BHARATHIDASAN UNIVERSITY

Tiruchirappalli- 620024
Tamil Nadu, India

Programme : M.Tech., Geological Technology and Geoinformatics

Course Title : Geoinformatics in Disaster Management
Course Code : MTIGT0704

Unit-4: Flood & Drought

Dr. J. SARAVANAVEL
Professor, Department of Remote Sensing
Bharathidasan University
Tiurchirappalli, Tamil Nadu
Email : drsaraj@gmail.com, saravanavel@bdu.ac.in

Remote Sensing & GIS in Flood Mapping

Unit:4. Flood: Definition, types and causes of flood - controlling factors of flood - Remote Sensing and GIS in flood mapping, prediction, warning, monitoring, flood preparedness, relief and rescue action, flood mitigation - Run-off Estimation: Soil Conservation Service (SCS)method- Flood scenario of India and Tamil Nadu - 2015 Chennai flood – Flood vulnerability mapping using historical flood data and post flood Remote Sensing data Detection of causative factors of flood - Remedial strategies

India is the worst flood-affected country in the world after Bangladesh and accounts for one fifth of global death count due to floods.

Around 40 million hectares of land in the country are subject to floods according to National Flood Commission, and an average of 18.6 million hectares of land is affected annually. The annual average cropped area affected is approximately 3.7 million hectares.

The most flood-prone areas in India are the Brahmaputra and Ganga River basins in the Indo-Gangetic-Brahmaputra plains in North and Northeast India, which carry 60 per cent of the nation’s total river flow.

The other flood prone areas are the north-west region of west flowing rivers such as the Narmada and Tapti, Central India and the Deccan region with major east flowing rivers like Mahanadi, Krishna and Cauvery

Heavy flood damages had occurred in the country during the monsoons of the years 1955, 1971, 1973, 1977, 1978, 1980, 1984, 1988, 1989, 1998 and 2004. Highlights of the flood damages are given below:

	Maximum	Average
Area affected (in lakh hectares)	175 (1978)	75.1
Crop area affected (in lakh hectares)	101.5 (1988)	35.1
Population affected (in crores)	7.045 (1978)	3.284
Houses damaged (in lakhs)	35.1 (1978)	12.2
Cattle heads lost	618248 (1979)	94830
Human lives lost	11316 (1977)	1587
Damage to public utilities (in Rs. crores)	5604.46 (1998)	820.67
Total damages (in Rs. crores)	8864.54 (1998)	1805.18

Though floods cannot be stopped, its damages can be minimized by proper management measures.

Flood disaster management demands efficient planning measures, implementation and policy making decisions, application of modern scientific and communication tools for smooth functioning of the system

For effective flood management, the concerned flood control departments require information at different phases of the flood disaster cycle

FLOOD

Flood is relatively high flow of runoff which overtakes the natural channel provided for the runoff *Chow(1956)*.

Flood is a body of water which rises to overflow land which is not normally submerged (Ward 1978)

Any high stream flow which overtops natural or artificial banks of a stream

Types of Flooding

Flooding - according to their duration:

1. Slow-Onset Floods

Slow-Onset Floods usually last for a relatively longer period, it may last for one or more weeks, or even months. As this kind of flood last for a long period, it can lead to lose of stock, damage to agricultural products, roads and rail links.

2. Rapid-Onset Floods

Rapid-Onset Floods last for a relatively shorter period, they usually last for one or two days only. Although this kind of flood lasts for a shorter period, it can cause more damages and pose a greater risk to life and property as people usually have less time to take preventative action during rapid-onset floods.

3. Flash Floods

Flash Floods may occur within minutes or a few hours after heavy rainfall, tropical storm, failure of dams or levees or releases of ice jams. And it causes the greatest damages to society.

Floods - according to their location:

1. Coastal Floods

Coastal Floods usually occur along coastal areas. When there are hurricanes and tropical storms which will produce heavy rains, or giant tidal waves created by volcanoes or earthquakes, ocean water may be driven onto the coastal areas and cause coastal floods.

2. Arroyos Floods

A arroyo is river which is normally dry. When there are storms approaching these areas, fast-moving river will normally form along the gully and cause damages.

3. River Floods

This is the most common type of flooding. When the actual amount of river flow is larger than the amount that the channel can hold, river will overflow its banks and flood the areas alongside the river. And this may cause by reasons like snow melt or heavy spring rain.

4. Urban Floods

In most of the urban area, roads are usually paved. With heavy rain, the large amount of rain water cannot be absorbed into the ground and leads to urban floods.

Snow-melt/Glacial Lake Outbursts Formation and Subsequent Bursting of Landslide Dams

Snowmelt is a gradual process and usually does not cause major floods. Glacial melt is usually slower than snowmelt and is not capable of causing severe flood. But sometimes glaciers hold large quantity of bounded water, which may be suddenly released with melting of ice block resulting into Glacial Lake Outburst Floods (GLOFs).

The rivers originating from the Himalayas in the northern part of the country, which are also fed by snowmelt from glaciers, are prone to flash floods. In 1929, the outburst of the Chong Khundam glacier (Karakoram) caused a flood peak of over 22,000 m3 / second at Attock. Glacial outburst is one of the suspected reasons for the flash flood experienced in Sutlej River on the night intervening 31July and 1 August 2000.

The blockage in the course of the Parechu in China (Tibet) caused by the landslide in 2004 gave way in 2005 and caused severe flooding and damage to infrastructure in Himachal Pradesh.

Littoral Drif t in River Estuaries

The flood problems of deltaic regions are attributed to various causes like flatter slope of drains and back flow due to tides. Littoral drift of sand in the form of sand dunes formation and consequent choking of outfalls of rivers into the sea is one of the causes for flood in deltaic regions.

The Biccavole and Tulabhaga drains in the Godavari eastern delta and the Panchanadi, Lower Kowsika, Vasalatippa and Kunavaram drains in Godavari central delta are some of the problem reaches.

Cloudbursts

Due to peculiar climatic conditions, some parts of the country experience sudden unprecedented heavy rain known as cloud bursts.

Hilly areas in Himachal Pradesh, Uttarakhand, the northern areas of West Bengal, Sikkim, Arunachal Pradesh, Manipur, Mizoram, Meghalaya, Nagaland and Tripura and the coastal areas in the states of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Maharashtra and Gujarat and Union Territories (UTs) of Andaman and Nicobar Islands and Lakhshadweep are more prone to such phenomena.

SOURCES OF FLOOD

Primary – Atmosphere

Secondary – Snow & Ice

- **Floods are physical phenomenon results from input of precipitation into a drainage basin**
- **Flood Magnitude: Depends on nature of precipitation and drainage basin**

CONTROLLING FACTORS OF FLOOD

A) Hydro – Meteorological

Excessive rainfall / sudden melt of snow

B) Morphological factors

(i) Drainage basin factor

(ii) River Channel factor

DRAINAGE BASIN FACTOR

Contributing Area

Aerial extent of Basin / sub basin that receives rainfall

(Semi arid and arid regions only part of basin gets rainfall Humid regions entire basin receives rainfall)

Drainage Density (DD = Total stream length / area)

Low DD – less runoff, increased infiltration and subsurface flow

High DD- High erosion and high run off

Climate

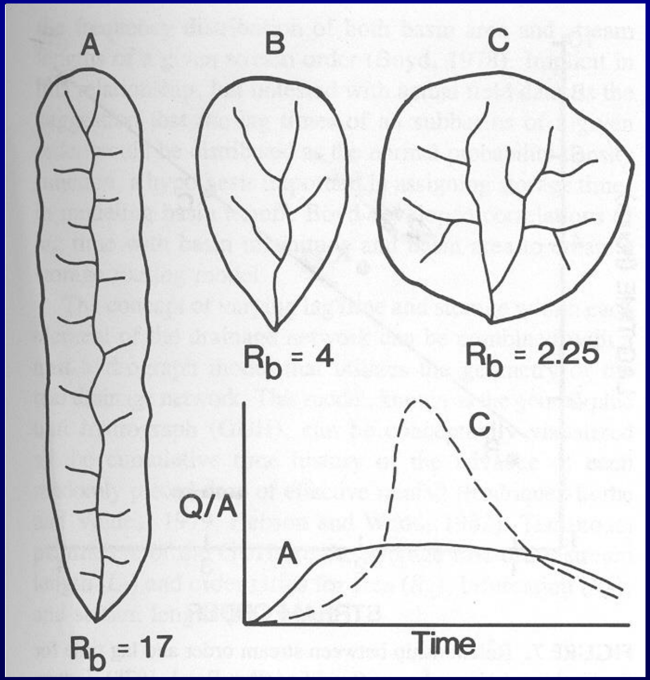
Dry climate – DD increases

Wet climate – DD decreases

Basin Morphometry

- Basin with equal shape – surface runoff tends to arrive simultaneously – flash flood

- Elongated Basin – runoff arrives to mainstream at different times – hence less flashy



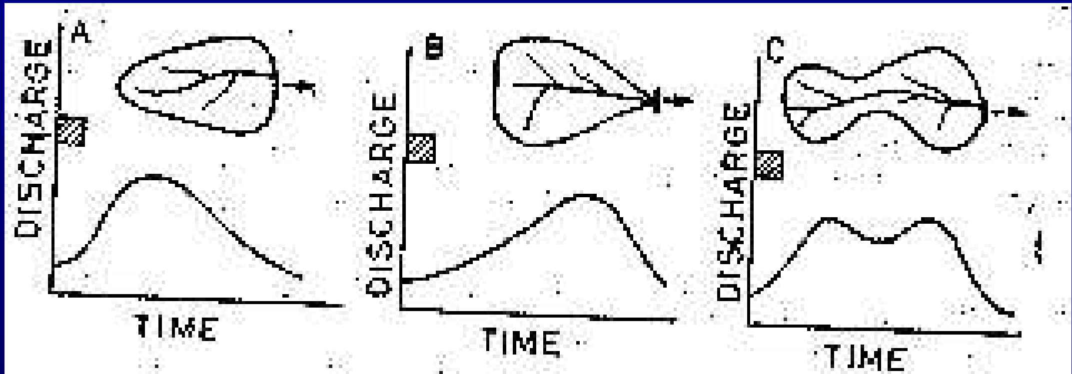


Fig. 6.2 Effect of catchment shape on the hydrograph

Peak Discharge

Flood likely to occur during maximum peak discharge to mean annual discharge ratio

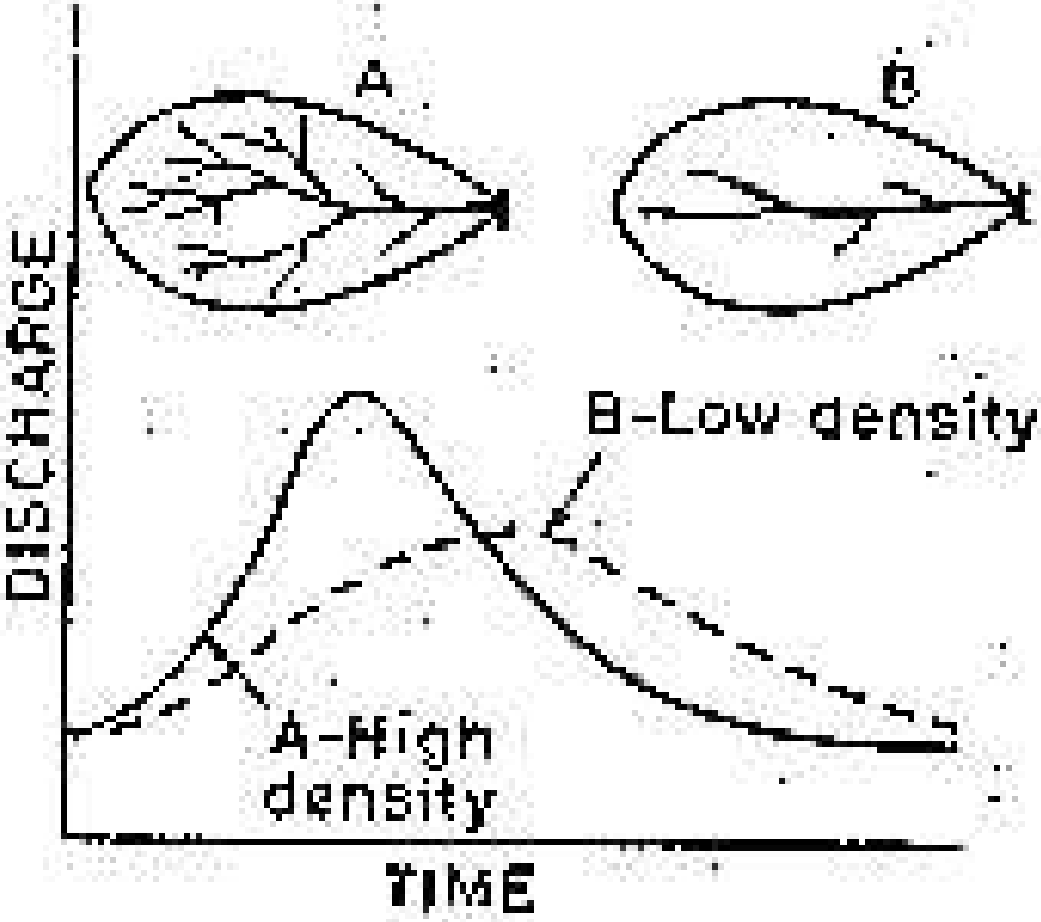


Fig. 6.3 Role of drainage density on the hydrograph

DRAINAGE BASIN FACTOR

Slope

More Slope – Runoff more, High erosion and overland flow

Less slope - less runoff, increased infiltration and subsurface flow

Lithology

Structure

Geomorphology

Lanuse/Landcover

River Channel Factors

Channel gradient and Bed Load

Steep gradient – carries coarse bed load causing channel, bank and flood plain erosion results in channel widening in downstream and finally causing flooding

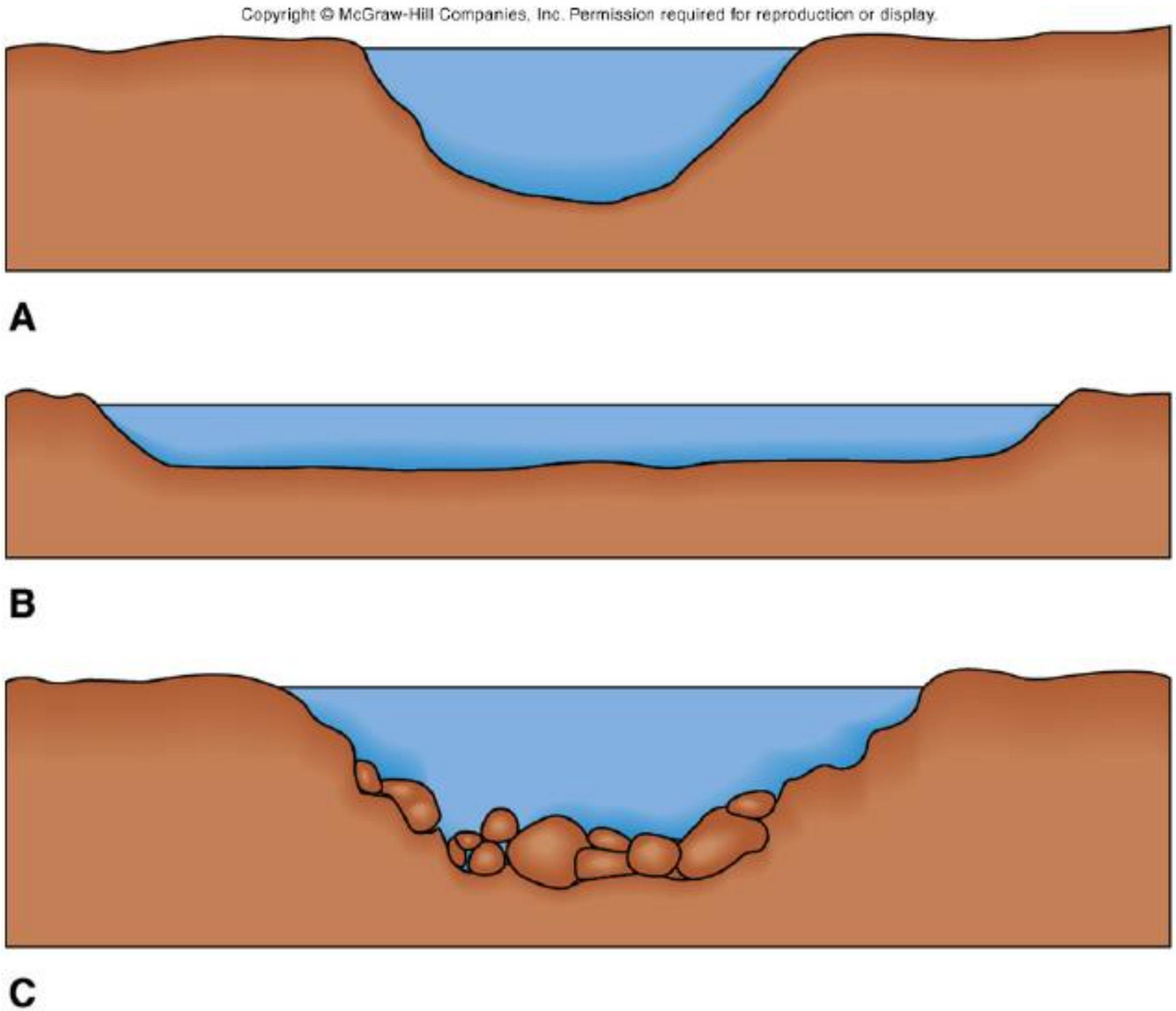
Gentle gradient – less bed load

Channel Geometry

Bed rock rivers – uplifted plateaus – narrow and deep - accommodate flood discharge

Alluvial rivers - channel will be widen - flooding

River channel factor controlling flood

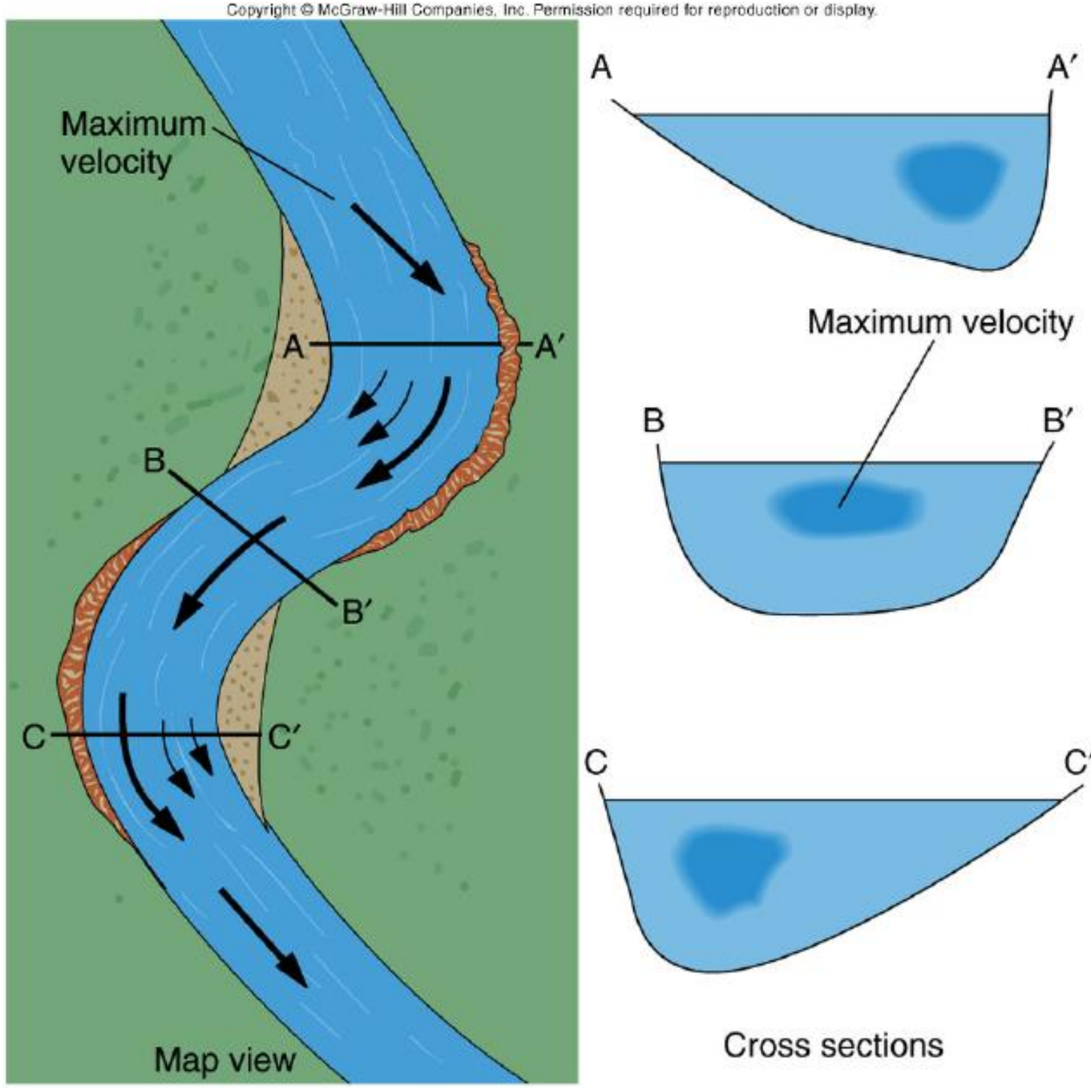


Semicircular
Flow fast

Wide channel
Flow slow

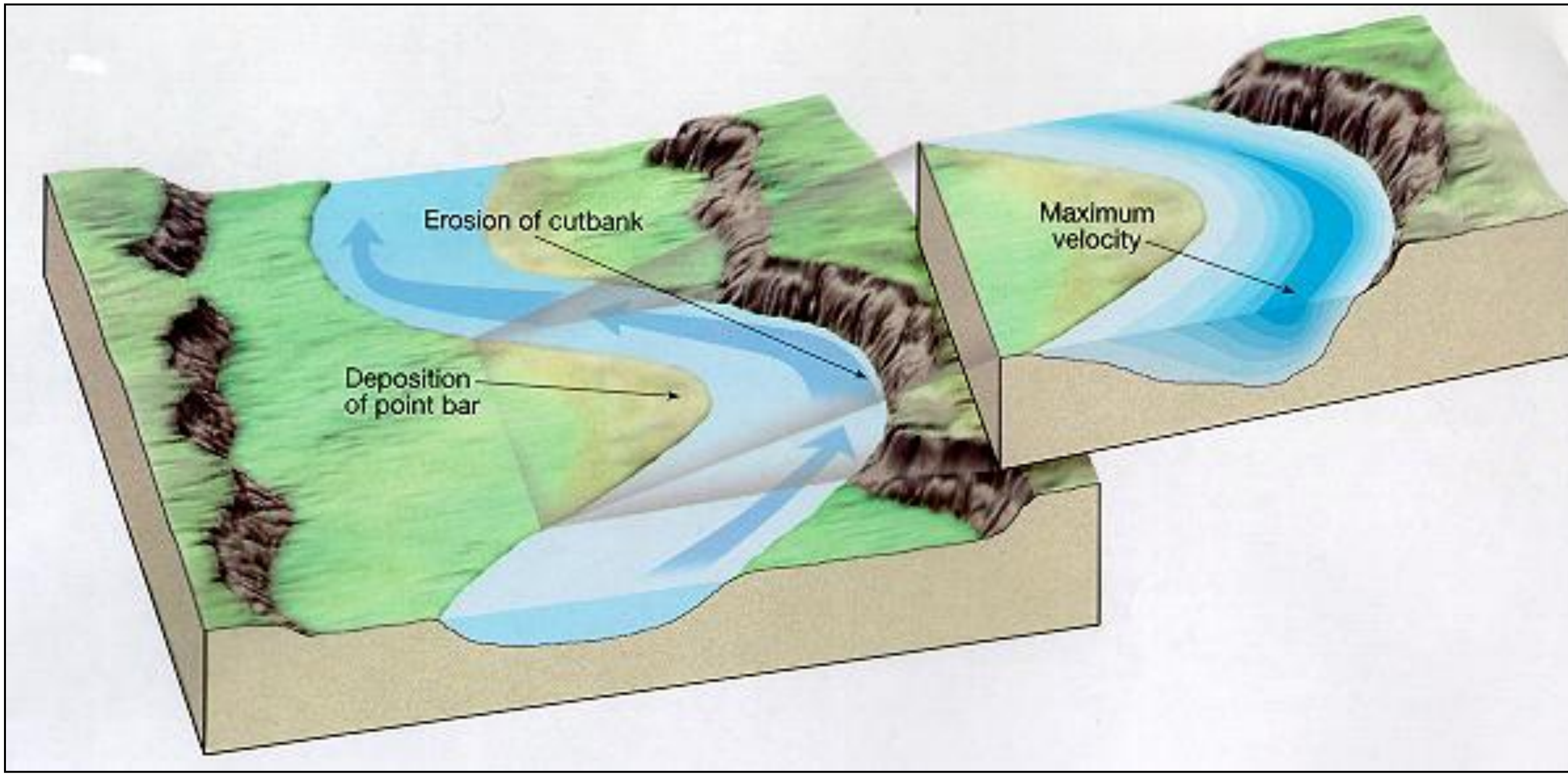
Rough bottom
Flow slow

River channel factor controlling flood



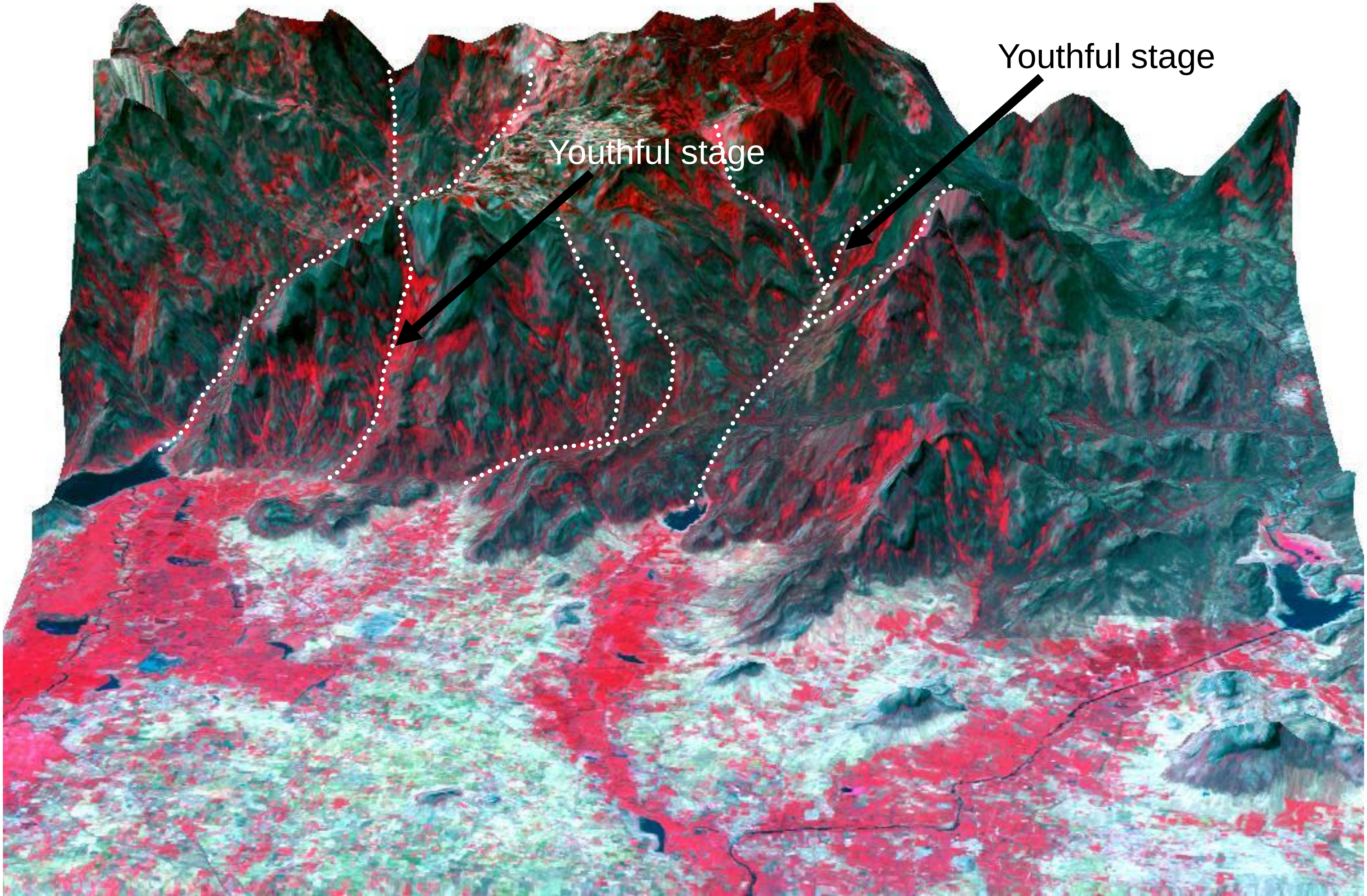
Velocity

Streams generally erode on outer (cut) banks where velocity is greatest, and deposit on the inner sides of bends where velocity is slower.

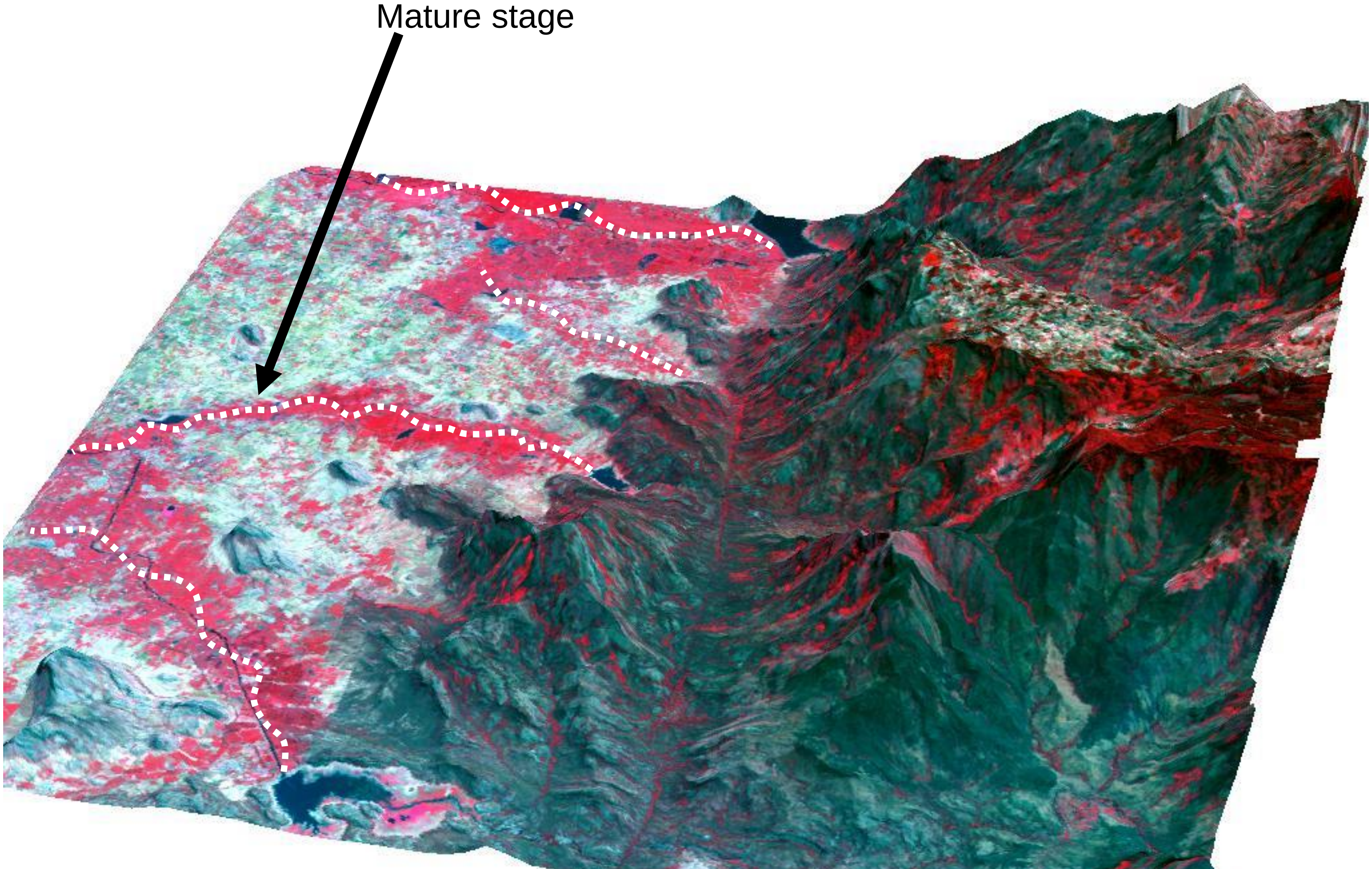


Meanders tend to grow as the flow erodes the banks, favoring development of meandering channels.

