FLOOD STUDIES USING REMOTE SENSING AND GIS

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Introduction

In India yearly average and maximum area affected from floods are nearly 8 and 18 million ha respectively. Annually affected mean and maximum crop area are nearly 3.5 and 10 million ha. Mean and Maximum population affected have increased to nearly 50 and 70 millions. Flood control measures namely construction of new embankments, drainage channels, afforestation etc. took place to combat this. Geographic distribution of embankments lengths constructed by the end of March 1993 was Assam (28 %), Bihar (17 %), Uttar Pradesh (11 %), Punjab (8 %), Orissa and West Bengal (7 % each), Gujarat (6 %), Andhra Pradesh and Harayana (4 % each) and rest of country (6 %). Through flood control programme nearly 12, 13, 11, 19, 3, 14, 3, 0, 12 % areas of these states were protected. These figures indirectly highlight states in country that are prone to flood. Ganga, Brahmaputra, Indus/ Ghaggar and Mahanadi rivers are more flood prone rivers in India.

Many structural and non- structural flood control measures are adopted in India. In spite of these measures, floods cause damages in both protected and un-protected flood prone areas repeatedly. During floods, damages to flood control structures, public/ private properties and infrastructure including transportation, houses, industries etc. take place. Human and cattle lives are lost. To plan flood control measures and manage floods, modern technology of remote sensing and GIS are being used in India.

Causes of flood

Monsoon rainfall: Heavy monsoon rainfall in a catchment causes large runoff in rivers and their tributaries.

Cyclonic rainfall: It is one of main cause of floods in coastal areas and mainland. Cyclone may originate from Arabian Sea or from Bay of Bengal or both. When cyclonic depression enters the land from ocean and persists for days, it causes heavy rainfall. The rainfall occurs over hundreds of km. More rainfall usually occurs seawards of the track and near the storm centre. But heavy rainfall may occur away from the centre of the storm, specifically, if the storm centre is in the middle of the peninsula.

Storm surge: In cyclones, the winds cause rise in the ocean water level. This causes inundation of the flat coastal area up to hundreds of km. Storm surge can be as high as 5 m or even more.

Tidal bore: In the coastal areas, the storm surge causes a reverse flow in the rivers which in turn inundates floodplains of the rivers.

Discharge from dams: When heavy rainfall occurs during September to November causing large inflow to reservoirs that are full, the forced outflow from reservoirs causes flood.

Dam break: Dam breaks/ breaches due to over toping/ piping of the earthen dam or structural failure in dam etc.

Floodplain

Floodplain is defined as the low lying land adjacent to a stream channel that gets inundated due to past or present flood event or is likely to be inundated from future flood event. Usually, land adjacent to river has low gradient and any increase in flood level in river causes inundation of these areas. In some instances, this area may be very large. Usually, area in the floodplain is fertile, and thus the inundation of this area causes loss of income to the farmers. The settlements also come up in the floodplain and thus, floods also cause loss to property and life due to submergence. To protect these areas, often embankments or dykes are constructed near major rivers. Villages in the floodplain are either enclosed by ring dykes or are raised. The dykes have affect in reducing the flooding. They are usually designed for floods of 25 years return period due to economical reasons. Floods of return period larger than 25 years may sometimes cause overtopping or breaches in the embankment. These may cause large-scale inundation and losses. The areas up to larger distance from the river course may get inundated due to flood wave propagation in such cases. Various definition of the floods/ floodplains are given below:

Base flood: Base flood is defined as flood of 100 years return period.

Base floodplain: Base floodplain is defined as area inundated due to passing of base flood in the river. This is also synonymous with regulatory floodplain and floodway.

Regulatory floodplain: The floodplain that is subject to floodplain land use regulations is called regulatory floodplain. It is a floodplain of 100-year return period.

Floodway: Floodway is floodplain that caries a flood of large magnitude, say 100 year return period, which is required to pass flood without causing much increase in height of the flood.

Severe flood: It is defined as the flood that causes at least a rise of the stage in the river two meter above the danger level.

Floodplain management

Floodplain management involves modifying floods or its impact to reduce the losses due to flood inundation and to provide relief to the people. The management activities may be driven by economic goal and/ or for preserving the natural value of the floodplain. The natural values include the hydrology of the floodplain, flora and fauna including fishes, water quality etc. Various management alternatives are listed below:

A. Modifying the floods
   Reservoir and dam
   Dykes
   River channel modifications
   Land treatment
   Diversions
   Detention basins

B. Modifying the susceptibility
   Floodplain regulations

Warning and preparedness
Floodproffing

C. Modifying the impact
Flood insurance
Relief and restorations

Remote sensing technique

Remote sensing provides synoptic and frequent observation of the earth surface. Frequent coverage of the earth surface is done through, in particular, satellite remote sensing. Earth is observed at twice daily to nearly 20 days interval through various sensors. Thus, it is possible to obtain coverage of the flood inundated area prior, during and after the flood event for flood inundation mapping and monitoring. The information generated can be used in flood fighting, flood control planning, flood management, floodplain zoning etc. Using conventional technique, delineation of flood-inundated area is difficult, costly and time consuming. Accessibility of inundated area will be difficult and it may not be feasible to map complete affected area due to accessibility and longer time taken in conventional survey. For real time applications, satellite data can be obtained through priority services of data providing agency.

