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Study on flood inundation mapping for Ratuwa River catchment using HECRAS 2D

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Abstract

Flooding has always been a major cause of loss of life and property in Terai plains of Nepal. Rivers originating from Chure range are fragile and susceptible to flash floods. Delineating flood plains and demarcating hazardous zones is essential in flood management. 2D capability of HRECRAS allows flood inundation mapping which has been used for mapping flood events in Ratuwa Khola in Eastern Nepal in this paper. 30 m DEM has been used to create terrain data. 2D flow area has been created around Ratuwa Khola and Mauwa Khola which is a major tributary of Ratuwa Khola. Snyder's Synthetic Unit Hydrograph has been used for generating flood hydrograph of various return period using Gumbel's distribution. Water surface elevation and velocity distribution obtained after 2D hydraulic simulation were used to determine the extent of flooding which was visually interpreted using RAS Mapper. Effect of flooding on various land use in the catchment was calculated and presented in map view. 3671.94 ha of extent has been inundated by 2yrs flood, 5020.32 ha for 25 yrs flood and 5589.93 ha of land was inundated by 50 yrs flood. The simulated result has been well validated with the findings of report prepared by Rastrapati Chure Conservation Program, in which flooding extent was quantified by observing satellite images from 1990 AD to 2015 AD for the period of 25 years. The results from this study can be used for flood management as well as for making land use and infrastructure development decisions.

Keywords

HECRAS 2D, Unsteady flow analysis, RAS Mapper

1. Introduction

Water is major natural resource in Nepal. Water resource play an important role in natural ecosystem and bio diversity of an area. Water and risk is a cross-cutting theme that encompasses many institutions as well as communities. Water, which is the most cherished boon of nature, can also be the cause of disastrous calamities. Nepal has been blessed with dense network of rivers originating from mighty Himalayas, Mahabharat range and Chure hill range as well. The average river density of 0.3 km per sq. km of more than 6,000 river systems in Nepal indicates the richness of water resource system in Nepal. The average annual runoff from all the rivers is over 220 billion m^3. Flood and erosion are the most common water induces hazards in Nepal. Increase in global temperature since 1950 has been observed throughout the world. The main cause of global warming is the anthropogenic greenhouse gases [1]. Increase in surface temperature enhances the evaporation and ultimately rainfall [2] .The burning issue of global warming is adding up the hazards like flood and erosion.

In situ flood observation is the best approach to analyze the flood risk [3]. Various hydraulic models are used to simulate the flooding events to support the decision-making process regarding the prediction and prevention of floods [4]. Traditionally 1-D hydraulic models have been used in analyzing flooding events. Many 1D hydraulic models are being replaced by 2D hydraulic models [5] since the performance of the 1-D model isn't satisfactory in plain topography. HEC-RAS (Hydrological Engineering Centre – River Analysis System) software has been widely used in 1-D analysis of flood. RAS Mapper is latest tool inclusion on HEC-RAS 5.0.1, which makes HECRAS capable of generating geometric data from underlying terrain and perform 2-D hydraulic simulation of flooding events. Application of such model in flood risk analysis has been a well proven technology all around the world.

Flooding which occurs all around the world in annual basis causes lots of harms to human life, property, livestock and crops. Deposition of sediments in the agriculture land, changes in soil fertility, changes in river morphology are some of the prominent environmental consequences brought about by flooding of an area. As per the Nepal Disaster Report 2017, there were 244 cases of flooding event in Nepal during the year 2015/16 which resulted in 101 deaths. Total economic and financial loss due to flooding was noted to be NRs. 47 million during 2015/16. Ascertaining the flood risk zone is essential in planning flood management programs. Flood insurance is an emerging concept in Nepal. It requires proper demarcation of flooding plains and flood risk zoning.

