FLOOD HAZARD MODELLING AND RISK ASSESSMENT USING REMOTE SENSING AND GIS

By

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CERTIFICATE

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My Late Parents

ACKNOWLEDGEMENTS

In the Name of Allah, the most Gracious and the most Compassionate. Blessings upon Prophet Muhammad (P.B.U.H) for guiding us towards the right path.

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LIST OF ABBRIVIATIONS

Abbreviation	Explanation
ADPC	Asian Disaster Preparedness Centre
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
DOS	Disc Operating System
ETM	Enhanced Thematic Mapper
ERDAS	Earth Resources Data Analysis Systems
FFC	Federal Flood Commission
GIS	Geographical Information Systems
GUI	Graphical User Interface
HEC	Hydrological Engineering Center
HEC-RAS	Hydrological Engineering Center River Analysis System
HEC-GeoRAS	Hydrological Engineering Center Geospatial River Analysis System
IUCN	International Union for Conservation of Nature
KPK	Khyber Pakhtunkhwa
LiDAR	Light Detection and Ranging
MW	Mega Watt
NASA	National Aeronautics and Space Administration
NDMA	National Disaster Management Authority
OCHA	Office for the Coordination of Humanitarian Affairs

ABSTRACT

Floods are the most devastating and frequently occurring natural hazard and pose serious risk to human lives, properties and infrastructure. In 2010 Pakistan experienced unprecedented flooding of its history. The city of Noshera and surrounding areas adjacent to Kabul river were severely affected by these floods. As it is not humanly possible to control this natural hazard, it is important to focus on reducing its impacts by better understanding flood related phenomena's. The objective of this study was to determine design discharge for 100 and 200 year return period using flood frequency analysis and develop flood inundation and velocity model for flood 2010 in HEC-RAS. The model was calibrated and validated with satellite imagery of flood event and based on calibrated model flood depth and velocity for 100 and 200 year return period was determined. In the final step result of HEC-RAS was integrated to determine flood hazard and flood risk of the study area. The result shows that built-up areas , roads and railway line adjacent to Kabul river are under high risk of flooding. Agriculture is mainly located in the moderate and significant risk zones. Use of high resolution DEM, surveyed cross sections and dense network of gauge stations are recommended for future work.

Chapter 1

INTRODUCTION

River plays an important role in the life of human beings. Rivers are a long-term source of water and the cheapest and fastest mode of travelling. They irrigate on regular basis the fertile alluvial plains formed by them. That is why the majority of human settlements are located on the river banks. Beside so many benefits these rivers also have negative impacts on the agriculture and human settlements amid floods. The main cause of the river floods is substantial precipitation for several hours or days that saturated the ground. Among the natural catastrophes flood is the most frequent and costly. Floods have claimed millions of lives in the last hundred years alone, more than any other natural disaster. In fact, one-third of the annual natural disasters and economic losses and more than half of all victims of natural disasters are flood related (Douben 2006). Floods are usually repetitive in nature and have enormous impacts on agricultural based economies like Pakistan. It is not humanly possible to stop the flood however, its impacts can be reduced by having better understanding of knowledge related to flood. The analysis of floods helps to understand flood characteristics and their causes. Flood studies helps in the identification of the source of the problem and can thus support decision making and contingency planning. Hence the need to quantify flood prone areas is critical to minimize flood damages.

Information of the runoff response of a river basin in case of heavy rainfall events is an extremely important engineering exercise for urban planning and management. Flood modeling is a combination of hydrological modeling, hydraulic modeling and visualization of river flood using GIS. Knowing the fact that the floods are part of human being life and that this natural phenomena can’t be fully controlled, it is important to focus and improve knowledge to reduce its impacts. In order to achieve this goal it is essential to develop more specific and scientific work for a greater understanding of the flooding phenomena.

1.1 FLOODS AND PAKISTAN

Pakistan has long history of destructive floods. The primary cause of floods in Pakistan is monsoon rainfall and glacier melting . Flood is a regular natural threat to the people living along the banks of different rivers of our country. (Mustafa 1998) Although death toll due to floods have minimized due to recent progree in flood related knowledge. Floods have caused huge losses to the economy, infrastructure, and affected huge segment of Pakistani population. Floods usually arise because of the storm systems that start from Bay of Bengal in monsoon from July to September (NDMA, 2010).

Floods are almost yearly occurring events in Pakistan. Since independence, Pakistan has experienced severe floods during 1950, 1956, 1957, 1973, 1976, 1978, 1988, 1992 and 2010 which brought huge human and financial losses. Floods of different magnitudes occurred between 1922 and 2010 in Punjab, Sindh and Khyber Pakhtunkhwa.

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In July 2010 monsoon floods hit almost the entire country. The unprecedented heavy monsoon rainfalls have set off both river and flash floods in many regions of the country resulting in huge number of deaths, displacement of People on large scale (Table 1.1). 78 out of 121 districts of the country were affected by the ensuing floodwaters, engulfing an area of 100,000 km^2. The floods claimed 1985 lives, affected 20.2 million people, damaged 2.4 million hectares of agricultural land and damaged or destroyed 2.1 million houses and 515 health facilities. Indiscrimate damage was caused to state infrastructure including: transport and communication networks, water and irrigation channels, power and energy plants and grids (Shabir 2013). Flash floods caused damages in hilly areas of Khyber Pakhtunkhwa, FATA, Gilgit Baltistan and Punjab (FFC, 2010).

1.2 Flood Hazard and Risk Mapping

Flood-risk mapping is an essential element of flood-risk management and is regulated by law in many European countries (Merz, Thieken et al. 2007; Schumann 2011). Flood-risk maps helps in the identification of intensity of flood hazard and the patterns of vulnerability and provides much needed data for settlement planning, wildlife habitat conservation planning, infrastructure designing , and flood mitigation and relief planning. Flood-risk mapping has become an increasingly critical tool keeping in view the increasing population densities in flood-prone areas throughout the world, including monsoon Asia, as well as changed flood dynamics due to the changing pattern of land use and climate.

Table 1.1. History of flood and associated damages in Pakistan(FFC).

Year	**Direct losses (US$ Million)**	**Lost Lives No**	**Affected Villages No**	**Flood Area (Km^2)**
1950	488.05	2190	10000	17920
1955	378.4	679	6945	20480
1956	318.2	160	11609	74406
1957	301	83	4498	16003
1959	234.35	88	3902	10424
1973	5134.2	474	9719	41472
1975	683.7	126	8628	34931
1976	3485.15	425	18390	81920
1977	337.55	848	2185	4657
1978	2227.4	393	9199	30597
1981	298.85	82	2071	4191
1983	135.45	39	643	1882
1984	75.25	42	251	1093
1988	857.85	508	100	6144
1992	3010	1008	13208	38758
1994	842.8	431	1622	5568
1995	376.25	591	6852	16686
2010	10000	1985	17553	160000
Total	**29184.45**	**10152**	**127375**	**567132**

The most well known methodology to define flood risk is the definition of risk as the product of hazard, i.e. the physical and statistical aspects of the actual flooding (e.g. extent, depth and velocity of flood inundation), and the vulnerability, i.e. the exposure of people and assets to floods and the susceptibility of the elements at risk to suffer from flood damage (Apel, Aronica et al. 2009).

Identification and assessment of flood risk requires modeling of floodplain inundation that allows land owners and river basin managers to make informed decisions on how to manage the risk. Essential datasets for flood inundation mapping are historical rainfall and runoff or Discharge data; catchment topography and land use data. The information obtained from flood inundation studies are often used to set freeboards for future development projects such as housing or public works like roads, bridges and levee systems.

1.3 HEC-RAS Model

HEC-RAS is a one dimensional hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers. Its first form was HEC-2 model produced by HCE the in 1964. The purpose of this model was to support hydraulic engineers in the stream channels analysis and delineation of floodplain. The HEC-2 model quickly became popular as a standard stream hydraulic analysis program, and its capabilities were further increased (Tate, Maidment et al. 2002). Initially the model was utilized to perform weir, bridge, and culvert analysis. Originally the HEC-2 model was designed only for mainframe computers however DOS was to be used for running on personal computer in mode(Yang, Townsend et al. 2006). In 1990's, Windows-based software became popular and there a was rapid increase in the use of it. The HEC also followed that trend and developed Windows-based module of HEC-2. The model was named River Analysis System (RAS). Visual Basic programming language was used for the development of graphical user interface (GUI) of the HEC-RAS and the algorithms for flow analysis working on the backend was developed in FORTRAN, most of these algorithms were derived from HEC-2 model (HEC, 1997).

HEC-RAS model is basically an integrated software system, which is developed for interactive utilization in a multi-tasking and multi-user environment. The model consists of GUI and has altogether separate hydraulic analysis part. HEC-RAS posses the capability to store and manage data. It also provides the graphics and reporting facilities to the users (Brunner 2010).

The HEC-RAS Model consist four different capabilities for performing one-dimensional river analysis: (1) steady flow water surface profile calculation; (2) Simulation of unsteady flows; (3) water quality analysis, and (4) Sediment transport analysis. All these four units utilize the representation of geometric data, common geometric and hydraulic calculation routines. Apart from the four river analysis techniques the model also consists of different hydraulic design functions that can be called once the essential water surface profiles are generated.

The HEC-RAS model has the capability to perform subcritical, supercritical, and mixed-flow regimes for a single river reach, streams comprising of complete channels network and also for dendritic stream systems. The model is also extremely useful in the studies of floodplain management and flood insurance (HEC, 2010). Flow data, stream channel geometry and topographic data of the basin are the basic input parameters required by HEC-RAS Model for flood inundation modeling. These input data are used to develop a series of cross-sections parallel to the stream channel and covering the entire flood plain. Stream banks are identified in each and every cross-section. Each cross-section is divided into three parts, i.e. main channel, right floodway, and left floodway. The surface roughness or manning's N values are higher in the floodway as compared to the main channel. Friction forces between the water and channel bed have huge influence on the resistance of flow in the floodway, leading to lower values of Manning coefficient.

The HEC-RAS is a one-dimensional hydraulic model which greatly support experts in hydraulic analysis of stream channel flow and floodplain delineation. The model output can be utilized in studies of flood insurance and management of flood plain

1.4 HEC-GeoRAS

The HEC-RAS system is designed to calculate water surface profiles in a full network of channels, a dendritic system, or a single river reach. HEC-GeoRAS is used as an ArcView GIS extension and is intended to process geospatial data for use with HEC-RAS. HEC-GeoRAS is used for the creation of HEC-RAS import file containing required and optional geometry layers from an existing DTM and complementary data sets. HEC-GeoRAS helps in the extraction of spatial parameters for HEC-RAS input, primarily the 3D stream network and the 3D cross-section definition. HEC-GeoRAS is also used to process the outputs of HEC-RAS.

1.5 Flood Modeling and Remote Sensing Data

Satellite based flood inundation mapping produced in near-real time are invaluable for disaster monitoring and relief and response efforts. Accurate mapping of the maximum flood extent is also required for the identification of deficiencies in existing flood control system and for the arbitration of damage claims later (Smith 1997). Satellite-based remote sensing images have been used to map the flood extent since the early 1970s. Most of the early studies used optical remote sensors, such as LANDSAT MSS and TM (Rango and Anderson 1974). Because optical sensors cannot penetrate clouds, which are nearly always accompanied by flood events, they have been mainly used to mark post-flood inundation extent. In recent studies radar sensors have been used in place of, or in addition to optical sensors (Qi, Brown et al. 2009).

DEMs have been widely used to support flood mapping and modeling process. They have been used as essential parts of GIS databases aiming at hydrological flood modeling (Correia, Rego et al. 1998) and for modeling the spatial extent of inundation. DEMs are however, often unavailable or of poor quality (i.e., resolution and accuracy) especially in developing countries. With the completion of the Shuttle Radar Topography Mission (SRTM), DEM availability for the entire globe has been improved (Rabus, Eineder et al. 2003). SRTM may be used for inundation modeling, but, similar to other DEMs, special attention needs to be paid to the quality of inundation models based on DEMs in any given situation (Sanders, 2007).

1.6 GIS Application in Flood Modeling

Geographical Information System may be defined as computer systems capable of assembling, storing, manipulating, and displaying geographically referenced data (USGS, 1998). Originally developed as a tool for cartographers, GIS has recently gained widespread use in engineering, designing and analysis, especially in the fields of hydrology, water quality and hydraulics. GIS offers capabilities to overlay spatial data layers and perform queries on spatial data, as a result of this process new spatial data is created. The results can be digitally mapped and tabulated. GIS facilitates efficient analysis of spatial data and helps in decision making.

Vast amount of information is captured and communicated through GIS which is an extremely useful tool for flood mapping and disaster reduction programmes. GIS is ideally suited for various floodplain management activities such as, topographic mapping, base mapping, , and for validation of mapped floodplain extents and depths through hydraulic models. Geographic information systems (GIS) has been widely used for the assessment of flood hazard and risk. These assessment are based on the hydrological analysis of the frequency, magnitude, duration of flood events and digital elevation models (DEMs) that represent the topography of the basin within which flood events occur.

One-dimensional hydraulic models are used by the USACE for flood inundation mapping . A one-dimensional model assumes the water moves only in one direction in relation to the model geometry. Cross-sections which depicts the topography of the river channel and surrounding overbank areas are digitized perpendicularly to the channel . The hydraulic model is then utilized to interpolate the underlying ground surface between cross sections and assess the water elevation at a specific time interval for each cross section. (Pfaffle 2011).

Once the interpolation of the ground surface between the cross-sections has been completed through hydraulic model, the results are put into a standard geographic information system (GIS). Geographic information system (GIS) is used to further consolidate the model results. The flood inundation is generated within the GIS by subtracting the surface elevations generated by hydraulic model from a digital elevation model (DEM). The accuracy of the modeled inundation is affected by the level of detail in the geometry that is put into the model. For example, the number and layout of the cross sections, the level of detail which defines the underlying topography of the cross sections, and the resolution and accuracy of the DEM (Pfaffle 2011) .

