ASSESSMENT OF FLOOD USING GEOSPATIAL TECHNIQUE FOR INDUS RIVER REACH: CHASHMA - TAUNSA

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ABSTRACT: *Floods are the most critical among all the natural calamities in world causing vast damages to life and property. It is thus essential to address this natural calamity by developing integrated approach for flood modelling and mapping for future prevention of flood and to decrease the effect it causes on property and people. In this study Indus River reach Chashma-Taunsa was selected for flood modelling and mapping for normal flood of 2006 and exceptionally high flood of 2010 due to which lot of damages occurred to life and property. Flood hydraulic modelling and floodplain mapping was integrated to perform flood routing for the computation of peak flow attenuation, assessment of lag time between inflow and out flow and to perform mapping for the estimation of flood zone depth and flooded area of reach. To perform hydraulic modelling and floodplain mapping HEC-RAS, ARC-GIS 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. HEC-RAS model accuracy has been determined by numerical prediction at upstream of Taunsa barrage of Indus River against the observed data. The statistical comparison by coefficient of determination (R^2) (0.95 & 0.90) and Nash and Sutcliffe coefficient (0.93 & 0.86) demonstrated that the numerical simulation of model has a good agreement with observed flow at upstream of Taunsa barrage. Model stability has been observed during simulation of the flood discharge in study reach. Comparison of lag times for observed and computed flood peaks 2010 and 2006 has been carried out, which show almost good agreement (3 days and 6 hours, and 2 days for 2006 and 2010 flood respectively are well matched with the observed values 3.5 days and 2 days and 6 hours for 2006 and 2010 flood respectively). Results of HEC-RAS model were exported in ARC-GIS to perform flood mapping. Flood maps of the whole study area were finally prepared for 2010 flood. Integrated modeling approach used in the study performs well to assess areas vulnerable to flood with estimation of depth and area of flooded extent; calculated as 8.1 m and 1900 km^2 respectively for 2010 flood.*

Key words: Flood maps; Hydraulic modelling; DEM SRTM; Time Lag; Indus River

1 INTRODUCTION

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] that causes 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 part 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 integrated modeling approach are essential 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. Integrated modeling approach by building hydraulic model and flood mapping are the most efficient way to evaluate the flood damage to property and people. The model shows the extent and depth of flooding to depict the area liable to flooding events. This study mainly focuses on Integrated modeling approach for the assessment of flood damages using geospatial techniques.

In this study Indus River reach Chashma-Taunsa was selected as study area for flood modelling and mapping for 2006 and exceptionally high flood of 2010 due to which lot of damages occurred to life and property. Indus River has been exposed to highest flood risks and damages since the creation of Pakistan i.e. in 1973, 1992 and 2010 etc. In year 2010 Pakistan experienced the worst flood of the history.

Monsoon periods of 2010 fetched heavy rainfall throughout the country, in many areas it turn into the historically peak rainfall. Observed flood hydrographs at Chashma and Taunsa are shown in Figure 1. Table 1 show the comparison of the 2010 monsoon rainfall with historical means (mm). Due to cloud burst and downpour in the Northern Areas, unprecedented rainfall occurred in the northern areas; causing increased the water stage in tributaries and hill torrents that ultimately caused to increase the water level in Indus River.

Hill torrents have contributed their flow in this reach; major contribution was from Sangar and Vehowa hill torrents that were 2166 and 3129 cumec respectively [6]. High flood remained in Chashma-Taunsa Reach from 25 July, 2010 to 05 August, 2010. Flood peak on 01 August, 2010 at Chashma Barrage recorded as 29,417 cumec which crossed the design capacity of the barrage. Taunsa Barrage experienced peak flood including breach 30,723 cumec on 02 August, 2010, crossing the historic climax of 22,332 cumec recorded in 1958. Barrage Left Marginal Bund breached at RD 32-34 due to extreme pressure on it, breach water entered in to Taunsa Panjnad Link canal and Muzaffargarh canal causing breach at several locations, breaching caused inundation of the agricultural lands and villages/houses in Muzaffargarh.

