Application of Hydrodynamic (HEC–RAS) Model for Extreme Flood Analysis in Far-West Province: A Case Study of Chamelia River Basin, Darchula District, Nepal

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KEYWORDS

Flood Frequency, Hydrodynamic Model, Flood Hazard, Chamelia River Basin,

ABSTRACT

Nepal is mountainous country originates the several rivers, rivulets and tributaries in different watershed systems mostly from higher level at north to lower level at south part of the country. Some research pointed prediction of the extreme flood level in such low land area can reduce hazard level significantly in the contest of Nepal. The HEC–RAS model is a one of the very successful tools for the rising of water level, flood hazard and inundation forecast purpose. Therefore, in the Chamelia river basin also applied this model for prediction of extreme flood analysis. In this regards Chamelia hydrological station observed extreme flood data (1965–2015) was used for frequency analysis by Gumbel's method. The frequency analysis in different return period 2, 5, 10, 20, 50, 100, 200, 500 and 1000 year results generated design flood of 364 m3/s, 516 m3/s, 617m3/s, 713 m3/s, 838 m3/s , 932 m3/s, 1025 m3/s, 1149 m3/s and 1242 m3/s magnitudes respectively. Flood hazard maps were prepared according to this generated flood magnitude by exporting the Hydrodynamic (HEC–RAS and HEC–GeoRAS) model into the ArcGIS environment the height of water level, flood hazard and Inundation areas in different cross-sectional were identified in the Chamelia river basin.

1. INTRODUCTION

Nepal is a mountainous country; it measures 880 km from east to west and between 130 – 260 km from south to north with total estimated area 1,47,181 km^2. The country shares a common boundary with India on the east south and west. Its Northern boundary is with Tibetan region of China. The country lies between latitudes 26^0 22' and 30^0 27' North and longitude 80^0 04' and 88^0 12' East. The topological features of Nepal are dived into five different regions from 60m in the south to Mt. Everest 8848m in the North with different climates: - Terai Region - 60 to 200m - Tropical Climate, Siwalik Ranges - 300 to 1500m - Mesothermal Climate, Middle Mountains - 1500 to 2500 - Mesothermal Climate, High Mountains - 2000 to 4000m - Microthermal Climate and High Himalaya Region - 4000 to 8848m - Alpine Climate. The country is predominantly a mountainous, mountains and great Himalayas account for 80% of Nepal total land area and only 20% of flat Terai region is suitable for cultivation (Dhimal, et al. 2018).

In Nepal 80 percent of the annual rainfall received between June to September during the monsoon season (Nayava, 1980). Similarly, the highest flood flow found is dominated by summer monsoon and greater groundwater contributions (Kansakar, 2002) in this season. In the monsoon season - floods, landslides and avalanches cause the loss of lives of about 300 people and damage to properties worth about 626 million NPR annually (DWIDP, 2007).

In this context, flood estimation is important to prevent upcoming flood disaster of any area. The physiography of Nepal has developed networking of dendritic drainage system forming numerous watersheds. Different watershed poses different characteristics which has significant impact in flooding of lower lands. Therefore, flood prediction of the area is one of a key model to prevent from flood disaster. Different models are developed for flood estimation in this type of ground. Among the several model, HEC-RAS is one of highly applying method to estimate food and several governmental and nongovernmental organization are using it as a successful tool. In this present study, a case study of use of HEC-RAS to analysis flood hazard is presenting. For the propose, a case of the Chamelia River basin was used.

2. OBJECTIV`E

2.1 Research goals

The main goal of this study is to explore the application of HEC – RAS model for flood hazard analysis in the Chamelia river basin Darchula district, Nepal. Beside the main goal, specific goals of the research include the review different applications of HEC-RAS model in the Nepalese basin; data and methodological framework for the HEC-RAS model; and prepare the flood hazard map for the Chamelia River basin using the HEC-RAS model.

2.2 Research motivation

Developing the policies for land use management planning in different river basin of Nepal for decision making of farmers can plan and choose wisely which crops to be grown in flood prone areas so as to minimize field crop losses associated with flood warning level thereby ensuring food security in the country.

2.3 Paper overview

The subsequent sections of this paper include; (a) Description of datasets (b) Applications of HEC- RAS Model in the Nepalese basin; (c) the methodological section which describes the datasets used, study area, framework for the HEC-RAS model, flood hazard map generation; (d) results and discussion section which contains a presentation of model results, flood hazard maps and discussions; (e) the conclusion and recommendation section.

