Remote Sensing, GIS and DEM Applications in Flood Hydrology

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Outline

- Floods and Potential use of Remote Sensing
- Real Time Monitoring of Floods
- GIS for Flood Damage Assessment
- Digital Elevation Models (DEMs)
- Delineation of Flood-prone Areas using Modified Topographic Index for Mahanadi Basin
- Integrated Approach to Flood Management
- Conclusions

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Introduction

- Floods are the most common and widespread of all natural disasters
- Floods cause damage to houses, industries, public utilities and property resulting in huge economic losses, apart from loss of lives
- Though it is not possible to control the flood disaster totally, by adopting suitable structural and non-structural measures the flood damages can be minimized
- For planning any flood management measure latest, reliable, accurate and timely information is required
- Remote sensing technology has made substantial contribution in every aspect of flood disaster management such as preparedness, prevention and relief.

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Potential uses of Remote Sensing for Flood Management

- Flood inundation mapping and monitoring
- Rapid and scientific based damage assessment
- Monitoring and mapping of flood control works
- Monitoring and mapping of changes in the river course
- Identification of river bank erosion
- Identification of chronic flood prone areas
- Inputs for flood forecasting & warning models

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Flood Inundation Mapping

- Once a flood event occurs, information on flooded areas and quick assessment of damages is required for planning flood relief activities
- Satellite remote sensing provides synoptic view of the flood-affected areas at frequent intervals for assessing
  - Progression and recession of the flood inundation in short span of time which can be used for planning and organizing the relief operations effectively

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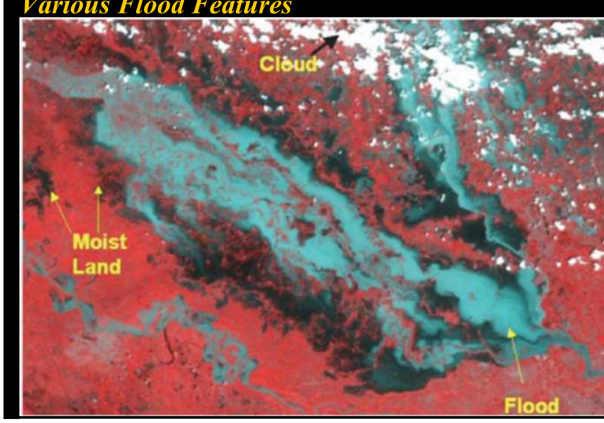
IRS P6 AWiFS Image showing Various Flood Features



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IRS Satellite Image (FCC) showing the Ganga River Basin

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IRS Satellite Image (FCC) showing the Brahmaputra River Basin

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Satellites and their Sensors used for Flood Mapping

S.No	Satellite	Sensor/ Mode	Spatial Res(m)	Spectral Res (µm)	Swath (km)	Used For
1	IRS-P6	AWiFS	56	B2: 0.52-0.59 B3: 0.62-0.68 B4:0.77-0.86 B5: 1.55-1.70	740	Regional level flood mapping
2	IRS-P6	LISS-III	23.5	B2: 0.52-0.59 B3: 0.62-0.68 B4:0.77-0.86 B5: 1.55-1.70	141	District-level flood mapping
3	IRS-P6	LISS-IV	5.8 at nadir	B2: 0.52-0.59 B3: 0.62-0.68 B4:0.77-0.86	23.9	Detailed level Mapping
4	IRS-1D	WiFS	188	B3: 0.62-0.68 B4:0.77-0.86	810	Regional level flood mapping
5	IRS-1D	LISS-III	23.5	B2: 0.52-0.59 B3: 0.62-0.68 B4:0.77-0.86 B5: 1.55-1.70	141	Detailed level Mapping
6	Aqua/ Terra	MODIS	250	36 in visible, NIR & thermal	2330	Regional level Mapping
7	IRS-P4	OCM	360	Eight narrow bands in visible & NIR	1420	Regional level Mapping
8	Cartosat-1	PAN	2.5	0.5- 0.85	30	Detailed level Mapping
9	Cartosat-2	PAN	1	0.45-0.85	9.6	Detailed level Mapping
10	Radarsat-1	SAR/ ScanSAR Wide	100	C-band (5.3 cm) HH Polarization	500	Regional level mapping
11	Radarsat-1	SAR/ ScanSAR Narrow	50	C-band (5.3 cm)	300	District-level mapping
12	Radarsat-1	Standard	25	C-band	100	District-level mapping
13	Radarsat-1	Fine beam	8	C-band (5.3 cm)	50	Detailed level mapping
14	ERS	SAR	25	C-band VV Polarization	100	District-level mapping

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Real-Time Monitoring of Floods

- Whenever a flood event occurs in India, NRSC provides flood maps showing flood affected areas and flood damage statistics in near real time
- Presently, this information is being provided to the user departments within 6 hours after procuring the satellite data
- During the last one and half decades, major flood events in Assam, Bihar, Uttar Pradesh, West Bengal, Orissa, Andhra Pradesh, Jammu & Kashmir, Rajasthan, Punjab have been successfully mapped using Indian Remote Sensing (IRS) and other satellites.

