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FLOOD INUNDATION MAPPING AND 1-D HYDRODYNAMIC MODELING USING REMOTE SENSING AND GIS TECHNIQUE

Mr. Praveen Kumar Thakur¹, Mr. Accarapol Sumangala²

¹Scientist/Engineer, Water Resources Division, Indian Institute of Remote Sensing-Dehradun, India; thakur.praveen@hotmail.com

²Department of Public Works and Town & Country Planning Rama 9 Rd. Huaykuang, Bangkok Thailand; accarapol@yahoo.com

ABSTRACT

This study is an attempt to develop an integrated methodology for flood mapping using combination of RADARSAT, IRS LISS-III/LANDSAT satellites images and Geographic Information Systems (GIS), and Hydrodynamic modeling for September 2003 flood event of Puri District, Orissa, India. The main objective of this study is to generate flood inundation maps using DEMs (ASTER), flood modeling using hydrodynamic models and comparing with the flood extent maps derived from RADARSAT SAR satellite images (4, 11, 13 September 2003). The flood inundation areas were extracted from RADARSAT images by visual and digital interpretation. Digital Elevation Models from ASTER was used to derive cross sections in flood plain and six cross sections were collected during field visit to Puri district, which were further adjusted from cross sections as derived from DEMs. The stage-discharge relationships were established using the observed flood gauge and discharge data at available cross sections. Hydrodynamic model HEC-RAS (Hydraulic Engineering Center-River Analysis System) is used to find the longitudinal profile, water level and routed discharge along Bhargavi, Kushabhadra rivers and flood mitigation canal at upstream of Kushabhadra river. This information was further used in Hec-GeoRAS GIS to find out the flood inundation area. The results of this study show that integration of GIS and hydrodynamic modeling is an efficient way to predict and map the flood areas.

KEYWORDS: Flood, RADARSAT-SAR, IRS LISS-III/LANDSAT, 1-D Hydrodynamic modeling, ASTER DEM, HEC-RAS.

INTRODUCTION

Floods are considered the most significant natural disaster affecting from the perspective of their frequency, financial cost and most importantly the impact on the population and the disruption to socio-economic activities. Flooding refers the inundation of an area by unexpected rise of water by both dam failure or extreme rainfall duration and intensity in which life and properties in the affected area are under risk.

There is one problem with the use of conventional passive sensor satellite imagery for flood inundation mapping as floods occur during or immediately after periods of heavy rainfall. In India, generally flood occurs during monsoon period and at that time due to the cloud cover, optical remote sensing image has their limitation in mapping the flood extent, so radar image can be used for accurately mapping the extent of flood. The active Synthetic Aperture Radar (SAR) sensor allows acquisition of images independent of cloud cover, so in many studies, combination of Geographic Information System (GIS), SAR imagery, high resolution digital elevation model (DEM) gives the flood inundation map with flood depth.

The advantage of 1-D hydrodynamic models is that they provide a very accurate description of the water levels and discharge along longitudinal river profile and at selected cross sections across the river. This study is an attempt to develop an integrated methodology for generate flood inundation map on using GIS and hydrodynamic modeling and to obtain flood risk map in flood area of Mahanadi delta Orissa.

OBJECTIVES

The broad objectives of this study are:

1. Analysis of the flood frequency to understand behavior of flood over study area from observed gauge and discharge data.

2. To generate the flood inundation maps using combination of 1-D hydrodynamic models and GIS environment.
3. To prepare flood risk map over study area.
4. To evaluate and compare the flood inundation area from microwave remote sensing data and that simulated from hydrodynamic models.

STUDY AREA

The study area is in Delta region of Puri District of Orissa state and is located at 85° 45' 22.32" E; 20° 21' 20.36" N to 86° 04' 01.65" E; 19° 48' 47.52" N. This District is closed to the Bay of Bengal. The District of Puri, the holy land of Lord Jagannath is located in the coastal track of Orissa. Its boundaries extend in the north to Jagatsinghpur District, in the south to the Bay of Bengal and Ganjam District, in the west to Khurda District and in the east to the Bay of Bengal. Figure 1 shows the 23rd October 2000 Landsat image of study area.

