted values for return periods of 2, 5,10,25,50, 100 and 200 years for rainfall in the Swat river basin and discharge in the Swat river at Munda Head works.

24 Hours Maximum Rainfall per Year in mm				Annual Peak Discharge of River Swat Munda Headworks		
Year	Saido Sharif	Malam Jabba	Peshawar	Year	Ft^3/Sec	m^3/Sec
1994	75		51	1999	51900	1467
1995	66.9		55	2000	31000	878
1996	46		142	2001	35000	991
1997	54		48.6	2002	36000	1019
1998	78		47	2003	90000	2548
1999	74.4		48	2004	49000	1388
2000	50.6		33	2005	36000	1019
2001	80.6		27	2006	40000	1133
2002	54.5		55	2007	33700	954
2003	99		71	2008	33600	951
2004	60	60	68	2009	35000	991
2005	63	60	72	2010	355000	10052
2006	64.4	93.9	56	2011	90000	2548
2007	100	83	84	2012	29000	821
2008	65	57.6	119	2013	20000	566
2009	78	38	76	2014	35000	991
2010	187	150	274	2015	25000	708
2011	60.7	62	54	2016	23000	651
2012	51	67.5	88	2017	19300	547
2013	136.5	97	79	2018	23000	651
2014	46	97	30			
2015	51	82	43.1			
2016	54.4	128	72.5			
2017	83.4	87	81.5			
2018	93.6	103	46.6			

Table 1: 24 Hours Maximum Rainfall Data (PMD, 2019; Irrigation Department KPK, 2019; Frontier Works Organization (FWO), 2019).

Use of statistical modelling software Mathwave EasyFit

The EasyFit software provided by Mathwave.com as a one-month free trial has been used to analyse the existing rainfall/ discharge data sets statistically. The EasyFit software uses the given data on the horizontal axis as "x". It provides the probability distribution Function, cumulative distribution and hazard function on the vertical axis as a function of x f(x) (Mathwave, 2019). In this study Log Pearson 3 (LP 3), Generalized Extreme Value (GEV), and Gumbel Maximum (Gumb Max) have been used to statistically analyse the rainfall/ discharge data for the Swat river basin using EasyFit software. These are considered the top best fit PDF methods (Millington et al., 2011) and have been used number of researchers. Log Pearson 3, GEV and Gumbel max are preferred as they fit the data well to predict return periods for storm/ flood frequency with a better ranking of the Goodness of fit test (Kamal et al., 2018; Deng, 2016; Liu et al., 2015; Rulfova et al., 2016; Bezak et al., 2014; Singo et al., 2012). These methods use estimation parameters based on the technique of movements (MOM) or method of L movements as per the length of the given data set (less than 50 entries or more than 50 entries) (Rowinski et al., 2002). The Goodness of Fit of these probability functions has been tested using Anderson Darling, Kolmogorov Smirnov and Chi-Squared using EasyFit inbuilt programming. However, Chi-Squared is not a top test choice by researchers (Millington et al., 2011; Cunnane, 1989; Cunnane, 2010).

Use of Log Pearson 3 equations to ascertain the probability of storm/ discharge events with return periods (Oke & Aiyelokun, 2015).

In this study, Log Pearson 3 performed at the top with the best Goodness of fit test ranking for all kinds of data; therefore, it has been chosen for further calculation using its equations for the determination of return periods taken from the study of Oke and Aiyelokun (2014) [41]. The given annual peak discharge "Q" and annual 24 hours max rainfall "R" data is converted into Logarithm value as under:

$$R_i = \text{Log}(R) \quad (1)$$

Calculation of Mean, Standard deviation, Skewness coefficient and Return Periods for storm/ flood frequency analysis (Oke & Aiyelokun, 2015).

The mean of R_i is calculated by summing all rainfall values and dividing by the total number of readings/ years.

$$R_{mean} = 1/n \sum R_i \quad (2)$$

Standard Deviations are calculated using the following equation:

$$S_d = (\sum (\text{Log}(R)\text{-Avg}(\text{Log } R))^2/(n-1))^{1/2} \quad (3)$$

Skewness is calculated as under:

$$\text{Skewness} = (\text{Log}(R)\text{-Avg}(\text{Log } R))^3 \quad (4)$$

Skewness Coefficient G is calculated using the following equation to determine the value of a Frequency Factor constant "K" from Hann Table (Hann,1977).

$$\text{Skewness Coefficient } G = n * (\sum (\text{Log}(R)\text{-Avg}(\text{Log } R))^3/(n-1)*(n-2)*S_d \quad (5)$$

