GOVERNMENT OF JAMMU AND KASHMIR,
DISASTER MANAGEMENT, RELIEF, REHABILITATION AND RECONSTRUCTION (DMRRR) DEPARTMENT

Jehlum & Tawi
Flood Recovery Project

JEHLUM & TAWI
FLOOD RECOVERY PROJECT

FEASIBILITY AND DETAILED PROJECT REPORT FOR FLOOD MITIGATION AND COMPREHENSIVE RIVER MANAGEMENT MEASURES IN TAWI BASIN

PRELIMINARY HYDROLOGY REPORT

OCTOBER, 2018

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Consultancy Services for Preparing Feasibility and Detailed Project Report for Flood Mitigation and Comprehensive River Management Measures for Tawi Basin

PRELIMINARY HYDROLOGY REPORT

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FEASIBILITY AND DETAILED PROJECT REPORT FOR FLOOD MITIGATION AND COMPREHENSIVE RIVER MANAGEMENT MEASURES FOR TAWI BASIN

PRELIMINARY HYDROLOGY REPORT

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1 INTRODUCTION

The present document is the **Preliminary Hydrology Report**, presented as part of the Consultancy Services for preparing *“Feasibility and detailed project report for flood mitigation and comprehensive river management measures for Tawi basin*” under the Contract Agreement established between the Joint Venture (**AQUALOGUS** & **OILTECH**) (the Consultant) and **Project Management Unit (PMU)**, Jhelum & Tawi Flood Recovery Project (JTFRP), Disaster Management, Relief, Rehabilitation and Reconstruction Department, Government of Jammu and Kashmir on the 29th June, 2018.

The contract in question is aimed at preparing feasibility and Detailed Project Reports (DPR) for flood mitigation and river management measures in Tawi River Basin.

The **Chapter 2** includes a description and characterization of the Tawi River Basin.

The **Chapter 3** provides an analysis of the hydrology data available and presents the performed preliminary quality analysis. Additionally, this chapter also presents the additional hydrological data required for the subsequent hydrology studies.

The **Chapter 4** presents the review and analysis of the historic floods in Jammu & Kashmir State and particularly in the Tawi River Basin.

The **Chapter 5** provides a preliminary climate characterization of the Tawi River Basin.

The preliminary hydrology analysis is presented in the **Chapter 6**, including the flood frequency analysis in the Jammu and Udhampur gauging stations.

The **Chapter 7** summarizes the most relevant findings obtained during the preliminary hydrology studies and includes some recommendations for upcoming studies and for the planning of flood mitigation and river management measures.

Finally, the **Chapter 8** includes the considered bibliography and references.

2 TAWI RIVER BASIN CHARACTERIZATION

Tawi River Basin (Figure 2.1) is one of the major sub-basins of Chenab River (a tributary of the Indus River) in western parts of the Himalayas. The river basin drains the area between N Lat. 32˚ 35’ and 33˚ 05’, and E Long. 74˚ 35’ and 75˚ 45’. In general, the basin is elongated in shape. Upstream catchment area of the basin is characterized by rugged mountainous topography, whereas the lower part of the basin consists of low hills and aggradational plains. The river originates from the lap of Kalikundi glacier, at an altitude about 4400 m above mean sea level.

Catchment area of the basin up to the India-Pakistan border is 2,168 km^2, and falls mostly within the Districts of Jammu, Udhampur and Doda in Jammu & Kashmir State. The river flows for about 140 km up to the point where it enters Pakistan.

As detailed in the **Preliminary Morphology Report**, the basin elevation varies between 400 m to 4400 m above mean sea level, and mean elevation of the basin is 2,200 m (Jain, Agarwal, & Singh, 2007). The general slope of the basin is from east to west in the upstream parts, while northeast to southeast in the lower portions.

The upper parts of the basin is covered by granitic rocks of Palaeozoic age, metasedimatries (e.g., carbonaceous slates, pyritous graphitic phyllite and schist associated with carbonaceous grey or white limestone, marble, gneiss and quartzite with granodioritic intrusive, calcareous slate and calcareous schist) of Salkhala Formation (Mesoproterozoic), undifferentiated rocks (e.g., dolomitic limestone and quartzite) of Sirban Group (Mesoproterozoic), Neoproterozoic rocks of Sincha (e.g., quartzite, dolomite, limestone, phyllite and slate), Gamir (purple shale, quartzite and flaggy limestone), Ramban (platy to thinly bedded limestone, carbonaceous shale/slate/phyllite, sandstone, greywacke, lenticular bands of diamictite and quartzite) and Baila (nodular graphitic and gypseous limestone and carbonaceous shale) formations of Parautochthonous Belt, Sauni Volcanics, undifferentiated rocks (e.g., red, brown and grey sandstone, claystone and shale, with inliers of limestone) of Murree Group (Eocene to Miocene age), rocks (i.e., nummulitic limestone, shale and sandstone) of Subathu Formation of Inner Tertiary Belt (Palaeocene to Eocene age).

Lower parts of the basin are underlain by the rocks of Upper Siwalik Group, such as sandstone, mudstone, pebble beds and boulder and conglomerate (Pliocene to Pleistocene age), Middle Siwalik Group, viz., sandstone with interbedded mudstone (Miocene to Pliocene age) and Lower Siwalik Group, such as sandstone, mudstone and conglomerates (Miocene age).

The extreme lower parts of the basin are developed on undifferentiated sediments of Quaternary period, older alluvium, terrace alluvium, channel alluvium, moraine and hill wash (Pleistocene to Holocene age) (Source: Geological Society of India).

Geomorphologically, the river basin has three meso-geomorphic surfaces; the upper one is in north of the Panjal Thrust with a maximum elevation of 4000 m, the middle one is between the Panjal thrust to the Udhampur thrust with an elevation of 700 m to 1900 m and the lower one is comprised of low-lying hillocks between Udhampur and Jammu (Verma, Singh, Srivastava, & Mishra, 2012).

The land cover of the Tawi River basin is presented in Figure 2.2. The most common land cover class in the Tawi river basin is cropland (38%), which occupies the vast majority of the western basin (west of Jammu city). Croplands are also found in the valley that separates Jammu from Udhampur, and encircling the latter city. The next major class of land cover is the mosaic formed by cropland and natural vegetation, which occupies 22% of the basin area, always neighbouring croplands, especially around Udhampur.

The basin also has a significant percentage of tree cover (35%), consisting in broadleaf and needleleaf forests. Needleleaf forests are slightly more common (20%), and are found mainly in high altitude locations such as the east portion of the basin. Broadleaf forests occupy a lower percentage of the basin (15%), and lower altitudes than needleleaf forests, mostly in the area southeast of Udhampur.

Unforested land not occupied by crops is rare in the basin: shrubland and grassland only represent 3% of the land cover in the basin and are mostly found north of Udhampur and near the Kali Kundli glacier. Lastly, the cities of Jammu and Udhampur occupy 2% of the basin.

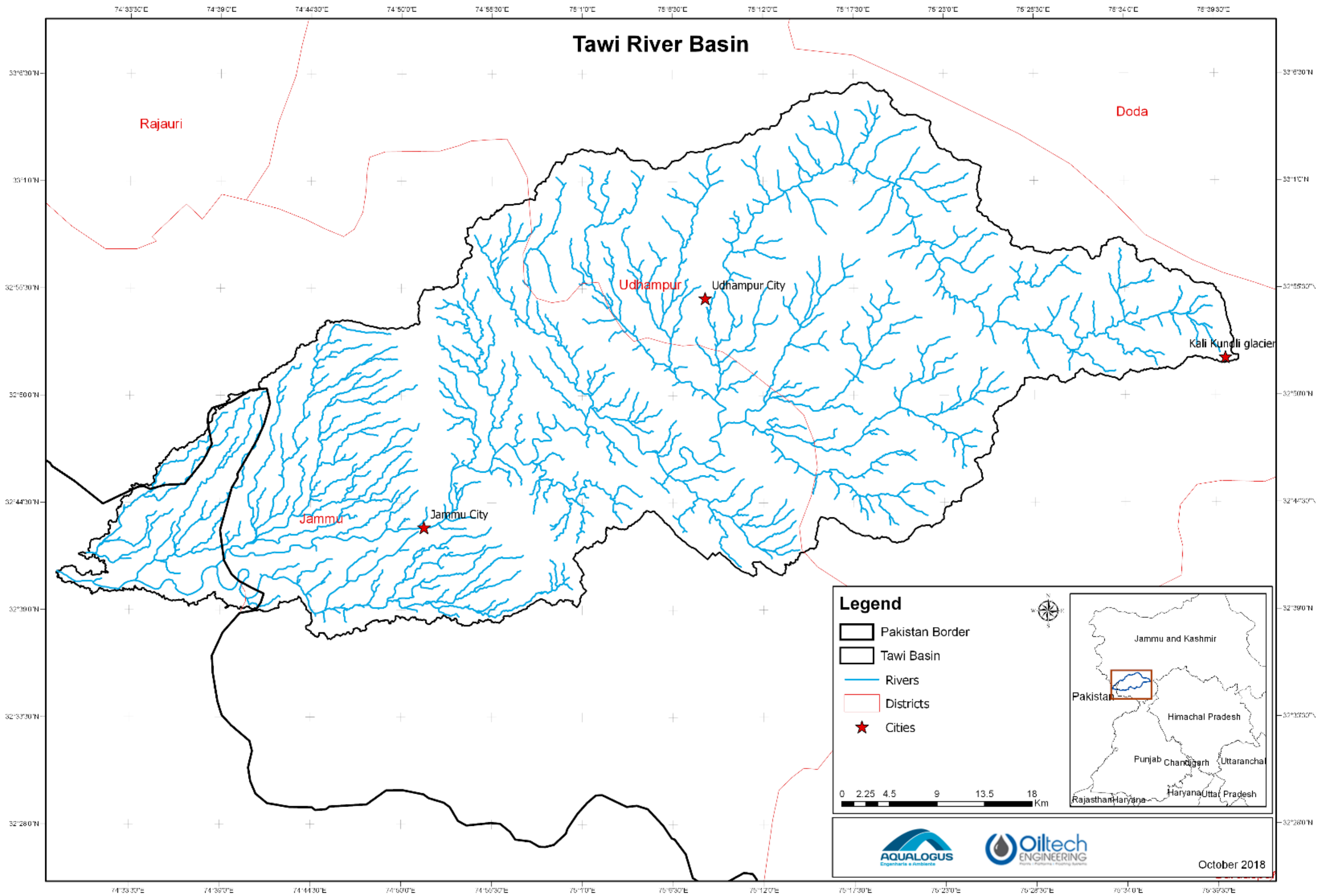

Figure 2.1: Tawi River Basin.