Time of peak flood and satellite overpass may not coincide and thus, the maximum extent of flood may not be possible to delineate directly due to receding of the flood. However, the area from where flood is receded will have wet soil and thus maximum extent can be delineated indirectly. During rainy season, the sky is often clouded and thus, the images are often either fully clouded or only part of flood-inundated area is visible. Active microwave radar data can offset this problem. The microwave EMR have cloud penetration capability and thus earth can be observed even in presence of cloud. Active microwave sensors are few in number, data acquisition are through prior programming and data are nearly ten times costly than optical data. For critical applications, these data can be used. Satellite data cannot be used for estimation of inundation depths. For real time applications, data obtained through priority services are costly than through regular service.

Interaction of EMR with water

EMR interacts with earth surface through reflection, absorption and transmission. Transmission of EMR takes place in transparent bodies e.g. water. In reflection, EMR is redirected to the media, namely air, from where signal has arrived. For water surface, specular reflection takes place. In specular reflection, the reflected EMR is directed in a single direction, angle of incident being equal to angle of reflection. A part of EMR is transmitted in water body. Transmitted EMR interacts with water molecules, dissolved and suspended particles/ molecules. Transmitted EMR is scattered and absorbed within water. Absorption of EMR increases with wavelength. In infrared band, absorption is very high. Penetration of EMR is dependent on both scattering and absorption. In infrared wavelength, penetration of EMR is only few cms, whereas for visible EMR, penetration can be of order of 1- 20 meters. Increased turbidity reduces penetration of EMR. Presence of chlorophyll also modifies signature of water. Floodwater carries high sediment load as compared to water in lakes and ponds. Thus, floodwater has high DN compared to water in lakes and ponds. This property is useful in discrimination of floodwater from lake and pond water/ wetland. Colors of flooded area in standard FCC of during flood images are cyan, blue and black. Areas flooded by river flows have cyan to blue color. Water collected in the low-lying areas in the countryside of the embankment has black color.

Similar to optical and infrared EMR interaction with water, microwave EMR is specularly reflected from water surface. Interaction of matter with MW depends on electrical properties of matter and smoothness with respect to wavelength. Moisture has low backscattering coefficient. Thus, at medium to large incidence angles, calm water has dark signature. At low incidence angles, since specularly reflected MW EMR is partly received by the sensor, water appears bright. Similarly, rough water surface due to large waves appears bright due to diffuse reflection caused by rough surface.

In flooded forest areas, double bounce affect takes place and thus, areas appears bright. In double bounce effect, specularly reflected MW signal from water, strikes stem of trees. From the stem, MW signal is reflected back towards the sensor. The tree canopy has diffuse reflection. Thus, total backscattering coefficient is increased in flooded forests compared to non-flooded forests due to double bounce effect of trees.

Inundation mapping

Optical remote sensing data

For inundation mapping, both visual interpretation and digital image processing techniques are in use. In visual interpretation, element of interpretation namely, color/ tone, texture, size, pattern, association, shape are used to identify objects and delineate flood inundation areas. A photo interpretations key is prepared in which elements are listed for objects. For interpretation, FCC or near infrared images can be used. Cloud shadows are difficult to differentiate from clear water areas. Similarly, flooded area and urban areas cannot be differentiated well.

Digital image-processing techniques

Density slicing

Density slicing of near infrared band DN may be used for delineating flood inundation areas. The threshold of DN for floodwater is selected through on- screen identification of floodwater. Water has DN lower than the threshold.

Image classification

In image classification, both supervised and unsupervised classification techniques have been used. In supervised technique, training samples are selected for various objects and statistical parameters are estimated. These parameters are used to determine probability measures for each class. A pixel is assigned a class for which the probability/ distance measures are highest or lowest respectively. With probability measure, multivariate normal distribution function is used. Distance measures e.g. Euclidian or Mahalanobis are used. In unsupervised classification, clustering techniques e.g. ISODATA, sequential clustering etc. are used. The clusters are assigned classes based on spectral signature, ground truth etc.

Normalized Difference Water Index (NDWI)

The index is determined by subtracting near infrared band DN from green band DN and finding ratio of this difference and sum of DN in green and near infrared bands. McFeeters developed the index in 1996. Areas with NDWI higher than zero were identified as water. However, the index was later used with threshold for water discrimination different from zero. The threshold was read by displaying the NDWI along with FCC. NDWI was also found suitable for delineating flood inundation areas. For example in delineation of flooded areas in Kahalgaon, Bihar, thresholds for IRS LISS III data were 50 and 60 on stretched NDWI data.

Radar

Active microwave or radar data are very useful in flood inundation mapping both for vegetated and non- vegetated floodplains. Open water appears in black tone. Flooded forests appear brighter than non- flooded forests due to double bounce scattering in former. Flooded sparse forests have medium brightness and thus are difficult to discriminate from other land features. Data are pre processed and then analyzed to obtain flooded extent. Pre processing depends on radar sensor. Radar data can be converted backscattering coefficient (σ^0) images. The images are further filtered to remove speckle noise. Speckle noise results in granular texture in images and it hinders identification of fine details. Commonly used filters for speckle removal are median and enhanced Frost filter. Filter window size can vary from 3 X 3 to 7 X 7. The filters remove speckle, retains edges and smoothens images. Filtered radar data are georeferenced and used for further analysis.

