FLOOD PLAIN MODELLING OF KRISHNA LOWER BASIN USING ARCGIS, HEC- GEORAS AND HEC-RAS

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Abstract. A flood is an overflow of water that submerges land which is usually dry. Floods can also occur in rivers when the flow rate exceeds the capacity of the river channel, particularly at bends or meanders in the waterway. This results in causing damage to human and property if they are in the natural flood plains of rivers or settled on the banks of rivers. To facilitate the appropriate measures for effective flood mitigation in advance, there is a need to model the flood plain which facilitates to locate the flood plain and its extent for effective flood mitigation measures. By understanding the extent of flooding and floodwater inundation, decision makers are able to make choices about how to best allocate resources to prepare for emergencies and to generally improve the quality of life. This research presents a straightforward approach for processing output of the HEC-RAS hydraulic model, to enable two and three dimensional floodplain mapping and analysis in the ArcView geographic information system. The methodology is applied to a stretch of river Krishna from downstream of Nagarjuna Sagar project to Kummariapalem which is located on upstream of Prakasam Barrage. The flood plain maps are developed for the flows corresponding to 2, 10, 25, 50 and 100 year return periods. The resulting surface model provides a good representation of the general landscape and contains additional detail within the stream channel. Overall, the results of the research indicate that GIS is an effective environment for floodplain mapping and analysis.

1. Introduction
A flood is a flow of high magnitude during which the river overflows its banks and inundates the adjoining area. Floods often cause damage to homes and commercial areas if they are located in the natural flood plains of rivers. Protective measures such as detention basins, levees, bunds, reservoirs and weirs are used to prevent waterway from overflowing their banks. Flood control structures such as dams can be built and maintained over time, to reduce the occurrence and severity of floods as well. By understanding the extent of flooding and floodwater inundation, decision makers are able to make choices about how to best allocate resources to prepare for emergencies and to generally improve the quality of life.

Depending upon the nature of work involved, flood protection and flood management measures may be broadly classified as structural and non-structural measures. The structural measures for flood control involve structurally intensive activities which bring relief to the flood prone area by reducing flood flows and thereby reducing the flood levels but these are cost intensive both in initial cost and maintenance cost. Non-structural measures involve the stakeholders in flood mitigation activities like creating awareness, preparation of the flood inundation maps, prevention of people occupying low lying and flood prone area and developing strategies for evacuating affected people during flood season. These measures provide a cost effective and reliable solution to flood management problems.
Floodplain management and mapping is a new applied method for the river engineering and is essential for prediction of flood hazards. The stretch of river Krishna between Nagarjuna Sagar Project and Prakasam barrage regularly gets affected due to flooding almost every year during the monsoon season, mainly due to lack of proper flood protection and limited resources. To understand the dynamics of flow of flood water in the river and the flood plain for the event, it is necessary to model the event using an appropriate model or combination of models. The results of the study can be used for hydraulic simulation by integrating with GIS analysis and could be effective for river training works and flood mitigation planning.

2. Literature review

Many studies of flood plain modeling have been carried out across the world. For the past few years, application of Remote sensing and GIS in terrain modeling and floodplain mapping was relatively limited. With the drastic advances in GIS, its usage has been increased in various fields and it began to be used to represent the flooded area on the land surface. Most of the prior works dealt with the digital elevation models (DEMs), analysis of square grids of regularly spaced elevation data for hydrologic applications. Callaghan et al. (1988) implemented methods for filling DEM depressions, creating flow direction and flow accumulation grids using DEM as the single input. These advances allowed for the delineation of watershed and drainage network. But, the use of DEM surface is generally not suitable for representation of large-scale terrain which is necessary for the hydraulic analysis of river. The triangular irregular network (TIN) model is preferred for hydraulic modelling of river channels.

Djokic et al. (1990) made use of TINs for storm drainage modelling in urban areas. He found that the TIN surface was very effective for the determination of parameters for design flow calculations. The flood extent for different return periods of 50, 100, and 200 years were estimated in the study. Hernandez et al. (2007) used GIS raster and feature data sets, to automate the pre-processing of input data and HEC-GeoHMS and HEC-GeoRAS for post-processing of HEC-RAS results. These tools are successfully linked with HEC-RAS to expedite the production of floodplain mapping and obtain accurate hydraulic results. HEC-RAS/HEC-GeoRAS have been used for steady flow simulation along 4km end of Zaremrood River to derive the extent of flood hazard by Karim et al. (2009). The results indicated that by integrating HEC-RAS model, GIS can be used as an effective tool for various kinds of floodplain modelling and different scenarios of river training practices.

Alaghmand et al. (2010) used HEC-RAS and HEC-HMS models for river flood hazard mapping for Sungai Kayu Ara river basin, located in the west part of the Kuala Lumpur in Malaysia. Using HEC-GeoRAS, stream geometry data was extracted from the digital elevation model (DEM). The hydrologic data, which was generated with HEC-HMS as initial flow and boundary conditions, was integrated with HEC-RAS steady flow data. HEC-RAS model results were post processed into ArcGIS using HEC-GeoRAS. The generated river flood hazard was based on water depth and flow velocity maps were prepared according to hydraulic model results in GIS environment.

