Use of Geo-Informatics in Flood Hazard Mapping: A Case of Balkhu River

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Abstract

Flood is one of the striking water induced disaster that hits most of the part of the world. In Nepal also it is one of the serious disasters which affect the human lives and huge amount of property. The study describes the technical approach of probable flood hazard analysis. Segment of Balkhu River within the Balkhu catchment of area 44.37 km2 from Kirtipur gorge to Bagmati confluence was taken as area of study. The total length of the study segment was 5485.89 m. One dimension HEC-RAS (Hydrologic Engineering Center-River Analysis System) model was used for the analysis. The study shows that higher flood depth increases and low flood depth decreases with increase in intensity of flood. Also, huge area of barren land area is affected by flood and few percentage of settlement area is affected by flood indicating the damages to the human lives. Huge area of barren land indicates that in future human lives are more prone to disasters as those lands have gone through planning for future settlement.

Keywords

Geo-informatics, flood hazard, flood frequency, Balkhu River

1. Introduction

Natural hazards have always been viewed as the detrimental consequences of the people's use of their environment (Penning-Rowsell *et. al* 1986). Every year, natural disasters take place in various parts of the world, killing a number of persons and destroying great deal of properties. Causes of natural hazards could be water, air, glacier etc. Among them, water induced disasters have recently been recognized as a world wide problem with loss of lives and properties and prolonged negative effects and untold miseries (Chalise et. al.1995).

Flood is one of the striking water induced disaster that hits most of the part of the world. Tsunami of Indonesia and Katrina of USA are the examples of severe natural disasters that brought floods in large magnitude which killed huge number of people and brought about tremendous amount of economic loss. Intensity and duration of flood greatly depend on pattern of the storm, characteristic of drainage basin as well as other factors too (Hoggan, 1997). Generally, high intensity rainfalls are assumed to be the main flood-generating events (Buttle and Xu 1988). Beside intense rainfall in urban areas, development of infrastructures, buildings pavements etc which increases surface runoff are the major causes of floods. Streets and paved areas are networked by channels of surface drains and underground sewers which decreases time lag to the river channel thus delivering it more rapidly to the river and hence causing urban floods. In addition, the constriction of river channel by bridge supports or riverside structures reduces carrying capacity of the channel. In recent years, among worldwide events, 90% of natural disasters have been related to weather and climate with nearly 70% of the people affected in Asia due to floods (Shrestha, 2006). South Asia ranks first in nearly all statistics related to water-induced disasters, particularly floods (Eriksson, 2006).

Water induced disasters of varying intensity and magnitude affect various parts of Nepal regularly. The principal triggering factor is the monsoonal rainfall which is mostly confined between June and September every year (Chalise, *et. al*. 1995). About 80% of annual rainfall occurs during monsoon season and thus, extreme floods during monsoon season occur due to this concentrated spells of heavy rainfall (Shakya, 1998). The draining of natural wetlands and the spread of towns across the countryside and many other human interventions has reduced infiltration leading to more frequent and higher floods (Shakya, et. al., 2006). In most of the urban cities of Nepal, flooding is due to the combination of extreme rainfall and urbanization. However, issue of urban flooding was highlighted when Katmandu got flooded in 2002 with total human death of 27. Most of the rivers were flooded with huge loss of property. Balkhu River was heavily flooded and flood level reached nearly 2.5 m from base at Oriental Colony and flood overtopped natural bank and extended up to 40 m either sides up to Tribhuvan University main gate (Ranjit, 2006). Three people living near the bank of Balkhu River lost their life among 27 deaths. The major cause of the flooding was the constriction of river channel for the human settlement.

Thus flood forecasting is very important for minimizing flood damage and loss of life and hence should be an integral part of flood control system (Singh and Singh, 1988). Among various non structural measures need for disaster mitigation, hazard mapping is one of the important nonstructural measures (Mahato, et. al., 1996). Land flood hazard areas can be delineated based on hydrologic studies for selected flood peak magnitudes and topographic information (Joshi, 1987). Flood hazard mapping is a process in which the aerial coverage of flood water is depicted in maps showing areas under different depth for particular flood event caused by direct flooding and / or impounding of water of rivers and tributaries of a particular return period (Sharma, 2004). However, flood hazard mapping and risk assessment in Nepal is still very rudimentary where most of the flood protection works are carried out at local level without proper planning and without considering the problem at the river basin scale (Awal, 2007).

