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Floodplain Mapping for Indus River: Chashma –Taunsa Reach

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Abstract

Floods are the most critical among all the natural calamities. Flood water inundate the floodplain areas and cause vast damages to life and property. It is thus essential to address this natural calamity to decrease the effect it causes to property and people. In this study, Indus River reach Chashma-Taunsa (252 km) was selected, that experienced exceptionally high flood in 2010, due to which huge damages occurred to life and property. In this study, flood hydraulic modelling and floodplain mapping has been performed to have initial assessment of flood vulnerability and to provide vision for emergency preparedness plan. Flood mapping can further precede flood hazard and risk maps. To perform hydraulic modelling and floodplain mapping HEC-RAS, ArcGIS and its extension Hec-GeoRas were used as tools. HEC-RAS model input cross-sections data were collected from physical survey and extracted from DEM SRTM 90 m by using Hec-GeoRas. Comparison was made between surveyed and SRTM DEM extracted cross-sections; to perform necessary verification and merging the channel data in DEM extracted cross-section. Frequency analysis has been conducted by using Gumbel's and Log Pearson Type III distributions to determine the flood peaks for extreme events. Frequency analysis result shows that the flood of 2010 in study area has return period of 180 years. Cross-sections data and results of frequency analysis were used in HEC-RAS to perform unsteady flow analysis for low to extreme events. HEC-RAS model was calibrated and validated for year 2010 and 2006, respectively. Coefficient of determination (R^2) 0.95 & 0.90 and Nash and Sutcliffe coefficient that 0.93 & 0.86 were calculated, that show good calibration and validation respectively. Results of HEC-RAS model were exported in ArcGIS to perform inundation mapping. Depth and area of flooded extent for 2010 flood were calculated as 8.1 m and 1900 km^2, respectively. Flood inundation maps of the whole study area were prepared for 25, 500 year and 2010 year return period flood. Floodplain maps show flooded area depth from 7.1 to 9.1 m for 25 year to 500 return period floods, respectively. Flood inundation maps will be an important tool for Engineers, Planners for emergency actions plans and for flood management.

Key Words: Floodplain maps; Frequency analysis; DEM SRTM; Inundation; Flood hazard and extent

1. Introduction

Rivers are considered the most essential resources for providing water to human beings and other living things. Floodplain and areas near rivers are heavily populated because of their suitable conditions for social and economic activities. River may cause non recoverable damages in the form of floods.

Flood is a high stage in a river, normally the level at which the river outflows its banks and inundate the adjoining area [1]. Floods are the most destructive among all the natural calamities in world [2] which cause a lot of losses of lives, properties, crops and wealth, etc. Even with several years of knowledge and technical techniques, floods still keep on its devastation nearly in every portion of earth.

Change of climate is the main cause to increase the risk of severe hydrological events [3]. Occurrence of flash floods and severe change of climate is aggravated by increasing urbanization in the world [4]. These growths have cited a great emphasis on the forecast of flood extent, damage and levels, for the reason of calamity management and regional and urban planning [5].

Flood destruction likelihood is increasing with urbanization and population rate of growth. To cope with flood problems inland engineering physical measures with their support by computer aided measures in form of flood models are necessary to execute in balance. Physical measures including the reservoirs, retarding basin, flood diversion embankments, etc. that can control or divert the large scale flood diversity. Computer aided flood models are being efficiently used most efficient to evaluate the flood damage to property and people. The model show the extent, depth of flooding to depict the area liable to flooding events of different return periods.

In this study Indus River Reach, Chashma-Taunsa was selected as study area that experienced exceptionally high flood in 2010 due to which lot of damages occurred to life and property. Indus River has been exposed to high flood risks and damages since the creation of Pakistan. In year 2010 Pakistan experienced the worst flood of the history. According to damage need assessment report by World Bank *"160,000 km^2 areas were damaged by the flood, which includes 1985 lives, 1.5 million damaged to property and houses, crop land area of about 17 million acres, 20 million populations was displaced and overall economic loss of 10 Billion Pak Rupees"* [6].

In this study an effort has been made to carry out numerical modeling of Chashma-Taunsa Reach of Indus River for the assessment of flood hazards expected to be caused due to floods of 25 years, 100 years, 200 years and 500 years return periods. This study results in the flood extent, depth, velocity and hazard maps of various return period floods. Flood risk maps can show the impact associated with these scenarios, i.e. number of affected personnel's, economic activity affected in the area [7].

HEC-RAS, Hec-GeoRas and ArcGIS have been used for hydraulic and floodplain mapping for this study area. These tools are used worldwide to carry out several studies including preparation of flood inundation maps and flood forecasting [8].

2. Related work and Literature Review

Several studies have been carried out worldwide for the hydraulic analysis of floods and floodplain in Hec-Ras, Hec-GeoRas and ArcGIS; by these analysis tools depths, extent, and area of inundation of flooding can be computed, that is used by the decision makers to prepare Early Preparedness Plan of actions. Some of the study's findings are listed below;

Ahmad [9] conducts a study to investigate the impact of Chenab River on district Muzaffargarh, downstream and upstream of Sher Shah Bridge. Frequency analysis was carried out by Gumbel's Method manually and by using DFW software, their comparison shows close results. Depth of water was obtained against different return periods flood by Hec-Ras. Water depth results by model were comparable with the observed data, by using Arc View water extent was marked at the floodplain area.

Ackerman [10],[11] conducted his work on River Salt floodplain that is located in Phoenix, AZ. HEC-RAS software with its collaboration with ARC-GIS and its extension HEC-GEORAS were used to build flood model and for analysis of floodplain extent calculation. HEC-GEORAS provide valuable information by generating flood extent, depth and velocity maps that can help in evaluation of impact and damage analysis that would be helpful in flood reduction measures. He concluded that the GIS enhance the capacity to process the geographic data in the form of DEM, for analyzing and visualizing the data. HEC-GEORAS act as a supportive tool to help in analysis and development of model for the real world presentation of the study area watershed to Engineers and Planners, but it's not mainly focus on engineering and technically concerns rather its play a bridge role between planners for the building of model and public issues.

Fosu et al, [12] studied the river inundation and hazard mapping of Susan River; Kumasi, Ghana. HEC-RAS, ARC-GIS and its extension HEC-GEORAS were used as tools for flood analysis. Flood results were marked on topographic map. Total flooded area computed was 2.93 km^2 and max inundation depth of 4.01 m was computed.

Hussain [13] used the SRTM Data for the generation of flood model to create flood zonal maps by the use of hydraulic model and GIS. DEM data was used for the extraction of cross-section data of Chenab River; accurate DEM data can save time and money for field survey. Model was run against the peak flood of 25,500 and 31,000 cumec for the generation of floodplain maps. Flood of magnitude 31,000 to 25,500 cumec inundate the adjoining floodplain areas by damaging 381 villages and 1264 km^2 of land area. Simulated results were compared with the observed data, their comparison show that the simulated water levels results are satisfactory.

Hamid [14] conducted a study to evaluate the flood disaster by Jhelum River in Kohala-Muzaffarabad Reach. Hec-2 software was used to determine the flood longitudinal profile of the reach. Frequency analysis was carried out by using Gumbel and Log-Pearson III to determine the flood peaks of different return periods. The results of frequency analysis show that by the use of Log-Pearson III for more than 100 year flood return data, its values are closer to observed values of discharge. Flood causes major damages in this reach to bridges, houses, roads, lands erosion and infrastructure. By the extent of flood the early preparedness plan can be established to cope with these disasters.

Haile and Rientjes [15] used DEM of resolution 1.5 m created from LIDAR (Light Detection and Ranging) and used as base line case for flood simulations. DEM was modified in this study, of resolution up to 15 m and serve as input to the flood simulations. By re-sampling to courser grid elements has resulted in an increased loss of detailed topographic properties that affect flood simulations. The geometric data was extracted from DEM and the flow movement analysis was carried out in SOBEK software. Study concluded that the good resolution of DEM can better extract the geometric properties that ultimately results in better simulations results. Flood extent, flow depth, flow velocity and flow pattern are the major parameters affected by DEM accuracy. The study concluded that the accuracy of DEM data has significant impact on the accuracy of results that facilitate in actual flood extent calculation.

Horritt et al, [16] conducted their study on Severn River, UK for a river reach of 60 km. HEC-RAS 1D, TELEMAC-2D and LISFLOOD-FP were used for this study. Remote sensing data through radar was acquired for flood extent mapping. Models calibrations were performed by using the channel friction coefficient and floodplain as free parameters, against both inundated area observed and discharge recorded downstream. The predictive power of the models results obtained from calibration against discharge and flood extent for one event was used for other events for validation purposes. For this reach both TELEMAC-2D and HEC-RAS show good results for the calibration against inundated area and discharge while the LISFLOOD-FP required free inundated area for calibration against data to create satisfactory results. The different predictive performances of the models stem from their different responses to changes in friction parameterization.

Tabyoui et al., [17] studied the hydraulic modeling and its application on Oued Inaouen (Taza, Northern Morocco) using HEC-RAS and GIS to assist in the design of the drainage facilities. They established a link between hydraulic model and flood mapping using GIS to facilitate the decision makers to identify where changes are required to cope with drainage.

