Flood Hazard Assessment Using Hydro-geospatial Technique: A Case Study of River Chenab from Qadirabad to Trimmu in Pakistan

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INTRODUCTION

- Pakistan is a flood prone country. Floods occur frequently due to heavy rainfalls in monsoon season, mostly augmented by the snowmelt.
- The Chenab River is the second largest river of the Indus river basin.
- It experienced past floods in 1973, 1977, 1988, 1992, 1995, 1996, 1997, 2006, 2013 and 2014.
- Whenever River Chenab overflowed, major cities and surrounding villages on both sides of the river were severely affected by floods.

PURPOSE OF STUDY

1. The first objective is to perform flood modeling of the 209 km reach of Chenab River using the HEC-RAS model. The river reach is from Qadirabad Barrage to Trimmu Barrage. The recent flood periods in 2006 and 2014 were considered in the model simulation.
2. The second objective is to assess flood hazards using two different hazard assessment criteria under the conditions with and without flood control infrastructures under various flood return periods.

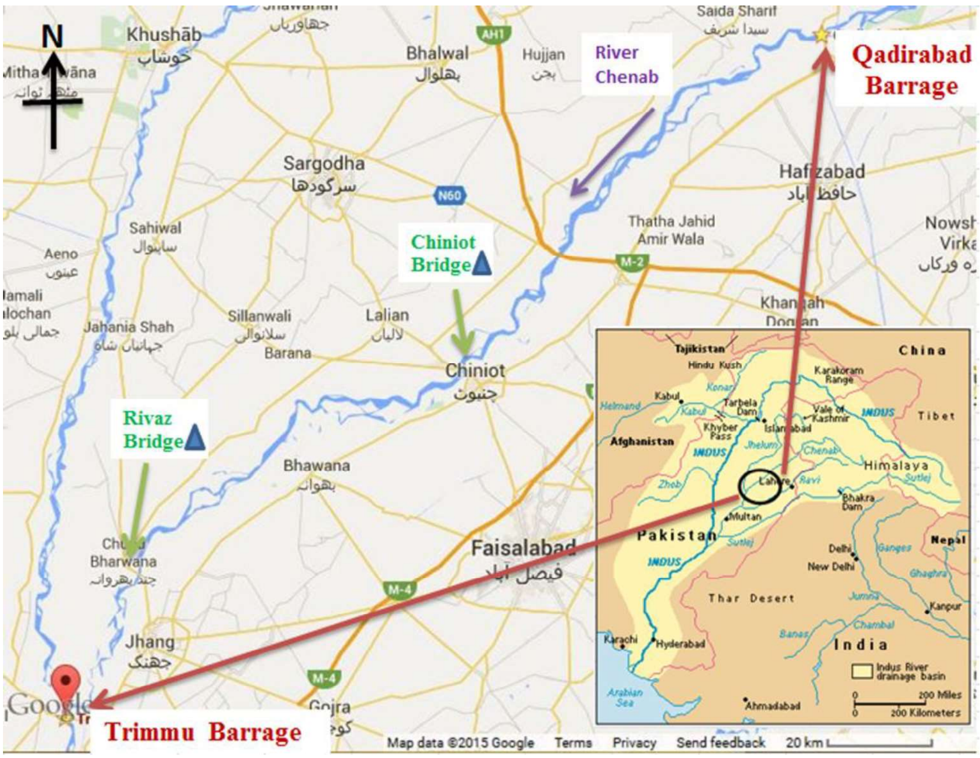
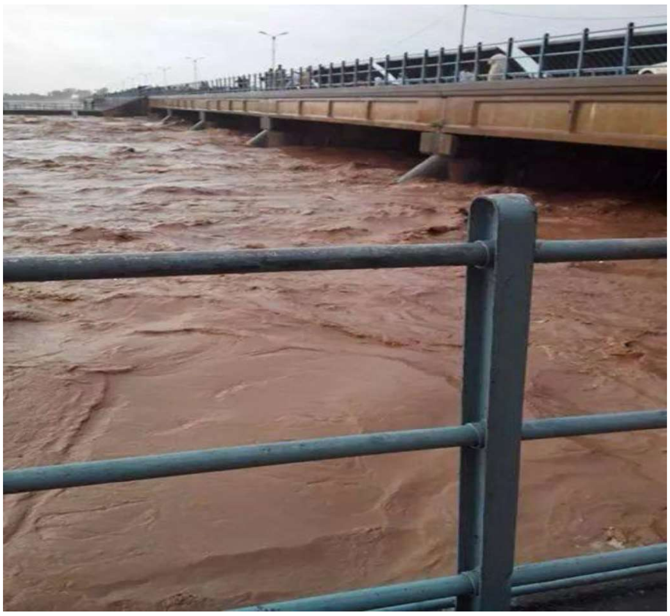