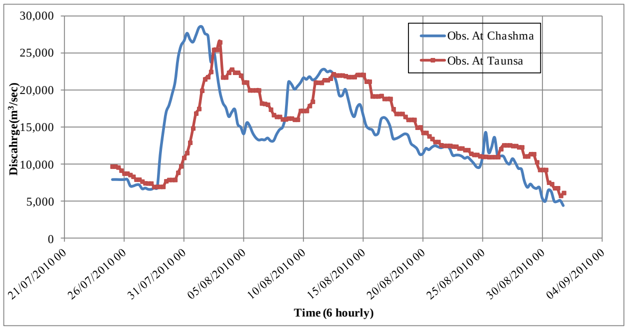


Figure 1: Observed flow hydrographs at Chashma and Taunsa (2010) (FFC, 2010)

Areas along the bank of river are vulnerable to flooding and consequent damages. Flooding arise in river floodplains in Districts Bhakkar, Mianwali, Layyah and Muzaffargarh. Flooding caused 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.

Table 1: Comparison of the 2010 Monsoon Rainfall with Historical Means (mm)

Station	Mean July Rainfall (1962-2010)	July 2010 Rainfall	Mean July-August Rainfall (1962-2010)	July-August 2010 Rainfall
Station	**1**	**2**	**3**	**4**
Gilgit (KP)	16.2	53	31.1	112
Muzaffarabad	359	359.4	576	758
Peshawar Airport (KP)	46	402	na	535
Saidu Sharif (KP)	152	471	189	757
Kakul(KP)	263	389	519	524
Cherat (KP)	93	388	187	618
Ballakot (KP)	372	327	650	528
Dir (KP)	154	317	301	609
Lower Dir (KP)	56	295	na	448
Dera Ismail Khan (KP)	80	147	110	282
Muree (Punjab)	364	579	665	848
Mianwali (Punjab)	na	528	na	703
Average	**178**	**355**	**359**	**560**

According to Damaged 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" [7].

In this study an effort has been made to integrate modeling approach for Chashma-Taunsa River Reach to perform flood routing for the computation of peak flow attenuation, assessment of lag time between inflow and out flow and to perform mapping for the estimation of flood zone depth and area of reach.

Hydraulic routing procedure is used for flood routing modeling. Hydraulic routing is based upon equation of continuity and the equation of motion for unsteady flow. The differential equation that explains this flow is known as the St. Venant equation. In general, in hydraulic studies, of hydraulic flood routing models are used [8]. HEC-RAS model with association of ARC-GIS and its extension Hec-GeoRAS were used for hydraulic modelling and flood mapping. These tools are used worldwide to carry out several studies including preparation of flood inundation maps and flood forecasting [8].

Flood mapping is an important tool for Engineers, Planners for land use planning, emergency preparedness plans, public awareness and for flood risk management. By knowing the extent and depth of flooding decision makers will be able to make choices to best allocate resources to cope with flood disasters. This will also be useful to identify areas at risk of flood.

2 RELATED WORK AND LITERATURE REVIEW

Different studies have been carried out worldwide for the integrate modeling and mapping of floods by using HEC-RAS, HEC-GEORAS and ARC-GIS; Flood analysis results show depths, extent, and area of inundation due to flooding that would be used by the decision maker to prepare Early Preparedness Plan of actions. Some of the recent studies are worth mentioning.

Collin et al, [10] 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.

Yuan et al, [11] studied the floodplain modeling in the Kansas River Basin using Hydrologic Engineering Center (HEC) Models. The objective was to assess the effect of land use changes in future in background of design storms of 100 year and to check the effective role of wetlands in flood peaks reduction. HEC-HMS model was setup to calculate the run off data for HEC-RAS model. Both models were calibrated and validated well. Results were used for future land use scenarios to mark flood extent.

Tabyoui et al, [12] 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.

Salajegheh et al, [13] studied the floodplain mapping in semi-arid region of Iran using HEC-RAS and ARC-GIS. Their study described how to link the results of hydraulic model with GIS based presentation and analysis. Procedure for collecting and processing of data employing GIS was also illustrated in the study.