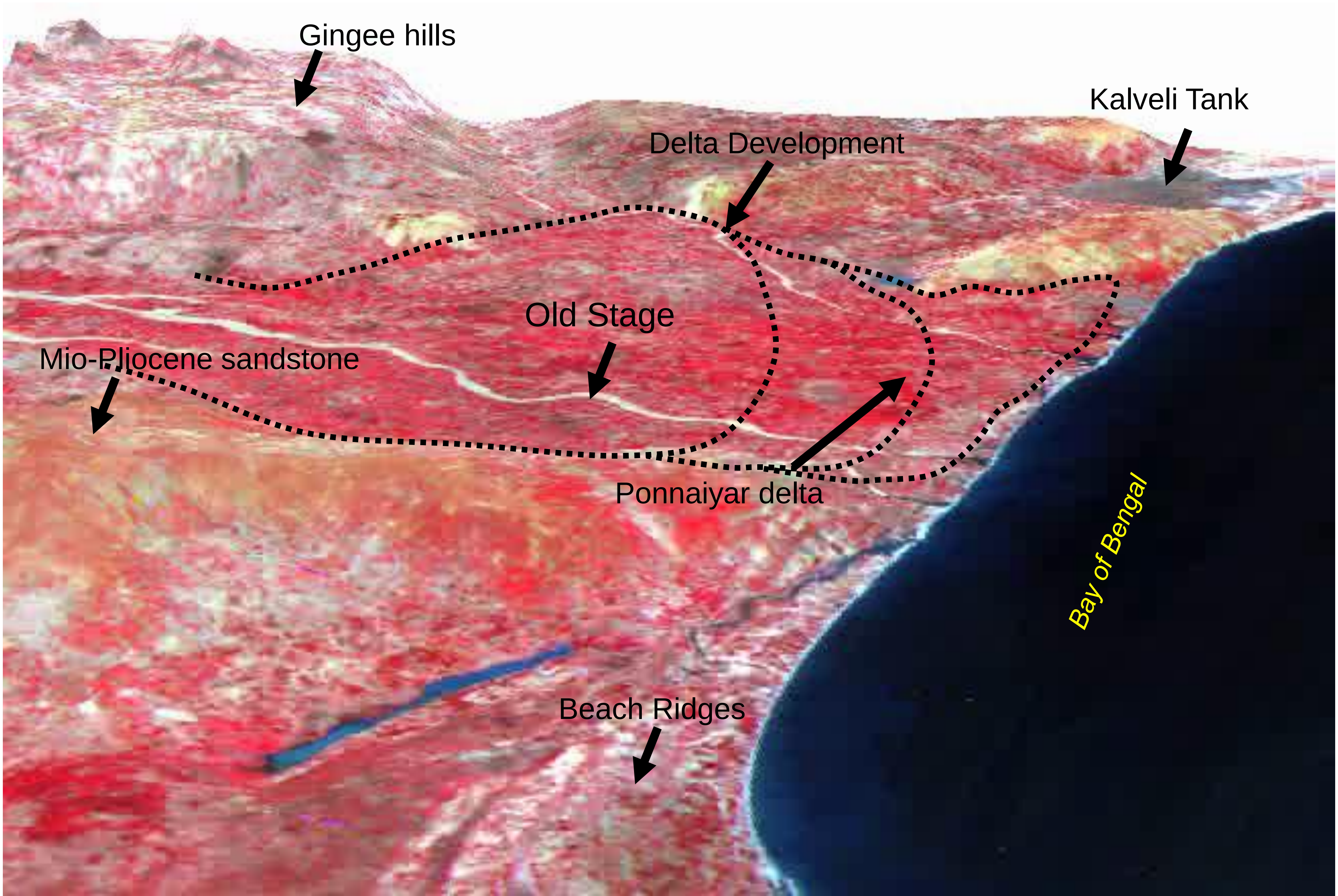
Youthful stage of River



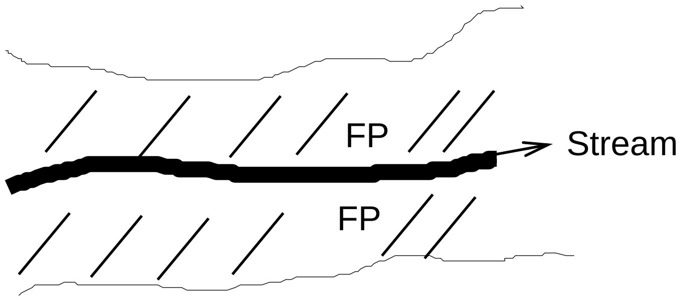
Mature stage of the River

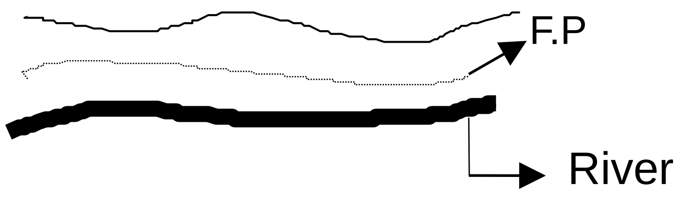


Old stage of the River



Paired Flood plain

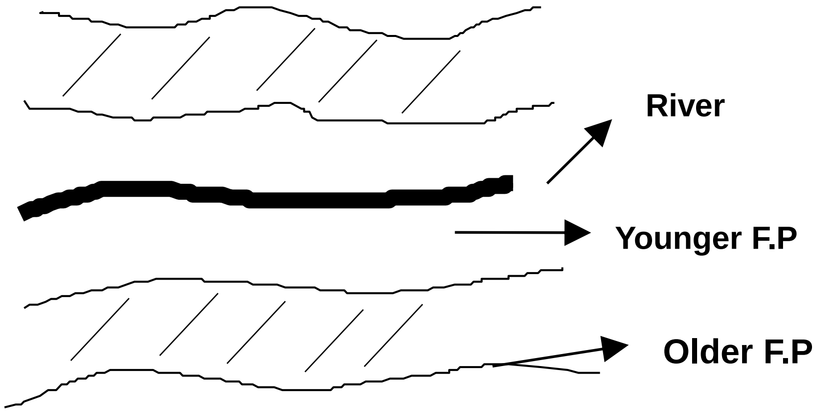




Unpaired Flood Plain

- ➔ **Shifting river**
- ➔ **Northern bank prone for erosion**
- ➔ **Northern bank prone for flooding**
- ➔ **Southern half have poor Ground water**
- ➔ **Southern bank is emerging**

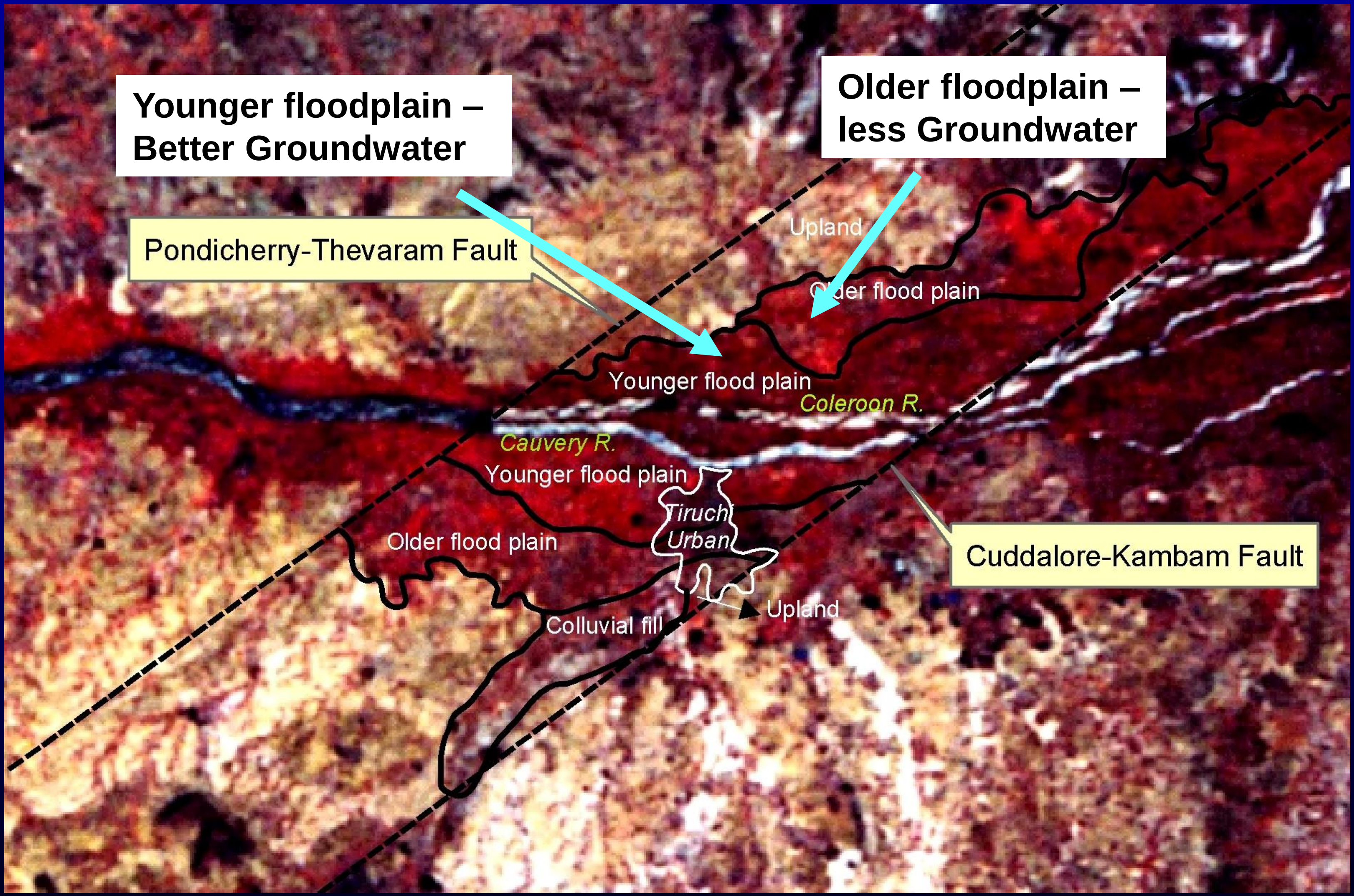
Older Flood plain and Younger Flood plain



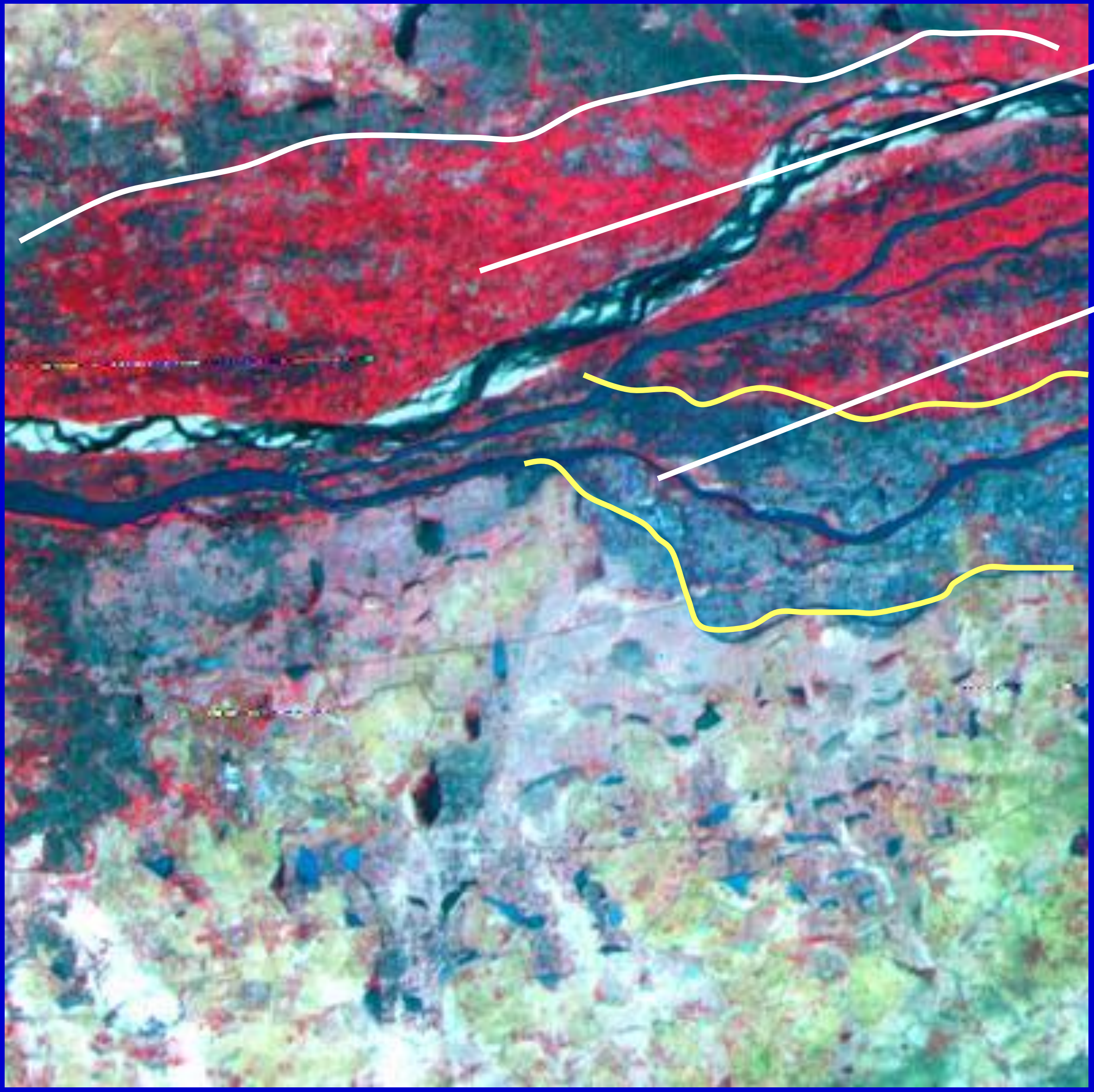
- ➔ Show distinct two levels with contrasting tone
  - Reasons,
    - (i) Rise of land
    - (ii) Fall of sea level
    - (iii) Excessive daming

- ➔ Resources / Environment
    - (i) Younger Flood plain - better Ground water
    - (ii) Younger Flood plain - prone for flooding
    - (iii) Younger Flood plain - better recharge zone.

Multi stage floodplains



FLOOD PLAIN MORPHOLOGY & FLOODING

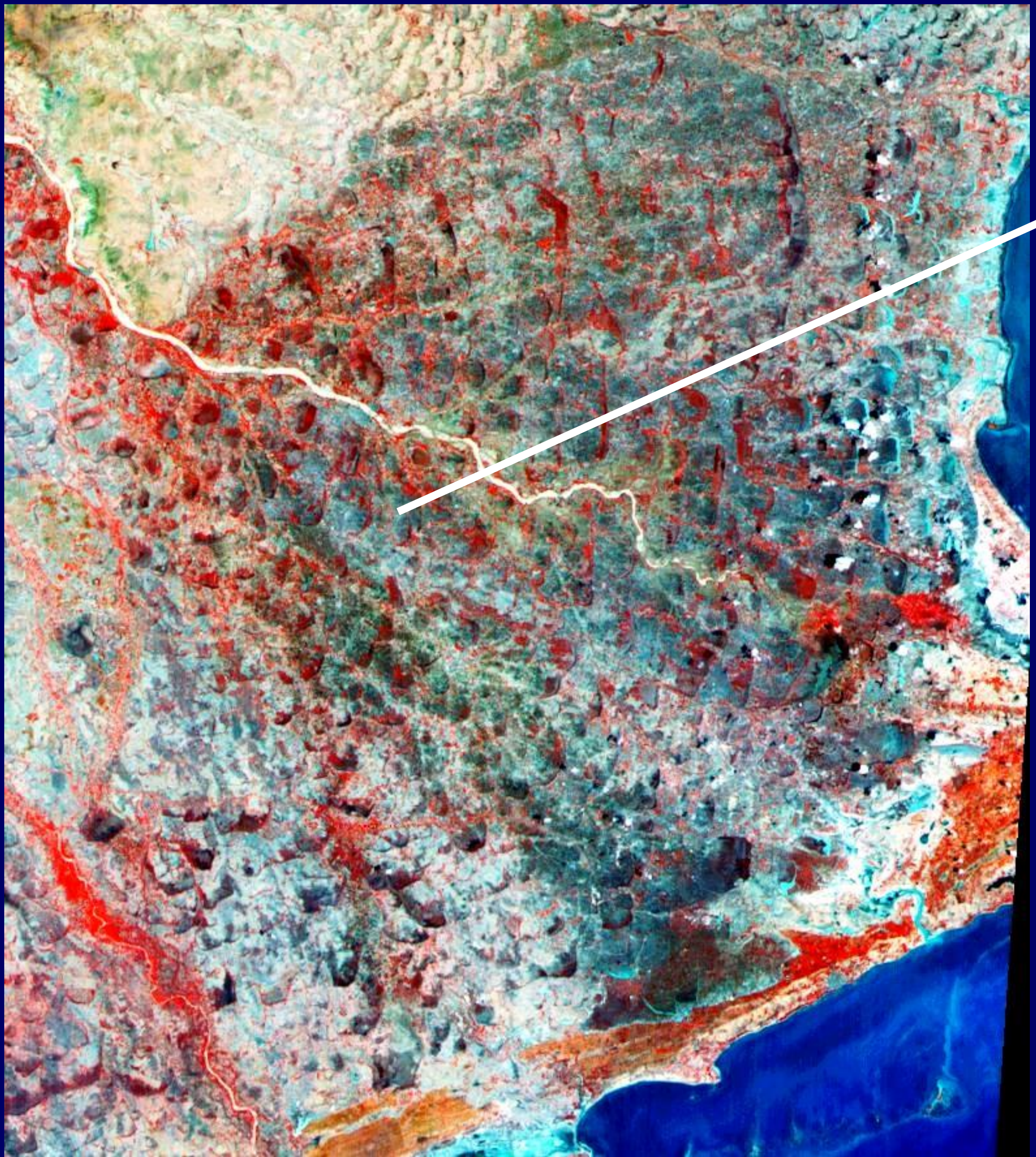


LOWER FLOODPLAIN

UPPER FLOODPLAIN


Paired Flood Plain

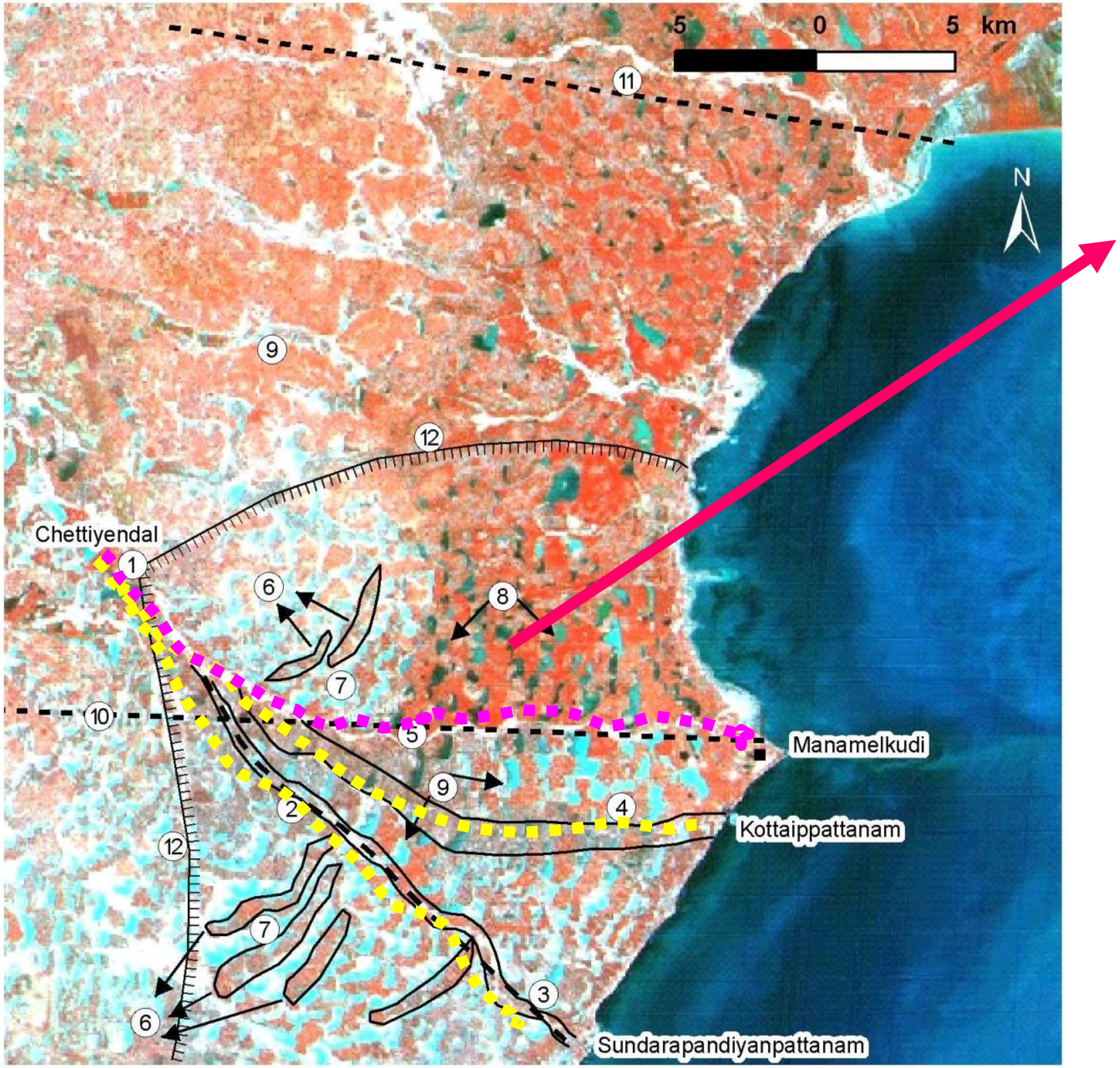
Deltas & Flooding



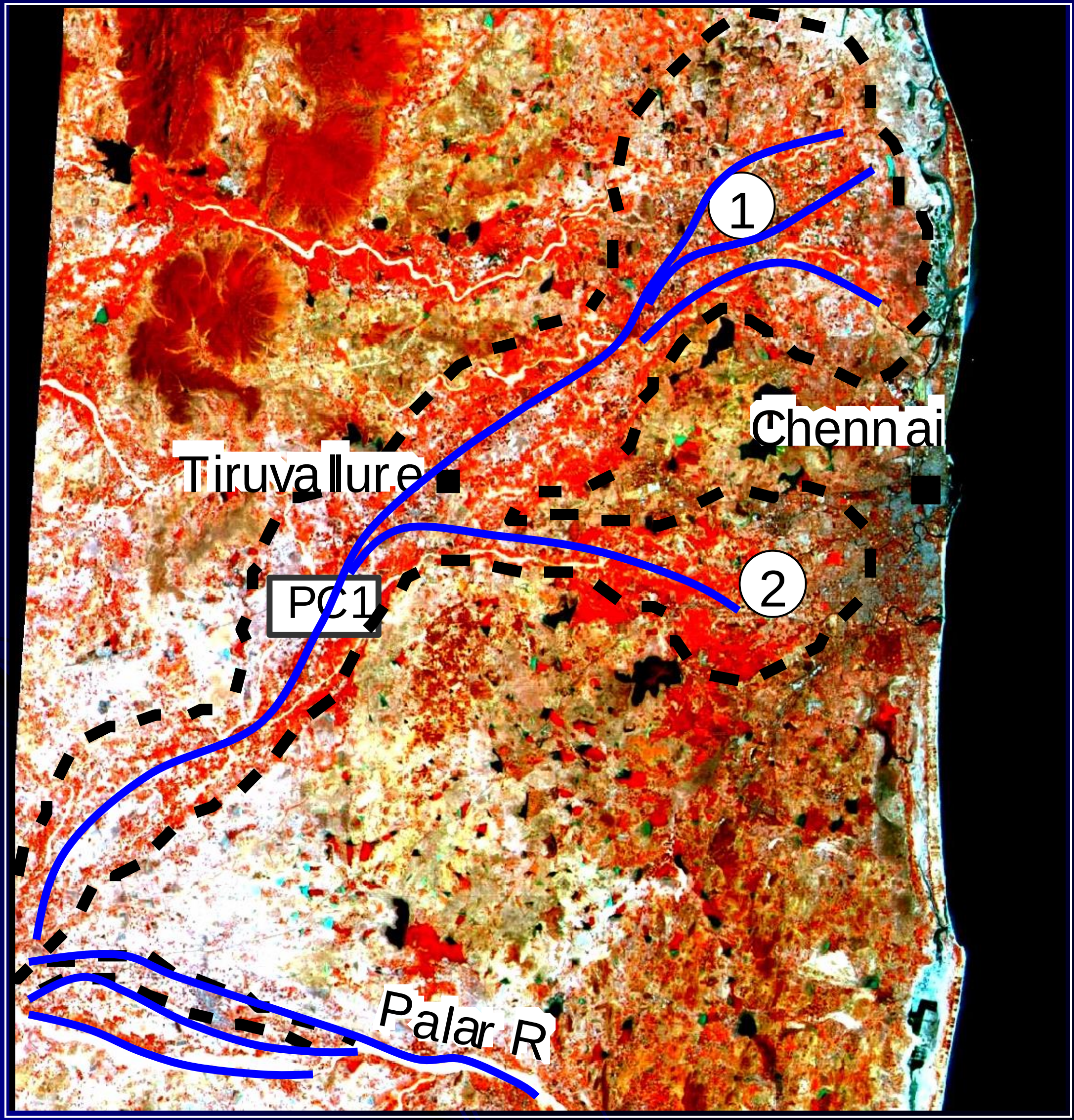
Water bodies lobate Deltas prone for heavy siltation – Tank breach flooding

Lobate Delta – Vaigai

Subsiding deltas Vellar & Flood

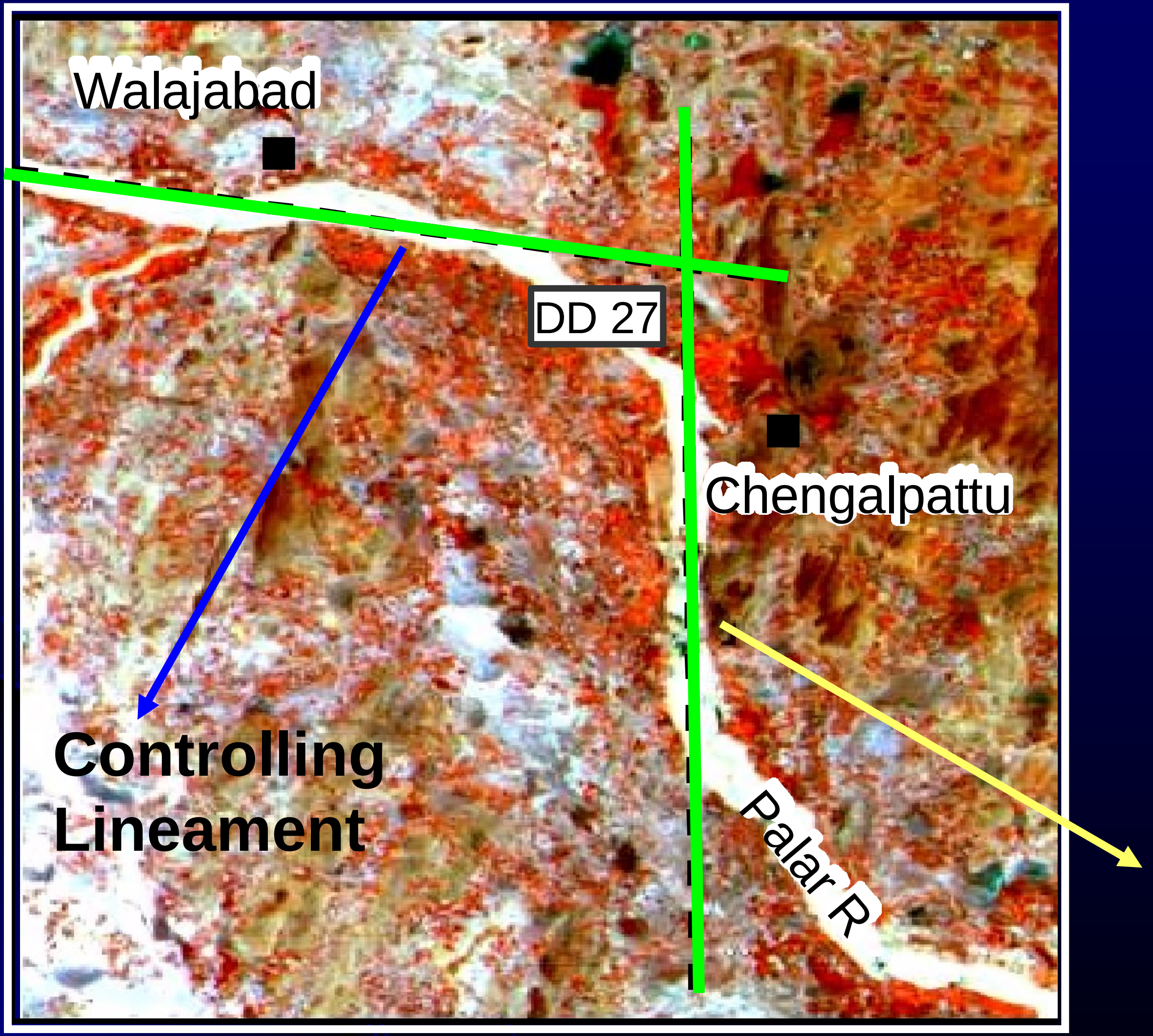


Water Bodies Prone for Floods

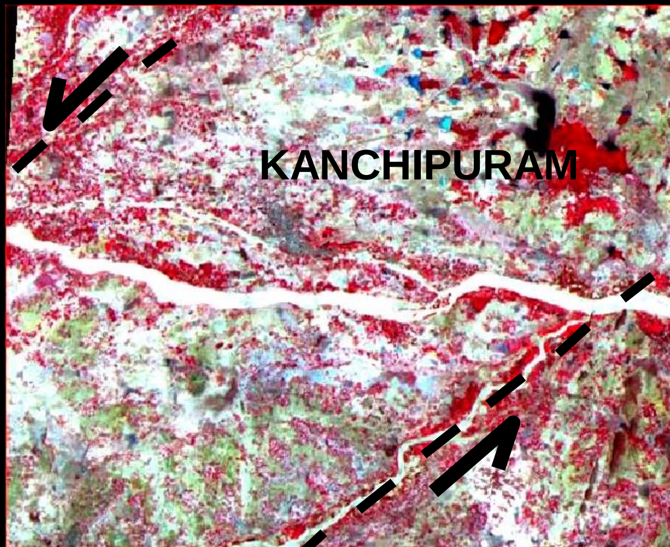


Palaeochannels & Flooding

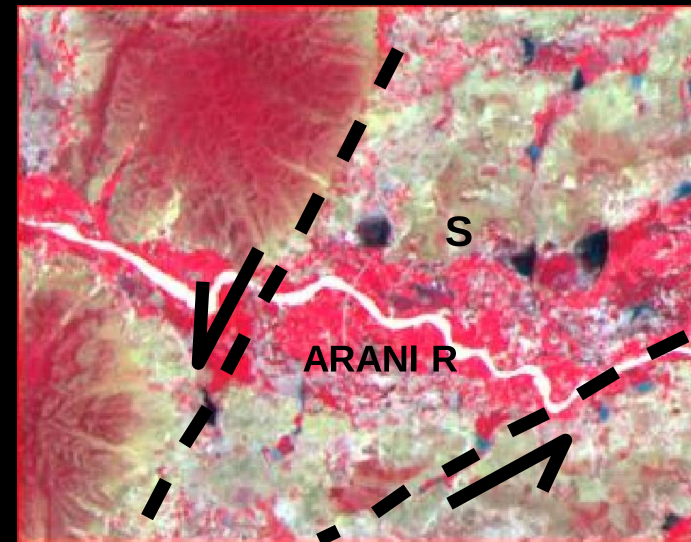
DRINAGE ABBERRATION & Flooding

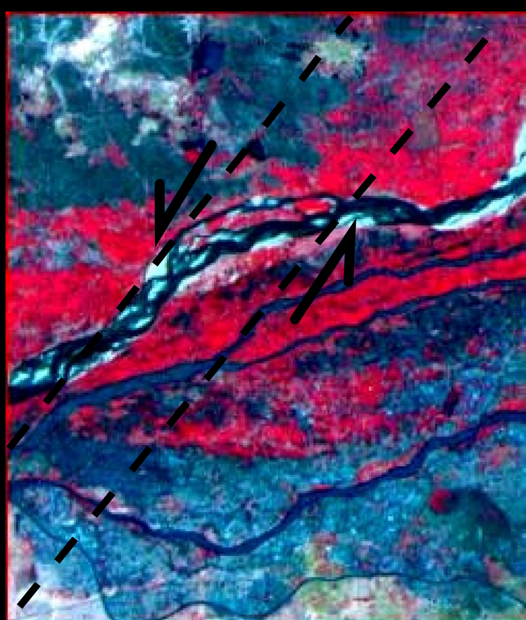


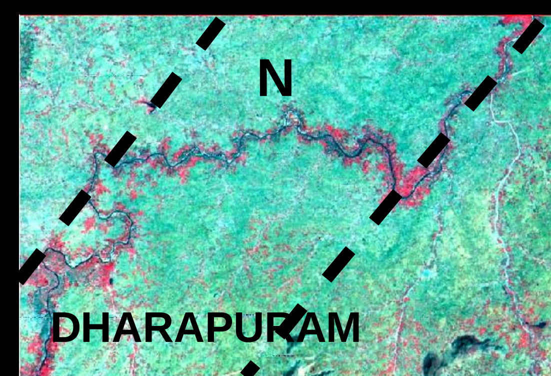
LATE HOLOCENE NE-SW FAULTS– DRINAGE ABBERRATION



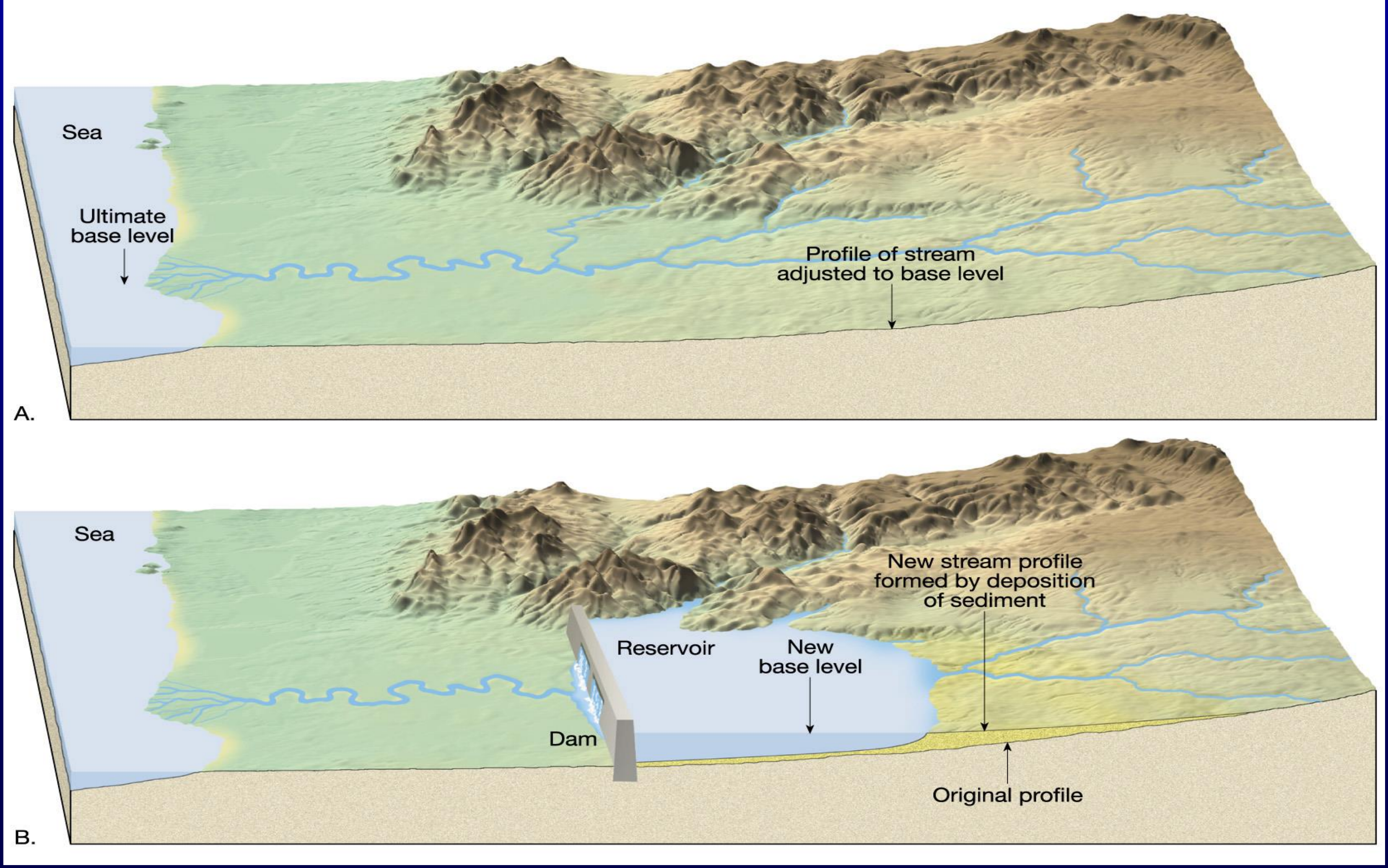
FLOODING
WATER LOG
SALINITY







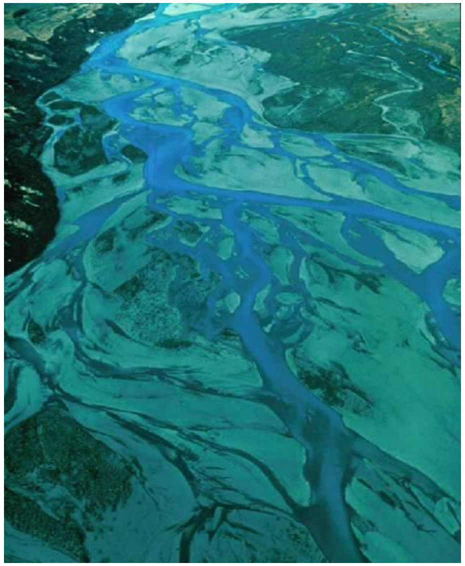
Damming & Flooding in Catchment
Adjustment of Base Level to Changing Conditions



Braided streams

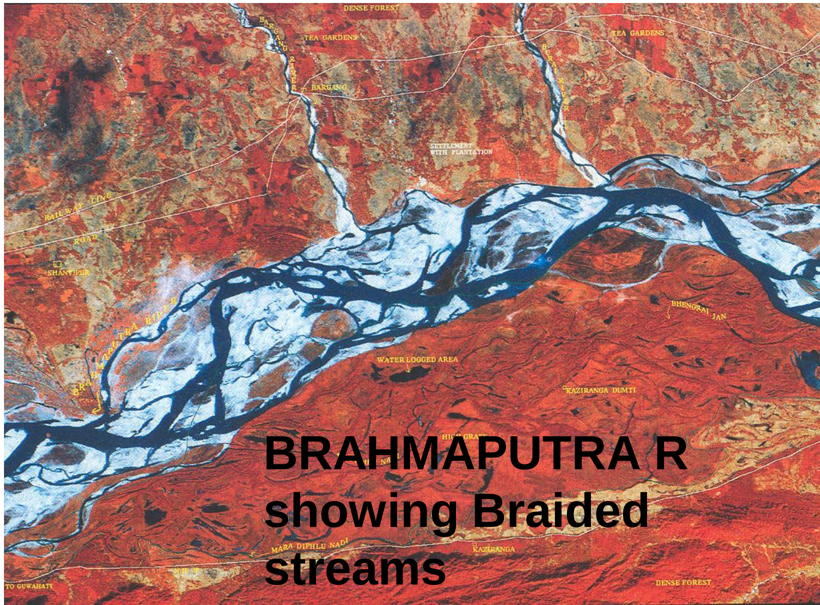
A network of converging and diverging *streams* separated from each other by narrow strips of sand and gravel.