2. Objectives

Major Objective of the study is to estimate flood disaster in a GIS environment. The specific objective of this study includes:

- Preparation of land use map
- Flood frequency analysis for different return periods
- Flood hazard mapping

3. Methods and Materials

GIS can be equated to both a computer database and a computer system for producing maps. There has been a significant increase in the use of Geographic Information System (GIS) globally in recent year. The technique provides operational tools for making policy, for planning for management and for making decision (Karim, 1995). The overall methodology used for the study is presented in figure 1.

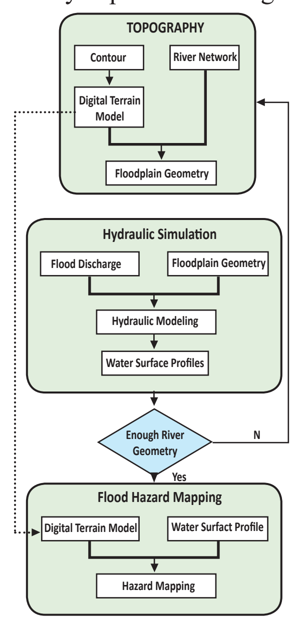

Figure 1: Flow diagram.

Erdas Imagine 9.0, Arc View 3.2a, HEC-RAS and HEC-GeoRAS as interface between ArcView and HEC-RAS were selected for the study and required available data were collected from different sources.

3.1 Data Requirement

The basic data input required for ArcView with GeoRAS extension are:

- River network data (left bank, right bank and main channel)
- Flow paths
- Digital Terrain Model (DTM) in the form of Triangulated Irregular Network (TIN)
- Cross section data normal to the river flow
- Land use map of the study area

Whereas, the HEC-RAS requires,

- River network data

- River geometry data
- Manning's roughness *(n)* value (Table 1)
- Flood discharge of different return period
- Levee geometric data

Table 1: Manning's roughness coefficient for different land use classes. *(USACE, 2002)*

S.No.	Land use type	Manning's Coefficient
1	Cultivation	0.035
2	Built-up area	0.017
3	Vegetation	0.100
4	Barren land	0.030

3.2 Data Preparation & Analysis

Contours with 1 meter interval were prepared by photogrammetry. On the basis of this and the contour developed by Kathmandu Urban Development Project (KUDP) with 2 meter interval, TIN was generated. The river network data was digitized from the map compiled from photogrammetry. The cross sections were taken at 25 m interval. The river segment where there is meandering, the cross sections are further added according to the requirement. The length of cross section ranged from maximum 441.65 m to 54.41 m. Total 195 cross sections were taken for the analysis (Figure 2).

Figure 2: Cross section along the study segment of the river.

Land use map of the study area was prepared by using Erdas Imagine V 9.0. IKONOS image of 2006 AD was used for the preparation which was collected from National Land Use Project, Ministry of Land Reform and Management.

Flood frequency analysis was done on the base of equation developed by Water & Energy Commission Secretariat (WECS) and Department of Hydrology & Meteorology (DHM) for 2-year and 100-year floods.

$$Q_2 = 2.29(A_{<3K})^{0.86}$$
$$Q_{100} = 20.7(A_{<3K})^{0.72}$$

Where Q is the flood discharge in m^3/sec and A is basin area in km^2. Subscript 2 and 100 indicate 2-year and 100 year flood respectively. Similarly, subscript 3k indicates area below 3000m altitude.

Further, following relationship was used to estimate floods at other return periods.

$Qf = \exp(\ln Q_2 + s\sigma_1)$ (WECS and DHM, 1990)

Where $\sigma_1 = Ln \frac{Q_{100}}{Q_2 \times 2.326}$ and *s* is the standard normal variants whose values are given in table 2.

