Hydrodynamic modeling of Subernarekha River and its floodplain using remote sensing and GIS techniques

Kiran Yarrakula, Debasis Deb* and Biswajit Samanta
Mining Engineering Department, Indian Institute of Technology, Kharagpur 721 302, India

Received 09 February 2010; revised 14 April 2010; accepted 19 April 2010

In this study, hydrodynamic modeling of Subernarekha River was conducted to develop a flood forecasting model. Digital Elevation Model (DEM) of study area was prepared using high resolution CARTOSA T-1 imageries and river cross sectional nodes were extracted from DEM. Remote sensing and GIS tools were used for data transforming from CARTOSA T-1 stereo images, inundation and damage areas. Results of hydrodynamic model of flood year 1997 matched quite well with those measured by Central Water Commission (CWC). Assessment of damage due to flooding of agriculture land, habitats, dense forest, mixed vegetation, scrubs, plantation, water bodies and barren land for 1997 were determined and elaborated.

Keywords: ARC GIS, CARTOSAT-1 DEM, HEC-RAS, Damage assessment, Hydrodynamic modeling, Validation

Introduction
Flooding induced by storm events is a major concern world over1-8. Subernarekha River is one of the longest flowing inter-state rivers in eastern parts of India (Fig. 1). Any flood inundation in mining area, may result in lot of radio-active pollutants accumulation in surrounding area. For this reason, flood inundation problems of Subernarekha River are of utmost important to mining companies, state government and local inhabitants. Remote sensing and Geographical Information Systems (GIS) based techniques are widely used for analysis, planning and framing of evacuation strategies in case of any flood related exigencies9,10. In this study, hydrodynamic modeling of Subernarekha River has been conducted to develop a flood forecasting model (Fig. 2).

Experimental Section
Digital Elevation Model of Study Area
Area under study lies within longitude of 86.29 E to 86.59 E and latitude of 22.35 N to 22.66 N in East Singhbhum district of Jharkhand. High resolution CARTOSAT-1 stereo data was procured from National Remote Sensing Centre (NRSC) for development of Digital Elevation Model (DEM). Refinements of imageries11 have been done using control points collected from Survey of India Toposheets. Projection system (UTM) and datum (WGS84) were used. DEMs were mosaiced and made as a single image (Fig. 3). Elevation of ground was found to be 24 m (Min.) and 709 m (Max.). Green area indicates hilly region and red area indicates low lying zones. Based on mosaiced DEMs, elevation contours (10 m) were prepared and verified with those of toposheets. Elevation levels were compared by taking random spot elevation points (233) from DEM as well as toposheets. DEM prepared by CARTOSAT-1 matched reasonably well with those of toposheets.

Comparison between Measured and Extracted River Cross Sections
River cross sections are key inputs for hydrodynamic modeling. Measured cross sections (MCSs) of river are available from Central Water Commission (CWC) at Adityapur on Kharkai River, and Jamshedpur and Ghatshila on Subernarekha River. Since MCSs are less for hydrodynamic modeling, 9 more MCSs were obtained by field survey between Ghatshila and Jamshedpur (reach length, 40 km). After preparation of mosaiced DEM, cross sections (239) at various locations were extracted using Arc View 9.1 from Jamshedpur to Bhoraghat. Error between MCSs and extracted cross sections (ECSs) was about 2.5% (Fig. 4). ECSs of channel and flood plains of river are presented at Jamshedpur, Ghatshila,
and Bhosraghat (Fig. 5). Bed elevation of river varies from 112.5 m at Jamshedpur to 24.95 m at Bhosraghat. ECSs from DEM were compared with MCSs. ECSs along with MCSs are displayed for Jamshedpur (Fig. 6a), Adityapur (Fig. 6b), and Mango Bridge (Fig. 6c).
Hydrodynamic Modeling of Subernarekha River

Runoff of river channel and floodplain were estimated using numerical modeling software, HEC-RAS. Using observed time series data of discharge and water levels, numerical analysis was performed considering unsteady flow condition. Mathematical framework and procedure of hydrodynamic modeling is explained as follows:

Unsteady Flow Equations

Water surface profiles and discharge at various locations along river were evaluated considering unsteady flow analysis in HEC-RAS software, which uses finite difference form of unsteady flow equations. Continuity equation describes conservation of mass for a system. For each time step, parameters of continuity
Fig. 5—Extraction of cross section of CARTOSAT-1 DEM from ARC View and HEC-Geo RAS software (cross-sections include flood plain)

Fig. 6—Comparison of river profiles at: a) Jamshedpur station; b) Adityapur station; c) Mango bridge
equation of hydrodynamic model were computed at each node.