Rivers split up within mother channels



- ❖**Indicate dams in up stream**
- ❖**Land emergence and seismicity**

- High sediment load
- Anastamosing channels
- Constantly changing course
- Floodplain completely occupied by channels
- Many small islands called mid-channel bars
- Usually coarse sand and gravel deposits.



BRAHMAPUTRA R showing Braided streams

Geological Parameters

Neotectonic activity cause

River rejuvenation
Frequent changes in river courses
Braiding of channels
Meanders etc.,

Sediment Transport

Heavy sediment load due to intensive catchments erosion – flooding in down stream

Human Activities

Improper landuse / land cover practises – increase runoff and soil erosion

Deforestation – increase surface runoff and decrease absorptive capacity

Construction of dams at improper sites

Lack of proper regulatory mechanisms

Obstruction of free flow of water – embankments, bunds etc.,

Consequence of Flood

- Excessive Soil Erosion, Landslide, etc. in Hilly region
- Flash flood in Foot hill Region
- River breach & Tank Breach in Plain and Coastal region
- Excessive siltation in the reservoir

FLOOD PREDICTION

In humid regions

Multi dated analysis of snow cap area
Area of snow melt
Thickness of snow melted
Estimating approximate volume of water going to drain

In Tropic and Sub- tropical regions

Cloud cover analysis using INSAT
Estimating approximate precipitation
Comparing with Past periodical flood history

FLOOD FORECASTING

Identification of main tributary supplying flood water to the basin

Collecting satellite driven rainfall estimates

Rainfall data captured on ground

A comprehensive communication network to transmit RS data along
With automated ground observation

Spatial information on catchments characteristics

- Geology
- Soil
- Landuse / Land cover

Preparation of rainfall runoff model

DEM data of the area

Using GIS – probable area of inundation

Role of Remote Sensing and GIS

Role of space applications in disaster management lies in its criticality to produce as well as disseminate the information on real/near real time basis.

The developments in space technology offer tremendous technological potential to address the crucial information needs during mitigation and preparedness, response and recovery/ relief phases of a flood.

Table 12.1: Information requirements for a disaster manager

S.No	Phase	Required Information
1	Flood preparedness (Before Flood)	– Chronically flood prone areas – Prior information on probable flood affected areas with considerable lead time – Optimum evacuation plans
2	Relief and Rescue (During flood)	– Flood affected areas – Flood damage statistics – Updation of the flood condition in terms of flood recedence and persistence etc.
3	Flood Mitigation (After Flood)	– Changes in the river course – The status of flood control works – River bank erosion – Drainage congestion – Flood Risk zones

Role of Space Technology….

During preparation phase

- **Using historic satellite remote sensing data acquired during floods, it is possible to provide the chronically flood prone areas in the form of a map showing severely affected, occasionally affected, etc.**

- **Prior information on probable flood affected areas using hydrological models can be provided**

- **Using flood inundation models in GIS environment, optimum evacuation plans can be generated for carrying out rescue operations**

During floods,

A flood map showing the spatial extent of the flood affected areas

Flood damage statistics like district-wise flood affected area, submerged crop, marooned villages and length of submerged road/rail can be provided

Satellite data can be used at regular intervals for updation of the flood condition on the ground in terms of flood progression, recedence and persistence

The main components of flood mapping and monitoring

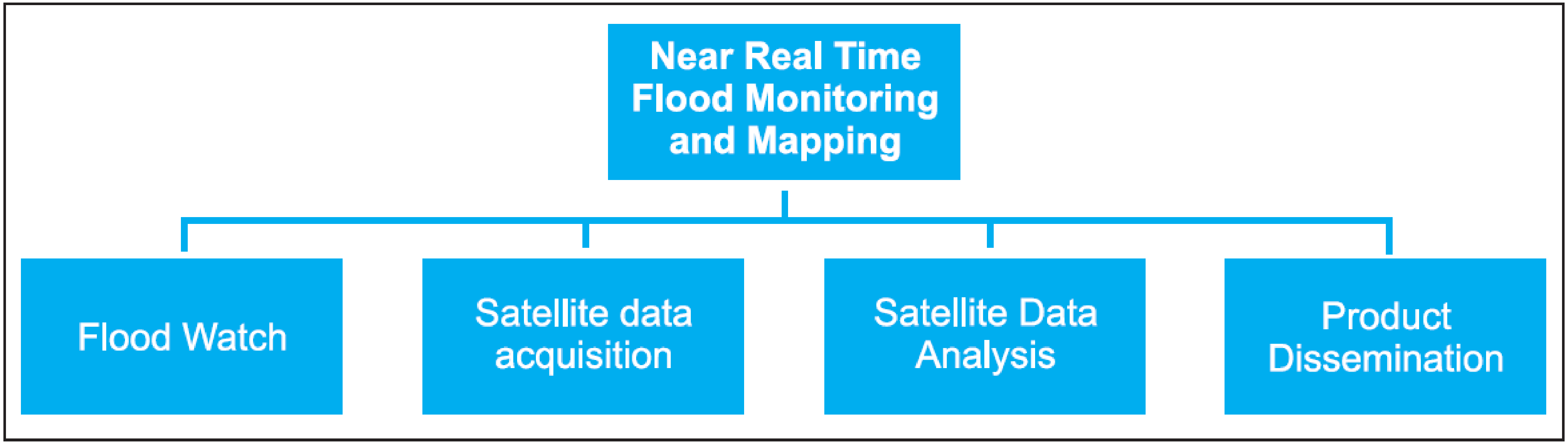


Figure 12.1: Components of the Near Real Time Flood Mapping and Monitoring Activity

FLOOD WATCH

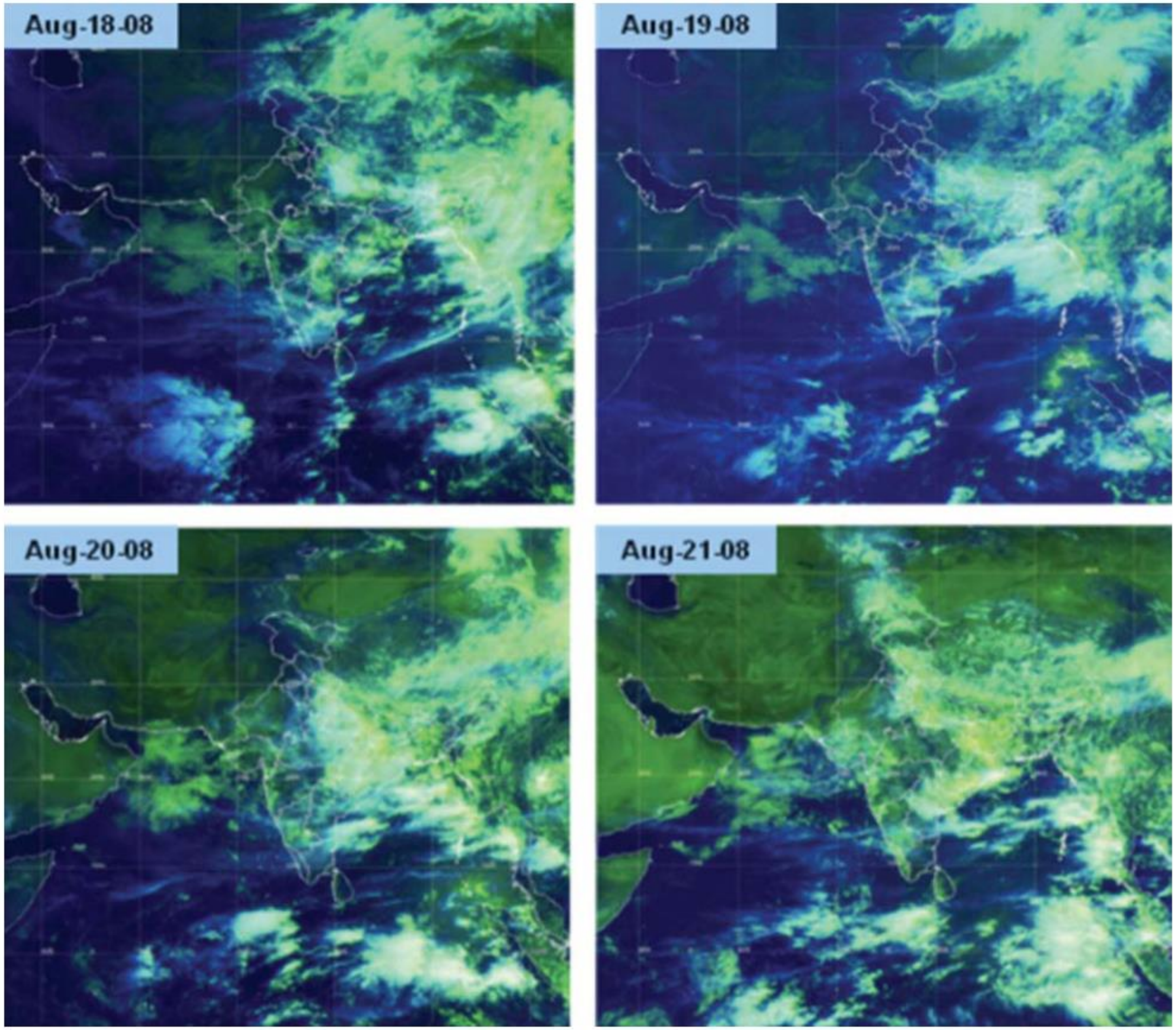


Figure 12.2: KALPANA-1 images showing cloud cover during 18-21 August 2008 (Source: www.imd.ernet.in)

Meteorological satellite KALPANA-1 images over the country were collected to understand the cloud cover pattern. The cloud cover over the country from 18-21 August, 2008 through a series of INSAT images

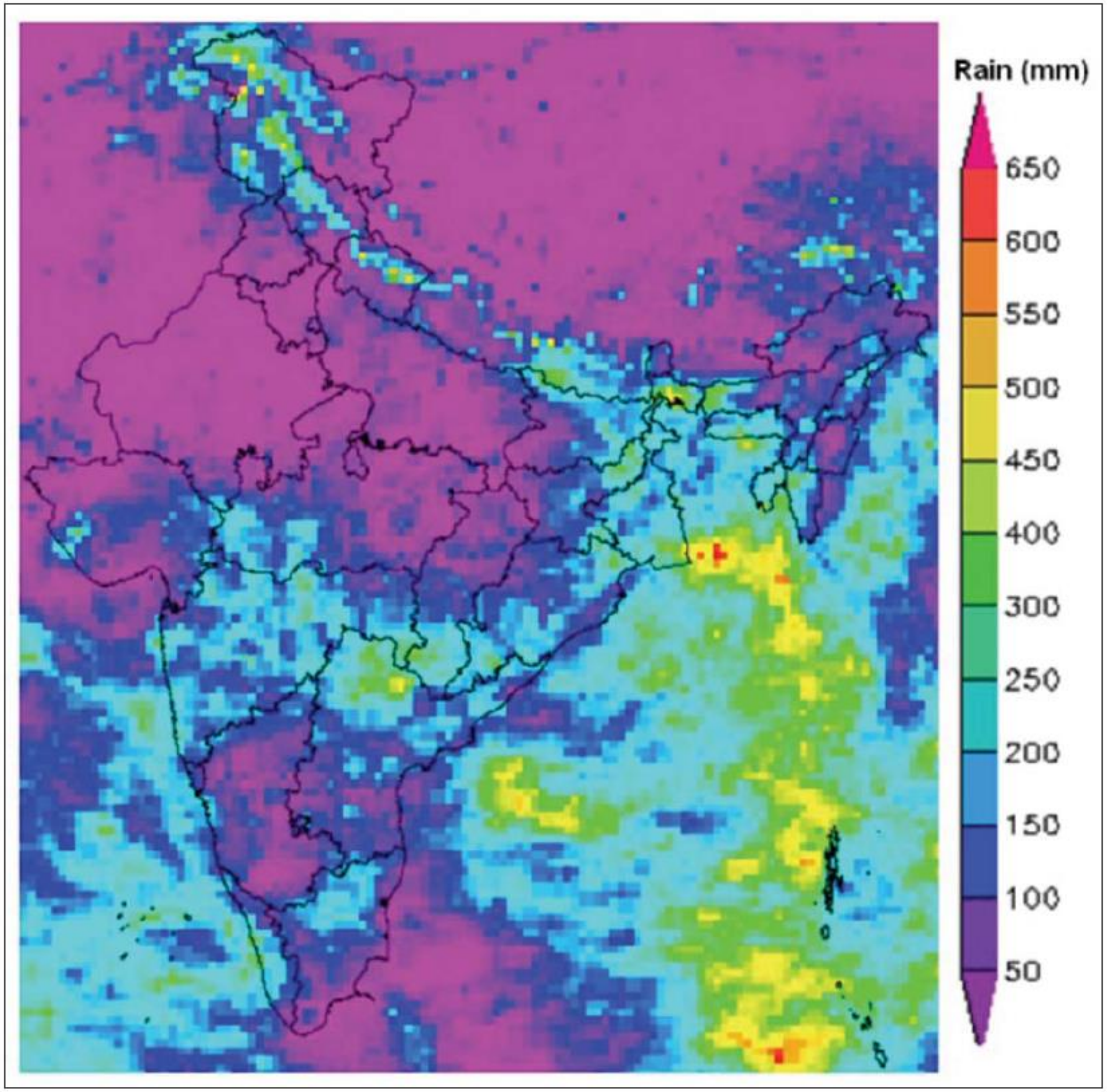
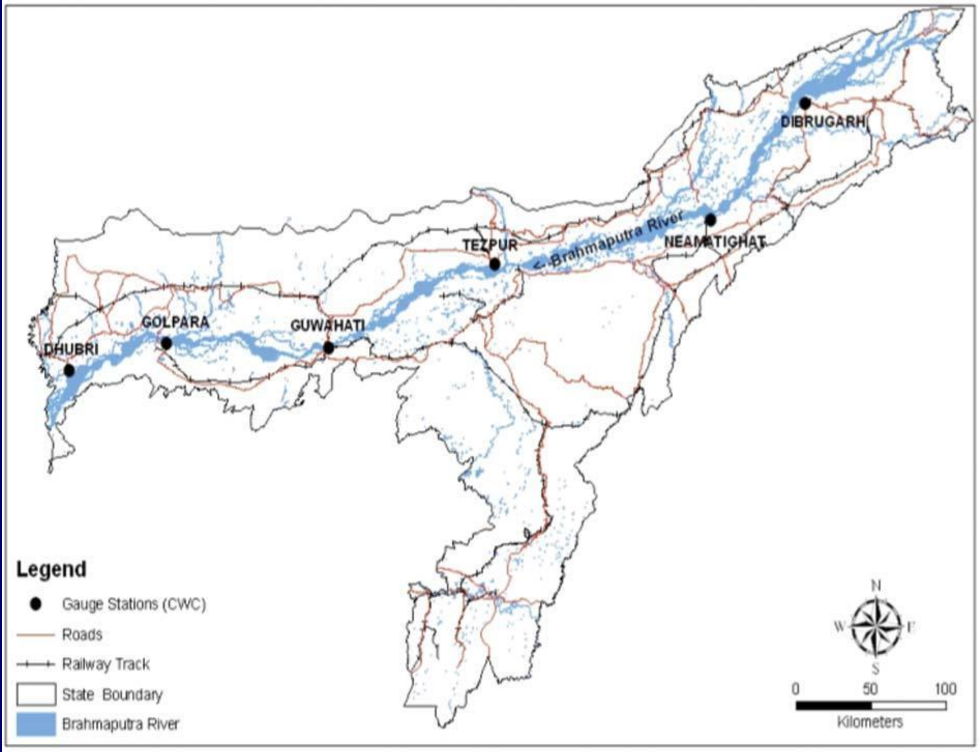


Figure 12.3b: Rainfall distribution maps from TRMM merged product

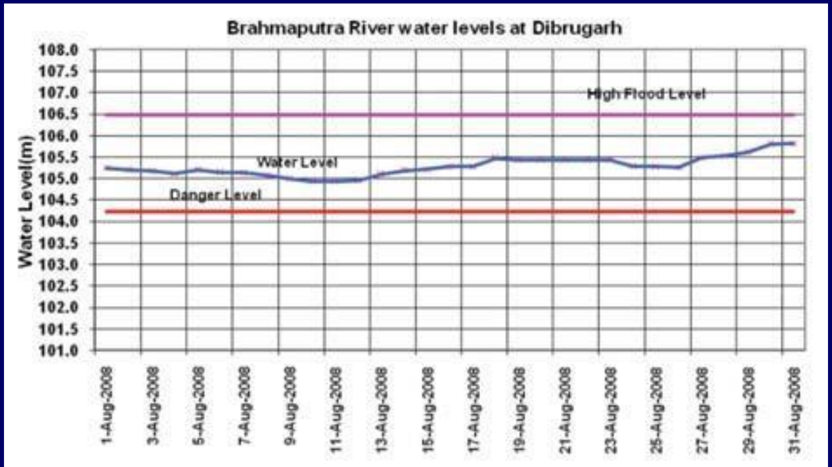
The rainfall distribution from Tropical Rainfall Measuring Mission (TRMM) merged products which are available on their website are also downloaded

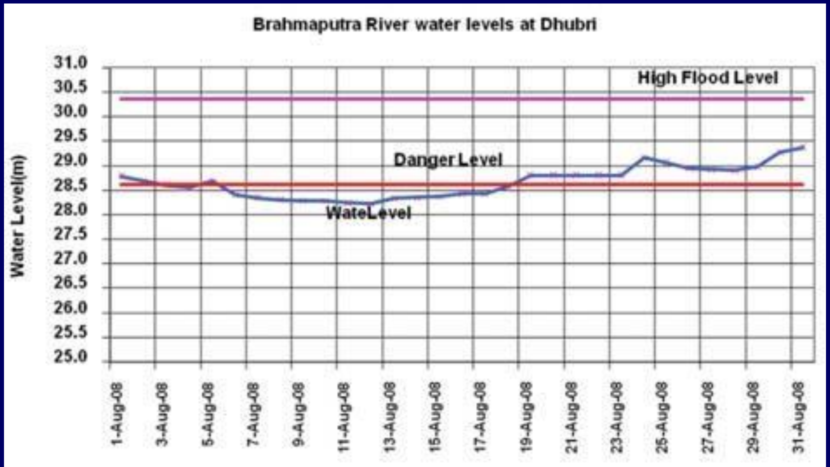
Water Level Data

The water level data of rivers and its tributaries at various gauge recording stations is obtained from CWC on daily basis



Location of gauge stations along river Brahmaputra in Assam





Satellite Data Acquisition

After the flood watch, the affected regions are identified and all the available satellites onboard covering the affected area are earmarked and coverage charts are prepared

Table 12.3: 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

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

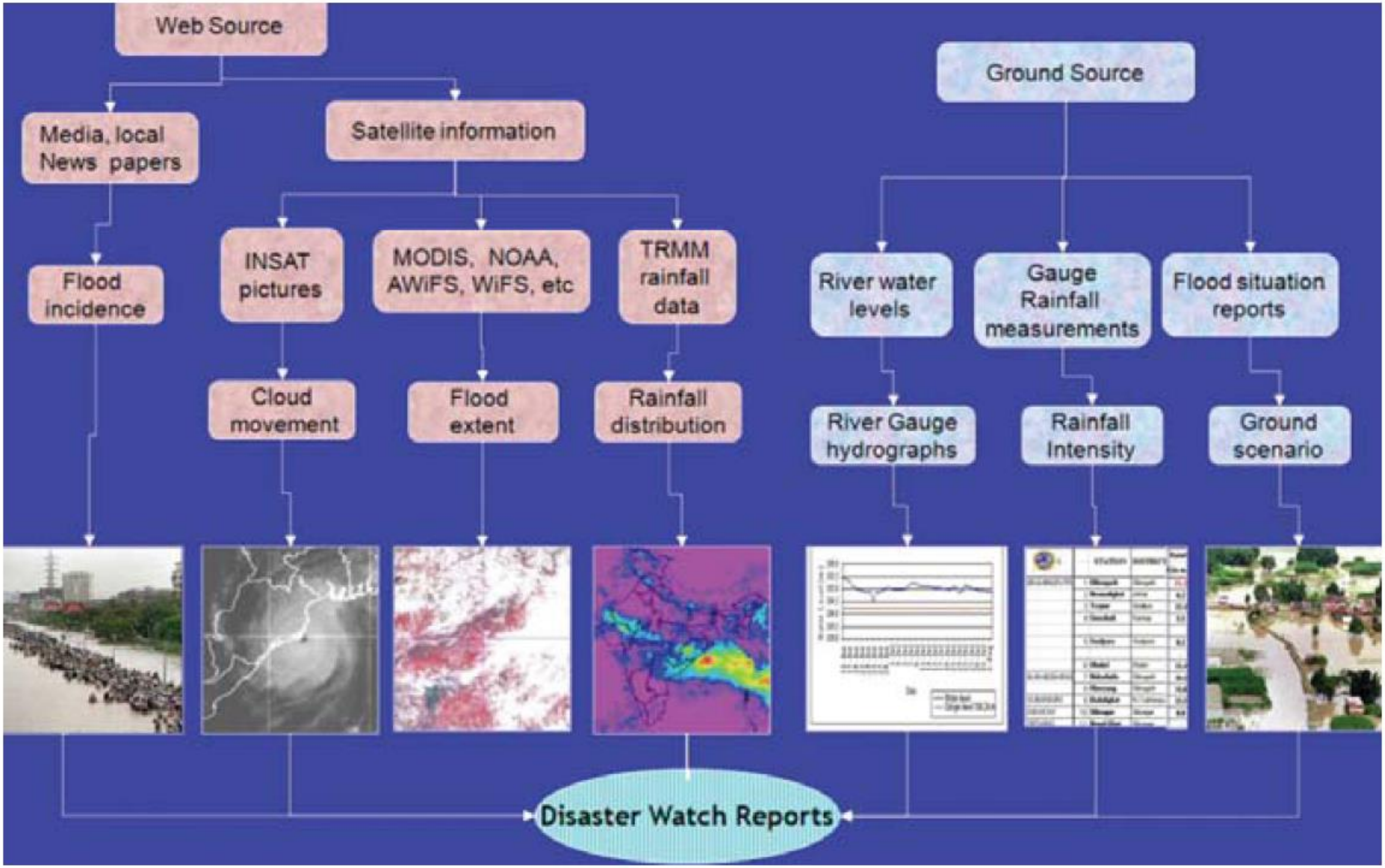
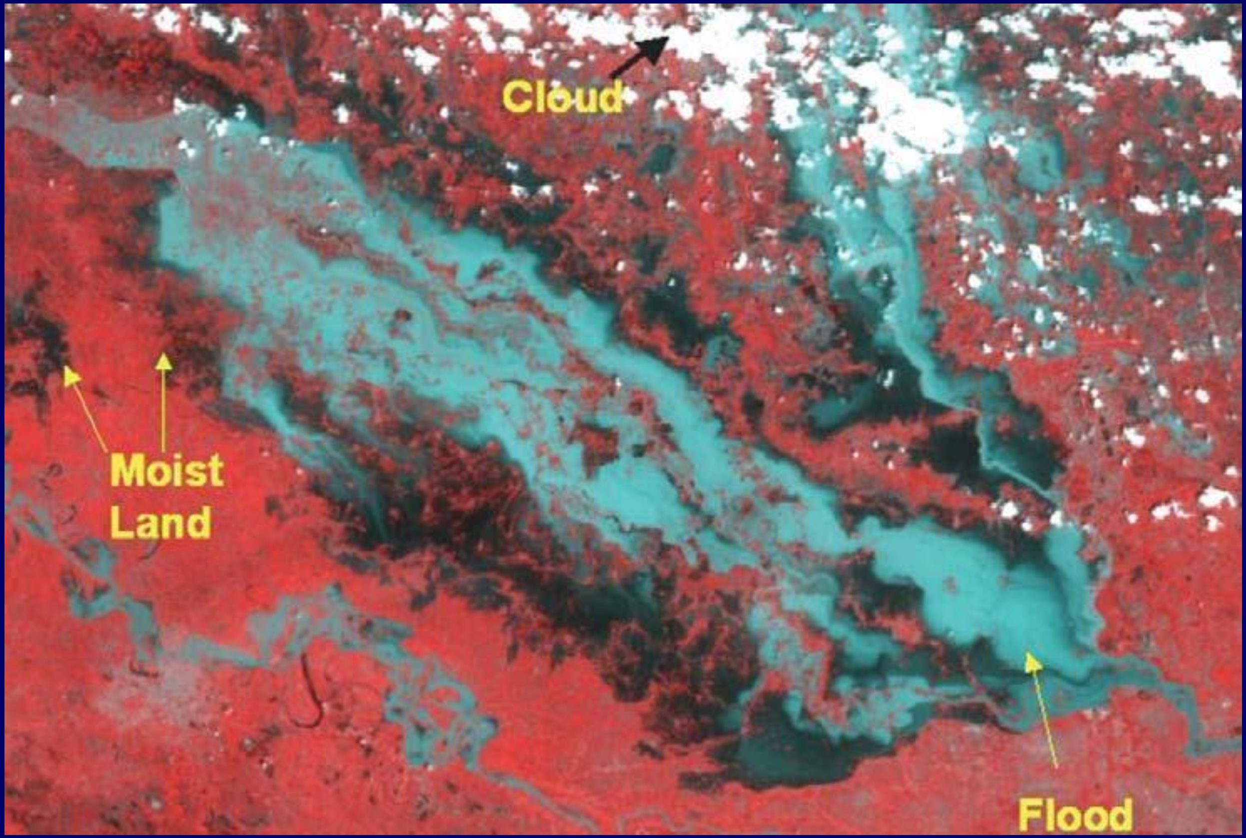


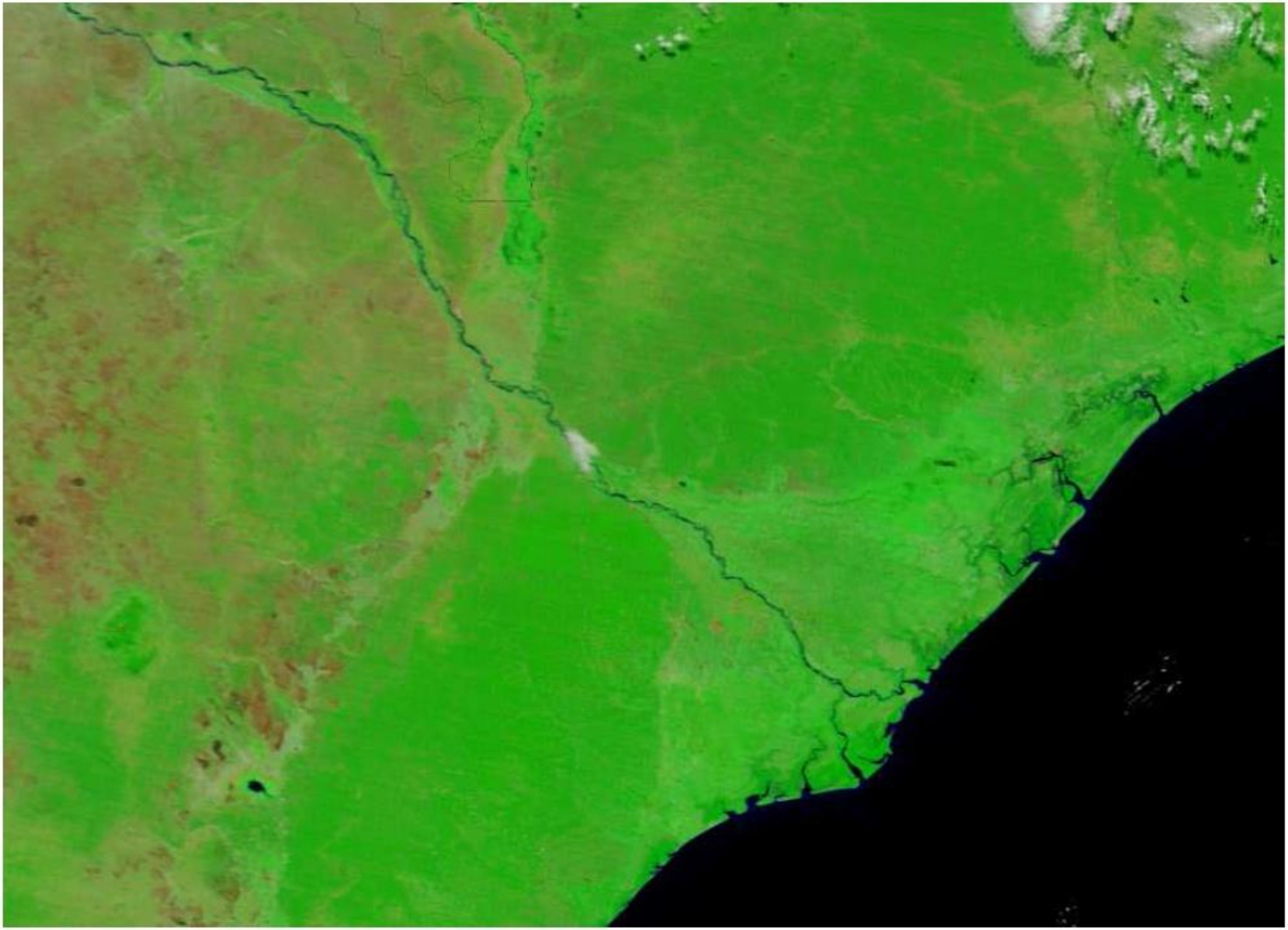
Figure 12.8: Elements for satellite data planning and acquisition



Satellite Data Analysis

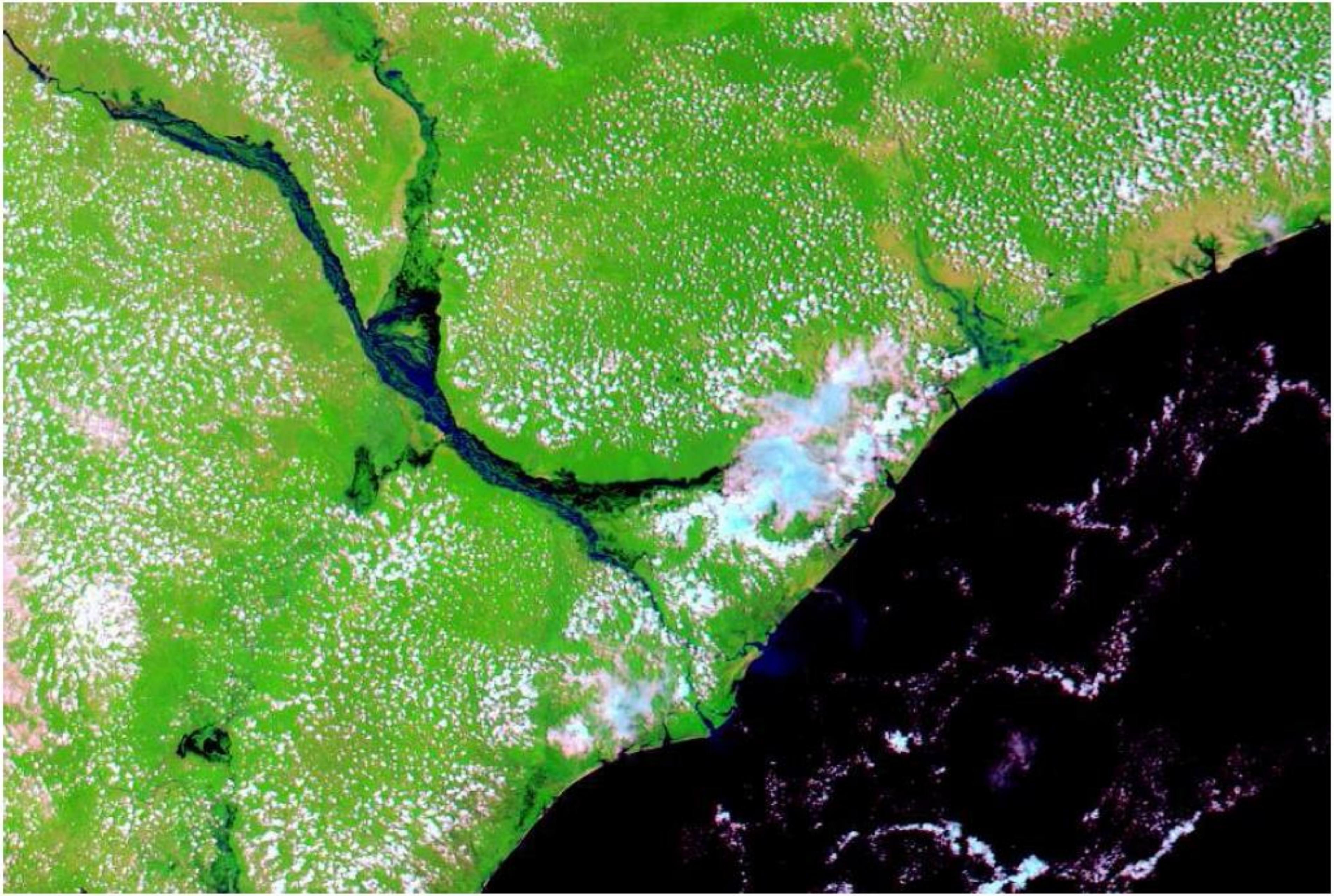
Optical Data

Optical remote sensors measure the reflectance from objects on the ground. Pure and deep-water bodies absorb most of the electro-magnetic energy and reflect very little energy. Flood water, because of different sediment concentrations, reflects considerable energy in different bands, including near infra red (NIR) region



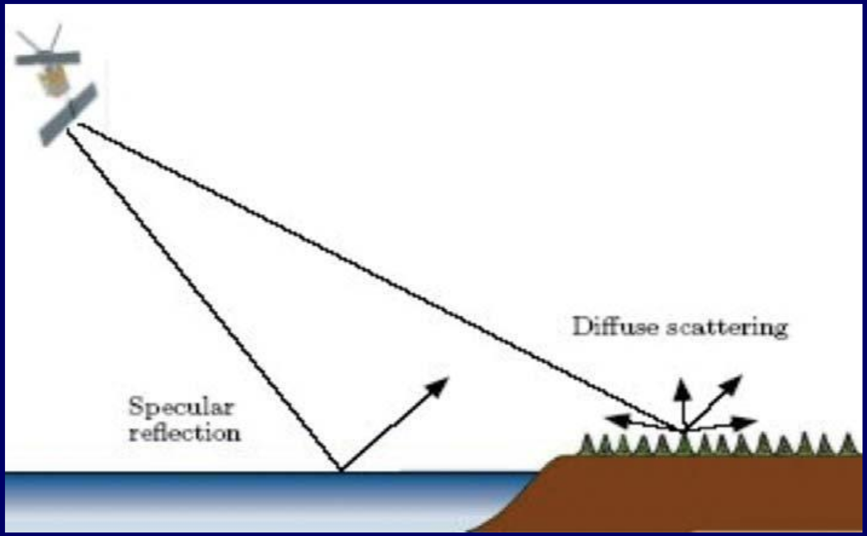
Dry season

8 January 2008



03 February 2008

Microwave Data



The advantage of using radar data over the optical data is its ability to penetrate cloud cover and also data acquisition during day and night.