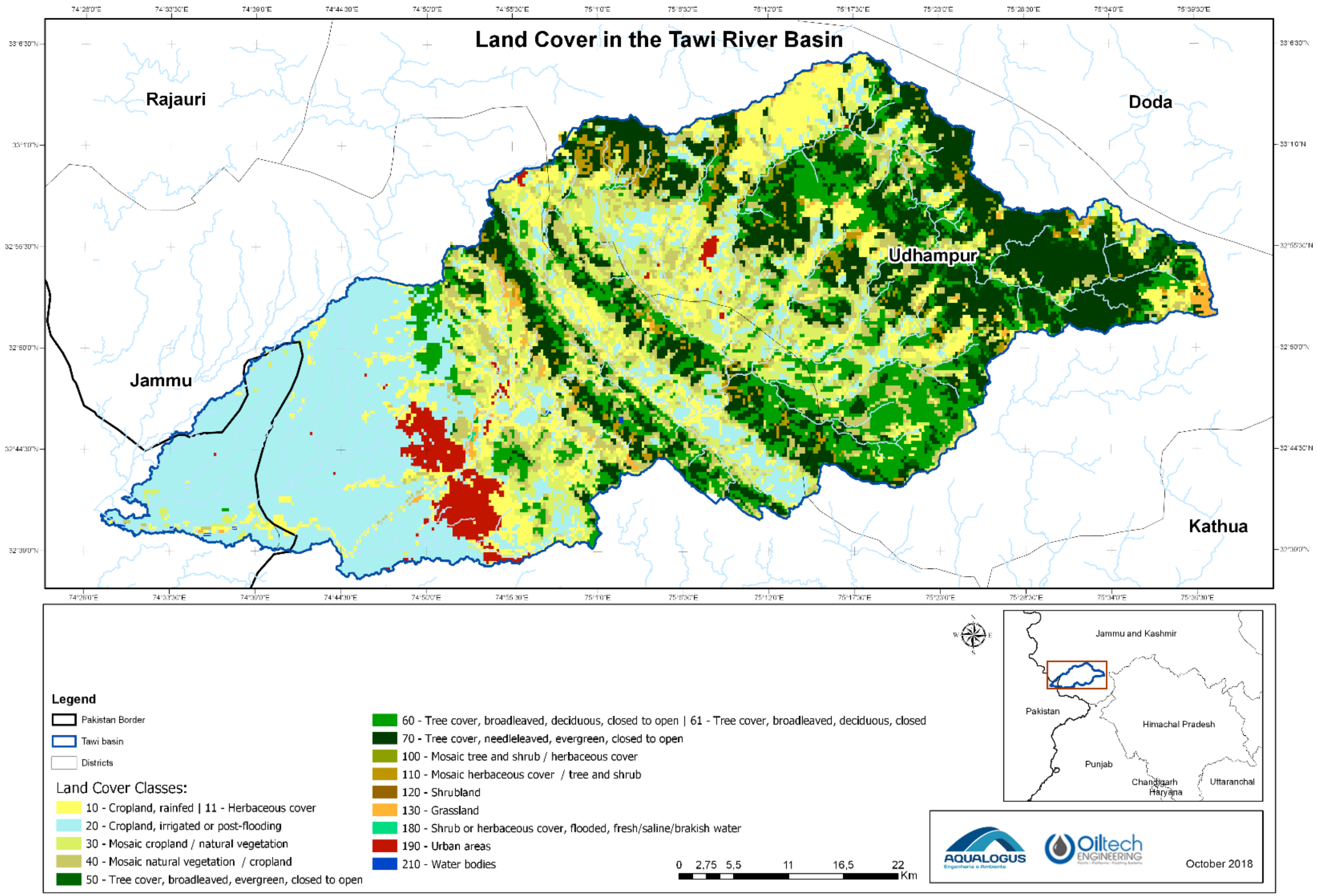

Figure 2.2: Land cover in the Tawi River Basin.

3 DATA AVAILABILITY AND QUALITY ANALYSIS

3.1 AVAILABLE DATA

The existing gauging stations in the Tawi River are established, operated and administered by the Irrigation and Flood Control (I&FC) Department – Divisions of Jammu and Udhampur. Currently, Tawi River is being gauged at Udhampur and Jammu, wherein hourly water levels are continually recorded.

Jammu and Udhampur gauging stations were established in 1988 and 1997 respectively. Table 3.1 shows the location of the gauging stations, catchment area and the period of data availability.

Table 3.1 – Gauging stations and available hydrological data in Tawi River.

Gauging Station	Location[1]		Catchment Area (km²)	Year of data		Source
	Latitude	Longitude		Hourly Discharges	Max. and Min. Discharges	
Jammu	32º 43'E	74º 51'N	2168	1988-todate	1988-todate	I&FC Dep. Jammu Div.
Udhampur	32º 56'E	75º 10'N	627	1997-todate	1997-todate	I&FC Dep. Udhampur Div

1. Coordinate System WGS84

The I&FC Departments (Jammu and Udhampur Divisions) and Project Management Unit (PMU), Jhelum & Tawi Flood Recovery Project (JTFRP), made available some of the available data on Tawi. These mainly include:

1. Monthly maximum and minimum discharge data at
   a. Udhampur gauging station from 1997 to 2018
   b. Jammu city gauging station from 1988 to 2017
2. Rating curves for Udhampur and Jammu city gauging stations
3. Sample hourly stage record for Udhampur gauging station for the months of August 1997, July 2005, August 2014 and September 2014
4. Sample hourly stage record for Jammu city gauging station for the months of August 1997, July 2005 and August 2014
5. Longitudinal section of the river Tawi from Kalikundi (Bhadarwah) to U/S of Tawi bridge
6. Longitudinal section of the river D/S of Tawi bridge along Nikki Tawi and Waddi Tawi

The monthly maximum and minimum discharge data along with the rating curve would be highly useful for doing the flood frequency analysis and assess the depth of flood for different annual exceedance probabilities or return periods at the two gauging sites.

The hourly stage record would be helpful in assessing the persistence or duration of high flows which would be highly helpful for designing appropriate measures for protecting the banks. Further, the hourly stage record would be helpful in estimating the travel time of flood from Udhampur to Jammu City and will assist in developing the flood warning system for the Jammu city.

The Jammu gauging station is located upstream of the Tawi Bridge in Bikram Chowk, presenting a controlled drainage area of around 2168 km^2 which corresponds to approximately 75% of the entire Tawi River Basin (*i.e.* up to the confluence with Chenab River in Pakistan). The Jammu Station is currently operational and the water-level observation period is 24 hours and records are taken at an hourly basis.

The Udhampur hydrological station is located about 80 km upstream of the Jammu station and 15 km upstream of the confluence of Duddar Nallah with the Tawi River, presenting a controlled drainage area of around 627 km^2 which corresponds to approximately 22% of the entire Tawi River Basin.

The location of the existing gauging stations in the Tawi River Basin and respective catchments are presented in Figure 3.1.