3. DESCRIPTION OF DATASETS USED

3.1 Hydrologic modeling datasets

The Rainfall and discharge data were collected from Department of Hydrology and meteorology (DHM), Government of Nepal. The Chamelia river hydrological station data from 1965−2015 was used for this study to calculate the average, minimum, maximum discharge and maximum basin rainfall the graphical view of collected data as shown in Figure 1. Similarly, the digital elevation model (DEM) data obtainable from Department of Survey, Government of Nepal, SRTM (http://vterrain.org/Elevation/SRTM/), and ASTER (https://www.youtube.com/watch?v=0H7AdfY1_gg&t=45) respectively.

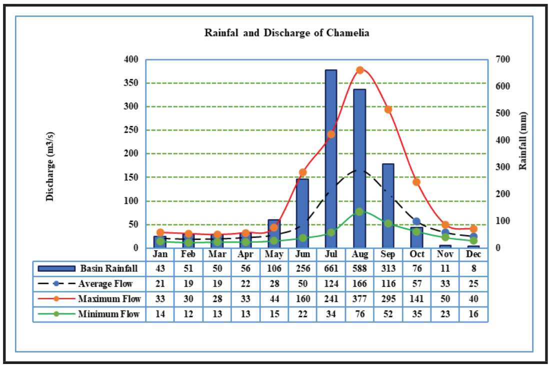

Figure 1: Basin rainfall and discharge of the Chamelia River at Darchula.

3.2 Hydraulic model datasets

Geometrical model datasets required for hydraulic modeling included the following; River name, reach name, river cross section station, downstream reach lengths (LOB, channel, ROB), main channel bank stations. These were all created during data processing using HEC GeoRAS in ArcGIS and then imported to HEC RAS model geometrical editor.

Manning's n values: Manning's value was estimated by "Roughness Characteristics of Natural Channels (1987)" published book by USGS water- supply paper (1849). The physical characteristics of the river Channel, Left Over Bank (LOB) and Right Over Bank (ROB). Contraction and expansion default coefficient parameter values for steady flow regime were automatically assigned by HEC RAS program and Steady flow datasets.

4. APPLICATIONS OF HEC- RAS MODEL IN THE NEPALESE BASIN

During the 2009 monsoon, seven villages were flooded by the swollen Kankai and Biring Rivers in southern Jhapa. More than 500 houses were submerged and thousands of hectares of paddy field were inundated. The Karnali River bifurcates into two branches downstream of Karnali Bridge, creating an island in the Rajapur area of Bardiya district. Floods from the Karnali River in the past have created havoc in the Rajapur area leading to loss of lives and property and causing widespread human suffering. Heavy rainfall in the lower West Rapti basin on 25-27 August, 2006 created havoc due to flooding. Similarly, Banke became the second most flood affected district in the country in 2007 due to flooding in the West Rapti River. At that time, the flood inundated the area for 3-4 days (ICHARM 2008). Gautam and Dulal, 2013, was using the hydrodynamic (HEC-RAS) model which was performed multiple profile and inundation analysis for danger levels and threshold runoffs foresting in different basins; Karnali (42890 sq. km), West Rapti (5200 sq.km), Narayani (31100 sq.km), East Rapti (579 sq.km), Koshi (54100 sq. km) and Kankai (1148 sq.km). Some other river basins of Nepal also applied the hydrodynamic (HEC-RAS) model by additional researcher which is summarized (Table 1).

Table 1: Summary of additional researcher using hydrodynamic (HEC-RAS) model in Nepal.

Reference (Author Publication Year)	Basin Area Sq. km	Paper or Report	Research title (Journal or Report Name)
Talcha bhadel, et. al., 2020	6368.00	Preceding	Numerical Simulation of Runoff Generation and Inundation Process of an Extreme Precipitation Event in Nepal. Proceedings of the 22nd IAHR-APD Congress 2020, Sapporo, Japan
Aryal, et. al., 2020	45269.00	Paper	A Model- Based Flood Hazard Mapping on the Southern Slope of Himalaya. (Water)
Pradhan and Adhikari 2019	99.00	Paper	Flood Hazard Mapping and Vulnerability Analysis of Bishnumati River, Kathmandu. (Environment Science)
Aryal, et. al., 2016	30.74	Paper	Flood Hazard Assessment in Dhobi-Khola Watershed (Kathmandu, Nepal) using hydrological model. (International Research Journal of Environment Sciences)
Adhikari et. al., 2014	2,918.22	Report	Determination of Flood Warning and Danger of Mohana and Macheli River (Mercy Corps Nepal, Inundation Figure 2)