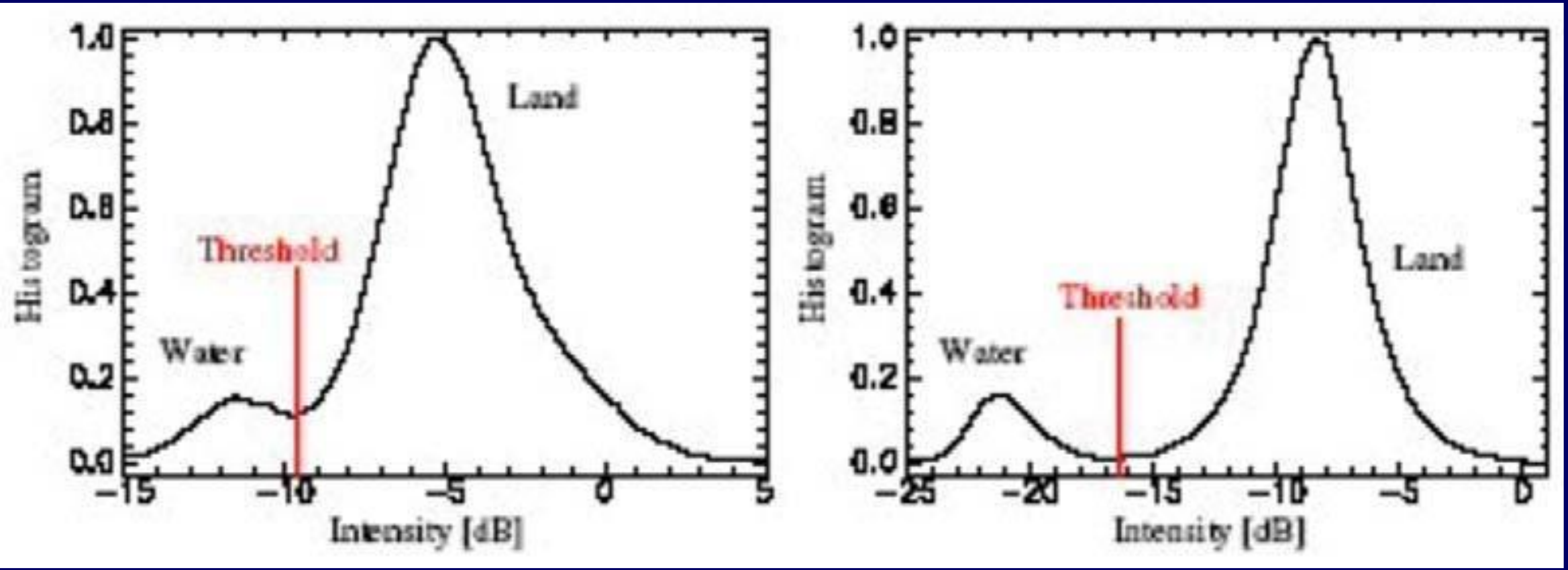
Water surfaces are generally smooth at radar wavelengths and can be regarded as specular reflectors which yield small backscatter.

The surrounding terrain is assumed to be rough at radar wavelengths which exhibits diffuse scattering with moderate backscatter

The backscatter depends on the frequency, incidence angle, polarization and is sensitive to the ripples on the water surface induced by wind waves.

Thresholding is the traditional method of detecting flooding in open areas. Intensities below the threshold are regarded as flood or open water, whereas pixels with intensities above the threshold are regarded as dry land.

We observe that for the 45º incidence angle case the water and land modes are easily separable with the proposed threshold, whereas the proposed threshold at 23º incidence angle introduce classification errors



Histograms of two SAR images covering same area with different incidence angles (Left: 23^0 & Right: 45^0)

FLOOD MAPPING

Remote Sensing & GIS Based Methodology

Before the onset of flood season, pre-flood satellite data over flood prone states are acquired and analysed.

River banklines, permanent water bodies and active river channel are extracted using digitization tools. These datasets and layers will be used as master data sets for further analysis.

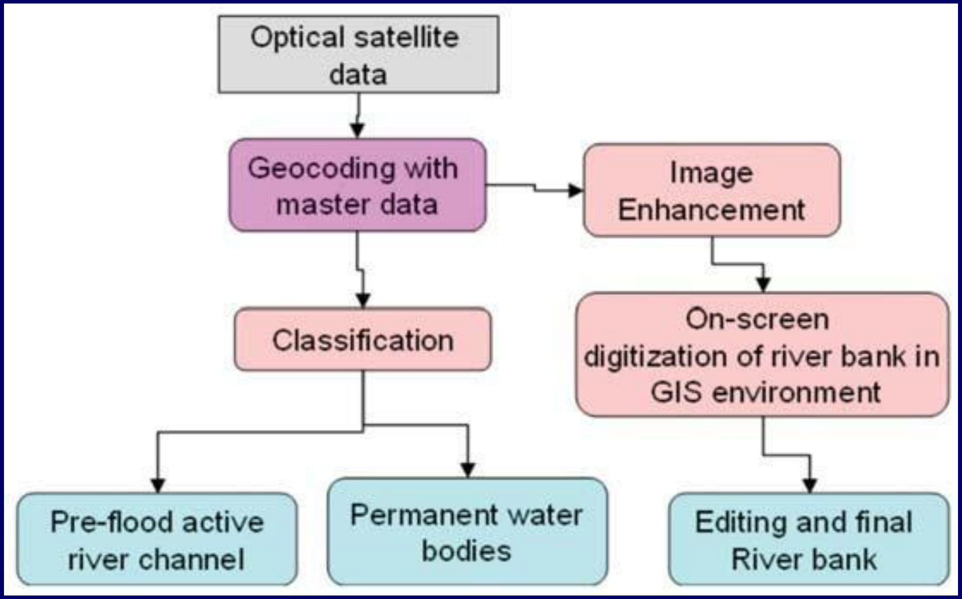
Such pre-flood master layers are prepared every year for all the flood prone rivers in the country.

The satellite data acquired during floods is geocoded with the respective master data sets.

In case of optical data, supervised classification is performed using the infra red band by providing about 10 training classes in water at different pockets. A cloud mask and a cloud shadow mask are also prepared.

Since signature of cloud edges mixes with the water signature, a model was developed to classify water and cloud using different spectral bands for AWiFS data

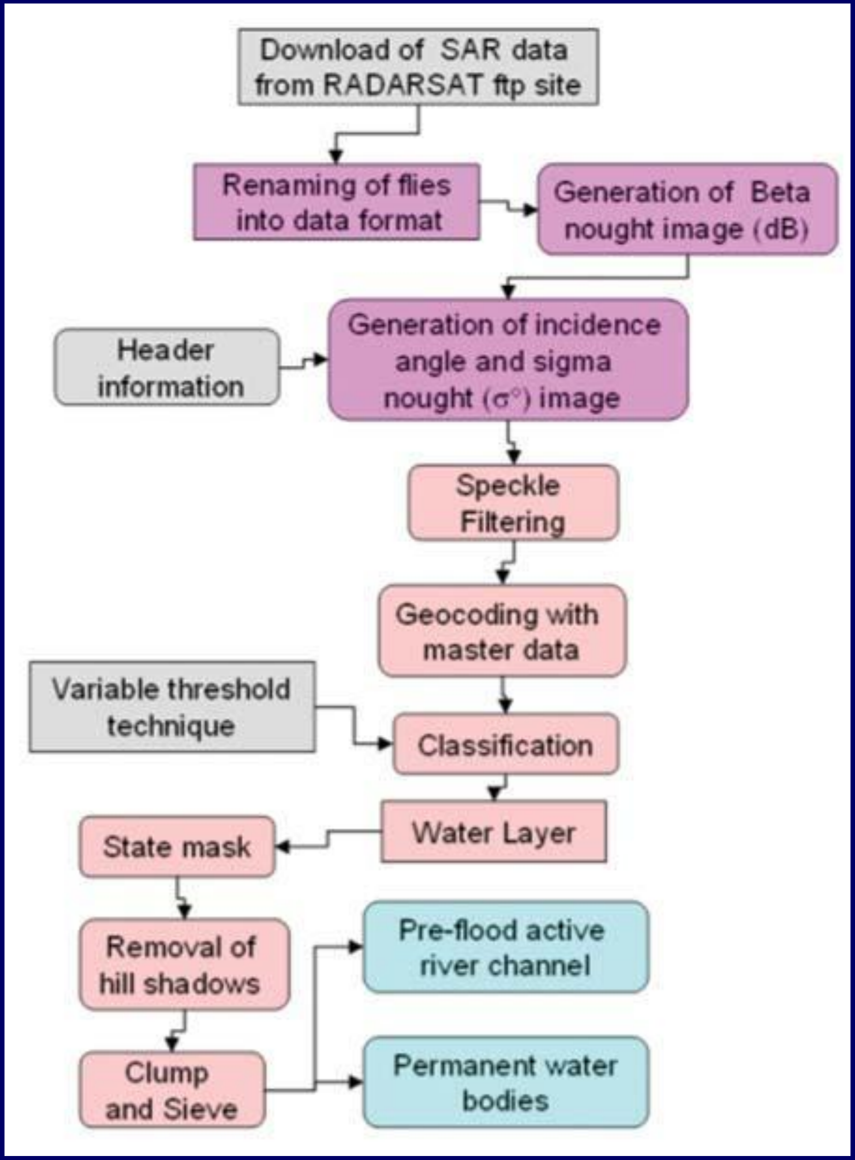
Flow chart for pre-flood analysis of optical data

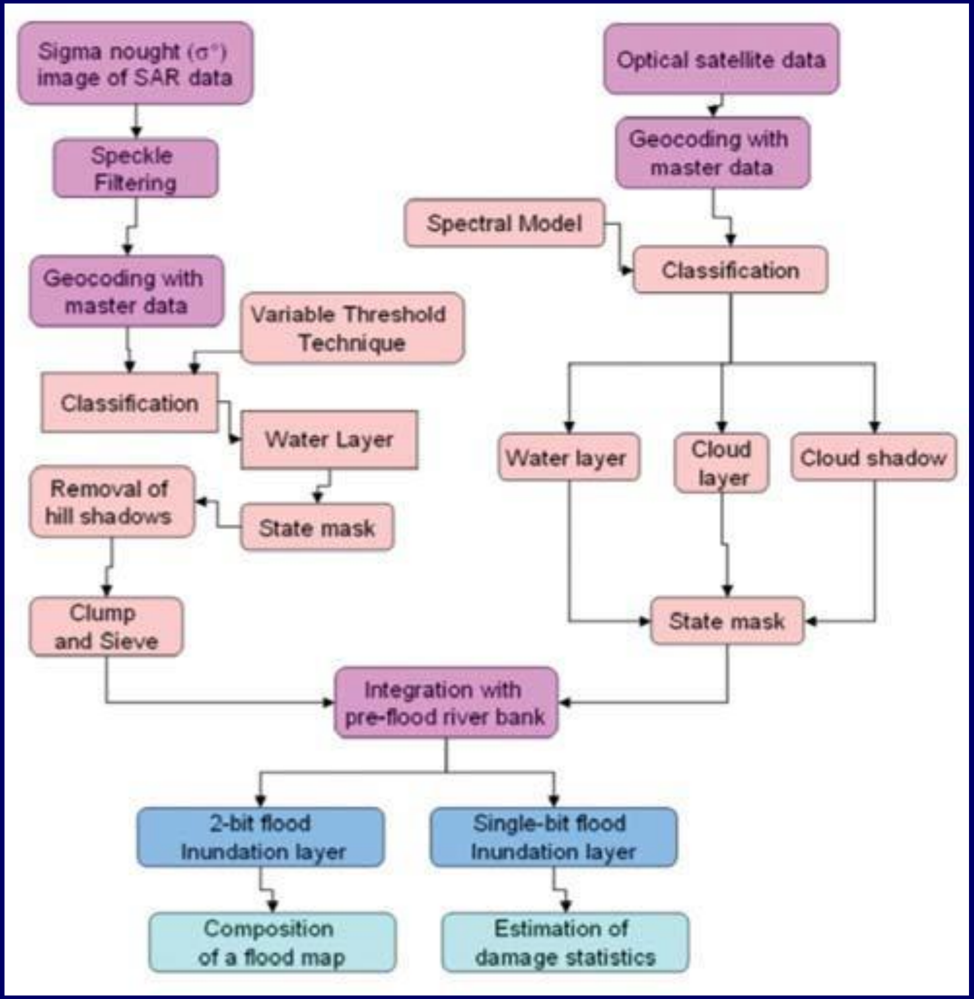


In case of SAR data, sigma nought is generated and using variable threshold model, water is classified. Post editing tools are applied and final flood layer is prepared.

The flood inundation layer is prepared by integrating the water layer with the pre-flood active river channel, permanent water bodies and river bank The flood inundation layer is prepared in 2-bit consisting of the pre-flood river bank, permanent water bodies, active river channel as one theme and flood layer as the second theme.

A single-bit flood inundation layer is also generated for estimation of damage statistics. The final flood inundation layer is converted from raster to vector format for composition of a flood map and generation of damage statistics.



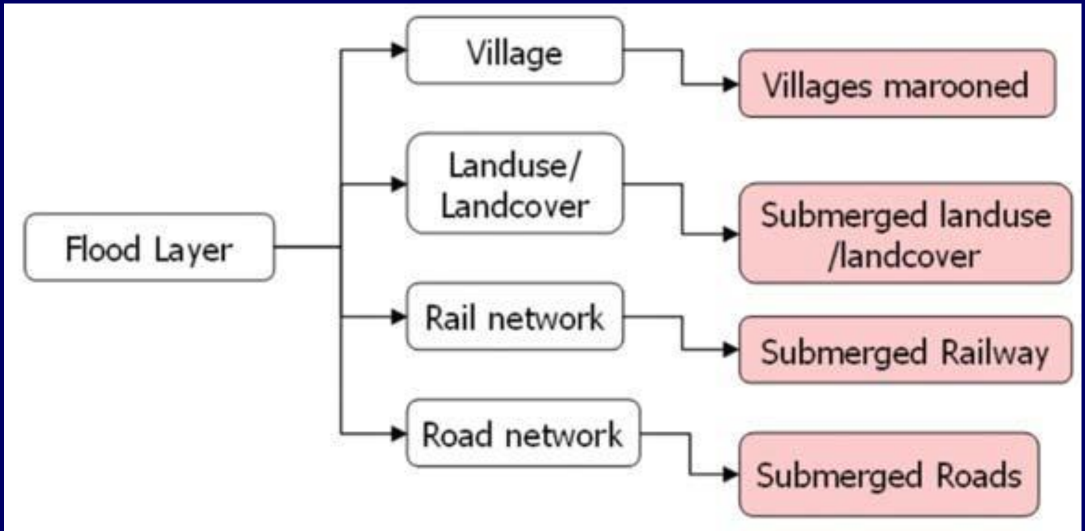


Methodology for analysis of satellite data during floods

Database Needed for Flood Mapping

Table 12.5: Database layers

S.No	Layers
1	**Administrative boundaries** – International – State – District – Taluk/Mandal/Block – Village Road – National Highway – Major Roads – State Highway – District Road – Village Road – Other Roads Railway Settlements Landuse/Landcover – Kharif crop – Double crop
2	**Pre-flood/water bodies**
3	Flood Inundation layer
4	Cloud cover

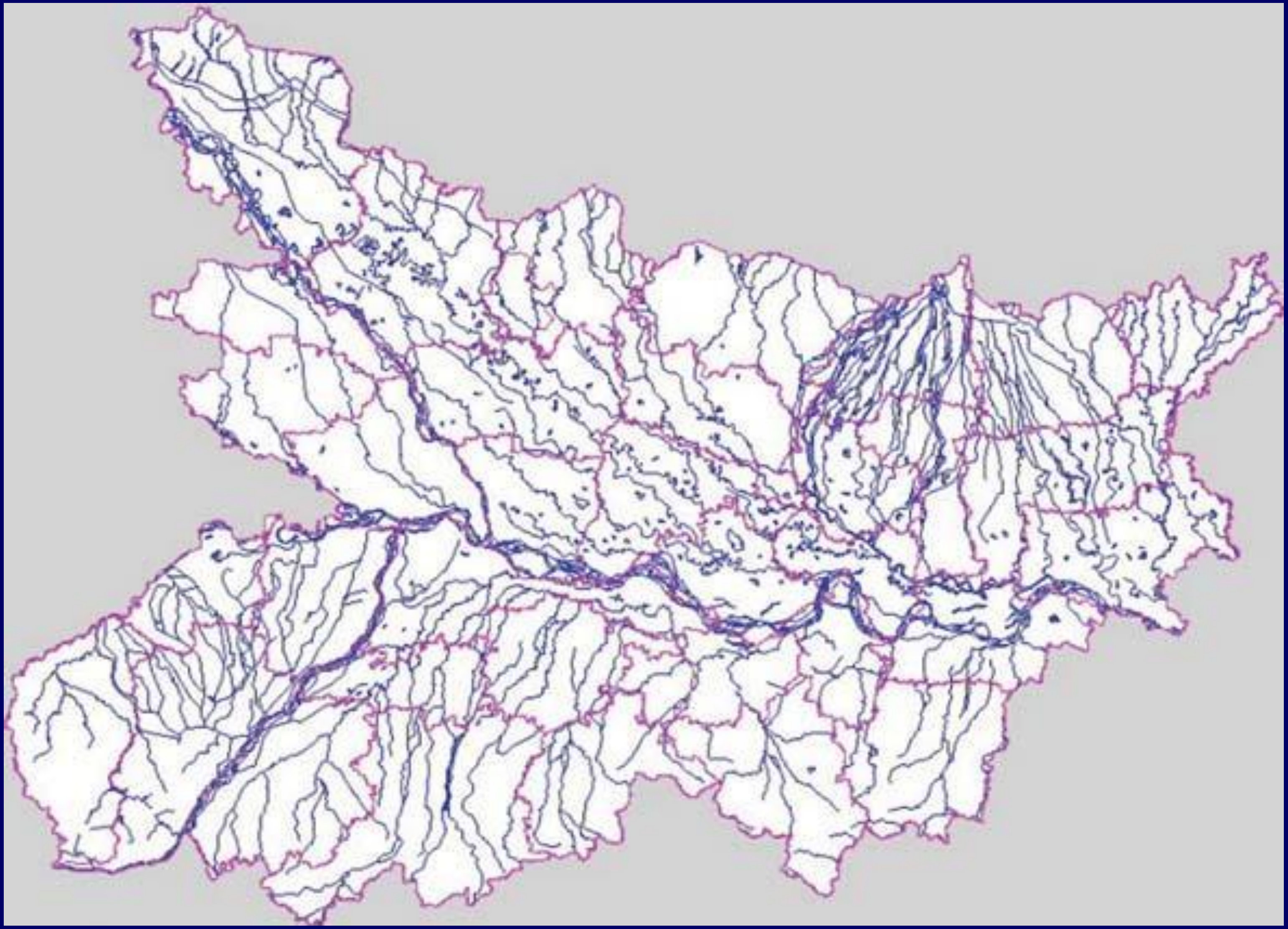


Generation of damage statistics

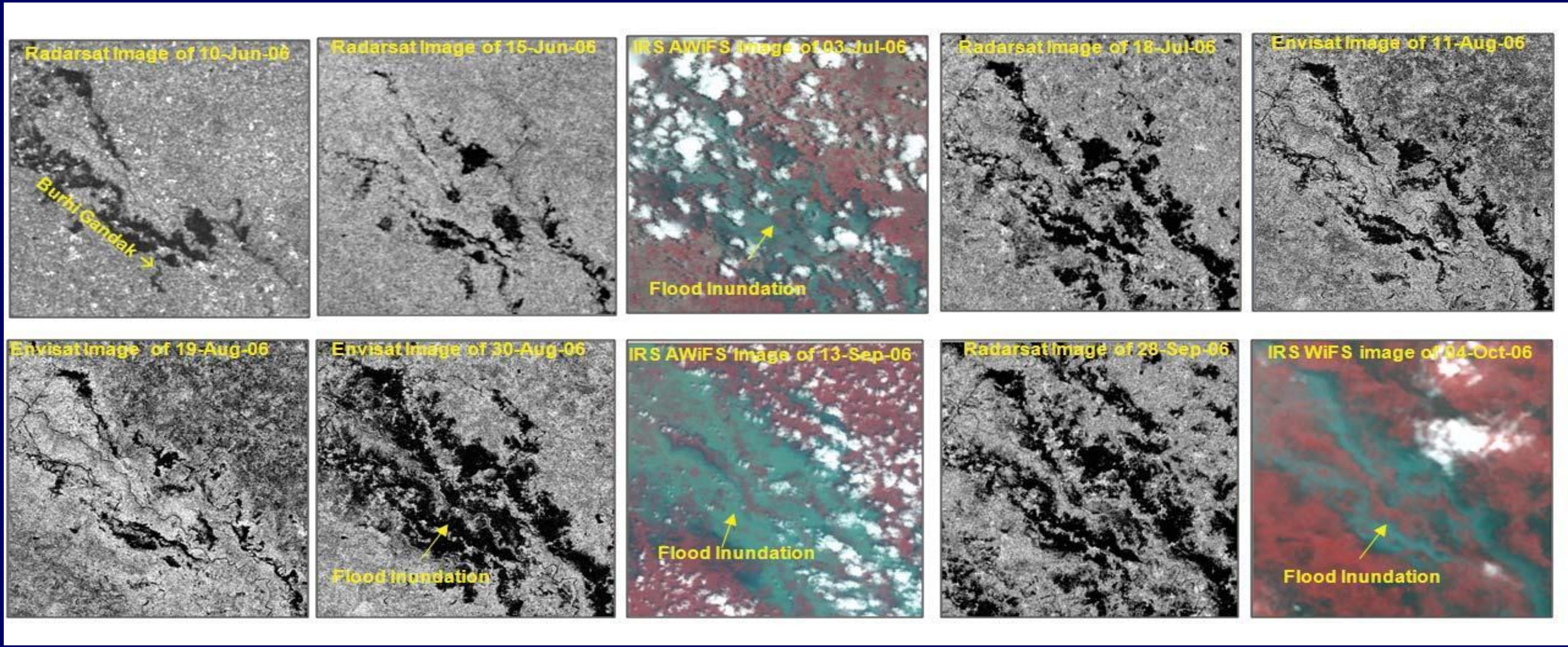
Case Study – 2006 Floods in Bihar, India

Bihar, the land-locked central Indian state that lies in the Gangetic basin, accounts for 16.5% of the flood-prone area and 22.1% of the flood-affected population in India. Out of 94.16 Lakh ha of geographical area, 68.80 Lakh ha is flood prone and 30 out of 37 districts of Bihar are flood prone.

The flood-prone area of Bihar has nearly tripled from 2.5 million hectares in 1954 to 6.8 million hectares in 1994.



River stream network in Bihar



Continuous monitoring from June to Oct., 2006

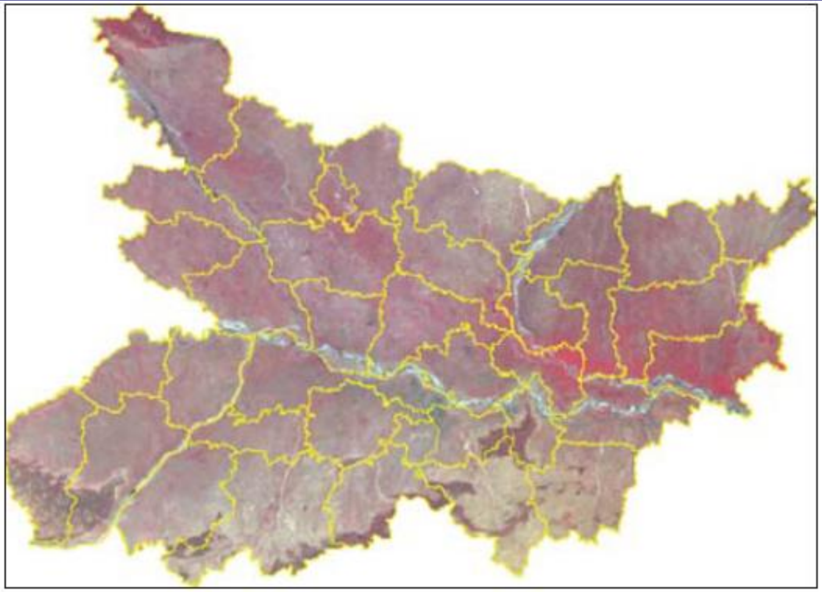


Figure 12.18a: Pre-flood AWiFS image of Bihar state

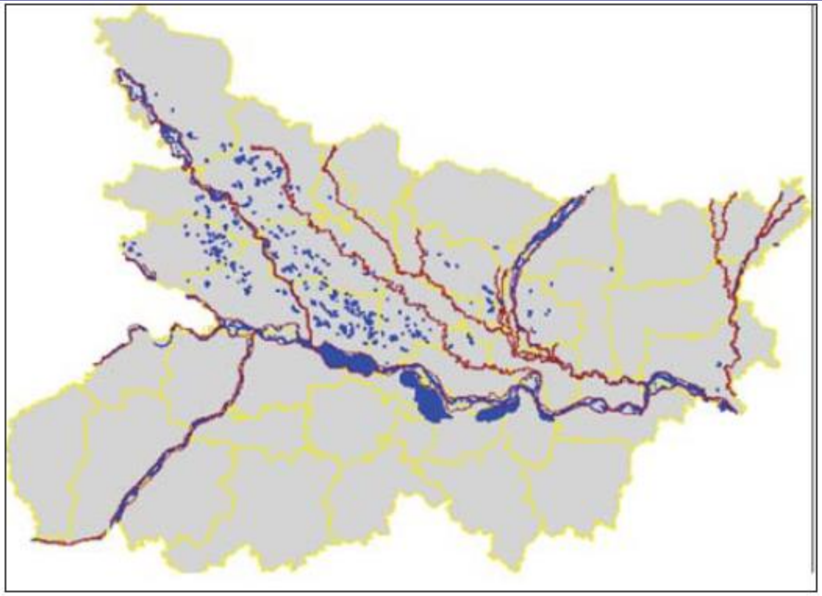


Figure 12.18b: River bank and permanent water bodies

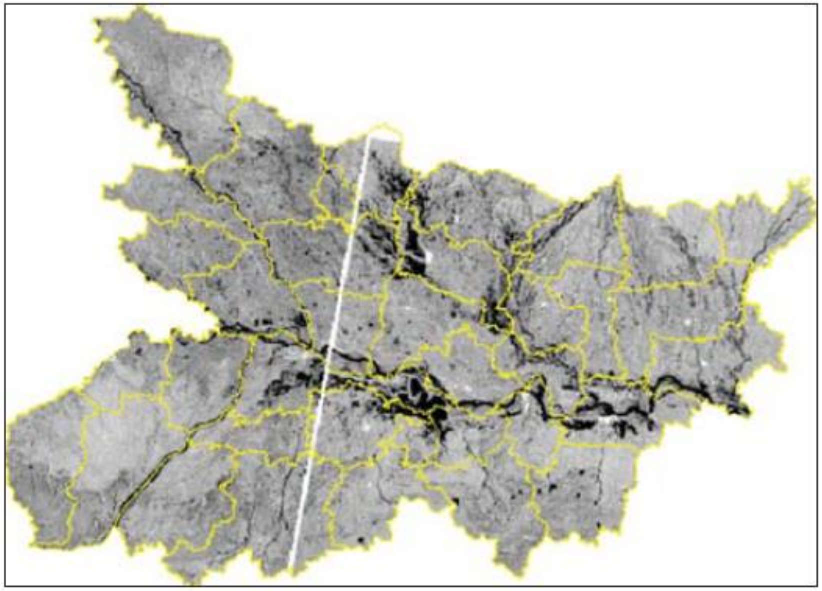


Figure 12.18c: Combined Radarsat image of 28 & 29 Sep., 2006 acquired during flooding

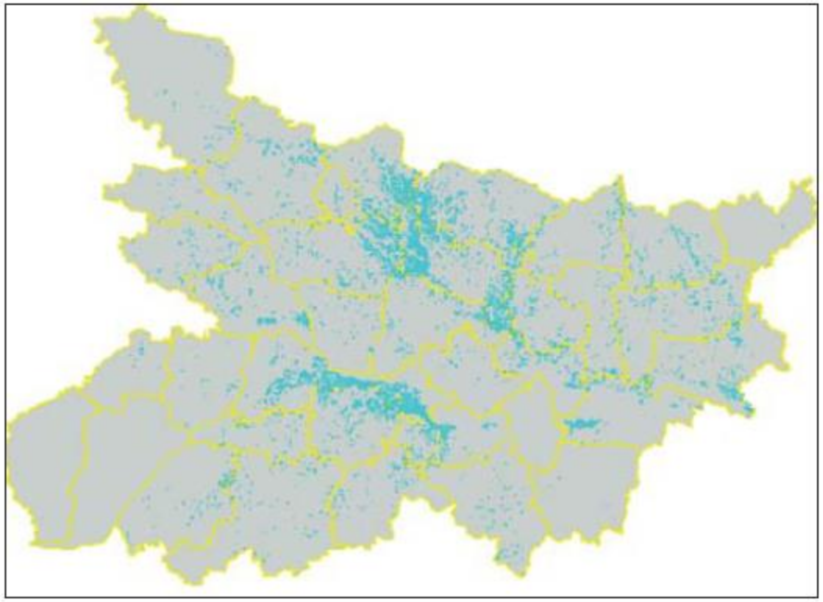
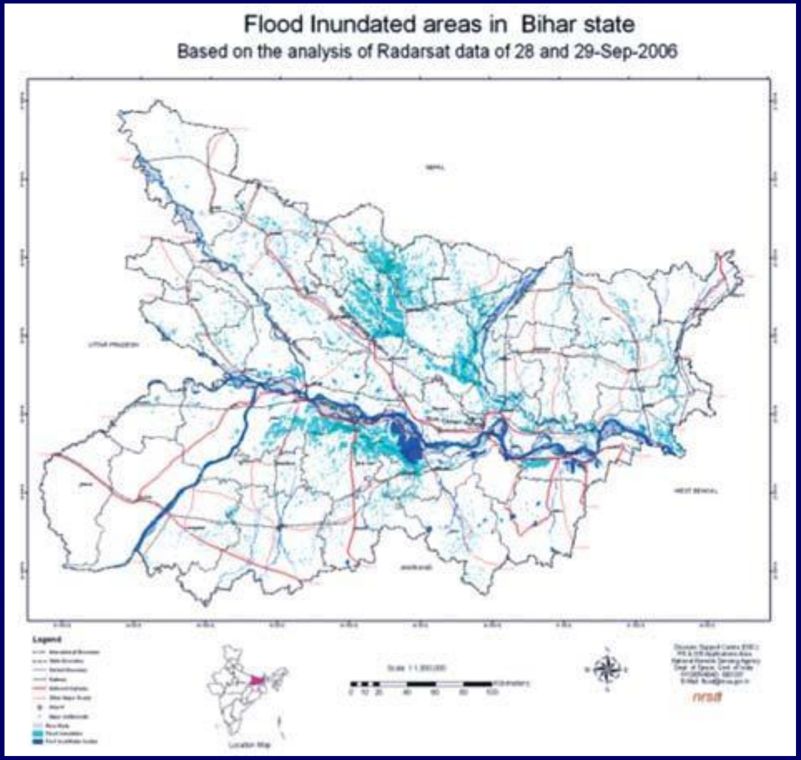
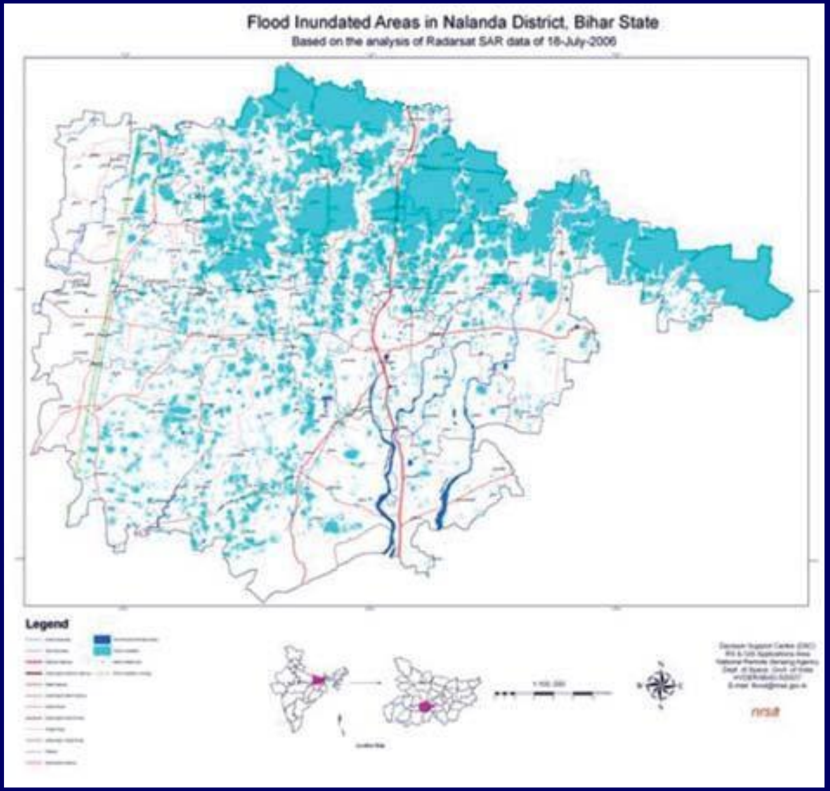
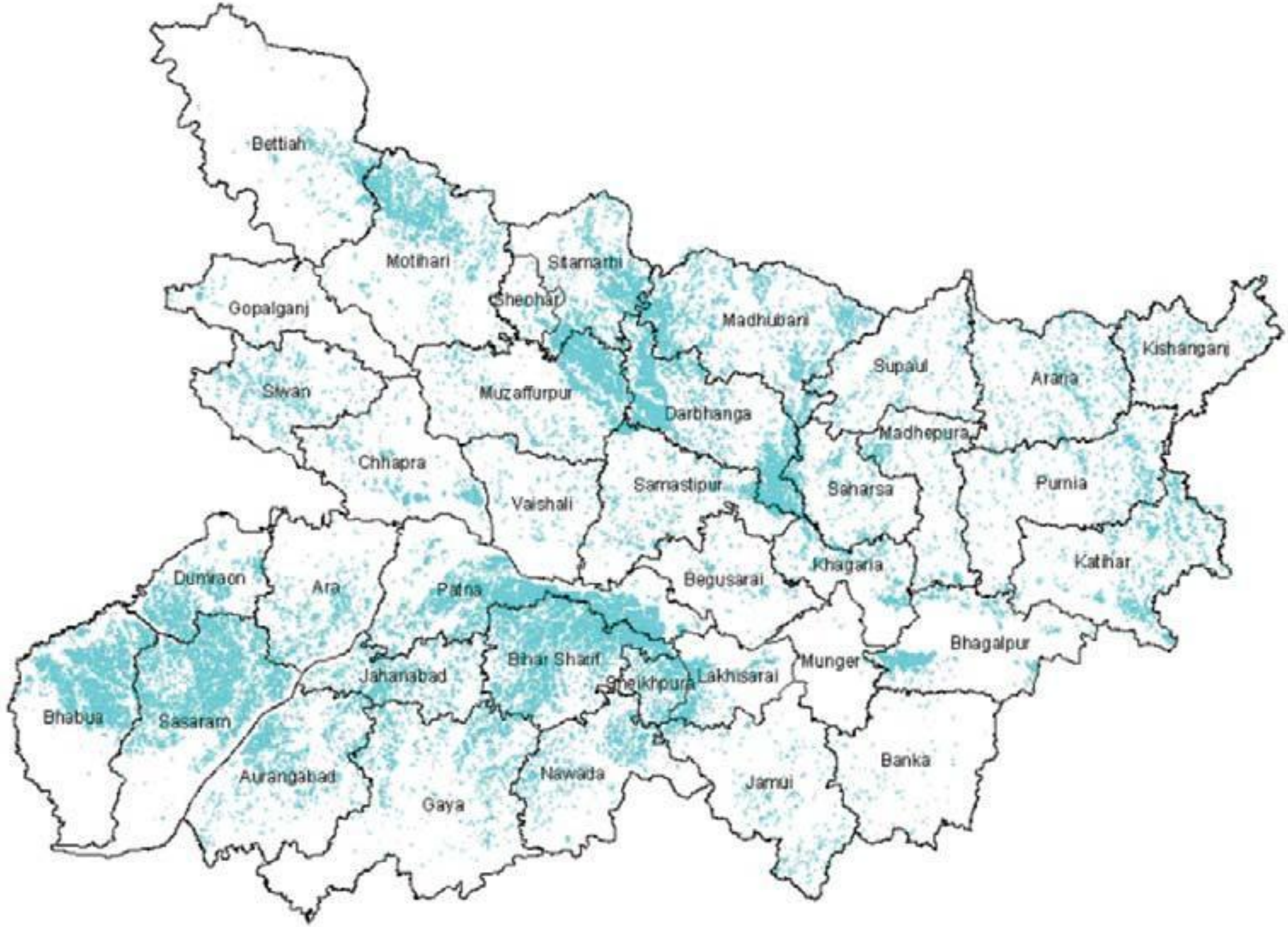