Table 2: Value of standard normal variant for various return period.

S.No.	Return period (T) in years	Standard normal variate (s)
1	2	0
2	5	0.842
3	10	1.282
4	20	1.645
5	50	2.054
6	100	2.326
7	200	2.576
8	500	2.878

Source: Sharma and Adhikari 2004

Table 3: Discharge values for different return periods.

S.No.	Return Period	Flood Discharge (m^3s^{-1})
1	10 year	147.9
2	20 year	192.03
3	50 year	257.72
4	100 year	313.42

After preparing all required data, the import file was created which is imported in HEC-RAS. This is the major part of the model where simulation is done. All the required modification, editing was done at this stage. The flood discharge for different return periods were entered in steady flow data. Reach boundary conditions were also entered in this window. Then, water surface profiles were calculated in steady flow analysis window. After finished simulation, RAS GIS export file was created.

The flow data were entered in the steady flow data editor for four return periods as 10-year, 20-year, 50-

year and 100-year. Similarly, upper most cross section RS (River Station) 5484.67 was taken as upper stream boundary. Boundary condition was defined as critical depth for both upstream and downstream.

Table 4: Critical depth value for different return period.

S. No.	Return Period	Critical Depth (m)	
		Upstream	Downstream
1	10-year	1312.945	1274.223
2	20-year	1313.399	1274.419
3	50-year	1314.009	1274.683
4	100-year	1314.445	1274.884

Sub critical analysis was done in steady flow analysis. Then after, water surface profiles were computed. The resulted was exported creating the RAS GIS export file and required flood depth and hazard maps were prepared simultaneously.

4. Results

4.1 Flood vulnerability analysis

The assessment of the flood area shows that a large percentage (more than 80 %) of vulnerable area lies on the barren land (Figure 3). Another effected area includes settlement area which shows the considerable impact of flooding on the human beings.

Table 5: Land use vulnerability for different return periods.

Land use class	Total Vulnerable Area (m^2)			
	10-year flood	20-Year flood	50-Year flood	100-year flood
Cultivation	12973	14064	15352	16183
Vegetation	15707	16676	18121	19185
Built-up area	59157	69979	79444	89517
Barren land	269173	281422	296786	313869
Total	357010	382141	409703	438754

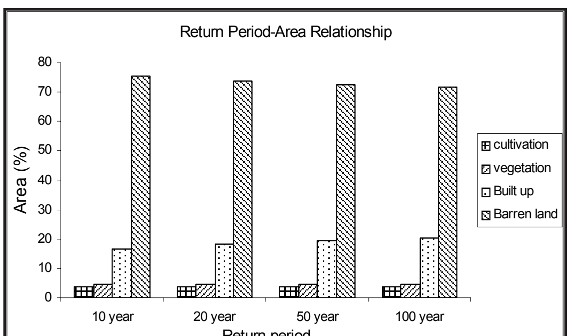

Figure 3: Flood area for different return period.

4.2 Flood hazard analysis

Water depth is the determining factor for the quantification of the flood hazard and potential of damage. In this study, hazard level is determined by reclassifying the flood grid depths at the interval of 0-0.5, 0.5-1, 1-1.5, 1.5-2, 2-2.5, 2.5-3 and >3. The area bounded by the flood polygon with these depth intervals were calculated to make assessment of the flood hazard level.

Table 6: Classification of flood hazard according to depth of water.

Water depth (m)	Total Flood Area (m^2)			
	10 years flood	20 Years flood	50 Years flood	100 years flood
0-0.5	65195	54733	40436	44959
0.5-1.0	118708	107254	84304	61793
1.0-1.5	89524	99249	100448	111826
1.5-2.0	40835	45106	68456	59824
2.0-2.5	30293	41304	41525	52171
2.5-3.0	25294	22599	35823	40419
>3	17446	42235	69092	98098
Total	387296	412480	440083	469089

The classification of flood depth area shows that most of the flooding area has water depth less than 2 meter. The area under flood with water depth greater than 3 m increases considerably with increase in intensity of flood. Flooded area with higher flood depth increases and lower depth decreases with increase in intensity (figure 4).