The return period is then calculated using the rank of the value of rainfall/ discharge in the data set "m" and the total number of entries/ years in the data "n":

$$\text{Return Period } (T_r) = 2n/(2m-1), \quad (6)$$

Where m=Rank, n=No of years

Exceedance probability is the reverse of the return period and is calculated by:

$$\text{Exceedance Probability} = 1/T_r \quad (7)$$

Now predicted/ design rainfall "RP" or discharge "QP" is calculated for 2, 5, 10, 25, 50, 100 and 200 years, taking the value of KT from the Hann Table (Haan, 1977) for each period and then taking anti Logarithm of the results obtained from the following equations:

$$R_T = R_{mean} + K_T * S_d \quad (8)$$

$$R_p = \text{Anti Log } R_T = 10^{(RT)} \quad (9)$$

This last equation gives us the predicted designed rainfall/ discharge as per the Log Pearson 3 method of Probability Distribution Function.

Results and Analysis

Saido Sharif

The data set for the 25 years of rainfall data collected from Saido Sharif PMD observatory has been analysed for GEV, Gumbel Max and LP 3 with the goodness of Fit tests on KS, AD and CS as shown in table 2. The results showed that LP 3 is the best-fit distribution function, ranking 1 in all Goodness of Fit tests for Saido Sharif data. Descriptive statistics and PDF parameters are given in table 3 and show that it is a set of 25 years of data, so the sample size is 25 with a mean rainfall of 74.92 mm, min was 46 mm, and max was 187 mm, and the standard deviation is 31.331. The combined PDF & CDF using all three probability functions are given in figure 4 and 5, showing that LP 3 and GEV fit correctly and provide a close correlation. In contrast, Gumbel Max is showing less performance in results output. LP 3 has been used to check PDF and HF for Saido Sharif. These graphs show a 40-60% probability of rainfall events from 40mm-70 mm and less than 4% chance of a storm event of 180 mm. CDF indicates that there is 95% less likelihood of a storm event of around 180 mm means only less than 5% chances of a storm of 180 mm magnitude. PDF and Hazard function calculated using LP 3 are given in figure 6 and 7, which show that there is a likely hazard of storm events of 40-70 mm (up to 40% hazard) as these will happen frequently but significantly less, i.e., 2-2.5% hazard of any big storm event of 150-180 mm.

Location	DF	Kolmogorov Smirnov (KS)	Anderson Darling (AD)	Chi-Squared (CS)
Saido Sharif	GEV	2	2	3
	Gumb. Max	3	3	2
	LP3	1	1	1
Peshawer	GEV	1	1	3
	Gumb. Max	3	3	1
	LP3	2	2	2
Malam Jabba	GEV	2	2	3
	Gumb. Max	3	3	2
	LP3	1	1	1
Munda Headworks	GEV	2	1	2
	Gumb. Max	3	3	3
	LP3	1	2	1

Table 2: Probability Distribution Ranking with Goodness of Fit Tests

Location	Statistic	Sample Size	Range	Mean	Variance	Std Deviation	Coef. of Variation	Std. Error	Skewness	Excess Kurtosis
Saido Sharif	Value	25	141	74.92	981.66	31.331	0.4182	6.27	2.2847	6.3676
	Percentile	Min	0.05	0.1	25% (Q1)	50% (Median)	75%(Q3)	0.9	0.95	Max
	Value (Rainfall in mm)	46	46	48.76	54.2	65	82	115	171.85	187
	PDF Parameters Location, Shape, Scale	GEV: k=0.32, s=14.82, m=59.7			Gumbel Max: s=24.429, m=60.819			Log Pearson 3: a=2.82 b=0.202 g=3.69		
Peshawer	Value	25	247	72.85	2442	49.41	0.678	9.88	3.0815	11.647
	Percentile	Min	0.05	0.1	25% (Q1)	50% (Median)	75% (Q3)	0.9	0.95	Max
	Value (Rainfall in mm)	27	27.9	31.8	47.5	56	80.25	128	234.4	274
	PDF Parameters Location, Shape, Scale	GEV: k=0.37, s=19.43 m=50.78			Gumbel Max: s=38.53 m=50.61			Log Pearson 3: a=4.66, b=0.23, g=3.1		
Malam Jabba	Value	15	112	83.6	727.7	26.976	0.3226	6.97	0.6522	1.4871
	Percentile	Min	0.05	0.1	25% (Q1)	50% (Median)	75% (Q3)	0.9	0.95	Max
	Value (Rainfall in mm)	38	38	49.76	60	93.9	97	118	150	150
	PDF Parameters Location, Shape, Scale	GEV: k=-0.26, s=25.47, m=74.29			Gumbel Max:s=21.03, m=71.4			Log Pearson 3: a=22.12, b=-0.071, g=5.95		
Munda Head works	Value	20	9505	1547.7	4.55	2134	1.3788	490	3.9041	16.026
	Percentile	Min	0.05	0.1	25% (Q1)	50% (Median)	75% (Q3)	0.9	0.95	Max
	Value (Rainfall in mm)	547	547	566	708	991	1133	2548	10052	10052
	PDF Parameters Location, Shape, Scale	GEV: K=0.73, s=241.4 m=785			Gumbel Max: s=1663.9, m=587.31			Log Pearson 3: a=0.84, b=0.75,g=6.38		