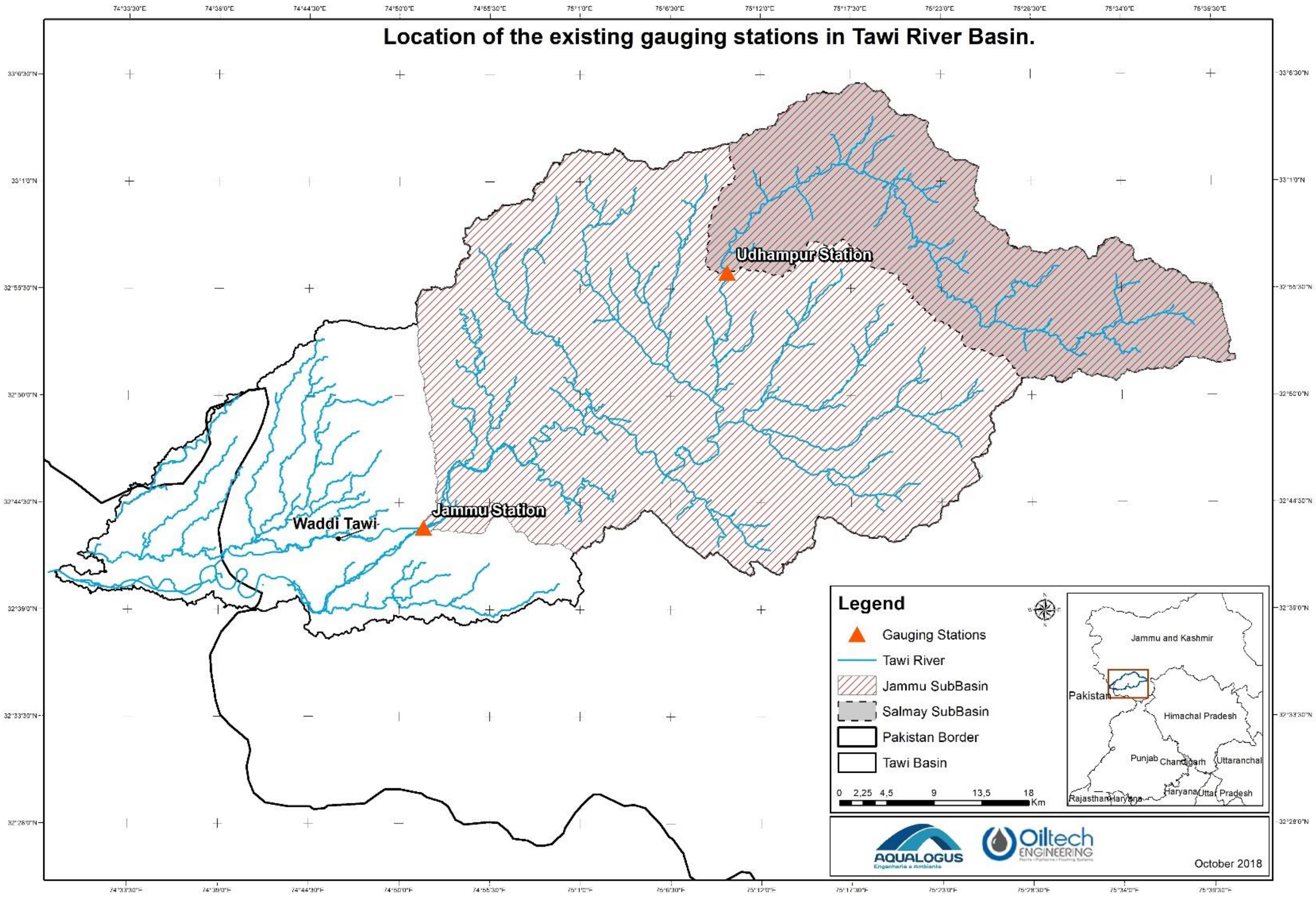

Figure 3.1: Location of the existing gauging stations in Tawi River Basin.

The team visited Flood Control Room at Tawi gauge site and hydrological station on Tawi River at Jammu city bridge on 8th August 2018. The Photo 3.1 below shows the hydrological station at Jammu, upstream of the Tawi Bridge in Bikram Chowk. The water levels are measured in the Jammu station by an inclined gauge constructed at the left bank of the river.

Photo 3.1: Hydrological station on Tawi River at Jammu City Bridge.

The highest flood level of 33 ft with discharge of 478,600 cusec was recorded on 6th September 2014 which was 16 ft higher than the danger level. The Table 3.2 below presents the different threshold levels for flood warning and highest flood levels.

Table 3.2 – Different threshold levels for flood warning and highest flood levels at Jammu city gauging station.

SN	Particulars	Stage (ft)	Discharge (cusec)
1	Alert Level	14	97,400
2	Danger Level	17	142,000
3	Evacuation Level	23	249,300
4	Highest Flood Level on 29-09-1988	31	427,000
5	Highest Flood Level on 6-09-2014	33	478,600

The Flood Control Room maintains phone numbers of different stakeholders and flood warning is communicated by phone when the river level reaches Alert Level.

The rating curve of the Jammu gauging stations is presented in the Figure 3.2.

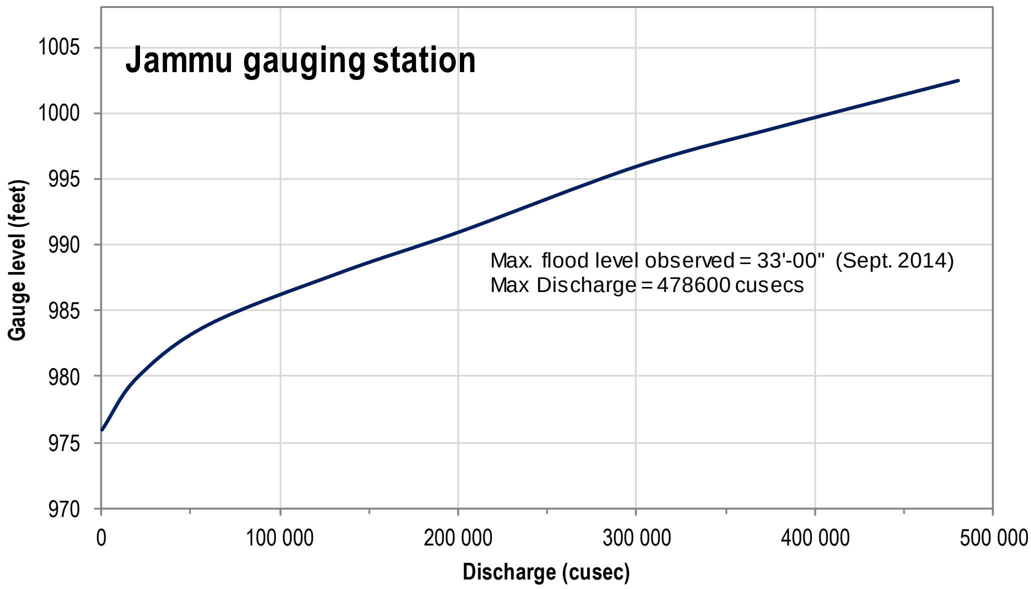

Figure 3.2: Rating curve of the Jammu gauging station.

The team also visited hydrological station at Salmay Bridge near Udhampur City. Photo 3.2 below shows the hydrological station at Udhampur. The water levels are measured by vertical gauges painted at the pier of the bridge. This station is very important for flood warning to the Jammu City and downstream.

Photo 3.2: Hydrological station on Tawi River at Udhampur

The rating curve of the Udhampur gauging stations is presented in the Figure 3.3.

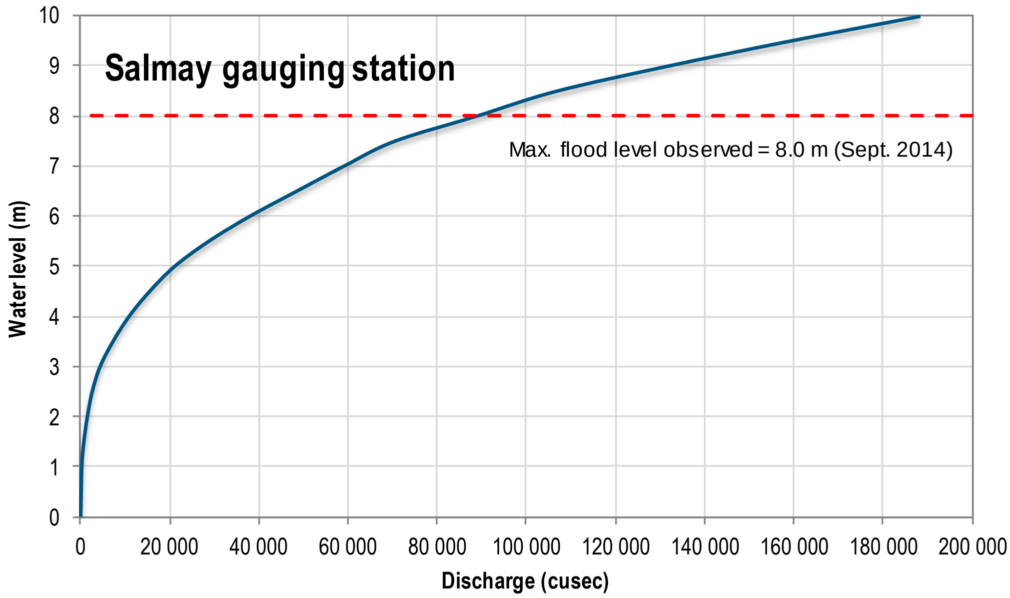

Figure 3.3: Rating curve of the Udhampur gauging station.

According to local staff at Salmay gauging station, the highest flood level of around 8 m was recorded on September 2014 floods, which corresponds to around 88,652 cusec.

Within the scope of the Assignment, the Consultant will assess the current hydrologic monitoring network and scrutinize the existing data time series, detecting possible malfunctions and damages/problems in the monitoring stations. In fact, with the passage of time, stream gauges may be displaced or destroyed or they may be changed in elevation as the result of natural (e.g. river scour or deposition, vegetation growth) and/or anthropic (e.g. vandalism) causes. Nonetheless, a preliminary quality analysis is presented in the following section.

3.2 PRELIMINARY QUALITY ANALYSIS

3.2.1 Preliminary remarks

Prior to the development of hydrological studies, the reliability assessment and data quality analysis for all relevant data must be conducted.

The first criterion applied to control the quality of the data is to check the gaps and inconsistencies in the time series and other data (*e.g.* rating curves). Stream flow should be stationary, consistent, and homogeneous, especially when used in frequency analyses. The consistency check of the collected data shall include a rough screening, comprising a visual detection of inconsistent data (*e.g.* gross errors/outliers, misplaced decimal points, significant difference data from neighbour/near stations). The detailed quality analysis will be conducted within the scope of the detailed Hydrology Report.

In terms of data quality analysis, the rating curves were preliminary assessed at this phase. Additionally, the following test for outliers was also applied to the maximum flood peak records: USGS (U.S. Water Resources Council) method.

3.2.2 Gauging stations rating curves

A power function relationship was fitted for the rating curves of Udhampur and Jammu gauging stations. The power function relationship seems to be fitting the given set of values at the Udhampur station very well up to 30ft of stage height. (Figure 3.4). However, beyond that the power function relationship seems to deviate from the given set of stage and discharge values. At the Jammu City gauging site, although the rating curve fit seem to be good (Figure 3.5) with a R^2 of 0.98, the power function curve seems to deviate somewhat at all range of stage values of the rating curve.

This may be an artefact due to the digitizing of the rating curve graph. For the detailed hydrologic study, it would be necessary to have a table of the actual rating curve values used for building the curve to avoid any errors. Further, it would also be essential to know in detail the procedure adopted to build the rating curves.