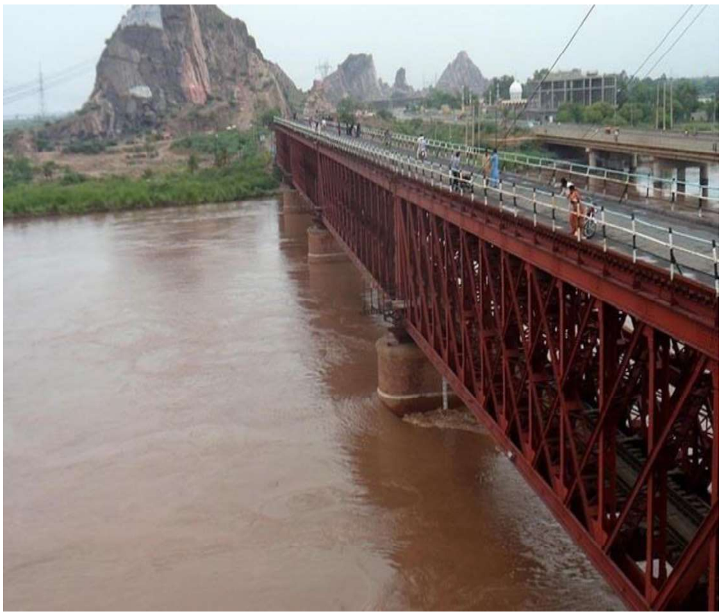
Fig 2: Study area Qadirabad to Trimmu barrage (with locations of gauging stations)

STUDY AREA

- The study area comprises of a selected river reach from Qadirabad Barrage to Trimmu Barrage.
- Qadirabad Barrage has a design capacity of 25,481 m^3/s while that of Trimmu Barrage is 18,262 m^3/s.
- There are two gauging stations in the study reach, one at Chiniot Bridge and another at Rivaz Bridge.
- Nine existing flood bunds or dikes were constructed along river sides.



Qadirabad Barrage during big flood in 2014



Chiniot Bridge during the flood

Inundated flood plain of Chenab River

Breached flood bund of Chenab River

People wading through flood water

Trimmu Barrage during flood in 2014

METHODOLOGY

The methodology comprises of

1) data collection and analysis,
2) flood frequency analysis, and design flood hydrograph,
3) flood modeling,
4) assessing effectiveness of flood control structure and
5) flood hazard assessment.

