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# Floodplain Mapping Using Hydraulic Simulation Model in GIS

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**Abstract:** In this research, a methodology was applied to integrate hydraulic simulation model, HEC-RAS and GIS analysis for delineation of flood extents and depths within a selected reach of Zaremroud River in Iran. Floodplain modeling is a recently new and applied method in river engineering discipline and is essential for prediction of flood hazards. It is necessary to simulate complicated hydraulic behavior of the river in a more simple way, for the purpose of managing and performing all river training practices. In this research, steady flow was simulated along 3 km end of Zaremroud River, upstream of the Tajan River in North of Iran. Floodplain zonation maps were derived using integrating of HEC-RAS and GIS analysis. Delineation of flood extents and depths within the floodplain were conducted in different return periods. Critical flooding area along the river was distinguished based on the grid layer of flood depths. The results indicated that hydraulic simulation by integrating with GIS analysis could be effective for various kinds of floodplain management and different scenarios for river training practices and flood mitigation planning.

**Key words:** Flood hazard, floodplain, HEC-RAS, GIS

## INTRODUCTION

Flooding is a serious natural disaster which has many socioeconomic and environmental consequences for all activities and infrastructure within an affected floodplain. Regarding to the continually-growing population of the world, it is certain that without proper guidance, a large number of homes will be built in areas that place them at the mercy of flood events (Walker and Maidment, 2006). Therefore, Accurate delineation of flood extents and depths within the floodplain is necessary for flood management and to make accurate decisions regarding construction and urban development, insurance and other regulated practices on land and property potentially affected by flooding (Noman *et al*., 2003).

Introducing of advance computer technology to hydraulic simulation provided greater flexibility for the purpose of floodplain mapping. Recent advances through the combination of hydraulic simulation model, HEC-RAS within Arcview GIS environment have the potential to further that flexibility to create geometric representations, simple import and export capabilities and displaying the results in spatial format in a more cost-effective manner. As Werner (2001) stated the end result of the process is not only quicker floodplain delineation with greater accuracy than traditional methods, but also a flow depth grid could be extracted, indicating the level of inundation in the floodplain. It is evident that GIS has a great role to play in floodplain mapping and other disaster management because natural hazards are multi dimensional and the spatial component is inherent (Coppock, 1995).

GIS greatly facilitates the operation of floodplain mapping and flood risk assessment. The main advantage of using GIS for flood management is that it generates a visualization of flooding that could be very useful in flood mitigation planning process. Floodplain mapping have been conducted by some researchers on several regions using integration of HEC-RAS hydraulic simulation model and GIS.

Earles *et al*. (2004) demonstrated the utility of the HEC-geoRAS model for floodplain delineation and determination of key hydraulic parameters and also, HEC-RAS capability of producing hydraulic results in Los Alamos, New Mexico, USA. Abdalla *et al*. (2006) introduced hybrid approach for flood risk assessment through GIS. The developed approach was based on the integration of hydraulic simulation and GIS analysis, which allows spatial-based visualization and prediction of flood disaster. The results indicated that the developed methodology was efficient in modeling and visualizing the spatial extent of different flood scenarios and in determining flooded areas at risk. Williams (2006) carried out a study on Santee River. It was outlined the advantages of integration to model the impact of the Santee River rediversion, which was completed in 1941.