Latif [18] evaluated the flooding hazard in Kabul River (confluence to Charsada, 76 Km) under various flood conditions. Further the effect of proposed Kalabagh dam (backwater, sedimentation) on Kabul River flooding hazard was also studied. Google Earth software was used to augment the cross-section data. Water profile was calculated by the use of Hec-Ras Software for various return period floods against different ground conditions. Simulated water levels were evaluated with observed levels and with permissible water levels for the estimation of flood hazard. Study finalized that Kabul River remains safe for current condition for high, medium, and low flood flows. Upstream 43Km reaches from Nowshera to Charsada show critical condition for very high floods due to downstream construction at Nowshera. Sedimentation and backwater caused by Kalabagh dam has insignificant effect on flooding at Nowshera. Channel modification by widening completely removes the flooding threats in the study reach.

Salajegheh et al, [19] studied the floodplain mapping in semi-arid region of Iran using HEC-RAS and ArcGIS. This study provides a link between hydraulic model and its representation in GIS. Procedure for collecting and processing of data is illustrated in his study.

Tariq [20] studied flood risk areas along River Chenab district Chiniot. He used Hec-Ras software for the flood model and concluded that it can be used very effectively for the simulation of flood. Furthermore, he concluded that to increase the accuracy of results GIS based data obtained through remote sensing should be used.

The various studies review presented here reveal that building the flood model by using 1-D hydraulic model and floodplain mapping using GIS give good representation of extent, depth that can give engineers and decision maker a well knowledge of the potential threat to the areas prone to flooding. Managements can reduce or eliminate the flood disaster by forecasting the magnitude, utilizing early prepared plans of action, and through early warnings evacuations.

Study reach of Indus River (Chashma-Taunsa) of Pakistan that is exposed to serious flooding condition is not much studied. Therefore, an effort is made to prepare hydraulic model and floodplain mapping of Chashma-Taunsa reach against different return periods flood.

2.1 Hydraulic Model (HEC-RAS) Description

Hec-Ras is one dimensional software, which is used worldwide for steady, unsteady flow analysis. Computation in Hec-Ras involves the solution of one dimensional energy Equation. Water surface profiles are computed from one cross-section to other by using standard step method. Energy Equation (1) is only valid for gradually varied flow Figure 1 and for rapid varied flow, Momentum equation is used in Hec-Ras.

$$z_1 + y_1 + \alpha_1 \frac{V_1^2}{1g} = z_2 + y_2 + \alpha_2 \frac{V_2^2}{1g} = +h_f$$

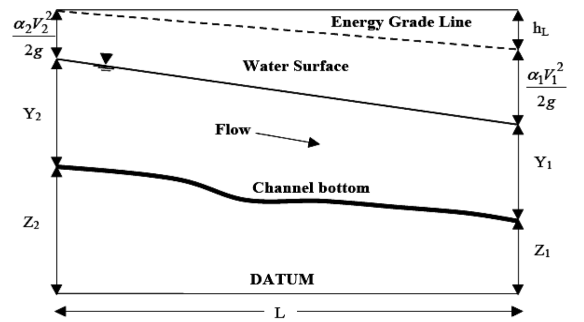


Fig. 1 Energy equation parameters for gradually varied flow

where, z_1, z_2 = channel bed elevation above a datum (m), y_1, y_2 = water depth at cross-sections (m), α= velocity weighting coefficient

3. Description of Study Area

River Indus is the largest river in Pakistan. Indus River takes its rise in Kailas Parbat in western Tibet on the northern side of the Great Himalaya Range at an altitude of 5,500 m+msl. Its source is a spring called Singikabad near Mansarower Lake. The river path is through Ladakh area of Jammu and Kashmir towards Gilgit Baltistan and after that flows in south way all along the whole extent of Pakistan to become the part of Arabian Sea of Karachi. The Indus river basin area extends 970,000 km^2 Indus total length is 3180 km. River slopes in the upper reaches till Kalabagh are steep, with an average of 3.7 m/km. From Kalabagh, Indus flows out into the plains, becoming a wide braided river with mild slopes, ranging from 0.24 m/km up to Mithankot to 0.11 m/km in its lower reach.

Indus River has been exposed to flooding over the last century, it has experienced various floods and the worst was year 2010 flood. Different Hill torrents contribute their flows in this reach during floods. Major contributions are through Sangar and Vehowa hill torrents, contributing 2,166 and 3,129 cumec flows respectively [21] in year 2010. Geology of area describes the existence of gravel, stones and mud. Land use of study area describes the agricultural land, villages and barren land. Study area has slope of 0.25 m/km.

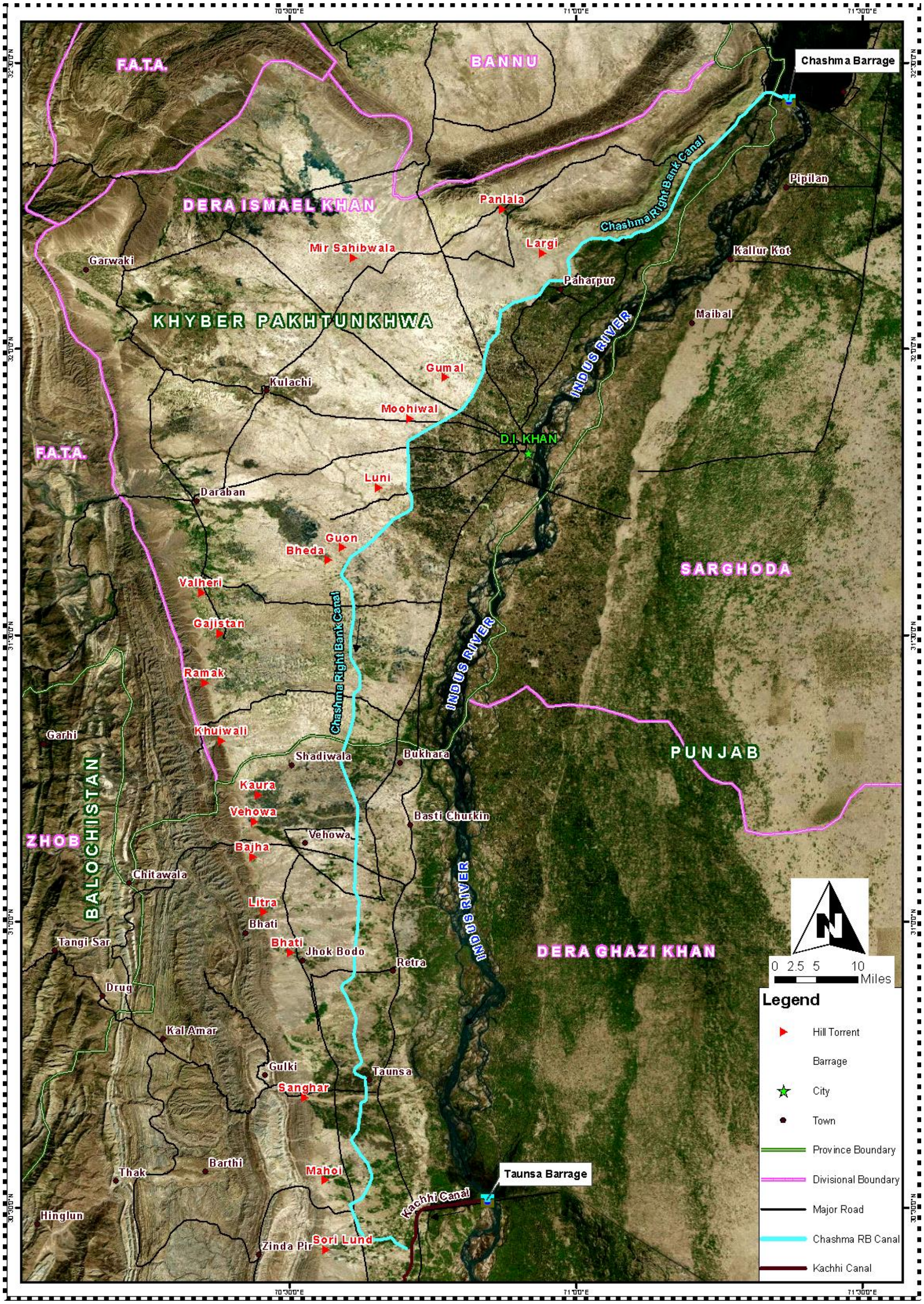


Fig. 2 Study Area Map for Chashma-Taunsa Reach

The study area is an Indus River Reach from just downstream of Chashma Barrage to Taunsa barrage just upstream. Chashma Barrage is located in district Mianwali and Taunsa Barrage in district Muzaffargarh of Punjab. Taunsa Barrage is located 20 km south of Taunsa city and 16 km from Kot-Addu city. This reach is 252 km long and was severely exposed to 2010 floods. The floodplain exists along the whole length of the reach, and flooding is the major problem in floodplains of this area. Figure 2 shows the map of the study area.

4. 2010 Flood Causes in Study Area

Monsoon periods of 2010 fetch heavy rainfall throughout the country, in many areas it turns into the historically peak rainfall. Observed flood hydrographs (6 hourly from July-September 2010) at Chashma and Taunsa are shown in Figure 3. Figure 4 shows the severe most rainstorms in 2010. Northern areas rainfall increased the water stage in rivers and hill torrents which ultimately cause to increase the water level in Indus River.