For obtaining thematic maps from radar data, techniques e.g. visual interpretation, density slicing, classification etc. can be used. Visual interpretation is simplest technique. Flooded areas are delineated based on interpretation key prepared. Histogram with two peaks is obtained from flooded area radar image. From this histogram, a threshold can be selected for delineating flooded area. Area with σ^0 smaller than threshold is assigned open water theme. Threshold for σ^0 varied in range of –6 to –4 dB for discriminating flooded and non- flooded forests.

Regression method

For dealing the situations when remotely sensed data are not available, a regression may be developed from past data of inundation area. The estimated inundation area, in turn, could be used in estimating damages. A regression relationship between inundation area and other hydrometeorological variables is established. This may used to estimate inundation areas from hydrometeorological variables. Variables namely gauge and rainfall data were used in Marigaon, Dhemaji and Dhubri districts and Kosi basin. In Assam, multiple- regression was used with correlation of 0.68 to 0.71. In Kosi, relationship with a single river gauge was established with coefficient of determination 0.973. Reason for lower correlation could be effect of factors other than the hydrometeorological variable. For example, duration of flood, breach location etc. could also influence the extent of flooding.

Damage estimation

Flood causes damages to life and property e.g. industry, business/ trade, houses, infrastructure, crop etc. Estimation of damages to houses, infrastructure is difficult using remote sensing technique. estimation of damages to crop has been done using the technique. Crop damage is estimated as follows:

Damage to crop= (Loss in yield+ cultivation cost)* Loss factor

For example, cost of damage for paddy was estimated as Rs 8505/ ha and cost of cultivation was Rs 4250/ ha in Assam. Normal yield for paddy varied from 550 to 1823 kg/ ha. The inundated crop areas were estimated by overlaying inundation area map and land use map. The loss factor was chosen based on general damage assessment in the area. General damage to crop in an area will depend on duration and depth of flooding. Difference in estimate from remote sensing technique and that by state Government was of order of nearly 60% for Marigaon district.

Infrastructure mapping

Embankment

Information on embankments is often needed in flood modeling, river migration studies etc. Retirement embankments are constructed due to erosion of existing embankment. Conventionally, embankment maps are prepared through ground surveys. The maps are not often revised due to high cost of survey. Remotely sensed data could be used in mapping of embankments due to low cost, frequently available data. Embankments are identifiable on medium (e.g. IRS LISS III) to fine resolution (e.g. IRS Pan, LISS IV etc.) data. Embankments are linear features and located on either side of river channels. They protect vast floodplain from flooding. On LISS III data, these are often visible in patches due to medium resolution. New embankments are more clearly identified. Once vegetation/ grass is established on embankment, contrast of embankments with surrounding reduces. On fine resolution panchromatic data, embankments are clearer compared to medium resolution data. Thus, satellite data can be used to update the embankment/ river channel maps frequently.

Villages

In floodplain large number of villages are located due to availability of land and water resources. There is further growth in habitation areas of existing villages as well as new habitation areas are developed. This increases susceptibility of population to floods. In past, there was natural selection of upland areas for habitation. But, with increase in population pressure, more and more floodplain areas are being occupied. Settlement maps can be prepared using remotely sensed data and may be integrated with flood inundation maps to determine flood affected population/ villages.

Landuse

Crop/ horticulture area in the floodplain is susceptible to flooding. A land use map may be prepared for the floodplain. The map may be overlaid with inundation map to estimate damages. The damages so estimated will be only approximate, since all crop area may not be cultivated at the time of flooding.

Non-flooded area

Uplands in the floodplain may not get flooded. Location of these upland parcels in vicinity of villages may be important in flood fighting. Upland parcels in vicinity (e.g. up to 500 m) of villages may be utilized for construction flood shelters. Such parcels should be of sufficient size for their effective utilization. Thus, delineation of these parcels is needed. This may be done using a during- flood image. Flooded areas with trees are misclassified as non- flooded area. View of areas beneath tree canopy is obscured in optical remote sensing data. Similarly, rooftops of flooded houses are misclassified as non- flooded areas. Such areas are to be eliminated from non- flooded area for flood- shelter analysis.

Channel migration

Channel migration is a natural process. All rivers, meandering or braided, exhibit some changes. Meandering rivers are river with single channel and braided rivers are rivers with multiple channels. For same river, both patterns may exist in different reaches. The type of a river pattern is dependent on river discharge and sediment load, bed slope, bank material etc. These characteristics are variable over time and space. This makes the river pattern variable over both time and space. However for certain river reaches, in general, definite channel pattern emerges. Using remote sensing the planform of the river can be studied over space and time. Planform characteristics can be related to river dominant discharge using many empirical formulas. Planform characteristics are also related to each other empirically.