The review of literature mentioned above revealed that many efforts have been made worldwide for floodplain modeling in different river basins but not much effort has been focused on the integrate modeling aspect using GIS on the River Indus. Therefore, there is a need to investigate the flood by building flood hydraulic models in the Indus River that could be used to predict the area under flood.

3 DESCRIPTION OF STUDY AREA

River Indus is the largest river in Pakistan. The 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. 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.

The discharge data 6 hourly for the year 2006 and 2010 at downstream of Chashma barrage and upstream of Taunsa barrage has been collected from Government of Punjab, Irrigation Department. The problem statement is shown in Figure 2.

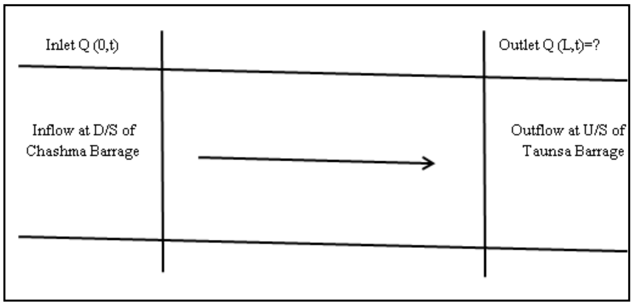


Figure 2: Problem statement Chashma - Taunsa Reach

The study area is an Indus River reach from downstream of Chashma Barrage to upstream of Taunsa barrage. Chashma Barrage is located in district Mianwali and Taunsa Barrage is located in district Muzaffargarh of Punjab. It is located 20 km south of Taunsa and 16 km from Kot-Addu town. The Chashma - Taunsa reach is 252 km long and was severely affected by to 2010 flood.

The floodplain exists along the whole length of the reach, and flooding is the major problem in floodplains of this area. Figure 3 show the map of the study area.

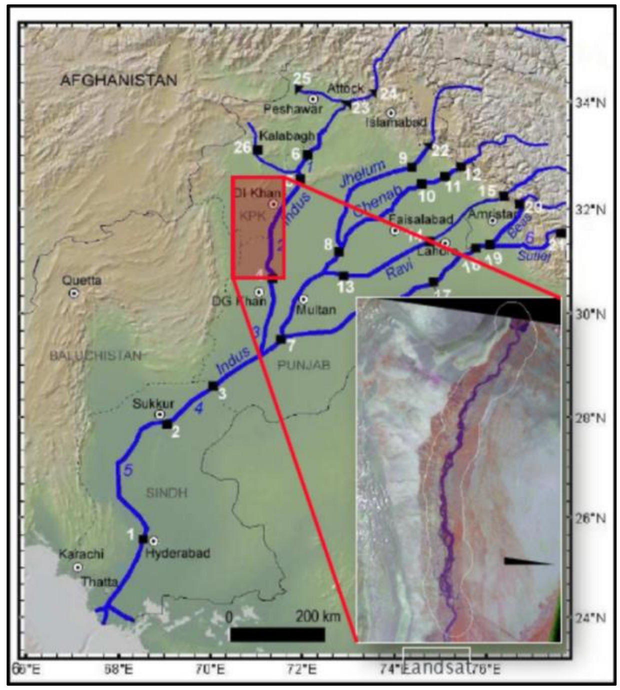
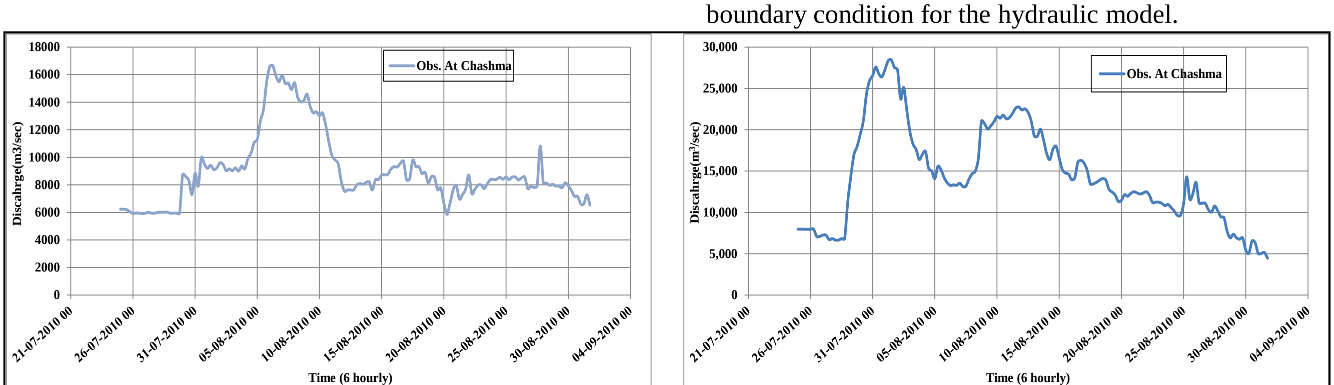