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Microwave Remote Sensing for Flood Mapping

- In adverse cloud conditions optical data from most of the satellites will not be useful
- Microwave SAR (Synthetic Aperture Radar) data has all weather capability. Radarsat provides such data

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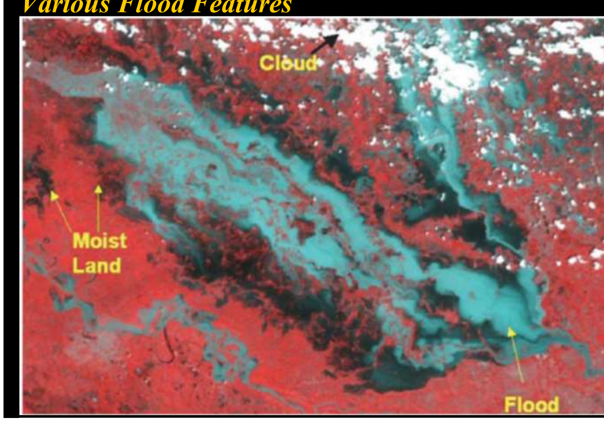
IRS P6 AWiFS Image showing Various Flood Features



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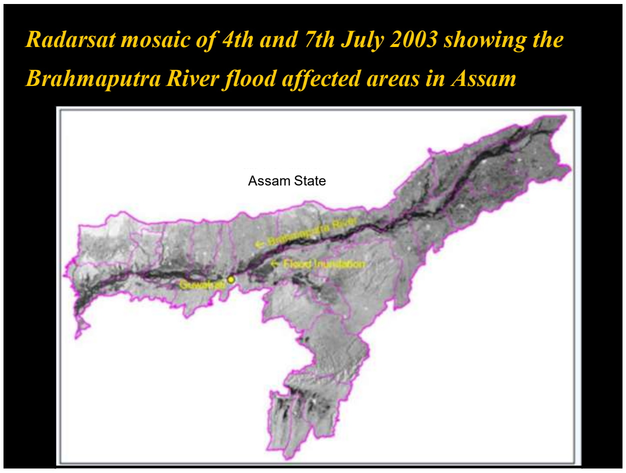

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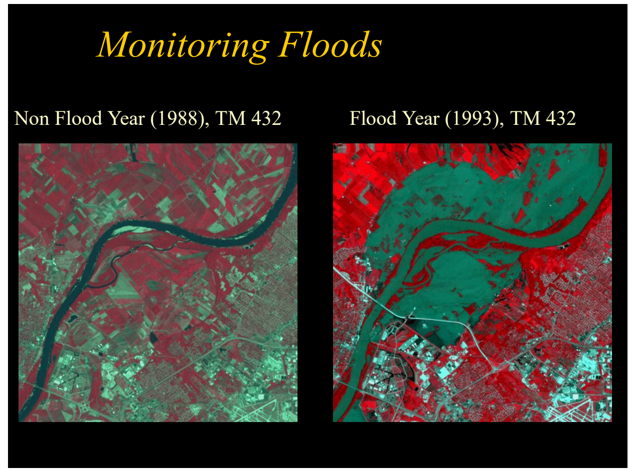

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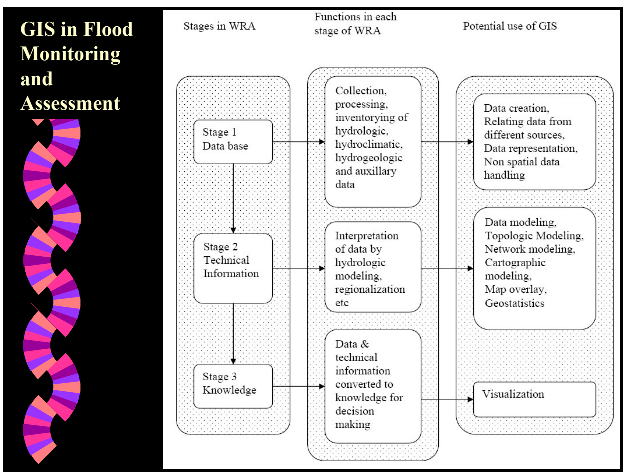

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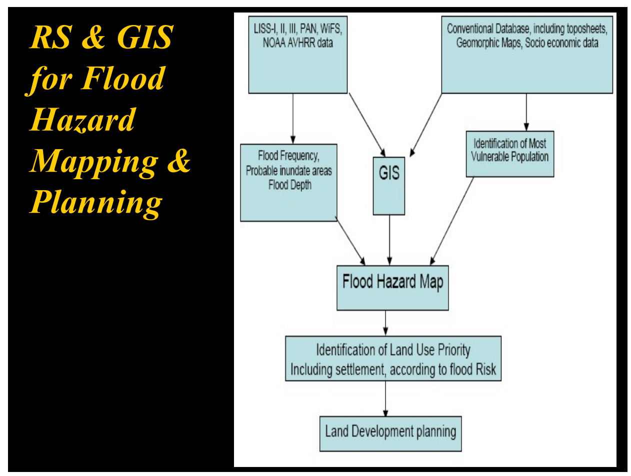