Quantification of channel changes

For quantification of channel changes, multidate satellite data are georeferenced and river channel is delineated. Active channel consists of both river water and river sand. Both during monsoon and post monsoon images can be used. In images acquired during monsoon period, the width of river is large and thus less river sand area is visible. In post monsoon images, width of rivers is small and sand bars are clearly visible. After delineation of channels, the channel migration is quantified using following methods:

1. Distances of both banks of river channels are measured from regularly spaced points on a fixed straight line. By subtracting these distances, migration of riverbanks is determined. The distances are also plotted with distance along fixed line on x- axis and distances to banks on y- axis.
2. In a variation of above method, instead of single straight line, multiple line segments may be used as fixed lines. This method may be useful in case, large changes in river orientation takes place within study reach.
3. In another method, fixed curved line is used and is drawn along the central line of recent river channel. This method may be useful to study bank erosion over short period of time.
4. Large migrations are visually identified and measured.

Channel avulsion

Due to morphological and tectonic reasons, avulsion is rivers takes place. Old course is converted to paeleao channel with misfit rivers. Misfit rivers are rivers with low mean discharge flowing in to valleys of rivers of large mean discharge. The changes may be episodic or slow. Period may be of order of 100’s of years. Oversized engineering structure may be left over misfit rivers and structures over new river courses will be rendered undersized. Channel avulsion takes place both in alluvial piedmont/ fan areas and in plains. In plains, avulsion may be due to tilting of plates.

Planform

River geometry also known as river morphology defines cross- section, planform and longitudinal profile for rivers. Planform is a plan view of the river. Remote sensing technique is a spatial mapping tool providing synoptic coverage. It is suitable for studying the river planform. Rivers are classified as straight, sinuous or meandering. The straight channels, with lengths larger than approximately ten times the width, are rarely found in nature. Sinuous or meandering river can be quantitatively characterized by properties e.g. wavelength, amplitude, radius, sinuosity etc.

Sinuosity: Sinuosity is defined as a ratio of channel length to the valley length.

Wavelength: Wavelength is defined as straight-line distance between equivalent successive points in the meanders i.e. a straight line distance between loops in same phase.

Amplitude: Amplitude is the distance between the crests of the successive opposing loops.

Radius: Radius is the radius of a meander loop.

Many of the meander characteristics are related with each other empirically and also to the hydrological quantities e.g. representatives discharge in a river.

Dury (1956) has related the wavelength and bankfull discharge:

$$L = 54.3Q_b^{0.5}$$

Where L is Wave length

Q_b is bankfull discharge

Leopold and Wolmand (1960) gave formula relating meander wavelength and loop radius:

$$L = 4.59r_c^{0.98}$$

Where L is wavelength
r_c is loop radius

Remote sensing based flood studies

Brahmputra (Marigaon district of Assam): Rao et al. (1998) have mapped inundation in Marigaon using IRS and ERS data. Three date ERS data were acquired at an interval of less than a week. The data corresponded to post flood and during flood (rising limb) dates. By overlaying administrative zone maps and land use map, the flood inundation extent and crop damage extent is computed at sub division (Mauza or Tehsil) level.

Speckle is removed from ERS data by applying median filter. Flood boundary is delineated using density-slicing technique.

Kosi: Flood inundation mapping and risk zoning is done in Kosi floodplain. Seven date satellite data are used that included both during and post flood data. Regression relationship between gauge height at a point and inundation extent is estimated with coefficient of regression computed as 0.972. Error after jack- knifing one point is 5.94%. The return period is determined for different flood extent and drainage congestion area is mapped (Rao et. al 1998).

Punjab: Rajiv Mohan et al (1993) have mapped flood affected area in Punjab using IRS LISS I FCC at 1:250,000 scale through visual interpretation of July 1993. Two flood affected categories namely severely flooded (>50% area submerged) and moderately flooded (25- 50% area submerged) are mapped. Less area is flooded in the Satluj floodplain, where as in Ravi, Beas and Ghaggar floodplains large area is flooded. Northern and eastern parts of Punjab are more flood affected. Embankment breach in rivers and canals, drainage congestion, release from dam (Pong dam on Beas), poor maintenance of drainage and embankments, silting, weed growth in drainage and siphons are stated to be main causes of flooding. For three district in Punjab namely Patiala, Fatehgarh and Rupnagar, ERS paper prints at 1:100,000 scale are visually interpreted to map flood affected areas (Dhaliwal et al 1995). For Rupnagar district, both moderately and severely flooded area is located in the western part of the study area. Latter areas are located at lower elevations than former.

Haryana: Hooda et al. (1995) mapped flood inundation in Hisar and Jind districts of Haryana using IRS LISS I FCC at 1:250,000 scale, for October 1988 and at 1:50,000 for July 1993 through visual interpretation. Latter data was useful in delineating standing water (dark to light blue) as well as wet soil areas (light to dark grey). The meteorological data indicate that though annual rainfall was not very high in these years, flooding was more than usual. Small stream and escape channels from northern side and heavy local rainfall caused floods. Other causes are drainage conjestion and silting and weed growth. Local depressions and palaeo channel are locations where floodwater gets stagnated. Ring dyke and maintenance/ extension of a diversion channel for Ghaggar, utilization of palaeo channels as drains etc. are the flood control measures suggested.