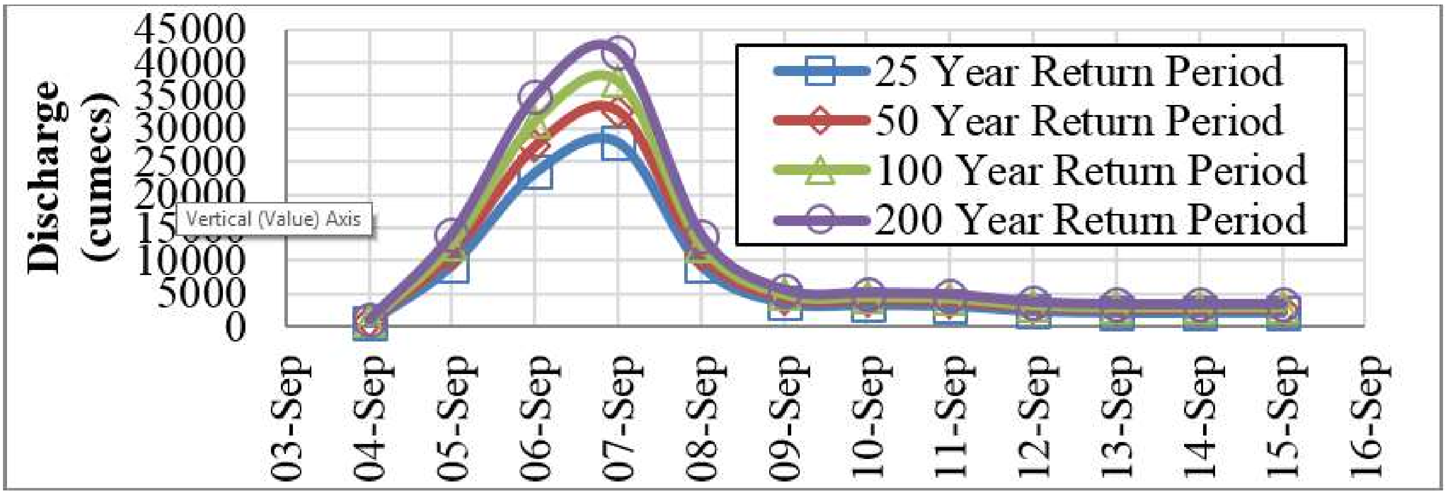
DATA COLLECTION

a) Historic flooding events in the study reach;
b) Annual flood peaks in Qadirabad-Trimmu reach from 1983-2015;
c) Daily outflow at Qadirabad Barrage for upstream boundary cond. ;
d) Daily stage at Trimmu Barrage for downstream boundary cond.;
e) Cross sections from field survey (only 60% available at 4 km interval). Remaining cross sections were based on DEM SRTM 30 m resolution using digitization in HEC- GeoRAS
f) Locations and geometry of existing flood bunds;
g) Stage-discharge rating curves at Qadirabad and Trimmu Barrages.

FLOOD FREQUENCY ANALYSIS AND DESIGN FLOOD HYDROGRAPHS

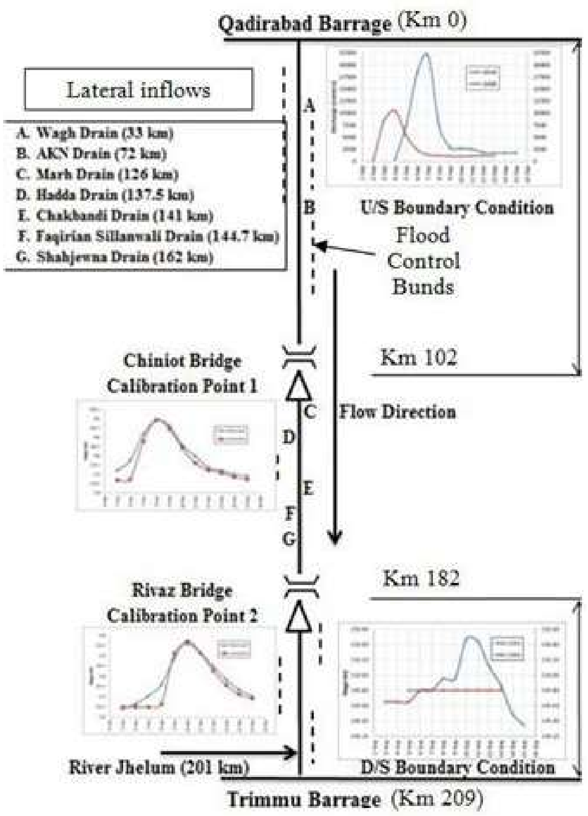
- Gumbel flood frequency analysis was applied on the observed peak discharges at the Qadirabad barrage under full gate opening from 1983-2015 and the flood peak discharges of 25, 50, 100 and 200 year return periods were determined.
- The past flood hydrograph of each year is normalized by taking its peak as 1. All normalized hydrographs of the past floods were overlaid with their peaks matched and averaged to obtain an averaged normalized flood hydrograph
- The design flood discharge hydrograph for each return period was obtained by multiplying the peak discharge of selected return period to the ordinates of the average normalized flood hydrograph