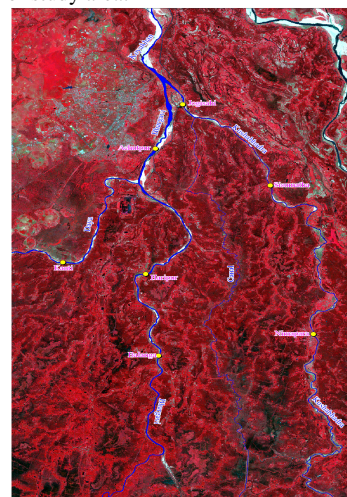


Fig. 1: 23rd October 2000 Landsat image of study area.

FLOOD STUDIES USING ACTIVE SAR

The use of airborne and satellite synthetic aperture radar (SAR) with its cloud penetrating day and night capacity has developed considerable potential for measuring flood extent. Ormsby and Blanchard, (1985); Pultz and Crevier (1997); carried out some of the earliest experimental work on SAR response to flooded vegetation using X-band, C-band and L-band imagery. They concluded that response depend on wavelength, plant volume and the geometry of the inundated vegetation. Wang, et al. (1995) has also studied radar backscatter from flooded forests in Brazil.

Honda et al., (1997) carried out a study "Flood Monitoring in Central Plane of Thailand Using JERS-1 SAR Data" for central plane of Thailand. A study on "Capability of Radarsat Data in Monsoon Flood Monitoring" (Shafiee, et. al., 2000) was carried out. In their study they used multi temporal and multi mode of RADARSAT data for monitoring of flood. Radar image processing and analysis including special filters were tested. The Radarsat images were combined with Landsat-5 TM and produce the window profile to confirm the flood area. Vector of flood area extracted from the radar images overlay on the Landsat-5 TM to produce the flood mapping. These studies showed that SAR images have potential and capability to monitor and map the flood event.

THEORY OF 1-D HYDRODYNAMIC MODELING

The 1-D hydrodynamic model is based on flow in open channel theory. Open channel flow is defined as the flow of a free surface fluid within a defined channel. Typical examples include flow in natural streams, flow in constructed drainage canals, and flow in storm sewers. The development of plans to effectively manage floodplains requires that hydraulic engineers understand the hydraulics of open channel flow, which depend on the flow classification, flow and conveyance, and the energy equation.

In open channel flow, the continuity equation for steady flow relates flow to velocity and area. The equation states that flow must be conserved between adjacent cross sections, the total energy per unit weight (energy head) has components of elevation head, pressure head, and velocity head and the momentum equation is expressed in the form of the Manning's equation.

Water surface profiles are computed from one cross section to the next by solving the Energy equation with an iterative procedure called the standard step method. The Energy equation is written as follows:

$$H = y + z + \frac{\alpha V^2}{2g} \quad (1)$$

where: H = energy head (m)
 z = base channel elevation (m)
 α = velocity weighting coefficient.

Based on these parameters, the water surface elevation is the sum of y and z . The change in energy head between adjacent cross sections is equal to the head loss:

$$H_1 = H_2 + h_L$$

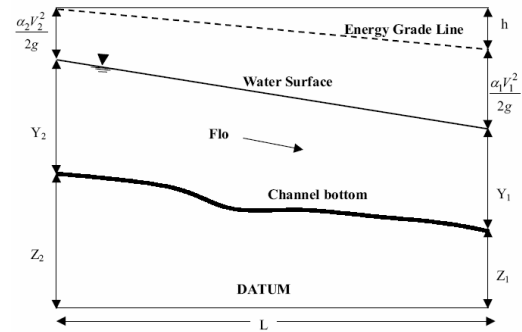


Figure 2.0 Energy equation parameters

(2)

where: H_1 = energy head at cross section 1 (m)
 H_2 = energy head at cross section 2 (m)
 h_L = energy head loss (m)

The head loss between the two cross sections is the sum of friction head loss and flow contraction/expansion head loss. Friction losses result from shear stress between the water and channel bottom:

$$h_f = L S_f$$

(3)

where: h_f = friction head loss (m)
 L = distance between adjacent cross sections (m)

Contraction/expansion head losses can occur as a result of the formation of eddies wherever there is a contraction or expansion of the channel:

$$h_o = C \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right|$$

(4)

where: h_o = contraction or expansion head loss (m)
 C = contraction or expansion coefficient

Consider the Figure 2.0 the flow from section 2 to section 1 must be conserved.

$$Q = V_1 A_1 = V_2 A_2$$

(5)

where: Q = flow rate/discharge (m^3/s)
 V_n = average velocity at cross-section n (m/s)
 A_n = area at cross-section n (m^2)

And conveyance is calculated from the following form of Manning's equation:

$$Q = K S_f^{1/2} \quad K = \frac{1}{n} A R^{2/3}$$

(6)

where: K = conveyance ($m^{8/3}$)
 S_f = average friction slope
 n = Manning roughness coefficient
 R = hydraulic radius (m)

The Manning coefficient (n) is a parameter that measures the effect of the roughness of the channel on the flow of water through it. The values, which vary based on channel terrain, are published in most hydraulic engineering books. The hydraulic radius (R) is calculated by dividing the cross-sectional area by the wetted perimeter. The value of channel slope (S) is derived from DEM of area.