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This resulted in rapid silting of the Charleston Harbor and in 1984 flow was rediverted into the Santee valley about 30 km downstream of the dam. Flooding pattern within the Santee floodplain has been altered by rediversion and operation of the hydroelectric plant on the rediversion canal. HEC-RAS 3.2 and the HEC-geoRAS extension for Arc-View were used to examine the flooding regime prior to and subsequent to rediversion operations. Yang *et al*. (2006) developed a direct-processing approach to river system floodplain delineation. Floodplain zones of the South Nation River system, located east of Ottawa, Ontario, were mapped in two dimensions and three dimensions by integrating the hydraulic model with GIS. HEC-RAS simulations were performed to generate water surface profiles throughout the system for six different design storm events. The in-channel spatial data were mapped in the GIS domain and floodplain zones for the six design storms were reproduced in three dimensions by overlaying the integrated terrain model for the region with the corresponding water surface Triangulated Irregular Network (TIN). Chuan and Jing (2006) explored the methodology for compiling the torrent hazard and risk zonation map by means of GIS technique for the Red River Basin in Yunnan province of China, where was prone to torrent. Six different factors were analyzed and superimposed to create the torrent risk evaluation map based on a 1:250,000 scale digital map. Alho *et al*. (2007) investigated Jökulhlaups that are the consequence of a sudden and significant release of meltwater from the edge of a glacier. Such floods are sourced commonly from ice-dammed lakes, but occasional volcanic eruptions beneath ice can produce intense jökulhlaups due to prodigious rates of meltwater release. It was presented the results of one-dimensional hydraulic modeling of the inundation area of a massive, hypothetical jökulhlaup on the Jökulsá á Fjöllum River in Northeast Iceland. Remotely sensed data were used to derive a digital elevation model and to assign surface-roughness parameters. Also it was used a HEC-RAS/HEC-geoRAS system to host the hydraulic model; to calculate the steady water-surface elevation; to visualize the flooded area; and to assess flood hazards.

In this research, 3 km end of Zaremroud River, upstream of the Tajan River, was selected. The main objective of this study is to accurate delineation of flood extents and depths within the floodplain based on the integration of hydraulic simulation model, HEC-RAS and GIS analysis. The results of this research could be used for flood mitigation planning purposes, regarding to the historical flood threatens in the study area.

## MATERIALS AND METHODS

**Study area:** Zaremroud River lies in about 15 km southeast of Sari, Mazandaran, Iran between 36° 26' 15" to 36° 26' 44" N latitude and 53° 8' 23" to 53° 9' 52" E longitude. The length of river is approximately 95 km that it flows eastward to westward to join Tajan River and ultimately draining in to the Caspian Sea. The area has a supper humid climate and the maximum precipitation occurs in autumn and minimum precipitation in summer. The maximum and minimum temperature in Zaremroud Catchment is 20.4 and 8.95°C, respectively; and the mean annual temperature is about 14.5°C. The length of river reach selected in this study is about 3 km of Zaremroud River. The village, Garmroud is located in the adjacent to this reach of river. According to a report from Mazandaran Jahad Agricultural organization the dangerous floods of this river caused lots of losses such as breaking down two bridge openings of river and destruction of Garmroud hydrometric station and some similar cases during recent years. In addition, the river stream causes bank undercutting that may cause land sliding some parts of village in the long term.

**Datasets:** The analyses of this research relied on two types of data; annual peak flow, GIS data including cross sections, elevation points and topographic map. Peak flow data recorded at Garmroud hydrometric station, located in upstream of the selected reach, was used for this study. The length of data set is 24 years from 1986-87-2000-01 water years. After evaluation of the accuracy of the data, flood frequency analysis could be conducted using different statistical distribution. The most commonly used statistical distribution for flood frequency analysis is included Log-Normal, Log-Normal III, Pearson III, Log-Pearson III and Gumbel. Estimated peak flow in 2 to 100 years return periods can be used as input for the hydraulic simulation of the river reach.

Topographic map of area with scale of 1:25000 and river plan with scale of 1:1000 was applied for TIN generation, using 3D analyst capability of ArcView. TIN is used for preparation of required data for hydraulic simulation in HEC-RAS. Whereas the surveyed points of the Zaremroud River plan have relative elevation, GPS have been used for determining absolute and correct positioning of all cross sections and elevation points. The HEC-geoRAS extension is used in conjunction with 3D analyst for interpolation of digital terrain data and Spatial Analyst for proper display of the output flow depth grids and velocity grids.

**Hydraulic simulation:** In this research HEC-RAS was used which is a numerical model that designed for hydraulic simulation. This model could be used to perform one-dimensional steady flow, unsteady flow calculations. The system is comprised of graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphical and reporting facilities. The steady-flow version of the model solves one-dimensional step-backwater calculations. To use this version for the natural river, it is assumed that flow is comparatively steady along the whole reach because time-dependent variables are not included in the energy equation; flow varies gradually between cross-sections due to the energy equation having a postulated hydrostatic pressure distribution at each cross-section; flow is one-dimensional and therefore the calculation is based on the premise that the total energy head is the same at every point in a cross section; the bed-slope of the channel is less than 10% because the pressure head is represented by water depth, which is measured vertically in the energy equation; and the energy slope is constant over the cross-section (Hydrologic Engineering Center, 2005).