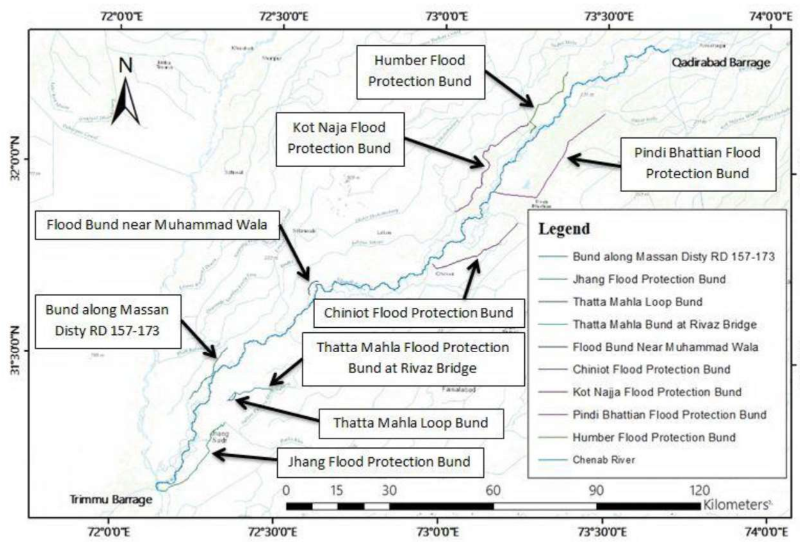
Constructed flood discharge hydrographs at Qadirabad of various return periods



HEC-RAS MODEL CALIBRATION AND VERIFICATION

- The river cross-section data and flood plain elevations were input to HEC-RAS.
- Due to flat topography of the flood plains, the river flood level was assumed to be horizontal across the river and its flood plains on its left bank and right bank.
- The model configuration of HEC RAS is shown in Fig.3.





Locations of nine flood bunds

Fig.3 Configuration of HES-RAS Model for the Chenab River Reach from Qadirabad Barrage to Trimmu Barrage

MODEL INITIAL AND BOUNDARY CONDITONS

- ***Initial and Boundary conditions***
- The initial flow condition along the river reach was assumed to be steady flow at a constant upstream discharge according to Manning equation .
- The upstream boundary condition was the measured discharge hydrographs at Qadirabad Barrage.
- The downstream boundary condition was the measured stage hydrograph upstream of Trimmu Barrage.
- The lateral inflows between Qadirabad Barrage and Trimmu Barrage were very small and negligible.

MODEL CALIBRATION AND VERIFICATION

- **Model Calibration**
- The observed and computed stage hydrographs from 5 to 15 September 2014 at the Chiniot Bridge and Rivaz Bridge were compared.
- The Manning n was initially assumed and adjusted by trial and error. It was found that n= 0.029 for main channel and 0.047 for floodplains.
- The observed and computed stage hydrographs agree satisfactorily with a correlation coefficient of 0.97 and Nash and Sutcliffe coefficient of 0.86
- **Model Verification**
- The model is verified for the flood from 3 to 14 September 2006 keeping Manning n's from the model calibration unchanged.
- Fig. 5 shows comparison between the observed and computed stage hydrographs at the Chiniot Bridge
- The agreement is satisfactory with correlation coefficient of 0.97, and Nash and Sutcliffe coefficient of 0.79.