The flood became even more devastated by the contribution of Kabul River and Swat River in Jinnah to Chashma Barrage reach. Hill torrents have also contributed their flow in this reach; major contribution was from sangar and vehowa hill torrents which were 2,166 and 3,129 cumecs respectively [22].

High flood remained in Chashma-Taunsa Reach from 25th July 2010 to 05th August 2010. Flood peak on 1st August, 2010 at Chashma Barrage recorded as 29,417.6 cumec, which cross the design capacity of the barrage. Taunsa Barrage experienced peak flood including breach 30,724 cumec on 2nd August, 2010, crossing the historic climax of 22,333 cumec recorded in 1958. Barrage Left Marginal Bund breached at RD 32-34 due to extreme pressure on it, breach water entered in to TP Link and Muzaffargarh causing breach at several locations, breaching cause inundation of the agricultural lands and villages/houses in Muzaffargarh.

Areas along the bank of river are vulnerable to flooding and consequent damages. Flooding arise in river floodplains in Districts Bhakhar, Mianwali, Layyah and, Muzaffargarh. Flooding caused a lot of damage, including the destruction of houses and other structures, disruption of communication lines, railways, canals and roads and loss of many human lives.

5. Methodology for the Study

In this study HEC-RAS, ArcGIS and its extension Hec-GeoRas were used as tools for analysis of DEM for extraction of geometric data, setup of hydraulic model to prepare floodplain maps for the assessment of potential flood hazard and their management. Figure 5 shows the methodology flow diagram, starting from data used, to extraction of data/features for flood model & finally setting of model & its calibration, validation & flood mapping. Each of these steps are described below.

- Collection of data for the preparation of spatial data base system in GIS: By using SRTM DEM in ArcGIS with Hec-GeoRas cross-section data was generated. Survey cross-sections data of the Chashma-Taunsa study reach was used with DEM extracted data to generate new cross-sections. The central portion in DEM extracted cross-sections were not a good representation of River creek. In new cross-sections DEM cross-sections central portion was replaced with available survey data.

- Flood peak discharges determination: Annual flood peaks of Chashma reach was used for frequency analysis. Gumbel's method and Log Pearson type III distribution were used to calculate the flood peaks of 25, 50, 100, and 200 year return periods. 2010 flood return period was also calculated by these distributions.

- HEC-RAS simulations: Hec-Ras model was setup for Chashma–Taunsa reach. The following setups were followed for the development of model: Drawing River Schematic Diagram, entering cross-sections data left over bank, right over bank distances;

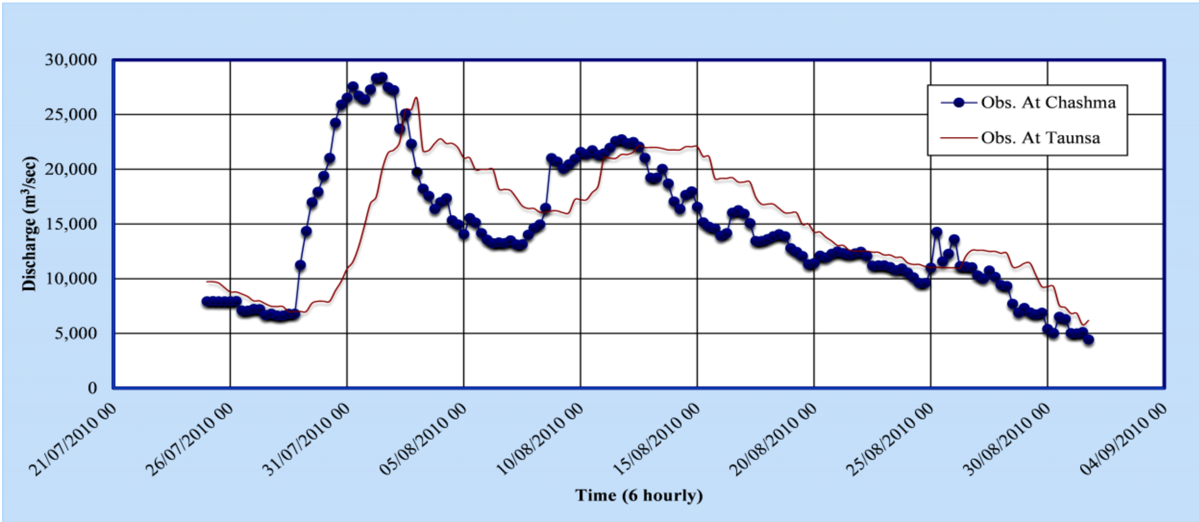


Fig. 3 Observed flow hydrographs at Chashma and Taunsa of 2010 flood

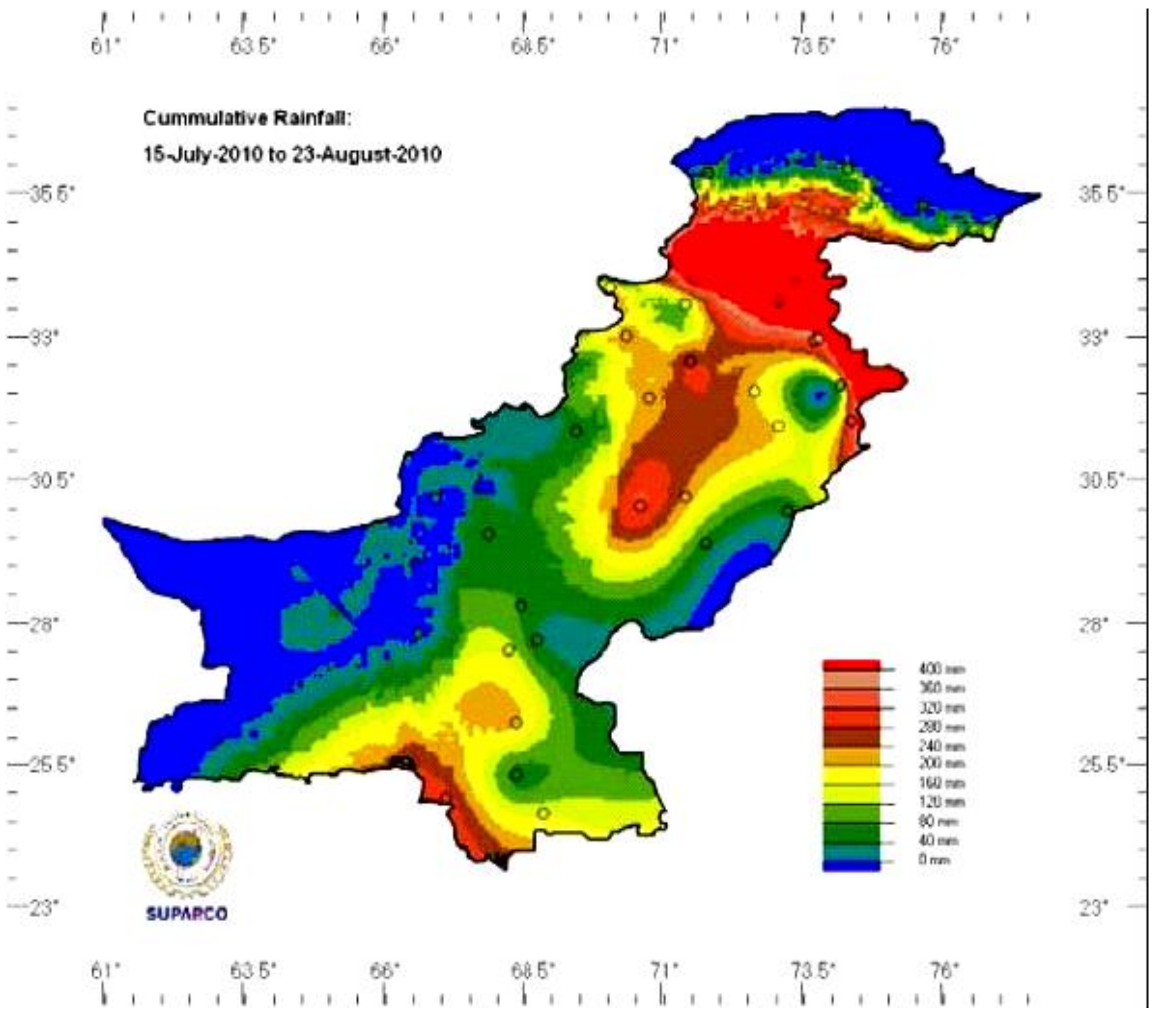


Fig. 4 Severe most rainstorms during 2010 (PMD, 2010)

- downstream reach length, Manning's n value and expansion and contraction coefficients, entering upstream and downstream boundary conditions, entering initial conditions, Perform unsteady flow analysis., Model was run to perform unsteady flow analysis for (25, 50, 100, 200 years return period & 2010 year flood)

Following steps involved for the proposed methodology of the study.