Ganga: Many studies are completed for flood inundation mapping in Ganga basin. Jha (1993) has mapped flood inundation in Punpun catchment using Landsat MSS FCC and visual interpretation technique. Punpun and Ganga confluence is located downstream of Patna. Catchment area in 8530 sq. km. Elevation ranges from 50 to 300 m and average annual rainfall varies from 992 mm to 1335 mm. Mainly lower catchment is flood affected due to depressions in topography. Other causes of floods are low bank height, drainage congestion etc.

Anil Kumar (1993) has mapped flood inundation and wet land classes in Ganga floodplain on IRS LISS II FCC through visual interpretation. Large extent of wet land is delineated especially on right bank of Ganga up to its confluence with Sone. FCC for November and March 1989 are used.

Chaturvedi and Rajiv Mohan (1983) have mapped flood inundation area in Ganga and its tributaries on Landsat MSS band 7 data of September 1982 through visual interpretation. The inundated floodplain width for Ganga varies from 2.5 km to nearly 7 km from 81°E to 82.7°E longitudes. Inundation width for tributaries namely Sai, Ami, Rapti and Ghaghra are respectively 1, 8, 4 and 9 km. Flood affected villages are marked. Floodplain is not uniformly inundated along length of river and also certain tributaries e.g. Yamuna, Bakiani, Varuna and many small left bank tributaries to Rapti are not affected by flood.

<u>Burhi Dihing, Assam:</u> Flood inundation mapping and zoning is done in a part of Burhi Dihing river basin. The basin is located in the plains west of the Jaipur- Digboi hill ranges. The length of the reach is approximately 60 km and the study area is approximately 1627 sq. km. Main tributaries are Sali and Tingrai and both are right bank tributaries. Of these Sali is larger tributary. This tributary joins the Burhi Dihning near the confluence with Brahmputra.

The satellite remotely sensed data are used to map the flood prone areas. January and May to December data of optical sensors IRS LISS-II and IRS LISS-III are used for period 1988 to 2002. The rule based classification is done in ERDAS imagine software. The rules are based on NDWI (Normalized Difference Water Index) and DN in image bands namely blue, green and infrared. Cloud shadow is misclassified as clear water and thus often excluded from analysis.

Inundation maps from various scenes are overlaid to obtain an inundation proneness score. The score is classified in to five classes namely very low, low, medium, high and water. Nearly, 306 sq. km has been found to be flood prone of which nearly half is located in the Burhi Dihing floodplain. Other area is located in the floodplain of the tributaries and in low-lying areas i.e. in paleo channels in the basin.

The flooding occurs specifically in wet years namely 1988, 1990, 1998, 2000. The map showing vegetation and non-vegetation areas are prepared using NDVI. The vegetation classes include forest, tea and crop areas. The map is overlaid on the flood inundation map to obtain the vegetation area that is affected by floods. Nearly 206 sq. km area of vegetation (mostly agriculture) is flood prone.

The Burhi Dihing migration is also investigated. The river is actively meandering in the floodplain. Specifically, there has been more meandering near Telpani RF and downstream of the Tingrai confluence. Likely villages that can be affected due to river meandering are also listed. There is also a cutoff in offing downstream of the Khowang.

<u>Manas, Assam:</u> The study area is located in Barpeta district, Assam. The rivers are shallow and carry large sediment load. Flood inundation mapping is done for July 1998 flood using satellite remotely sensed data of IRS LISS-3 and WiFS sensors. The average

floodplain width during the flood for Manas and anabranch is 3 to 4 times the bankful width.

Gai, Assam: The study area lies in Dhemaji distrct in Upper Assam. The river originates in the lower Himalaya in Arunachal Pradesh. It is called Sisi in upper part. Further down, the river traverses piedmont region. Dhemaji and Sisiborogaon towns are located west of the river. Total study area in nearly 882 sq. km, out of this piedmont and lower catchment areas are respectively 380 and 503 sq. km. The above piedmont catchment lies in Arunachal Pradesh. NH- 52 and North- Eastern railway line passes through the study area. Mean annual rainfall ranges from 1362- 3661 mm, most occur in months of June to September.

Data of optical sensors namely LISS-II and LISS-III onboard IRS (Indian Remote Sensing Satellite) are used from (year) 1996 to 2001. In all 13 scenes are used. Out of these, nine scenes are used for months June to September. Data are registered with a reference image and registration accuracy is achieved of nearly one pixel. NDWI images are derived from data. Rule based classification technique is applied on multispectral data and NDWI images. The rules are based on the spectral signature of various themes. First, areas with infrared DN higher than red DN are classified as non water/ non sand class. Cloud shadow and clear water is delineated based on low DN in infrared band. Following this, river water and flood inundation area rule is applied. Under this rule, the infrared DN is low, blue/ green band DN is high and NDWI values are high. Sand has high DN in blue/ green bands. The water, inundation, sand casting/ sand bars classes are overlaid to obtain flood prone areas.