Table 3: Descriptive Statistics and PDF Parameters of Data Set of Saido Sharif

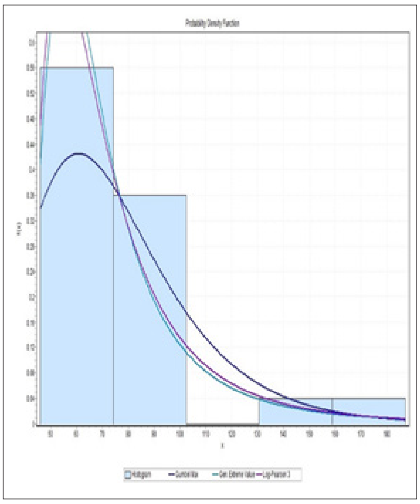

Figure 4: Combined PDF for Saido Sharif

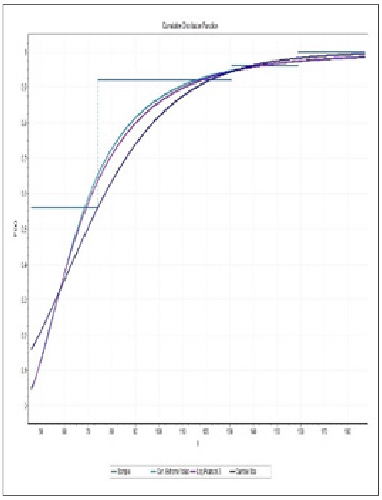

Figure 5: Combined CDF

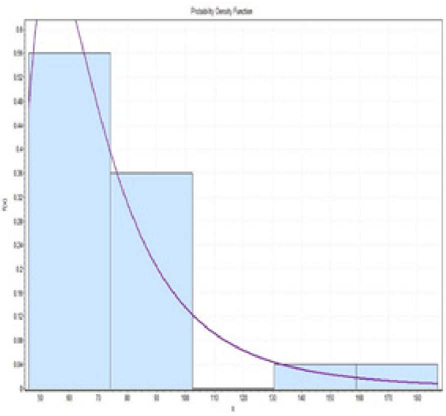

Figure 6: PDF of Saido Sharif using LP 3

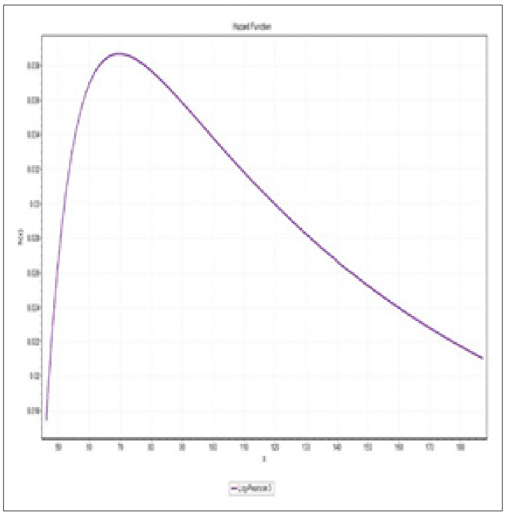

Figure 7: Hazard Function of Saido Sharif using LP 3

Peshawar

The data set for the 25 years of rainfall data collected from the Peshawar PMD observatory has been analysed for GEV, Gumbel Max and LP 3 with the goodness of Fit tests on KS, AD and CS as shown in table 2. The results showed that Generalized Extreme Value is the best fit distribution function, ranking 1 in Kolmogorov Smirnov and Anderson Darling Goodness of Fit tests for Peshawar data and 3rd on Chi-Squared test, followed by Log Pearson 3, which is ranked number 2 and Gumbel max on 3rd ranking. Descriptive statistics and PDF parameters are given in table 3 and show that the sample size is 25 with a mean rainfall of 72.852 mm, min was 27 mm, and max was 274 mm with gross variance, and the standard deviation is 49.414. The combined PDF & CDF using all three probability functions are given in figure 8 and 9. These graphs show a 40-75% probability of rainfall events from 45 mm-75 mm and an almost 1% probability of occurrence of the storm of more than 270 mm. GEV and LP 3 are performing better for this data set. Graphs using GEV for CDF and HF show 99% less likelihood of a storm event of 270 mm means only less than 1% chance of a storm of 270 mm magnitude. PDF and Hazard function calculated using LP 3 are given in figure 10 and 11, which show a 30% likely hazard of storm events of 40-80 mm as these will happen frequently but only 1% hazard of any big storm event more than 270 mm.