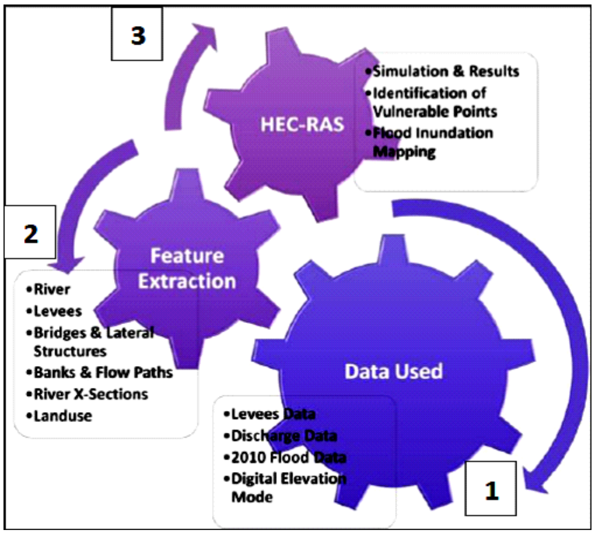


Fig. 5 Methodology Flow Diagram

5.1 Data Acquisition

Different data sets were collected for this study comprising; historic flood events in the target area from Federal Flood Commission of Pakistan, Indus river Annual flood peaks in Chashma- Taunsa (1976 to 2013), Indus River 6 hourly inflow outflow data and stage data (15^{th} June to 31^{st} August) during 2010 flood at Chashma and Taunsa barrage (for upstream and downstream boundary conditions) for calibration purposes, Indus River 6 hourly inflow outflow data and stage data (15^{th} June to 31^{st} August) during year 2006 at Chashma and Taunsa barrage (for upstream and downstream boundary conditions) for validation purposes.

River cross-sections data for defining river geometry for 1999 survey. Rating Curves for the control stations (Barrages), Operation plan of Barrages, Flood control strategy and management plan of the district (Layyah, DG Khan, Bhakkar, etc.) and provincial government including bund breaching strategy, Obstructions in the way of flood (bunds, roads, railway line, irrigation, drainage canal, culverts, temporary cut/breach in term of location etc.), Manning Roughness Coefficient 'n' value for the land use type covering the river and the floodplain area (Value at start was estimated through site visit, exact value was calculated through calibration). Breach location and sizes and Hill Torrents data in Study Reach.

5.1.1 Spatial and land use data

SRTM DEM 90 m resolution data was collected and. cross-sections data were extracted by analyzing DEM in Hec-GeoRas. Later it was used for the generation of flood maps.

Detail land use map of the study area was developed in GIS, map show all the features as river creak, barrages, roads, canals, flows, cropped area, topography of the area, flood bunds and spurs, etc. Land use data of study area is shown in Figure 6.

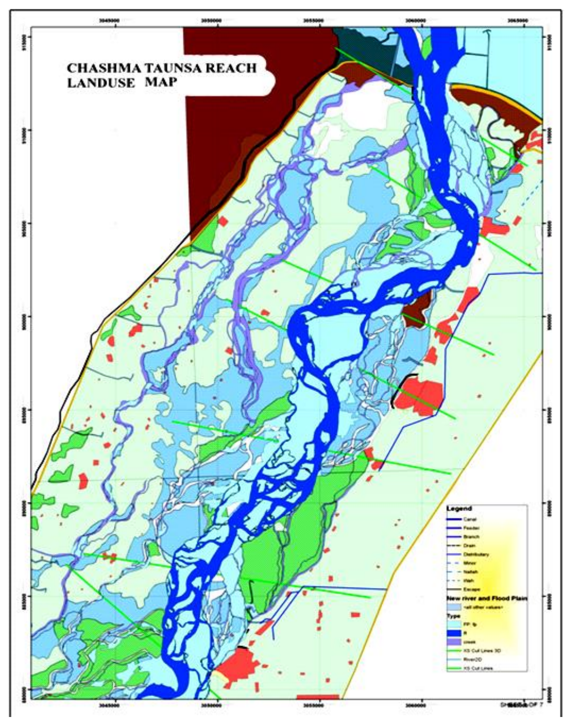


Fig. 6 A sample Land use map of Study Area (42 km reach d/s of Chashma) [23].

5.2 Hec-GeoRas Application

Hec-GeoRas is the tool used for the processing of geospatial data that is used for the development of hydraulic model for the analysis of flow profile [24]. GeoRAS provided assistance to engineers for the development of data in GIS, to extract useful information for hydraulic modelling. GeoRAS provide a complete procedure for the development of data that are required for hydraulic modelling.

For the generation of geometric data available Digital Terrain Model of the study area is marked with stream center line, flow path lines, river banks and cross–section lines. Stream centerline is served as river reach system. River centerline was digitized along the flow direction Cross-section lines are marked from left to right in the direction of flow. Survey cross-section data was added in GIS. Cross-sections were marked on same locations as of the survey cross-section, extend was increased to represent floodplain areas. Attribute data was assigned to the layers and finally this data was exported in HEC-RAS for flow analysis.

5.3 Cross-section data Development

For this study DEM (SRTM 90m) was used for the extraction of geometric data to generate cross-sections in collaboration with survey data. DEM calibration was carried out by comparing the DEM data elevations with the physical survey and Google earth elevations. A slope based correction that was obtained by plotting regression was applied to the DEM data by using the map algebra command in GIS. The corrected DEM data was used for the extraction of cross-sections in Hec-GeoRAS as shown in Figure 7 & Figure 8.

Data extracted from DEM do not incorporate river channel shape below water surface. Channel data collected from bathymetric survey merged in the DEM extracted cross-sections to enrich the cross-sections shape. Figure 8 shows the comparison between physical survey cross-section and DEM extracted cross-sections. Large difference in DEM & Bathymetric elevation highlight the limitation of DEM based elevation data.

5.4 Determination of Peak Discharges

For the preparation of floodplain maps to have an assessment of flood hazard for low to high probability flood; discharges of different return periods were required. Frequency analysis was carried out by using Gumbel's and Log Pearson Type III distributions for the calculation of discharges.

Annual flood peaks data for Chashma was collected from (1971-2013) as shown in Figure 9. Different parameters were calculated from peak values of discharge data annually observed, like mean values, standard deviation, recurrence interval and skewness. These parameters were then used for the calculation of frequency distributions, which inform about the possibility of a range of discharges as a purpose of exceedance probability or recurrence interval [25].

To ensure that the data are considerably accurate from the hypothetical distribution, fit test are required [26]. For the evaluation of Gumbel's and Log Pearson III distributions Stat Assist software was used. Goodness of fit tests were performed in Stat Assist by using Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared. By assessing critical values at different significance levels (α) Gumbel's distribution was selected as best for flood frequency analysis.

Gumbel's method of probability is used for acute value study of hydrological and meteorological events as flood [27], [28]. By using Gumbel's distribution graph was plot between reduce variate K and discharge, (Figure 10) equation of the line was obtained through which discharges of various return periods were calculated and vice versa. Table 1 shows the flood magnitude for different return periods.

5.4.1 Flood 2010 return period

The Discharge 29,417 m^3/sec was observed at Chashma in 2010, after performing frequency analysis the return period of this flood was computed as 180 years.