Water, inundation and sand classes are assigned score. A composite inundation proneness score map is obtained by overlaying individual inundation proneness score maps. In overlay operation all individual scores are added on per pixel basis. This score is classified interactively to six classes; namely very low, low, moderate, high, very high proneness to flood and water. Nearly 374 sq. km (42%) was flood prone. The flood prone area in piedmont and lower catchment was respectively 60 (16%) and 314 sq. km (62%) Floods in Gai were caused by embankment breach in Brahmaputra and floods in Jiadhal etc.

Bangladesh: NOAA data are used in Bagladesh to prepare flood hazard/ risk maps for 1988 flood. Three images during flood and one after flood event are taken and classified to obtain flood inundation and depth of inundation (qualitative) maps. From the flood inundation maps, the ‘frequency of inundation map’ is obtained. The hazard score is developed for variables namely land use, physiography, geomorphology and elevation based on the ‘flood frequency’/ inundation depth. The ratings are developed from flood frequency and depth each. The ratings are multiplied for a combination of variables and best possible combination is selected. The best combination is one where ratings tally for both flood frequency and depth. From the flood hazard-rating map, the risk maps are derived for the districts. Mean hazard rank is determined for the districts. The ranks are grouped to obtain the risk rank (1- 5) for the districts.

Operational use in Relief and Disaster Management System

Operational use in relief activities is being done by Department of Space since 1993. A Disaster Management System was designed and tested for year 1998 in thee districts namely Dhemaji, Marigaon and Dhubri in Assam by ISRO, NRSA, Regional Remote Sensing Service Centre (RRSSC), Kharagpur, Assam State Remote Sensing Application Centre (ARSAC), Cetral Water Commission (CWC), National Informatics Centre (NIC), and State Government. GIS layers namely administrative units (up to village level) and infrastructure such as roads, rail etc., were prepared in Arc/ Info software from 1: 63,000 scale sub- division maps and 1: 50,000 Survey of India (SOI) topographic maps respectively. Advantages of these data are that information on flood, land use, damages etc can be immediately obtained in GIS environment. Near real time satellite data were processed. Flood inundation data were generated as polygon in GIS and provided to Assam Remote Sensing Application Centre for damage estimation. Land use maps prepared by RRSSC were also used in damage estimation. The damage estimation method requires improvement, as damages estimated by the method did not tally perfectly in all districts. For example, crop damage was nearly same as that estimated by State Agencies for Dhemaji district in 1993. In Marigaon, two estimates were Rs 15 and 25 crores respectively. In the method, crop damage was estimated using inundated crop area (ICA), a loss factor and damage per unit area. ICA was obtained by overlaying land use map with flood inundation map. Loss factor was adjudged based on duration of standing water in the area. For prolonged inundation, it was taken as 100 %. For example in 1993 flood, in Dhemaji district crop remained submerged for long period and all crops were assumed damaged. Damage is sum of cost of cultivation and crop yield (in Rs/ ha). For example in Assam, paddy damage was Rs 8,500.00/ ha. Cultivation cost of paddy was Rs 4250/ ha. A limitation of the method was that due to cloud cover, it was not possible to estimate ICA for all floods. A methodology was developed to estimate ICA from hydrometeorological data. For inundation crop area estimation regression relationships with river gauge and rainfall data were also established for each district. Correlation factor varied from 0.68 to 0.96. Correlation was high for Dhemaji district and low for Marigaon and Dhubri districts. Damage to infrastructure is possible to map on post monsoon satellite images. The cost factors for infrastructure types are used to estimate total infrastructure damage. Optical remote sensing technique can only be applied to cloud free area and thus information may not be available for complete inundation area unless active microwave data are used.

Decision Support System (FLOOD WATCH)

Danish Hydraulic Institute (DHI) has implemented a Decision Support System for floods in Bangladesh. The DSS has telemetry, GIS and hydrological model components. Various layer e.g. rivers, administrative sub divisions gauging locations etc. were prepared in ArcView. Hydrological modeling is performed in MIKE 11 software that uses NAM rainfall- runoff simulation model to simulate inflow in to river. Forecasts are generated for 24, 48 and 72 hours. Water levels at gauge stations for these forecasts are displayed in different color symbols. Warning bulletins are generated and disseminated. For forecasts, sub- divisions likely to be flooded are televised in thematic map form.

Date sources

Gridded Rainfall data

TRMM data are available at site http://agdisc.gsfc.nasa.gov/Giovanni/aovas/. Research quality TRMM rainfall data are available at time interval of 3- hour, daily, 10-day and monthly from archives. The data can be downloaded by specifying geographic coordinates of the area and period of the measurement. Fig. 2.4 shows the TRMM grid for the Sabarmati basin. Data are available in ASCII files. Data are available at several geographic resolutions of 15´ X 15´ or lower. ASCII output was generated for 3- hourly accumulated rainfall data (in mm) using 'time series area- averaged or single point' plot type option for each grid of size 15´ X 15´.

SRTM DEM

Shuttle Radar Topographic Mapping Mission (SRTM) data were used in the study to extract physical characteristic of the channel network and its schematization. SRTM is an International project for near global high resolution topographic mapping. Main agencies involved in the project are U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA). The mission used space borne RADAR interferometry. SRTM payload was outfitted with two radar antennas. One antenna was located in the Shuttle's payload bay, the other on the end of a 60-meter (200-feet) mast that extended from the payload bay once the Shuttle was in space.