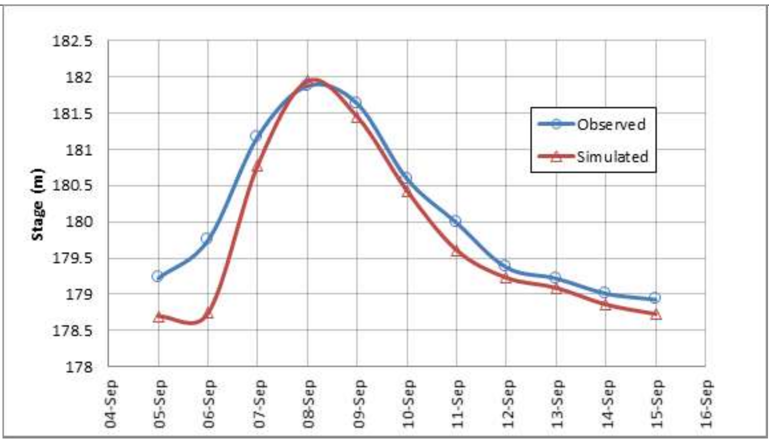


Fig.4 Results of model calibration at Chiniot Bridge, 2014

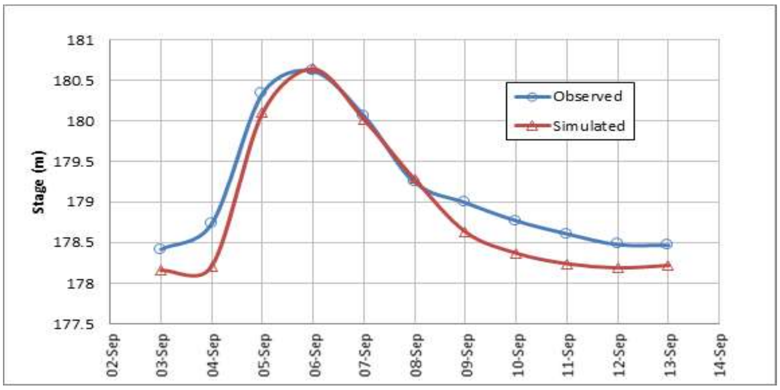


Fig.5 Results of model verification at Chiniot Bridge, 2006

EFFECTIVENESS OF FLOOD CONTROL BUNDS

- HEC-RAS model was used to determine effects with and without flood control bunds for various return periods.
- The results of HEC-RAS model were exported to Arc-GIS through its tool HEC-GeoRAS to generate maps of flood inundation area and depth of various return periods
- Comparisons for the cases with and without flood bunds were done to assess the effectiveness of flood control infrastructure on the basis of inundation depths and flooding areas

FLOOD HAZARD ASSESSMENT

- Two assessment criteria are used namely ESCAP criterion and DEFRA criterion.
- ESCAP flood hazard criterion is based on flood inundation depth with reference to three critical depths of 0.8, 1.0 and 3.5 m .
- ESCAP flood hazard map classifies flood depths in four intervals namely: 0.0-0.81 m as low, 0.82-1.00 as medium, 1.01-3.50 as high and 3.51-higher as very high
- DEFRA considers flood hazard to people (FHR) as function of depth and velocity:

$$FHR = d. (v + 0.5) + DF \qquad (1)$$

- Where d = depth of flooding (m), v = velocity of flow (m/s) and DF = debris factor (equal to 1 if d > 0.25m otherwise 0).
- The hazard to people was calculated and plotted using criterion below (Table 1).

TABLE 1 DEFRA CRITERIA FOR FLOOD HAZARD TO PEOPLE

Flood hazard rating FHR= d(v+0.5)	Degree of Flood Hazard	Description
<0.75	Low	Caution (Flood zone with shallow flowing water or deep standing water)
0.75-1.25	Moderate	Dangerous for some (i.e. children, flood zone with deep or fast flowing water)
1.25-2.5	Significant	Dangerous for most people (Danger: flood zone with deep fast flowing water)
>2.5	Extreme	Dangerous for all (Extreme danger: flood zone with deep fast flowing water)

RESULTS AND DISCUSSIONS

Effectiveness of Flood Control Bunds

- With the existing flood bunds, the computed maximum depths in the floodplains for 25, 50, 100 and 200 year return floods were 11.73, 12.58, 13.46 and 14.46 m respectively.
- Without flood bunds, the inundation depth and flooded area increased by about 8-10 % except for the 200 year flood, the effect of flood bunds is not significant
- Hence the flood bunds are effective only for the floods of 100 year return period and smaller.
- For the floods larger than 100 year , e.g. 200 year flood, the effectiveness of the flood control bunds is not ensured.

RESULTS AND DISCUSSIONS(CONT.)

- The individual effectiveness of each flood bund was determined.
- The results shown that out of the nine bunds, four of them namely : Thatta Mahla, Thatta Mahla Loop, Jhang and Massan Disty are not safe for floods larger than 100 year.
- For 200 year flood, these bunds were overtopped by flood depths of 2.77, 2.77, 1.40 and 2.94 m respectively.
- These four bunds need to be raised and strengthened in order to ensure safety against the heavy floods.