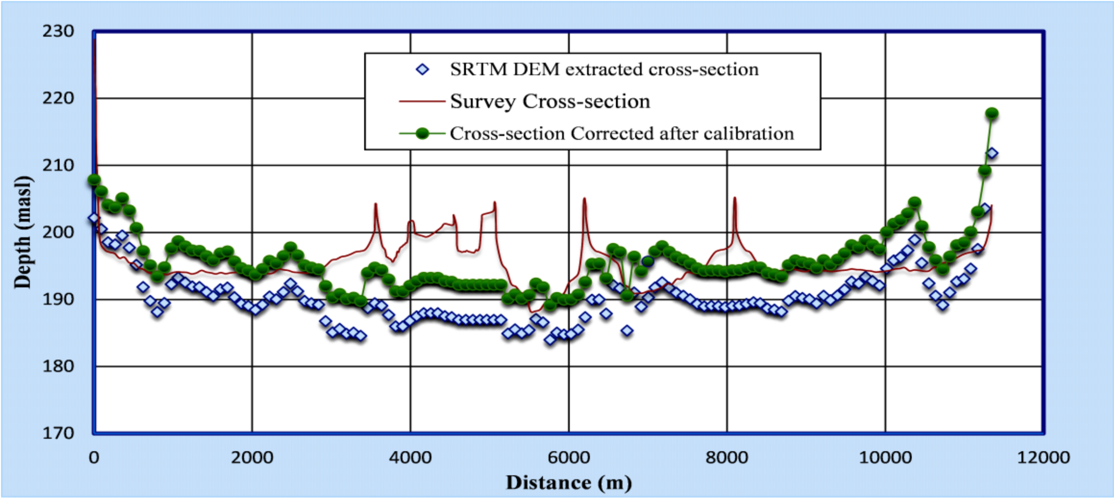


Fig. 7 Comparison of cross-sections; Corrected after calibration

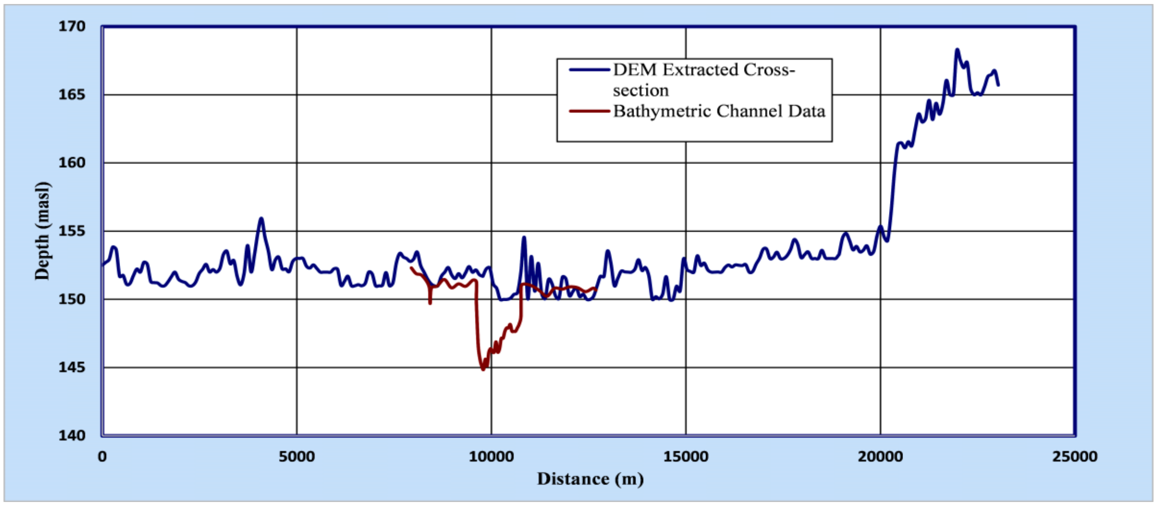


Fig. 8 Bathymetric data incorporation in DEM extracted cross-section

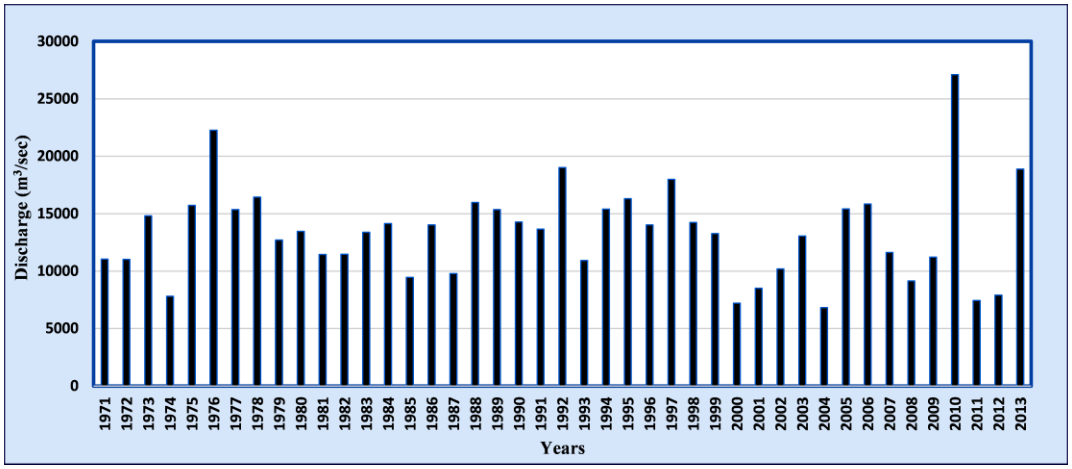


Fig. 9 Instantaneous Max. Discharges at Chashma (1971- 2013)

Table 1: Flood magnitudes for different return periods

Probability Distribution	Return Period. Tr.	Reduced dVariate	Discharges Estimated
	(Years)	K	(m^2sec.)
Gambers Distribution	25	1.0438	22671
	50	2.5923	25095
	100	3.1367	27500
	200	3.6791	29897
	500	4.3947	33058

5.4.2 Generation of Flood Hydrograph for Different Return Periods

After frequency analysis the flood peaks of different return periods were obtained, using these values the flood hydrograph were generated. Year 2010 flood hydrograph was used as a reference hydrograph. 25, 50, 100 and 200 year return period flood hydrograph were developed and are shown in Figure 11.

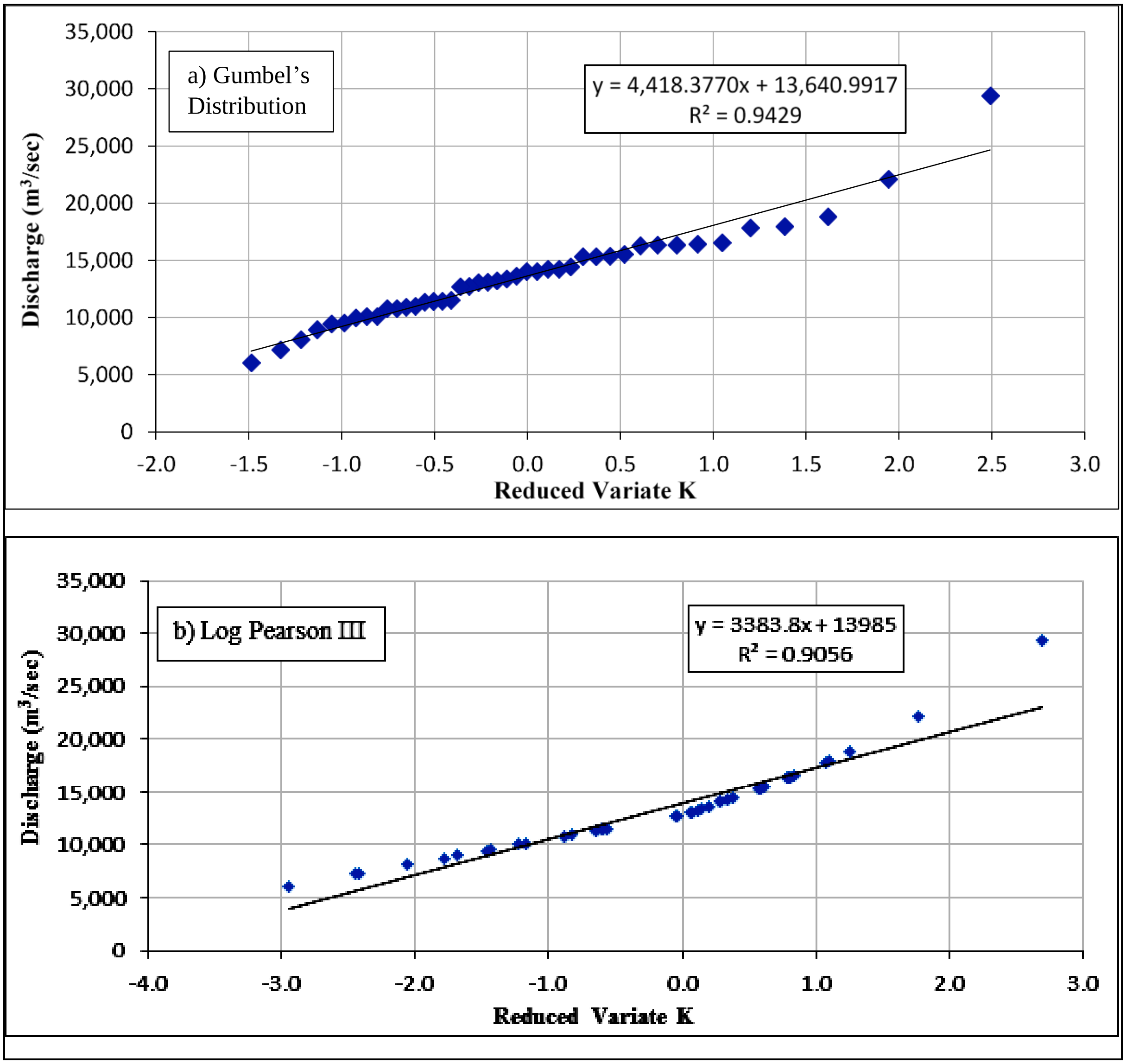


Fig. 10 Frequency plot (Q~K), a) Gumbel Distribution & b) Log Pearson III for Chashma (1971-2013)

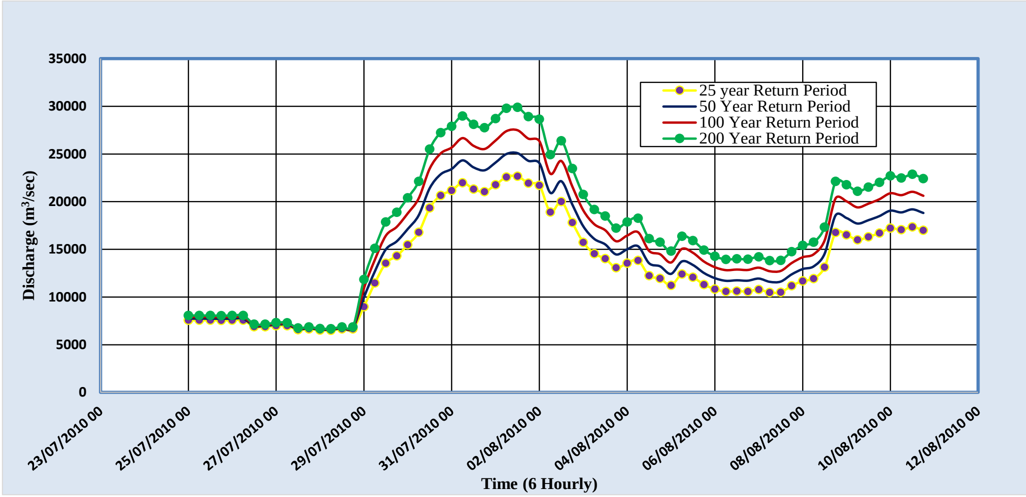


Fig. 11 Frequency Distributions; Different Return Periods Flow Hydrograph at Chashma

6. HEC-RAS Application

Line diagram of hydraulic model steup in Hec-Ras is shown in Figure 12. Releases from Chashma Barrage are used as upstream boundary and stage hydrograph upstream of Taunsa Barrage is used as downstream boundary condition. Generated cross-section data was entered in Hec-Ras to represent the geometry. Bridge tab of Hec-Ras software was used to enter Darya Khan Bridge geometry data (height, opening, etc.) Lateral Structure tab was used to entered breach geometry, breach time, propagation of breach. Six hourly flow hydrograph and stage hydrograph (25th July 2010 to 10th Aug 2010) downstream of Chashma Barrage and upstream of Taunsa Barrage respectively were entered as upstream and downstream boundary conditions. Lateral flow tab was used to enter Sangar and Vehowa Hill Torrents data. After entering all necessary data unsteady flow analysis was performed. Similarly, model was run to perform flow analysis against different return periods flow hydrograph as boundary conditions after calibration and validation of model.