1.7 Problem Statement

Flood is almost yearly occurring phenomena in the adjacent areas of Kabul River and it is not humanly possible to stop this natural hazard. Flood occurs in this area due to excessive rainfall and snow melting in summer season. Residential and agricultural areas in the vicinity of river Kabul are prone to flood. No flood warning and prediction system exist in the area which can alert the local population for safe exit to nearby locations in case of floods. In response to the existing problem a strong need was felt to design a study which integrates GIS, remote sensing and hydrological models to simulate the 2010 flood and use design discharges for different return period for future flood scenario to identify areas prone to sever floods.

1.8 OBJECTIVES

The main objective of the study was to quantify the flood hazard and flood risk of the study area 2010 floods events using GIS and Remote Sensing. The specific objectives of the study was to

1. Simulate flood extent, depth, and velocity of flood event of 2010
2. Determine the probability of return period for 100 and 200 year flood
3. Determine the flood vulnerability/risk assessment of flood hazard

MATERIALS AND METHODS

2.1 Study Area

Study area comprised of 17 Km long stretch of Kabul river located in the north of Noshera district (fig 2.1). The selected study site extends from 33° 58' 00" to 34° 06' 00" North latitude and from 71° 50' 00" to 72° 01' 00" East longitude (Figure 2.1). Noshera cantt, Noshera kalan, Kandar, Kheshgi, Amangarh Azakhel and Pirpiai are the important settlement in the study area. Kabul river flows from west to east in the study area. Kabul river originates in Afhanistan and enters Pakistan at Shalman area of Khyber Agency. Kabul River is mainly a snow-fed and its discharge is significantly increased in summer months. Kunnar and Swat are the important tributaries of Kabul river. After irrigating the district of Peshawar, Charsadda and Noshera, river Kabul finally joins rive Indus at Attock. Study area is part of the fertile Peshawar vale. Agriculture in the Peshawar vale mainly depends on water of Kabul river. Two-third of the Peshawar Valley is irrigated by canals, diverted from Kabul and Swat Rivers. This has improved agricultural yields but the original designs had inadequate drainage and this has led to considerable water logging and salinity in the area. Floods are regularly observed in the Kabul river and in the recent history city of Noshera was severely affected by these floods.

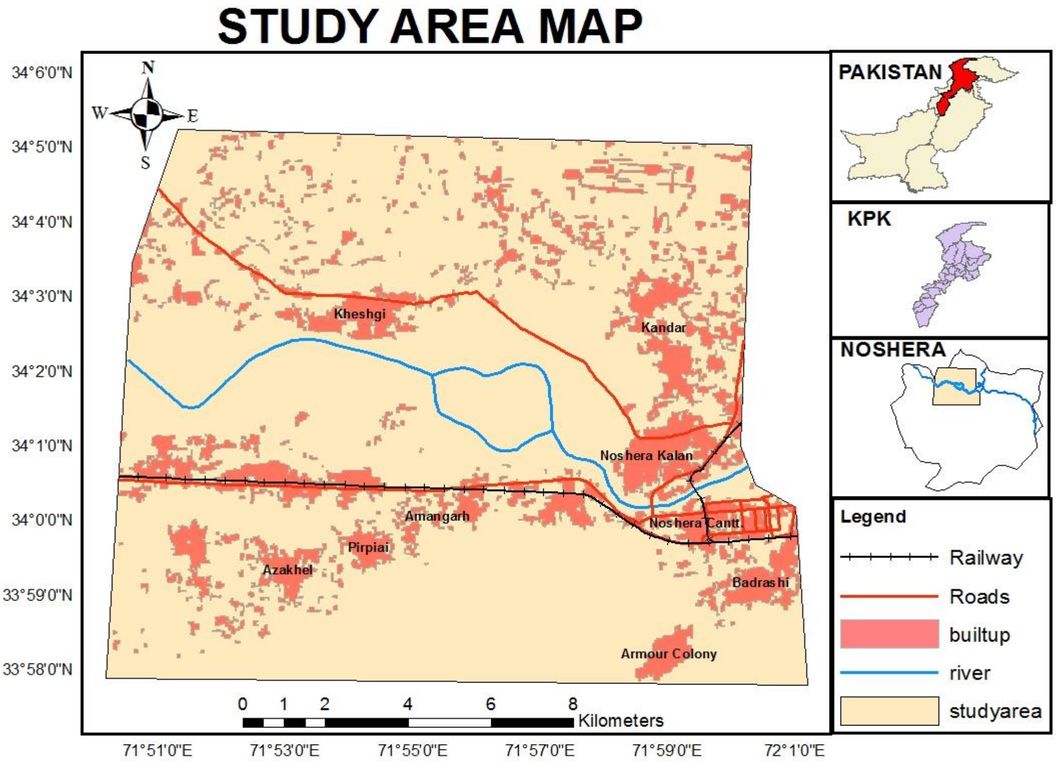


Figure. 2.1. Study area map.

2.1.1 Rainfall

The average annual rainfall at Risalpur during 1988-2014 is 684 mm. The area receives maximum rainfall i.e. about 60% in the months of February, March, July and August. It is thought that winter rains contribute relatively more to groundwater recharge than monsoon rains which are in form of thunder storms. Monsoon rains have more runoff often cause severe floods in Kabul river (Mustafa 1998).

2.2 Data Acquired and Sources

Flood inundation modeling requires set of attribute and geospatial data. River discharge data for period 1981-2011 was obtained from FFC, Islamabad. Flood Frequency analysis was carried out on this data using Gumbel Extreme Value Type 1 and Lognormal probability distribution to determine flood discharge for 100 year and 200 year return periods. Two Landsat TM 30m satellite images were acquired from USGS GLOVIS site. The June 2010 image was used to extract pre-flood LULC. LULC which was used for the extraction of Manning's N or Roughness values. Land sat image of 28-08-2010 was used to get flood extent 2010. Flood extent 2010 was used for the validation of HEC-RAS model. Aster 30m DEM was acquired from http://earthexplorer. Data collected from different source for this project are mentioned in table 2.1.

2.2.1 River Discharge Data

A number of gauge stations are located at different sites on Kabul River and its tributaries, where river flow is recorded on daily basis. These gauge stations includes Warsak Head works, Adezai Bridge, Nowshera Bridge, and Pirsabak obtained from Fedreal Flood Commission of Pakistan for Noshera gauge station.

Table 2.1 Summary of the data used

Data	Date	Specification	Source
Discharge Data	(1981-2011)	Annual Instantaneous Peaks	FFC, Islamabad.
LAND SAT	11-06-2010	TM 30 m (June, 2010)	http://Glovis.usgs.gov
LAND SAT	28-08-2010	TM 30 m (August 2010)	http://Glovis.usgs.gov
DEM	-	ASTER 30m Resolution	http://earthexplorer

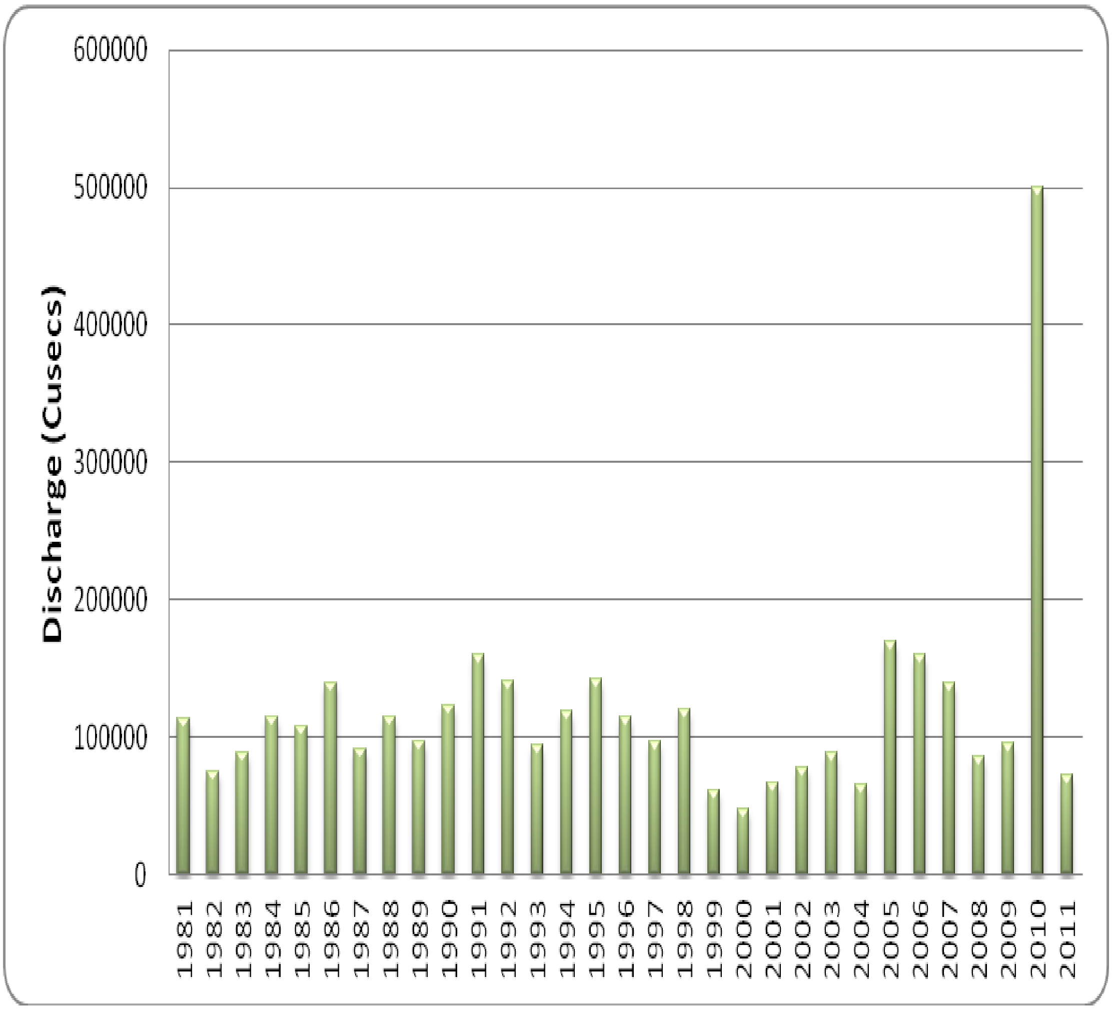


Figure 2.2. Annual Peak flow data from 1981-2011 (source FFC).

gauge stations. Daily discharge data (figure 2.2) for 31 years (1981 - 2011) was Annual peak flow data were extracted from the daily discharge data and used for flood inundation modeling and determination of design dischages for different return periods. Annual peak data is one of the essential parameter required byHEC-RAS model for flood inundation modeling

2.2.2 Digital Elevation Model

Surface elevation data is the most important data set required for flood modeling. ASTER 30m Digital Elevation Model (DEM) (fig 2.3) was used in this study. Aster DEM is produced from ASTER stere-paired satellite imageries The Aster ASTER DEM is produced from ASTER Stereo-paired satellite The ASTER DEM surface coverage is from 83°N to 83°S and consists of 22,600 tiles. Each tile covers 1°by1°area which is equal to 60 km by 60 km area on ground surface. The DEM was downloaded from the ASTER GDEM website (http://www.gdem.aster.ersdac.or.jp/ search.jsp)

2.2.3 Satellite Imagery

Satellite images are considered as the best source of collecting enormous information about the flood situation over large areas. These images can be very effective for mapping flood extent provided they are acquired for the duration of flood event. In flood situations, satellite images are used for mapping flood extent. HEC-RAS based flood modeling required land-cover information, an important but optional input to the model. Land sat image of July 2010 (Fig 3.4) was used to extract pre flood Land Use Land Cove Classes. Land-cover information is required to apply the Manning's n values to the water flow. Moreover, satellite image of

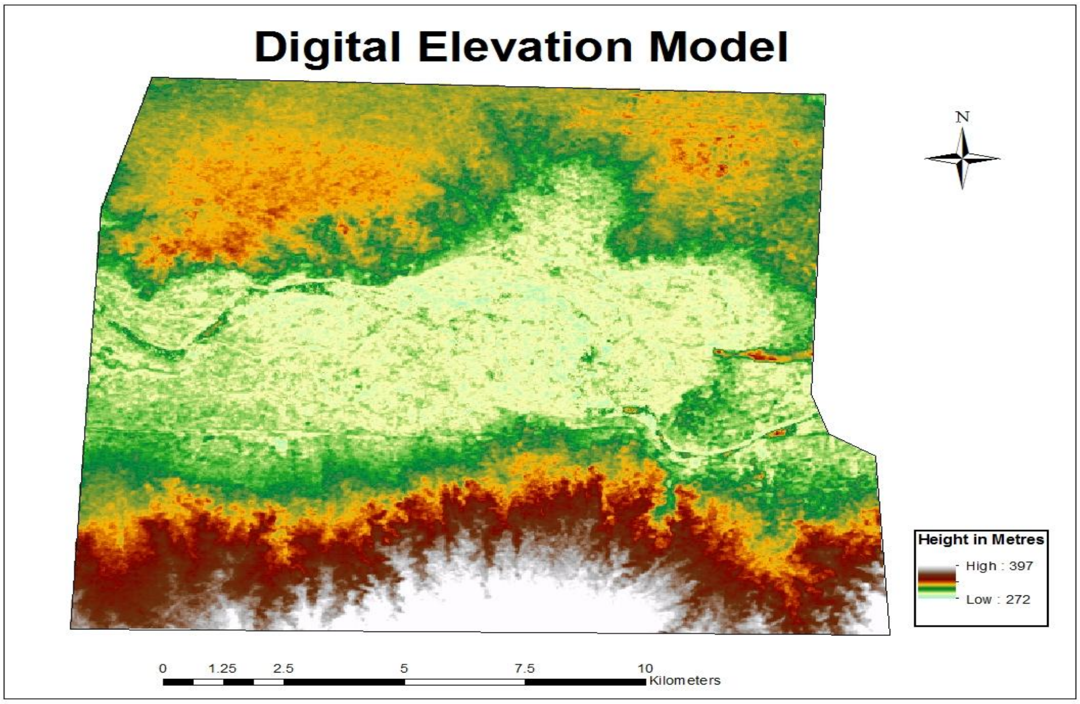


Figure.2.3. Aster 30m DEM of Study Area.