This paper demonstrate 2-D flood mapping capability of HECRAS. The same has been applied for analyzing flood in Ratuwa River which flows through eastern border of Damak city in Eastern Terai region of Nepal. The primary objective of the study is to develop flood plain mapping and estimate the effect of flooding on land use pattern of the study area.

2. Study Area

Ratuwa River is a river flowing through eastern border of Damak city in Jhapa district of Nepal. At lower reach of Ratuwa River it flows along the border of Jhapa and Morang. It originates from chure range and meets Kankai River down south in Bihar India before merging to Ganga River. Ratuwa, Biring and Kankai Rivers are the major rivers causing inundation problem in Jhapa district. Ratuwa has always been a matter of discussion in terms of flooding in Eastern Nepal. The catchment of Ratuwa Khola covers three districts mainly Jhapa, Morang and Illam. Mauwa Khola is the major tributary of Ratuwa Khola. Total catchment area of Ratuwa Khola is 400.66 km^2 at Indo-Nepal border. 99.26 km^2 of the catchment lies in Chure hill range, 53.28 km^2 of the catchment lies in Bhawar range, 217.29 km^2 of the catchment lies in Terai range whereas small portion of the catchment 30.83 km^2 lies in Mahabharat range. Hence, we can conclude that significant portion of the catchment lies in Chure-Bhawar range. Geo morphological feature of Chure range has significant influence on behavior of Ratuwa Khola. 15 *km* reach of Mauwa Khola has been considered in the modelling whereas 51 *km* reach of Ratuwa Khola has been considered in the modelling. Out of which 20.38 *km* of reach length lies downstream of confluence between Mauwa Khola and Ratuwa Khola. Damak city lies on the left bank of Ratuwa Khola, it has been identified as flood risk zone frequent flooding events occurring in this area impacting a dense urban population around it. Thus, timely information to those residing near the bank of Ratuwa Khola is vital in safe guarding life and properties.

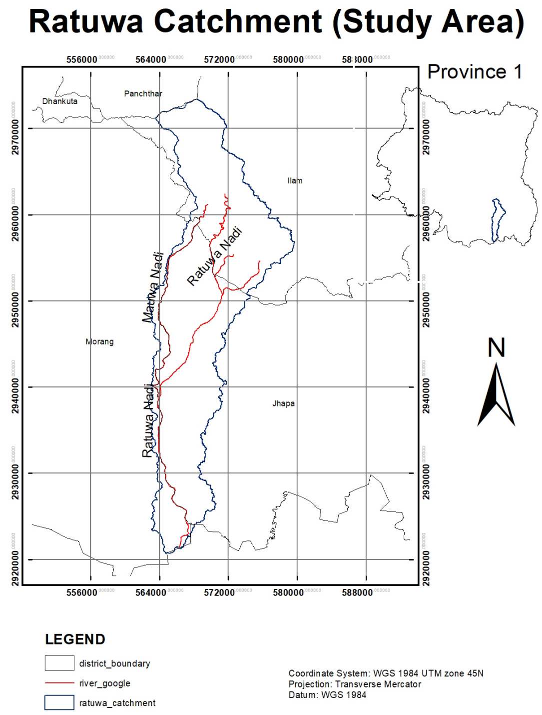

Figure 1: Study area (Catchment map of Ratuwa River)

30 m spatial resolution, SRTM(Shuttle Radar Topographic Mission) Digital Elevation Model (DEM) was used for the study area which was obtained USGS website.https://earthexplorer.usgs.gov/. In the catchment elevation ranges from 68.28 m to 2076.74 m. 272.87 m is the mean catchment elevation. Average basin slope is 1:0.67. For the simulation of HEC-RAS hydraulic model, rainfall data was obtained from Department of Hydrology and Meteorology (DHM). Raingauge station no 1408 Damak lies in the study area, which is the only influencing rain gauge station for the study area as obtained from Thiessen polygon. Land use map developed by Rastrapati Chure Conversation Program

was used as input data for land use in the study area.