Malam Jabba

The data set for the 15 years of rainfall data collected from Malam Jabba PMD observatory has been analysed for Generalized Extreme Value, Gumbel Max and Log Pearson 3 with the goodness of Fit tests on Kolmogorov Smirnov KS, Anderson Darling AD and Chi-Squared CS as shown in table 2. The results showed that Log Pearson 3 is the best fit distribution function with ranking 1 in KS, AD and CS Goodness of Fit tests for Malam Jabba, followed by GEV, which is ranked number 2 and Gumbel max on 3rd ranking. Descriptive statistics and PDF parameters are given in table 3 and show that the sample size is 15 with a mean rainfall of 83.6 mm, min was 38 mm, and max was 150 mm with a standard deviation is 26.976. The combined PDF & CDF using all three probability functions are given in figure 12 and 13. These graphs show a higher probability of rainfall of 80 mm whereas 40 -50 % probability of rain events from 70 mm-90 mm and almost 4% probability of occurrence of the storm of more than 150 mm. LP 3, GEV, and Gumbell Max perform closely for this data set (short set of 15 entries). Graphs using LP 3 for CDF and HF show that there is 90% less likelihood of a storm event of 150 mm means less than 10% chance of a storm of 150 mm magnitude. PDF and Hazard function calculated using LP 3 are given in figure 14 and 15, which show a 40% likely hazard of storm events of 80-100 mm as these will happen frequently but only 7% hazard of any big storm event more than 150 mm.