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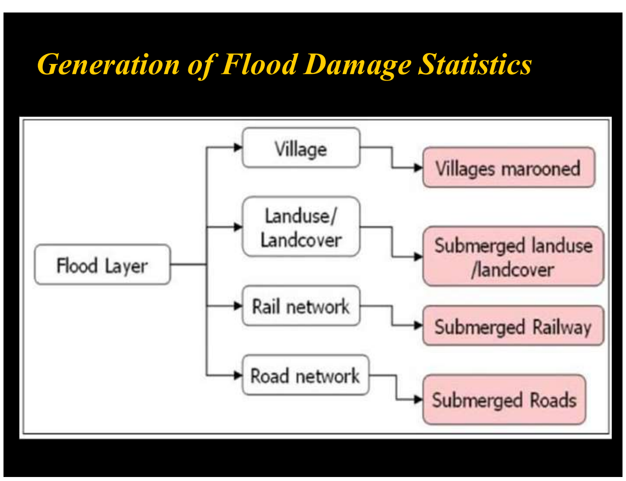

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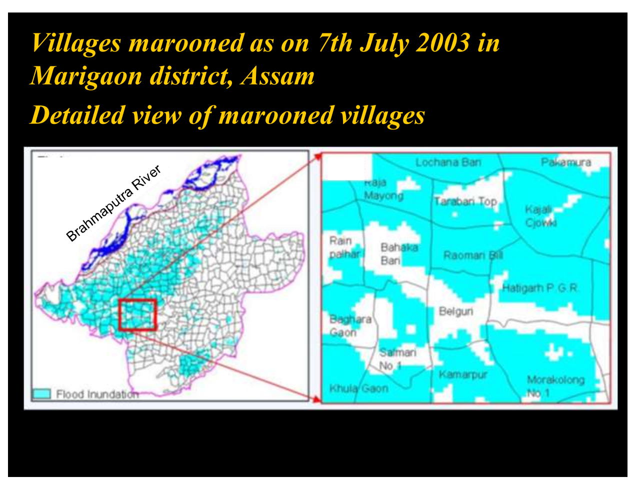

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Utilization of Flood Images from RS & GIS

S.No	Deliverables	Utilization
1	Flood map	To map inundated areas for organizing relief operations
2	Flood damages – Extent of inundation – Crop area submerged – Number of Villages marooned – Length of Road/ railway network affected/submerged	Quick assessment of flood damages, for providing relief & Rehabilitation
3	Flood control works and River configuration	Strengthening of existing & planning of future flood control works
4	River Bank erosion	Planning anti erosion works
5	Identification of chronic flood prone areas and Floodplain zoning	Hazard zonation & floodplain regulation, planning flood control works

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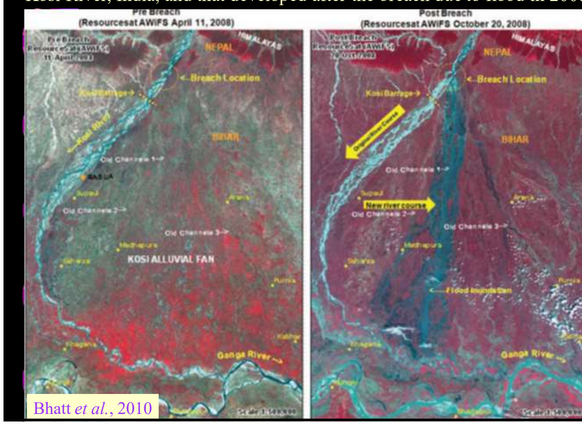
Satellite images (Resourcesat AWiFS) showing the original course of the Kosi River, India, and that developed after the breach due to flood in 2008



Bhatt *et al.*, 2010

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IRS CARTOSAT and LISS IV images showing before and after a flood event in the Kosi River, India

Bhatt *et al.*, 2010

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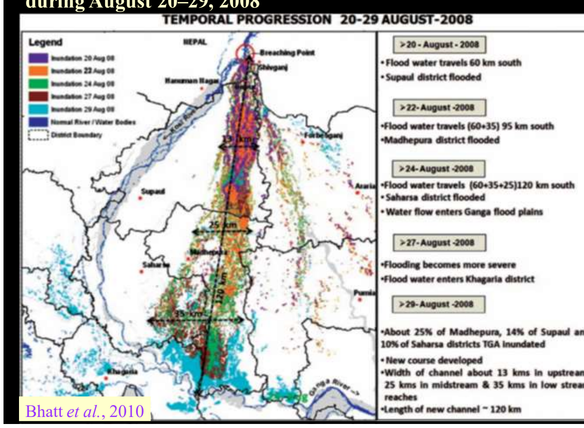
Temporal progression of Kosi River flood inundation in India during August 20–29, 2008



Bhatt *et al.*, 2010

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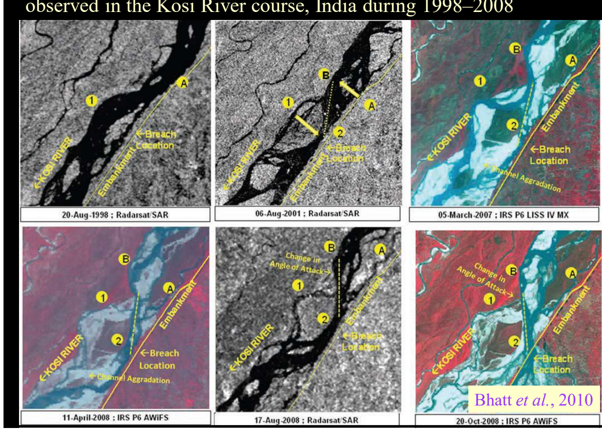
Satellite images (RADARSAT and IRS P6) showing the changes observed in the Kosi River course, India during 1998–2008