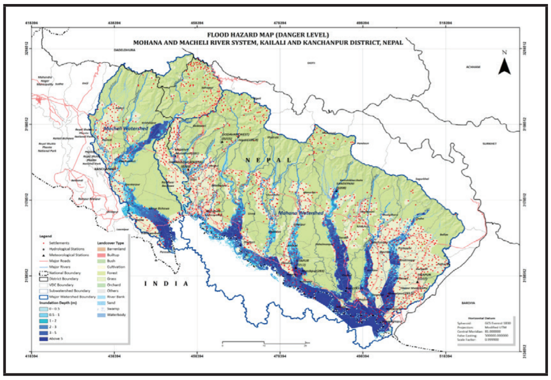

Figure 2: Inundation Map of Extreme flood of Mohana and Macheli River Basin

(Source: Mercy Corps Nepal, 2014)

5. METHODOLOGY

5.1 Terrain processing steps

Terrain processing involved the following steps; 1. Fill Sinks, 2. Flow Direction, 3. Flow Accumulation, 4. Stream Definition, 5. Stream Segmentation, 6. Catchment Grid Delineation, 7. Catchment Polygon Processing, 8. Drainage Line Processing, 9. Adjoint Catchment Processing performed in sequential order.

5.2 Description of the study area

The Chamelia river basin is located in the territory of Apihimal Darchula district in Far-West Province of Nepal. The elevation of the basin is ranged from lowest elevation 521.76 m to highest elevation 7083.6 m. The length of main stream extended from the origin (Apihimal) to Karnali river confluence about 80 km, whereas the average slope of the basin is 0.077 of the Chamelia river basin. The total basin area 1,586 Sq. km of Chamelia river basin up to Karnali river confluence shown in Figure 3.

5.3 Framework for the HEC-RAS model

Generally, to run the HEC-RAS hydro-dynamical model required the hydrological data (extreme of historical flood records), Digital Elevation Model (DEM) and processed geometrical (river center line, bank line, flow path and cross sectional) data by HEC-GeoRAS model (HEC 2002) for the inundation analysis. The geometric data found by using the GIS environment by processing the HEC-GeoRAS model, GIS data development (Figure 4). Then these data were imported to the hydrodynamic HEC-RAS (HEC 2019) model.

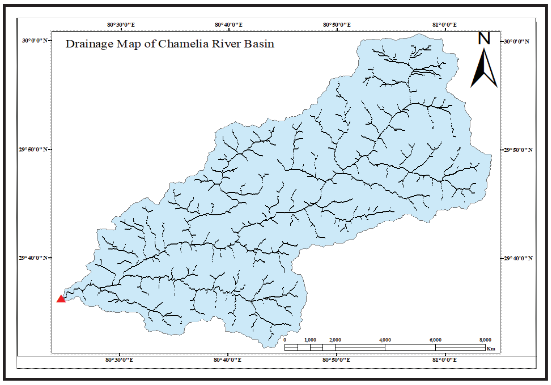

Figure 3: Study area Chamelia River basin, Darchula District

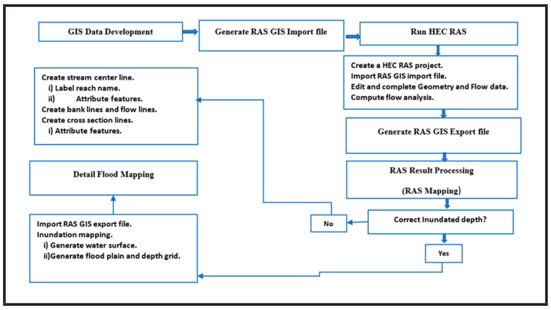

Figure 4: The methodological framework for HEC-RAS model.

5.4 Hydraulic modeling

The Hydrodynamic modelling for extreme flood of High, Medium and Low risk is level performed in HECRAS Software. For the hydraulic computation, the geometric data of river must be imported and flow data must be entered. The required geospatial data is processed from HEC Geo-RAS, a GIS extension tool and exported to HECRAS format.

The Hydraulic data including extreme flood data and associated boundary condition are given into flow plan of HECRAS. The steady state flow simulation is then performed for water surface profile calculation for various magnitudes of discharge.

Once the hydraulic computation is done, the water surface and velocity results again are imported to HEC Geo-RAS for spatial analysis. The automated delineation of water surface of flood Inundation mapping is done with the RAS output files in HEC Geo-RAS Environment.