Calibration of Manning’s n value is performed by comparing, simulated and observed flow hydrograph and stage hydrograph for 2010 flood. Validation of the model for the 2006 flow events was performed by same parameters as used in calibrations. Figure 13 shows the longitudinal profile of study reach computed by Hec-Ras for 2010 flood. Once the satisfactory accuracy was obtained the model results were used to perform floodplain modeling.

7. Flood Inundation Mapping in ArcGIS

Flood extents for various return period floods from Hec-Ras Model were exported to ArcGIS. ArcGIS with its tool Hec-GeoRas was used to prepare floodplain maps. Hec-GeoRas extract water surface data from HEC-RAS and integrate in floodplain map in GIS. Triangulated Irregular Network map was created for the area by using water surface analysis. Floodplain maps overlaid on topographic maps show the water surface extent and depth. The impact associated with the extent and depth can be evaluated for the assessment of affected buildings and population.

For different flood scenarios (25, 50, 100, 200 and 500 year) floodplain maps were prepared. Flood hazard was checked by analyzing the area flooded under these scenarios. In risk maps impact associated with these scenarios were analyzed by seeing affected population and property. Floodplain extent from GIS was compared with observed MODIS (August-September) daily satellite data Figure 18, which shows satisfactory results.

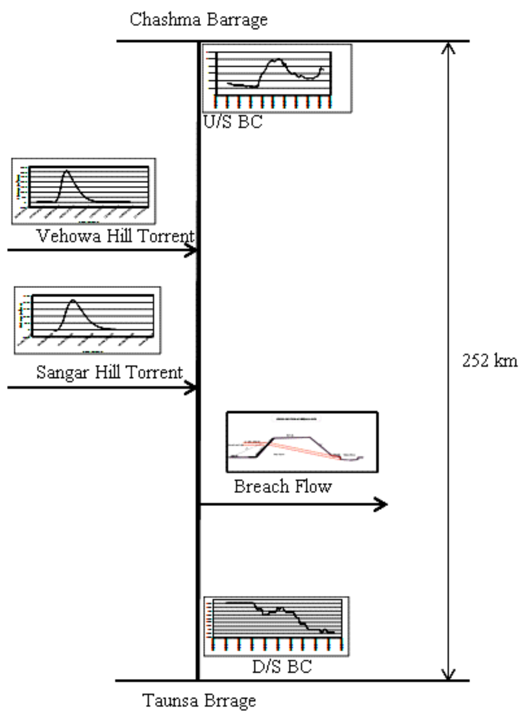


Fig. 12 Conceptual Model (Hec-Ras)

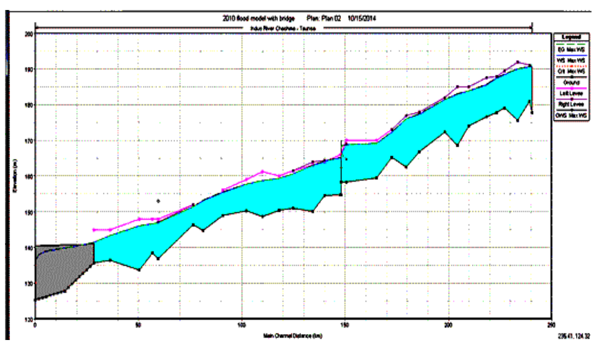


Fig. 13 Longitudinal profile of study reach for 2010 flood

8. Results and Discussions

Modelling of Indus River, Chashma-Taunsa reach resulted in the generation of floodplain, extent, depth and velocity maps. Analysis of maps was done with different scenarios; results for the generation of these maps are discussed here;

8.1 Hec-Ras Calibration and Validation

The study Chashma-Taunsa Reach have no sufficient gauges installed for the periodic measurements of stage and discharge data. Only stage data available is just d/s of Chashma Barrage and u/s of Taunsa Barrage. Both of the stations were used as boundary conditions so no comparison can be of good value. However, in order to have idea of water levels at Chashma Barrage, stage data observed at Chashma Barrage was compared with simulated; the results show a good comparison Figure 14).

At the LMB 10 km u/s of Taunsa Barrage stage level (139.81 m) was available; which was compared with simulated stage (139.51m) that show a difference of 0.21%.

For the calibration of results the comparison was made between observed and simulated hydrograph at Taunsa; Manning's n value for the main channel selected is 0.027 and for overbanks 0.045. Comparison show that the simulated hydrograph matches well with observed (Figure 14 & Figure 15). Observed and simulated results were checked by statistical parameters Table 2 shows the comparison of results. Coefficient of determination and Nash and Sutcliffe coefficient show that calibrated and observed results matches well.

Table 2: Calibration Results by statistical coefficients using 2020 flood

Calibration Results	
Volume Diff. (Dv) (%)	3.96
Coefficient of Determination $(R)^2$	0.95
Nash - Sutcliffe Co-efficient 'E = 1-(($Q_{obs.}$ -$Q_{simulted}$)^2 / ($Q_{obs.(Avg)}$ - $Q_{simulted}$))^2	0.93

Validation of the flow hydrograph was performed for the year 2006.Comparison was made for observed and simulated hydrograph (Figure 16) at Taunsa upstream keeping the calibrated parameters constant, comparison shows a good model. Stage Hydrograph was also compared for the year 2006. Observed and simulated stage data was compared (**Fig.**).Validation results were checked by statistical parameters. Table 3 shows the comparison of results.

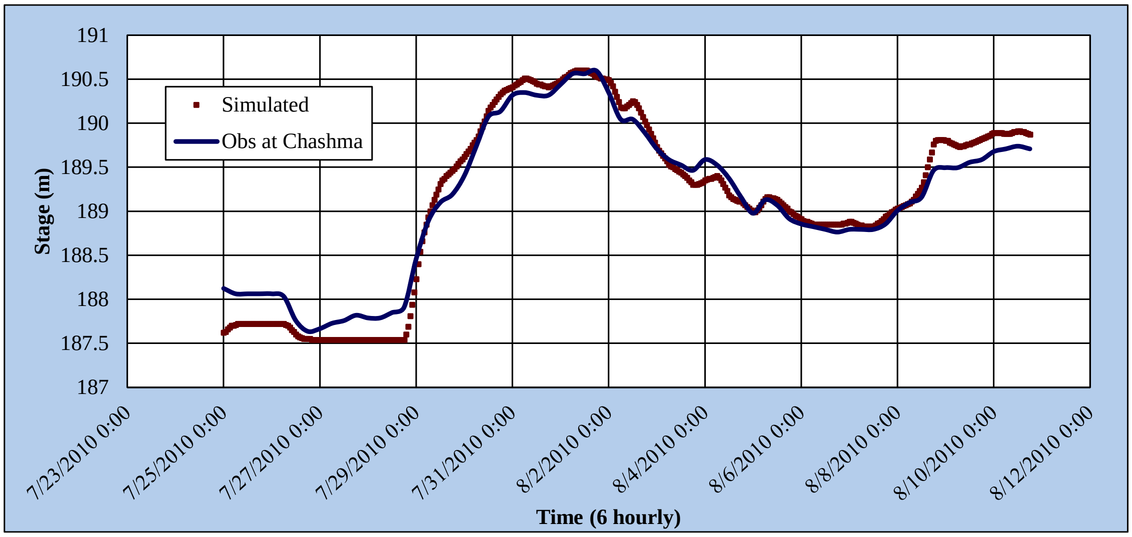


Fig. 14: Calibration of Model; Stage Hydrograph Observed and simulated at Chashma, 2010 flood