For the development of a terrain model, Tate et al. (2010) used a GIS based approach, based on stream channel representation of the HEC-RAS hydraulic model. The approach required a digital elevation model DEM, GIS representation of the stream geometry and a completed HEC-RAS simulation as input. The channel data was exported from HEC-RAS to GIS, hydraulic model coordinates were converted to geographic coordinates. A digital terrain model was subsequently synthesized by merging HEC-RAS data of the stream channel with comparatively lower-resolution DEM data for the floodplain. The resultant surface model provides a good representation of the general landscape and contains additional detail within the stream channel.
A study on the flood zone of Karkheh River using hydraulic model HEC-RAS and GIS was carried out by Kamanbedastel et al. (2011). Topographical map, digital elevation model and hydrological data were used for the study. The results indicated that hydraulic simulation by integrating HEC-RAS model, GIS can be used as an effective tool for various kinds of floodplain managements and different scenarios of river training practices.

3. Study Area and Methodology

3.1 Study Area

The stretch of river Krishna from downstream of Nagarjuna Sagar Project (chainage 0.0 km), in Nalgonda District of Telangana state to Kummaripalem in Krishna district of Andhra Pradesh which is located on the upstream of Prakasam barrage (chainage 192 km) is considered for the present study. It is located between 79° 31' E and 80° 60' E and 16° 50' N and 16° 57' N which is shown in Figure 3.1.

![Location Map of Study Area Using GIS](image)

Figure 3.1 Location Map of Study Area Using GIS

The important soil types found in the basin are black soils (regur), red soils, laterite and lateritic soils, alluvium, mixed soils (red and black, red and yellow, etc.) and saline and alkaline soils.

3.2 Data Required:

The main objective of the HEC-RAS program is to compute water surface elevations at all locations of interest for given flow values. The data needed to perform these computations are divided into geometric data and steady flow data.

3.2.1 Geometric Data

The basic geometric data consists of the connectivity of the river system (schematic diagram of the river system), cross sections data reach, lengths, energy loss coefficients (friction losses, contraction and expansion losses), and stream junction information. If hydraulic structures (bridges, culverts, etc.) are present in the river system, the details and characteristics of those are also needed.

3.2.2 Steady Flow Data

Steady flow data, needed to perform a steady water surface profile calculation, consist of (i) Flow
regime, (ii) Boundary conditions, and (iii) Peak discharge information.

3.3 Data Availability

The data available for the study to carry out the simulation and their sources are presented in Table 3.1.

| Data Collected                        | Source                                      |
|---------------------------------------|---------------------------------------------|
| Digital Elevation Model (30m resolution) | Earthexplorer.usgs.gov.in                   |
| Streamflow data                       | http://www.india-wris.nrsc.gov.in/eris.html |

3.4 Methodology

In this study the topography of the river was obtained by using ArcGIS and HEC Geo-RAS. This GIS data was imported to HEC-RAS for further steps. Flood frequency analysis is carried out to find discharges corresponding to 2, 10, 25, 50 and 100 year return periods. For these discharges corresponding to 2, 10, 25, 50 and 100 year chance events HEC-RAS analysis is carried out to generate water surface profiles and other hydraulic details.

3.4.1 Watershed delineation of the study area

Watershed delineation process is carried out for identifying the stream location in Digital Elevation Model. Various tools available in Arc Toolbox, like Hydrology, Map Algebra, Spatial Analysis and Raster tools are used for doing all the steps involved in watershed delineation process. These steps consist of computing the Fill, Flow accumulation, Flow direction, Basin, Rater to Polygon, Raster Calculation and Raster to Polyline. The watershed delineation of the DEM is shown in Figure 3.2.

![Figure 3.2. Flow Accumulation Grid of the DEM](image-url)
3.4.2 Generation of Triangulated irregular network (TIN)

Triangulated Irregular Network (TIN) is a digital data structure used in GIS for the representation of a surface. A TIN is a vector based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (x, y, and z) that are arranged in a network of non-overlapping triangles. TINs are often derived from the elevation data of a rasterised DEM. The first step in the pre-processing stage is to create a DEM of the river system in a TIN format. The TIN must be constructed with a special care in order to provide accurate analyses. Elevation data for each cross section is extracted from the TIN. The TIN also serves for determining floodplain boundaries and calculation of inundation depths. The TIN was constructed using 3D Analysis tools in ArcMap. The TIN is loaded and HECGeo-RAS extension is added for extracting the topography of the river and import to HEC-RAS. The pre-processing is done using the HEC-GeoRAS for creating physical attributes in GIS, and then exporting them to the HEC-RAS geometry file. For this, RAS layers in ArcMap, which are used to create geometric data sets will be modelled in HEC-RAS. Only two RAS layers are needed to map a floodplain (Stream Center line and Cross Section Cut lines). All other layers are optional. The RAS layers can be created in one step and will be stored collectively in a GeoDatabase, which HEC-GeoRAS creates automatically. By default, this GeoDatabase will be saved in the same location as the ArcMap project with which the users are working and will be given the same name.