Figure 3: Study Area Map

Different hill torrents contributed their flows in Chashma-Taunsa reach during 2010 flood. Major contributions were through Sangar and Vehowa hill torrents, with catchment area of 5407 km^2 and 3621 km^2 respectively and contributing 2166 and 3129 cumec flows respectively. Land use of study area comprises of the agricultural land, villages and barren land. Study area has slope of 0.25 m/km.

Floods for two years 2006 and 2010 have been selected for the study that are classify as Normal and Super flood as peak discharges in flood conditions. Hydrographs illustrated in Figure 4 for two years 2006 and 2010 at downstream of Chashma barrage of Indus River are used as upstream boundary condition for the hydraulic model.



(b) Normal Flood 2006

(a) Super Flood 2010

Figure 4: Observed annual flow for year 2006 and 2010 at downstream Chashma barrage

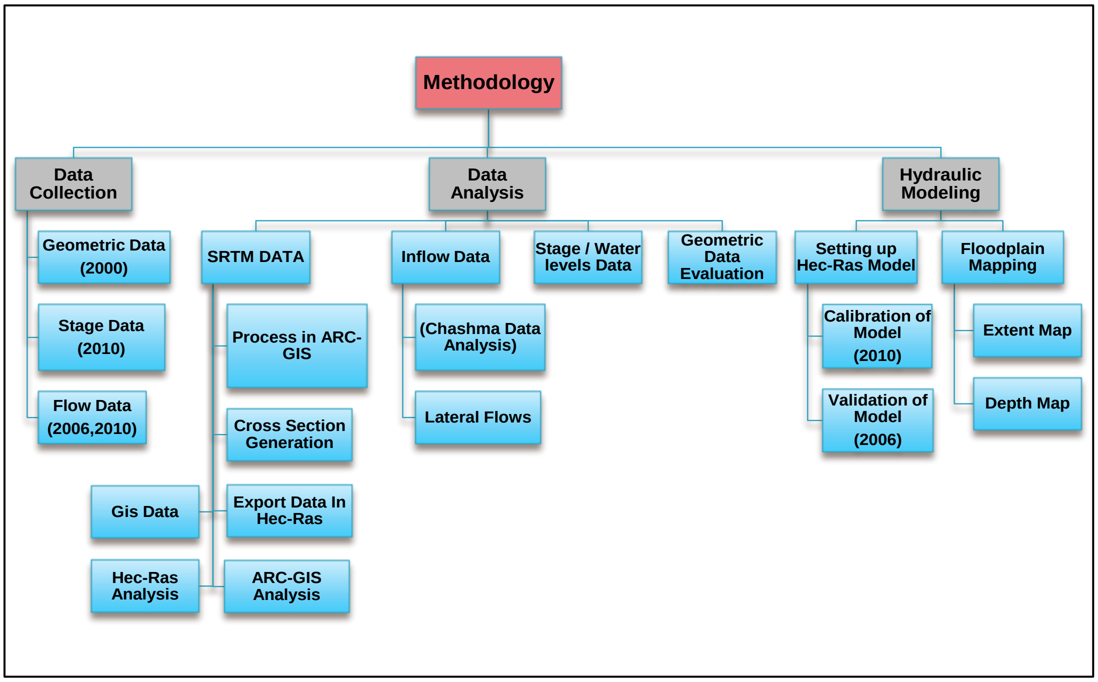


Figure 5: Methodology Flow Diagram

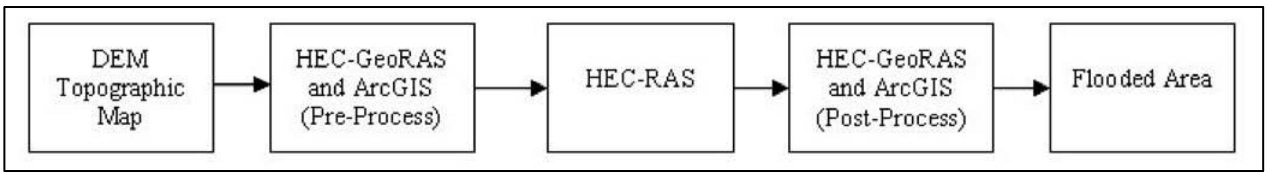


Figure 6: Conceptual flow chart for river flood modelling

4 GENERAL STRATEGY FOR THE STUDY

In this study HEC-RAS, ARC-GIS and its extension Hec-GeoRAS were used as tools for analysis of DEM data for extraction of geometric data, setup of hydraulic model to prepare flood maps **Error! Reference source not found.** hows the methodology flow diagram. Stepwise procedure for hydraulic modelling and flood mapping is explained in next sections.

5 HYDRAULIC MODELLING

Integrated modelling approach has been used for hydraulic modeling and flood mapping; HEC-RAS and GIS software's have been used for river flow modeling and mapping. The technical approach and conceptual diagram for river flood modeling is described in Figure 6

5.1 Hec-GeoRAS Application

Hec-GeoRAS is tool used for the processing of geospatial data that is used for the development of hydraulic model for the analysis of flow profile [14]. GeoRAS provided assistance 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 is required for hydraulic modelling.

For the generation of geometric data available Digital Elevation Model of the study area is marked with stream center line, flow path lines, river banks and cross–section lines. This data is exported in HEC-RAS for flow analysis.

5.2 HEC-RAS Application