Bhatt *et al.*, 2010

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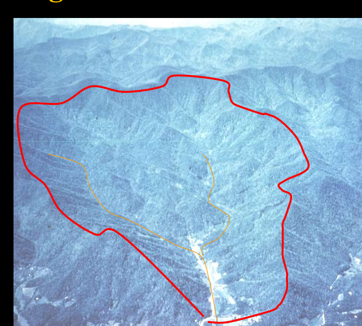
Digital Elevation Models



Any numeric or digital representation of the elevation of the land surface

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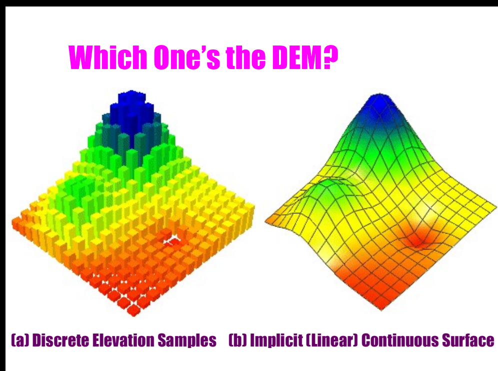

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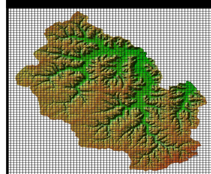
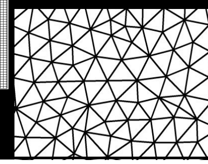
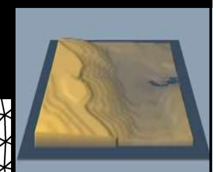
DEM - Types

Mainly three Types of DEM

- Grid (regular square grid)
- TIN (Triangular Irregular Networks)
- Contour

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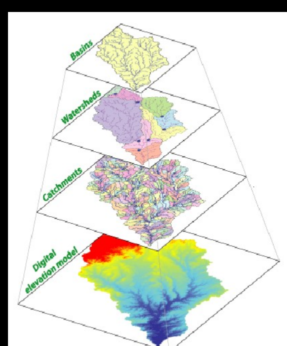
Terrain Attributes from DEM

- Flow direction
- Flow pathways
- Flow accumulation
- Stream network
- Catchment area
- Upstream contributing area for each grid cell
- Slope/ Aspect

Indices calculated

- Wetness indices
- Topographic indices



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Direction of Steepest Descent

1

67	56	49
53	44	37
58	55	22

Slope: $\frac{67-44}{\sqrt{2}} = 16.26$

1

67	56	49
53	44	37
58	55	22

$\frac{67-53}{1} = 14$

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Eight Direction Pour Point Model

32	64	128
16		1
8	4	2

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Flow Direction Grid

↘	↘	↓	↓	↙
→	↘	↓	↙	↓
↗	→	↘	↓	↙
↘	→	↓	↓	↓
→	→	→	↘	←

2	2	4	4	8
1	2	4	8	4
128	1	2	4	8
2	1	4	4	4
1	1	1	2	16

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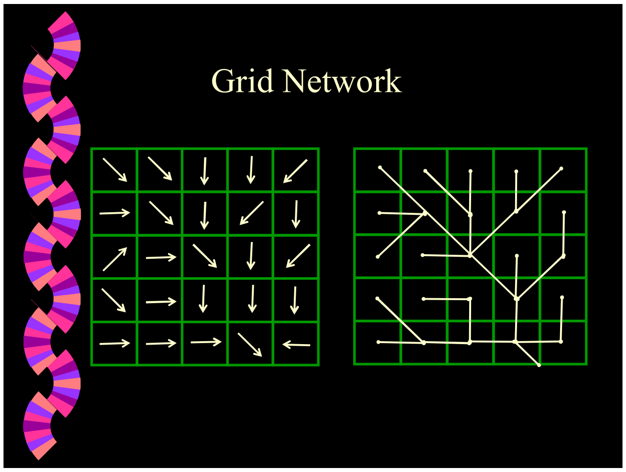

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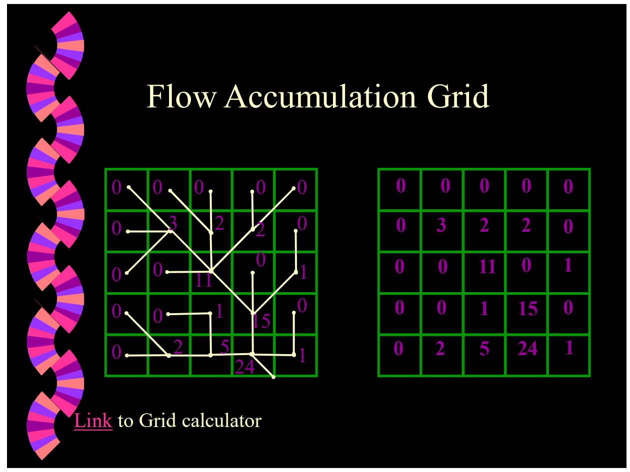

