2D Flood Simulation and Development of Flood Hazard Map by using Hydraulic Model

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Abstract A flood is an overtopping of water from channel banks which submerges land which is usually dry. In India, floods in Godavari and Sabari River are observed several times but 2006 flood was one of the severe events which affected Khammam district extensively. The present paper demonstrates the analysis of severe flood of Khammam using hydraulic modeling. For this purpose HEC-RAS 2D a Hydraulic model was used to simulate the behavior of study area which covers part of Godavari River and Sabari River in Telangana and Andhra Pradesh states. Model provides detail temporal simulated parameters like depth of water, water elevation with respect to M.S.L and Velocity of flowing water. SRTM 30m posting, river discharge data, LULC for assigning Roughness coefficient was used as input to the model. HEC-RAS Simulated flood results were validated with remotely sensed Radarsat satellite observations. Performance of HEC-RAS model was evaluated according to the criteria of measure of fitting raster cells with satellite data. Validation results showed that performance of HEC-RAS model is very effective and can be used by hydrologist or water resources engineers for planning and development.

Keywords Flood inundation simulation; Godavari; RADARSAT; Sabari; SRTM

1. Introduction

Floods are one of the major natural disasters affecting the South-Asian region. India and Bangladesh are two from eight South-Asian countries which are reported to be worst affected countries in the world, accounting to be 1/5th of global death count due to floods (Agarwal and Sunita, 1991). In India, nearly 40 million of land is prone to floods. Floods are frequent phenomena in the country occurring during monsoon season (June-October), which affects to crop lands, infrastructure as well as lives. Repetitive flood inundation is threatening human life and property which indeed requires effective flood risk assessment (Matgen et al., 2007). Prediction of flood inundation is not straightforward since the flood inundation extent is highly dependent on topography and it changes with time. Flood prediction is a very complex process in both spatial and temporal contexts whereas the Conventional engineering methods is time consuming. Application of the hydraulic numerical modelling for flood analysis and flood plain management is a strategic and essential tool for an integrated flood plain management...
Flood risk assessment and management are fundamental steps for identifying prone risk areas, current hazards, and reducing them in future flood events (Ranzi, 2011). To propose measures on flood management it needs basic understanding of flood analysis. There are two approaches of understanding, first is, in situ flood observations (Hagen and Lu, 2011) but in situ observation are not available all the time, so another one is observing flood by Remote sensing satellite data (Haq et al., 2012; Chormanski et al., 2011) but it still limits us to know the temporal behavior in flood event. So, in order to develop flood hazard and risk zone maps and to know the temporal behaviour of flood event it is essential to simulate the flood inundation by numerical models. The studies of Flood inundation modelling using hydrodynamic models approach for designing river engineering and irrigation schemes and mapping flood risks has been carried out by various researchers worldwide (Werner, 2004; Bates et al., 2005; Patro et al., 2009). There are various numerical models like HEC-RAS (Hydrologic Engineering Corporation- River Analysis System) developed by US Army of Corps of Engineers, MIKE developed by Danish Hydraulic Institute, Denmark (DHI, 1997). SOBEK developed at the Delft Hydraulics, Delft have been developed for floodplain delineation and flow simulation to delineate the floodplain zones and calculate the associated risk. All these models have capability to solve 1D and 2D equations. For present study HEC-RAS model is used to simulate flood inundation for study area. HEC-RAS releases new version 5.0 Beta with 2D capability which is a great innovation for futuristic flood studies (MoyaQuiroga et al., 2015). The study goal is to analyze the 2006 flood event of part of Godavari and Sabari river north eastern part of Telangana.

Figure 1

2. Study Area

Figure 1 depicts the Godavari River stretched from Perur to Kunavaram and Sabari River stretched from Konta in Chattisgarh to Kunavaram in Andhra Pradesh state (2006). The origin of Godavari River is Brahmagiri Mountain (Western Ghats) in Nashik District; Maharashtra River flows from West to east and falls into Bay of Bengal 93 km south of Rajahmundry. The river Sabari is a tributary of River Godavari It merges in river Godavari at Kunavaram, about 40-km from Bhadradchalam town. The Godavari basin is bounded, on east by Eastern Ghats and on the West by the Western Ghats on the North by the Satmala Hills, the Ajanta Range and the Mahadeo Hills on the South. Sabari River is 280 mm/km. The study area lies in between latitudes 18° 38’ and 18° 25’ and longitudes 80° 12’ and 80° 26’. The type of soil observed in the study area are Red sandy loams, clay loams, Alluvial, Sandy Alluvial, Deltaic Alluvial,
Coastal sandy loams, Heavy clays and Saline soils (Shodhganga Chapter IV). These soils are low pervious in nature generating more runoff on surface and hence favouring Inundation. The study area of Godavari river stretch is about 186.6 km and Sabari river stretch is about 37.07 km. In Khammam district Mandals (small town) like Kunavaram, Vararamachandrapuram and Kukunuru.