Steady flow analysis is applied to calculate water surface profiles for steady gradually varied flow condition. Additionally the steady flow component is capable of modeling subcritical, supercritical and mixed flow regime water surface profiles (Snead, 2000). The basic computational procedure in HEC-RAS model is based on the solution of the one-dimensional energy equation. The energy equation is written as Eq. 1. Energy losses are evaluated by friction (i.e., Manning's equation) and contraction/expansion coefficient multiplied by the change in velocity head.

$$y_{2}+z_{2}+\frac{a_{2}v_{2}^{2}}{2g}=y_{1}+z_{1}+\frac{a_{1}v_{1}^{2}}{2g}+h_{e} \tag{1}$$

Where:

$y_1, y_2$ = Depth of water at cross sections
$z_1, z_2$ = Elevation of the main channel inverts
$v_1, v_2$ = Average velocities (total discharge/total flow area)
$a_1, a_2$ = Velocity weighting coefficients
$g$ = Gravitational acceleration
$h_e$ = Energy head loss

The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations, hydraulics of bridges and evaluating profiles at river confluences in stream junctions. Water surface profiles are computed from one cross section to the next by solving the energy equation with an interactive procedure called the standard step method.

The basic data requirements for simulation are included: geometric data, study limit determination, river system schematic, cross section geometry, ineffective flow areas, reach lengths, energy loss coefficients, Manning's n, Equivalent Roughness 'k', contraction and expansion coefficients, steady flow data, boundary condition, flow regime. Selection of a suitable value for Manning's n is very significant to the accuracy of the computed water surface profiles.

Boundary conditions are another part of model that must be completed. Boundary conditions are necessary to establish the starting water surface at the ends of the river system. In a subcritical flow regime, boundary conditions are only required at the downstream ends of the river system. If a supercritical flow regime is going to be calculated, boundary conditions are only necessary at the upstream ends of the river system. If a mixed flow regime calculation is going to be made, then boundary conditions must be entered at all open ends of the river system. Ultimately after completing of all essential data, model could be run.

## RESULTS AND DISCUSSION

In this research, steady flow was simulated along 3 km end of Zaremroud River, upstream of the Tajan River in North of Iran. HEC-RAS simulation model in combination with GIS capabilities was used for this purpose. After preparing the project file, a TIN theme was extracted based on georeferenced field cross sections and topographical data in order to prepare required data to be processed. Topographic map with scale of 1:25000 and river plan with scale of 1:1000 were applied for TIN generation using 3D analyst capability of ArcView. The HEC-geoRAS extension is used in conjunction with 3D analyst for interpolation of digital terrain data and Spatial Analyst for proper display of the cross sections. The stream centerline and left and right channel banks, flowpath and cross section cut lines themes have prepared and then generate RAS GIS import file for hydraulic simulation in HEC-RAS model.

Frequency analysis of peak flow data was conducted to select the most accurate input for the hydraulic simulation of the river reach. It has shown that Log-Pearson III is the best distribution to estimate peak flow in different return periods, regarding to the least differences between observed and estimated peak flow. Table 1 has shown magnitude of peak flow in 2-100 years return periods. Peak flow estimated using

Table 1: Peak flow rates for 2-100 years return periods

| Return period (years) | 2 | 5 | 10 | 20 | 50 | 100 |
|---|---|---|---|---|---|---|
| Peak flow (M3/s) | 66 | 134.1 | 195.1 | 291.7 | 378.8 | 479.7 |