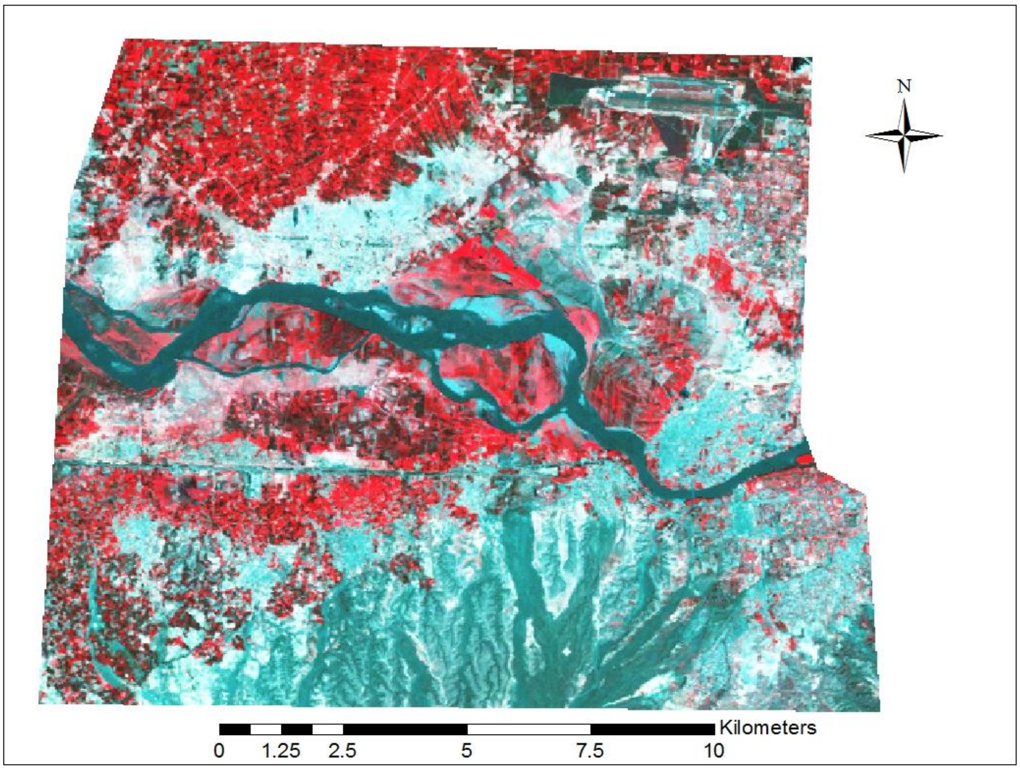


Fig 3.4 Land sat 5 TM image of July 2010.

the 28 August. 2010 (Fig 3.5) was used to extract flood extent which was used for the validation purpose of flood 2010 model generated through HEC-RAS. Similarly, satellite imageries also helps in the extraction of geometric data of the river schematic required for flood inundation modeling.

2.3 ANALYTICAL FRAMEWORK

Various geo-spatial datasets and attribute dataset are required for the flood hazard and risk studies. Geo-spatial datasets include digital elevation model, satellite images, whereas time series discharge data was used as the attribute dataset. Satellite image of pre-flood period was used for the classification of land use and land cover as well as for the preparation of RAS geometry. Time series discharge data was utilized to estimate the magnitude of 100 and 200 years flood through flood frequency analysis using Lognormal and Gumbel Type 1 probability distribution functions. Model was calibrated and validated. Based on this calibrated and validated model flood magnitude and the RAS geometry, HEC-RAS based flood modeling was done and the model was calibrated to produce reliable flood maps. The whole methodology was divided into the following three steps and shown in figure 2.6.

- Data collection and pre-processing
- Model preparation and execution
- Post-processing of the computed results

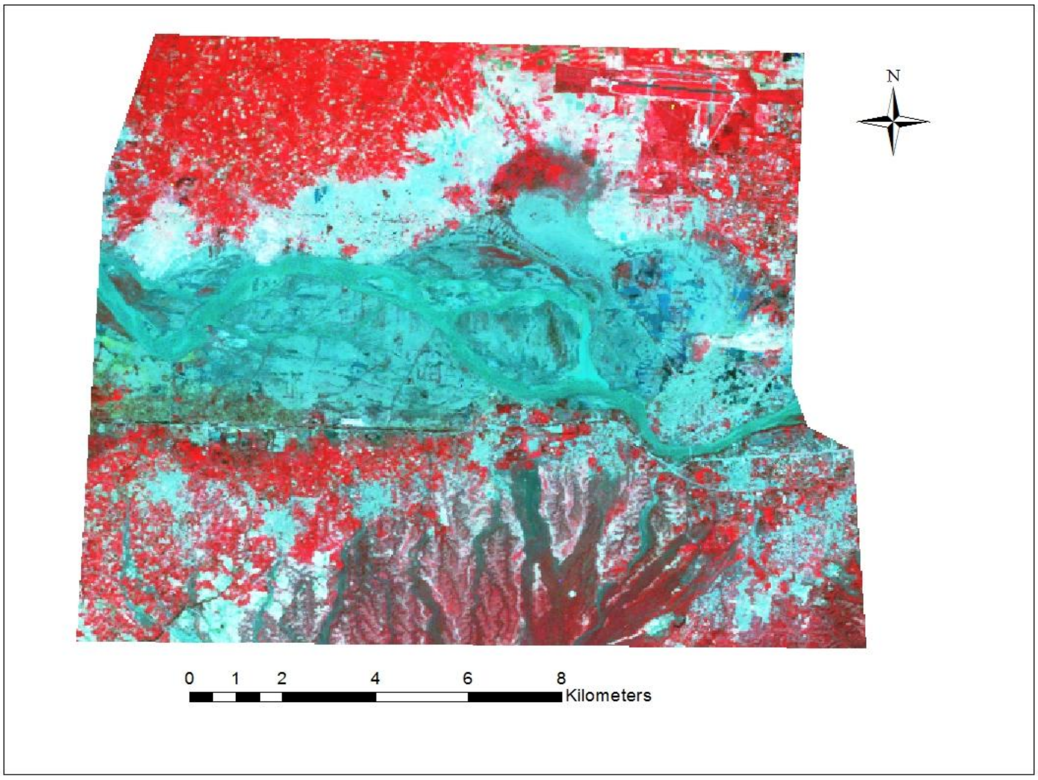


Figure. 3.5 Land sat 5 TM image of August, 2010

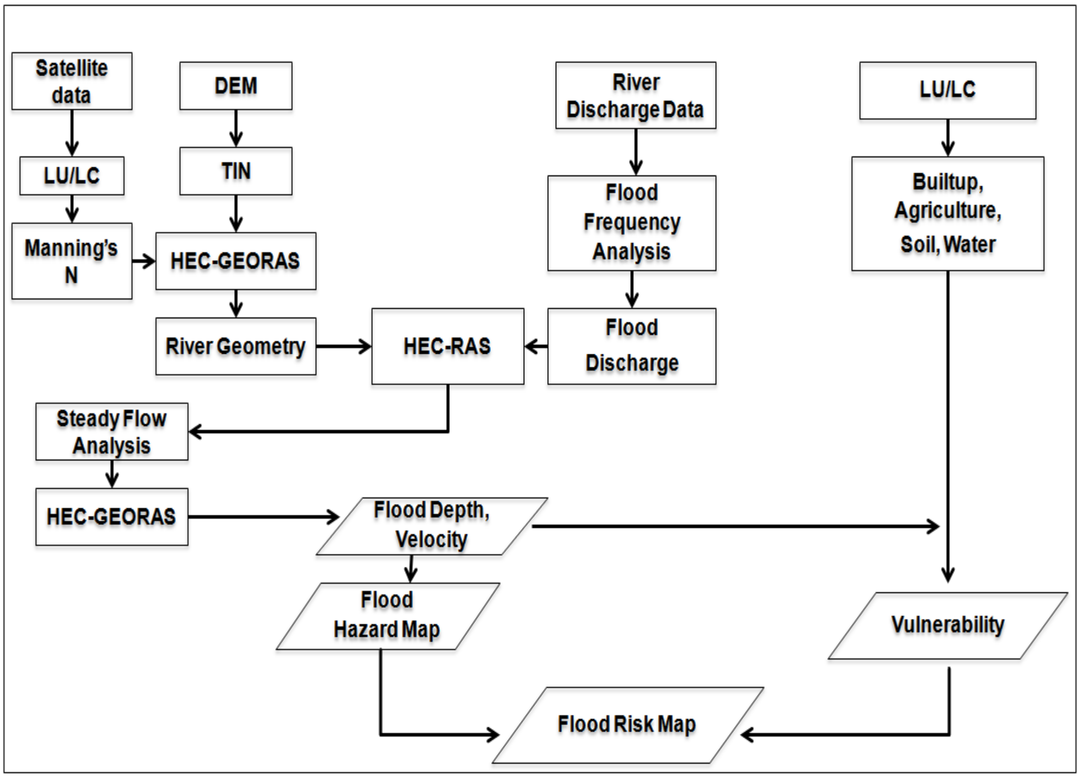


Figure 2.6. Detail methodology for Flood Hazard Modeling and Risk Assessment

2.3.1 Data Pre-Processing

In this step geometric database was developed the for the 17 Km reach of Kabul river of the study area. River geometry data was prepared with the help of HEC-GeoRAS model. River geometry prepared in HEC-GeoRAS was imported into HEC-RAS. DEM which is the most important parameter required by HEC-GeoRAS Model, was converted to TIN. ArcGIS 3D Analyst was used to convert ASTER 30m DEM into TIN. The Geometric data was in the form of RAS layers. These RAS layers included Stream Centerline, Flow Paths Centerline, Main Channel Banks, Cross-Section Cut Lines and the Land use (Manning's n values). RAS layers were digitized one by one and there attributes i.e., topology, length/stations, Manning's n values and elevations were populated according to the layers requirements (Nandalal 2009). Though no tributary was joining the Kabul river in the study area of this project, the river was divided into three reaches as there was split flow conditions in the middle of the study area. Total of 140 cross-sections at interval of 70m to 200m were digitized on three reaches. Each cross-section intersected Stream Centerline, Main Channel Banks, and Flow Paths Centerline. The cross-section covered area on both sides of the channel where the maximum flooding was possible. After creating the rivers geometric database the RAS GIS import file (RASImport.sdf) was generated and exported to HEC-RAS.

2.3.2 Land Use LandCover Classification

Landsat image of June 2010, was classified using object oriented classification method in Ecognition 8.7. Image was first segmented into image objects. Different scale parameters and shape index was used for the segmentation process. After segmentation process, image was classified into different land use and land cover classes i.e. vegetation, barren soil, built up area and water (Fig 2.7) using NDVI and LWM ratios. Default Manning's n (Nandalal 2009), or roughness values were assigned to each class in land use map.

2.3.3 Flood Frequency Analysis

Knowledge of the frequency and magnitude of flood-peak discharges is essential for project design, hazard and risk zonation and water-resources management. Various approaches can be used to estimate the magnitude of flood-peak discharge and associated exceedance probability (Pitlick 1994). Most important of these method are as following;

- Rational method
- empirical method
- flood frequency analysis
- Unit hydrograph method
- Watershed modeling

Among these methods flood-frequency analysis approach is based on statistical inference and is most widely used in hydrology (Jain, Agarwal et al. 2007). Flood frequency analysis is used to relate magnitude of a variable to frequency of occurrence. In flood-frequency analysis, characteristics of the observed instantaneous flood-peak magnitudes are assessed and a probability distribution is selected to fit the observed peak data. The analysis is also termed as at-site analysis because only data at the study site are used. This analysis produces a best-fit line (a flood-frequency curve) between the observed flood-peak magnitudes and their estimated exceedance probabilities (Soong 2004). From flood-frequency curve, the

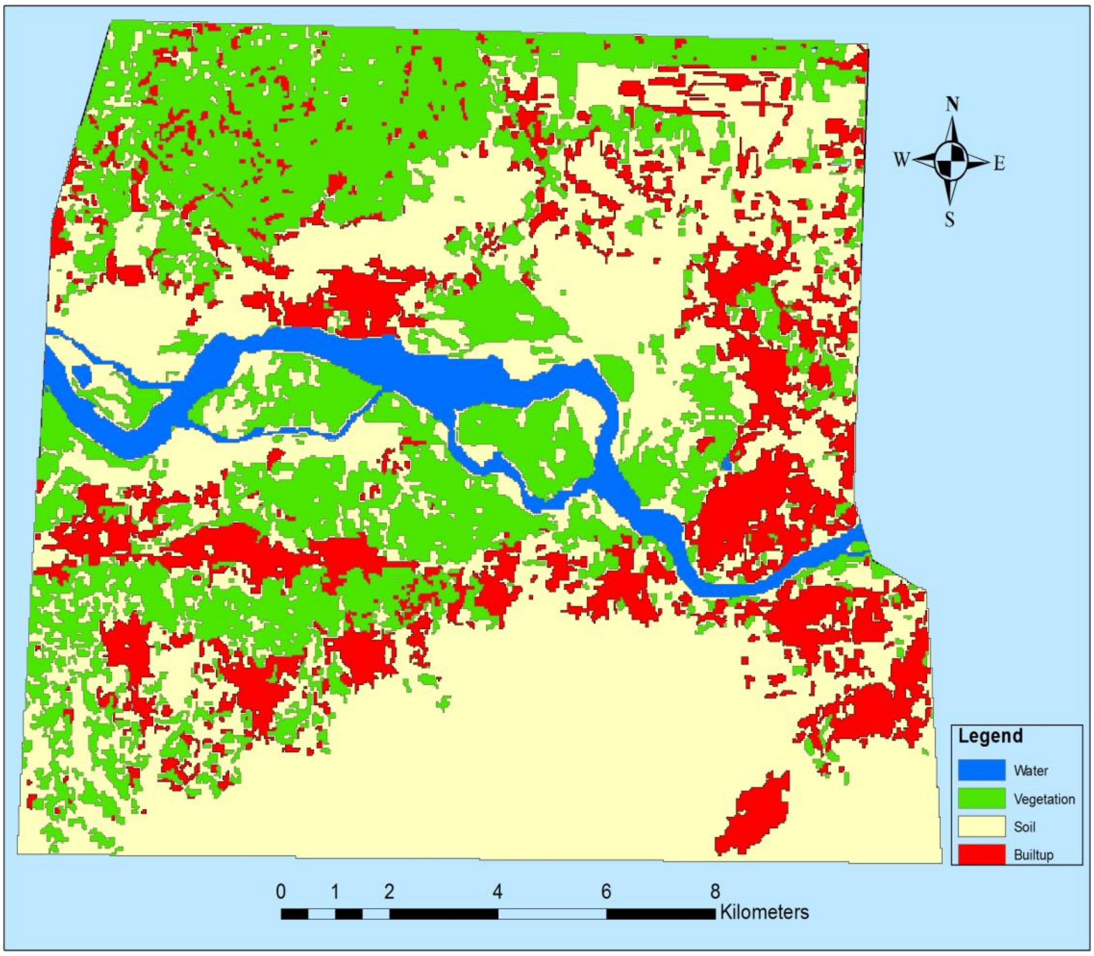


Figure.2.7 Pre Flood 2010 Land Use L and Cover map.

magnitude of flood-peak discharge at different probably can be estimated for the given location. The advantages of flood-frequency analysis over other methods are that the flood discharges for different probabilities are estimated based on observed flood-peak magnitudes. Exceedance probabilities are estimated from actual floods, not from rainfalls as in the design-storm method in the rainfall-runoff modeling approach. The accuracy of quantiles estimated by the flood-frequency analysis is however affected by, data availability and representativeness of the available data.