Velerupadu and Boorugumpadu were badly affected and V. R. Puram, Chintoor and some part of Kunavaram were affected by Sabari River. Flood affects crops, Pakka buildings and 60 villages where flood water last for eight days. In East Godavari district, mandals like Katrenikona, Mummidivaram, Inavalli are submerged in Godavari water and near about 40 villages and about 2000 victims were severely affected (Sewa Bharati, 2006).

3. Data Used

Spatial Hydraulic modeling requires data of two type’s Geographical data and Hydraulic data. Geographical data such as Digital Elevation Mode (DEM) which gives a description of elevation of an area, for the study area SRTM (Shuttle Radar Topographic Mission from USGS) of grid cell size 30 m (1 arc-second) was used. Hydraulic data deals with the time series Discharge data of Godavari River at Perur gauge station and for Sabari River at Konta gauge station. Discharge data at an interval of 12 hrs were obtained for flood event from Central water commission (CWC) Hyderabad. For the Perur and Konta gauge station Daily discharge data is available from 2000. Land Use Land Cover (LULC) of 1:250000 scales derived from Advanced Wide Field Sensor (AWiFS) data of 56 m grid size were used in order to assign manning ‘n’ roughness coefficient. The study simulates flood event from 04 Aug 2006 12.00 hours to 10 Aug 2006 24.00 hours. This time stamp was selected because the study area was severely affected by flood.

4. Methodology

4.1. DEM Preprocessing

SRTM 30 m DEM is used and clipped to study area extent. DEM Preprocessing is required if DEM contains null values if any. These null values can be filled by fill and sink hydrology tool. In order generate geometric statistics; the projection of DEM should be in projected coordinate system, for present study area WGS_1984_UTM_Zone 44N Projection was used, where WGS_1984 is a Datum.

4.2. HEC-RAS Model Setup

The projected DEM is basic input to hydraulic modeling. Model converts DEM into terrain in the form of Triangular Irregular Network (TIN) file. TIN file is a vector representation of DEM Figure 2 shows terrain created from DEM. Further, study area was defined by 2D closed polygon. The 2D polygon
area covers probable areas that are liable to inundate. This area can be defined by two methods in order to minimize optimization of 2D Mesh cells. First method is to define 2D polygon area based on previous floods extend observed by satellite. Another method is to define polygon by digitizing the 2D polygon boundary connecting higher elevated areas like hills and mountains. For present study, second method was adopted as high elevated hills are surrounding to the study area. After Defining 2D Polygon area computational cells area generated. The cells are rectangular in shape and at boundary it may be rectangular or polygon up to 8 sides. Cell size was kept to be 30 m in order to enclose DEM cell size. Figure 3 shows 2D polygon with computational cells, these cells are also called as Mesh.

Further, three boundary condition assigned to study area. Two inflow hydrograph boundary condition and one normal depth boundary condition. Inflow hydrograph one at Perur gauge site on Godavari River and one at Konta gauge site on Sabari River. Figure 4 shows the assigned boundary condition to study area. Similarly Inflow hydrograph at Perur and Konta gauge site for the event obtained from CWC is shown in Figure 5. The normal depth 0.00032 slope was assigned according to the topographic conditions of the study area.