Figure 12.18d: Extracted single-bit flood inundation layer from 28 & 29 Sep., 2006 image

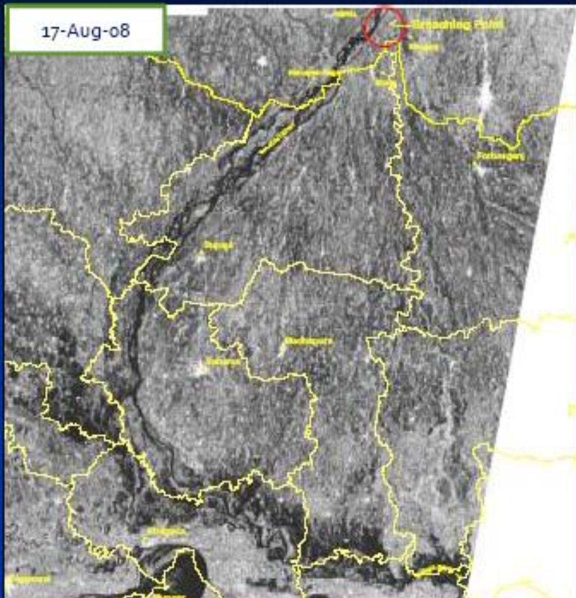

Flood Inundated areas in Bihar state
Based on the analysis of Radarsat data of 28 and 29-Sep-2006
Legend
nrsa

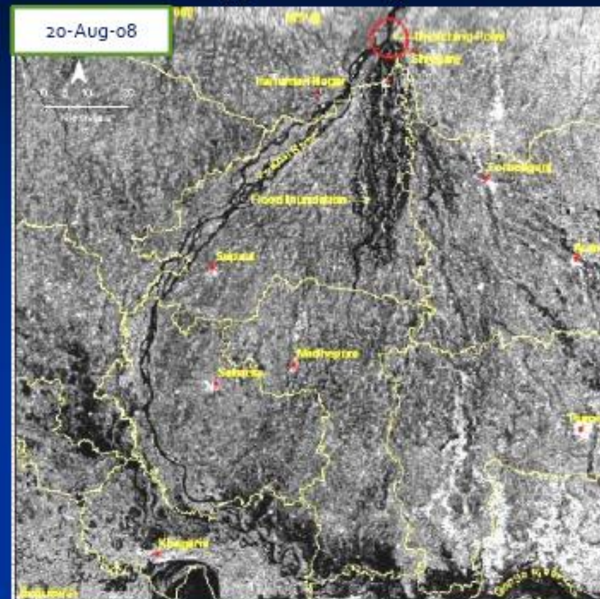

Flood Inundated Areas in Nalanda District, Bihar State
Based on the analysis of Radarsat SAR data of 18-July-2006
Legend
nrsa

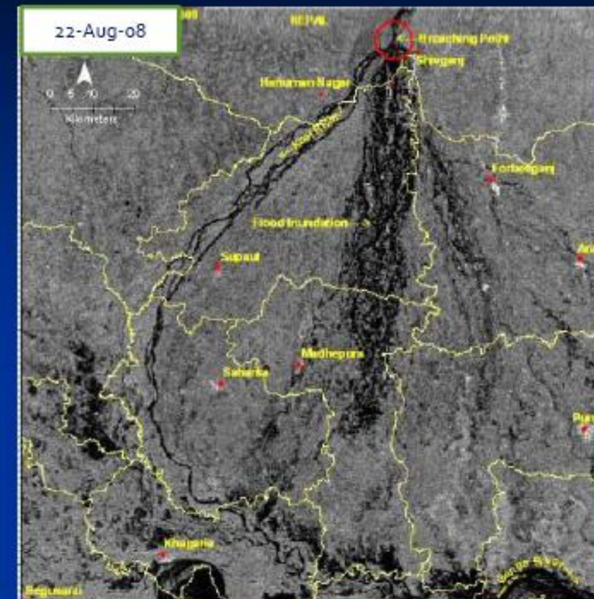

Bettiah
Motihari
Sitamarhi
Sheohar
Gopalganj
Madhubani
Supaul
Araria
Kishanganj
Siwan
Muzaffurpur
Darbhanga
Madhepura
Chhapra
Samastipur
Saharsa
Purnia
Vaishali
Khagaria
Katihar
Dumraon
Ara
Patna
Begusarai
Bhagalpur
Bihar Sharif
Munger
Jahanabad
Sheikhpura
Lakhisarai
Bhabua
Sasaram
Aurangabad
Nawada
Banka
Jamui
Gaya

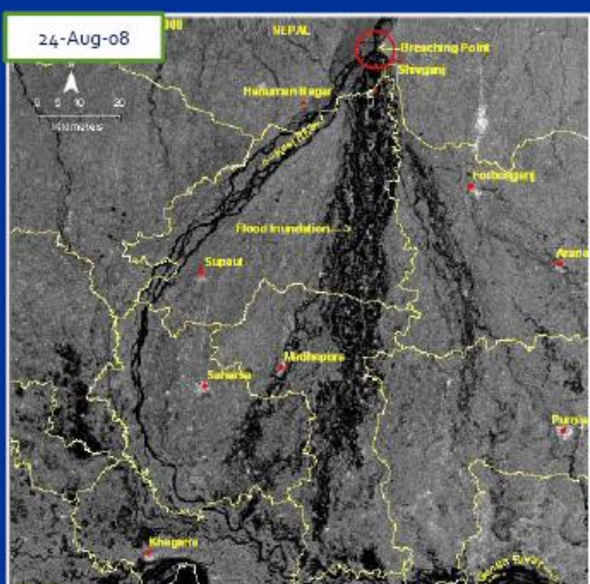
Kosi Embankment Breach-2008

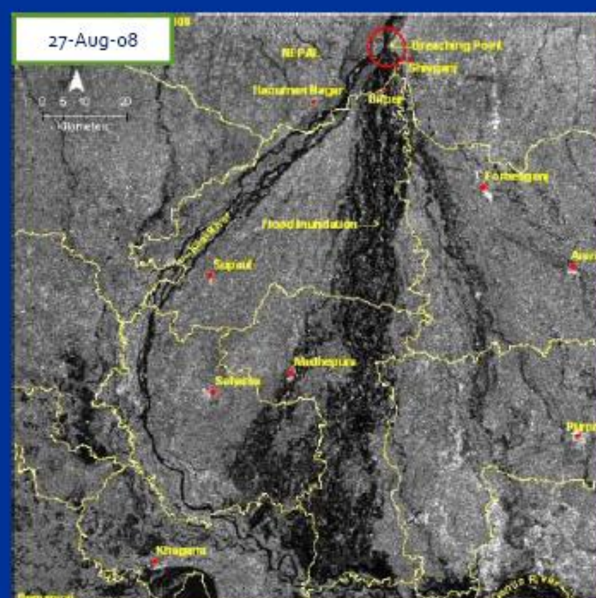
Monitoring Using Temporal Microwave Data

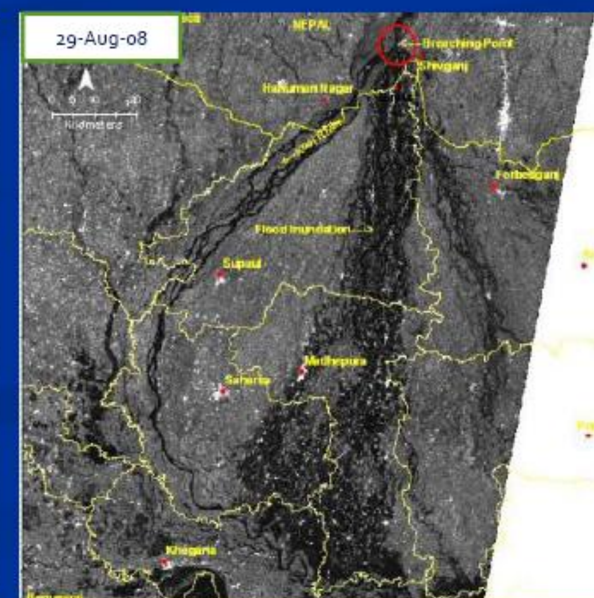




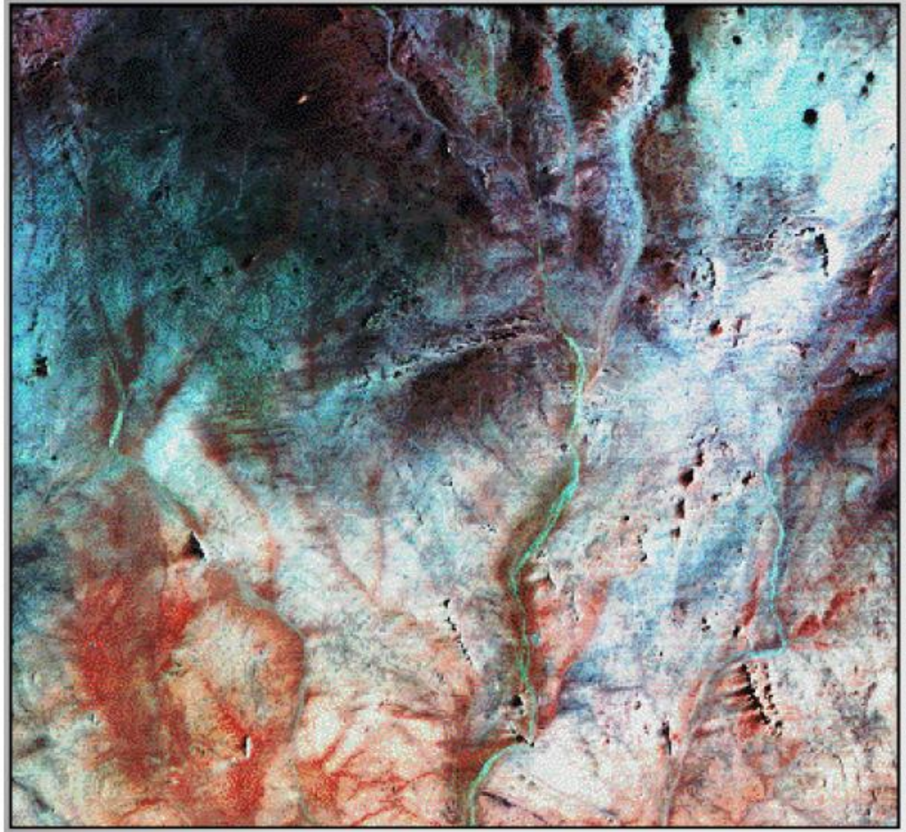


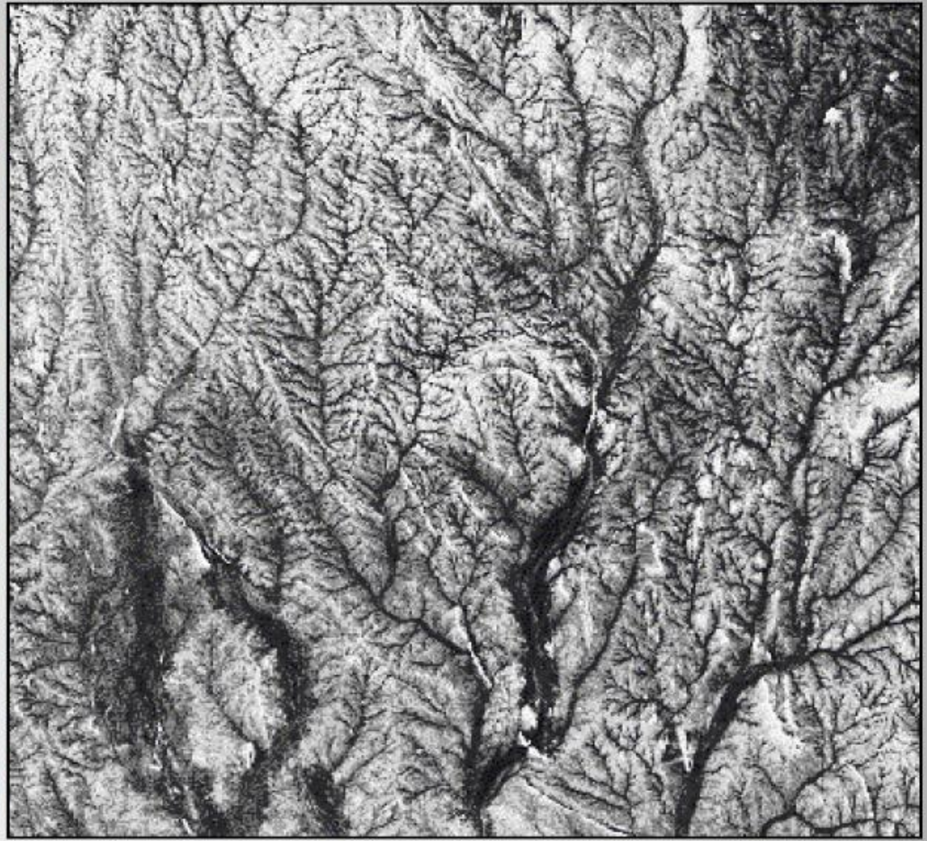






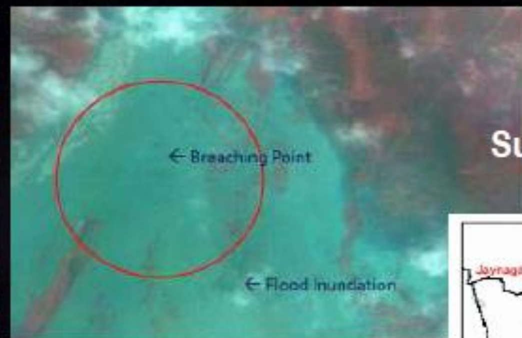
Paleochanels buried under dry sand cover appear with a dendritic pattern hardly visible on optical images. The gravel bed (in bright = high energy deposits) is less visible on ERS image than on Landsat. On the radar image, the coarse material appears in bright and the fine one in dark (fine sand).





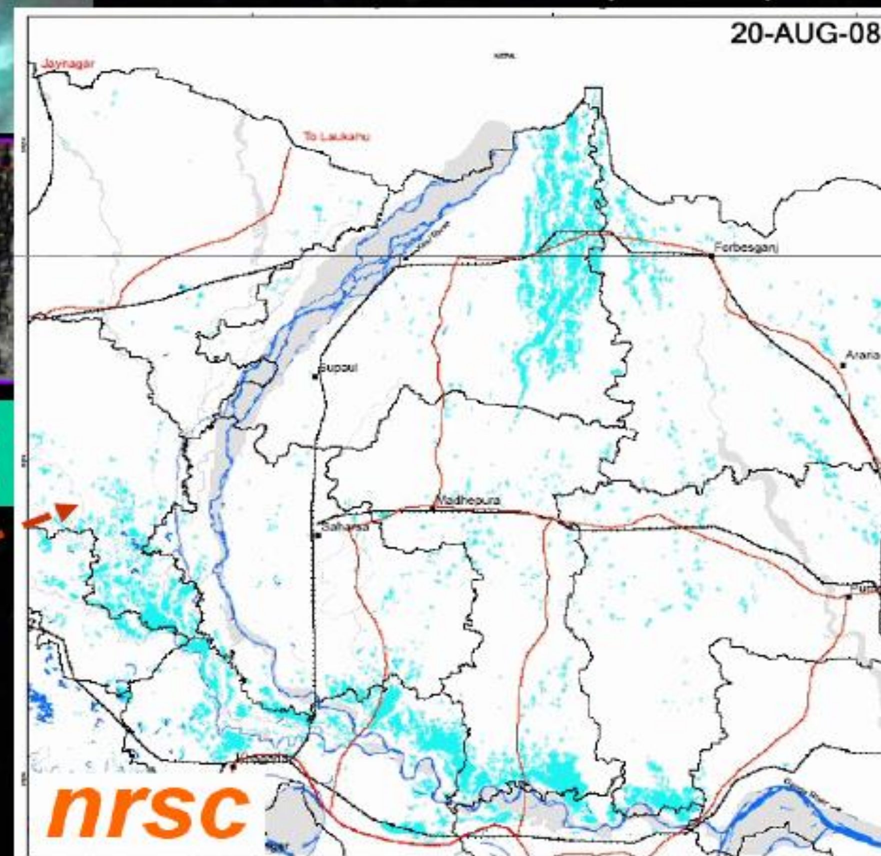
Kosi Embankment breach - Bihar Floods

EO



Inundation Status - Sept 15, 2008

Madhepura - 45, 006 ha; Supaul - 30,474 ha; Saharsa - 14,347 ha; Purnia - 1,997 ha; Araria - 4,406 ha.



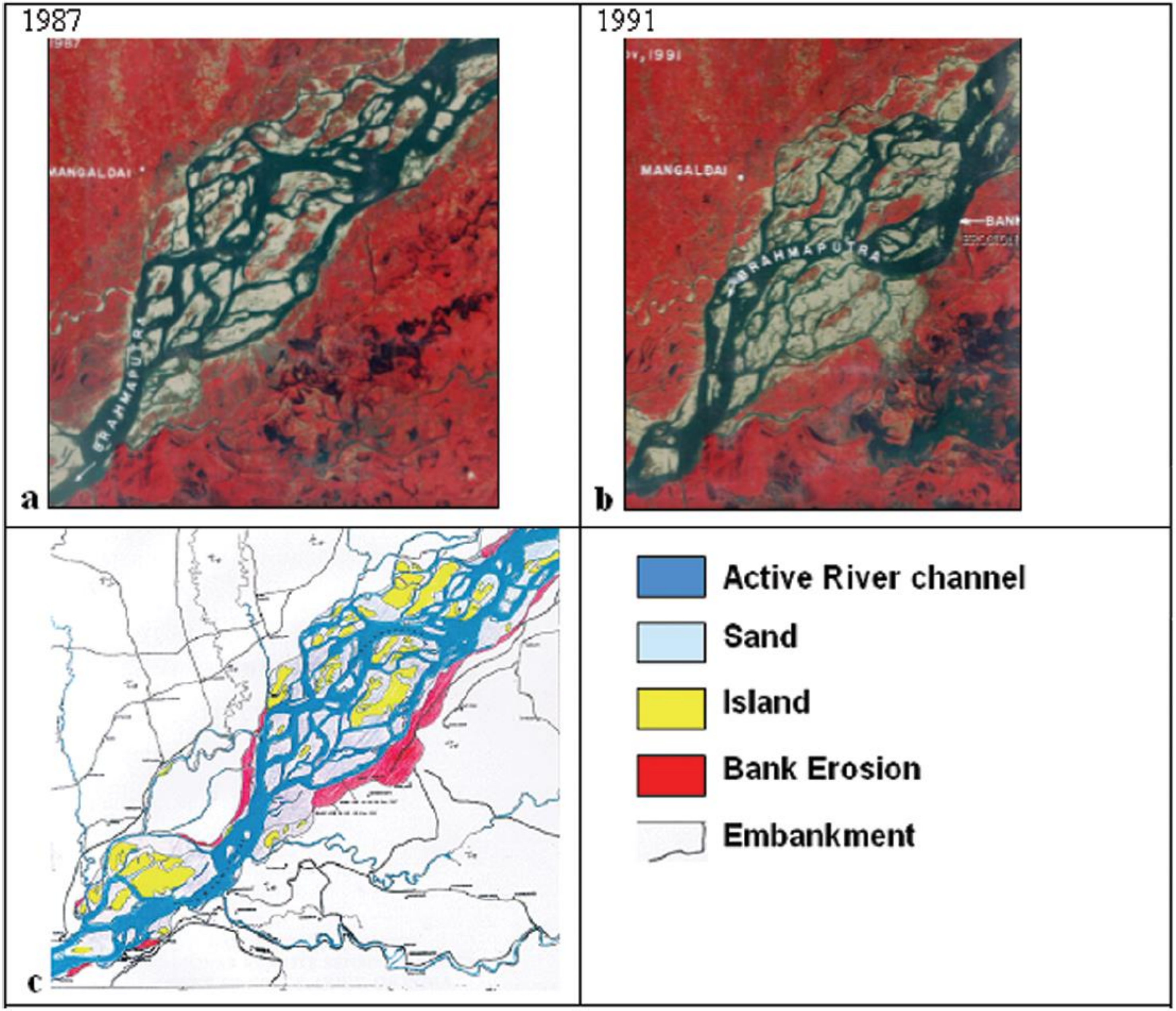
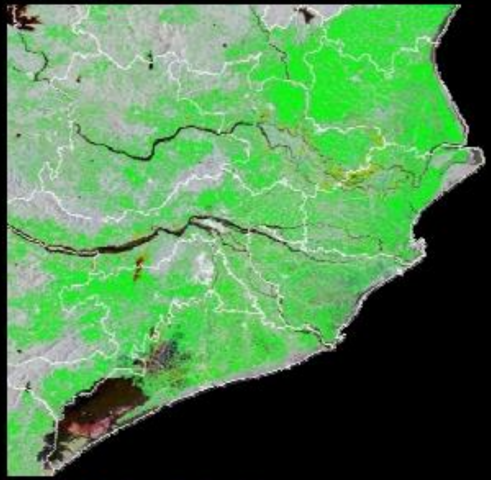


Figure 12.24: (a) Landsat –TM satellite image of 1987, (b) Landsat –TM satellite image of 1991 and (c) Bank erosion maps derived from 1987 & 1991 satellite data

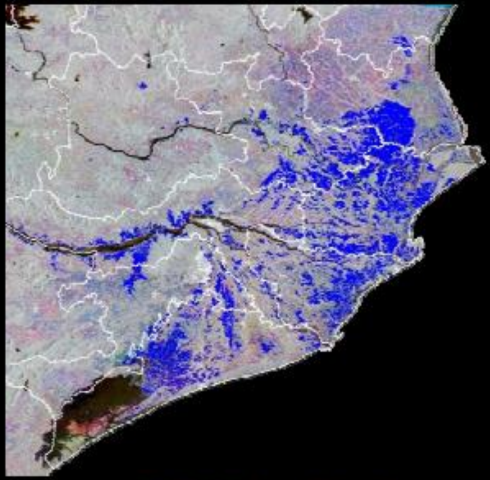
INTEGRATION OF FASAL AND FLOOD – ORISSA STATE

Classified data showing Rice



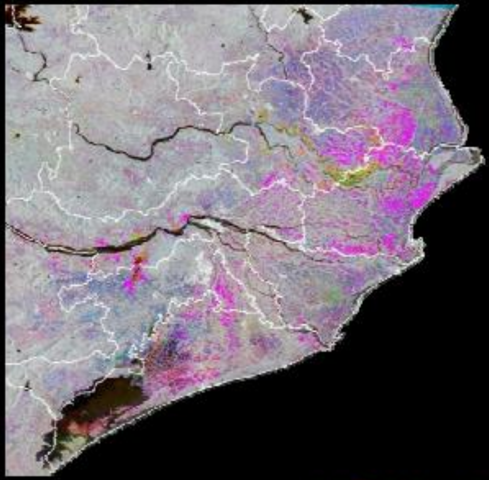
14.0 Lakh ha

Inundated area (Courtesy: DSC)

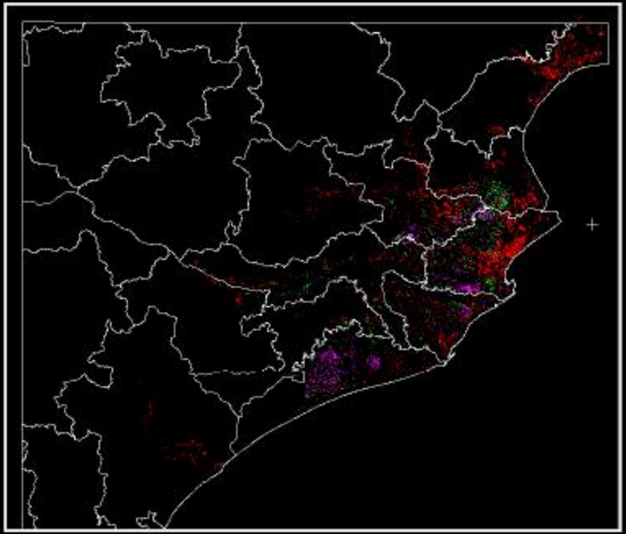


3.75 Lakh ha

Inundated Rice cropped area



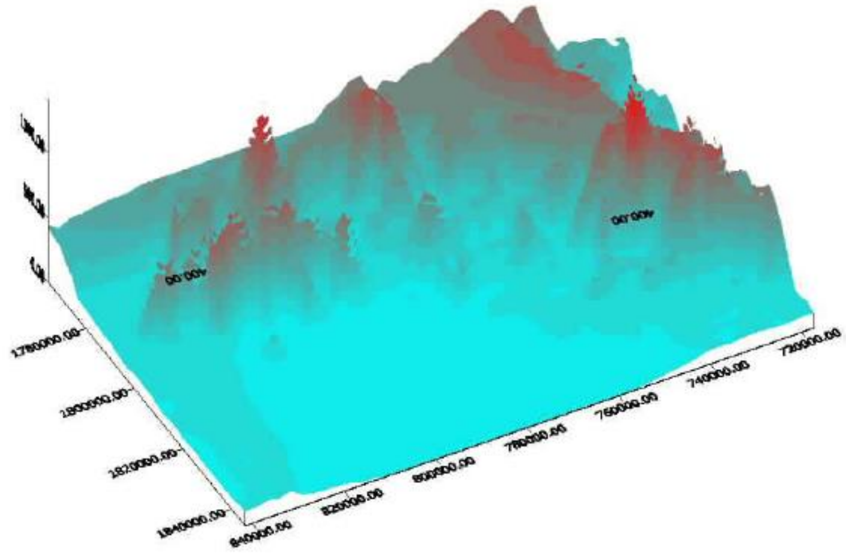
1.54 Lakh ha



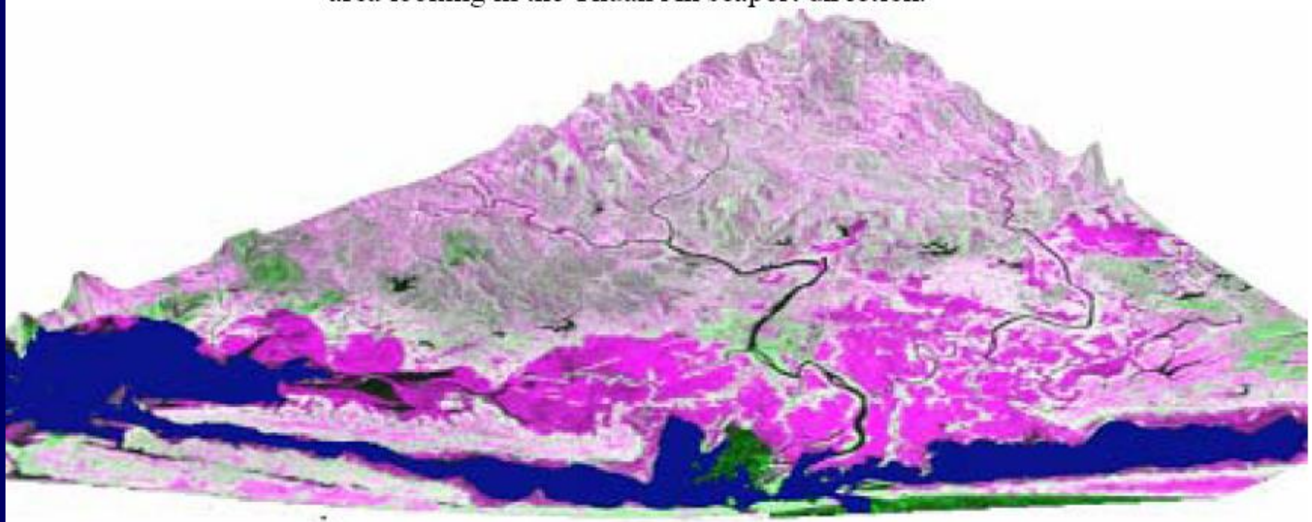
Duration of Flood	Data used	Inundated Area (ha)	Inundated rice cropped area (ha)
01 day	Scansar-N 18-09-08	204010	99923
07 Days	Scansar-w 24-09-08	73890	30941
12 days	Scansar-W 29-09-08	90423	27949
TOTAL		375709	154819

MAPPING OF LOW LYING AREAS AND WATER LOGGED AREAS USING DEM

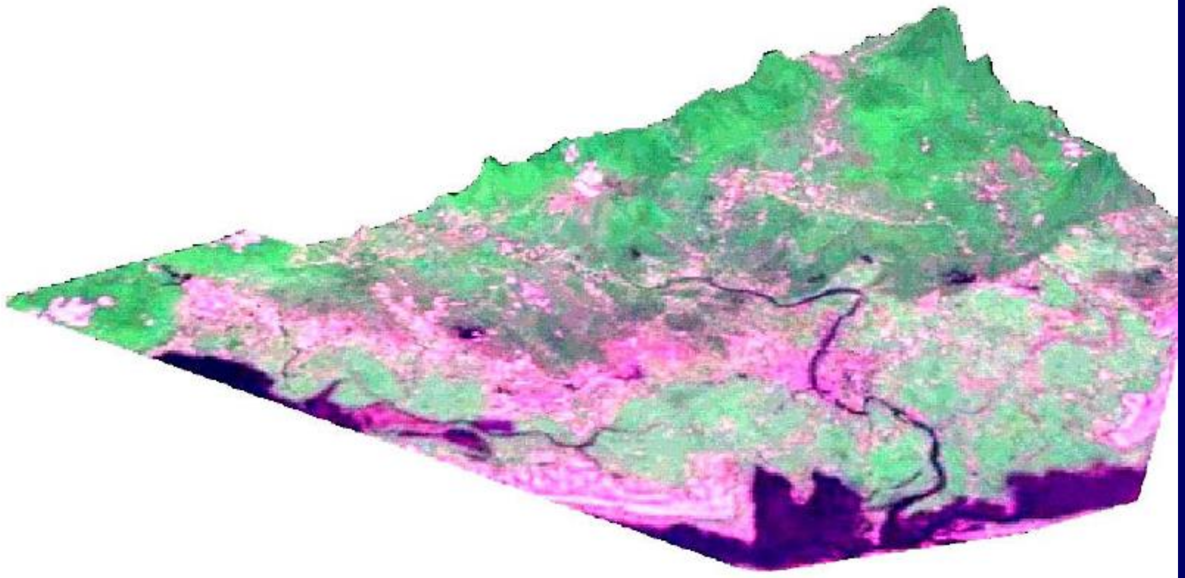
Digital Elevation Model of flood affected regions is a very important parameter in flood studies. With various limitations in optical and microwave data as discussed above, it is possible to overcome these with fine DEM



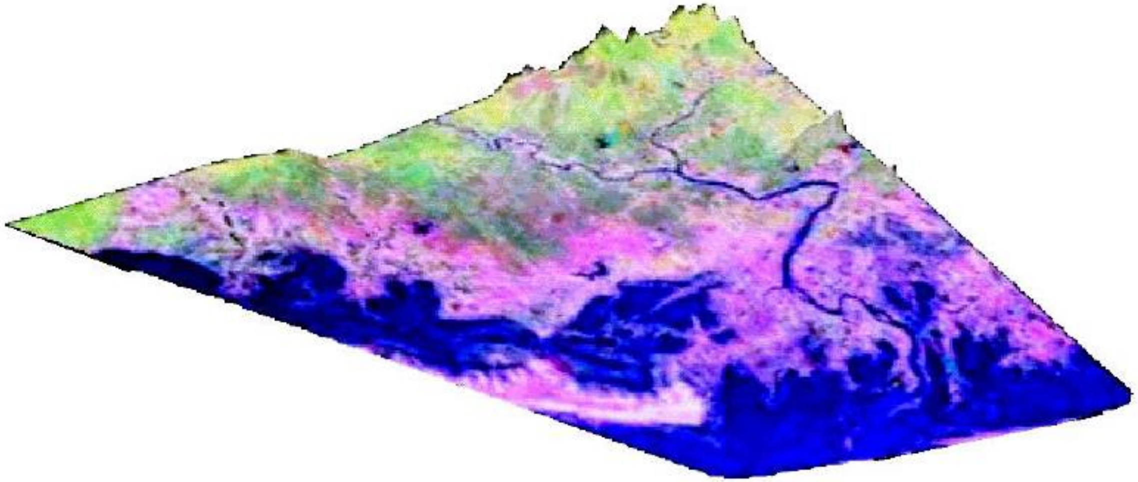
Picture 3: Three dimensional model of Thua Thien Hue area looking in the Thuan An seaport direction.