The global SRTM data are available at CGIAR-CSI GeoPortal (Jarvis et. al 2008). The data is provided to promote the use of geospatial science and applications for sustainable development and resource conservation in the developing world. The data are provided in mosaiced 5° tiles. The tiles are produced from a seamless dataset to allow easy mosaicing. These are available in two formats, namely ArcInfo ASCII and GeoTiff. Data are geographic latitude- longitude data and are in WGS84 datum.

Global Land One-kilometer Base Elevation (GLOBE)

GLOBE DEM is an internationally designed, developed, and independently peer-reviewed global digital elevation model. The DEM has a latitude-longitude grid spacing of 30 arc-seconds (30"). Prior to it, two different global DEM of this resolution were available. These were prepared separately by NASA and USGS, USA. The USGS DEM is called GTOPO30. The DEM were based on digital terrain elevation data and other data sources available at that time. GLOBE has utilized several other data sources in addition to these. The DEM are not useful for mission critical applications and are required to be interpreted cautiously.

Hydrological modeling

Flood inundation maps can be prepared through both one and two dimensional hydrodynamic models. Widely used softwares for in one dimensional hydrodynamic modeling are HEC RAS and Mike-11. For two dimensional modeling Mike 21 may be used. HEC RAS is public domain software. Mike-11 and -21 are commercial softwares. Such applications are useful in disaster management. For such application input data can be prepared in GIS and thematic maps of villages and infrastructures can be displayed on the flood inundation maps. Flood inundation can also be shown in animation.

Review

A review of the literature brings out a few studies in which attempts have been made to develop flood inundation maps by using the rainfall runoff modeling and flow routing. Mimikou and Baltas (1994) used HEC-1F model for runoff forecasting in Pinioc river basin (area 2763 km^2) in Greece. Radar rainfall fields were used and the bias in radar rainfall was removed using raingauge data. Cross correlation of radar images was done to obtain storm velocity and in turn forecast rainfall. Model performance was evaluated using bias in mean observed flow, percent error in peak and efficiency. Model with radar data performed better (efficiency varied from 0.75- 0.95) than that for raingauge data. Model also performed well in one and two- hour forecasting mode.

Aronica et al. (1997) have used a two- dimensional finite element- based hydrodynamic model for the flood inundation simulation for Imera river coastal floodplain (area 22 km^2) in Sicily. Study area was discretized into 7168 elements. The model incorporated partially explicit scheme for the vertical discontinuities in the terrain. Total rainfall depth and maximum rainfall intensity were 229 mm and 56 mm hr^{-1} respectively. The inflow from the catchment (area nearly 1800 km^2) was obtained through a rainfall- runoff model. Maximum discharge was of the order of 3500 cumec. The RMS error in the simulated water depth was 0.51 m for 25 locations. Calibrated values of the Manning's roughness coefficients were 0.05 and 0.0333 for the floodplain and river, respectively. The model took nearly 1.5 hours for 28 hour simulation on a Pentium machine. Note that a large computation time is a hindrance in the practical applications of such models.

An automated flood-warning decision support system (FW-DSS) was developed for Sacramento County, California, USA, by Ford (2002). The system consisted of an emergency operation plan (EOP) and a forecasting system as the components. EOP had four components, namely the surface observation system (SOS), STORM Watch, WatchDog Software and information dissemination. The SOS consists of the raingauges and water level observation stations. Data were transmitted from the SOS to the base stations and manipulated in a commercial software namely STORM Watch. The WatchDog was developed in house for the threat recognition. It worked on the threat rules which were based on the stage, rate of rise of stage etc. It disseminated the information through the print memo, email, paging etc. The flood inundation maps corresponding to the water stages and profiles were generated off-line and displayed in real time for the given stages. The forecasting system used the public domain software namely HECDSS, HEC1F, PRECIP and UNET (Gee 1998) and a specifically developed graphical user interface (GUI) to facilitate use of the HEC software within the system. Recently, HEC1F and PRECIP have been modernized and combined with new algorithms in HEC HMS software (Scharffenberg and Fleming 2006). The GUI facilitated the program execution, data input and visualization of results. The data from the STORM Watch were obtained in the HECDSS and in turn in the PRECIP to generate the mean areal precipitation (MAP). Latter was input in to the HEC1F. The Forecasted MAP was used to estimate the runoff hydrograph for the headwater watersheds. These hydrographs were routed using a one- dimensional hydraulic method in the UNET to generate forecasted stages.

HEC-HMS

The Hydrologic Modeling System (HMS) is designed to simulate the precipitation-runoff processes of a dendritic watershed system. A basin is conceptualized as consisting of elements namely sub basin, reach, junction, reservoir, diversion, source, and sink. Computation proceeds from the upstream to downstream elements. In each sub basin, rainfall excess is computed. The excess rainfall in each time step is convoluted to obtain a runoff hydrograph at the sub basin outlet. These hydrographs are routed in each channel reach and combined to get the hydrograph at the basin outlet. A number of methods are incorporated in the model for excess rainfall computation, unit hydrograph synthesis and river routing. Structures, namely, gated, ungated spillway and pumps can be incorporated in the model. For gated spillway, the model can handle fixed gate opening only. Gridded and lumped rainfall data can be input.