0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	1

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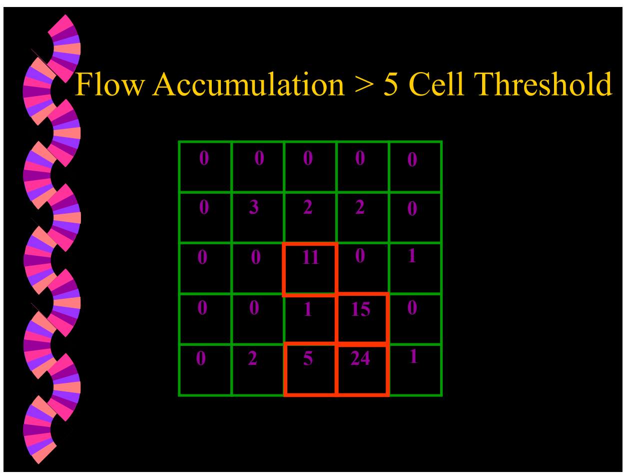

0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	1

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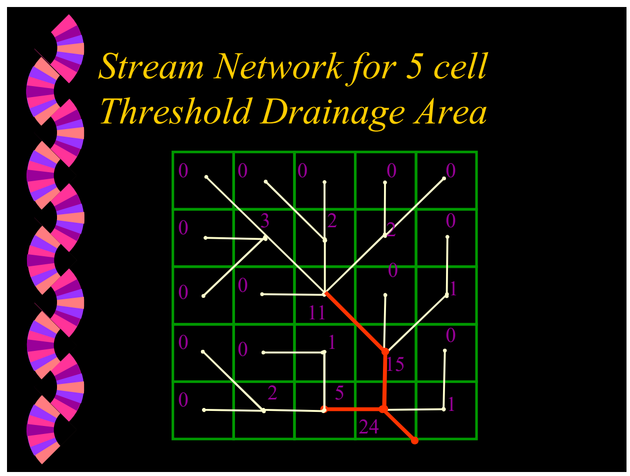

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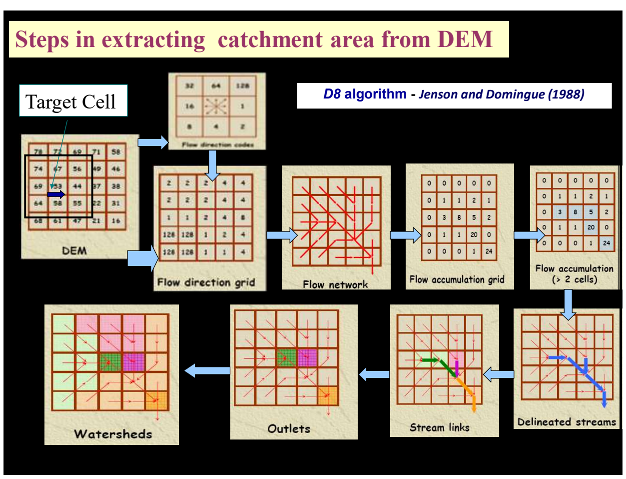

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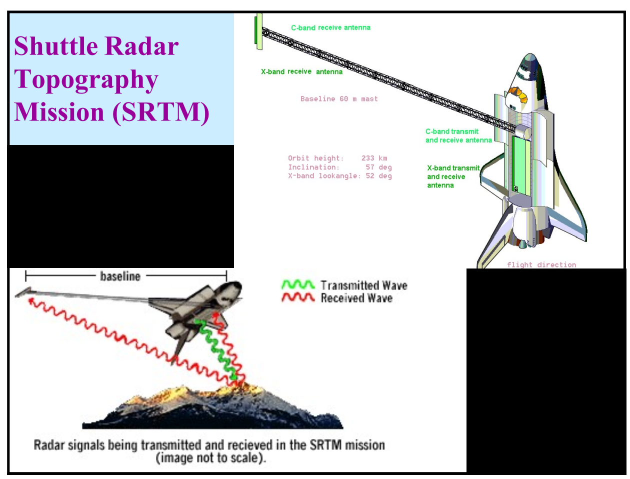

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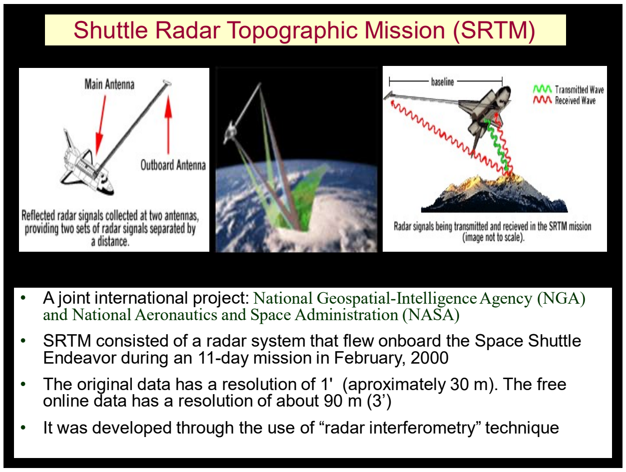

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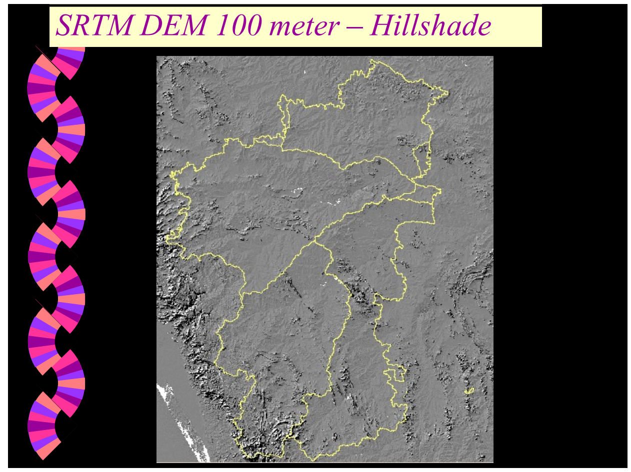