Picture 4: Three dimensional digital model covered by flooded area taken from RADASAT picture at the time of flood in Thua Thien Hue on November 6th 1999. The dark purple areas represent flooded areas.



Picture 5: Three dimensional model of a digital image at Huong River valley in the dry season. (5/1999)



Picture 6: Three dimensional model of digital image at Huong river valley in the rainy season. (28 September 2000)

Light Detection and Ranging (LiDAR) is a data collection technique that uses a beam of light to make range-resolved remote measurement of features within the path of a reflected beam of light. The New Brunswick government, through the Department of the Environment and Emergency Measures Organization (EMO), collected LiDAR data sets for great part of the province of New Brunswick after the flood in 2008.

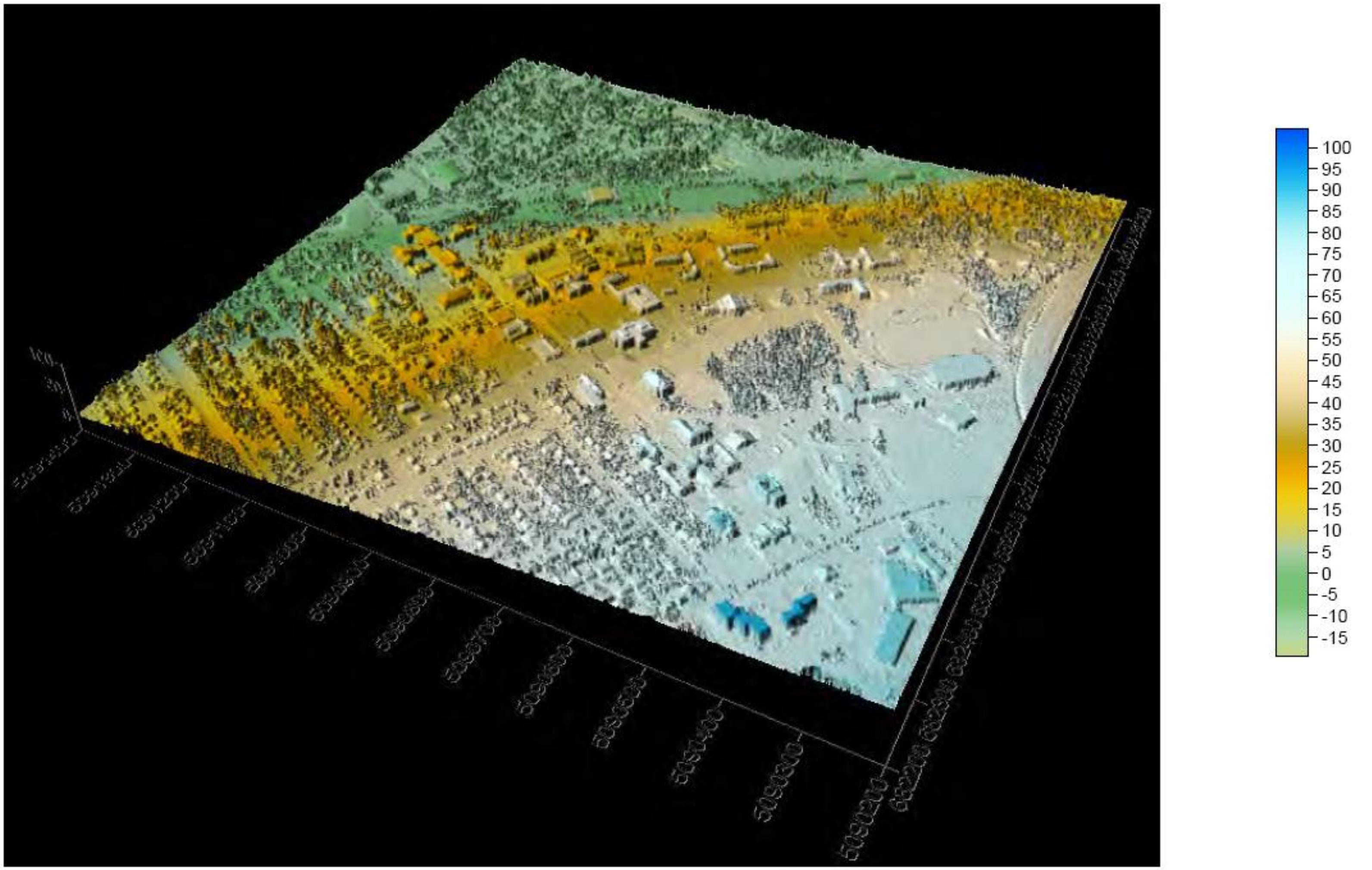


Fig. 6. Downtown Fredericton LiDAR data

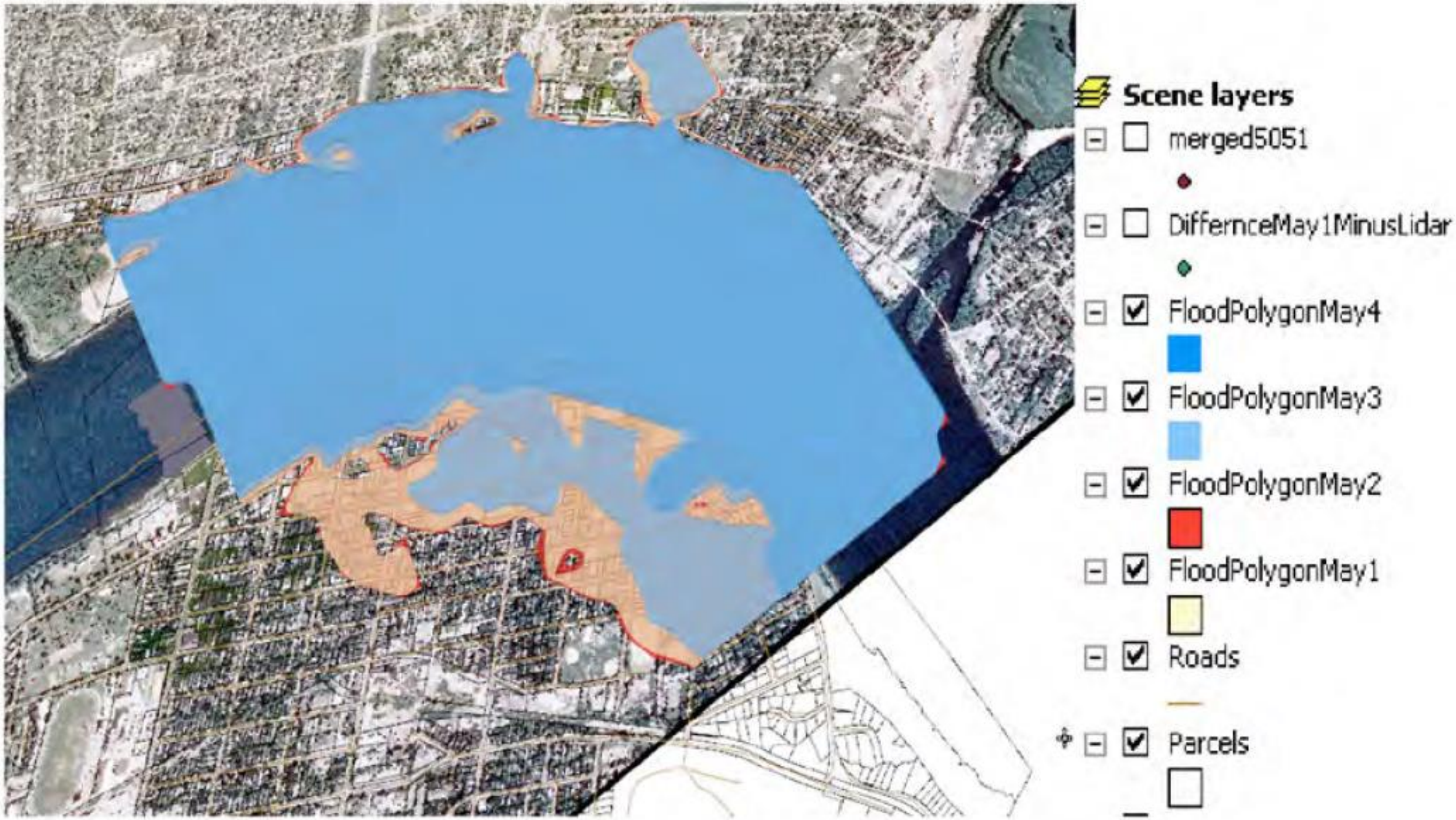
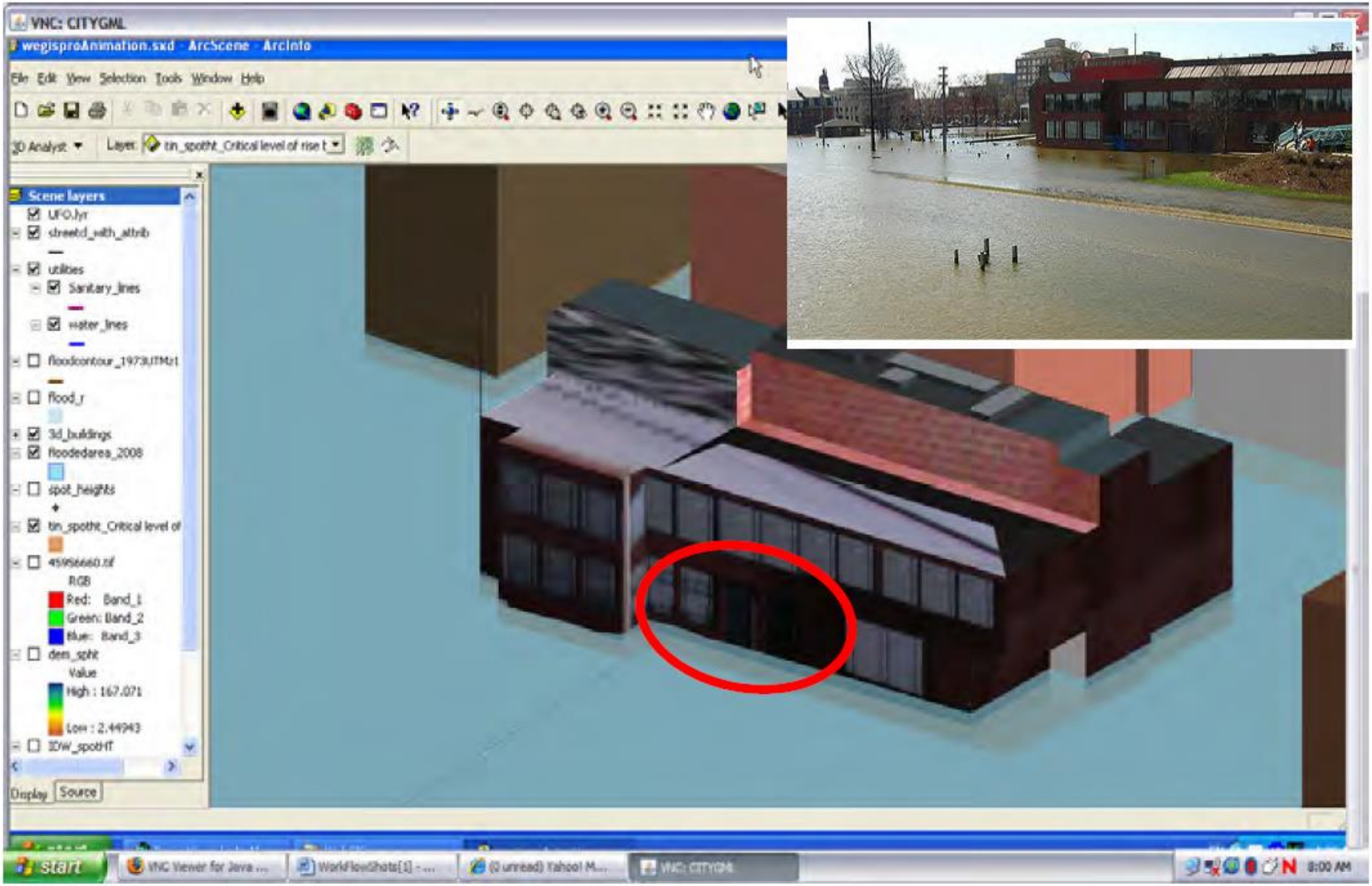
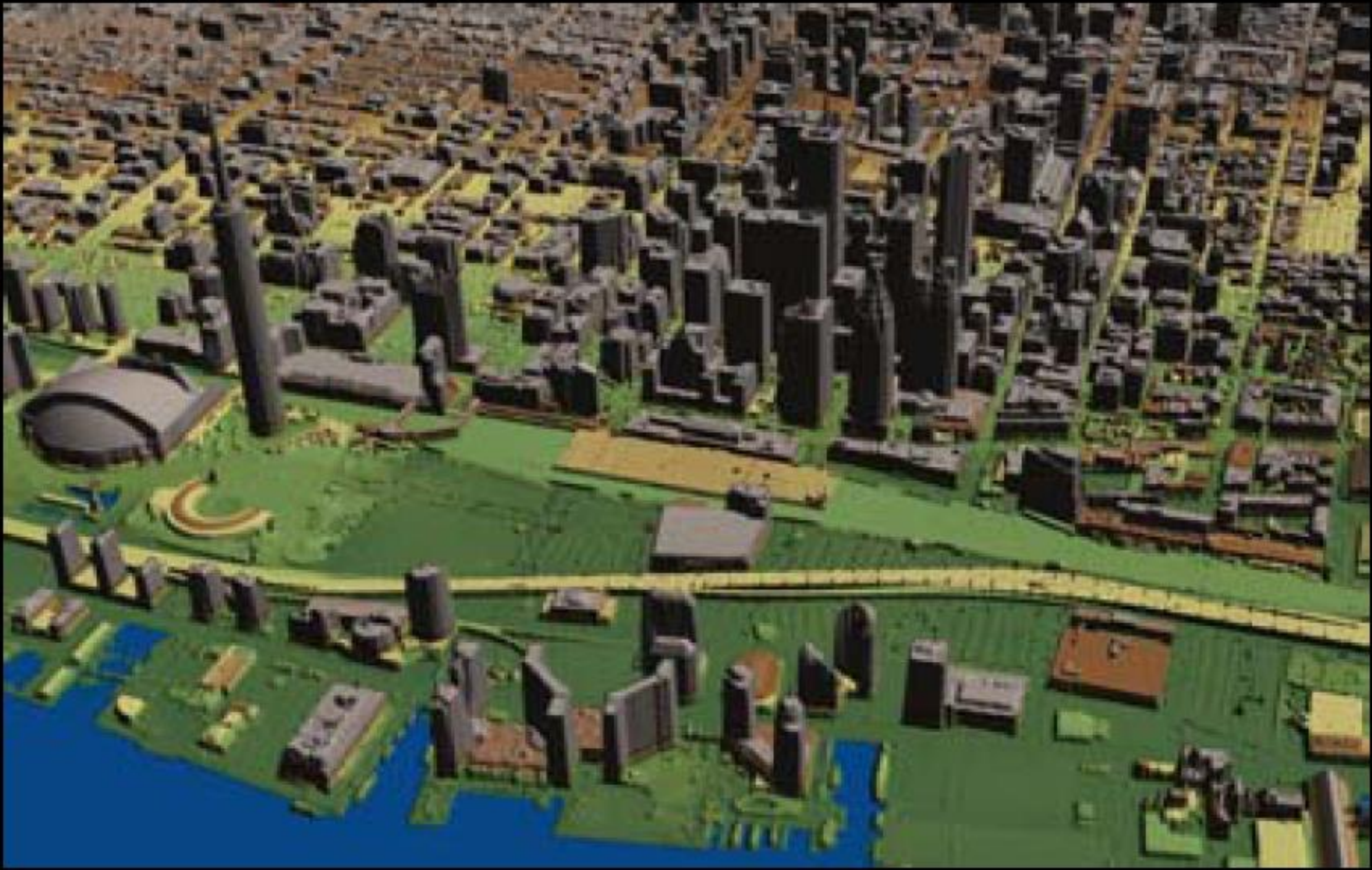


Fig. 12. Flood progression modelling

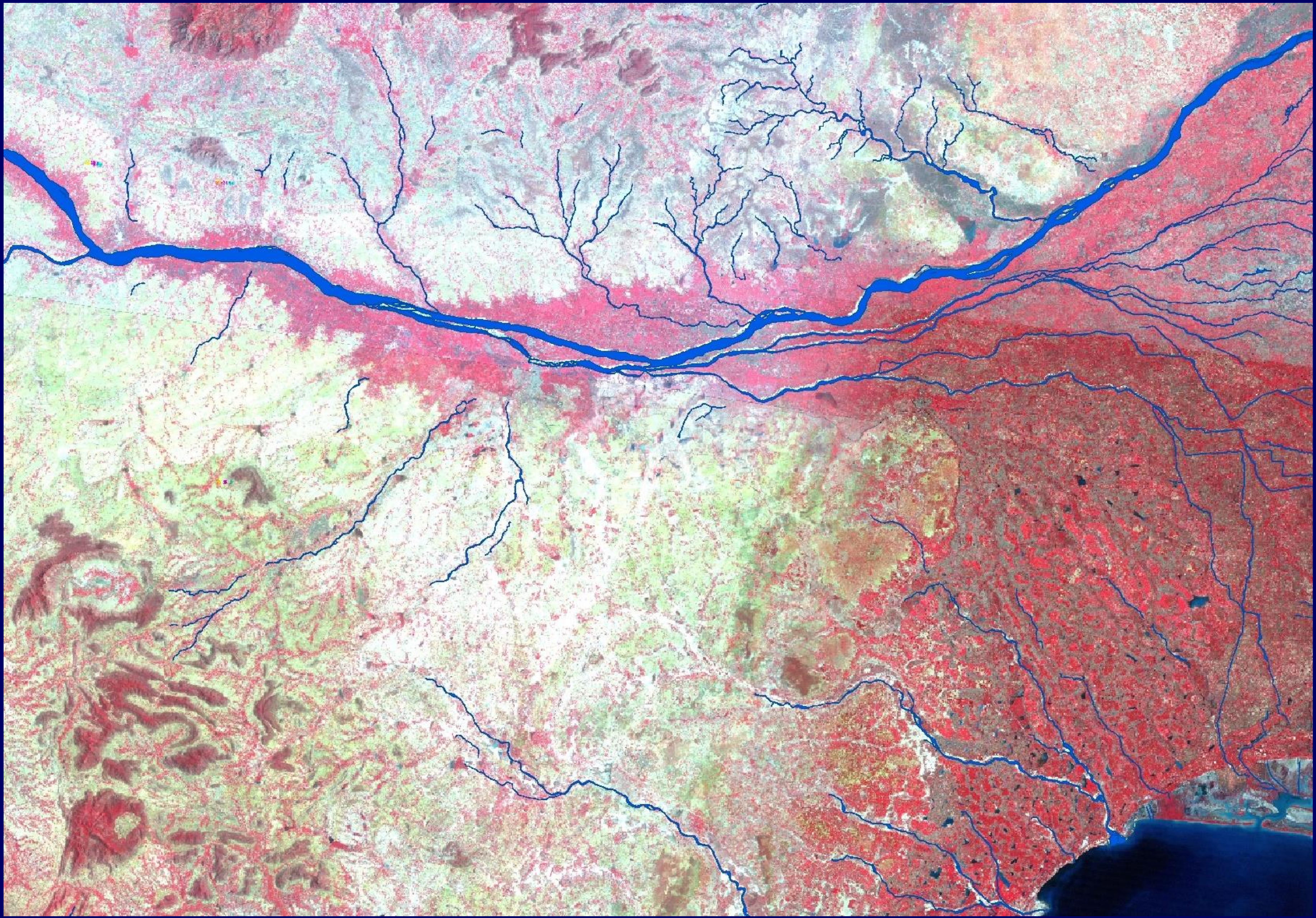


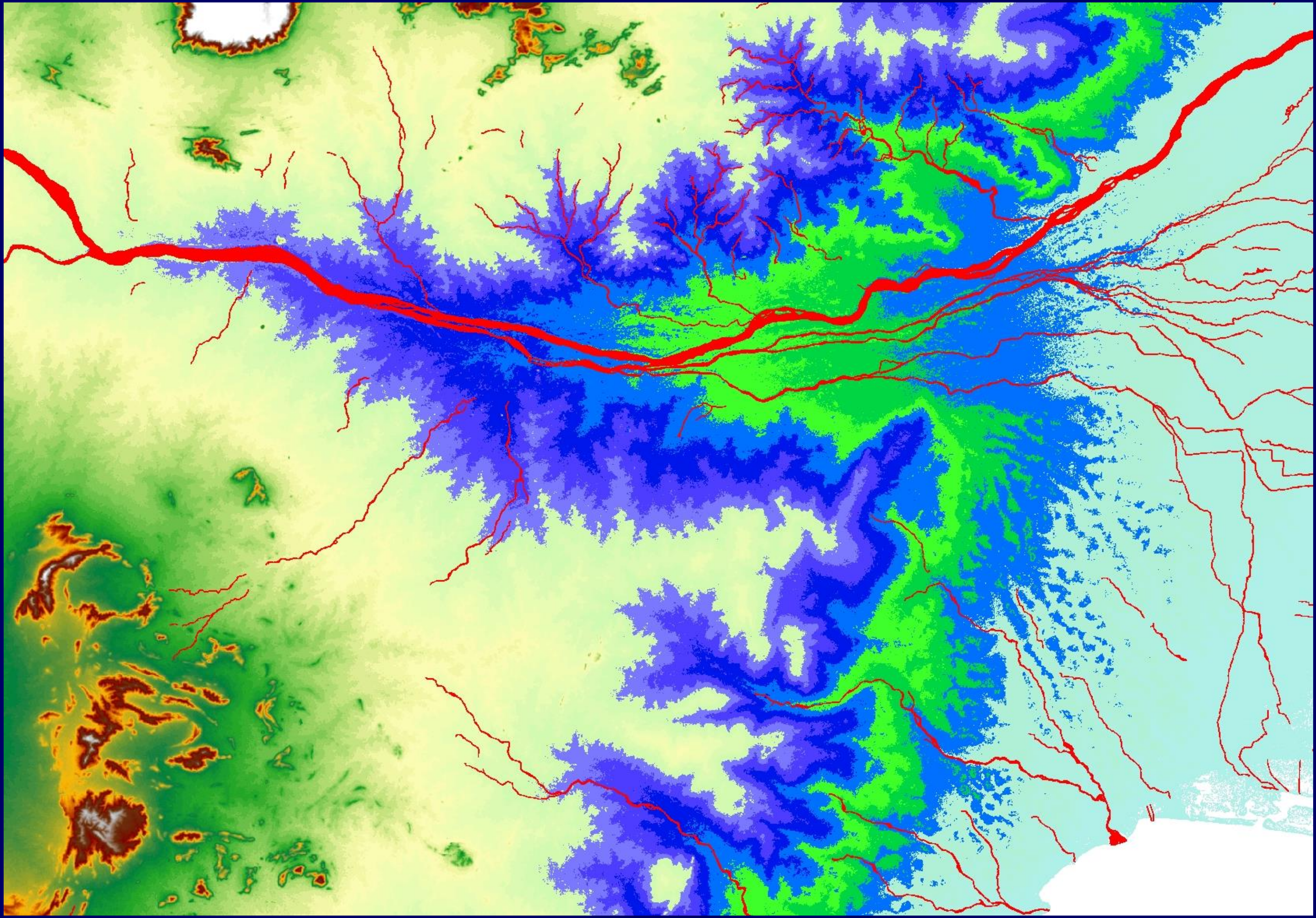
VNC: CITYGML
wegisproAnimation.sxd - ArcScene - ArcInfo
File Edit View Selection Tools Window Help
3D Analyst
Layer: tin_spotht_Critical level of rise t
Scene layers
UFO.lyr
utilities
Sanitary_lines
water_lines
floodcontour_1973UTMz1
flood_r
3d_buildings
floodedarea_2008
spot_heights
tin_spotht_Critical level of
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
dem_spht
Value
High : 167.071
Low : 2.44943
IDW_spotHT
Display
Source
start
VNC Viewer for Java ...
WorkFlowShots[1] - ...
(0 unread) Yahoo! M...
VNC: CITYGML
8:00 AM

Toronto, Canada

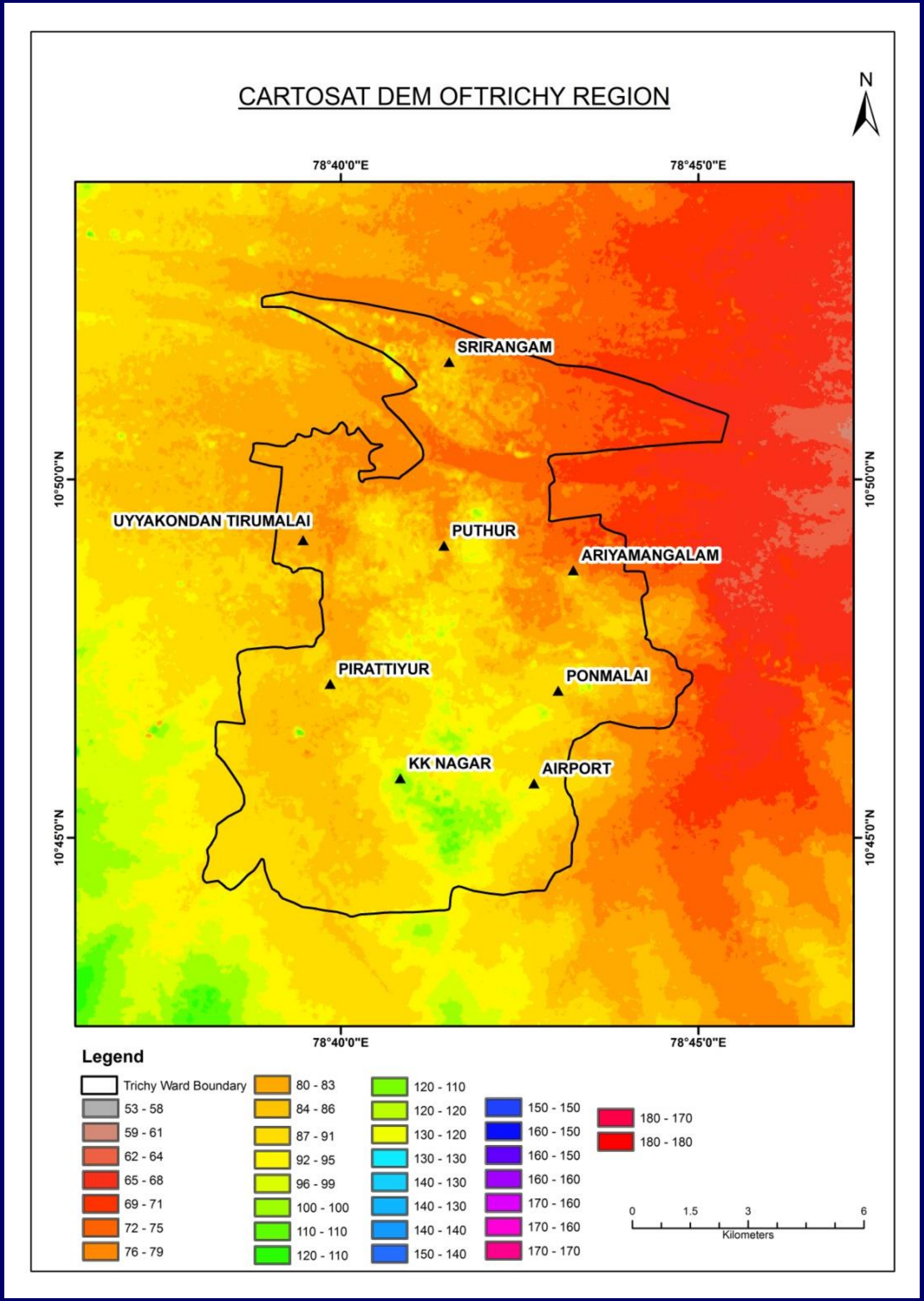


CAUVERY RIVER IN TRICHY – THANJAVUR PLAINS

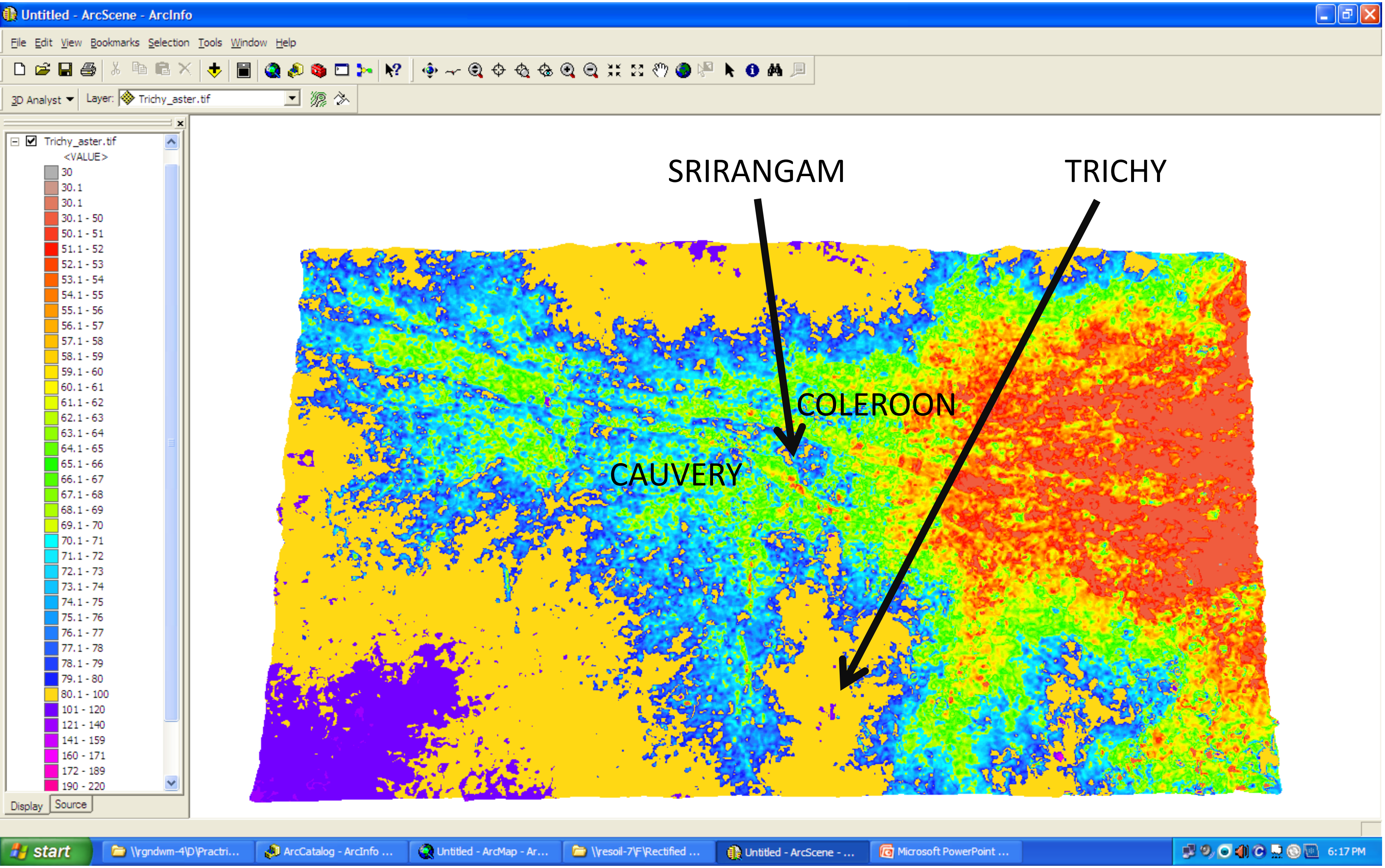


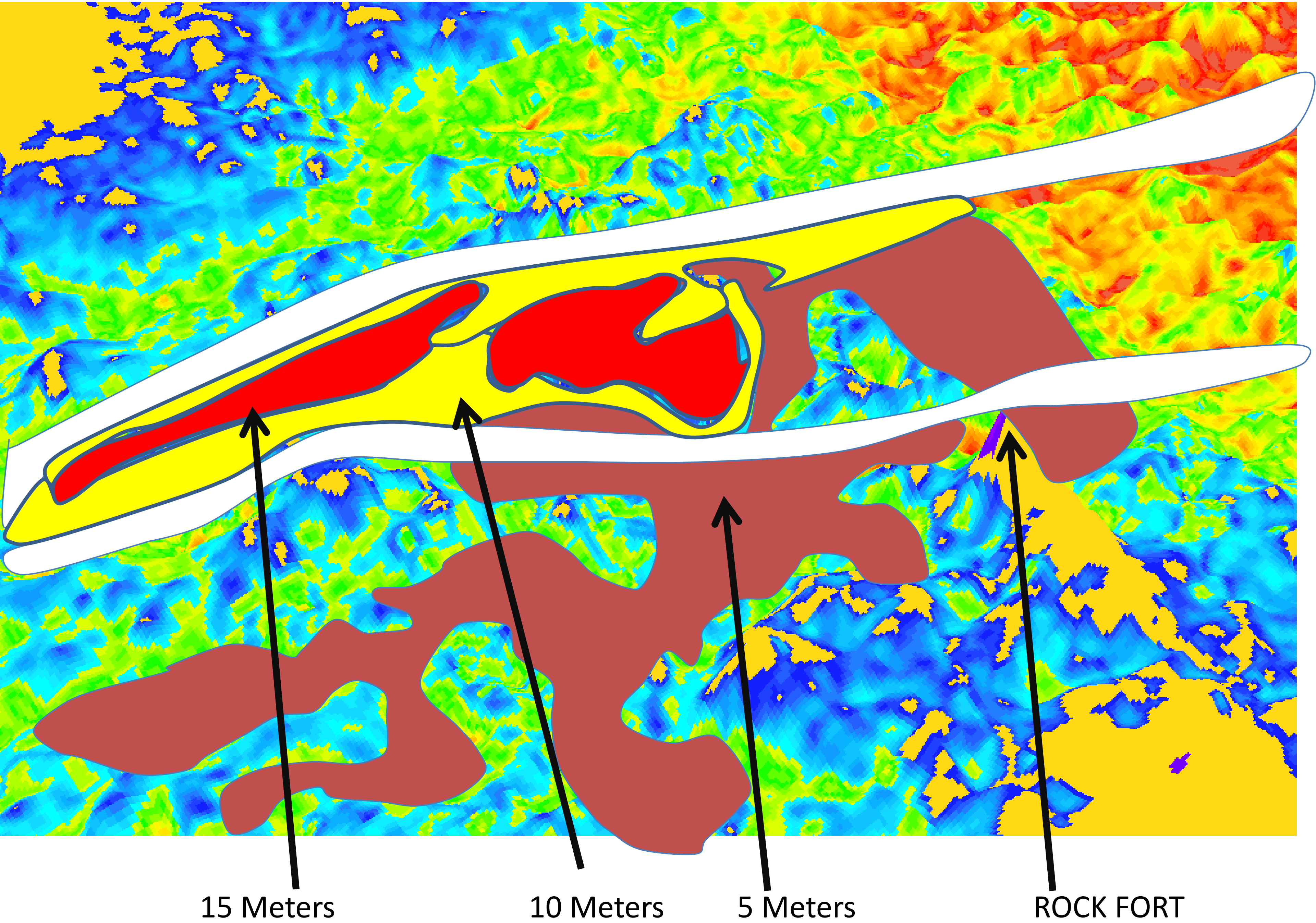


SRTM DATA vs FLOOD INUNDATION



CARTOSAT DEM of TRICHY URBAN


Untitled - ArcScene - ArcInfo
File Edit View Bookmarks Selection Tools Window Help
3D Analyst
Layer: Trichy_aster.tif
Trichy_aster.tif
<VALUE>
30
30.1
30.1
30.1 - 50
50.1 - 51
51.1 - 52
52.1 - 53
53.1 - 54
54.1 - 55
55.1 - 56
56.1 - 57
57.1 - 58
58.1 - 59
59.1 - 60
60.1 - 61
61.1 - 62
62.1 - 63
63.1 - 64
64.1 - 65
65.1 - 66
66.1 - 67
67.1 - 68
68.1 - 69
69.1 - 70
70.1 - 71
71.1 - 72
72.1 - 73
73.1 - 74
74.1 - 75
75.1 - 76
76.1 - 77
77.1 - 78
78.1 - 79
79.1 - 80
80.1 - 100
101 - 120
121 - 140
141 - 159
160 - 171
172 - 189
190 - 220
Display
Source
SRIRANGAM
TRICHY
COLEROON
CAUVERY
start
Untitled - ArcScene - ...
Microsoft PowerPoint ...
6:17 PM



15 Meters
10 Meters
5 Meters
ROCK FORT

FLOOD DAMAGE ASSESSMENT

Using pre and post flood data along with ground information **Flood damage can be estimated**

Change detection between normal and flood flow

DEM along with satellite data to identify flood inundated areas even under vegetation cover

Landuse type wise flood risk assessment

Microwave data – Since flood is often associated with heavy cloud cover, the use of radar data from ERS, JERS and RADARSAT permits the imaging of flooded areas through the clouds

FLOOD DAMAGE ASSESSMENT ….