3.4.3 Digitization of Stream centerline

The Stream centerline layer is very important, because it represents the river network for HEC-RAS. Digitizing of the stream centerline starts with selecting the sketch tool from the Editor Toolbar, and digitization proceeds in the direction of river flow. That is, digitizing must begin at the most upstream end of the stream, and proceed towards downstream ending at the outlet or beginning of the next downstream reach. After digitizing the Stream centerline layer, the next task is to assign River code. Each river in HEC-RAS, as well as each reach within a river, is assigned a unique name. This is accomplished by the selection of Assain River Code/Reach Code menu item and assigning appropriate name. Digitizing of river center line is shown in Figure 3.3.

![Figure 3.3 Digitizing of River Centerline Using DEM](image)

3.4.4 Cross sectional cut lines

Cross-sectional cut lines are one of the most important inputs to HEC-RAS. They are used to extract
the elevation data from the terrain and to create a ground profile across the flow. The intersection of cut lines with other RAS layers such as centre line and flow path lines are used to compute HEC-RAS attributes such as bank stations (locations that separate main channel from the floodplain), and downstream reach lengths (distance between cross-sections). Each cross-sectional cutline represents each cross-section of the river and they must be drawn perpendicular to the flow direction of river by intersecting stream center line, bank lines and flow path lines. Digitising of cross sectional cut lines is shown in Figure 3.4.

![Digitizing of Cross Sectional cut lines](image1.jpg)

**Figure 3.4** Digitizing of Cross Sectional cut lines

### 3.4.5 Exporting GIS data to HEC-RAS

The last step is to create a GIS import file for HEC-RAS so that it could import the GIS data to create the geometry file. Firstly, it is necessary to define which layers would be exported to HEC-RAS. Using RAS Geometry feature of HECGeo-RAS the GIS Data can be imported to HEC-RAS. The imported geometry data of river cross-sections is shown in Figure 3.5.

![Geometric Data imported to HEC-RAS](image2.jpg)

**Figure 3.5** Geometric Data imported to HEC-RAS

### 3.4.6 Flood frequency analysis for the flow data

From the available daily flow data at all the hydro meteorological stations, annual maximum flows are found and flood frequency analysis is carried out for the annual maximum flow data. For fitting the suitable distribution to the data, Chi-Square goodness of fit test is performed at all the hydro meteorological stations of the study area. Chi-Square test is one of the most commonly
used tests and can be used for testing the goodness of fit of any distribution. The test makes a comparison between the actual number of observations and the expected number of observations.

4. Results and analysis

The HEC-RAS model is calibrated with observed daily discharge data of monsoon season (June to September) of the year 1978 for different Manning’s ‘n’ i.e. ‘n’ starting from 0.03 up to 0.05. Though the simulation has been carried out for Manning’s ‘n’ from 0.03 up to 0.05 with increment of 0.0025 (say 0.03, 0.0325, 0.035, 0.0375, 0.04 etc.), and it is found that at a value of Manning’s ‘n’ 0.03, the model is giving better results by comparing observed and simulated flows as shown in Figure 4.1. Flood frequency analysis is carried for available flow data. HEC-RAS analysis is carried out for flows corresponding to 2, 10, 25, 50 and 100 year return periods. Floodplain maps are generated in ArcGIS by importing HEC-RAS outputs to ArcGIS again with the HEC Geo-RAS. To obtain floodplain map ‘Base map’ is added by loading ‘GOOGLE EARTH’ into ArcGIS. The generated water level boundary file of flow corresponding to each return period is superimposed on to the ‘GOOGLE EARTH’ and floodplain map is obtained. For sample, the water surface profile and flood plain map corresponding to flow of 100 year return period are shown in Figure 4.2 and Figure 4.3.

Figure 4.1 Comparison of Observed and Simulated Flows of Monsoon Season of Year 1978 at Wadenapally (RS 70561.64) for n=0.03
Figure 4.2 Water Surface Profile Plot of River Krishna for a Flow of 100 Year Return Period

Figure 4.3 Flood Plain Map for a Flow of 100 Year Return Period
5. CONCLUSIONS

The following are the important conclusions drawn from the present study:

1. In the present study, the Manning’s ‘n’ value for the river reach has been determined as 0.03 based on the calibration of the model. The model performed reasonably well during calibration using daily discharge data of monsoon season (June to September) of 1978 at Wadenapally with NSE as 0.963, deviation in peak as 2233.939 m³/s and percentage deviation in peak as 13.32% lower than observed peak flow.

2. Visualising the results in longitudinal profile (Water Surface Profile Plot) helps in understanding the variation in water levels at all cross sections at the same time. In the present study, the water surface profile plots and flood plain maps are generated for flows corresponding to 2, 10, 25, 50 and 100 year return period.

3. It can be observed, from the generated floodplain maps, that in the downstream side of the river there is more flood inundation extent because of the effect of Prakasam barrage.

4. From chainage of 140 km to 160 km the slope is too steep, with lesser Froude’s number and narrower cross section, which leads to high velocity which may cause erosion.

5. The results obtained in this study provide essential information for administrative to analyse and manage flood hazards and also formulate remedial strategy.

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