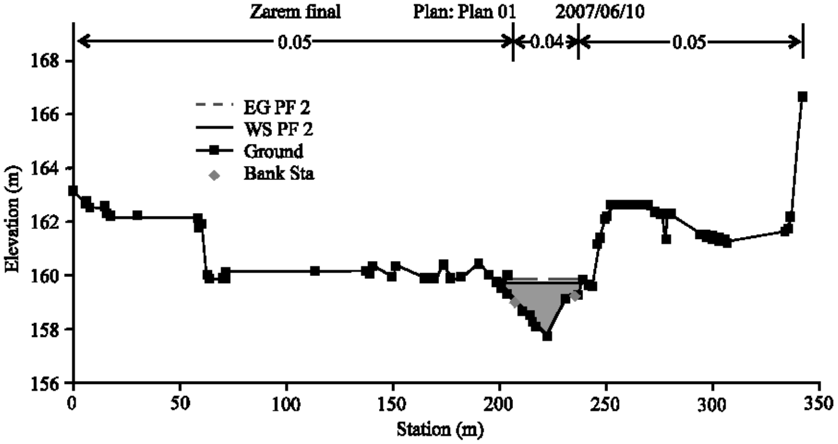

Fig. 1: Flood level for 2 years peak flow rate in one of the cross sections

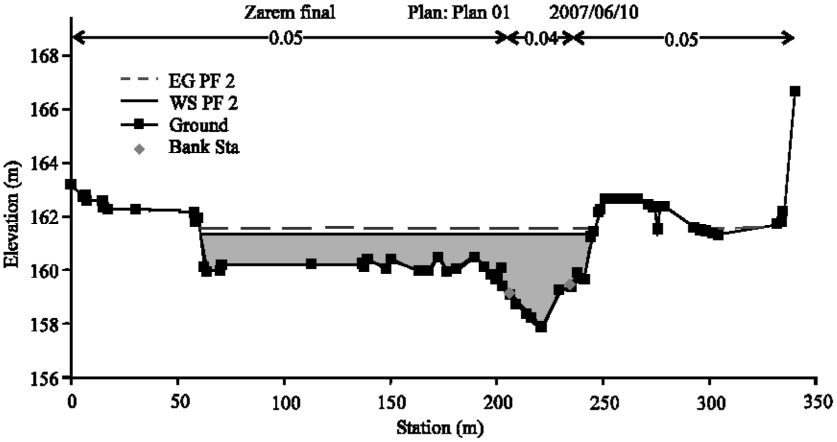

Fig. 2: Flood level for 100 years peak flow rate in one of the cross sections

flood frequency analysis (Table 1) was used as the steady flow data for simulation. Normal depth for upstream and critical depth for downstream was considered as boundary conditions for this analysis. Other inputs such as Manning's n value, river system schematic, contraction and expansion coefficients, flow regime entered to model and HEC-RAS model has run for steady flow and mixed flow regime.

Flood levels in one of the analyzed cross sections can be shown in Fig. 1 and 2 for 2 and 100 return periods, respectively. There is more than 1.5 meter difference between flood levels in two mentioned return periods (Fig. 1, 2). One of the most important results of HEC-RAS simulation is preparing different water surface profiles of different T-year floods. In the next step, the results of hydraulic simulation within HEC-RAS model were exported to GIS for floodplain delineation and further analysis. Delineation of flood extents and depths within the floodplain of Zaremroud River was conducted in different return periods based on the integration of hydraulic simulation results and GIS analysis using the HEC-geoRAS extension of ArcView. Figure 3 and 4 have shown flood affected area for the 2 and 100 years flood events, as a sample in the study area.

Critical flooding area along the river could be distinguished based on the grid layer of flood depths. As can be shown in Fig. 3 and 4, flood affected area for 2 and 100 years flood events were compared. Flood affected area for 100 years event is much larger, as it can be very close to the residential area of Garmroud village. As an implication result of this study, flood affected area in the upstream reach of the river were evaluated. As can be shown in Fig. 4, two sample critical area were specified using A and B remarks. It has shown that in point A, flood extents are affected some area near the village. To prevent the flood hazard to the village (section A),