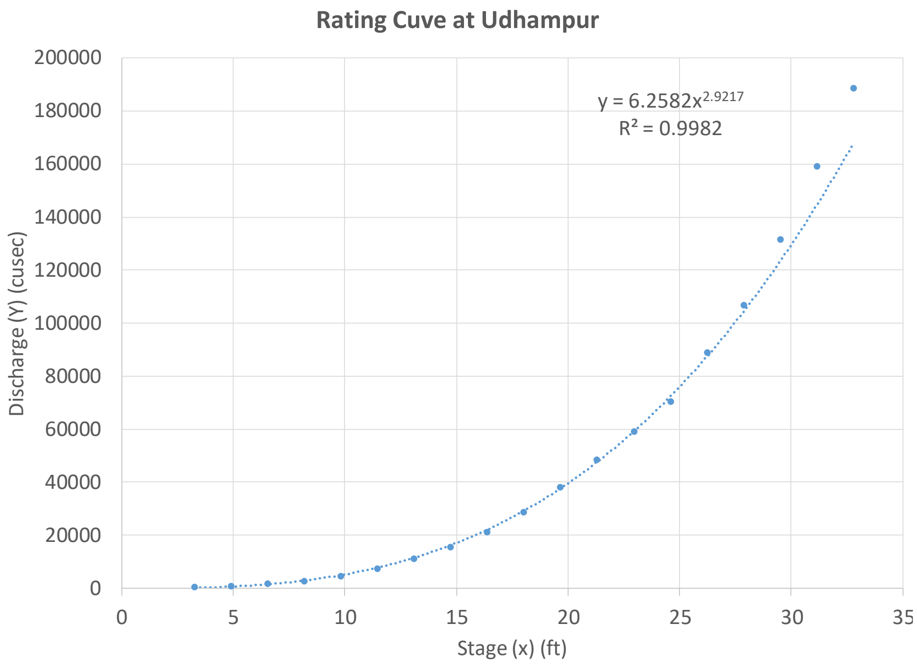

Figure 3.4: Rating curve of Udhampur gauging station.

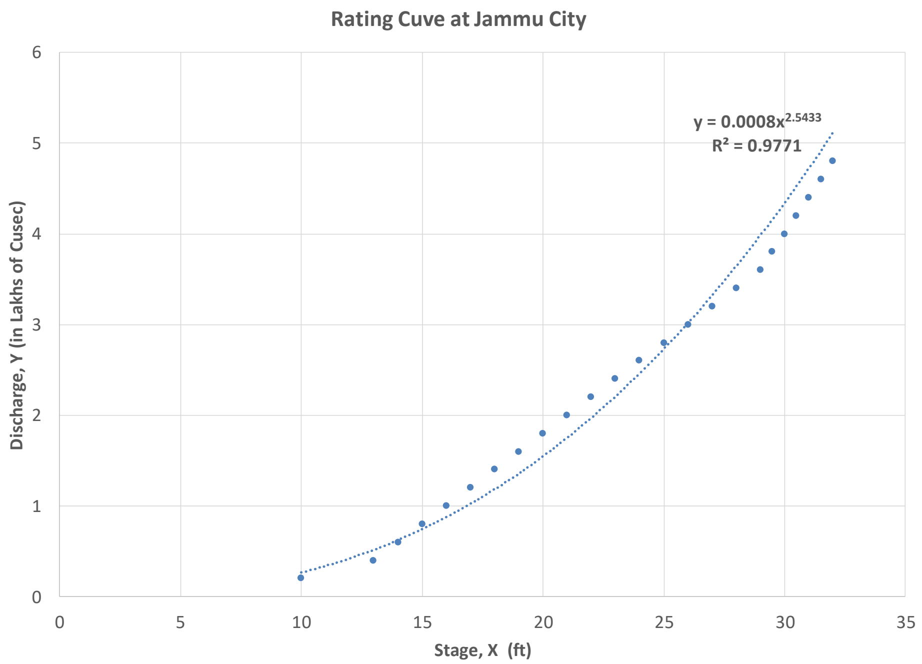

Figure 3.5: Rating curve of Jammu City gauging station.

3.2.3 Test for outliers of the maximum flood peaks

Outliers are data points which depart significantly from the trend of the remaining data. Concerning hydrological data, outliers may indicate errors (*e.g.* misplaced decimal points, mistaken measurements), may indicate data unrelated to the rest of the data set, or may be perfectly valid data that indicates unusual hydrological conditions. Thus, before proceeding with hydrological studies, the data was scrutinized and assessed, since the retention, modification, deletion of potential outliers can significantly affect the statistical parameters computed from the data. Accordingly, all procedures for treating outliers require judgement involving both statistical and hydrologic considerations.

In order to detect inconsistent data and possible outliers in the series of maximum flood peak data, the U.S. Water Resources Council method (USWRC, 1981) was applied.

The U.S. Water Resources Council method recommends that if the station skewness is greater than 0.4, then a test for outlier should be performed, considering the following equation:

$$X_H = X + K_N S \quad or \quad X_L = X - K_N S$$

Where X_H or X_L is the high or low outlier threshold in log units respectively, X is the mean logarithmic of systematic peaks, S is the standard deviation and K_N is the K value from Appendix 4 of USWRC's Bulletin 17B for sample size N.

If the logarithms of peaks in a sample are greater than X_H in the previous equation, then they are considered high outliers. On the other hand, if the logarithms of peaks in a sample are lower than X_L in the previous equation, then they are considered low outliers.

The results for outliers test as per the USWRC method are presented in the Table 3.3 for Jammu and Udhampur Stations. As show in Table 3.3, only the maximum flow of 2009 in Udhampur Station is identified as a low outlier (42 m^3/s). This value will be evaluated in the subsequent studies. Additionally, a detailed quality analysis will be conducted within the scope of the further hydrology studies.

Table 3.3 – Outlier Test results for Jammu and Udhampur Stations

Sr. No.	Year	Jammu Station			Udhampur Station		
		Peak discharge (m^3/s) [X]	Log_{10} [X]	Outlier Test	Peak discharge (m^3/s) [X]	Log_{10} [X]	Outlier Test
1	**1988**	1084	3.04				
2	**1989**	12091	4.08				
3	**1990**	4480	3.65				
4	**1991**	3154	3.50				
5	**1992**	1008	3.00				
6	**1993**	6241	3.80				
7	**1994**	3075	3.49				
8	**1995**	4388	3.64				
9	**1996**	6507	3.81				
10	**1997**	4955	3.70		4498	3.65	-
11	**1998**	1388	3.14		812	2.91	
12	**1999**	1574	3.20		1073	3.03	
13	**2000**	1699	3.23		1073	3.03	
14	**2001**	2030	3.31		1073	3.03	
15	**2002**	3154	3.50		812	2.91	
16	**2003**	2758	3.44		123	2.09	
17	**2004**	3406	3.53		1550	3.19	
18	**2005**	5768	3.76		4498	3.65	
19	**2006**	2758	3.44		1073	3.03	
20	**2007**	3406	3.53		596	2.78	
21	**2008**	1898	3.28		307	2.49	
22	**2009**	1481	3.17		42	1.63	**low outlier**
23	**2010**	2571	3.41		596	2.78	
24	**2011**	2459	3.39		205	2.31	
25	**2012**	2721	3.43		1073	3.03	
26	**2013**	4021	3.60		1550	3.19	
27	**2014**	13552	4.13		3724	3.57	
28	**2015**	2758	3.44		812	2.91	
29	**2016**	4955	3.70		1072	3.03	
30	**2017**	2030	3.31		812	2.91	
Average			**3.49**			**2.91**	
Standard Deviation			**0.27**			**0.48**	
No.of Years			**30**			**21**	
Skewness			**0.44**			**0.89**	
K_N			**2.56**			**2.41**	
X_H (Value for High outlier)			**4.19**			**4.08**	
X_H (Value for Low outlier)			**2.79**			**1.75**	

3.3 ADDITIONAL HYDROLOGY DATA REQUIRED FOR A COMPREHENSIVE ANALYSIS

For a detailed hydrologic and hydraulic analysis, the following additional datasets are required:

- River cross section data at the two gauging sites, Udhampur and Jammu city as well as at other locations where they are available
- Table of the stage – discharge rating curves at Udhampur and Jammu city and the procedure used for deriving the curves (Manning's "n" based rating curve or measured values extrapolated using curve fitting).
- Meteorological data as given below:

Type of data:	Frequency/Particular:	Period of available data:
Station details	Station name, latitude, longitude, elevation	
Rainfall	daily (hourly if available), monthly normal (1981-2010 period), 24-hour maximum rainfall for last 30 years, Intensity-Duration-Frequency Curves	At least Last 10 years (last 30 years if available)
Temperature	Daily (maximum and minimum) or hourly (if available), monthly normal (1981-2010 period)	At least Last 10 years (last 30 years if available)
Pan Evaporation	Daily, monthly normal (1981-2010 period)	At least Last 10 years (last 30 years if available)
Relative humidity	Daily or hourly (if available), monthly normal (1981-2010 period)	At least Last 10 years (last 30 years if available)

- Detailed soil map, soil thickness, depth to bed rock and soil hydraulic properties data
- Aquifer thickness of the top unconfined aquifer
- Ground water height of the top unconfined aquifer
- Detailed landuse / landcover map

4 HISTORIC FLOODS ANALYSIS

4.1 REVIEW AND ANALYSIS OF HISTORIC FLOODS IN JAMMU & KASHMIR

Review of the literature on historic floods occurred in Jammu & Kashmir evidently indicates that the region experienced recurrent floods during the past centuries (Table 4.1). It is interesting to note that 20th century witnessed eight major flood events in the region, while seven major floods occurred during the last 18 years, which reflects the increased frequency of occurrence floods in the region. Prevalence of flood events exhibit characteristic spatial pattern, wherein majority of the devastating flood events occurred in Kashmir Valley (especially in Jhelum River) or in Led and Ladakh. Further, most of the floods of the region were happened during the months of July to September, and hence, can be correlated with the precipitation concentration of the monsoon rainfall. However, severe floods were also reported due to glacial outburst. In 1929, the outburst of the Chong Khundam glacier (Karakoram) caused a flood peak of over 22000 m^3/s at Attock (Pakistan). Similarly, the flash flood experienced in Sutlej River on 31st July and 1st August 2000 was also a result of glacial outburst (NDMA, 2008). In addition, cloudbursts occurring as a result of peculiar climatic conditions and highly rugged topography are a major reason for the flash floods across the region, and recent years show substantially large number of floods due to cloudbursts, compared to last century.