**Boundary Conditions**

Stage hydrograph was used as boundary condition at upstream node at Jamshedpur, and at downstream node near Bhosraghat. Newton-Raphson iterative method was applied to obtain solutions. In addition, Gara nallah, one of the main tributaries of Subernarekha River, feeds substantial amount water inflow to river at Chakradharpur station. However, neither discharge nor water level data were available at this station. In order to account influence of Gara nallah, lateral inflow hydrograph was prepared and used as boundary condition in hydrodynamic model.

**Calibration of Model**

Friction slope of channel and floodplain is related to Manning’s roughness coefficient (MRC), a user-input parameter to calibrate hydrodynamic model. The model was calibrated using stage hydrograph data of flood years of 1985 and 1988. MRC varied to achieve close agreement between measured and model results of water level and discharge. MRC of 0.11 for banks and 0.047 for channel were found suitable to obtain desired water level and discharge values at measured stations located in Jamshedpur, Ghatshila, Jamsholghat and Bhosraghat. MRCs were used for analysis of runoff.

**Validation of Model**

Using calibrated hydrodynamic model, discharge and water level were validated during monsoon period from 16th June to 22nd September for 1997. A flood occurred along reaches of Subernarekha River resulting in devastating consequences. Validation process would be an indicative of how developed model simulates actual flood situation. Performance indices [Nash-Sutcliffe Coefficient ($E_n$), index of agreement ($d_a$), and % of deviation in peak] were used for validation process.

Measured and model predicted discharge with time is plotted for Jamshedpur (Fig. 7a) and Ghatshila (Fig. 7b) gauging sites. Severe flood occurred along reaches of Subernarekha River on 5th August 1997, resulting in discharge of water at Jamshedpur (6254 m$^3$/s) and Ghatshila (10583 m$^3$/s) gauging sites. Model predicted fairly well with water level at Ghatshila (Fig. 8a) and Jamsholghat (Fig. 8b) gauging sites. Index of agreement between model results and measured values varied (0.89-1.0 %), with deviation in peak ranges from -5.53 % to 0.32 % (Table 1). These results suggest that hydrodynamic model can be applied to forecast water level and discharge of Subarnarekha River.

**Results and Discussion**

**Damage Assessment**

Assessment of damage due to flood is an integral part of flood inundation mapping. Looking into floodplain
mapping (Fig. 9), major flood occurred at plains of Medinapore district of West Bengal. For assessing damages, satellite imageries of IRS P6 with LISS III sensor (spatial resolution, 23.5 m) were used to classify entire river basin into following 8 land use and land cover classes (Fig. 10): i) agriculture land; ii) habitats; iii) dense forest; iv) mixed vegetation; v) scrubs; vi) plantation; vii) water bodies; and viii) barren land. For classification of objects using ERDAS IMAGINE 8.5, supervised classification technique with nearest neighborhood algorithm was used. Accuracy of land use and land cover classification was assessed by selecting objects at 500 random locations of image. Overall classification accuracy (79.6%) with kappa statistics of 73.35% was achieved. Prepared land use and land cover classification map was overlaid by flood inundation map constructed using hydrodynamic model to assess damage due to flood along river reaches (Fig. 11). Analysis indicates that in 1997 flood affected areas (total, 13873.75 ha) were: agriculture land, 6228.38; habitats,
4663.69; dense forest, 11.81; mixed vegetation, 1706; scrubs, 181.38; plantation, 867.44; water bodies, 94.19; and barren land, 120.88 ha. Since Medinapore district of West Bengal, India, has huge agriculture land nearby Subernarekha River, it is most affected land due to flood followed by habitats.

Conclusions

Hydrodynamic modeling of Subernarekha River was conducted for a reach length of 154 km from Jamshedpur to Bhosraghat for forecasting flood levels. DEM was prepared using high resolution CARTOSAT-1 stereo imageries and 239 river cross sections were extracted for unsteady flow analysis of river. ECSs were validated by MCSs at 12 different locations along river. Results of hydrodynamic model in terms of water level and discharge were compared with flood data available for 1997. Nash-Sutcliffe coefficient of efficiency of discharge parameter of model was found 0.85-0.94, while deviation of peak discharge was -18.32% to 0.11%. Deviation of peak water level only varied from -5.53% to 0.32%. Thus, hydrodynamic model of Subernarekha River can forecast floods for different return periods. Assessment of damage of 1997 flood revealed that almost 13873.75 ha land in basin was affected, out of which 6228.38 ha belonged to agriculture land and 4663.69 ha in habitats. Water level over 3.5 m was covered around 3233.31 ha of land near Subernarekha River.

Acknowledgements

Authors thank Board of Research in Nuclear Science (BRNS), Mumbai, for sponsoring this project. Authors also thank Central Water Commission (CWC), for providing data.

References