In this component of HEC - RAS modelling is developed for the calculation of water surface profiles for steady gradually varied flow. In Steady state modelling, the model calculates water levels at discrete cross-sections as according to the flows prescribed by the user. The one-dimensional energy equation is used to compute the unknown variable (stage). Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head).

The energy equation is based on principle of conservation of the energy and it states that the sum of the potential and kinetic energy at particular cross section is equal to the sum of the potential and kinetic energy at any other cross section plus or minus energy loss or gains between the sections. Then the water surface profiles are computed from one cross-section to another by solving the equation with an iterative procedure.

5.5 Pre-processing to develop the RAS GIS import file

For the hydraulic computation, the geometric data of river must be imported and flow data must be entered. The required geospatial data can be processed from HEC Geo-RAS, a GIS extension tool. The spatial GIS import file created in Geo-RAS are river, reach, and stations identifiers, cross-sectional cut lines, cross-sectional surface lines, cross sectional bank stations, downstream reach lengths, main channel, cross sectional roughness coefficient etc. These datasets are produced and processed from the existing digital elevation model (DEM).

5.6 Post-processing to generate GIS data from HEC-RAS results

Once the hydraulic computation is done, the water surface and velocity results again may be imported to HEC-Geo-RAS for spatial analysis. The automated delineation of flood plain can be done with the RAS output files. Based on the HEC-RAS output files the cross-section theme and bounding polygons can be generated and the water surface.

5.7 Running HEC-RAS Model in Chamelia River:

To access the extreme flood water level, hydrodynamic modelling was performed in Chamelia river using HEC-RAS and HEC Geo-RAS model to generate the scenarios of flood inundation at 2, 5, 10, 20, 50, 100, 200 500 and 1000 years return period with the subcritical flow regime. Simulation runs in the above different return periods were performed successful simulation of cross section and river profile channel distance of results can be seen in Figure 5 and Figure 6 respectively.

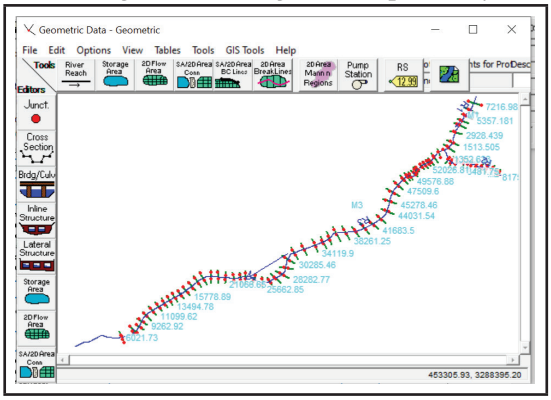

Figure 5: Geometrical and cross-sectional data during the model setup.

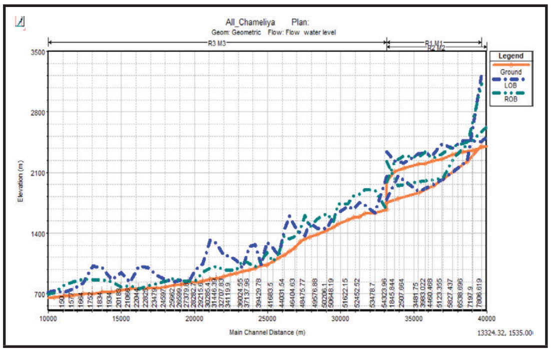

Figure 6: Elevation with main channel distance profile of Chamelia river.

5.8 Flood hazard map generation

Flood hazard maps were generated at 2, 5, 10, 20, 50, 100, 200, 500 & 1000-year return periods (Table 2) of extreme flood discharge with steady flow environment. In HEC-RAS model inflow boundary condition were selected for simulation to extent the inundated map of the Chamelia river. The simulated result was exported from HEC-RAS model to the ArcGIS for preparing the flood hazard maps. According to the field condition and extreme flood discharge the risk level were determined the depths of inundation map shown in Figure 8b and Figure 8b.

6. RESULTS AND DISCUSSION

6.1 Hydrological Result of Chamelia river

The observed peak discharge of Chamelia river at the gauging station corresponding to the 2, 5, 10, 20, 50, 100, 200, 500 and 1000 years return period flood frequency analysis by using the Gumbel's method results are depicted in Table 2.

Table 2: Gumbel's method frequency analysis result of Chamelia river discharge data (1965-2015).