Among the various paleo-floods, recent floods of August 2010 and September 2014 have caused human casualty and severe economic losses. It is reported that the rainfall during 3-7 September 2014 was 200% more than the monthly normal of September and 21% more than monthly normal of August. Moreover, the flood peak in Tawi River at Sidari (Jammu) during the period was more than 13500 m^3/s. The flood peak of 6th September 2014 was a result of high intensity rainfall of the order of more than 33 mm/hour between 1 am and 3 am.

Table 4.1 – List of historical flood events occurred in Jammu& Kashmir region (after Kelman et al., 2018)

Sl. No.	Year	Remarks
1	879	Slipping of Khadanyar mountains below Baramulla, blocking the Jhelum River.
2	883	Earthquake-induced landslides and flood in Kashmir Valley
3	1833	Flood, seemingly from a glacial outburst in Shayok Valley
4	1841	Flood in Kashmir Valley, where 92 people were died
5	1858	Flood caused by the Shyok glaciers or the Ghammesar landslide in Ladakh

Sl. No.	Year	Remarks
6	1893	52 hours of continuous rainfall beginning 18th July, and flood affected in Srinagar and adjacent areas
7	1903	Severe flooding on 23rd July in Kashmir Valley and Srinagar
8	1929	Flood in Shyok River, Ladakh
9	1948	Flood in Kashmir Valley, especially Jhelum River
10	1950	Flood in Kashmir, and nearly 100 People lost their life
11	1957	Flood in Kashmir Valley
12	1959	Flood in Kashmir Valley
13	1992	Floods and landslides due to heavy rainfall, and 200 people died in Indian-administered Kashmir and over 2000 people died in Pakistan-administered Kashmir
14	1996	Flood
15	2000	Flood in Sutlej River due to glacial outburst
16	2006	Flood
17	2010	Cloudburst led to floods in Leh during 6th August, where 204 people died
18	2011	Cloudburst at Bagger
19	2014	Flood in Kashmir Valley and Jammu Province during 6th September, and nearly 2 million people were affected
20	2015	Cloud burst and flash floods in Ladakh in August 2015
21	2017	Cloudburst at Thatri Doda

4.2 REVIEW AND ANALYSIS OF HISTORIC FLOODS IN TAWI RIVER

Tawi river basin has a long history of flooding. The Figure 4.1 presents the maximum flood peaks in Udhampur and Jammu gauging stations. Based on the monthly maximum observed records of 30 years from 1988 to 2017, discharges exceeding 1 lakh cusec seem to have occurred 15 times at the Jammu City gauging station. The most relevant events occurred in the years of 1989, 1990, 1993, 1995, 1996, 1997, 2005 and 2014.

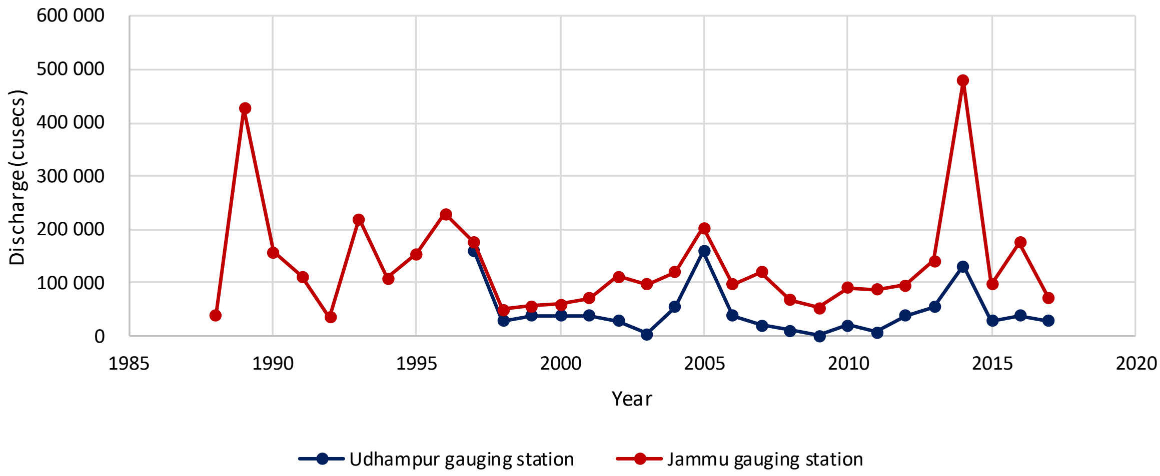

Figure 4.1: Maximum flood peaks in Udhampur and Jammu gauging stations.

Prior to the 2014 floods, the event in September 1989 was the highest observed on record with an estimated discharge of 4,27,00 cusec in Jammu gauging station from the rating curve. Further, in July 1989 another flooding event with a discharge of 2,29,800 cusec have also been recorded.

Based on the hourly stage records from the two gauging stations (Jammu and Udhampur), the floods of August 1997 occurred on 26 – 27, August 1997 in two spells. The first spell on 26 August 1997 occurred between 15:00 hours and midnight for a duration of 10 hours with a maximum stage height of 23’ 4”. The second spell on 27 August 1997 continued for a 24hr duration from 9:00 hrs with a maximum stage height of 30’ 0” at Udhampur. For the same event, the maximum flood stage at the Jammu city gauging station was only 18’ 5”. However, as there were several missing values, it is not immediately apparent if 18’ 5” was in fact the actual maximum stage height obtained for this flood at the Jammu City gauging station.

During July 2005 (Figure 4.2), a long duration spell for a duration of 17 hours seem to have occurred on 7 July 2005 from 6:00 hrs to 22:00hrs with a maximum stage of 31’ 8” at Udhampur occurred at 9:00 AM. At Jammu city, the maximum flood stage recorded was 20’ 6” recorder at 10:00 AM.

A preliminary assessment of the stage hydrographs at Udhampur and Jammu City gauging station was made for a flood observed during July 2005 (Figure 4.2). It shows that a flood with a stage height of 15ft or more at Udhampur does get realized at Jammu City gauging site after a few hours. However, for flows below 15ft at Udhampur, the flows get considerably attenuated due to the increase in width of the river.

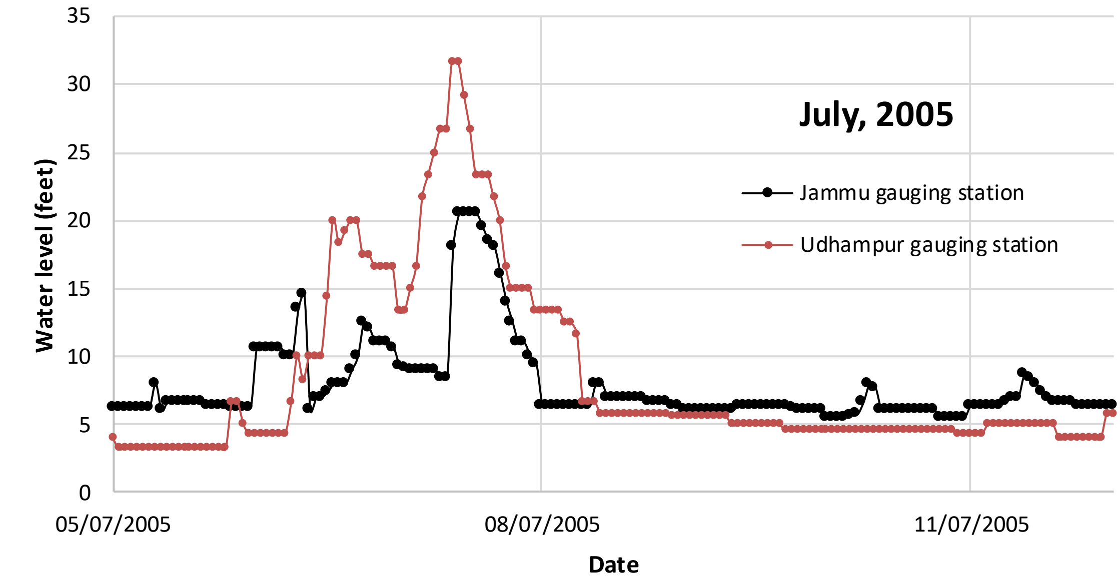

Figure 4.2: Hourly stage hydrograph for a flood observed in 2005 from the sample data.