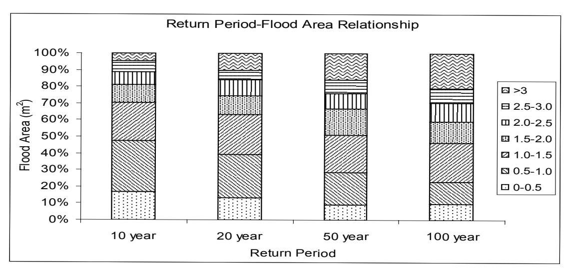

Figure 4: Relationship between return period and flood area.

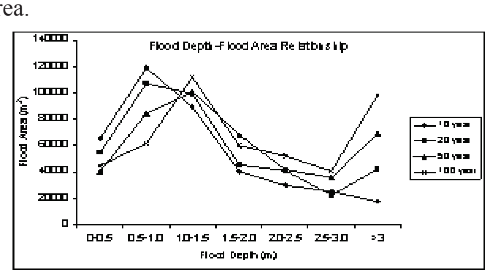

Figure 5: Relationship between flood depth and flood area.

The curves were also plotted between flood discharge, flood depths and flood area to examine the relationship between those parameters. Figure 5 and 6 shows typical plot between these parameters at the lowest cross section (RS 1.608). The plots show the gradual reduction of the slope of the relationship curve with increase in discharge.

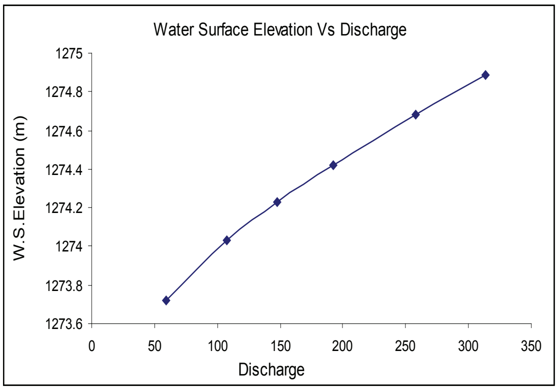

Figure 6: Flood stage versus discharge (at RS 1.608).

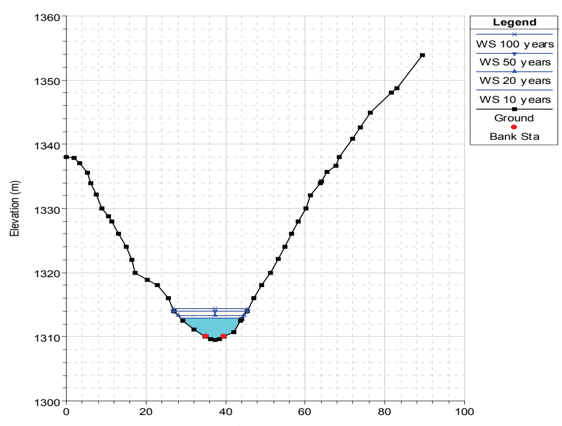

Figure 7: Cross section of upper stream (RS 5484.67) showing water surface for different return periods.

5. Conclusion and discussions

River floods related problems in the areas at the bank of the rivers are increasing with the settlement at the flood plain areas. Many squatter settlements by landless people developed at the flood plains of different river are causing serious problems. Construction of high walls, dams, embankment etc. have been made to overcome the flood damage, but is not able to control the flood due to the squeezing of the river channel. From the result obtained from the model application, it is seen that there is considerable flooding in the study area even at flood discharge of 2-year return period. This shows that channel capacity is not enough to carry the flood discharge. Even in 2-year return period, the flood depth exceeded 3 meter. Thus the flood vulnerability map shows risk to the settlement area in the floodplains implying the need of further flood protection. The flood vulnerability was assessed with regard to land use pattern of the study area. It shows that huge percentage of vulnerable area lies under cultivation land in different flood frequencies. Part of settlement area is also affected by different flood frequencies showing considerable impact of flooding on the human beings of the area.

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