Return Period Year	Flood Flow (m^3/s) (R1)	Flood Flow (m^3/s) (R2)	Flood Flow (m^3/s) Station	Flood Flow (m^3/s) (R3)
2	9	11	264	364
5	13	16	374	516
10	16	19	447	617
20	18	22	517	713
50	21	26	608	838
100	24	29	676	932
200	26	32	743	1025
500	29	36	833	1149
1000	31	39	900	1242

6.2 Hydraulic model results

In 100 year, return period flood flow at hydrological station at Chamelia river was calculated flood flow 676.0 m3/s in the cross section (R1) 7216.982 of the river. Other output data such as flood velocities in the channel (Vel Total) 5.34 m/s), Cross-section area 130.78 m2), Top width of the channel (43.94 m), and the maximum water level depth 2.88 m in the channel (Max Chl Depth 4.30 m), similarly other few cross -section result are shown in Table 3.

Table 3 Chamelia river HEC RAS model output flow results at the gauging station

River Cross Section	Left Sta (m)	Right Sta (m)	Cross-Section Area (m^2)	Top Width (m)	Vel Total (m/s)	Max Chl Depth (m)	Hydr. Depth (m)	Total Flow (m^3/s)	Rimarks
R1 (M1) RS: 7216.982	1007.89	1262.89	130.78	43.94	5.34	4.30	2.88	676.0	
R2 (M2) RS: 8175.308	327.27	740.89	154.64	54.10	5.32	4.66	2.86	823.0	
R3 (M3) RS: 54323.96	903.04	1255.49	170.18	56.05	5.48	4.36	3.04	932.0	
R3 (M3) RS: 8537.769	374.54	1000.98	170.26	56.21	5.47	4.56	3.03	932.0	Figure 5

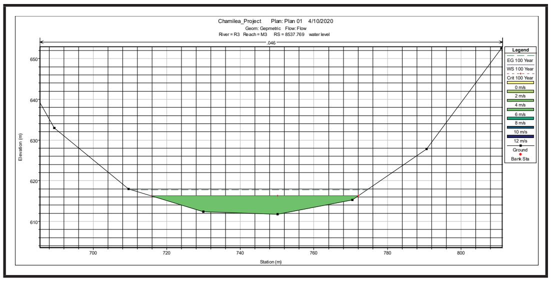

Figure 7: Flow distribution according to the cross section of Chamelia river.

6.3 Flood hazard maps of Chamelia river:

The flood hazard maps were extent in different return period (2, 5, 10, 20, 50, 100, 200, 500 and 1000 year) floods in Chamelia river, the sample of 100-year return period flood inundation map is depicted in Figure 8a and Figure 8b.

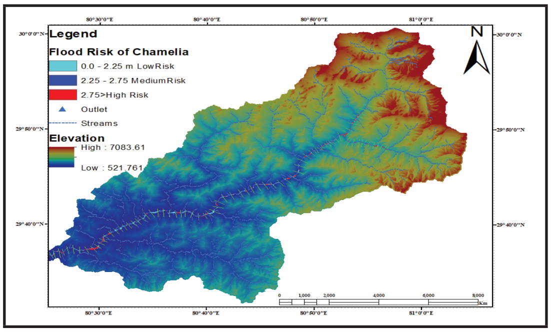

Figure 8a: Flood hazard maps of Chamelia river.

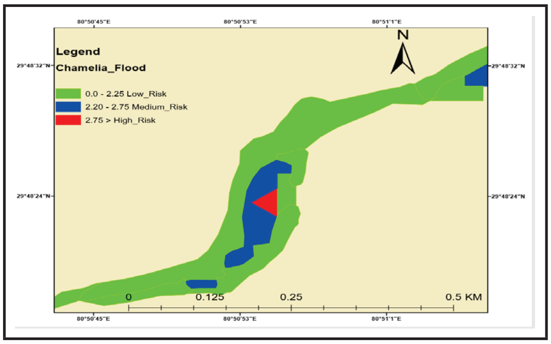

Figure 8a: Zooming view of Flood hazard maps.

7. CONCLUSION

Successfully applied the HEC GeoHMS in ArcGIS environment to generate the geometric data for hydraulic (HEC- RAS version 5.0.7) model in the Chamelia river basin. The flood hazard map generated using the HEC-RAS model is the best for estimating the maximum channel depth, hydraulic depth and water level defined cross section.

7.1 Recommendations

The high-resolution DEM will be better for estimating the reliable height of water (Flood) level. Similarly, discharge measurement, land use data, social data with field survey will be highly applicable for the validation of the result.

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