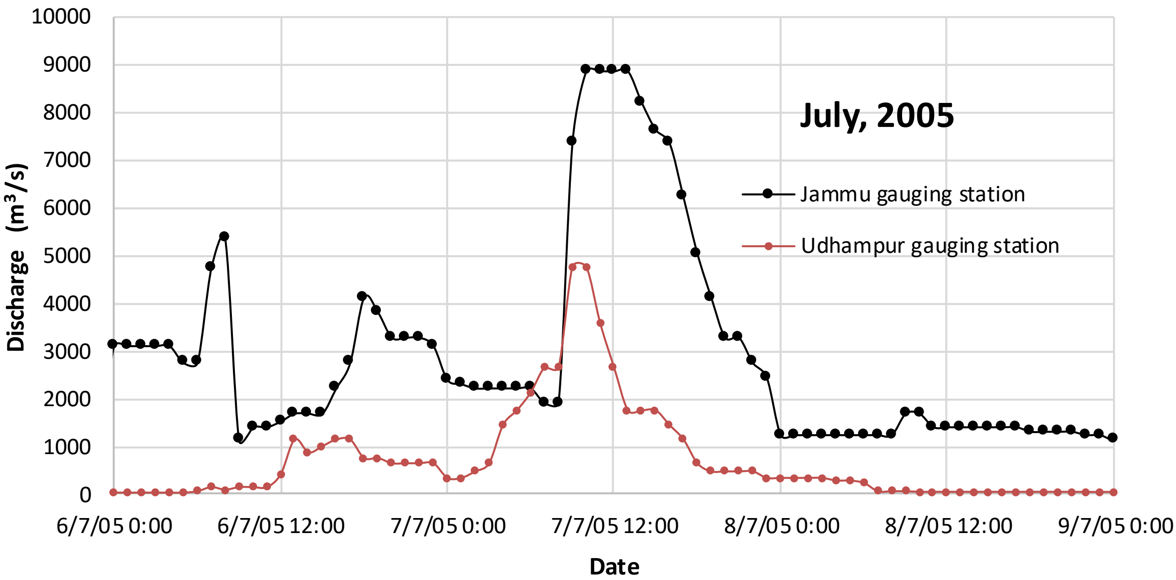

Figure 4.3: Hourly discharge hydrographs for July 2005 flood based on the rating curves

From the hourly discharge hydrographs, it is clear that the flood wave takes between 1hr to 3hr to travel from Udhampur to Jammu City. However, a detailed hydraulic model study is needed to understand the travel time of flood wave in the development of the flood forecasting system for the Jammu city.

From the available records of hourly stage data, the flooding of 4 – 6 September 2014 seems to have occurred in 3 spells with the longest spell being for a duration of 38hrs with a maximum stage height of 30’ 0” in Udhampur gauging station, similar to the maximum stage recorded during August 1997. However, the duration of the flooding was much longer as shown in Figure 4.4.

The maximum flood stage recorded at the Jammu city gauging site was 33' 0", the highest ever recorded at this site, with an estimated discharge of 4,78,000 cusecs. In contrast to this, during the floods of 1997, for a stage height of 30' at Udhampur, the stage height of flood at Jammu city was only 18' 5". This indicates that considerable amount of discharge has been contributed by the intermediate catchments between Udhampur and the Jammu city during the September 2014 floods as compared to the August 1997 floods.

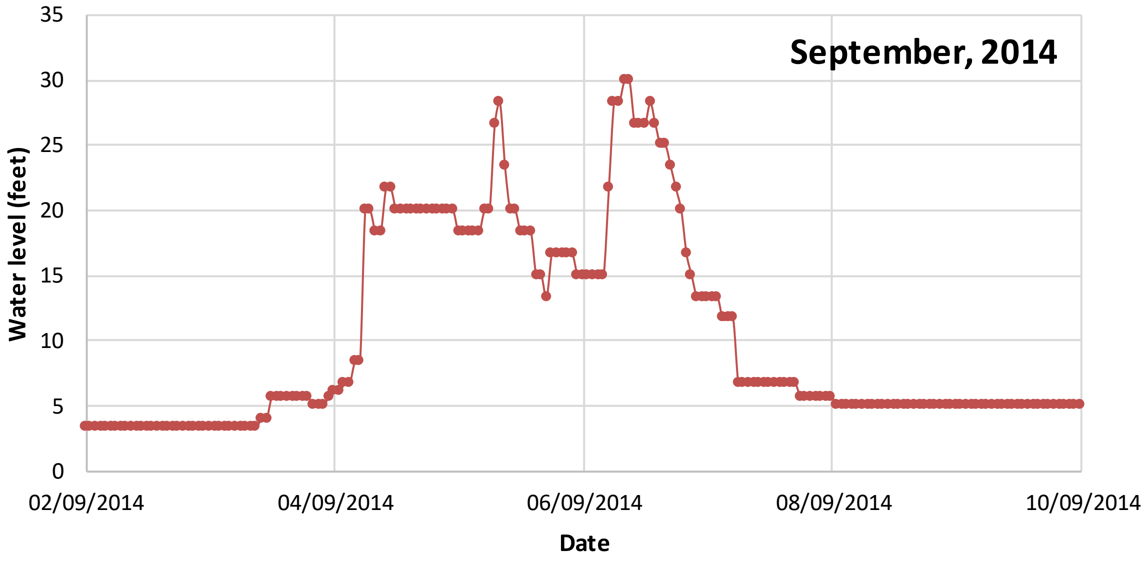

Figure 4.4: Hourly stage hydrograph for a flood observed in Udhampur on September 2014.

The main causes of 2014 floods in the state are the following:

i) High intensity continuous rainfall on 4-6 September, 2014
ii) Land degradation, soil erosion, deforestation, unscientific road construction, encroachment on steep hill slopes and unmanaged agricultural practices resulting siltation and rising of river bed
iii) Urbanization leading to increased exposure, decreased infiltration and increased runoff
iv) Obstruction of natural drainage and congestion of urban drainage system resulting overflow of surface runoff

According to the records of India Meteorological Department, the Jammu, Udhampur and Doda districts received 467.3 mm, 582.1 mm and 383.3 mm rainfall respectively in the month of September 2014, which were 339%, 165% and 297% of the normal rainfall (Source: http://hydro.imd.gov.in/hydrometweb/(S(ai1ydf45uwusrh3cpolbhe55))/DistrictRaifall.aspx).

The floods of September 2014, the biggest of those that have ever hit the State of Jammu and Kashmir, have caused immense damage resulting in loss of land, lives, houses, public infrastructure, and business hubs etc. The devastating floods claimed 281 lives (196 in Jammu and 85 in Kashmir), 29 people were missing, hundreds of houses were destroyed and thousands of people were displaced. About 6000 Km road was damaged and 3000 water supply schemes were affected. About 60 major and minor roads have been cut off and over 30 bridges washed away. Near about 5642 villages were affected by flood and 800 villages which were completely submerged (Bhat, 2016). The floods destroyed rice and apples which were at the harvesting stage. The floods adversely impacted education and tourism sector.

Rapid Damage and Needs Assessment (RDNA) mission of the World Bank estimated the total damages and loss caused by floods at about INR 211,975 million (equivalent US$ 3,550.45 million), most of it to housing, livelihoods, and roads and bridges, which combined represented more than 70 percent of the damages in terms of value. Public service infrastructure and equipment of hospitals and education centers were also severely damaged.

The following lessons can be learned from September 2014 floods in Jammu and Kashmir.

- A resilience approach is needed for flood risk management by mainstreaming DRR into development.
- The preparedness, response, rehabilitation and recovery need to be strengthened.
- The flood forecasting and early warning system needs to be established for Tawi River and Standard Operating Procedures need to be developed for forecast-based flood preparedness.
- A campaign to raise public awareness on flood risks and early warning systems is necessary.
- Local capacities should be built in emergency preparedness and response.
- Resilient livelihoods and risk transfer mechanism should be developed.
- Disaster Risk Governance (policy, legislation, institutions) should be strengthened.

5 PRELIMINARY CLIMATE CHARACTERIZATION

Tawi River Basin is exposed to temperate sub-humid climate, characterized by two distinct seasons, winter and summer. Based on the IMD 0.25˚ x 0.25˚ gridded precipitation data, mean annual rainfall of the basin varies from about 600 mm to 2500 mm (Figure 5.1), with significant monthly variability. In general, July and August are the wettest months contributing about 55% of the annual rainfall budget, and November is the least rainy month with about 2–3% of the annual rainfall. Indian summer monsoon rainfall starts from beginning of July with heavy thunder showers and continues up to mid of September. As a result, Tawi River experiences heavy floods during the months of July and August. Upper parts of the catchment are snow fed, whereas the lower parts are dominantly rain fed. The summer months are characterized by elevated discharges due to snow melting in the Kalikundi glacier valley, while low discharge is experienced during the months of October, November and December (Jain et al., 2007).

According to the IMD 1˚ x 1˚ gridded temperature data, mean monthly temperature of the basin varies between 0 and 35˚C with cyclic seasonal fluctuations (Figure 5.2). In general, temperature reaches the maximum during the months of May to July, whereas the minimum temperature registers during the months of December to February.

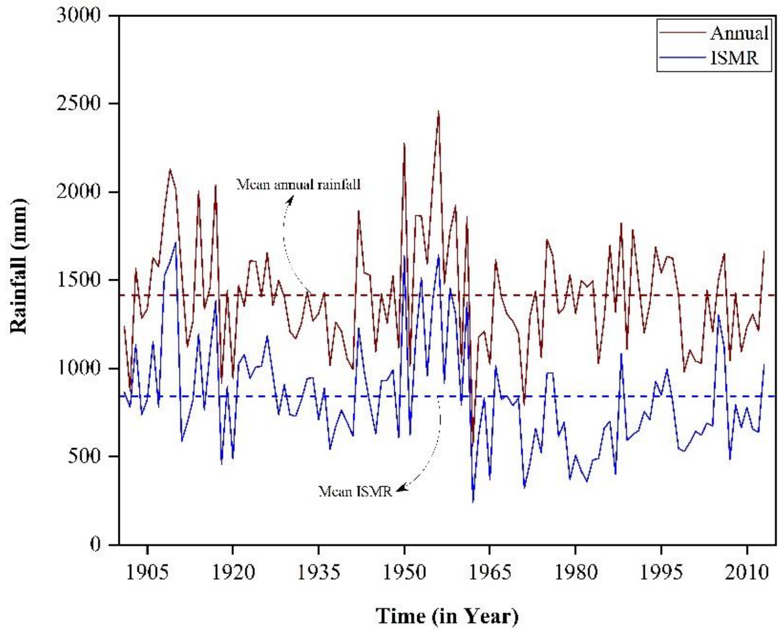

Figure 5.1: Temporal variation of rainfall of Tawi River Basin at annual and summer monsoon scales