(HEC-RAS) is a one-dimensional model, comprised of graphical user interface (GUI), intended for hydraulic analysis of river channels. Generated cross-section data was entered in HEC–RAS to represent the geometry. Six hourly flow hydrograph and stage hydrograph (25 July 2010 to 31 Aug. 2010) downstream of Chashma Barrage and upstream of Taunsa Barrage respectively were entered as upstream and downstream boundary conditions. After entering all necessary data unsteady flow analysis was performed.

Calibration of model was performed by adjusting manning's n value, simulated and observed flow hydrograph and water elevations were compared. Validation of the model for the 2006 flow events was performed by same parameters as used in calibrations. After validation the model results were used to perform flood mapping.

5.3 Flood mapping in ARC-GIS

Results of HEC-RAS Model were exported in ARC-GIS. ARC-GIS with its tool Hec-GeoRAS was used to prepare flood map. Flood map overlaid on topographic map 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 personnel's.

6 RESULTS & DISCUSSIONS

Computed and observed hydrographs at upstream of Taunsa barrage has been compared for year 2006 normal flood (Figure 7). Observed and simulated hydrographs shows good agreement. There was only one flood peak in 2006 flood period; observed peak discharge is matching well with the simulated discharge. The simulated and observed maximum peak has a difference of 2.5%.

The statistical comparison were carried out for observed and measured hydrographs; coefficient of determination (R^2) and Nash and Sutcliffe Coefficient were calculated as 0.90 and 0.86 respectively; that show good agreement between simulated and observed results. Observed and simulated hydrographs shows a volume difference of 2.64% between them. The peak flow lags time of simulated and observed between Chashma and Taunsa was compared; the observed lag time is 3 days and 6 hours, whereas model computed lag time as 3.5 days.

In year 2010 a super flood stroked the Chashma and Taunsa Barrage in July and August due to heavy monsoon rainfalls; the assessment of flood in Chashma- Taunsa reach was carried out by routing the flood discharge downstream of Chashma Barrage up to upstream of Taunsa Barrage to compare it with observed discharge at Taunsa. In year 2010, two flood peaks were observed in Chashma Taunsa reach. One major flood peak reached the Chashma barrage at 1st August, 2010 after little absorption in Chashma reservoir it passed all the way down to Taunsa Barrage.