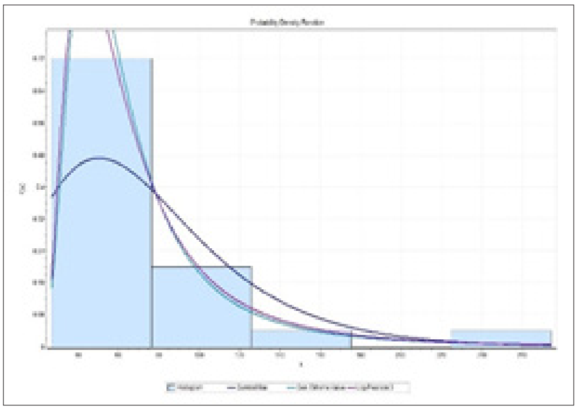

Figure 8: Combined PDF for Peshawar

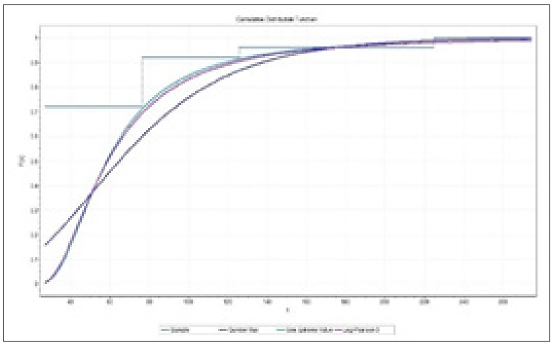

Figure 9: Combined CDF for Peshawar

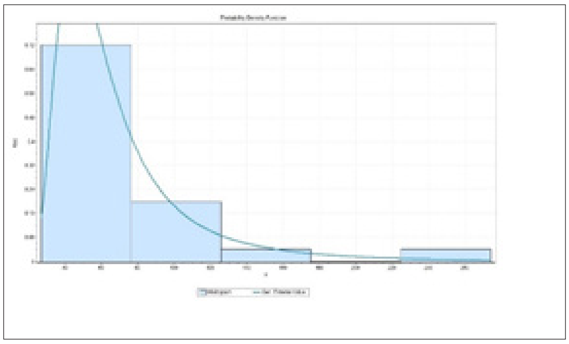

Figure 10: PDF using GEV for Peshawar

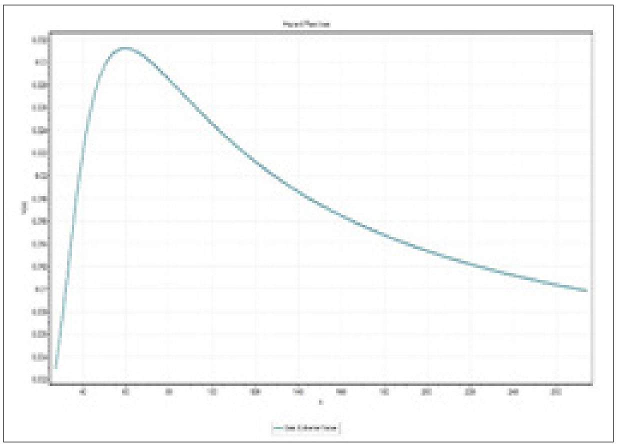

Figure 11: HF using GEV for Peshawar

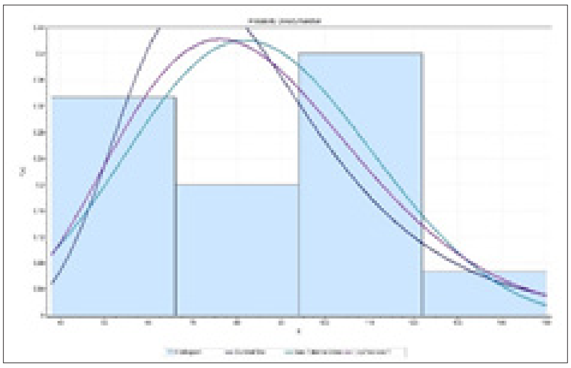

Figure 12: Combined PDG for Malam Jabba

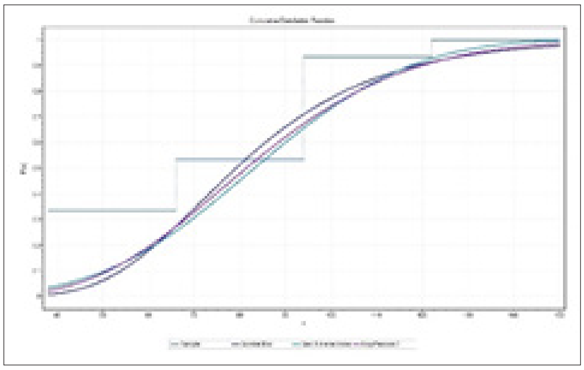

Figure 13: Combined CDF for Malam Jabba

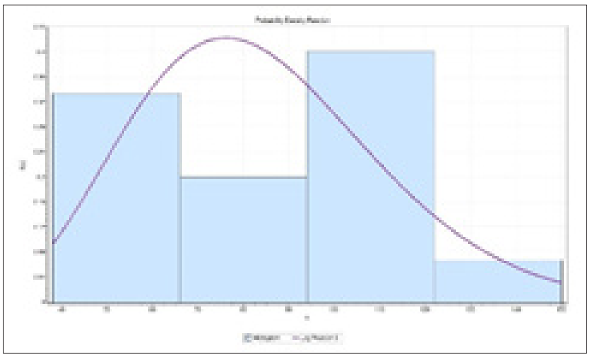

Figure 14: PDF using LP 3 for Malam Jabba

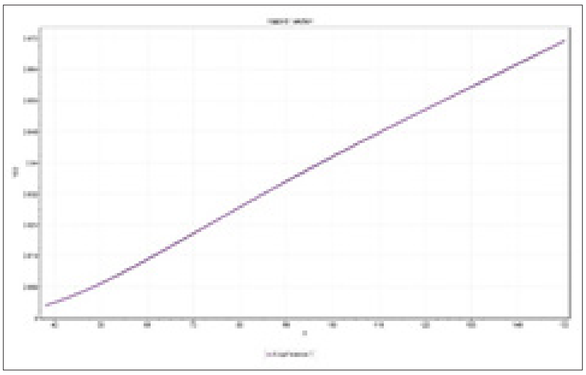

Figure 15: HF using LP 3 for Malam Jabba

Munda Head Works

The data set for Munda Headworks on Swat River has been analysed using Generalized Extreme Value, Gumbel Max and Log Pearson 3 with the goodness of Fit tests on Kolmogorov Smirnov, Anderson Darling and Chi-Squared as shown in table 2. The results showed that Log Pearson 3 is the best fit distribution function with ranking 1 in KS & CS and 2nd in AD Goodness of Fit tests for Munda Headworks flow data, followed by GEV, which is ranked number 2 and Gumbel max on 3rd ranking. Descriptive statistics and PDF parameters are given in table 3 and show that the sample size is 20 with a mean discharge of 1547.7 m3/sec, min was 547 m^3/sec, and max was 10052 m^3/sec with a gross variance of $4.6x10^6$ and standard deviation of 2134. The combined PDF & CDF using all three probability functions are given in figure 16 and 17. These graphs show that there is an 80% probability that flows in the river will be less than 1000 m^3/sec, whereas there is a 40 -70 % probability of river flow from 600 m^3/sec -800 m^3/sec and almost 1% probability of occurrence of the flood of more than 6500 m^3/sec. LP 3 and GEV are performing closely, but Gumbel Max does not correlate well with this data set and is out of correlation with other probability functions. Graphs using LP 3 for CDF and HF show 99% less likelihood of a flood event of 6500 m3/sec or more means less than 1% chance of a mega flood of 10050 m^3/sec magnitude. PDF and Hazard function calculated using LP 3 are given in n figure 18 and 19, which show that there is a 4% likely hazard of flood events of more than 1000 m^3/sec as these will happen frequently and can be absorbed well by the channel, but less than 1% hazard of any mega flood event more than 6500 m^3/sec. The Munda dam has been planned on river Swat at Munda to store water in case of flash flooding and regulate it to pass through the headworks gradually to avoid any cause to structure as was done in 2010. If this dam is constructed, it will perform as a multifunction reservoir for storage, irrigation, hydroelectric production, flood water regulation, and a safety cushion for structures/valleys downstream (WBP, 2005).