DATA USED

- Landsat ETM+ of path 139 and row 46 acquired on 23rd October 2000 (pre-flood). It has 7 bands, with a spatial resolution 30 meters, shown in figure 1.
- Radarsat image during peak flood and post flood, dated 4th September (peak flood), 11th September and 13th September 2003 shown in Figure 3.2 respectively.
- Digital Elevation Model (DEM): The study area is in restricted zone, so small scale topographic maps are not available. Therefore, ASTER DEM acquired on 25th September 2004 which was available from the public domain on internet has been used in this study.

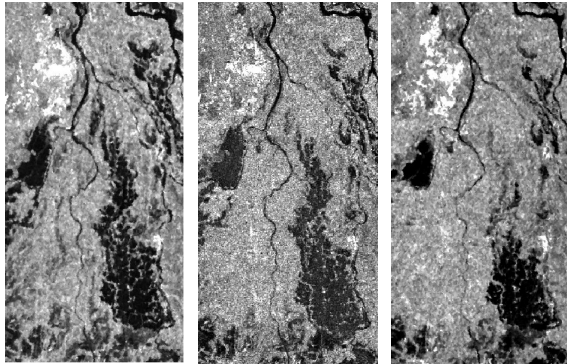
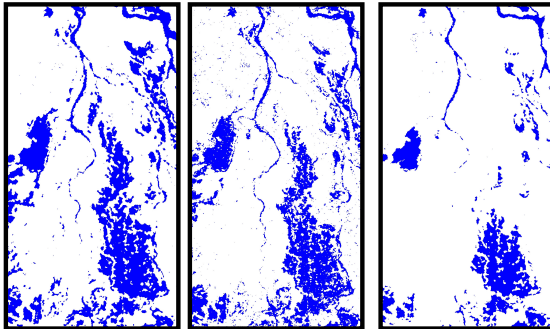


Fig. 3.0 RADARSAT-SAR of 4, 11 and 13 September 2003

RESULTS

Flood Inundation Maps using SAR

The flood inundation maps are prepared in ILWIS 3.2 by using slicing technique for three different dates 4th September 2003, 11th September 2003 and 13th September 2003. To prepare the map of threshold digital number (DN value) for water body was defined and the flood inundation maps were generated by an IFF command. It was found that flood area on 4th September 2003 about 363.023 km², 11th September 2003 about 329.15 km² and 13th September 2003 about 180.27 km².



a) 4th September 2003 b) 11th September 2003 c) 13th September 2003
Fig. 4.0: Flood inundation maps using RADARSAT-SAR

Flood Inundation Maps using Hydrodynamic Models

The inputs data files, i.e., river network, cross-section and storage area were created in Hec-Geo-preRAS and exported for hydrodynamic simulation in HEC-RAS. The 1-D Hydrodynamic modeling was done in HEC-RAS and the results of the simulated water surface profiles matches closely to the observed gauge data at available five river cross sections as given in table 1. The input hydrograph and adjusted cross section data with simulated water profiles for Sisumatha gauge site is given in figure 5, 6, 7. The results of hydrodynamic modeling done in HEC-RAS were again exported to HEC-Geo-postRAS for simulating and mapping flood inundation area in GIS environment. The flood inundation maps generated from geopostRAS are shown in figure 8.