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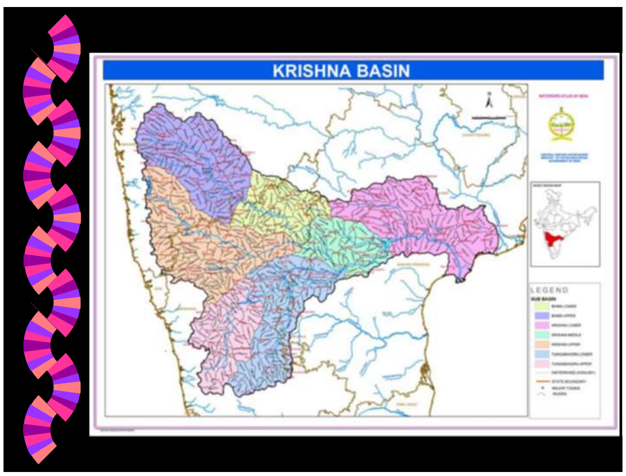

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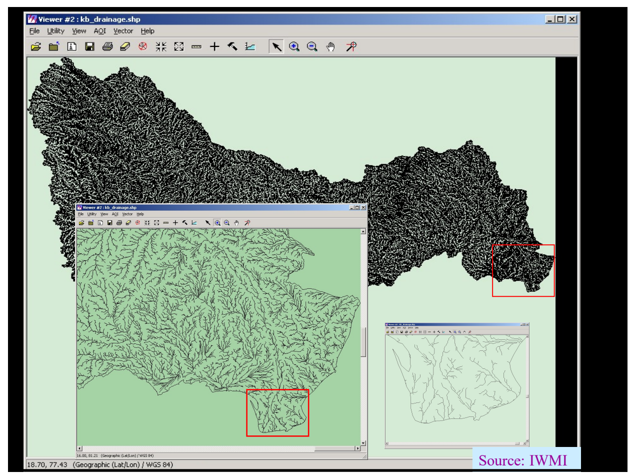

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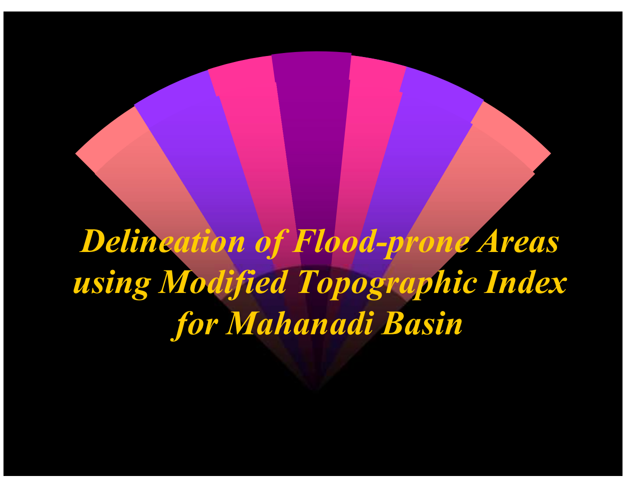

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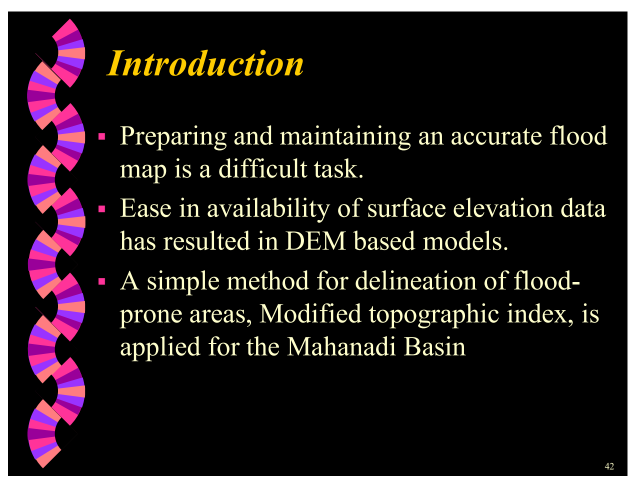

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Topographic Index

- Topographic index (Kirkby, 1975) is defined as

$$TI = \frac{\ln a_d}{\tan \beta}$$

TI is the topographic index
a_d is the drained area per unit contour length
tan β is the local slope.

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Modified Topographic Index (MTI)

- The modified topographic index (Manfreda, 2008) is given by

$$TI_m = \frac{\ln(a_d^{\,n})}{\tan \beta}$$

TI_m is the modified topographic index
n is an exponent ≤ 1.

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Delineation using MTI

- It allows the delineation of the portion of the basin as exposed to flood inundation assuming that it is the area characterised by the modified topographic index exceeding a given threshold TI_{ms}
- The threshold will be estimated by using a flooding map of the basin, which is assumed to have correct representation of flooding and non-flooding areas
- Modified topographic index map is compared with flood inundation map, and value of modified topographic index above which area is considered as inundated is obtained

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Delineation using MTI (Contd.)