The 2nd flood peak came after seven days at Chashma Barrage and passed downward by augmented its flow by the contribution of hill torrents (i.e. Sangar and Vehowa) to Taunsa Barrage. The two flood peaks were modeled in HEC-RAS; the comparison of simulated and observed hydrographs and flood peaks in 2010 at upstream of Taunsa Barrage are shown in Figure 8. Comparison between simulated and observed hydrographs shows good
agreement; floods peaks simulated shows good match with the observed values; whereas the volume difference between observed and simulated hydrographs is 4%.

The statistical comparison for observed and measured hydrographs were carried out; coefficient of determination (R^2) and Nash and Sutcliffe Coefficient were calculated as 0.95 and 0.93 respectively; that show good agreement between simulated and observed results. The peak flow lags time of simulated and observed between Chashma and Taunsa was compared; the observed lag time is 2 days and model computed lag time is similar to observed lag time; that depicts good model accuracy.

6.1 Flood map

Flood map for the 2010 flood was prepared in GIS that show the extent of 2010 flood as1900 km^2 for study reach. Flooded area was overlaid on land use map of the study area the outcome of the flood map shows the effected land areas and structure.

Flood maps 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 (Figure 9). In general high water depth was obtained in the main river channel and reduces accordingly in floodplain areas.

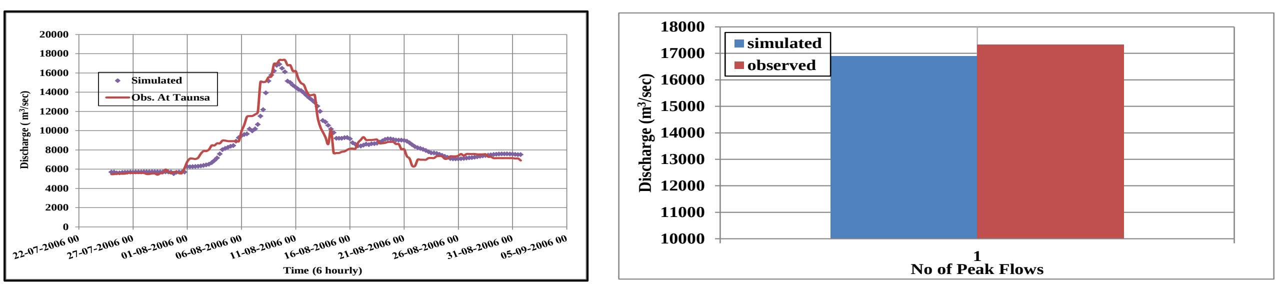


Figure 7: Computed and observed hydrographs at upstream of Taunsa barrage along with peak in 2006

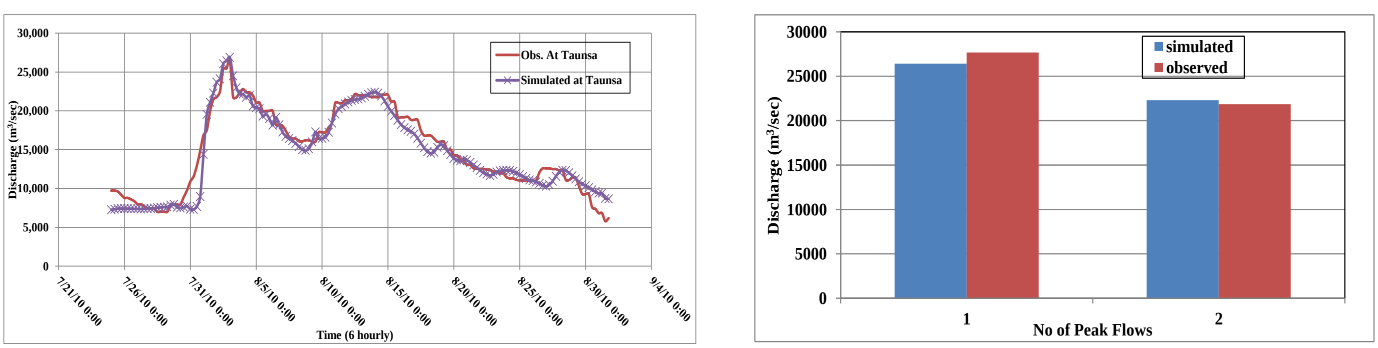


Figure 8: Computed and observed hydrographs at upstream of Taunsa barrage along with peak in 2010