In the flood-frequency curve, the exceedance probability (P) means the chances that the magnitude of the corresponding flood peak have been equaled or exceeded by an actual flood peak in a specified time interval. Flood frequency analysis involves the fitting of a probability model to the sample of annual flood peaks recorded over a period of observation, for a catchment of a given region. The model parameters established can then be used to predict the extreme events of large recurrence interval(Pegram and Parak 2004)

Frequency analysis method has been used in this study to calculate the 100 and 200 year flood magnitude. A number of statistical techniques are available for frequency analysis, such as, Extreme Value Type I Distribution or Gumbel Distribution Lognormal probability distribution and Log Pearson Type III Distribution. For this project Extreme Value Type I Distribution or Gumbel Distribution and Lognormal probability distribution were utilized to determine 100 and 200 year flood discharges.

2.3.4 Extreme Value Type I or Gumbel Distribution

Estimation of maximum discharge is one of the major problems in designing the hydraulic structures along open channels. Accurate estimation of peak flood frequency discharges can benefit in making hydraulic structures safer. Standard statistical probability distribution functions often used in water resource engineering have been mentioned in the literature e.g. Normal, Log Normal, Pearson, Log Pearson Type III & Extreme Value Type I (EVI or Gumbel 32 Distribution) (Wilson, 1990; Wurbs and James, 2009). Each distribution can be utilized to predict magnitude of design floods. Extreme value distributions of Fisher-Tippett are of three types. Most common of these is the type I distribution, which is normally referred to as Gumbel type or simply Gumbel distribution. This distribution is of extreme order statistics. The distribution was used for estimation of magnitude of 100 and 200 year flood from available annual peak discharges' time series data of 31 years (1981 to 2011).

In Gumbel Extreme Value Type I Distribution (EVI), (Ponce, 1989) the cumulative density function F(x) is given by Eq. 2.1

$$F_{(X)} = \exp(-\exp(-y)) \quad \text{......Eq. 2.1}$$

Annual peak data obtained from FFC was sorted from low to high and ranks were assigned. Lowest rank was given to lowest data while highest rank was assigned to the maximum data value. In the next step left side probability was calculated for each data value by the following equation 2.2

$$p_L = R/N+1 \quad \text{......Eq.2.2}$$

Where

P_L = is the Left sided probability

R = Rank of data value

N = Number of observation

Return period for each observation was determined by equation 2.3

$T = 1/1 - p_L$ Eq.2.3

In the next step plotting position for each observation was determined using equation 2.4

$y = \ln(-\ln(-p_L)$ Eq.2.4

Using the graphic functionalities of excel the calculated reduced variates y were plotted along Y-axis and the relevant annual peak data were plotted along X-axis Figure 2.8. After assessing the graph it was found that it did not fitted the data well so the outlier of flood 2010 was removed. Reduced variate Y was again calculated and plotted against observed discharge data. This time it fitted well the data. The equation for calculating value of reduced variate y for different return period was obtained from excel graph.

$Y = (0.00001 * X) - 0.8298$ ....Eq. 2.5

To calculate flood discharge for 100 and 200 year return period equation 2.3 and equation 2.4 was used. Flood discharge for 100 year return period was 543305 cubic foot per second and for 200 year return period was 612871 cubic foot per second.

2.3.5 Lognormal Probability Distribution

The annual maximum flow series is usually not well approximated by the normal distribution; it is skewed to the right, since flows are only positive in magnitude, while the normal distribution includes negative values. When a data series is left-bounded and positively skewed, a logarithmic transformation of the data may allow the use of normal distribution concepts through the use of the log-normal distribution. This transformation can correct this problem through the conversion of all flow values to logarithms. This is the method used in the log-normal distribution:

Table 2.2 variables calculated for Gumbel probability Distribution

S.NO	**Q**	**Rank**	**PL**	**T**	**Y**
1	47.3	1	0.03	1.03	-1.24
2	61.5	2	0.06	1.07	-1.02
3	65.9	3	0.09	1.10	-0.86
4	66.8	4	0.13	1.14	-0.73
5	72.6	5	0.16	1.19	-0.62
6	74.9	6	0.19	1.23	-0.52
7	77.6	7	0.22	1.28	-0.42
8	78.1	8	0.25	1.33	-0.33
9	86.6	9	0.28	1.39	-0.24
10	89.3	10	0.31	1.45	-0.15
11	91	11	0.34	1.52	-0.07
12	94.8	12	0.38	1.60	0.02
13	95.9	13	0.41	1.68	0.10
14	96.8	14	0.44	1.78	0.19
15	97.1	15	0.47	1.88	0.28
16	108	16	0.50	2.00	0.37
17	114	17	0.53	2.13	0.46
18	114.4	18	0.56	2.29	0.55
19	115	19	0.59	2.46	0.65
20	115	20	0.63	2.67	0.76
21	118.3	21	0.66	2.91	0.86
22	120.6	22	0.69	3.20	0.98
23	123.2	23	0.72	3.56	1.11
24	139	24	0.75	4	1.25
25	139.9	25	0.78	4.57	1.40
26	140.6	26	0.81	5.33	1.57
27	142.4	27	0.84	6.40	1.77
28	159.7	28	0.88	8	2.01
29	160.6	29	0.91	10.67	2.32
30	169.3	30	0.94	16	2.74
31	500	31	0.97	32	3.45

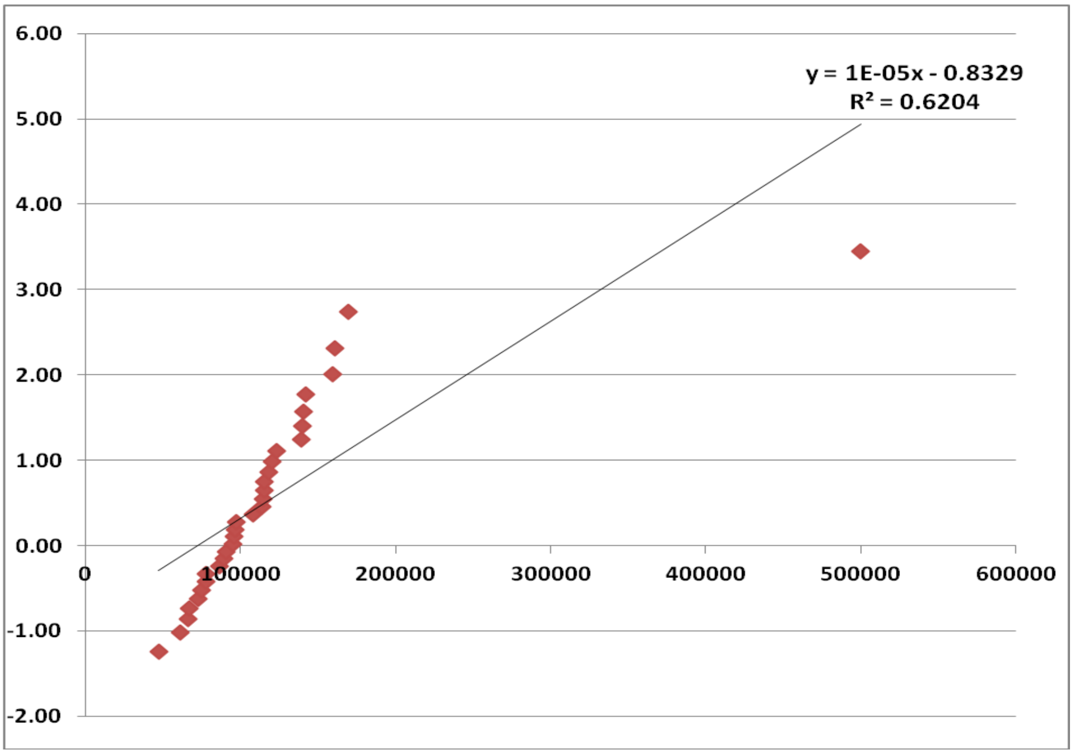


Figure 2.8. Gumbel Probability Curve with peak flood flow 2010

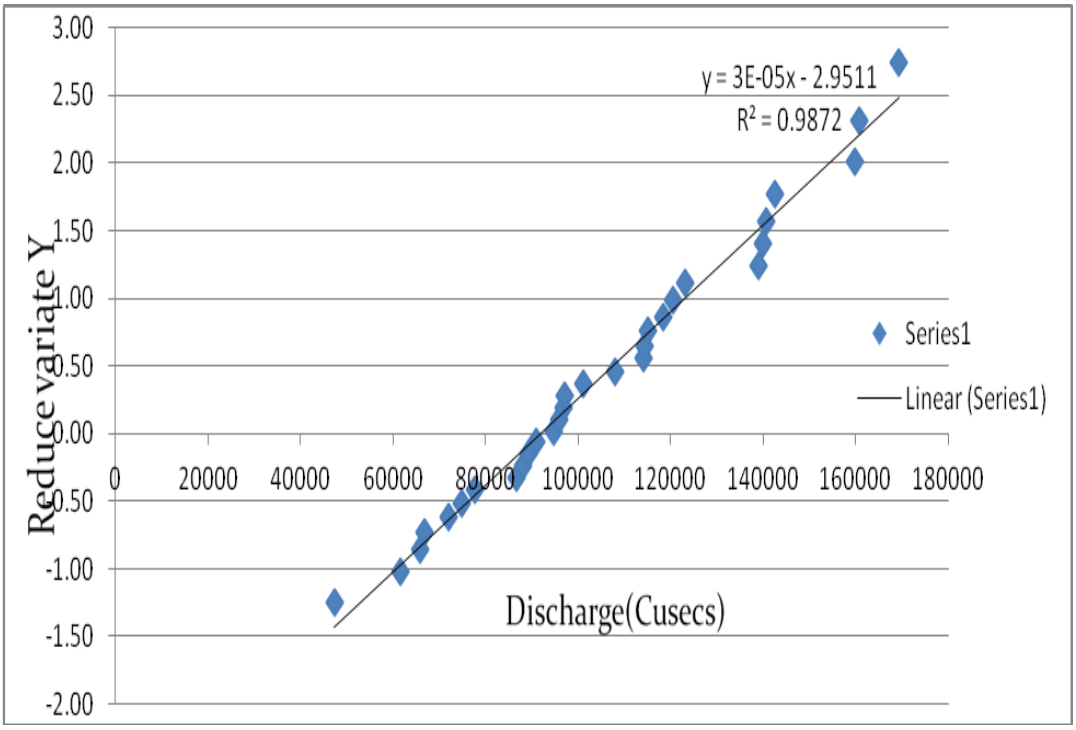


Figure. 2.9. Gumbel Probability Curve without peak flood flow 2010.

$X_{LN,T} = X_l + K_{LN,T} S_l$

where:

$X_{LN,T}$ = logarithm of predicted discharge, at return period

X_l = average of annual peak discharge logarithms

$K_{LN,T}$ = normal deviate (z), of logarithms for the standard normal curve

S_l = standard deviation

2.3.6 TIN Creation

Digital surface models are represented in two ways: by the combination of data points into nets (triangular irregular net – TIN) or by regular tessellation (Burrough and McDonnell, 1998). The use of regular tessellation for the representation of a terrain model at a large scale is not appropriate for the hydraulic analysis of river channels due to poor definition of areas with sharp relief changes (Bonham-Carter, 1996). TINs are used for flood modeling as they provide a better representation of the geometry of the channel allowing adjustment of the density of the net elements to the amount of data variation (Bates et al., 1996). The TIN model enables the input of additional data such as points of maximum height, depressions and breaks of slope; this results in accurate representation of floodplain features such as river banks and alluvial terraces, as well as human constructions such as roads, dykes and weirs, which all influence the hydraulic behavior of the river. In both cases, mesh resolution is a key parameter in hydraulic modeling, as it defines both the size of the smallest feature represented in the DTM, and computation time (Casas, Benito et al. 2006). DEM was converted to Triangulated Irregular Network (TIN) (Fig 3.10) because more errors arise on using DEM if the length of cross section is increased as compared to TIN.