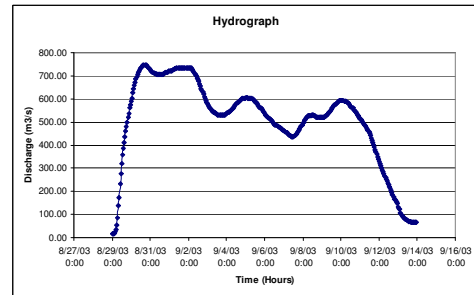


Fig.5: Discharge Hydrograph at Sisumatha gauge site

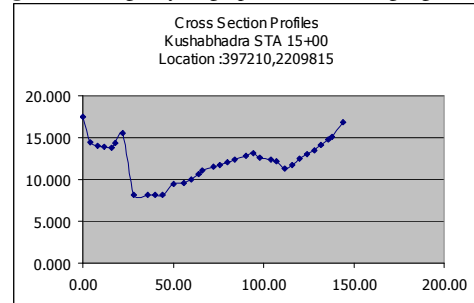


Fig.6: Kushabhadra River X-Section at Sisumatha gauge site

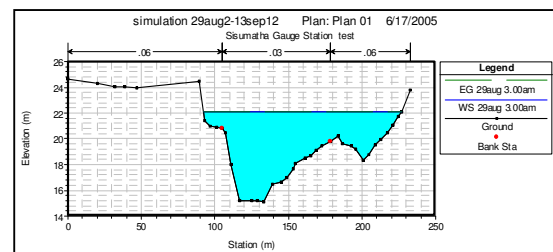


Fig.7: Water level results in each cross-section

Comparisons of flood inundation maps shows that flood maps generated by RADARSAT-SAR imagery (figure 5), and flood area extent derived from hydrodynamic model. (figure 8) almost matches with each other. The flood area statistics is given in table 1

Table 1: Flood area from HD Modeling and SAR analysis

Date	Flood area from HD models (km ²)	Flood area from SAR (km ²)
4 Sep 2003	333.96	363.02
11 Sep 2003	293.50	329.15
13 Sep 2003	102.45	180.27

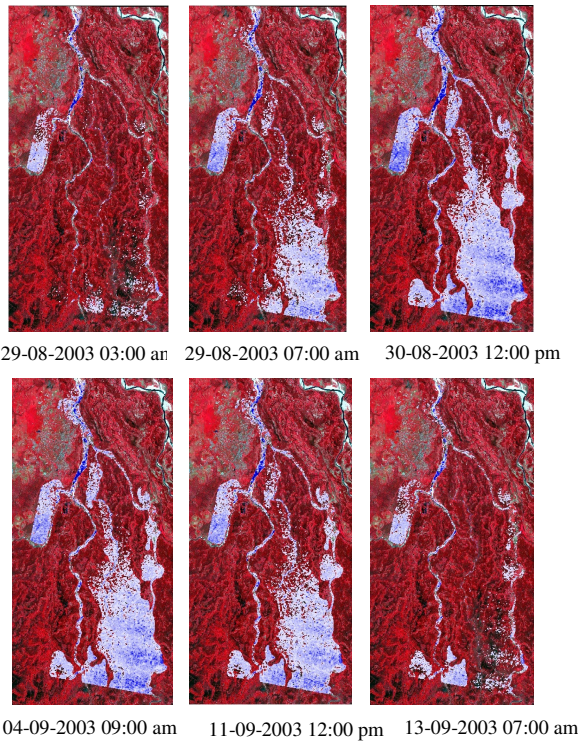


Fig. 8: Flood inundation maps from hydrodynamic model

Date	Time	Jogisahi		Simamtha		Achalpur		Balanga	
		Simulated	Gauge	Simulated	Gauge	Simulated	Gauge	Simulated	Gauge
29 Aug 2003	3:00 AM	24.30	27.65	22.09	21.11	29.62	30.40	14.97	15.95
29 Aug 2003	5:00 AM	25.10	28.25	22.33	21.76	31.40	30.98	15.26	16.13
29 Aug 2003	7:00 AM	27.19	28.89	22.66	22.65	32.26	31.52	16.07	16.67
29 Aug 2003	12:00 PM	28.44	29.51	24.12	24.50	33.46	32.76	18.38	18.31
30 Aug 2003	12:00 AM	30.92	30.50	25.24	25.66	34.63	33.98	20.00	19.93
30 Aug 2003	7:00 AM	31.38	30.73	25.68	26.02	34.38	34.17	20.41	20.41
30 Aug 2003	12:00 PM	31.46	30.78	25.84	26.14	34.00	34.18	20.58	20.60
2 Sep 2003	12:00 AM	30.84	30.54	25.63	25.98	31.40	33.49	20.38	20.37
4 Sep 2003	9:00 AM	30.31	30.20	25.29	25.56	32.17	33.21	20.03	19.79
7 Sep 2003	12:00 PM	28.43	29.62	24.63	25.06	31.92	33.00	19.61	19.47
9 Sep 2003	9:00 AM	30.27	30.14	25.24	25.49	33.08	33.40	20.05	19.78
11 Sep 2003	12:00 PM	28.50	29.54	24.69	25.12	31.90	33.08	19.73	19.61
13 Sep 2003	7:00 AM	25.63	27.71	22.67	22.66	28.28	31.38	18.23	18.19
Correlation		0.99		0.99		0.77		0.99	