Land use pattern in Ratuwa Khola catchment
Various land use can be identified in the catchment of Ratuwa catchment. Since, Ratuwa Khola is situated in Eastern Region which is also known as greenery of Nepal, cultivable land incorporates major land use in this catchment followed by forest. 11.34 km^2 of area is covered by human settlement. 99.84 km^2 of area is covered by forest which mostly lies in Chure Bhavar range above Mahendra Highway. 217.01 km^2 of area has been cultivated. Paddy is the major food crop of the region. Few water bodies are also situated in the catchment mainly in the form of fishery ponds. Most of the human settlement is concentrated around Mahendra Highway. Damak is major city situated in this catchment which gets affected during flooding events. Damak lies along the western bank of Ratuwa Khola.

Land use pattern in Ratuwa catchment has been summarised below:

Table 1: Land use pattern in Ratuwa catchment

Land Use	**Area(km^2)**
Barren land	2.04
Bushes/Grass	37.55
Cultivated land	217.01
Forest	79.84
Riverbed	20.78
Settlement	11.34
Waterbodies	1.22
Mahabharat range	30.83

3. Methodology

HECRAS has the ability to perform two-dimensional unsteady flow routing by solving either Full Saint Venant equation or the Diffusion wave equation. Diffusion wave equation is set as default in the model, whereas the need for full Saint Venant equation for the problem to be modeled needs to be verified. Diffusion wave equation permits use of coarser mesh size and larger computation time step hereby saving considerable computational resource. Since, the problem of Flood inundation mapping involves unsteady Gradually varied flow, coarser mesh size seems satisfactory as the water surface slope doesn't change rapidly. The following Diffusive wave equation in 2D considering finite volume approximation is solved by HECRAS to compute water depth and surface profile at all the computational mesh.

$$\frac{\partial Q}{\partial t} + \frac{\partial A}{\partial t} = 0 \quad (1)$$

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial t}(\frac{Q^2}{A}) + g\frac{\partial y}{\partial x} - g(S_o - S_f) = 0 \quad (2)$$

Computational cell in HECRAS can have three to eight faces. Each cell is is a detailed elevation volume/area relationship that represents the details of underlying terrain. The cell faces are detailed cross sections, which get processed into detailed elevation versus area, wetted perimeter, and roughness. This feature allows the user to use larger cell size and still obtain accurate results. Meanwhile, model was run with coarser mesh of 100m∗100m, and subsequently the size was reduced for each run. Convergence of result was observed beyond mesh size of 50m∗50m. The same has been used in the model.

The computational time step was chosen considering the numerical stability of the solution. Numerical stability is checked based on Courant Number (C). For Diffusion wave equation Courant Number (C) as high as 5.0 still gets stable and accurate results. Since, flood inundation mapping involves Gradually Varied Flow(GVF) larger time step is permitted. Hence, considering the above mentioned criterion computation time step was chosen to be 1 min (60 sec).