Table 2.3 variables calculated for lognormal probability

Q	**Log**	**Rank**	**Cum**	**z**	**Mean+z+sdev**	**Lognormal flow**
47000	4.6749	1	0.0192	-2.07	4.65	44497
61500	4.7889	2	0.0513	-1.63	4.72	53507
65900	4.8189	3	0.0833	-1.38	4.77	59442
66800	4.8248	4	0.1154	-1.20	4.81	64523
72600	4.8609	5	0.1474	-1.05	4.83	68473
74900	4.8745	6	0.1795	-0.91	4.86	72336
77600	4.8899	7	0.2115	-0.80	4.88	75969
78100	4.8927	8	0.2436	-0.69	4.90	79451
86600	4.9375	9	0.2756	-0.60	4.91	82836
89300	4.9509	10	0.3077	-0.50	4.93	86164
91000	4.9590	11	0.3397	-0.41	4.95	89467
94800	4.9768	12	0.3718	-0.33	4.97	92772
95900	4.9818	13	0.4038	-0.24	4.98	96105
96800	4.9859	14	0.4359	-0.16	5.00	99486
97100	4.9872	15	0.4679	-0.08	5.01	102940
108000	5.0334	16	0.5000	0.00	5.03	106490
114000	5.0569	17	0.5321	0.08	5.04	110162
114400	5.0584	18	0.5641	0.16	5.06	113987
115000	5.0607	19	0.5962	0.24	5.07	117997
115000	5.0607	20	0.6282	0.33	5.09	122235
118300	5.0730	21	0.6603	0.41	5.10	126751
120600	5.0813	22	0.6923	0.50	5.12	131610
123200	5.0906	23	0.7244	0.60	5.14	136899
139000	5.1430	24	0.7564	0.69	5.15	142730
139900	5.1458	25	0.7885	0.80	5.17	149272
140600	5.1480	26	0.8205	0.91	5.19	156768
142400	5.1535	27	0.8526	1.05	5.22	165612
159700	5.2033	28	0.8846	1.20	5.25	174489
160600	5.2057	29	0.9167	1.38	5.28	190937
169300	5.2287	30	0.9487	1.63	5.33	211937
500000	5.6990	31	0.9808	2.07	5.41	254848

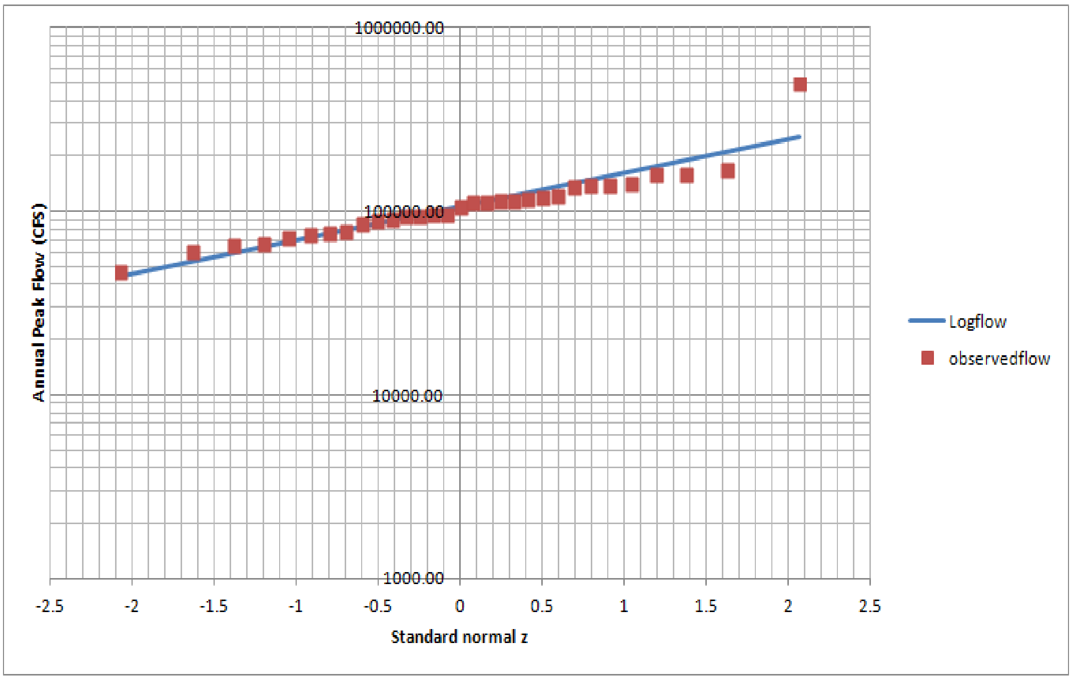


Figure 2.10 Lognormal probability curve.

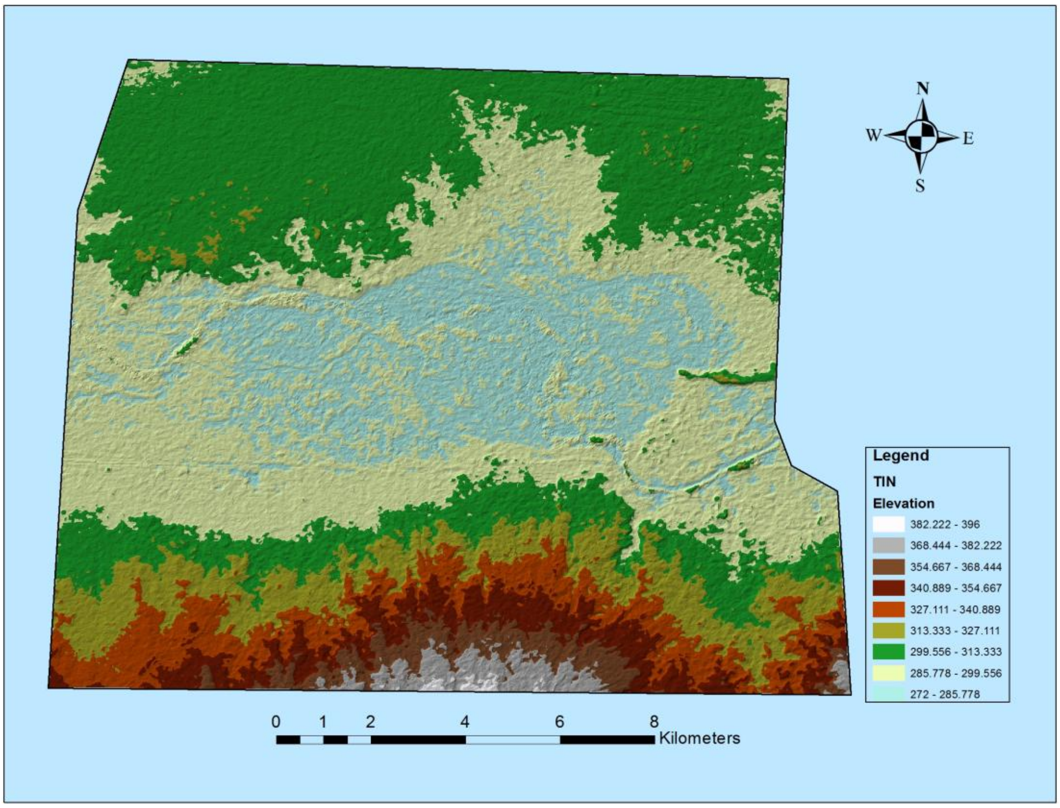


Figure. 2.11. TIN of the study area

Therefore, the TIN data was used in HEC-GeoRAS for the development of necessary and optional layers of river schematic.

2.3.7 Geometric Data preparation

HEC-GeoRAS extension was used for the preparation of RAS geometry (Fig.2.11) in ArcGIS. RAS geometry data for HEC-RAS consist of necessary and optional feature classes. Necessary RAS feature classes comprised of stream centerline and cross-sectional cut lines while optional RAS feature classes included main channel banks, flow path centerlines, bridges, ineffective flow areas, blocked obstructions and the land-cover classes. All these RAS layers were directly digitized from the satellite image of study area. River was divided into three reaches because there was split flow condition in the middle of Kabul river. Total of 103 cross-sections at an average interval of 150 to 200 meter were digitized in all the three reach. River schematic and the relevant geometric data prepared in HEC-GeoRAS are shown in Figure 2.12.

2.3.8 Model Execution

The purpose of this phase was the estimation of the flood extent, depth and velocity for the year of 2010 and for 100 and 200 year return periods. For model execution the peak flood discharge data for the flood seasons of 2010 was chosen for flood analysis. Boundary conditions for the upstream and downstream of river was selected in terms of water levels corresponding input peak discharge for the selected gauge station. Steady flow analysis technique was used for August 2010. The HEC-RAS model is specifically built for hydraulic modeling and simulation. It was basically selected to perform one dimensional steady flow simulation for differen

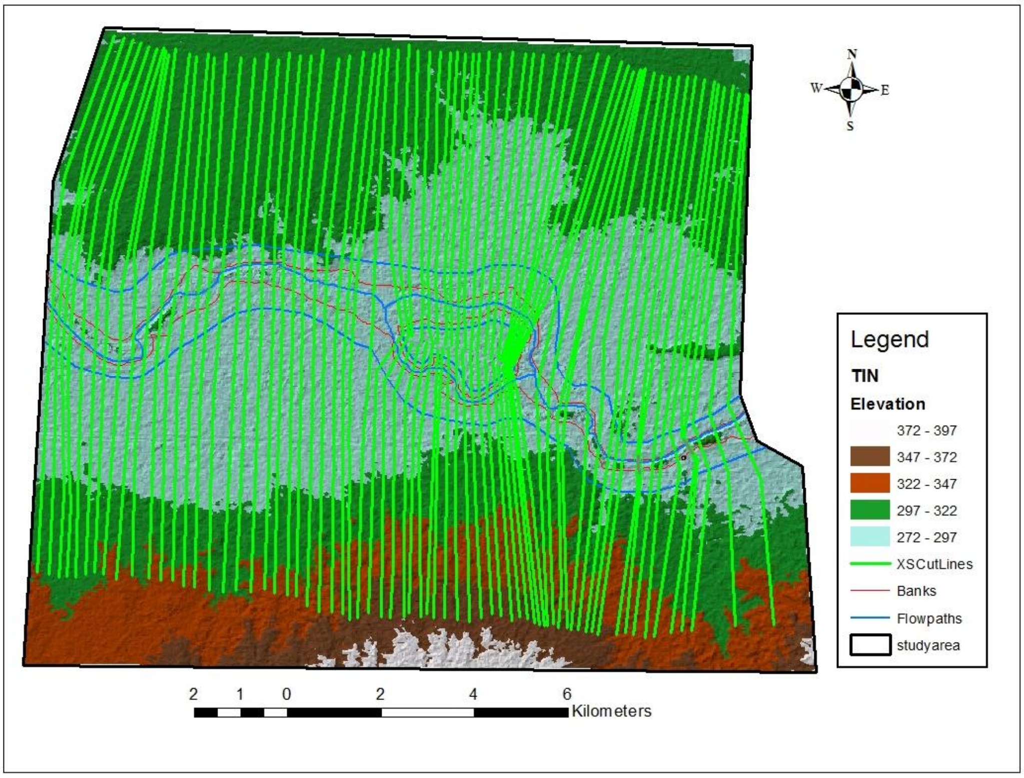


Figure. 2.12 Map showing RAS geometry.

flood scenarios. The geometric data produced with the help of HEC-GeoRAS was exported to the HEC-RAS model for steady flow analysis. First Peak flood discharge data at Kabul river Bridge gauge station of August 2010 flood was selected for Steady Flow simulation. Steady flow was compute by the model successfully for. The steady flow analysis produce the water surface profile at each cross section. The extent of flooded area was shown by 3D profile.The HEC-RAS steady flood simulation data was exported again into ArcGIS supported format for the generation of flood inundation mapping

2.3.9 Post RAS Processing

After running the steady state flow simulation successfully in HEC-RAS model, the computed results were exported in XML readable format.The HEC-RAS exported data were then imported in ArcGIS for post RAS processing and visualization of the model results using HEC-GeoRAS. The HEC-GeoRAS provides the facilities of flood inundation mapping and visualization to the user. Different GIS analysis were performed.

RESULTS AND DISCUSSION

3.1Flood Model 2010

In July 2010 Kabul River was flooded due to heavy monsoon rainfall and inundated the low laying areas in Charsadda and Nowshera Districts. The Peak discharge of 500000 cusecs, which was observed on 29/07/2010 at Kabul river gauge station was used in HEC-RAS Model for water surface profile calculation. In HEC-RAS model, the Manning's *n* value is the roughness parameter which is very important for the computation of water surface profiles (Cook 2008). The selection of suitable Manning's *n* value for the riverbed and floodplain is very important to the accuracy of the generated water surface profiles (HEC, 2010). Relevant Manning's n values for all these four land-cover classes were identified from literature and are shown in table 3.1. The Steady flow simulation was calculated by using the peak discharge of 29/07/2010 of Kabul River which was 500000 cusecs. The inundated area calculated with HEC-GeoRAS model was 73km^2 (Figure 3.1)

3.2 HEC-RAS Model Calibration and Validation

Channel resistance (Manning's *n*) is the only parameter that can be adjusted for calibration of the model. It is highly changeable and depends on numerous factors including roughness of the surface, irregularities of channel, vegetation, channel alignment, scour and deposition, obstruction, channel shape and size, discharge, seasonal variations, suspended material and bed-load (HEC, 2010). According to HEC (2010), the Manning's *n* suggested for the main channel should be between 0.025 for a straight and clean channel to 0.150 for very weedy reaches.