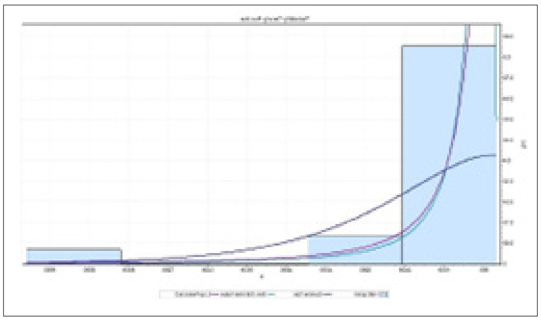

Figure 16: Combined PDF for Munda H/W

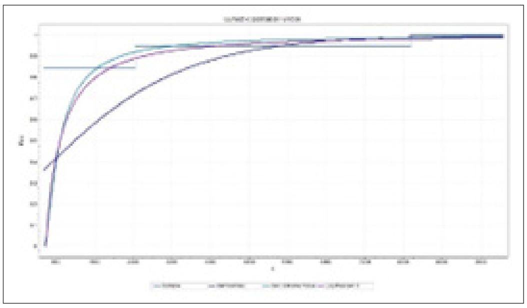

Figure 17: Combined CDF for Munda H/W

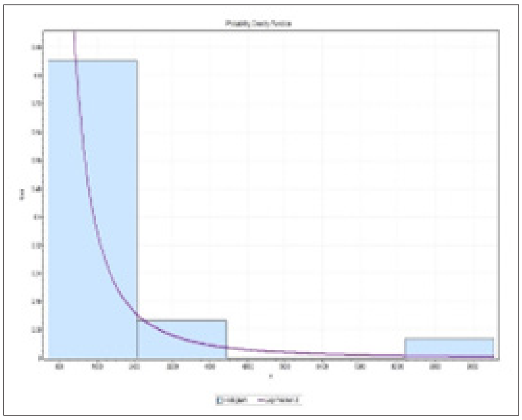

Figure 18: PDF for Munda H/W

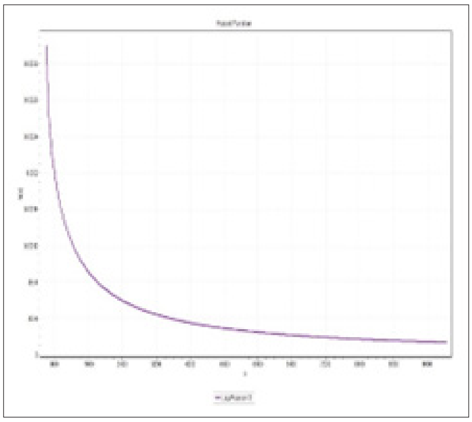

Figure 19: HF for Munda H/W

Storm/ flood frequency analysis using Log Pearson 3 Equations and K value Table

Log Pearson 3 has been used for Swat River's storm/ flood frequency analysis using LP 3 equations 1 – 9 given in earlier sections above, using frequency factor K table (Haan, 1977). These equations have been used to determine Mean values (Ri/Qi) of rainfall/ flow after taking their Logarithm. Standard Deviation Sd, Skewness coefficient G, return period Tr, exceedance Ex, and predicted rainfall/ flow have been calculated for frequency analysis and forecast of storm/ flood events for 2,5,10, 25, 50, 100 and 200 years periods as shown in Table 4.

Observation Station	Saido Sharif Rainfall (mm)	Peshawar Rainfall (mm)	Malam Jabba Rainfall (mm)	Munda Headworks Discharge m^3/sec
Mean Ri/Qi	1.84757	1.80256	1.90045	3.04207
S_d	0.14692	0.21528	0.14524	0.29415
G	0.02572	0.04293	-0.009	0.24876
T_r	50	50	30	40
$E_x=1/T_r$	0.02	0.02	0.03333	0.025
2 Yrs R_T	70	63	80	1110
5 Yrs R_T	93	96	105	1950
10 Yrs R_T	109	120	122	2625
25 Yrs R_T	129	156	143	3600
50 Yrs R_T	148	185	158	4425
100 Yrs R_T	182	216	173	5325
200 Yrs R_T	215	238	188	6300