$$Cr = v\frac{\nabla t}{\nabla x} \quad (3)$$

Model Configuration

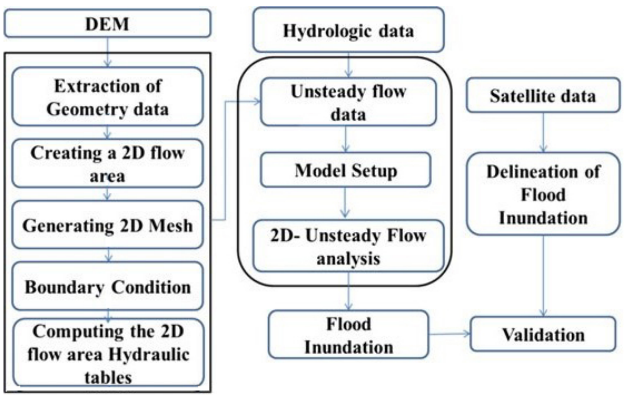

Figure 2: Flowchart of methodology

DEM obtained from above mentioned source was imported to RAS Mapper to create a terrain. The terrain is used to extract topographical features of the 2D flow area. 2D flow area was drawn by demarcating a polygon around the river course and probable flood plains. Computational cells of size 50m∗50m were created inside the 2D flow area. Hydraulic properties of each computation mesh was calculated. Boundary condition lines were draw at upstream reach and outlet boundary condition was drawn at the outlet. The geometry data was loaded in HECRAS. Unsteady flood hydrograph was assigned to the upstream boundary conditions whereas normal depth was assigned to the outlet boundary condition with slope of 0.002. For unsteady model run, a plan was created, geometry file created above was selected, unsteady flow data was selected, computation time step of 60 sec was selected, floodplain mapping was checked and finally the model was computed. The results were graphically obtained in RAS Mapper.

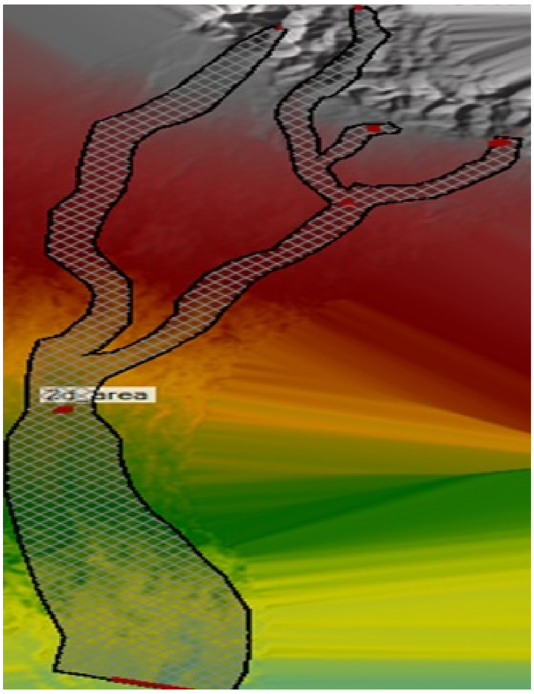

Figure 3: 2-D geometric data created in RAS Mapper

Hydrological Analysis

Estimation of flood discharge is important in flood analysis of an area. Since, no any gauging station is available in Ratuwa Khola, sophisticated hydrological modelling software isn't useful in analyzing flood discharge in the catchment. Validation of estimated hydrograph isn't possible due to lack of gauging station in the river. Due to the shifting nature of river course and breaded nature of river originating from Chure, the crossectional area of the river isn't same during the course of time. Hence the developed rating curve isn't found to be reliable. Unreliability of the rating curve is the major reason behind absence of gauging station in Ratuwa Khola.

The unit hydrograph of Snyder (1938) is based on relationship found between three characteristics of a standard unit hydrograph. They are effective rainfall duration, peak direct runoff rate, basin lag time. From these relationships, five characteristics of a required unit hydrograph for a given effective rainfall duration can be calculated [6]. The characteristics are peak discharge per unit of watershed area, the basin lag, the base time, widths of the unit hydrograph at 50 and 75 percent of the peak discharge.Raingauge station no 1408 Damak lies in the study area which has been taken as rainfall input to the catchment.

Flood hydrograph has been generated for the return period of 2 yr., 25 yr. and 50 yr. Flood discharge hydrograph of base time 72 hrs (3 days) was generated which is also the input to the unsteady flow data. The total catchment was divided into 5 sub basins, flood hydrograph was generated independently for all the sub basins. Characteristics of sub basins like area, longest flow path, centroidal flow path, basin slope, river slope has been presented in the table below:

Table 2: Physical characteristics of subbasins of Ratuwa Catchment

Basin Id	**Area** (km^2)	**Longest flow path** (km)	**River Slope**	**Centroidal flow path** (km)
71	136.88	34.97	0.002	18.17
88	95.19	449.88	0.059	14.11
94	28.84	209.78	0.015	7.06
99	39.37	71.42	0.005	11.6
108	100.35	332.03	0.036	22.14