Table 3.1 Manning's n values for land-cover classes

Land use Classes	**Manning's N**
Builtup Areas	0.08
Barren Land	0.05
Agriculture	0.04
Water	0.035

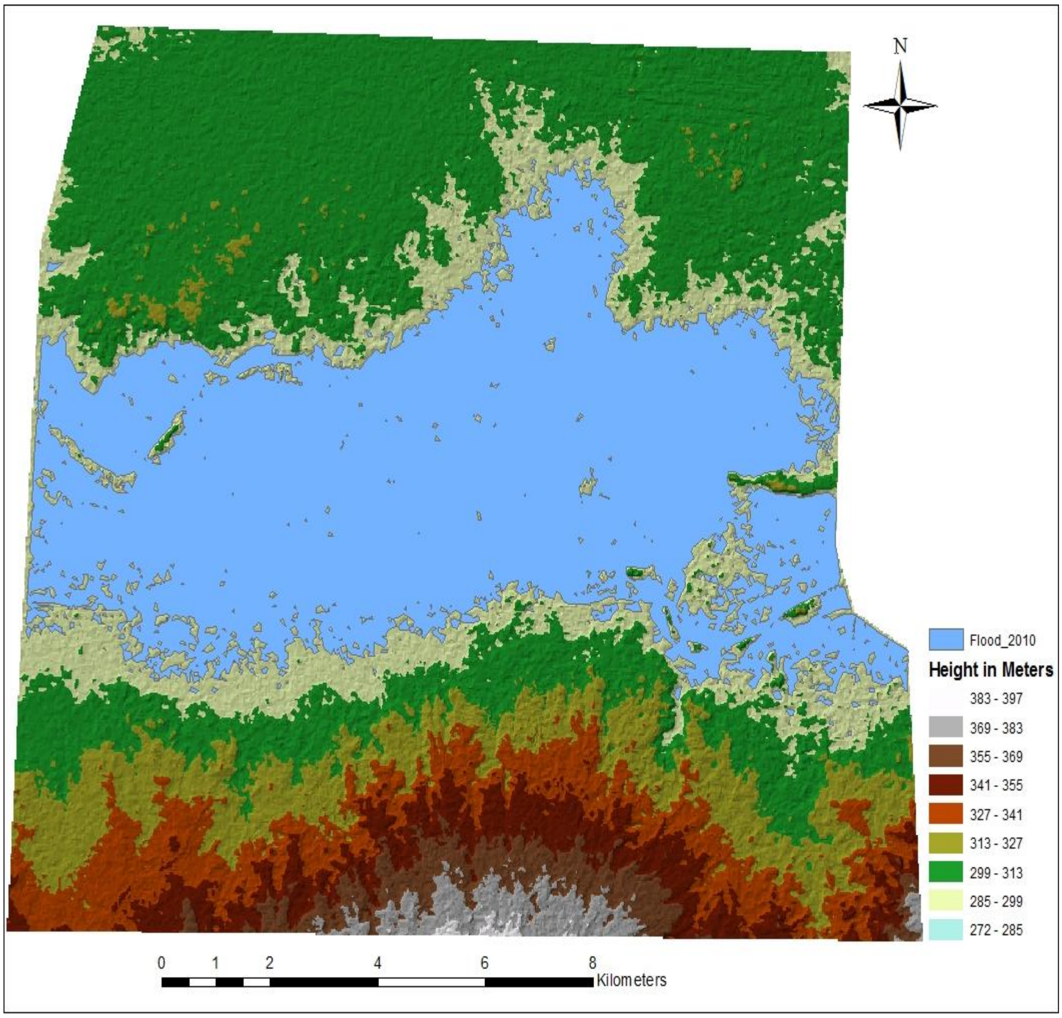


Figure. 3.1 Pre calibrated flood 2010 extent.

The Manning's *n* for floodplain should be between 0.025 and 0.02. In recent researches the Manning's n values that have been used for one-dimensional models lies between 0.026 and 0.065 for floodplains (Casas, Benito et al. 2006). (Horritt and Bates 2002) used Manning's n values between 0.03 and 0.05 for main channel and between 0.06 and 0.10 for the floodplain. (Nandalal 2009) used Manning's n values between 0.02 and 0.035 for river and higher values between 0.5 and 0.85 for floodplain.

Landsat 30m satellite imagery of August 28, 2010 was used for the calibration of the model results. Flood extent of Landsat image was determined by using Object Oriented classification in Ecognition 8.7. The inundated area extracted from Landsat image was $65km^2$ as shown in Figure 3.2.

Although the result of HEC-RAS was quite satisfactory and there was a difference of $8km^2$ with flood extent extracted from classified image. There was slight mismatching between the HEC-RAS flood extent and flood extent of classified image of August 2010 in the north side. So the Manning's n values for built-up and agriculture classes were slightly decreased from 0.08 to 0.06 and 0.05 to 0.45 respectively. The Manning's n were changed both along and across the river (Nandalal 2009).

The model was calibrated using new set of Manning's n values and new flood extent was 71 km^2. Due to excessive cloud cover satellite imageries were not available for validation of the model results, therefore, model results were validated with the UNOSAT flood extent (fig 3.3). UNOSAT flood extent was 65 km^2 in area and difference with the model results was 6 km^2. The model was tuned

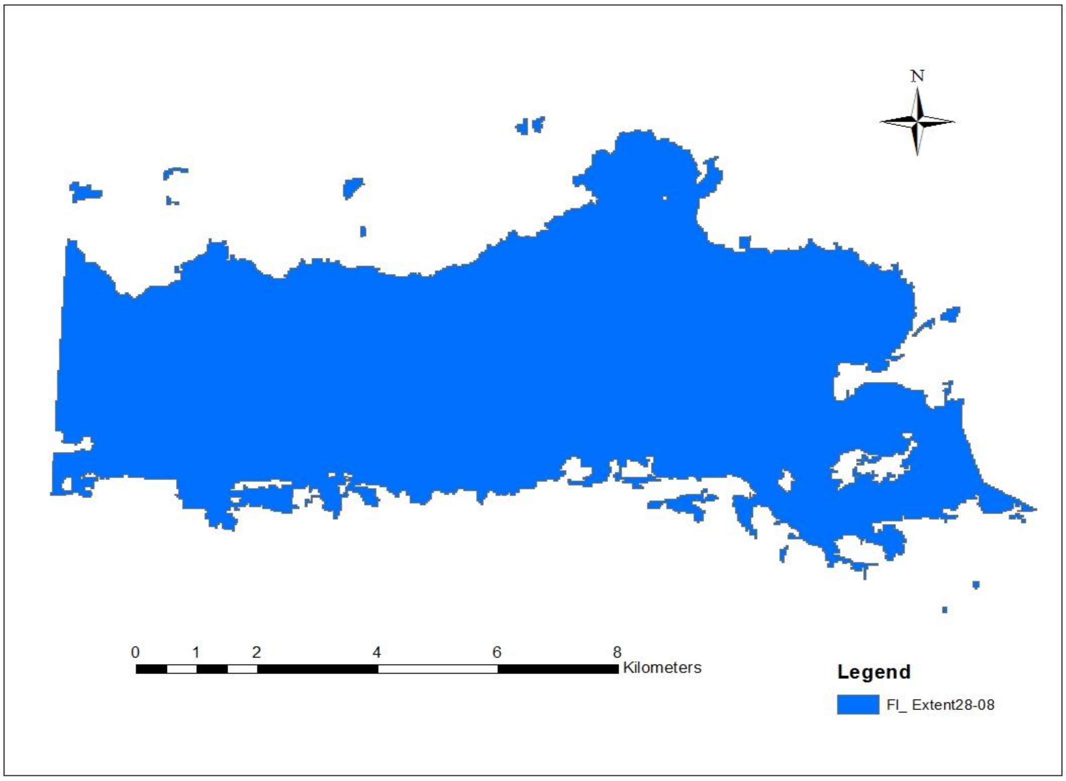


Figure.3.2 Flood Extent 2010 extracted from Landsat image of July, 2010

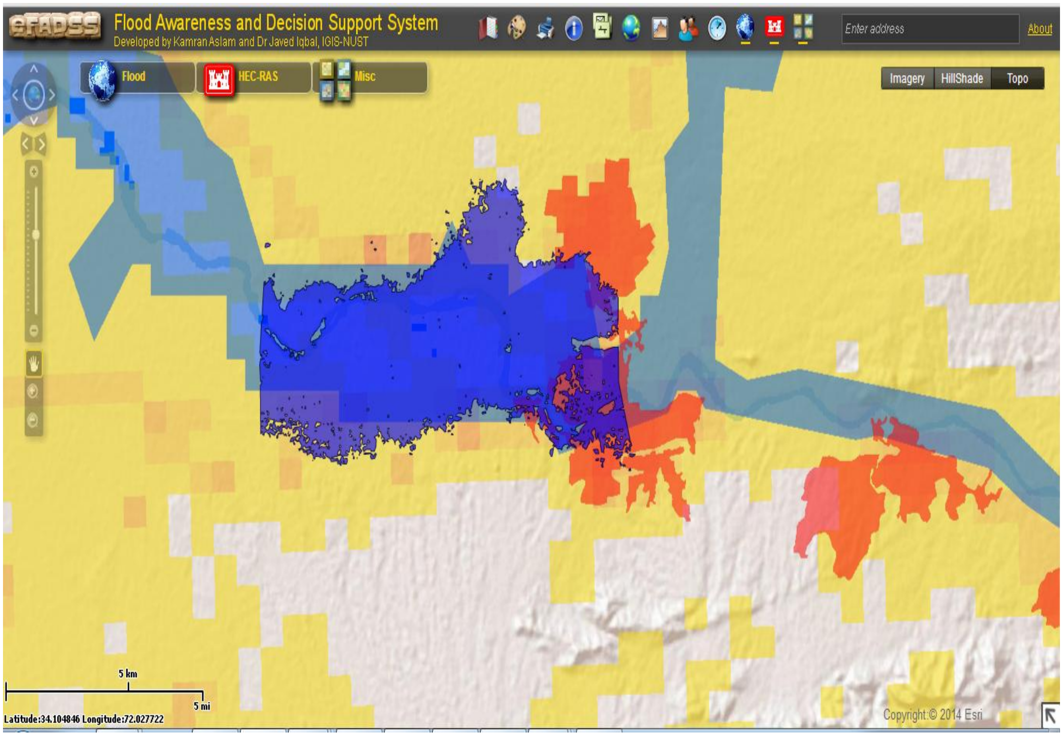


Figure.3.3. UNOSAT flood extent.

to the new set of Manning's n values, which showed approximately identical flood extent to the Satellite imagery flood extent. Based on the calibrated and validated flood 2010 model, flood depth (Fig. 3.4) and velocity for flood 2010 was calculated.(Fig. 3.5)

3.3 100 and 200 Year Flood Model

From lognormal probability curve it was found that it fits well to the historical flood peak data from 1981 to 2011 as compared to Gumbel Extreme value Type 1. Therefore, flood discharges for 100 and 200 year flood were determined through lognormal probability distribution and was used for flood inundation for design discharges. Flow data for 100 and 200 year return period was converted to cubic meter per second. Based on the calibrated and validated flood 2010 model flood depth and flood velocity for 100 year (fig 3.6 & 3.7) and 200 year return period (fig 3.7 & 3.8) was determined Though there was not much difference in the flood extent of 100 year and 200 year return period in comparison to flood extent 2010, flood depth of 100 year and 200 year was slightly greater than flood 2010.

3.4 Flood Hazard Assessment

For the assessment of flood hazard, it is necessary to study the impacts of floods. Flood impacts depends upon the severity and magnitude of primary hazard parameters e.g. flood depth and velocity etc (Wood 2007). Flood maps produced as a result of flood hazard assessment are detailed flood plain maps complemented with type of flood, the flood extent; water depths or water level, flow velocity or the relevant water flow direction. Flood hazard maps, indicates where the combination of current velocity and water depth may be dangerous

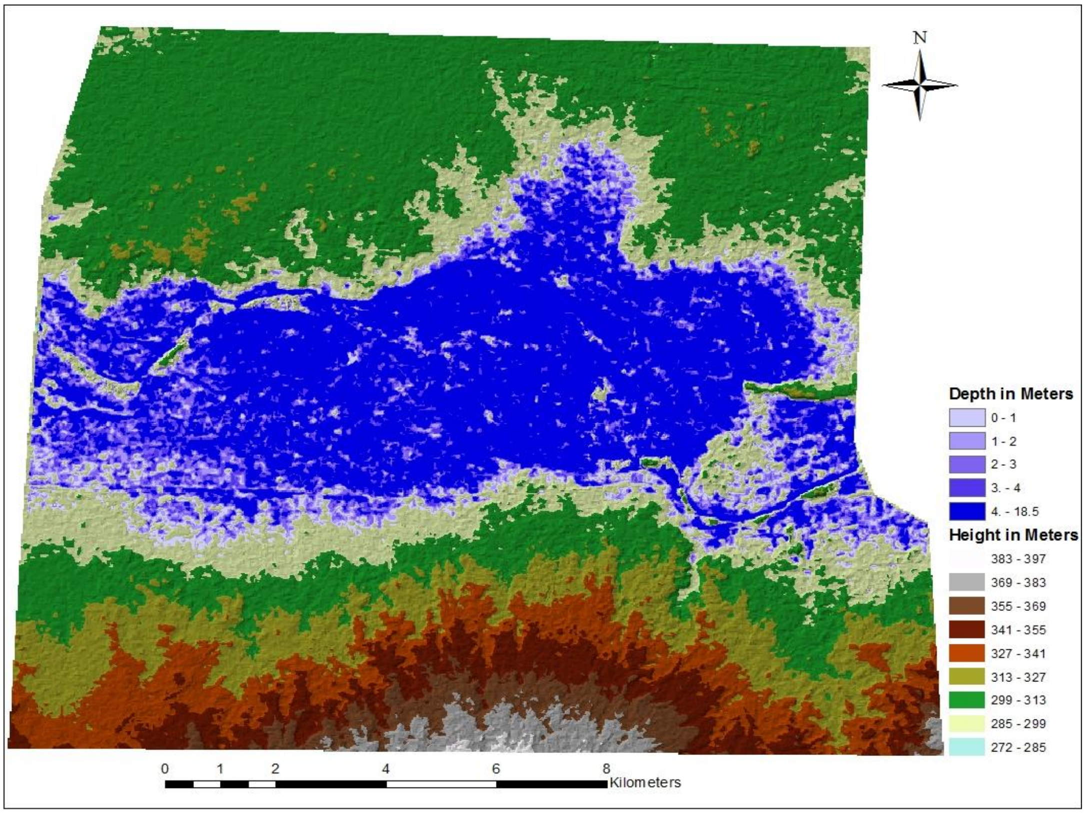


Figure 3.4. Flood depth map 2010.