Table 4: Storm/ Flood Frequency Analysis with LP 3 Equations and K Factor

Calculation of predicted rainfall and discharge for 2,5,10,25,50,100 & 200 years

The predicted rainfall events for Saido Sharif, Malam Jabba, and Peshawar have been illustrated in figure 20. Maximum rainfall in Saido Sharif has been recorded as 187 mm in 2010, which is more than its 100 years return period rainfall of 182 mm. Malam Jabba's maximum recorded rainfall was 150 mm in 2010; almost the 50 year return period predicted a value of 158 mm. Peshawar witnessed a maximum rainfall of 274 mm in July 2010, more than 200 years of the expected rainfall forecast of 238 mm. The predicted flood flow values for return periods in Swat River at Munda Headworks have been shown in figure 21. The maximum recorded flood discharge in Swat River at Munda Headworks was 10052 m3/sec, almost double the predicted flood value for 200 year return period. All this data and results show gross variations in the same valley, which entails having deliberate analysis and liberal planning/ designing parameters for any hydraulic structures, any mega construction in Swat valley/ river basin which are likely to disturb natural drainage patterns or have any impact on climate/ ecology/ hydrology such as the construction of an 81 Km long four lanes wide expressway in river catchment along the river on an elevated embankment which will disturb the drainage pattern.