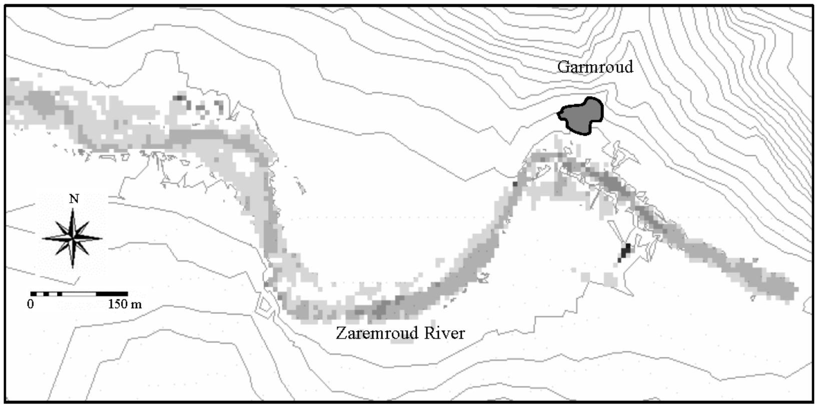

Fig. 3: Flood affected area for 2 years flood events

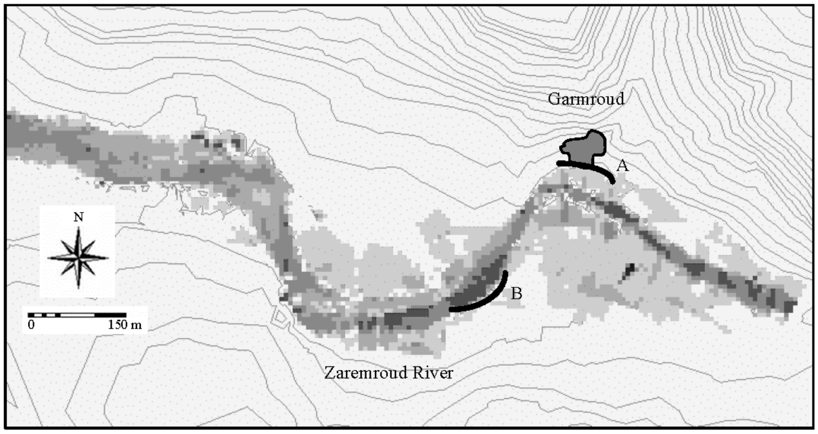

Fig. 4: Flood affected area for 100 years flood events

structural measures including flood walls and levees construction and also channel excavation and modification, should be considered for future flood mitigation plans.

Application of hydraulic modeling in GIS environment provides the capability to simulate flood depth in different part of the floodplain. Delineation of flood depths within the floodplain have shown in Fig. 3 and 4 for 2 and 100 years return periods, respectively. Hydraulic levels can be seen very variable, which is depends on geometry of the channel and the hydraulics condition of the river system. As can be seen in Fig. 4, flood depths are critical just before second meander (section B), about 300 m after the location of the village, which is one other sample point in the reach that have critical flood hazard. In this section, transition of the flow condition from subcritical to supercritical and vise versa could be analyzed. Structural measures including flood walls and levees construction and also channel excavation and modification should be considered for future flood mitigation plans at the section B. Structural measures could prevent floodwaters from inundating surrounding farmland and residential areas.

Hydraulics simulation for floodplain mapping could be beneficiary in several aspects for land and water resources management and also engineering purposes. It can be applied to prevent unwise land use in floodprone areas and flood insurance studies, based on modeling of water surface elevations for design flood events. The design of bridge and culvert openings for roadway crossings of streams and consequences of flood reduction measures such as dams, levees and channel modifications could be predicated on proper floodplain hydraulic analysis. Increasing the size, slope, or depth of the channel or decreasing its roughness can lead to a reduction in flood levels because of the additional channel capacity. On the other hand, channel modifications can also have negative effects, such as increasing in flow velocity, which could be simulated using hydraulic model.

## CONCLUSION

This study focused on integrating of hydraulic simulation with GIS analysis. Results of this study can reasonably separate high-hazard from low-hazard areas in the floodplain to minimize future flood losses. The evaluation of floodplain delineation are rather complex and demanding activities, which require a comprehensive approach to hydraulic floodplain simulation and can be largely enhanced by using GIS capabilities. Flash floods cause serious inundation hazards in area under urban development. Structural and non-structural flood mitigation measures are necessary for flood hazard control in critical area, where was specified in this research. As Correia *et al.* (1998) stated GIS is a valuable tool for addressing urban growth modeling and defining possible floodplain management measures. Also one of the most important conclusions made from this study is that use of GIS for the undertaking of a hydraulic simulation has the potential to be both an accuracy improving and cost-saving for floodplain and flood hazard mapping.

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