Table 3: Simulated flood discharge of subbasins of Ratuwa catchment

Basin Id	Peak flood (m^3/s)		
	2yrs	25yrs	50yrs
71	137.61	255.78	298.08
88	114.12	212.12	247.2
94	44.34	82.42	96.01
99	47.4	88.1	102.67
108	96.33	179.05	208.66

4. Results and Discussions

With the various inputs, mainly unsteady flow data, terrain, 2d flow area, boundary conditions 2D unsteady HECRAS model was run with computational time step of 1 min. The simulated extent of flooding in Ratuwa Khola has been compared with the flooding obtained from report prepared by Rastrapati Chure Conservation Program, in which flooding extent in the river has been prepared by analyzing satellite images over the course of 25 years from 1990 to 2015. The simulated result has well agreed with the results from the report.

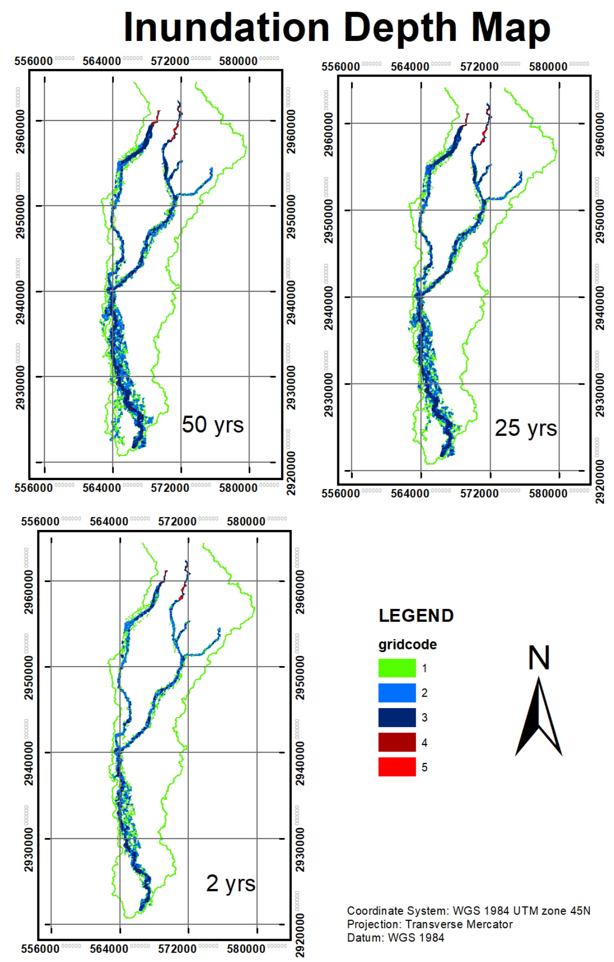

Figure 4: Inundation depth map of various return period

The figure above shows inundation depth map for flood of various return period. The depth has been classified into 5 grid codes. During flooding of 2 yrs return period maximum inundation depth is 17.16 m and mean depth is 0.97 m, for 25 yrs return period maximum inundation depth is 17.54 m and mean depth is 1.12 m whereas for 50 yrs return period maximum depth is 17.65 m and mean depth is 1.14m.

Table 4: Inundation depth legend description

Grid code	Depth range (m)
1	0-0.5
2	0.5-1.5
3	1.5-5.0
4	5.0-10.0
5	>10.0

Effect of flooding on various land use in Ratuwa catchment is presented in the table below. During flooding event of 2 yr return period total of 3671.94 ha of land is flooded out of which 1943.74 ha of land is cultivable land. 5020.30 ha of land is flooded during flooding event of 25 yrs return period whereas 5589.93 ha of land is flooding during flood of 50 yrs return period. The effect of flooding on land use can be visualized in the map below as well.