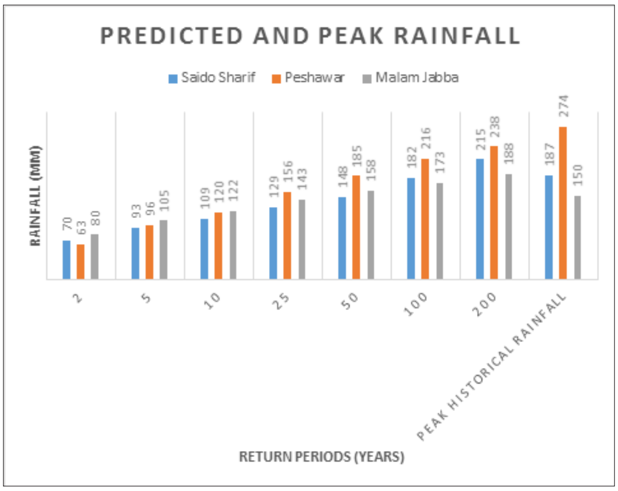

Figure 20: Combined Predicted Rainfall Graph

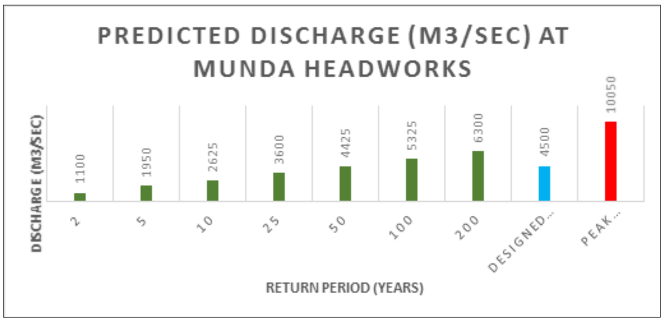

Figure 21: Predicted Discharge Graph – Munda Headworks

Discussion

Pakistan is an agricultural country with natural perennial rivers and artificial canals for irrigation purposes, mainly depending on the Indus River basin system. The anthropogenic activities and heavy modifications have been made in land irrigation and hydropower production. Still, unfortunately, the system has not been managed well and has significantly less storage capacity, which causes disastrous flooding almost every year (Bibi et al., 2018; Albaniainia, 2010; Riaz, 2011). It is essential to undertake flood hazards mapping/ modelling, hydrological studies/ statistical analysis and frequency analysis to predict future storms/floods (Ewemoje & Ewemooje, 2011; Ologunorisa & Abawua, 2005). The 2010 historical flood in Pakistan has inflicted tremendous loss to the economy of around $10 billion, 2000 deaths, thousands of injured, millions of people displaced and houses damaged. Above all, the fall of health fatalities was approximately 3.7 million due to outbreaks of different diseases/ malnutrition (Natural Disaster Management Authority (NDMA), 2010; World Health Organization (WHO), 2011; Ali, 2013). Swat river also swelled in 2010 and played a catastrophic role in the miseries/ losses of the 2010 national calamity. The worst effect was damage/ washing off Munda Headworks, which took more than six years and millions of dollars in restoration/ reconstruction. To avoid this kind of loss in such an extreme event, this study has made an effort to assess the storm/ flood frequency in the future for 2, 5, 10, 25, 50, 100 and 200 years to incorporate preventive measures. Swat river is one tributary of the Indus river system, which flows in distinct three types of areas, i.e., mountains, semi mountains and plains, throughout its length of 280 km before merging into the Kabul river and finally into the Indus river. The slope is very steep in hilly areas, 21m/km to mild in plains, 2m/km. The steep slopes and narrow, shallow river channels flash flooding out of its banks. The flash flooding destroys everything, including roads, bridges, agricultural land, houses and wildlife in its floodplain, which makes up almost 30% of the Swat valley (Mohsin, 2016). Swat River's annual peak discharge data at Munda headworks has been collected from PMD/ KPK Irrigation Department Gauging Station for the last 20 years, as shown in Table 1. The data shows an average flow of around 1000 -2500 m^3/sec except for the super flood in 2010, which was 2.5 times its designed capacity. The collected data has been used to statistically predict the rainfall in the Swat river basin and discharge in the Swat river for 2, 5,10,25,50,100 and 200 years return periods, as shown in figure 20 and figure 21. Swat river has already experienced a flood of 10050 m^3/sec in 2010, almost double the predicted discharge of 6300 m^3 /sec for 200 years. The destruction caused by the 2010 super flood due to cloud burst/ storm of around 180 mm rainfall almost thoroughly washed away the structure of Munda headworks, as shown in figures 22 – 25(Mohsin, 2016). It took about six years to restore/ reconstruct the Headworks with a cost of Rs. 800 Million, with an increase in design capacity by 2830 m3/sec to 7330 m3/sec, which is more than 200 years of the predicted flood, thus making it relatively safe (Jamal, 2017; The Nation, 2016). The expected surge of different return periods compared with peak floods shows an uncertain/ unspecified flow in the river that has a history of damaging bridges, roads, infrastructure, and built-up areas in its flood plain in the last few decades. The likelihood of reoccurring such events has been predicted in this study within 40 years, though it can occur anytime in case of a cloud burst. Therefore, the destruction of Munda headworks in 2010, its restoration of the structure in 2016 to a reasonable economic capacity and predicted rainfall/ discharge in the Swat River basin necessitate having a regulating reservoir that gives enough allowance to absorb the flash flooding and then regulate the water into the river and its canal with minimum damage to infrastructure, life and property. Therefore, the option of construction of Munda dam near Munda headworks is inevitable. It can be proffered from this study that the flooding in Swat river will be unpredictable with high magnitude and super flood event can repeat in 40 years predicted period, so proper water regulation with suitable water reservoirs along distributary channels is required to be constructed as a prevention measure. Sound flood levees, maintenance of cross drainage structures and monitoring of crisscrossing channels in the catchments are also required to retain the overflowing flooding water to specified areas instead of spreading it to the whole flood plain.

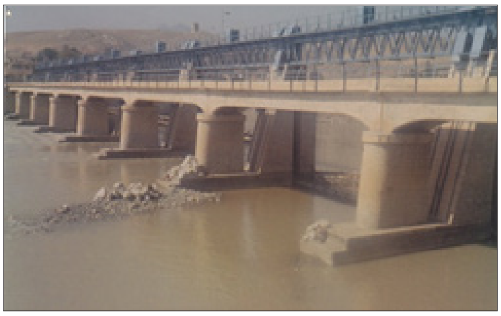

Figure 22: Munda Headworks with Normal flow before flood 2010 [50]

Figure 23: Munda Headworks during flood 2010 – flow above the structure [50]

Figure 24: Munda Headworks Structure destroyed after flood 2010 [50]

Figure 25: Munda Headworks in 2016 after restoration/ Reconstruction [50]

Conclusion

The floods are devastating natural hazards that primarily impact the affected areas' population, habitat, wildlife, and economy. It is essential to carry out proper hydrological studies before constructing or disturbing the natural drainage/ flow paths in a catchment. Moreover, flood/ storm frequency analysis using probability techniques is helpful in future prediction of such hazards for risk mitigation/ preventive measures. Pakistan has been suffering from floods due to monsoon spells and snow melting in the summer season. The swat river basin is volatile, with unpredictable storm events and flooding. Therefore, proper frequency analysis is required to plan cross drainage structures as the construction of expressways on elevated embankments will add to inundation/ flooding if drainage remains inadequate. It is recommended that structural/ non-structural measures be considered with well-coordinated/ integrated flood fighting measures. No development should be undertaken without statistical studies, frequency analysis and flood zoning. The resources of the National Disaster Management Authority NDMA should be placed as per flood mapping/ zoning and the degree of vulnerability of areas to carry out immediate remedial/ rescue & relief measures. The National Water Policy and National Flood Protection Plan NFPP IV recommendations should be implemented with resource allocation to avoid flood suffering in future by any flash flood/ storm event (Ali, 2013; NFPP-IV, 2018). The environment should be preserved to a natural condition, and tourists should be educated not to spoil nature.

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