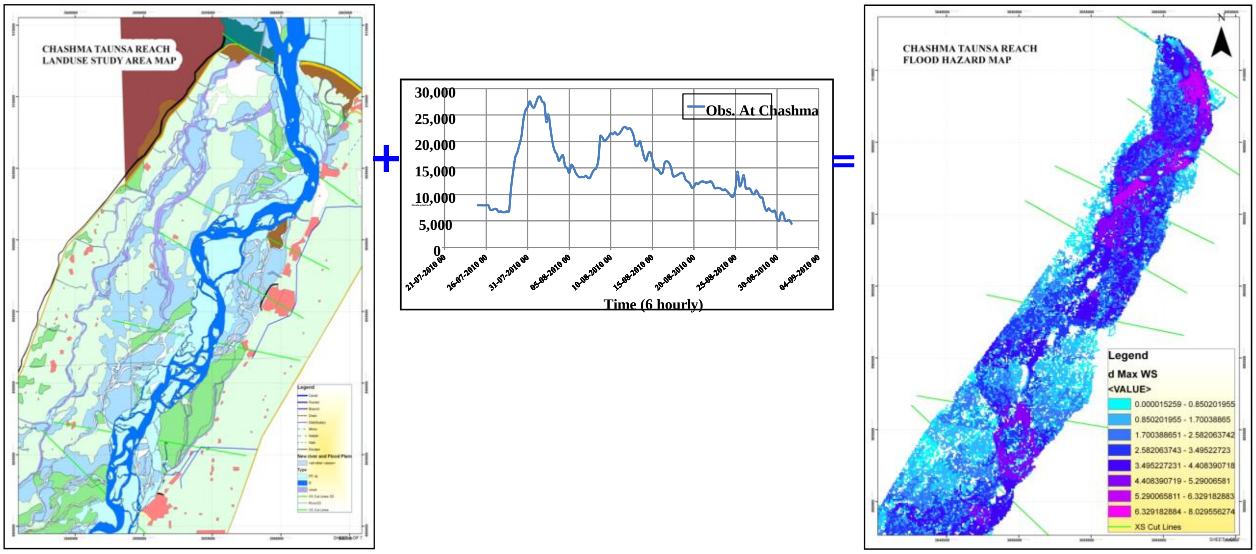


Figure 9: Flood map for 2010 flood and resulting inundation extent

7 CONCLUSIONS

HEC-RAS model unsteady flow analysis has been carried out for flood routing between Chashma- Taunsa reach of Indus River for 2006 normal and 2010 super flood; The simulated and computed hydrographs upstream of Taunsa Barrage statistical comparison shows the satisfactory results i.e. coefficient of determination (R^2) and Nash and Sutcliffe Coefficient as 0.90 & 0.86 and 0.95 & 0.93 for 2006 and 2010 flood respectively, which show a good base for the generation of flood inundation in channels.

Model computed peak flow attenuation and lag time are well matched with the observed values (i.e. 3 days and 6 hours, and 2 days for 2006 and 2010 flood respectively; simulated 3.5 days and 2 days and 6 hours for 2006 and 2010 flood respectively).

Flood area computed in model shows good match with the satellite observed data, which indicate that the computed flood extents are reliable. Simulated flood area due to 2010 flood is computed as 1900 km^2 and depths in the study area due to 2010 flood vary from 0.15 m to 8.1 m, which will be helpful for planner for the preparation of preparedness and evacuation's plans in future.

8 RECOMMENDATIONS

Analysis was based on 90 m SRTM DEM which may be refined for more accurate results using fine resolution DEM. Verification of DEM data was carried out by using survey data of year 1999. It should be verified on the basis of latest data surveyed. 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. Flood depth and extent map produced in this study may be used in planning land use features in floodplains.

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