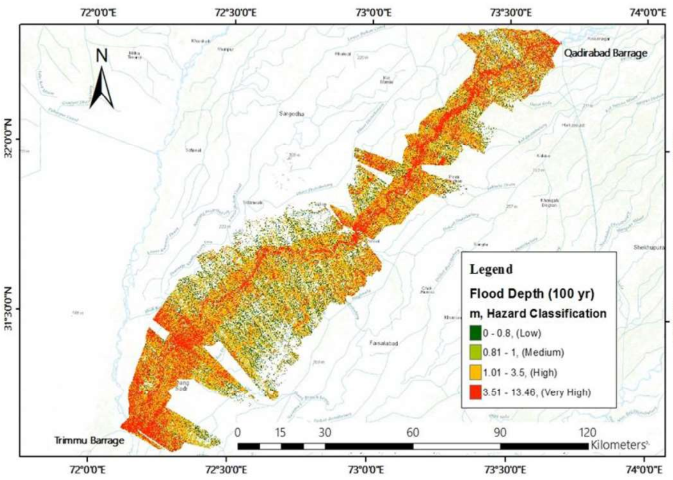


Fig.6 Flood hazard map for 100-year return period flood using ESCAP assessment criterion

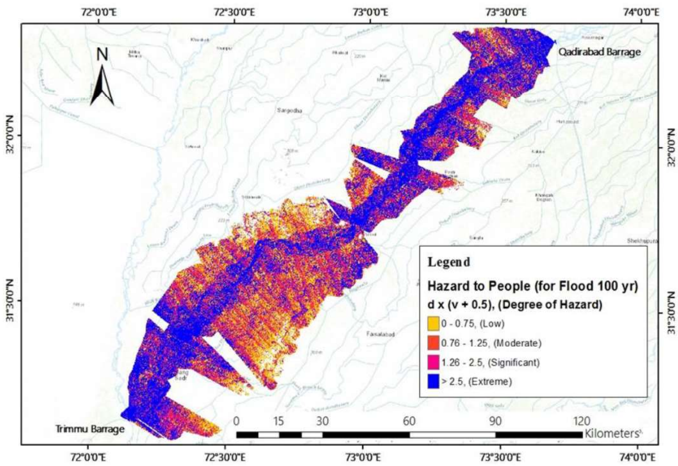


Fig. 7 Flood map of hazard to people for 100-year return period flood using DEFRA assessment criterion

FLOOD HAZARD ASSESSMENT

- Figs. 6 and 7 show the flood hazard maps according to ESCAP and DEFRA criteria for the 100 year flood with the flood control bunds.
- For the 25-, 50-, 100- and 200- year floods, both assessment criteria show increasing trends of hazard under the existing flood bunds.
- For ESCAP criterion, the hazard level in the flood plains was mostly low and moderate for 25 year flood, medium and high for 50 and 100 year floods, high and very high for 200 year flood.
- For DEFRA criterion, the flood hazard to people was low for 25 year flood, moderate for 50 year flood, moderate and significant for 100 year flood and extreme for 200 year flood.

CONCLUSIONS AND RECOMMENDATIONS

- Flood inundation along 209 km Chenab River reach from Qadirabad to Trimmu Barrages was computed by HEC-RAS model.
- The novelty of this study is the application of two assessment criteria namely ESCAP and DEFRA to assess the flood hazard impacts with and without the existing flood control bunds.
- The ESCAP criterion considers flood hazard based on flood depth but not flood velocity.
- While the DEFRA criterion considers both depth and velocity in assessing the flood hazard to people.
- The two criteria are different but when used together they are useful in reducing flood hazard to people and infrastructure.
- The nine existing flood bunds were assessed and found that five of them are safe and can control flood up to 200 years.
- The four bunds namely: Thatta Mahla, Thatta Mahla Loop, Jhang and Massan Disty were not safe for the floods more than 100 years. They must be strengthened.
- Recommendations:

  -The missing river cross sections should be surveyed in the future

  -Flood risk assessment should be consider including land-use, population, private properties and public infrastructures.

  -Other flood hazard assessment methods should be considered, for example, FEMA Multi-hazard Loss Estimation or HAZUS-MH ; and National Flood-risk Management Guidelines of National Flood Risk Advisory Group of Australia .

THANK YOU