Mapping flood river configuration

Most Indian rivers changes its course after flood, helps to erect flood control structures

Mapping inundation and erosion prone areas

Identification of drainage congested areas

After flooding, waters are being get stagnated – delineate such basins and provide planning for draining and planning for future improvement

FLOOD RISK ZONE MAPPING

On the basis of past flood Classified as

Prohibition zone : no building activities, only appropriate agriculture activities

Restrictive zone : Building activities under proper preventive measures

Warning zone : Areas liable to inundation by large flood

This can be easily done by using Remote sensing, DEM and GIS

Run-off Estimation SCS-CN method

The Soil Conservation Service (SCS) method developed United States Department of Agriculture (USDA), is another method used to estimate surface runoff from the rainfall. This method takes into account the land use, hydrological soil cover and antecedent moisture conditions for predicting the yield from the basin.

For the simpler storm, the relation between rainfall, runoff and retention can be expressed as,

$$\frac{F}{S} = \frac{Q}{P} \qquad \ldots (1)$$

where,

F	-	Actual retention in mm
S	-	Potential maximum in mm ($S \geq F$)
Q	-	Runoff in mm
P	-	Precipitation in mm ($P \geq Q$)

The volume of runoff (Q) depends upon the volume of precipitation (P) and the volume of storage that is available for retention. The potential retention S is a constant for a particular storm because it is the maximum that can occur under the existing conditions if the storm continues without limit.

The actual retention F varies because it is the difference between P and Q, or

$$F = P - Q \qquad \ldots (2)$$

The equation (1) can therefore be rewritten:

$$\frac{(P - Q)}{S} = \frac{Q}{P} \qquad \ldots (3)$$

Solving for Q produces the equation:

$$Q = \frac{P^2}{(P + S)} \qquad \ldots (4)$$

which is the rainfall-runoff relation in which the initial abstraction is zero.

If an initial abstraction (I_a) greater than zero is considered, the amount of rainfall available for runoff is ($P - I_a$) instead of P. By substituting ($P - I_a$) in equation (1), the following equation result.

$$\frac{F}{S} = \frac{Q}{(P - I_a)} \qquad \ldots (5)$$

where $F \leq S$, and $Q \leq (P - I_a)$. The total retention for storm consists of I_a and F. The total potential maximum retention (as P gets very large) consists of I_a and S.

Hence the equation (2) becomes

$$F = (P - I_a) - Q \qquad \ldots (6)$$

By substituting the value of F in equation (3) becomes

$$\frac{(P - I_a) - Q}{S} = \frac{Q}{(P - I_a)} \qquad \ldots (7)$$

Solving for Q equation (7) becomes

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \ldots (8)$$

which is the rainfall – runoff relation with the initial abstraction taken into account.

Initial abstraction consists mainly of interception, infiltration, surface storage, are of which occur before runoff begins. The relation between I_a and S (which includes I_a) was developed by means of rainfall and runoff data from experimental small watersheds. The empirical relationship is:

$$I_a = 0.3S \qquad \ldots (9)$$

The term S is the potential maximum retention and it is given by

$$S = \left(\frac{25400}{CN}\right) - 254 \qquad \ldots (10)$$

where CN is known as the Curve Number, which can taken from the tables, Chapter – 7, SCS Hand book, Section – 4 (1972)

Substituting the equation (9) in (8) gives,

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \qquad \ldots (11)$$

Hydrological Soil Group

Soil properties greatly influence the amount of runoff. In the SCS method, these properties are represented by a hydrological parameter: the minimum rate of infiltration obtained for a bare soil after prolonged wetting. The influence of both the soil's surface condition (infiltration rate) and its horizon (transmission rate) are thereby included. This parameter, which indicates a soil's runoff potential, is the qualitative basis of the classification of all soils into four groups. The Hydrological Soil Groups, as defined by the SCS soil scientists, are:

Group A: Soils having high infiltration rates even when thoroughly wetted and a high rate of water transmission. Examples are deep, well to excessively drained sands or gravels.

Group B: Soils having moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. Examples are moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils having low infiltration rates when thoroughly wetted and a low rate of water transmission. Examples are soils with a layer that impedes the downward movement of water or soils of moderately fine to fine texture.

Group D: Soils having very low infiltration rates when thoroughly wetted and a very low rate of water transmission. Examples are clay soils with a high swelling potential, soils with a permanently high watertable, soils with a clay pan or clay layer at or near the surface, or shallow soils over nearly impervious material.

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods-grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1] Average runoff condition.

[2] *Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50% to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6] *Poor:* Forest, litter, small trees, and brush have been destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table 2-3c.—Runoff curve numbers for arid and semiarid rangelands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition[2]	A[3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1] Average runoff condition. For rangelands in humid regions, use table 2-3b.

[2] *Poor:* <30% ground cover (litter, grass, and brush overstory).
Fair: 30% to 70% ground cover.
Good: >70% ground cover.

[3] Curve numbers for group A have been developed only for desert shrub.

Table 2-3d.—Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way).		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders).		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2a).					

[1] Average runoff condition.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed based on the impervious area (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2-3a.—Runoff curve numbers for cultivated agricultural lands[1]

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Straight row + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	Contoured & terraced + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Straight row + CR	Poor	64	75	83	86
		Good	60	72	80	84
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured + CR	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured & terraced	Poor	61	72	79	82
		Good	59	70	78	81
	Contoured & terraced + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured & terraced	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition.
[2] *Crop residue cover (CR)* applies only if residue is on at least 5% of the surface throughout the year.
[3] Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good $\geq$ 20%), and (e) degree of surface roughness.
Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 4.5 Conversion table for Curve Numbers (CN) from Antecedent Moisture Condition Class II to AMC Class I or Class III (after Soil Conservation Service 1972)

CN AMC II	CN AMC I	CN AMC III	CN AMC II	CN AMC I	CN AMC III
100	100	100	58	38	76
98	94	99	56	36	75
96	89	99	54	34	73
94	85	98	52	32	71
92	81	97	50	31	70
90	78	96	48	29	68
88	75	95	46	27	66
86	72	94	44	25	64
84	68	93	42	24	62
82	66	92	40	22	60
80	63	91	38	21	58
78	60	90	36	19	56
76	58	89	34	18	54
74	55	88	32	16	52
72	53	86	30	15	50
70	51	85	25	12	43
68	48	84	20	9	37
66	46	82	15	6	30
64	44	81	10	4	22
62	42	79	5	2	13
60	40	78	0	0	0

Table 4.4 Seasonal rainfall limits for AMC classes (after Soil Conservation Service 1972)

Antecedent Moisture Condition Class	5-day antecedent rainfall (mm)		
	Dormant season	Growing season	Average
1	2	3	4
I	< 13	< 36	< 23
II	13 – 28	36 – 53	23 – 40
III	> 28	> 53	> 40

Antecedent Moisture Condition

The soil moisture condition in the drainage basin before runoff occurs is another important factor influencing the final CN value. In the Curve Number Method, the soil moisture condition is classified in three Antecedent Moisture Condition (AMC) Classes:

AMC I: The soils in the drainage basin are practically dry (i.e. the soil moisture content is at wilting point).

AMC II: Average condition.

AMC III: The soils in the drainage basins are practically saturated from antecedent rainfalls (i.e. the soil moisture content is at field capacity).

Table 4.6 Values of rainfall depth and corresponding direct runoff depth as a function of rainfall duration and AMC Class for a design return period of 10 years

Design rainfall			Direct runoff	
Duration (h)	Intensity (mm/h)	Depth (mm)	Depth (mm) AMC II	Depth (mm) AMC III
1	2	3	4	5
1	88	88	25	50
2	53	106	37	66
3	39	117	44	76
4	32	128	52	86
5	27	135	58	93
24	8.7	209	118	163
48	5.6	269	172	222
72	4.6	331	229	283

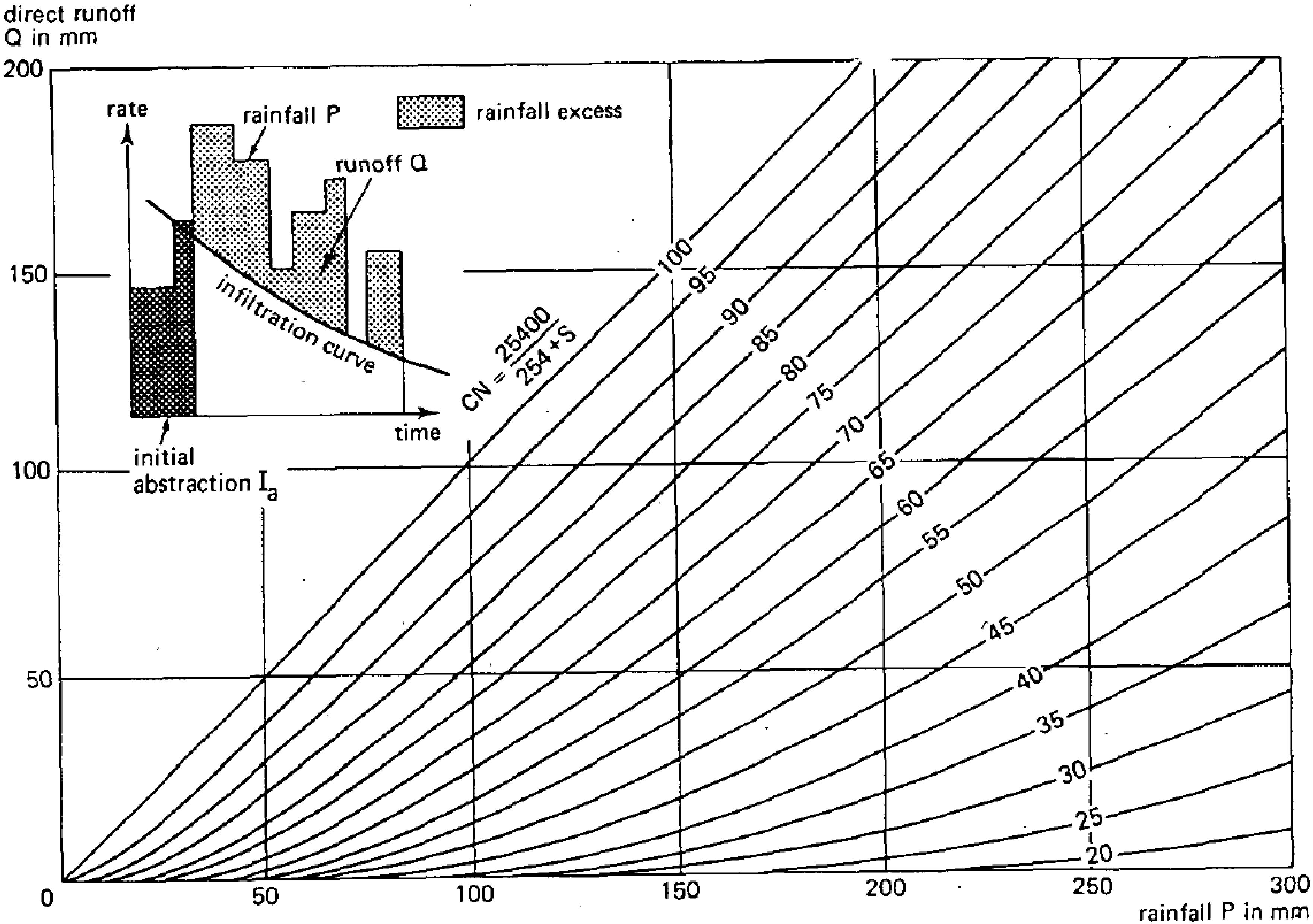


Figure 4.9 Graphical solution of Equation 4.5 showing runoff depth Q as a function of rainfall depth P and curve number CN (after Soil Conservation Service 1972)

TABLE : 1 Weighted Curve Number (AMC II) For The Study Area

S. No.	Land use	Type of soil	Area(sq.km)	CN	%area	%area*CN	Weighted CN
1	Dense Forest	C	7.18	58	3.19	185.17	
2	Degraded Forest	C	2.05	60	0.91	54.61	
3	Gullied\Ravinuous land	C	0.11	91	0.05	4.59	
4	Build up land	C	4.15	91	1.85	168.00	
5	Water bodies	C	6.82	95	3.03	288.00	
6	Upland with\without scrub	C	0.54	85	0.24	20.24	79.34
7	Fallow\harvested land	C	29.82	79	13.26	1047.48	
8	Agricultural plantation	C	103.30	69	45.93	3169.28	
9	Crop land	C	70.93	95	31.54	2996.15	
		Total	224.90		100.00	7933.52	

FLOOD – TAMIL NADU

- Tamil Nadu is one of the fast developing states with very high water demands
- Hence it is a state which is massively mining surface and groundwater resources
- out of 388 blocks, more than 120 blocks fall under over exploited category
- Thus, there is a serious water crisis in Tamil Nadu
- The condition worsens due to inadequate rainfall

Contd…

- **But, frequent floods occur in different parts of Tamil Nadu due to natural & anthropogenic processes**
- **Natural processes are**
  - ♣ **Release of excess water from Karnataka during heavy rains and the resultant floods in low lying areas of Cauvery basin**
  - ♣ **Rains in the Western Ghat regions and flooding in rivers like Tamrabharani & Vaigai**
  - ♣ **Rains in the midland regions & flooding (Floods 2005)**

Contd…

Anthropogenic reasons are

- ➔ Destruction of forest & vegetal cover
- ➔ Excessive soil erosion ,Siltation of reservoirs, river beds and tanks
- ➔ Choking of irrigation channels and supply canals, Unauthorized cultivation along irrigation channels
- ➔ Unauthorized encroachments of flood plains, irrigation channels, etc.,
- ➔ Indistinct network of rivers, tanks and irrigation channels
- ➔ Weak / broken / damaged irrigation structures

Contd…

- ➔**Weak / broken / damaged irrigation structures**
- ➔**How ever whether the floods are due to natural or anthropogenic as & when it occur , the only war footing action is the evacuation of the flood and push it into the ocean irrespective of the water scarcity of the flooded areas**
- ➔**Tamilnadu is also not an exception for the same , as there are no concrete plans for flood mitigation and flood water harvesting technology as well**

Contd…

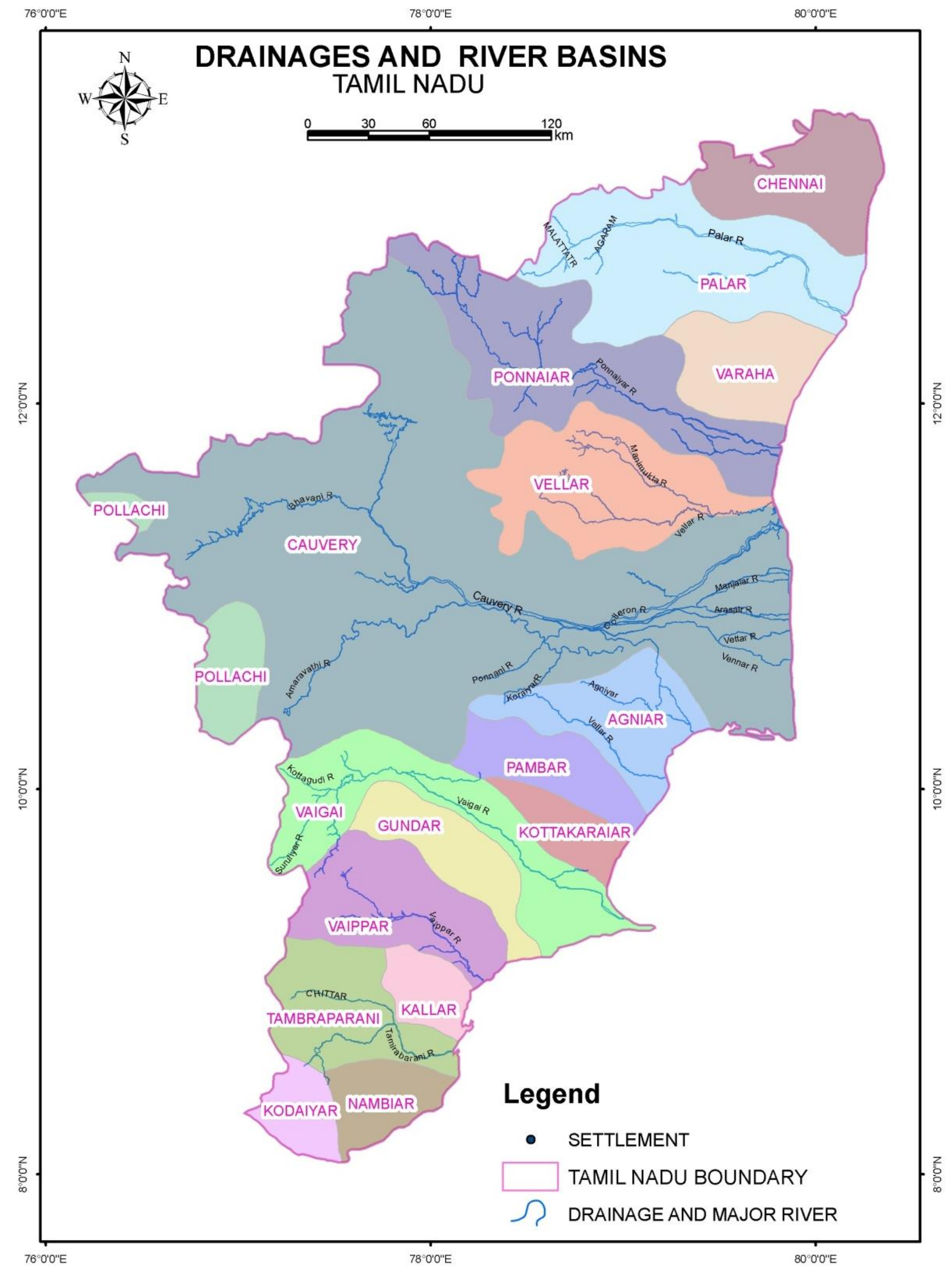
METHODOLOGY

- ★ Mapping of Flood prone areas coarsely by taking (2005) Floods as example with the help of post Flood "MODIS" (Moderate Resolution Imaging Spectro Radiometer) satellite data
- ★ Identification of causative factors of Flood by GIS modeling of Flood vs
  - Rock types
  - Lineaments
  - Active tectonics
  - Geomorphology
  - Landuse/land cover
  - Groundwater level etc.
- ★ Feasibility of mitigation strategies

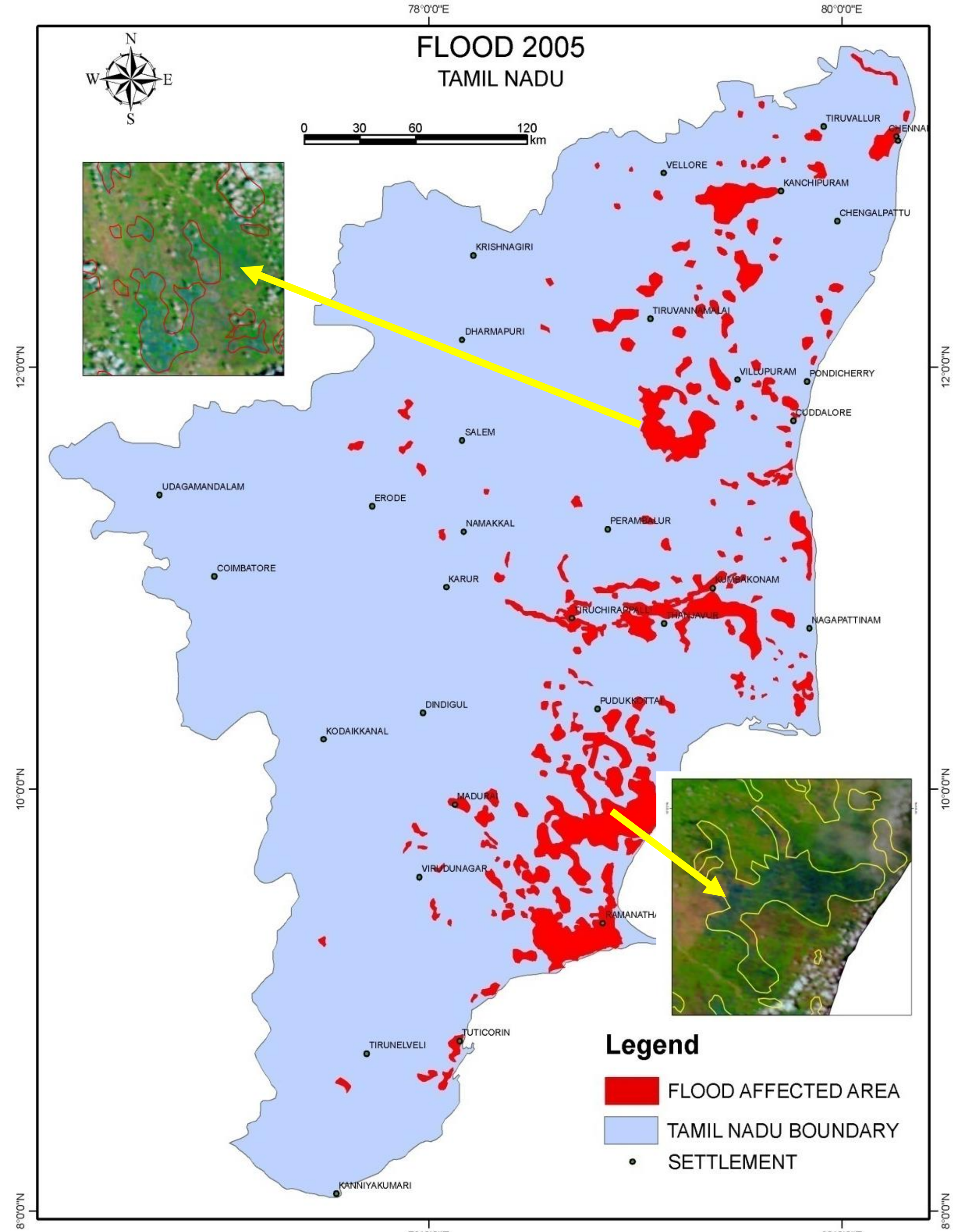
Methodology………..contd…

- **Feasibility of Flood water harvesting**
  - ★ Flood budgeting
  - ★ Identification of recharge windows
  - ★ Estimation of allowable recharge
  - ★ Detection of water surplus
- **Deficit water**
  - ★ Plans for insitu recharge
  - ★ Plans for inter basin water transfer through optimal routes



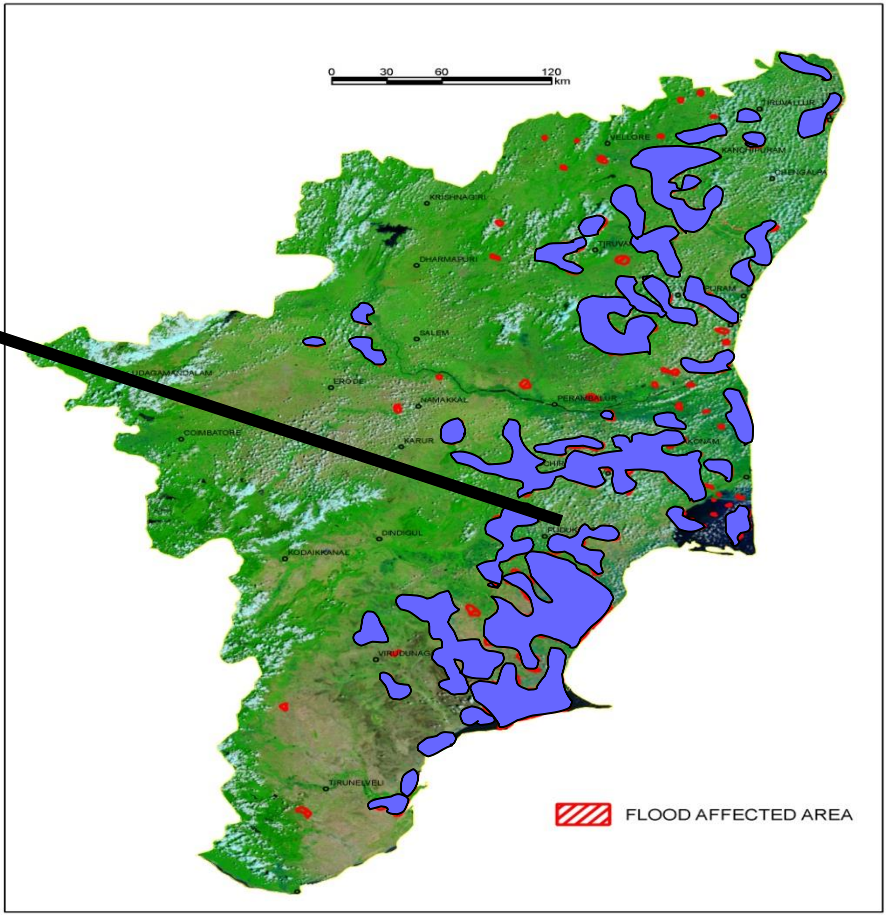
DRAINAGES AND RIVER BASINS
TAMIL NADU
N
S
E
W
0
30
60
120
km
76°0'0"E
78°0'0"E
80°0'0"E
12°0'0"N
10°0'0"N
8°0'0"N
CHENNAI
PALAR
Palar R
MALATTATR
AGARAM
VARAHA
PONNAIAR
Ponnaiyar R
VELLAR
Manimukta R
Vellar R
POLLACHI
CAUVERY
Bhavani R
Cauvery R
Coleron R
Manjalar R
Arasalr R
Vettar R
Vennar R
Amaravathi R
Ponnani R
Koraiyar R
Agniyar
AGNIAR
Vellar R
PAMBAR
KOTTAKARAIAR
Kottagudi R
VAIGAI
Vaigai R
Suruliyar R
GUNDAR
VAIPPAR
Vaippar R
CHITTAR
TAMBRAPARANI
Tamirabarani R
KALLAR
KODAIYAR
NAMBIAR
Legend
SETTLEMENT
TAMIL NADU BOUNDARY
DRAINAGE AND MAJOR RIVER



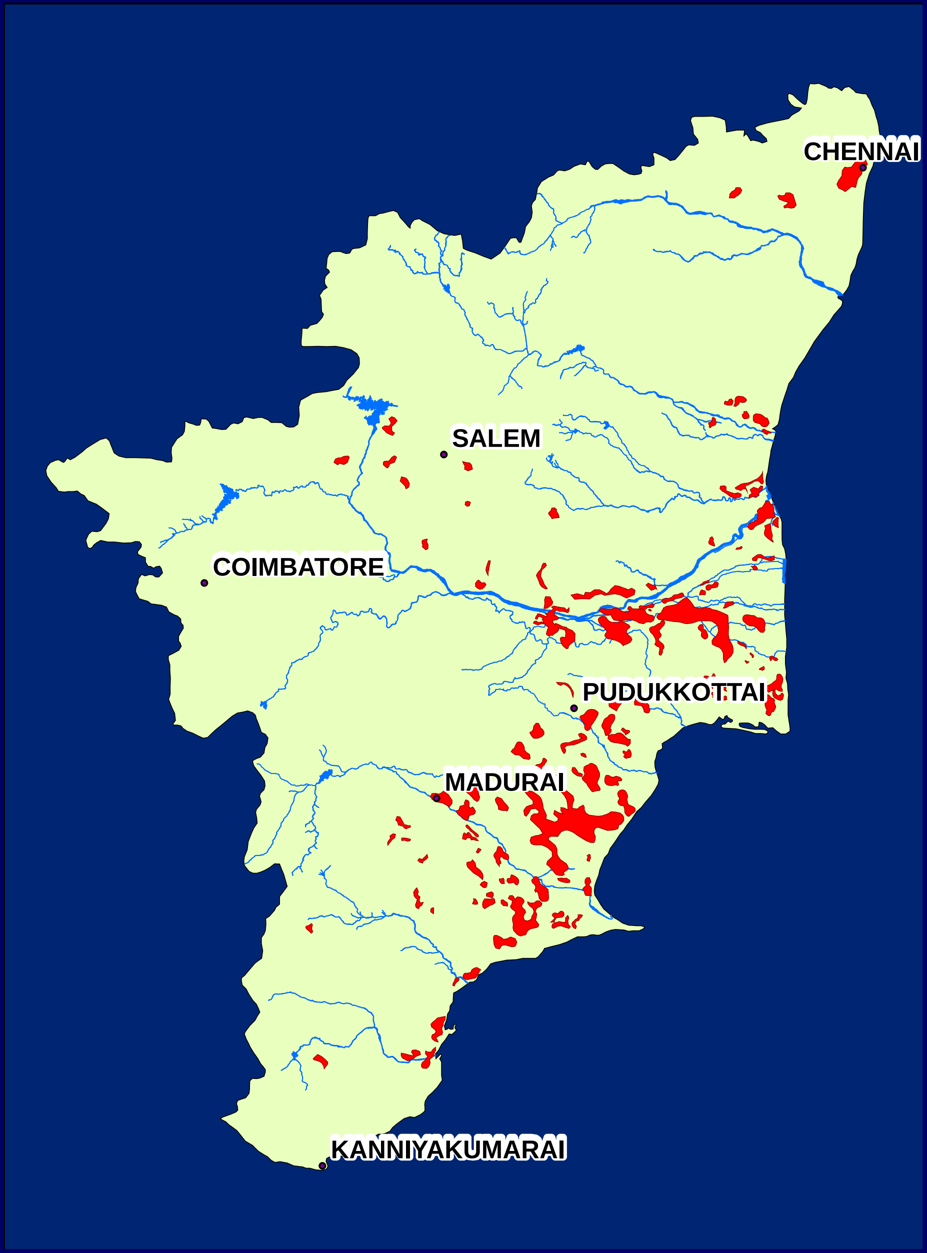
FLOOD 2005
TAMIL NADU
78°0'0"E
80°0'0"E
12°0'0"N
10°0'0"N
8°0'0"N
0
30
60
120
km
N
S
E
W
TIRUVALLUR
CHENNAI
VELLORE
KANCHIPURAM
CHENGALPATTU
KRISHNAGIRI
TIRUVANNAMALAI
DHARMAPURI
VILLUPURAM
PONDICHERRY
CUDDALORE
SALEM
UDAGAMANDALAM
ERODE
NAMAKKAL
PERAMBALUR
COIMBATORE
KARUR
KUMBAKONAM
TIRUCHIRAPPALLI
THANJAVUR
NAGAPATTINAM
DINDIGUL
PUDUKKOTTAI
KODAIKKANAL
MADURAI
VIRUDUNAGAR
RAMANATHA
TUTICORIN
TIRUNELVELI
KANNIYAKUMARI
Legend
FLOOD AFFECTED AREA
TAMIL NADU BOUNDARY
SETTLEMENT

Identification of flood prone areas from historical floods & multi dated satellite Data sets and creation of GIS data bases