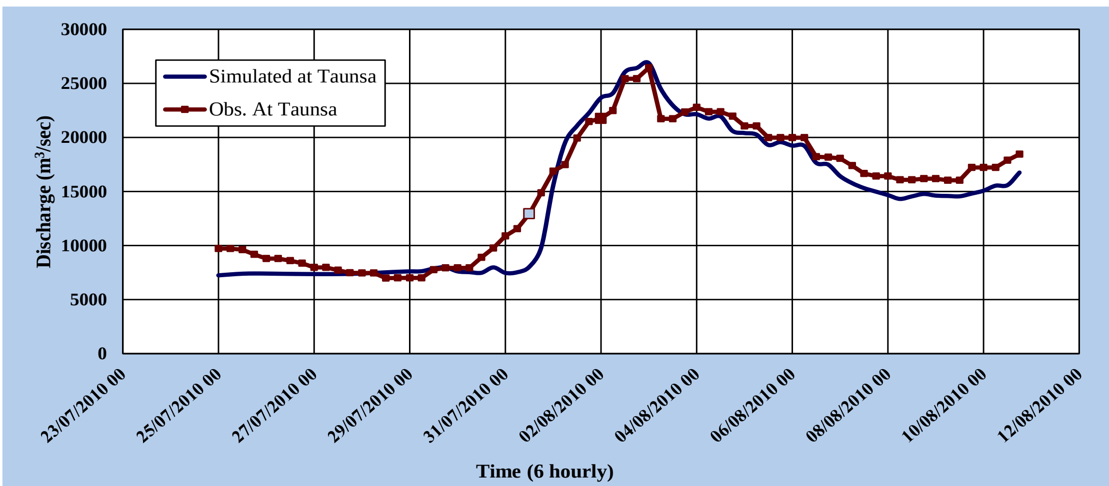


Fig. 15: Calibration of the model; Flow Hydrograph observed and simulated at Taunsa, 2010 flood

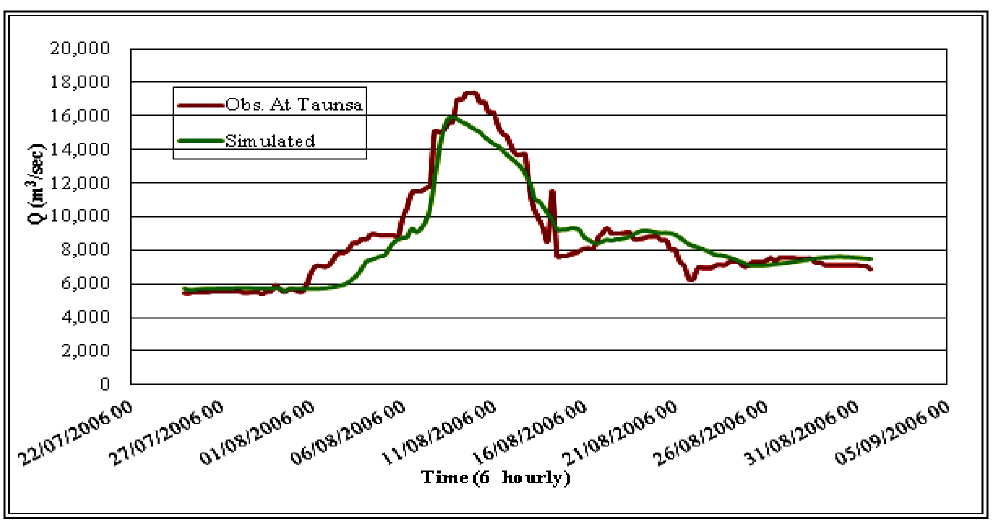


Fig. 16: Validation of model; flow Hydrograph; observed and simulated at Taunsa, 2006 flood

Table 3: Validation Results by using flood 2006

Validation Results	
Volume Diff. (Dv) (%)	2.84
Coefficient of Determination (R)	0.90
Nash - Sutcliffe Co-efficient 'E=1-((Q_{obs} -$Q_{simulted}$)^2/($Q_{obs.(Avg)}$-$Q_{simulted}$))^2	0.86

8.2 Flood Extent Map

Flood extent map used as a base for the establishment of danger and risk maps, Land use planning, city and village planning, risk management, rural planning and awareness building.

Floodplain maps developed show the extent of 2010 flood and different return period's peak flows. Flooded area was overlaid on land use map of the study area (Figure 18). The outcome of the flood extent map shows the affected land areas and structure.

The major bridge on this reach is Darya Khan Bridge the flood water has not impacted the bridge. The flood water has not overtopped the levees/embankments however, at some places due to negligence in maintenance of embankments breaching occurred and flood calamity increased causing damage to the property and land areas.

8.3 Flood Depth Map

Flood plain mapping resulted in the formation of extent and depth map. Model show a depth of water closes to zero to a maximum value of 8 m. In general high water depth was obtained in the main river channel and reduces accordingly in floodplain areas. The contribution of hill torrents water in main channel has also caused to increase in water level. Figure 19 shows the depth map of the study area.

8.4 Flow Validity Map

The inundation mapping produced show variable velocity of flow in river main channel and floodplain areas. High velocities were noted in main channel. Model results show 3.59 m/s the maximum velocity in river channel. Figure 21 shows the velocity map of the study area.

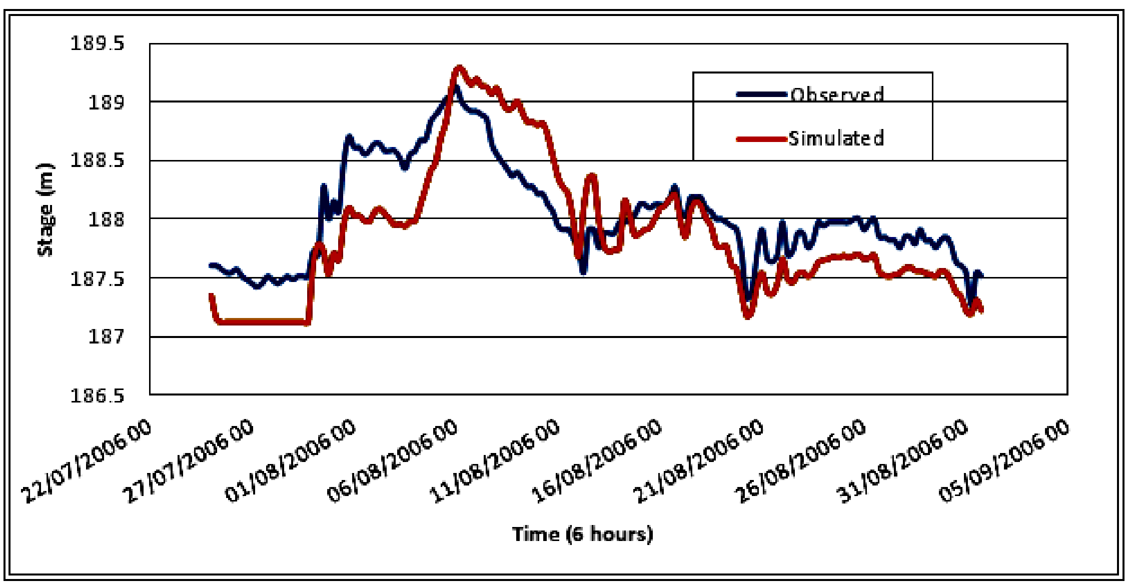


Fig. 17: Comparison of mode; stage hydrograph observed and simulated at Chashma, 2006 flood