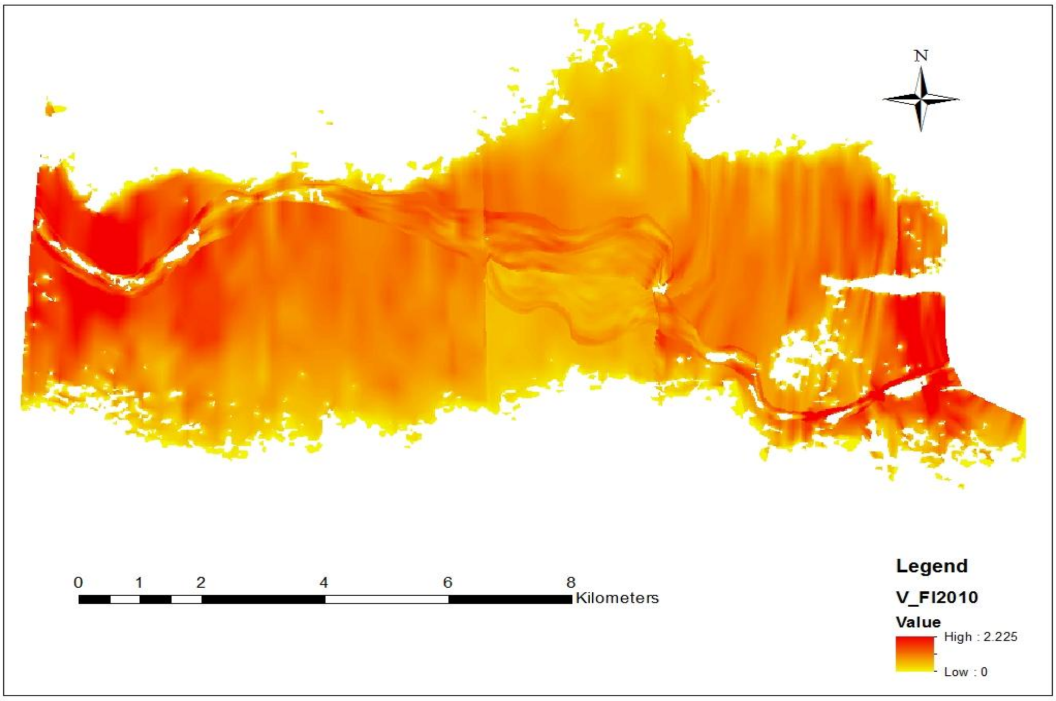


Figure 3.5. Flood velocity map 2010.

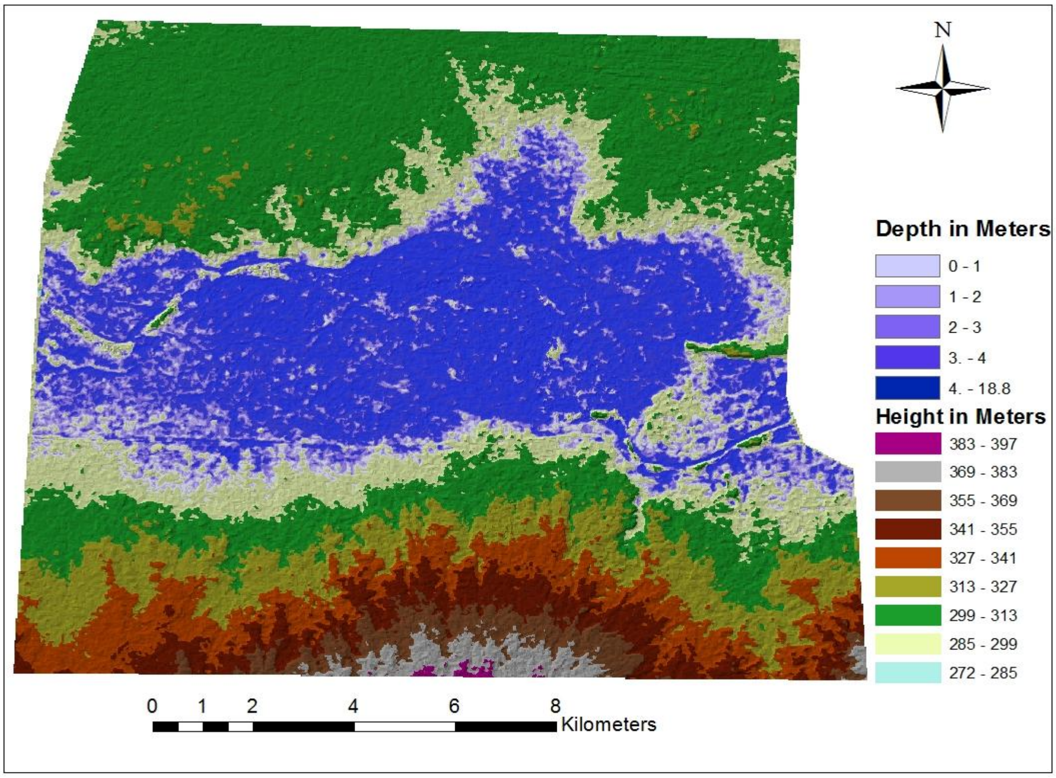


Figure 3.6. Flood Depth for 100 Year return period.

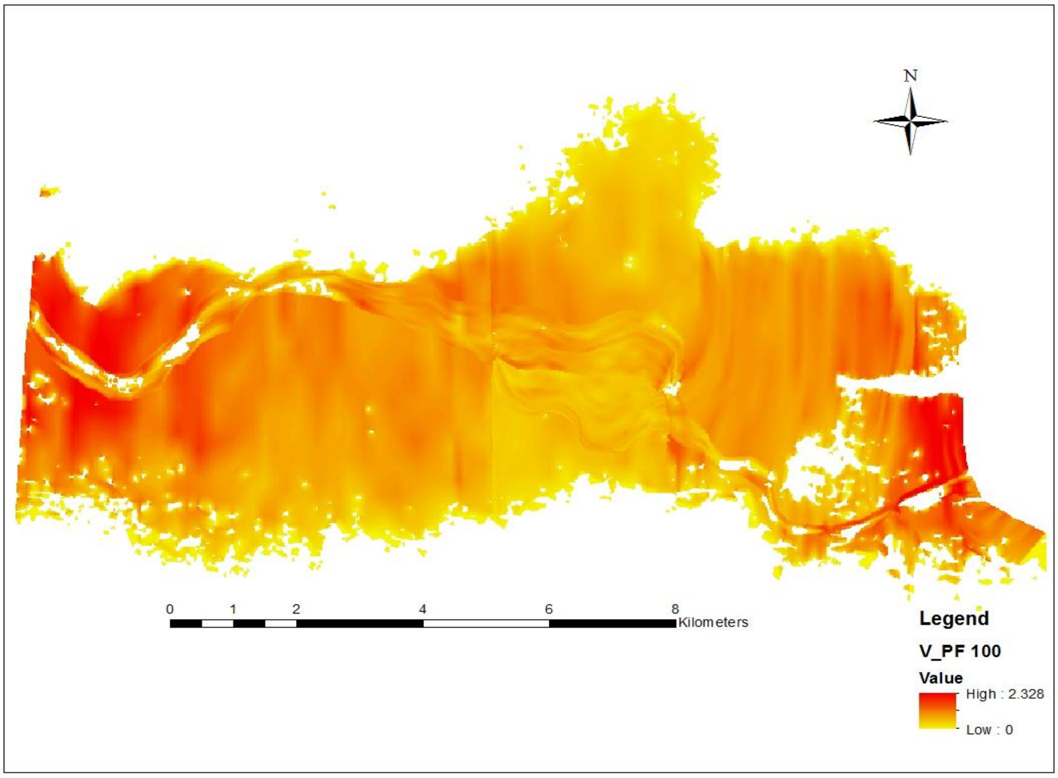


Figure 3.7. Flood velocity for 100 Year return period.

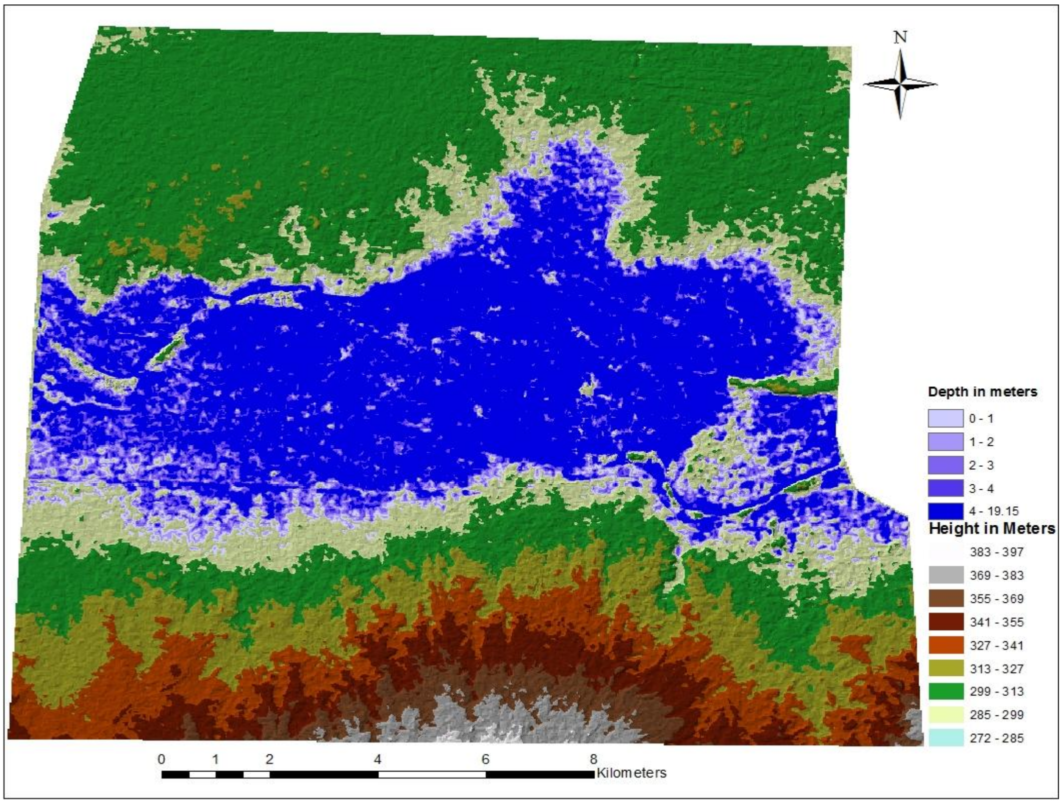


Figure 3.8. Flood depth for 200 year return period.

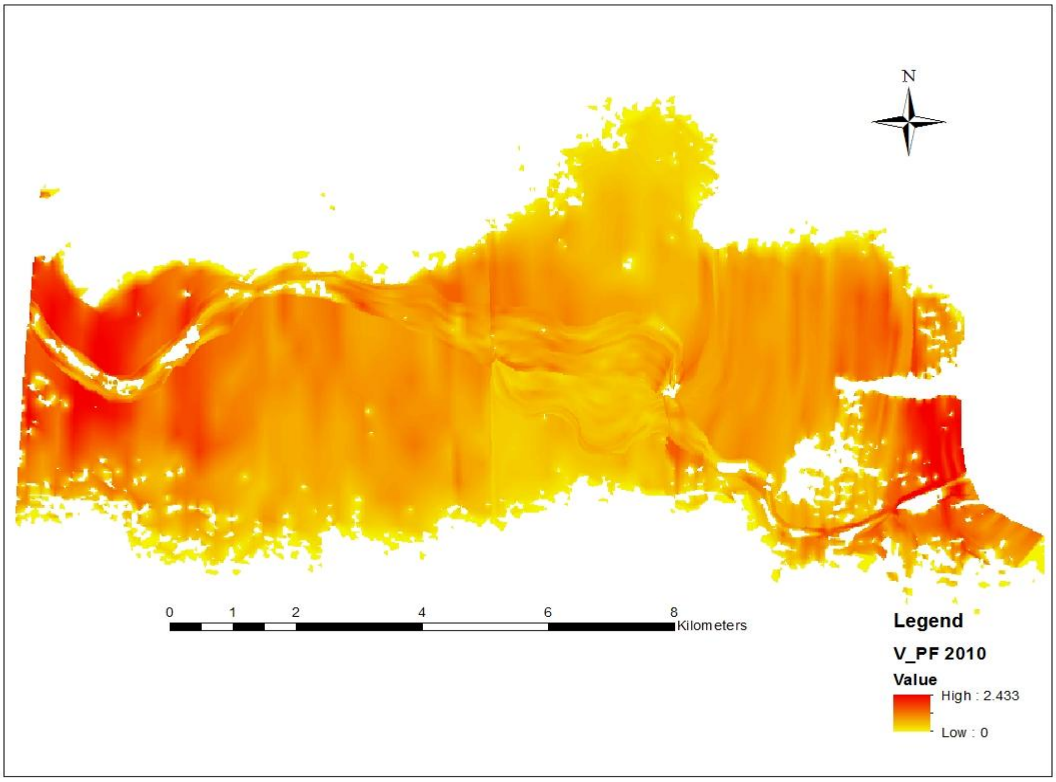


Figure 3.9. Flood velocity for 200 year return period.

(Evans, Gunn et al. 2007). In this study flood hazard was assessed taking into consideration the parameters of flood depth and velocity. Flood hazard was calculated on the basis of given formula;

$FH = D \times V$ ....(Eq4.1)

Where

$FH =$ Total Flood Hazard

$D =$ Flood Depth and

$V =$ Flood Velocity.

Flood hazard (Fig 3.11) was determined using two parameters of flood depth and velocity. Different experiment have been performed by researchers to study the combine impact of flood and velocity on human and vehicles stability, fatalities due to drowning and damage and destructions. Flood hazard (fig 3.3) was categorized on the basis of product of flood depth and velocity keeping in mind the result of above mentioned experiments (Table).