![Inflow Hydrograph at Perur and Konta Gauge site on Godavari and Sabari River respectively](image)

**Figure 5:** Hydrograph at Perur and Konta Gauge site on Godavari and Sabari River respectively

### 4.3. HEC-RAS Simulations

HEC-RAS 2D 5.0.1 beta version has capability to solve two equations such as Diffusion wave and full momentum equation. Diffusion wave considers parameters such as Gravity, Friction and Pressure. Whereas Full momentum equation considers parameter like Gravity, Friction, Pressure, Acceleration, Turbulent eddy viscosity, Corollis effect. Both equations are derived from Continuity equation. For present study, Full momentum equation was used to simulate the flood event as all parameters are considered. The full momentum equation (1 and 2) as shown below for two directional specific flows p and q.

\[
\frac{\partial p}{\partial t} + \frac{\partial (pq)}{\partial x} + \frac{\partial (p^2)}{\partial y} = -n^2pq\sqrt{\frac{p^2 + q^2}{h^2}} - gh\frac{\partial s}{\partial x} + pf + \frac{\partial}{\partial x}(hr_{xx}) + \frac{\partial}{\partial y}(hr_{xy}) \ldots 1
\]
\[
\frac{\partial q}{\partial t} + \frac{\partial}{\partial x} \left( q^2 \right) + \frac{\partial}{\partial y} \left( pq \right) = -n^2 \frac{q}{g} \sqrt{\left( \frac{q^2 + q^2}{h^2} \right)} + gh \frac{\partial s}{\partial y} + \frac{q}{\rho} \frac{\partial}{\partial x} \left( h \tau_{xy} \right) + \frac{\partial}{\partial x} \left( h \tau_{xx} \right) \ldots 2
\]

Where,

\( p \) and \( q \) are the specific flow in the x and y directions \((m^2/sec)\), \( n \) is the manning’s resistance, \( s \) is the surface elevation in \((meters)\), \( h \) is the water depth \((meters)\), \( g \) is gravitational acceleration \((m/sec^2)\), \( \rho \) is the density of water \((kg/m^3)\), \( \tau_{xx}, \tau_{yy}, \tau_{xy} \) are the components of effective shear stress and \( f \) is the Corollis/(sec).

4.4. Model Performance

Model Performance has been evaluated based on measures of fit \( F_1 \) and \( F_2 \) (MoyaQuiroga et al., 2015; Horrit et al., 2007; Di Baldasarre et al., 2009). It depends on the simulated raster cells that are fitted with the satellite image. It gives the degree of accuracy of the model, \( F_1 \) ranging from 0 to 1 and \( F_2 \) ranging from -1 to 1. The equation of \( F_1 \) and \( F_2 \) is given in the equation 3 and 4 respectively.

\[
F_1 = \frac{A}{A+B+C} \ldots 3
\]

\[
F_2 = \frac{A-B}{A+B+C} \ldots 4
\]

Where, \( A \) is correctly predicted cells, \( B \) is Over-predicted cells and \( C \) is under predicted cells. The value closer towards 1 indicates model performance is better.

4.5. Flood Hazard Map

The flood Hazard was developed for the study area according to the simulated flood depth in inundated areas. The hazard classification was assigned according to the Japan ministry of land infrastructure and transport (MLIT) shown in Table 1.

| Flood hazard | Depth (meters) | Hazard     |
|--------------|---------------|------------|
| H1           | <0.5          | Very low   |
| H2           | 0.5-1         | Low        |
| H3           | 1-2           | Medium     |
| H4           | 2-5           | High       |
| H5           | >5            | Extreme    |

There are five flood hazard classifications \( H_1, H_2, H_3, H_4 \) and \( H_5 \) according to depth of inundation. \( H_1 \) hazard (depth less than 0.5 meter) is entitled to be very low as people can evacuate easily on their feet. \( H_2 \) hazard (depth 0.5-1 meter) is entitled to be very low, in this zone, evacuation becomes difficult for adults and infants, animals may get exposed to hazard. \( H_3 \) hazard (depth 1-2 meters) is a medium zone, where people may get drowned but they will be safe in their homes having plinth level to be 0.6 to 1 meter. \( H_4 \) hazard (depth 2-5 meters) is entitled to high hazard zone where all people in this zone are not safe in their homes but at the most they may be safe on their roofs. \( H_5 \) hazard (depth greater than 5 meters) is an extreme hazard zone where people are not safe even on their roofs.

5. Results and Discussion

The HEC-RAS model results are in two decimal floating point raster stored in tiff file format. The simulated results are in the form of flood inundation with depth, velocity, water surface elevation with
respect to time. Results for desired date and time can be achieved within the simulated period such as 04 Aug 2006 12.00 hours to 10 Aug 2006 24.00 hours at one hour time interval. For present study, simulated results for 07 Aug 2006 at 08.00 hours was taken into consideration for validating with RADARSAT satellite image acquired on same date and time Figure 6 shows the RADARSAT image and its derived flood extent.