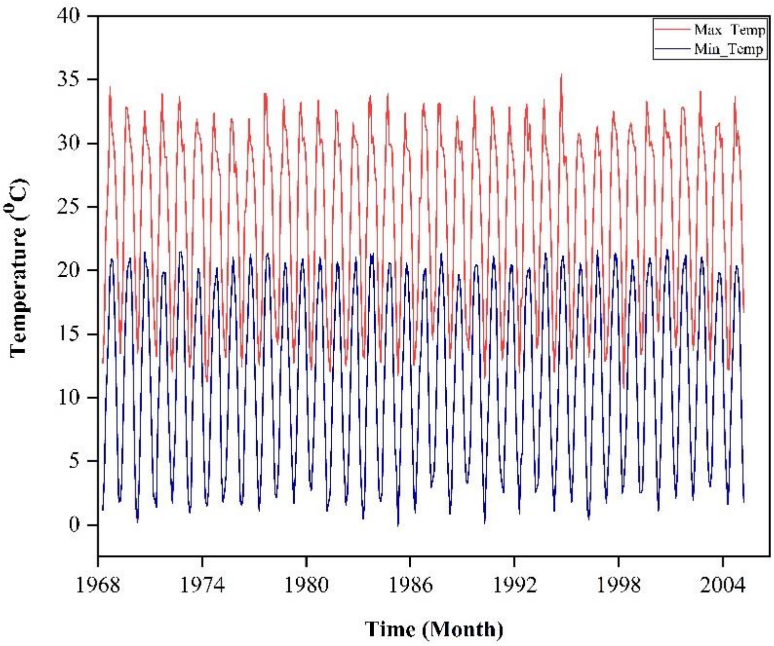

Figure 5.2: Temporal variation of maximum and minimum temperature of Tawi River Basin at monthly scale (1969-2005)

6 PRELIMINARY HYDROLOGY ANALYSIS

6.1 TAWI RIVER BASIN HYDROLOGY

Major portion of the Tawi river lies in the Saiwalik range. The upper Saiwalik range is characterized by Boulder bed and sand rocks up to Udhampur. The intermediate range called the Kandi Belt (South of Saiwalik hills) is made of course sediments, boulders, cobbles and pebbles (between Udhampur and Jammu), whereas, the area further to the west of Jammu is generally made of fine sediment, gravel sand, silt and clay. The water holding capacities of most parts of the Tawi basin is typically very low. Further, due to severe weathering, the soils get pulverised and tend to form pasty semi-fluid mass cementing the pores leading to surface detention and subsequently runoff (NIH, 2000). Hence, either the water will percolate quickly due to excessive permeability in the upper ranges or more runoff due to cementing of pores in the middle / lower ranges.

The upper and middle portion of the Tawi river primarily has a deciduous and evergreen forest cover at higher elevations (> 1500m) interlaced with rainfed agriculture up to Udhampur in the lower elevation ranges. The area below Jammu is primarily characterized by irrigated cropland, primarily Paddy.

In the Tawi basin, July and August are generally the wettest months with about 55 % rainfall and November is the least rainy month with about 2-3% of total rainfall. Monsoon starts from 1st July with heavy thunder showers and continues up to mid September. Normal annual rainfall is the basin varies from 1110 to 1500 mm.

The average maximum and minimum monthly flows at Jammu gauging station (1988-2017) are presented in the Figure 6.1 and Figure 6.2 respectively. The average maximum flows occur evidently from July to September. On the other hand, the average minimum flows occur from October to February.

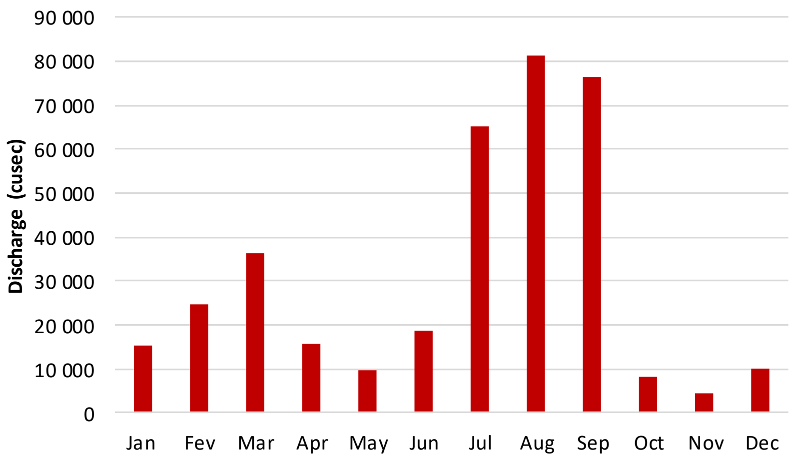

Figure 6.1: Average maximum monthly flow at Jammu gauging station (1988-2017)

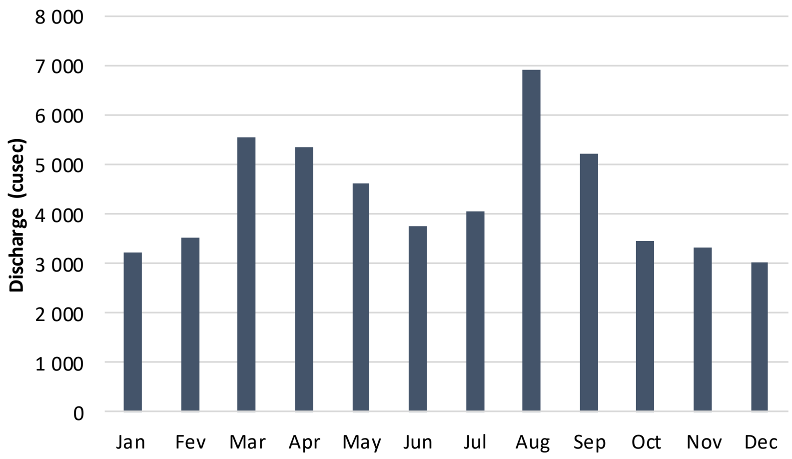

Figure 6.2: Average minimum monthly flow at Jammu gauging station (1988-2017)

The Table 6.1 and Figure 6.3 presents the major Nallahs in the Tawi River basin.

Table 6.1 – Major Nallahs in Tawi River Basin.

No.	Nallah	Catchment area (km^2)
1	**Balole**	**155**
2	**Sohagni**	**320**
3	**Chirwa**	**35**
4	**Ballini**	**97**
5	**Sardan**	**87**
6	**Jhajjar**	**147**
7	**Gambir**	**105**
8	**Ram Nagar WaliKhad**	**487**
9	**Duddar**	**275**

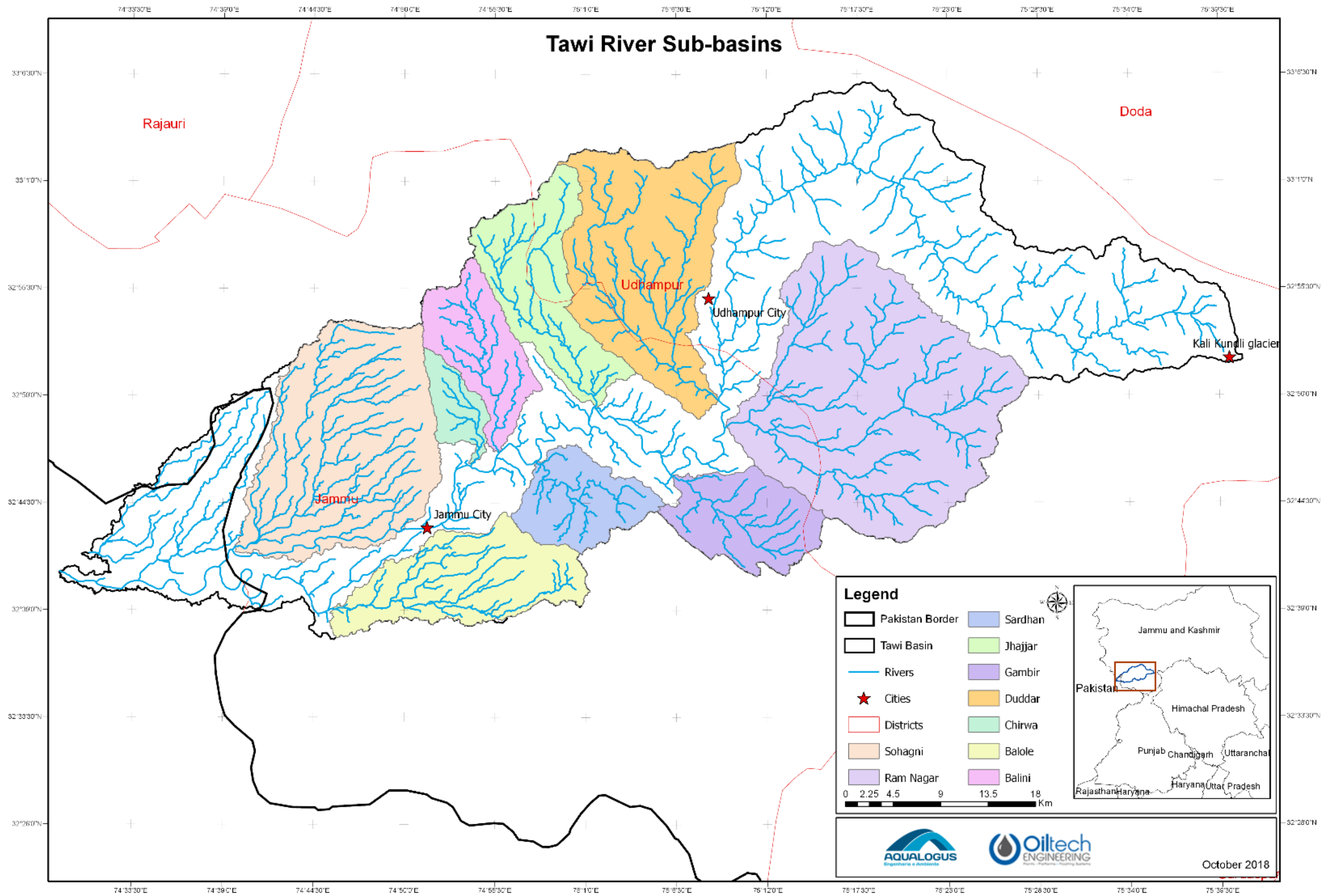

Figure 6.3: Major Nallahs in Tawi River Basin.