3.5 Vulnerability

Vulnerability may be defined as the degree of fragility of a (natural or socio-economic) community or a (natural socioeconomic) system towards natural hazards. It is a set of conditions and processes resulting from physical, social, economical and environmental factors, which increase the susceptibility of the impact and the consequences of natural hazards. Vulnerable classes were extracted from LULC classification. Due the relative importance built-up area assigned higher weights of 7 . Vegetation which comprised mainly of trees, parks and agriculture fields with crops was assigned a relative weight of 3. Bare soil which

Table 3.2. Risk to life thresholds based on a combination of depth-velocity (Priest et al., 2008)

Dept*Velocity (m^2/sec)	**Hazard**	**Description**
0 - 0 .75	Low	Shallow flood water or deep standing water
0.75 _ 1.5	Moderate	Dangerous to most people Deep or fast flowing water. Fatalities due mainly to exposure to the hazard
1.5 - 2.5	Significant	Dangerous for all Extreme danger from deep, fast flowing water. Fatalities due to hazard exposure.
> 2.5	High	Dangerous for all Extreme danger from deep, fast flowing water and risk of building collapse.

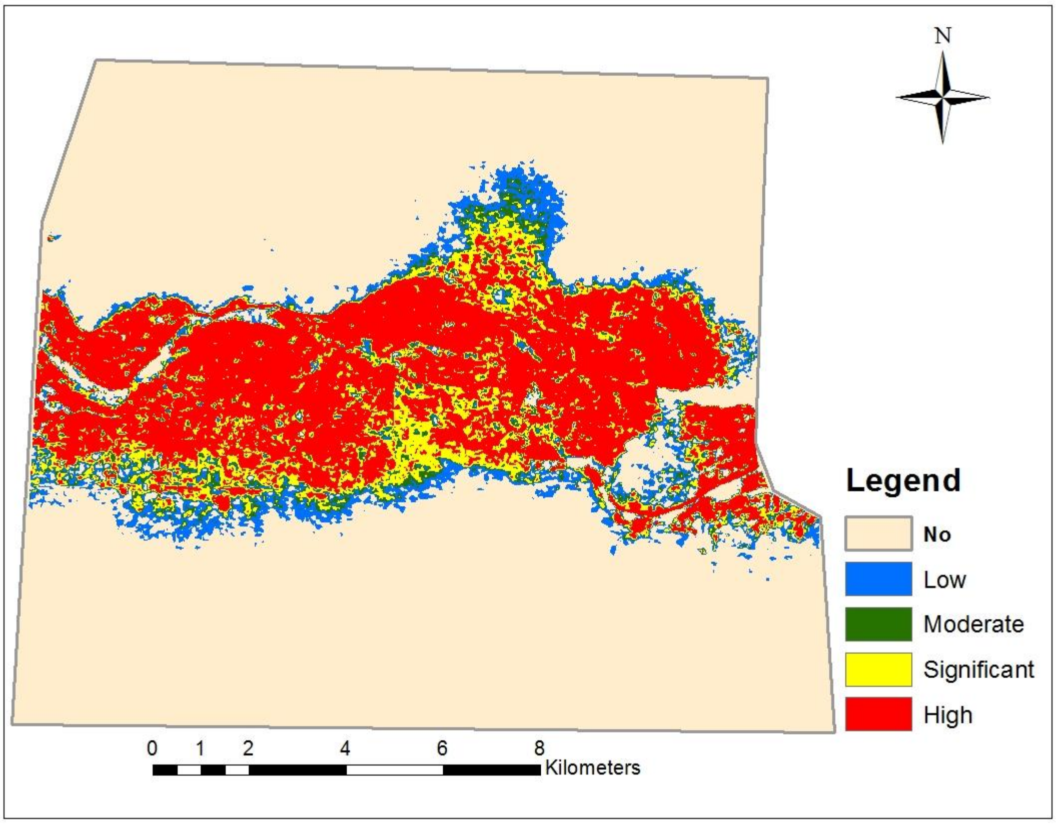


Figure 3.10. Flood hazard map of the study area.

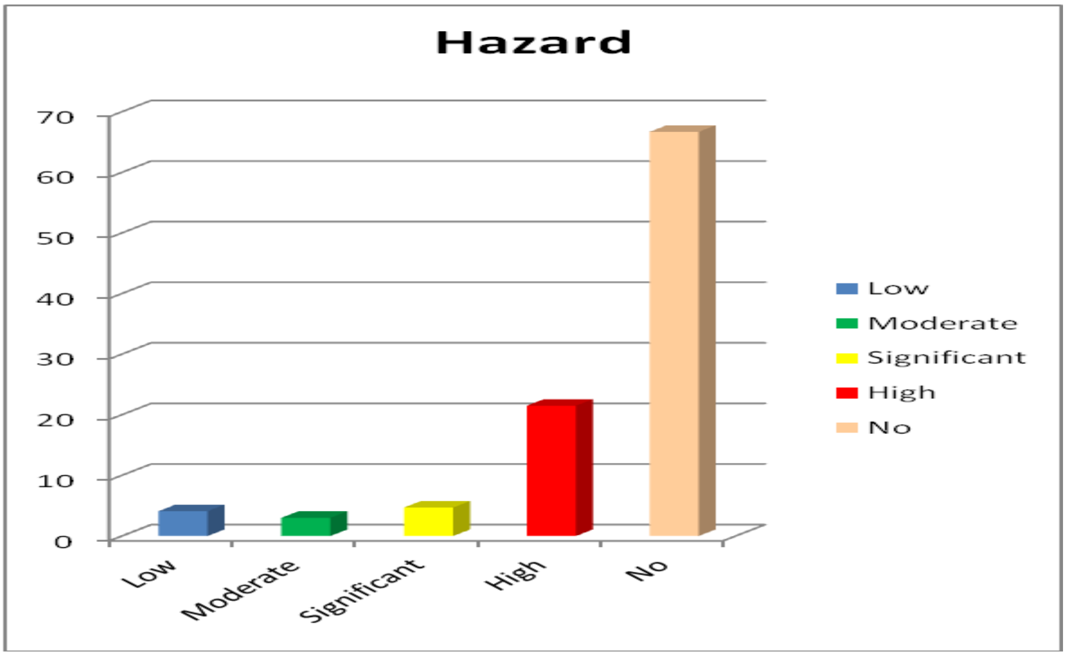


Figure.3.11. Graph showing percentages of land and land cover in different risk zones.

consist of agriculture fields without crops and soil was given a weight of 1. .

3.6 Flood Risk

The risk faced by people must be seen as a crosscutting combination of vulnerability and hazard. Disasters are a result of the interaction of both; there cannot be a disaster if there are hazards but vulnerability is (theoretically) nil, or if there is a vulnerable population but no hazard event (Blaikie, Cannon et al. 2004) These three elements: risk (R), vulnerability (V), and hazard (H), can be written in a simple form:

$$R = H * V \quad \text{...} 1$$

Flood risk maps indicate potential adverse consequences associated with floods under several probabilities, expressed in terms of: the indicative number of inhabitants potentially affected; type of economic activity of the area potentially affected. Flood risk matrix (table 3.11) was prepared by combining flood hazard map and flood vulnerability index. Flood risk map (3.11) categorized into different categories and final flood risk was prepared.

Table.3.3. Flood risk matrix and risk categories.

HAZARD				
	High (4)	4	12	28
	Significant (3)	3	9	21
	Moderate (2)	2	6	14
	Low (1)	1	3	7
VULNERABILITY		Soil (1)	Vegetation (3)	BUP (7)

Risk
Low
Moderate
Significant
High

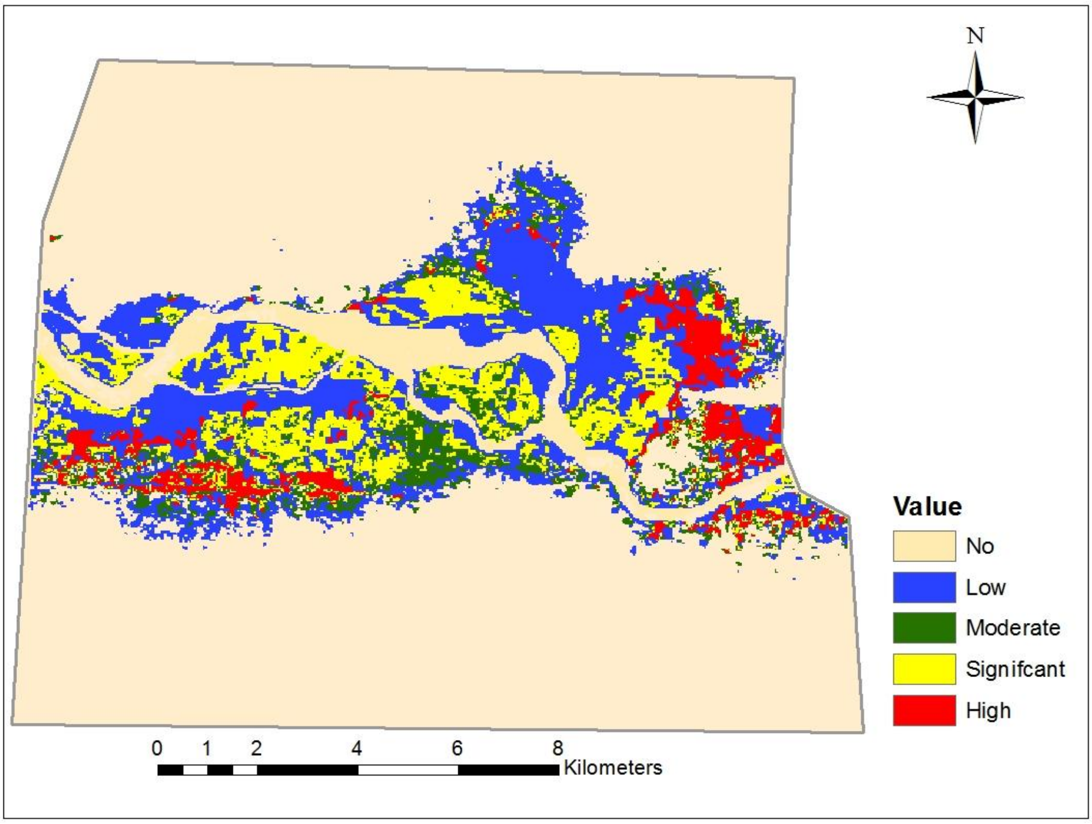


Figure 3.12. Flood Risk map of the study area.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Flooding is a regular phenomena of the Kabul river and poses serious risk to parts of Noshera city and surrounding areas adjacent to the Kabul river. Flood risk is going to increase in future due to high rate of population growth and unplanned urban sprawl. HEC-RAS and HEC-GeoRAS offers good functionalities to model flood inundation. The model can be used to predict water levels at the downstream of rivers on the basis of discharge recorded at upstream.

The research study presented an approach for automated flood inundation mapping and terrain modeling. The connection between spatial analysis and display of floodplain data using ArcGIS and the hydraulic modeling using HEC-RAS Model was provided in this research.

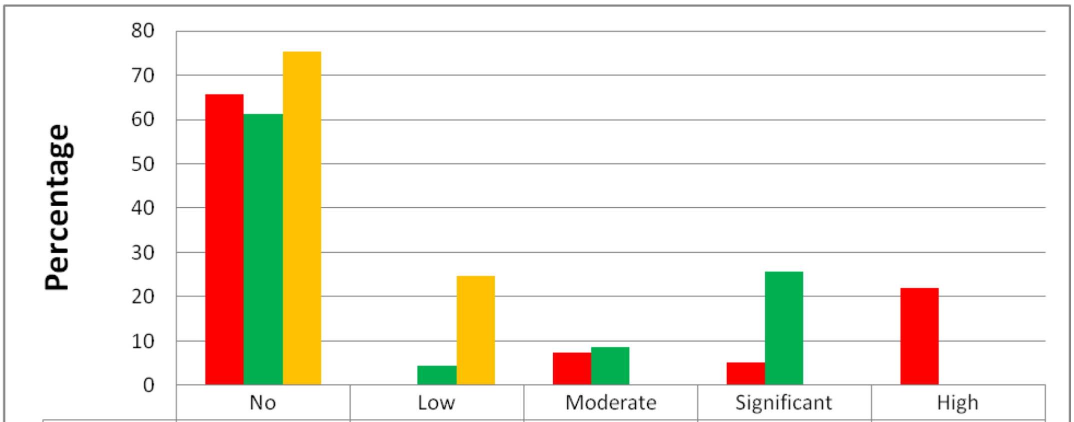
One of the aims of the research study was to calibrate the HEC-RAS using August 2010 flood event data. The flood inundated area calculated before the model calibration was 73 km^2 and after the model calibration it was reduce to 71 km^2 . Calibrated model predicted that extent of 2010 flood was 71 km^2 and average depth during flood was 5 to 6 meter. Parts of Noshera Cantt, Noshera Kalan, village fo Kandar and parts of village Azakhel and Pirpiai were inundated by these floods.

Flood hazard map shows that 20 % of the total study area was in high hazard zones. Significant, moderate and low hazard zones were less than 10 % each. Low hazard zones are located mostly at the outer rims of the flood extent where flood depth as well as velocity was low.

Flood risk map shows that 3.5 % of the total area was in high risk zones which mainly consist of built-up areas. Significant risk zone consist of 8.2% of the total area and moderate risk zone comprised of 3.6 % of the total area. Low risk zones consist of 13.7% of total area. Risk map also identified that parts Noshera cantonment, Noshera Kalan, village of Kandar and pats of Azakhel and Pirpiai villages on Grand Trunk road were under severe risk of heavy floods. Similarly parts of GT road and railway line in Noshera cantonment and Noshera kalan areas as well as near Azakhel and Pirpiai are in high risk zones. Percentages of LULC classes located in different risk zones are shown in graph 4.1

4.2 RECOMMENDATIONS FOR FURTHER RESEARCH

- High resolution topographical data is recommended for future work, the accuracy of the results can be increased by the use of high resolution DEM.
- The use of surveyed river cross section data from topographic survey is recommended for future work.
- Dense network of gauge stations could have improved the result.



	No	Low	Moderate	Significant	High
Builtup	65.6	0	7.3	5.1	22
Vegetation	61.3	4.5	8.5	25.7	0
Soil	75.3	24.7	0	0	0

Figure.4.1.Graph showing percentages of various LULC classes in different Risk zones.

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