**Figure 6:** Radarsat image during flood event and its derived flood extent on the right

![Radarsat image during flood event and its derived flood extent](image)

The evaluated measures of fit $F_1$ and $F_2$ by using the GIS tools like Arc-GIS and ERDAS shown in Table 2.

**Figure 7:** Simulated flood inundation layer

![Simulated flood inundation layer](image)
| Sr No. | Correctly predicted cells A | Over predicted cells B | Under predicted cells C | F1 A/(A+B+C) | F2 (A-B)/(A+B+C) | Flood observed (FO) | Flood simulated (FS) | FS/FO |
|-------|-----------------------------|------------------------|-------------------------|--------------|------------------|-------------------|---------------------|------|
| 1     | 142331                      | 42476                  | 49527                   | 0.61         | 0.43             | 45272             | 43579.74            | 0.96 |

Since $F_1$ and $F_2$ are closer to 1 indicates the accuracy of model performance which tends to be better and the ratio of flood simulated to flood observed is 0.96 this means 96 percent of inundated area is matched. The Figure 8 shows the variation of inundation with respect to time.

![Figure 8](image)

**Figure 8: Variation of flood Inundation with respect to time and discharge (Figure 5)**

The flood hazard map was developed by considering the extreme inundation (maximum depth) simulated by the model. The hazard classification was done based on Japan ministry of land infrastructure and transport (MLIT) shown in Table 1. Figure 9 shows the flood hazard map for study area.

The depth is classified into five classes from $H_1$ to $H_5$ shown in Figure 9. Many villages on east and west side of Sabari river and north and south side of Godavari river got affected. Total of 301 villages affected for study area out of which 36 villages are of extreme category. The villages falling in extreme category are Chidumurum, Chatti, Kummur, Bojaraigudem, Jallagudem, Markandeyulapeta, Tallagudem, Regulapadu, Abhicherla, Kuturgutta, Kuturu, Muluru, Bhagvanpuram, Repaka, Peddarukur, Ravigudem, Chinnaruku, Gundugudem, Chintharajupalle, Waddegudem, S. Kothagudem on the either side of Sabari River and Rekapalle, Pocharam, Pochavaram, Kukunoor, Tipurapendamedu, Gommuru, Morampalle, Nagineprolu, Dantenam, Tekulagudem, Peddagollagudem, Ramachandrapuram forest, Thathakur, Dacharam and Tirumalapuram are on Either side of Godavari River river. Same villages are also in the $H_3$ and $H_4$ hazard zone category.
6. Conclusion

The HEC-RAS model performance shows better performance when compared to RADARSAT satellite image. Inundation increases with increases in discharge values as shown in Figure 2. The villages falling in extreme category H₅ are Chidumurum, Chatti, Kummur, Bojaraigudem, Jallagudem, Markandeyulpeta, Tallagudem, Regulapadu, Abhicherla, Kuturgutta, Kuturu, Muluru, Bhagyanpuram, Repaka, Peddarukur, Ravigudem, Chinnaruku, Gundugudem, Chintharajupalle, Waddegudem, S. Kothagudem on the either side of Sabari River and Rekapalle, Pocharam, Pochavaram, Kukunoor, Tipurapendamedu, Gommuru, Morampalle, Nagineprolu, Dantenam, Tekulagudem, Peddagollagudem, Ramachandrapuram forest, Thathakur, Dacharam and Tirumalapuram are on Either side of Godavari River are most vulnerable villages as depth simulated in some part of this villages are greater than 5 meters so people from this villages an event occasion are suggest to move towards higher elevation such that away from river towards northeast if village are on northern side of bank of Godavari river and move towards southeast if village are on southern side of bank of Godavari river. For Sabari river, villages lying on East side of are suggest to move towards east direction and villages lying on west side of Sabari river are suggested to move towards to the west side away from river.
List of Abbreviations

DEM – Digital Elevation Model; CWC – Central Water Commission; MLIT – Ministry of Land Infrastructure and Transport (Japan); AWiFS – Advanced Wide Field Sensor; LULC – Land Use Land Cover

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