Table 2: Comparison of simulated & observed gauge data

DISCUSSTIONS

The comparison of the Radarsat and hydrodynamic models shows the slight difference in the flooded area; this can be due the fact that in hydrodynamic modeling we have considered only three river reaches for flood simulation, whereas Radarsat Image shows water inundation for the entire delta river network of the study area. For accurate comparison, further image processing of Radarsat image is required to *exclude* the areas which are not modeled by the hydrodynamic models.

The results of this study shows that the accuracy of the simulated water flows and flood inundation maps can only be improved with incorporation of accurate high resolution DEMs and more dense network of river cross sections.

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Annexure I: FIELD PHOTOGRAPHS



a) Khukhai bridge site near Bhubaneswar



b) Flood Mitigation Canal



c) Kushabhadra downstream at Nimapara Bridge



d) High flood level at Nimapara Bridge Gauge Site



e) Bhargavi downstream at Balanga



f) Agriculture area besides Bhargavi River near Dhauli

Annexure II: Methodology Flow Chart

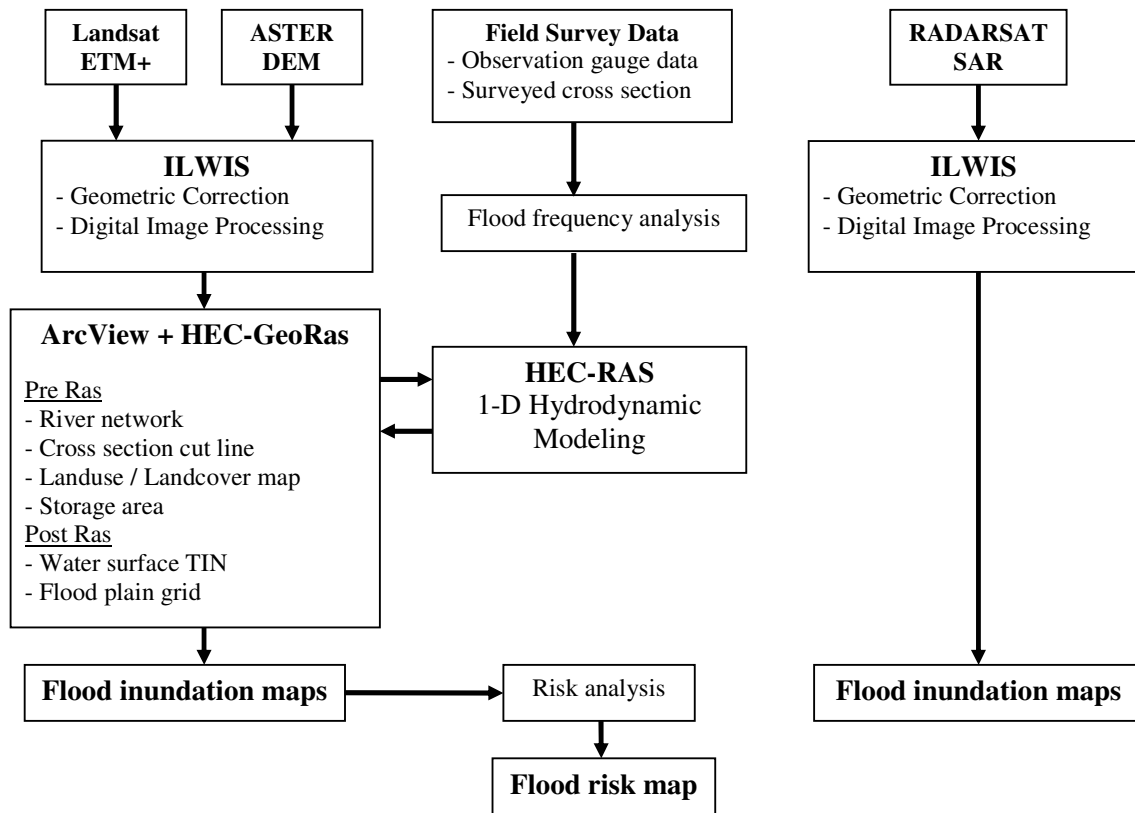


Figure: Flow chart of methodology