- To estimate the threshold, two error functions are defined

$$ER1 = \frac{Non\ flooding\ areas\ with\ TI_m \geq TI_{ms}}{Non\ flooding\ areas\ from\ flooding\ map} \times 100$$

$$ER2 = \frac{Flooding\ areas\ with\ TI_m \leq TI_{ms}}{Flooding\ areas\ from\ the\ flooding\ map} \times 100$$

- *ER1* - Percentage of non-flooded area whose value of the modified topographic index is greater than the threshold
- *ER2* - Percentage of flooded area which has a modified topographic index value less than the threshold.

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Delineation using MTI (Contd.)

- The objective is to define a threshold value which minimizes both errors in the delineation of the flood inundation areas.
- The sum of two errors (*ER1* + *ER2*) represents an objective function that can be used for the estimation of the two parameters TI_{ms} and n.
- An iterative algorithm is used on this function to search for a minimum value of (*ER1* + *ER2*), to obtain the two parameters.

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Study Area

- The study area lies between East longitudes 80° 30' and 86° 50', and North latitudes 19° 15' and 23° 35'.
- Length of the river is about 900 km, and it has a catchment area of approximately 1,41,600 km^2.
- Climate in the basin of Mahanadi is predominantly sub-tropical.
- Annual rainfall varies from 1143 mm to 2032 mm over the entire basin, average being 1438.1 mm.

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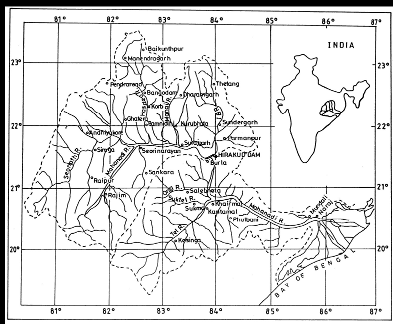

Mahanadi Basin Map

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Data Used

- Digital Elevation Models (DEMs)

DEM	Spatial Resolution (m)
ASTER Global DEM	30
SRTM	92
GMTED2010	228
	455
	911

- Flood inundation maps for three flood events (2006, 2008 and 2011) were used.
- Annual maximum discharge data at Naraj for a period of 38 years was used for flood frequency analysis

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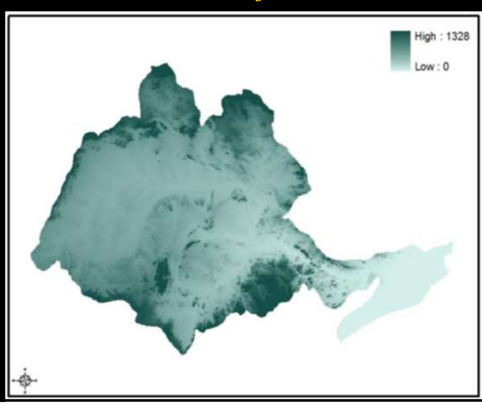
ASTER Global DEM of Mahanadi Basin



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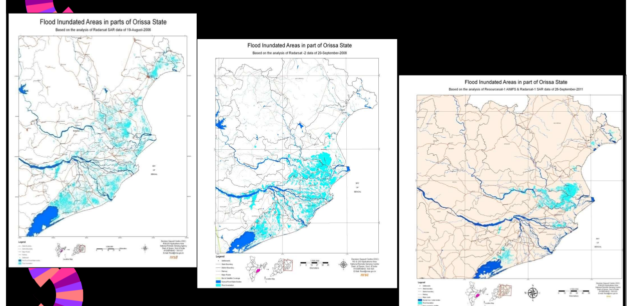
Flood inundation maps for 2006, 2008 and 2011



Source: NRSC, Hyderabad

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Methodology

- GIS analysis was performed on the DEMs to obtain the specific catchment area maps and slope maps.
- Analysis was also performed on the flood inundation maps obtained from NRSC.
- ArcMap, ERDAS Imagine and MapWindow GIS were used to perform all the operations.
- Iterations are carried out for each value of the exponent to obtain modified topographic index.
- It is compared with the flood inundation map to obtain '*n*' and 'TI_{ms}' having the minimum error.

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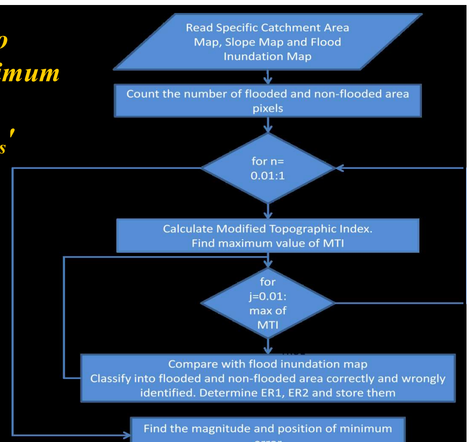
Flowchart to Obtain Minimum Error, 'n' and 'TI_{ms}'



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Methodology (Contd.)

- ‘n’ and ‘TI_{ms}’ obtained are used to produce flood inundation maps.
- Flood frequency analysis is performed by fitting the annual maximum flow data to three probability distributions: normal, log-normal and Gumbel distributions.
- Tests for goodness of fit were performed by using the χ^2 test and the Kolmorgov-Smirnoff test.