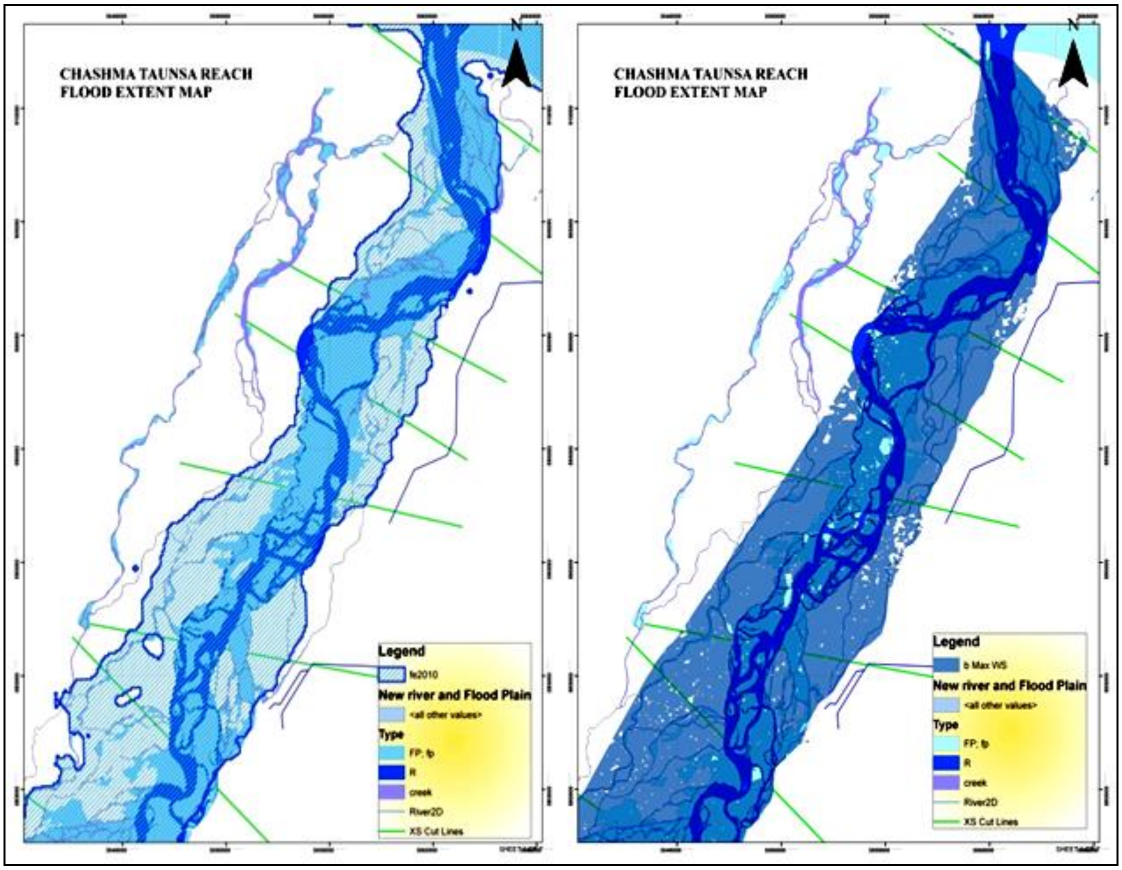
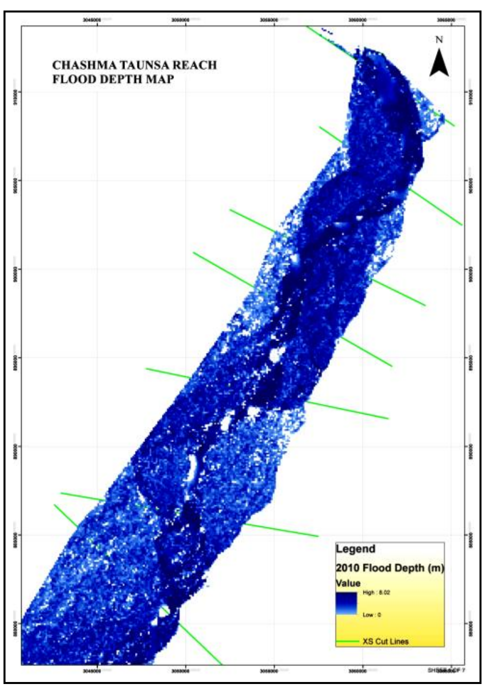
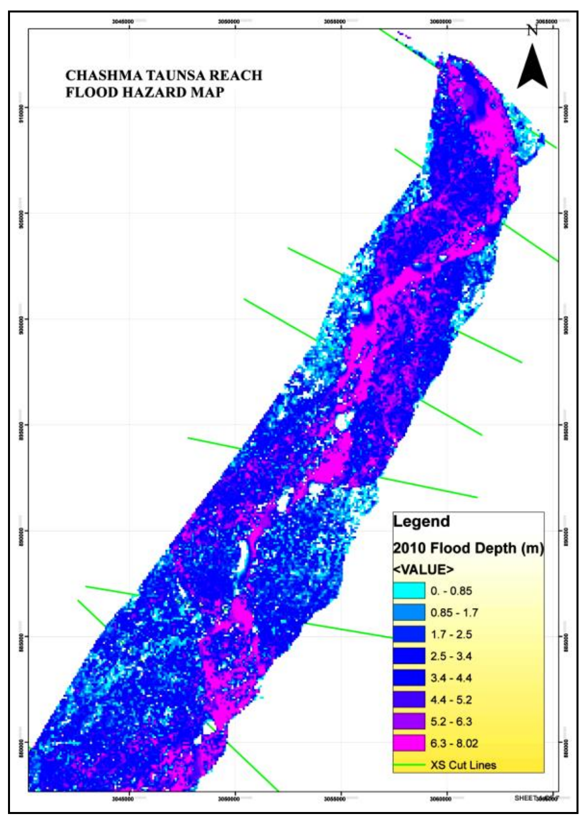


Fig. 18 Comparison of satellite and simulated flood extent for 2010 flood





8.4.1 Flood Hazard Map

By using the flood extent, depth and velocity maps, flood hazard map can be prepared. Flood hazard map was prepared by attributing flooded area at different flood depths (eight intervals of depth)corresponding to each depth interval flooded area was calculated and is shown in hypsometric curve Figure 20) shows the flood hazard map for study area.

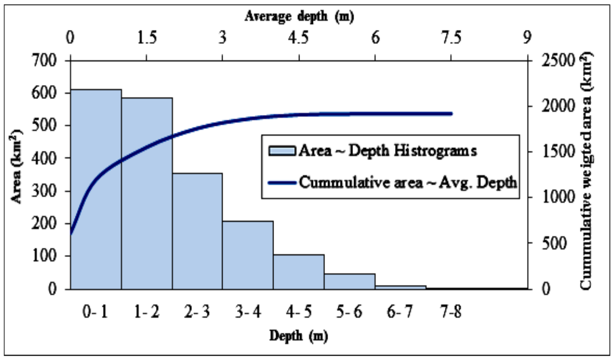


Fig. 20 Cumulative hypsometric curve and flooded area histograms

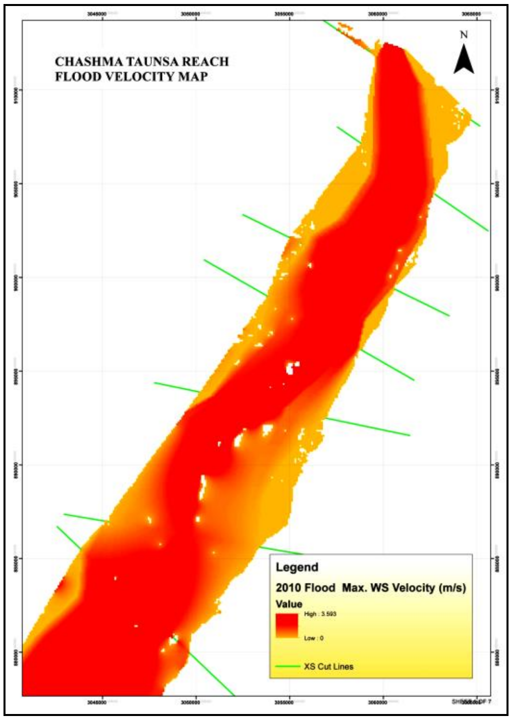


Fig. 21 A sample flood Velocity Map of Study Reach for 2010 Flood, d/s of Chashma (42 km Reach)

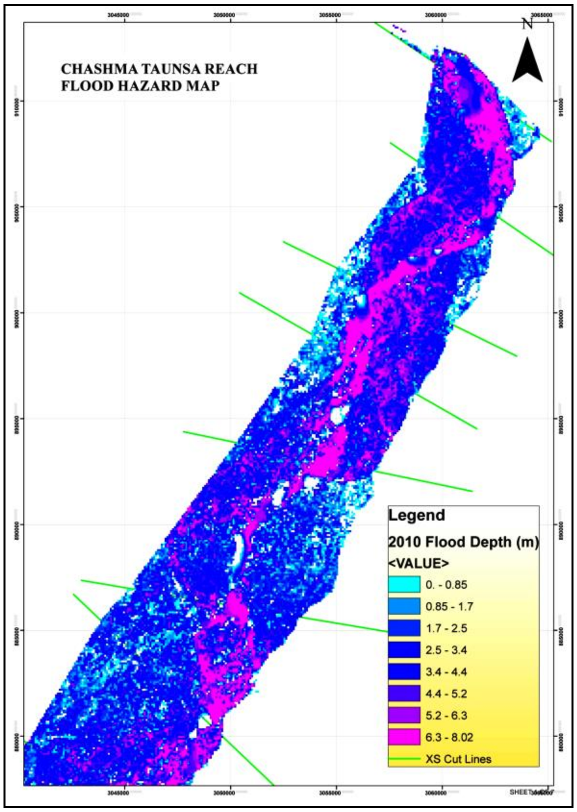


Fig. 22 A sample of flood Hazard Map of Study Reach for 2010 Flood d/s of Chashma (42km)

9. Conclusions

Following main conclusions are drawn:

1. From frequency analysis, it is estimated that flood 2010was of 180 years and 300 years return period at Chashma and Taunsa respectively.

2. Unsteady flow from Chashma-Taunsa reach of Indus River has been well calibrated and validated, which show a good base for the generation of flood inundation maps for the study reach.

3. Simulated flood inundation depths in the study area due to 2010 flood vary from 0.15 m to 8.1 m.

4. Flood area simulated maximum depth for 25 year and 500 year flood is 7 m and 9.1 m respectively.

5. Floodplain map showing the extent and depth represent the areas under flood, which will be helpful for planner, for emergency preparedness and evacuation's plans in future.

10. Recommendations

Following main recommendations are drawn

1. Analysis was based on 90 m SRTM DEM which may be refined for more accurate results using fine resolution DEM.

2. Study is carried out using survey data of year 1999. It should be done on the basis of latest River Survey.

3. For an efficient analysis there must be several gauges along the river reach to observe stage and discharge flood levels during flood seasons; observed levels should be periodic rather than single peak values.

4. Laterals contribution in reach needs to be monitored in every flood season by the installation of real time stream gauging networks; this will be very helpful for the estimation of actual flood in Main River.

5. Breach flows estimated during 2010 flood may be compared with the volume of inundation downstream of breach.

6. Flood depth and extent maps produced in this study may be used for the development of flood zoning and in planning land use features in floodplains.

7. Combination of 1D and 2D model should be used, to have accurate idea of lateral flows direction, depth and velocity in floodplain areas (Ras Mapper is now available in newly released HEC-RAS 5 beta version).

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