Mike-11

Mike 11 Enterprise edition comprises of Mike-11 Hydrodynamic model (HD), Structure Operation (SO), Dam Break (DB), Advection- Dispersion (AD) and Rainfall-Runoff (RR) module. The edition is available with unlimited computational nodes. For GIS interface to the model, additional module namely Mike-11 GIS was obtained. This module is an extension to Arc View 9.2 software. The module provides GIS interface for data preparation for Mike-11 model. Mike-11 GIS module can be used for creating river network and cross section files in Mike-11 formats. In the river network, river reaches, their names, start chainages and structures can be defined. The network can be added from existing shape file.

Mike Zero is a common window interface to hydrological software of DHI. Apart from providing common interface, many utility programs, e.g. time series editor, animator, plot composer, Autocal etc. are provided in Mike Zero.

Inundation mapping through hydrologic/ hydraulic models

Flood inundation is caused due to backwater effect, overflow from river banks, failure of dykes, overland flow, channel flow etc. These result in the inundation of the floodplain or low lying areas adjacent to the rivers causing losses to life, property, agriculture land, infrastructure etc. In flood mitigation, inundation maps and animation of flood inundation may be useful. Typical flood inundation map prepared in Mile 11 software is given in Fig 1.

Conclusions

Potential of remote sensing technology is established through many applications in flood studies. For flooding due to embankment failure, available flood prone and sand casted areas maps can be useful to know likely areas to be effected from future floods. It is essential to identify the places where river flows close to the embankments. These areas can be likely places for the embankment failure. Flood mitigation measures can be taken up for such areas. Technique is also useful in flood relief and damage estimation.

On the other hand, flood inundation mapping can also be done using quasi two dimension models such as Mike-11. For correct inundation mapping, field measured river cross sections should be integrated with that from SRTM. Further, characteristics/ location etc. of the links connecting the flood channels in the quasi two dimensional representations affect the simulation results. In case flood inundation maps are available, various parameters should be calibrated and validated by tallying these maps with those prepared from the models. Then only, the model so prepared can be useful in inundation mapping in forecast mode.

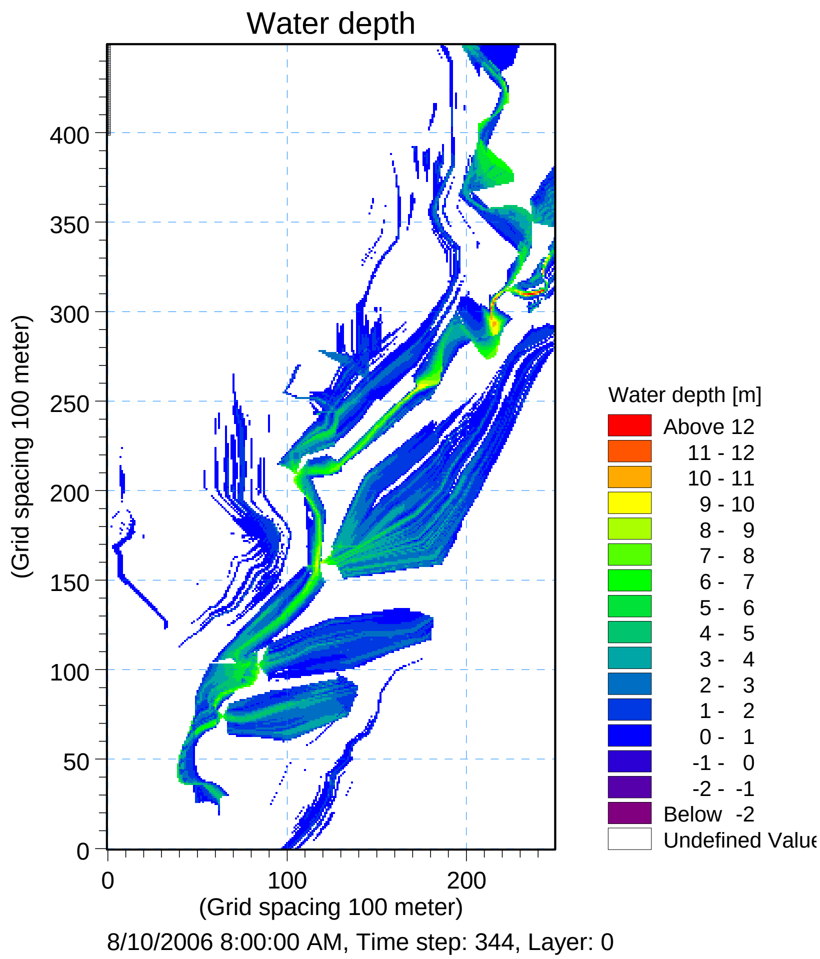

Fig. 1 Flood inundation depth map for Sabarmati basin upstream of Watrak confluence