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Results

Parameters Obtained from the Method and the Errors Corresponding to the Parameters for the Three Flood Events

Event (Year)	2006	2011	2008
Magnitude (1000 cumecs)	(36.33)	(38.71)	(44.76)
DEM Resolution (m)	n		
900	0.01	0.01	0.01
450	0.04	0.01	0.01
225	0.04	0.01	0.01
90	0.03	0.01	0.01
30	0.01	0.01	0.01
DEM Resolution (m)	TI_{ms}		
900	6.13	5.49	5.27
450	6.24	5.21	5.08
225	5.61	4.78	4.09
90	5.28	4.38	4.32
30	3.22	3.22	2.87
DEM Resolution (m)	$ER1 + ER2$		
900	43.63	37.23	38.70
450	42.63	43.09	39.88
225	39.96	43.97	21.84
90	32.42	37.98	35.51
30	17.40	18.51	18.39

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Results (Contd.)

- The error reduces as the spatial resolution of the DEM reduces.
- It was also noted that ER1 (the over-estimation) was significantly larger than ER2 in all the cases.
- As the flood magnitude increases, TI_{ms} has reduced, indicating that a larger area will be under flood inundation.

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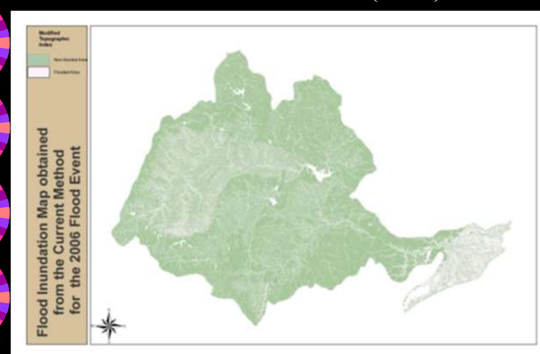
Flood Inundation Map for the 2006 Flood Event from SRTM DEM (90 m)



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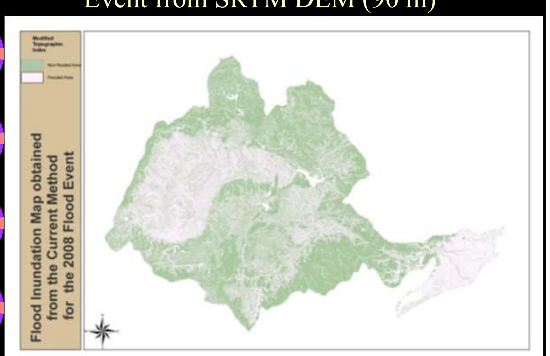
Flood Inundation Map for the 2008 Flood Event from SRTM DEM (90 m)



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Flood Inundation Map for the 2011 Flood Event from SRTM DEM (90 m)

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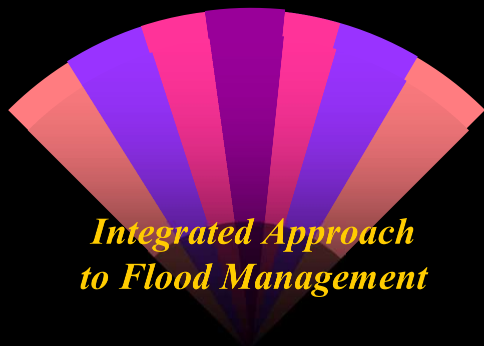

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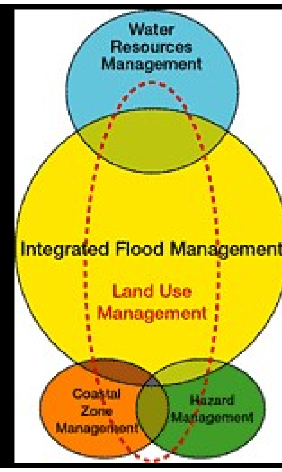
Integrated Flood Management (WMO, 2009)



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Integrated Flood Management Plan

- Manage the water cycle as a whole
- Integrate land and water management
- Manage risk and uncertainty
- Adopt a best mix of strategies
- Ensure a participatory approach and
- Adopt integrated hazard management approaches.

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Strategies and Options for Flood Management (WMO, 2009)

Strategy	Options
Reducing Flooding	Dams and reservoirs
	Dikes, levees and flood embankments
	High flow diversions
	Catchment management
	Channel improvements
Reducing Susceptibility to Damage	Floodplain regulation
	Development and redevelopment policies
	Design and location of facilities
	Housing and building codes
	Flood proofing
	Flood forecasting and warning
Mitigating the Impacts of Flooding	Information and education
	Disaster preparedness
	Post-flood recovery
	Flood insurance
Preserving the Natural Resources of Flood Plains	Floodplain zoning and regulation

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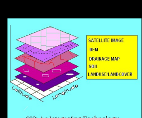
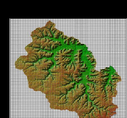
Integration of RS, GIS, DEM and Hydrological Models

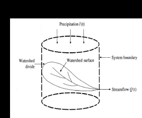
RS



GIS



DEM



Hydrological Model

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Conclusions

- Strong potential for use of RS, GIS and DEM for Flood Hazard planning, mitigation and management
- Proper image processing of remotely sensed data, DEM and spatio-temporal analyses with GIS would be very effective for Flood Management

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