Table 5: Effect of flooding on various land use pattern

Land use	Inundation area (ha.)		
	2 yrs	25 yrs	50 yrs
Barren land	1.34	1.78	1.77
Bushes/Grass	629.44	799.04	841.98
Cultivated land	1943.74	2833.16	3274.54
Forest	78.31	89.82	92.03
Riverbed	871.33	1087.08	1145.39
Settlement	62.93	110.36	132.01
Waterbodies	84.84	99.08	102.2
Grand Total	**3671.94**	**5020.32**	**5589.93**

There is 36 percent rise in inundation area for 25 yrs return period as compared to 2 yrs return period. Inundation area as per Rastrapati Chure Conservation Program report is 5797.6 ha which is close to the simulated result of 5020.32 ha. Hence, this result shows good validation with the results obtained from satellite imagery database.

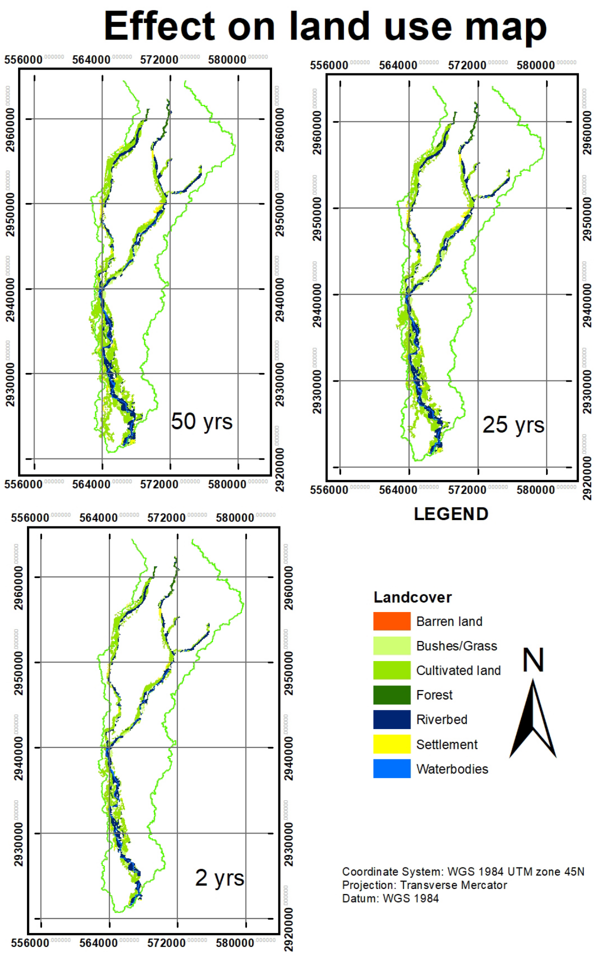

Figure 5: Effect of flooding on various land use in Ratuwa Khola

5. Conclusions

Rivers originating from Chure range are among the least studied rivers in Nepal. Lack of gauging station and other relevant data makes it difficult to carry out studies in the rivers originating from Chure range. Effect of flooding on Ratuwa Khola was studied in this paper. 2-D unsteady flow analysis feature of HECRAS has been exploited to obtain effect of various flood events on land use of Ratuwa catchment. Hence, 2D unsteady flow analysis is found to be suitable to depict the time series result for the given flow condition. 2-D HECRAS modeling has taken over 1-D modeling, and has proven to be an effective tool for flood modeling.

Animation capabilities provided in HEC-RAS gives the clear understanding with visual result. Flood maps are useful is demarcating hazardous zones around river flood plains. It serves as an important tool in decision making during infrastructure development planning. It can be also deployed for early flood warning system, thus saving life and property. Historical flood database can be studied along with numerical model studies in order to develop comprehensive flood management system at local and regional level. Such study should be extended to other rivers originating from Chure for preparing national database.

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