6.2 FLOOD FREQUENCY ANALYSIS

Flood frequency analysis of the annual maximum discharge data was carried out for the two gauging sites existing in Tawi River, near Udhampur and Jammu cities. The annual maximum discharge data were fitted with log-normal 2- parameter (LN2), log-normal 3-parameter (LN3), Log-Pearson III (LP3), Gumbel, Extreme value – I (EVI) and Generalized extreme value (GEV) distributions to find out the best probability distribution representing the peak flows. The results were tested for their goodness of fit using K-S tests.

For the Udhampur site, observed record of maximum discharge was available for 21 years from 1997 to 2017. The summary of results for the Udhampur gauging station are presented in Table 6.2.

Based on the distribution fitting, LN2 seem to be the best with the least standard error and the highest correlation coefficient. Hence, LN2 was chosen as the best distribution. Based on the fitted distribution, the 1997 flood of 158845 cusec seem to have a recurrence interval of 16 years.

Table 6.2 – Summary of Results of Flood Frequency Analysis for Udhampur station

	Distributions					
Return Period	**LN2**	**LN3**	**LP3**	**Gumbel**	**EVI**	**GEV**
2	28826	34470	33873	39222	39438	32251
5	73553	69471	74384	87912	74948	64308
10	120074	96911	103494	120149	98459	93205
20	179961	126233	130846	151071	121011	128555
50	283728	168581	163977	191097	150202	188799
100	384318	203687	186664	221091	172077	247825
Goodness of Fit						
Standard Error	13961.57	17223.74	18079.75	21119.19	21119.19	15268.25
Correl. Coeff., r	0.9551	0.9309	0.9235	0.8940	0.8940	0.9461
KS*	0.162	0.162	0.162	0.162	0.162	0.162

*Critical Values of KS for N = 21 and 95% confidence level = 0.28724

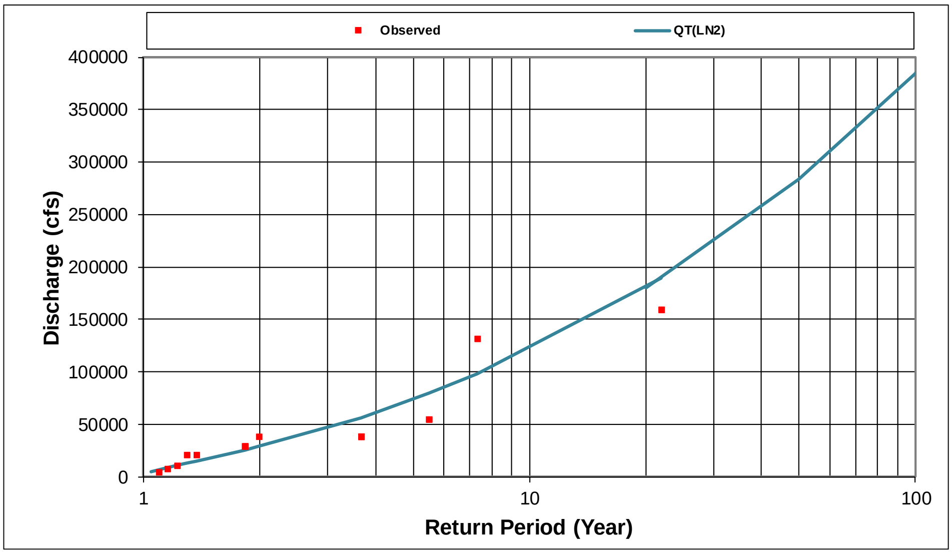

Figure 6.4: Flood frequency distribution for the Udhampur gauging station.

At the Jammu City gauging site, the annual maximum discharge data of Tawi River from 1988 to 2016 were fitted with different distributions to find out the best probability distribution representing the peak flows. The summary of results for the Udhampur gauging station are presented in Table 6.3.

Based on the fitting, GEV was found to best fit the data with minimum standard error and maximum correlation coefficient (Table 8.2). The results were tested for their goodness of fit using Chi-Square, K-S and found to fit well at 5% significance level.

Table 6.3 – Summary of Results of Flood Frequency Analysis for Jammu City Gauging station

	Distributions					
Return Period	**LN2**	**LN3**	**LP3**	**Gumbel**	**EVI**	**GEV**
2	108729	103313	103833	117975	118731	103566
5	184101	183655	180721	221390	197955	176028
10	242507	253252	248214	289860	250409	240188
20	304452	332635	327339	355537	300723	317567
50	393260	454804	454271	440551	365851	447311
100	466415	561793	570752	504256	414654	572462
Goodness of Fit						
Standard Error	30003.24	24424.25	24041.99	40075.22	40075.22	23940.83
Correl. Coeff., r	0.9569	0.9716	0.9725	0.9217	0.9217	0.9728
KS*	0.033	0.033	0.100	0.167	0.100	0.033

*Critical Values of KS for N = 30 and 95% confidence level = 0.2417

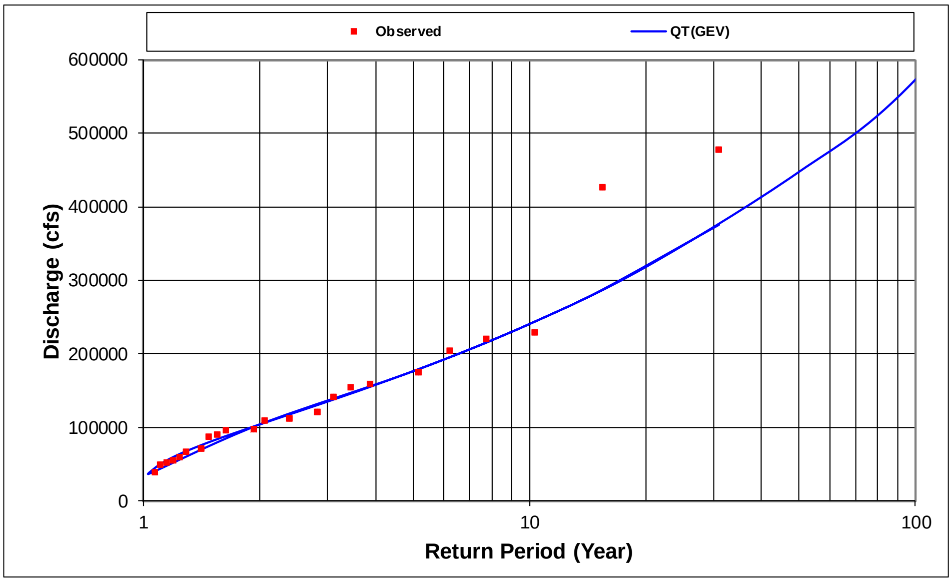

Figure 6.5: Flood frequency distribution for the Jammu gauging station.

Before conclusions could be drawn from this preliminary flood frequency assessment of the Udhampur and the Jammu city gauging sites, it is important to understand the procedure / methodology adopted in deriving the rating curve that is currently used at both these sites in converting the measured stage in to discharge values. According to the obtained information, data of streamflow measurements (with current meter, ADCP or other method) were not performed in the Tawi River Basin. Therefore, rating curves might have been established based on Manning's method.

Further, it may be a better option to fit the frequency distribution to the measured maximum stage values to get the flood stages directly for different return periods. This would be useful while designing the levees along the length of the river based on the flood stage itself for an accepted level of hydrologic risk within the service life of the levee.

7 SUMMARY AND RECOMMENDATIONS

In this report a preliminary analysis of the floods in Tawi based on the measured data has been carried out. A preliminary analysis of the three important floods on record 1997, 2005 and 2014 shows that they are flashy in nature and tend to persist for a considerable duration. Depending on the magnitude of the floods, it may take anywhere between 1 hr to 3 hr for the flood to travel from Udhampur to Jammu city. A detailed hydraulic model may be setup to assess the travel time of flood between the two gauging sites

The floods of 1997 and 2014 resulted in a very high flood magnitude from the provided rating curve. The discharge values reported from this extreme flood values need to be verified through a detailed hydraulic and / or hydrologic model and if needed the rating curve need to be updated based on this analysis.

The upper part of Tawi is characterized by rugged mountainous topography. Hence, suitable sites for natural water retention measures need to be explored along different subbasins of the Tawi River. In addition, the degraded ranges of Shiwaliks could be revegetated through an integrated reforestation effort for reducing the runoff and increasing infiltration and percolation of rainfall, thus minimizing flood magnitudes. A detailed assessment of the topography, along with the land use / land cover, soil and discharge data is needed to identify potential sites for flood mitigation and river management measures. These data along with hydrologic and hydraulic modelling would need to be carried out for arriving at possible options.

Further, levees and other associated appurtenances such as gabions and spurs would be needed at critical sections for containing the river within the flood plain itself and prevent loss to life and property. For this a detailed assessment of topography and flood depth would be needed along with a detailed hydraulic and flood plain modelling.

Automatic water level recorders with telemetry may be installed at Udhampur and Jammu city. This when coupled with weather forecast and inflow forecasting models would help in getting at least 6hr to 24 hr lead time in preparing for any flood like conditions.

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