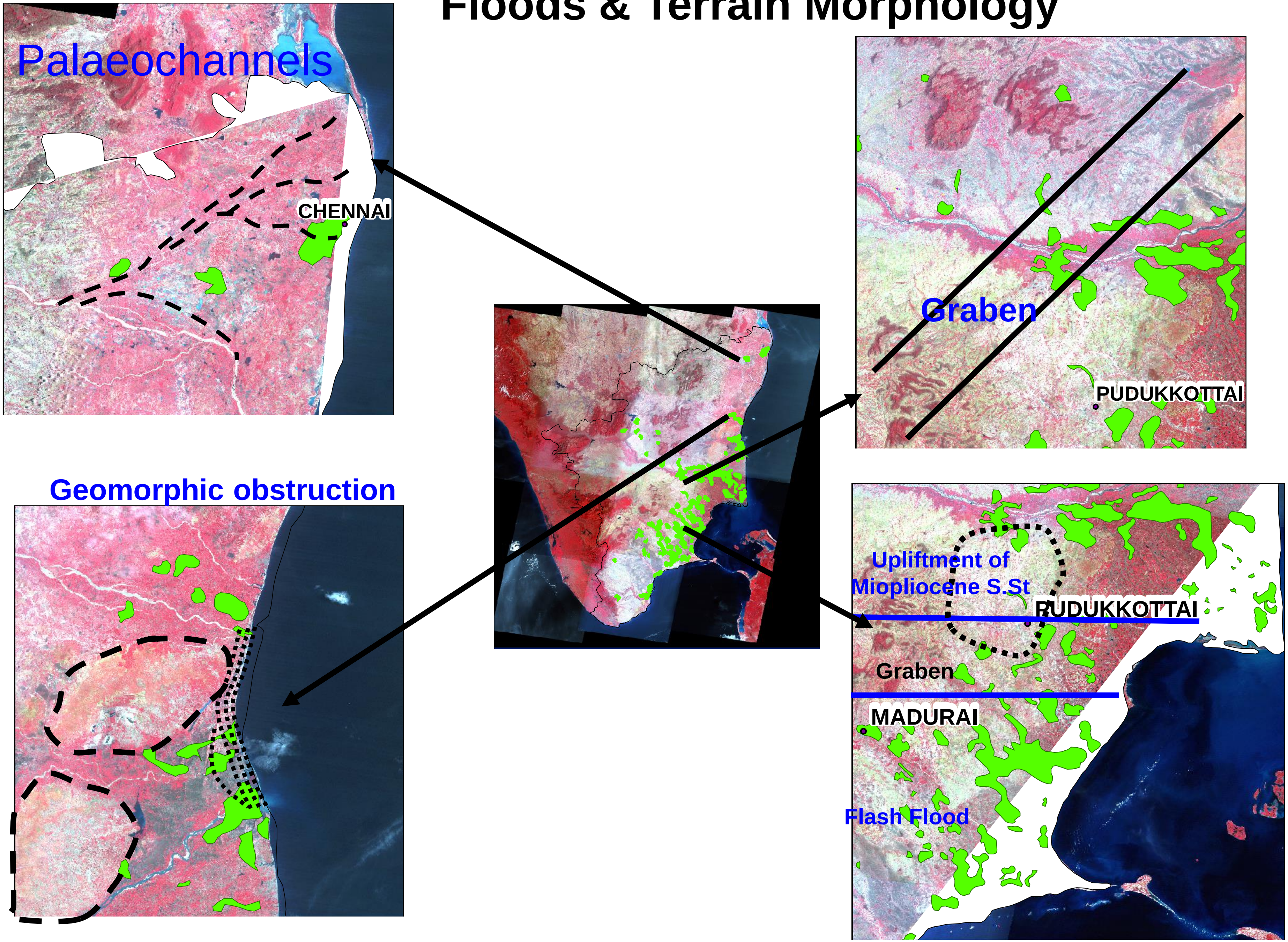
Sample flood map – MODIS data



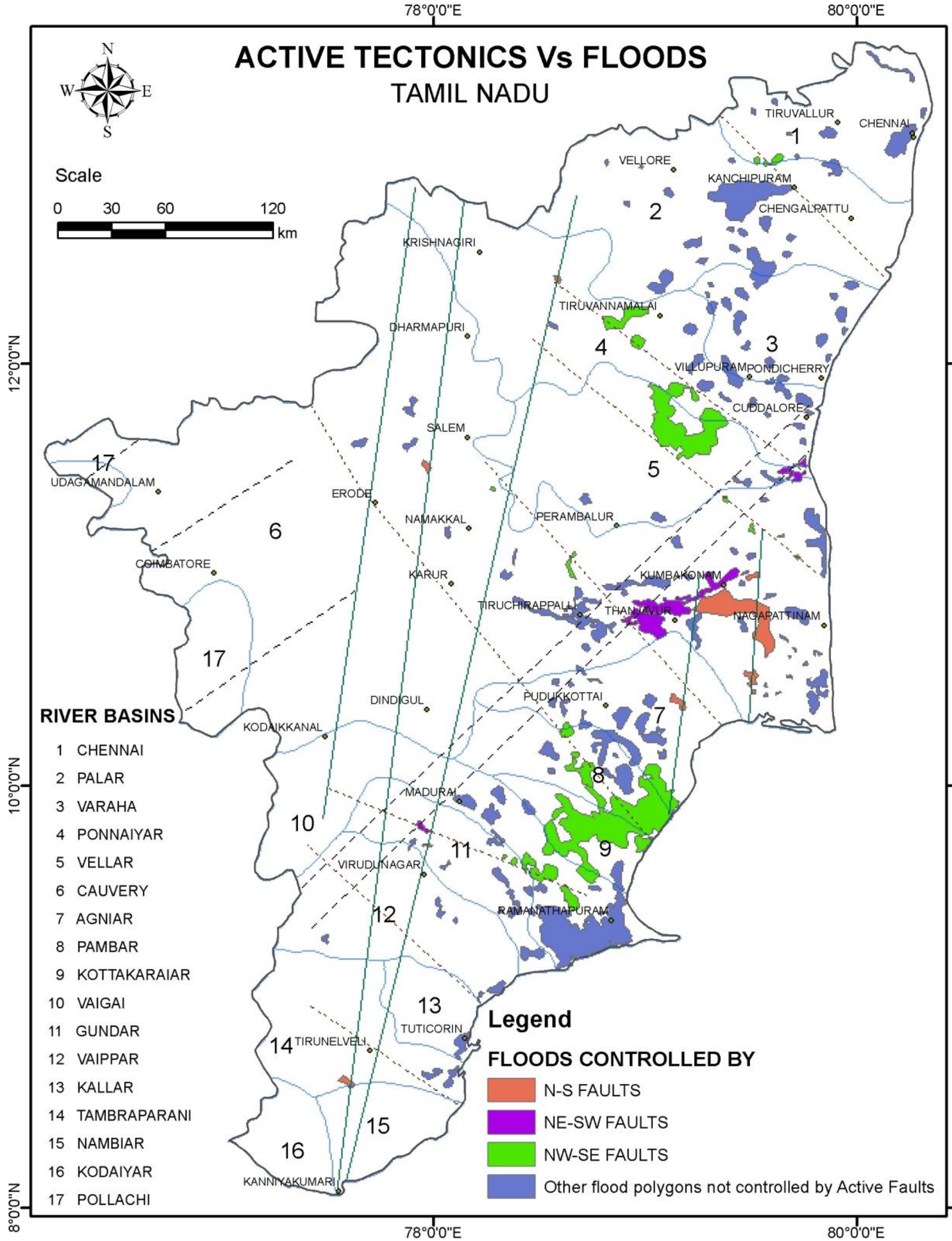
FLOODS IN TAMIL NADU - 2005



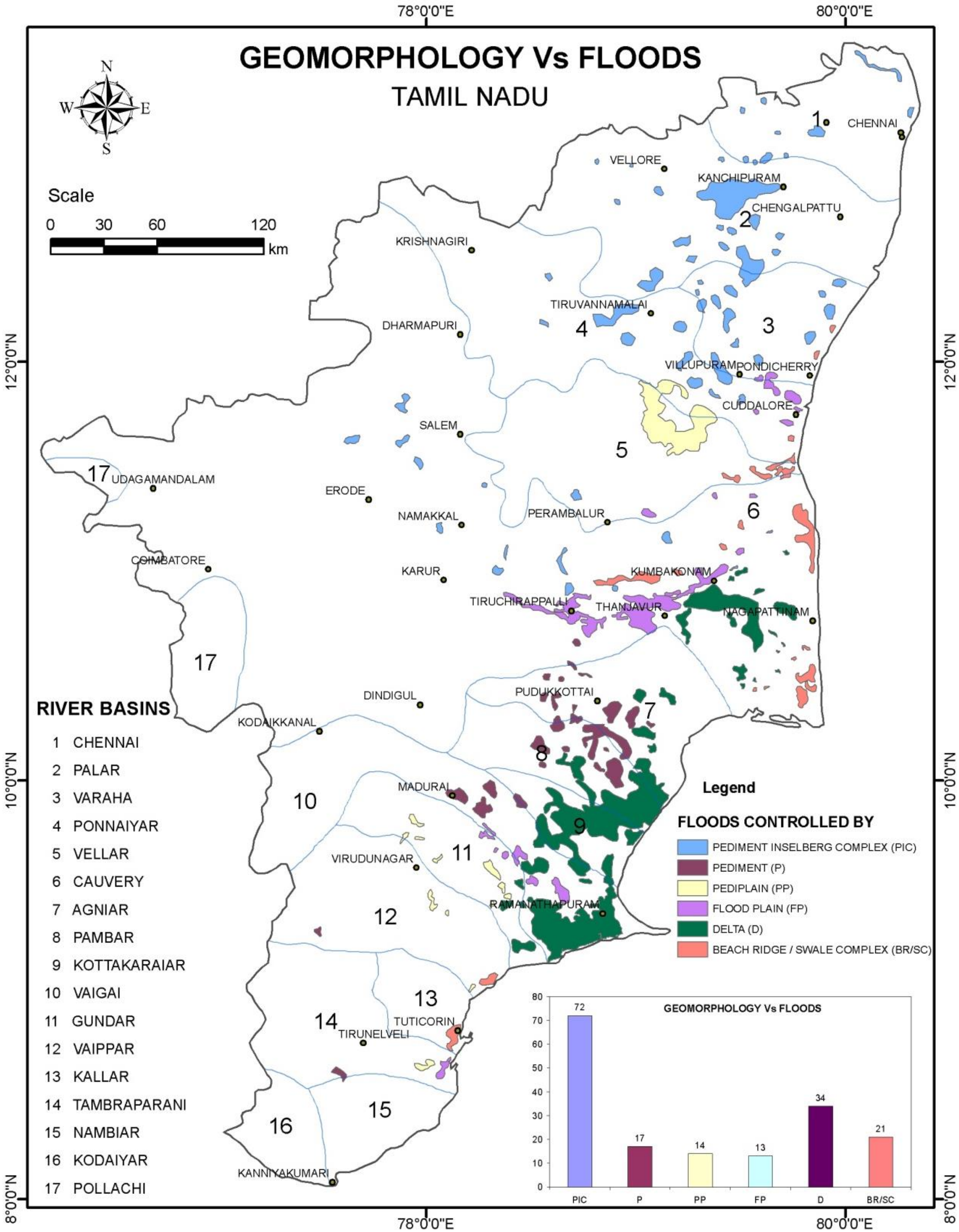
Floods & Terrain Morphology

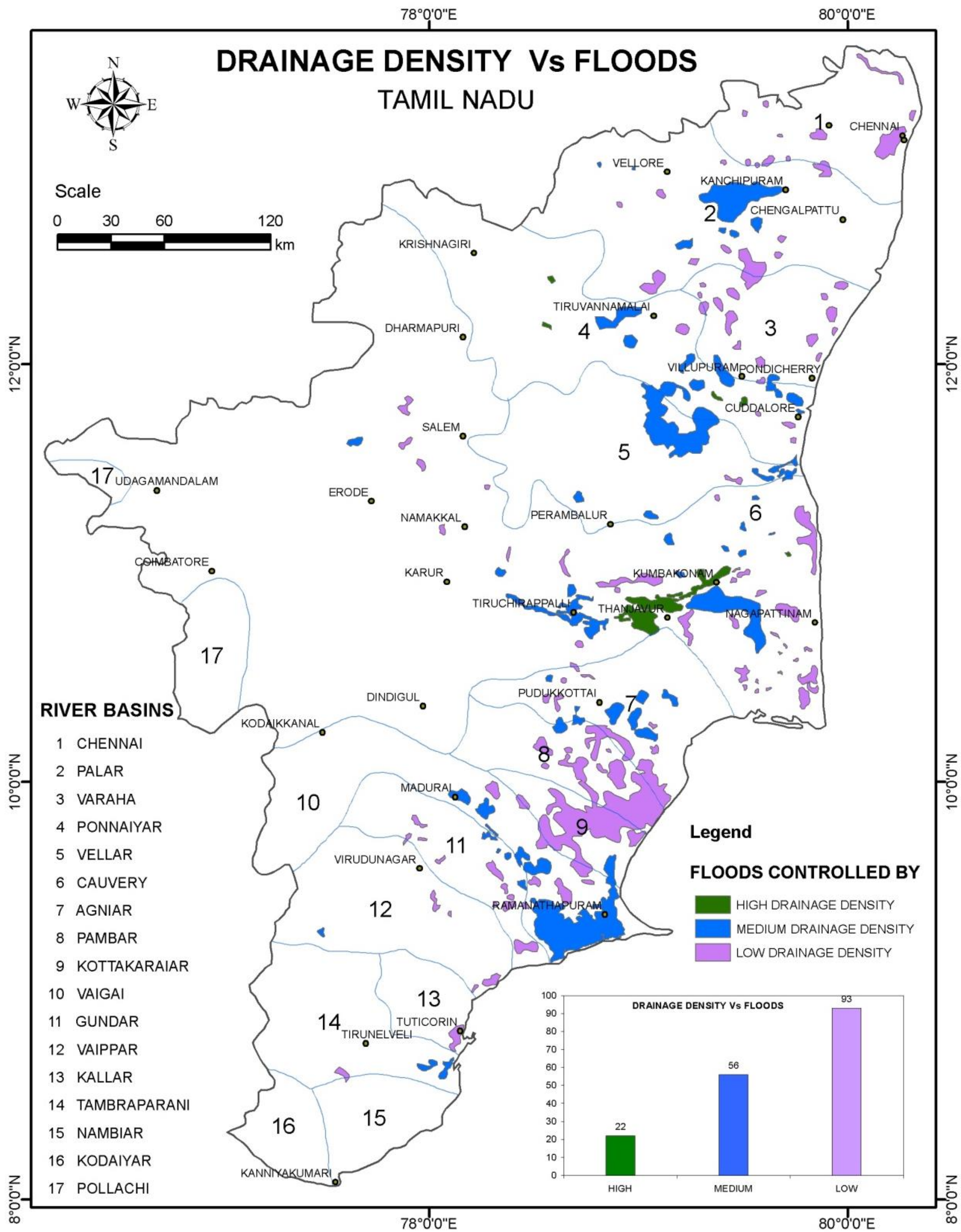


Interface Dynamics between Flood and Geosystems

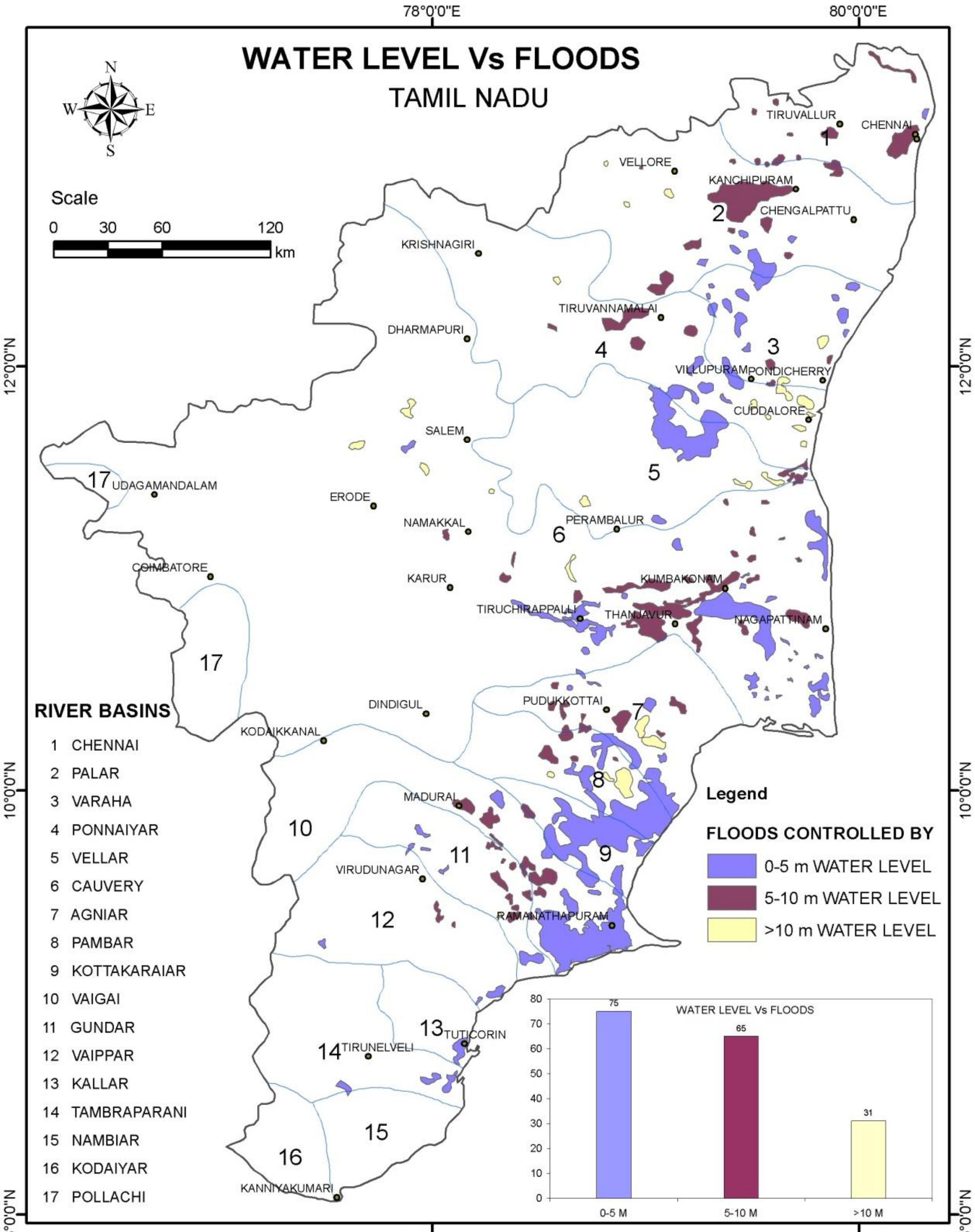


ACTIVE TECTONICS Vs FLOODS
TAMIL NADU
N
E
S
W
Scale
0 30 60 120
km
78°0'0"E
80°0'0"E
12°0'0"N
10°0'0"N
8°0'0"N
TIRUVALLUR
CHENNAI
VELLORE
KANCHIPURAM
CHENGALPATTU
KRISHNAGIRI
TIRUVANNAMALAI
DHARMAPURI
VILLUPURAM
PONDICHERRY
CUDDALORE
SALEM
UDAGAMANDALAM
ERODE
NAMAKKAL
PERAMBALUR
COIMBATORE
KARUR
KUMBAKONAM
TIRUCHIRAPPALLI
THANJAVUR
NAGAPATTINAM
DINDIGUL
PUDUKKOTTAI
KODAIKKANAL
MADURAI
VIRUDUNAGAR
RAMANATHAPURAM
TUTICORIN
TIRUNELVELI
KANNIYAKUMARI
RIVER BASINS
1 CHENNAI
2 PALAR
3 VARAHA
4 PONNAIYAR
5 VELLAR
6 CAUVERY
7 AGNIAR
8 PAMBAR
9 KOTTAKARAIAR
10 VAIGAI
11 GUNDAR
12 VAIPPAR
13 KALLAR
14 TAMBRAPARANI
15 NAMBIAR
16 KODAIYAR
17 POLLACHI
Legend
FLOODS CONTROLLED BY
N-S FAULTS
NE-SW FAULTS
NW-SE FAULTS
Other flood polygons not controlled by Active Faults

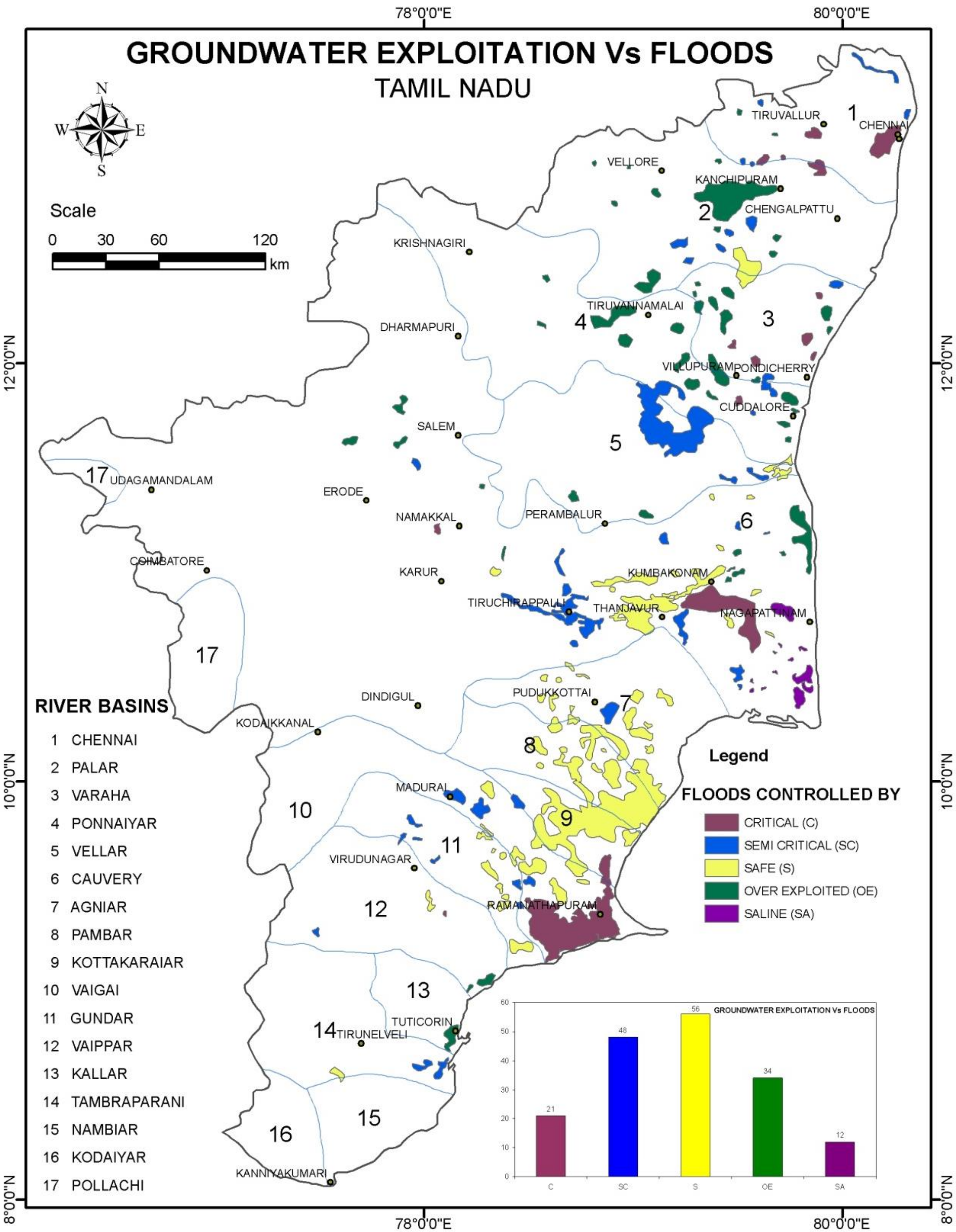

GEOMORPHOLOGY Vs FLOODS
TAMIL NADU
N
W
E
S
Scale
0 30 60 120
km
78°0'0"E
80°0'0"E
12°0'0"N
10°0'0"N
8°0'0"N
CHENNAI
VELLORE
KANCHIPURAM
CHENGALPATTU
KRISHNAGIRI
TIRUVANNAMALAI
DHARMAPURI
VILLUPURAM
PONDICHERRY
CUDDALORE
SALEM
UDAGAMANDALAM
ERODE
NAMAKKAL
PERAMBALUR
COIMBATORE
KARUR
KUMBAKONAM
TIRUCHIRAPPALLI
THANJAVUR
NAGAPATTINAM
DINDIGUL
PUDUKKOTTAI
KODAIKKANAL
MADURAI
VIRUDUNAGAR
RAMANATHAPURAM
TUTICORIN
TIRUNELVELI
KANNIYAKUMARI
RIVER BASINS
1 CHENNAI
2 PALAR
3 VARAHA
4 PONNAIYAR
5 VELLAR
6 CAUVERY
7 AGNIAR
8 PAMBAR
9 KOTTAKARAIAR
10 VAIGAI
11 GUNDAR
12 VAIPPAR
13 KALLAR
14 TAMBRAPARANI
15 NAMBIAR
16 KODAIYAR
17 POLLACHI
Legend
FLOODS CONTROLLED BY
PEDIMENT INSELBERG COMPLEX (PIC)
PEDIMENT (P)
PEDIPLAIN (PP)
FLOOD PLAIN (FP)
DELTA (D)
BEACH RIDGE / SWALE COMPLEX (BR/SC)
GEOMORPHOLOGY Vs FLOODS
0 10 20 30 40 50 60 70 80
PIC 72
P 17
PP 14
FP 13
D 34
BR/SC 21



DRAINAGE DENSITY Vs FLOODS
TAMIL NADU
Scale
0 30 60 120 km
78°0'0"E
80°0'0"E
12°0'0"N
10°0'0"N
8°0'0"N
CHENNAI
VELLORE
KANCHIPURAM
CHENGALPATTU
KRISHNAGIRI
TIRUVANNAMALAI
DHARMAPURI
VILLUPURAM
PONDICHERRY
CUDDALORE
SALEM
UDAGAMANDALAM
ERODE
NAMAKKAL
PERAMBALUR
COIMBATORE
KARUR
KUMBAKONAM
TIRUCHIRAPPALLI
THANJAVUR
NAGAPATTINAM
DINDIGUL
PUDUKKOTTAI
KODAIKKANAL
MADURAI
VIRUDUNAGAR
RAMANATHAPURAM
TUTICORIN
TIRUNELVELI
KANNIYAKUMARI
RIVER BASINS
1 CHENNAI
2 PALAR
3 VARAHA
4 PONNAIYAR
5 VELLAR
6 CAUVERY
7 AGNIAR
8 PAMBAR
9 KOTTAKARAIAR
10 VAIGAI
11 GUNDAR
12 VAIPPAR
13 KALLAR
14 TAMBRAPARANI
15 NAMBIAR
16 KODAIYAR
17 POLLACHI
Legend
FLOODS CONTROLLED BY
HIGH DRAINAGE DENSITY
MEDIUM DRAINAGE DENSITY
LOW DRAINAGE DENSITY
DRAINAGE DENSITY Vs FLOODS
HIGH 22
MEDIUM 56
LOW 93



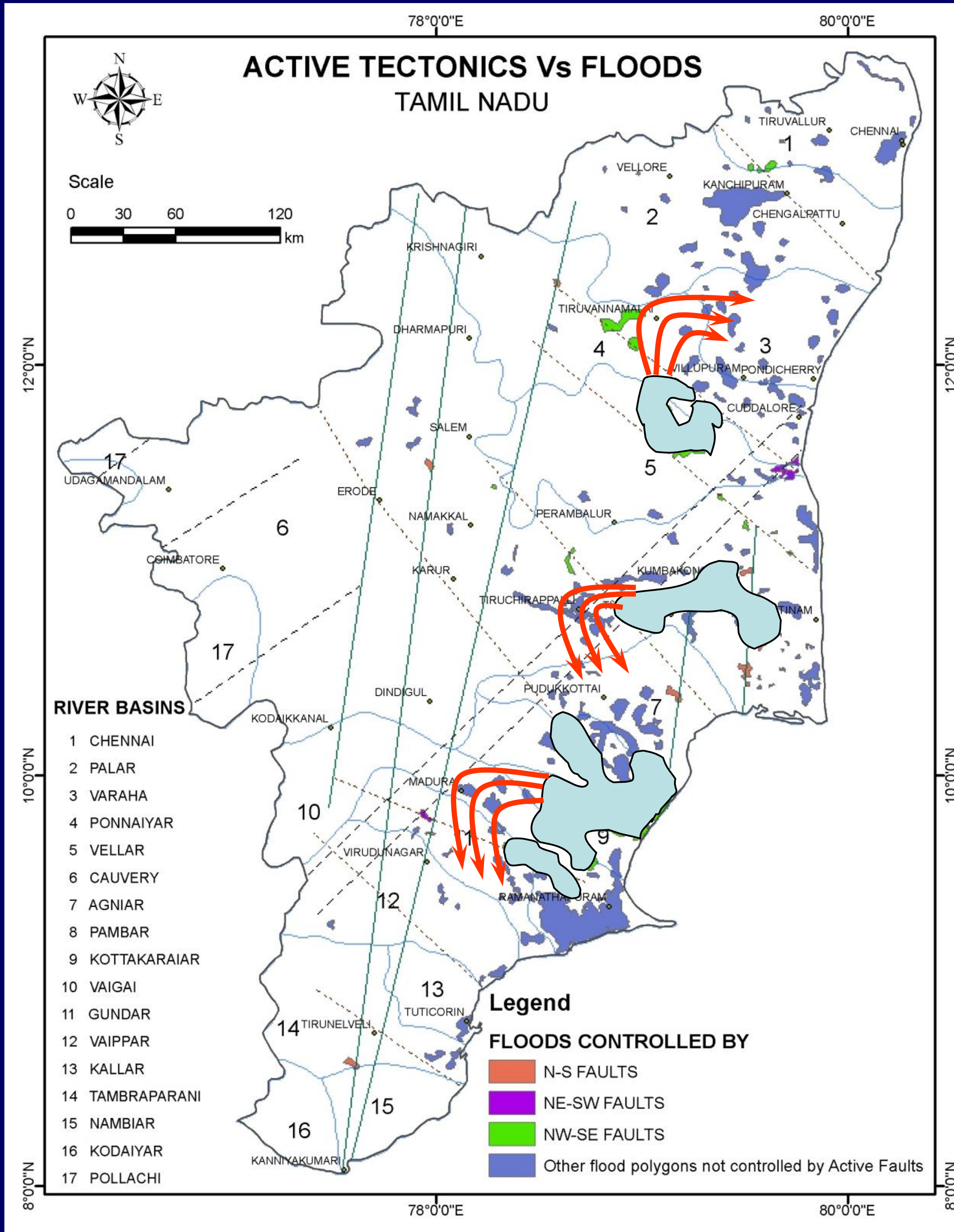
WATER LEVEL Vs FLOODS
TAMIL NADU
N
S
E
W
Scale
0
30
60
120
km
78°0'0"E
80°0'0"E
12°0'0"N
10°0'0"N
8°0'0"N
TIRUVALLUR
CHENNAI
VELLORE
KANCHIPURAM
CHENGALPATTU
KRISHNAGIRI
TIRUVANNAMALAI
DHARMAPURI
VILLUPURAM
PONDICHERRY
CUDDALORE
SALEM
UDAGAMANDALAM
ERODE
NAMAKKAL
PERAMBALUR
COIMBATORE
KARUR
KUMBAKONAM
TIRUCHIRAPPALLI
THANJAVUR
NAGAPATTINAM
DINDIGUL
PUDUKKOTTAI
KODAIKKANAL
MADURAI
VIRUDUNAGAR
RAMANATHAPURAM
TUTICORIN
TIRUNELVELI
KANNIYAKUMARI
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
17
RIVER BASINS
1 CHENNAI
2 PALAR
3 VARAHA
4 PONNAIYAR
5 VELLAR
6 CAUVERY
7 AGNIAR
8 PAMBAR
9 KOTTAKARAIAR
10 VAIGAI
11 GUNDAR
12 VAIPPAR
13 KALLAR
14 TAMBRAPARANI
15 NAMBIAR
16 KODAIYAR
17 POLLACHI
Legend
FLOODS CONTROLLED BY
0-5 m WATER LEVEL
5-10 m WATER LEVEL
>10 m WATER LEVEL
WATER LEVEL Vs FLOODS
0
10
20
30
40
50
60
70
80
75
65
31
0-5 M
5-10 M
>10 M



GROUNDWATER EXPLOITATION Vs FLOODS
TAMIL NADU
78°0'0"E
80°0'0"E
12°0'0"N
10°0'0"N
8°0'0"N
N
S
E
W
Scale
0 30 60 120
km
TIRUVALLUR
CHENNAI
VELLORE
KANCHIPURAM
CHENGALPATTU
KRISHNAGIRI
TIRUVANNAMALAI
DHARMAPURI
VILLUPURAM
PONDICHERRY
CUDDALORE
SALEM
UDAGAMANDALAM
ERODE
NAMAKKAL
PERAMBALUR
COIMBATORE
KARUR
KUMBAKONAM
TIRUCHIRAPPALLI
THANJAVUR
NAGAPATTINAM
DINDIGUL
PUDUKKOTTAI
KODAIKKANAL
MADURAI
VIRUDUNAGAR
RAMANATHAPURAM
TUTICORIN
TIRUNELVELI
KANNIYAKUMARI
RIVER BASINS
1 CHENNAI
2 PALAR
3 VARAHA
4 PONNAIYAR
5 VELLAR
6 CAUVERY
7 AGNIAR
8 PAMBAR
9 KOTTAKARAIAR
10 VAIGAI
11 GUNDAR
12 VAIPPAR
13 KALLAR
14 TAMBRAPARANI
15 NAMBIAR
16 KODAIYAR
17 POLLACHI
Legend
FLOODS CONTROLLED BY
CRITICAL (C)
SEMI CRITICAL (SC)
SAFE (S)
OVER EXPLOITED (OE)
SALINE (SA)
GROUNDWATER EXPLOITATION Vs FLOODS
21
48
56
34
12
C
SC
S
OE
SA

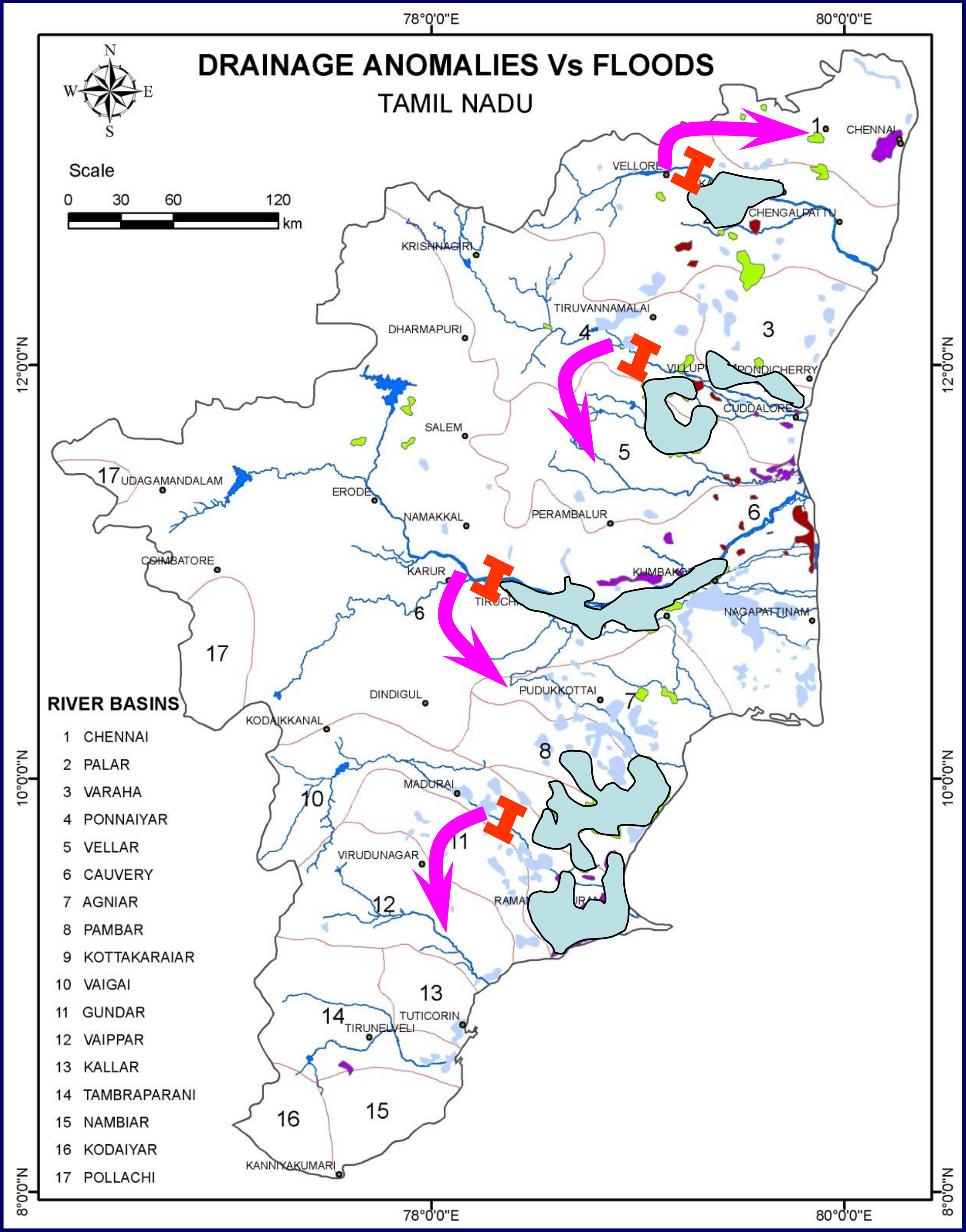
MITIGATION STRATEGIES

- Pump out and transfer water from flood prone to water starved basins
- Check dams
- Drainage reorganization / create adequate drainages
- Construction of protection walls
- Depression of groundwater levels prior to monsoon to facilitate the faster infiltration of flood water, etc.



FLOOD CONTROLLED BY ACTIVE FAULTS

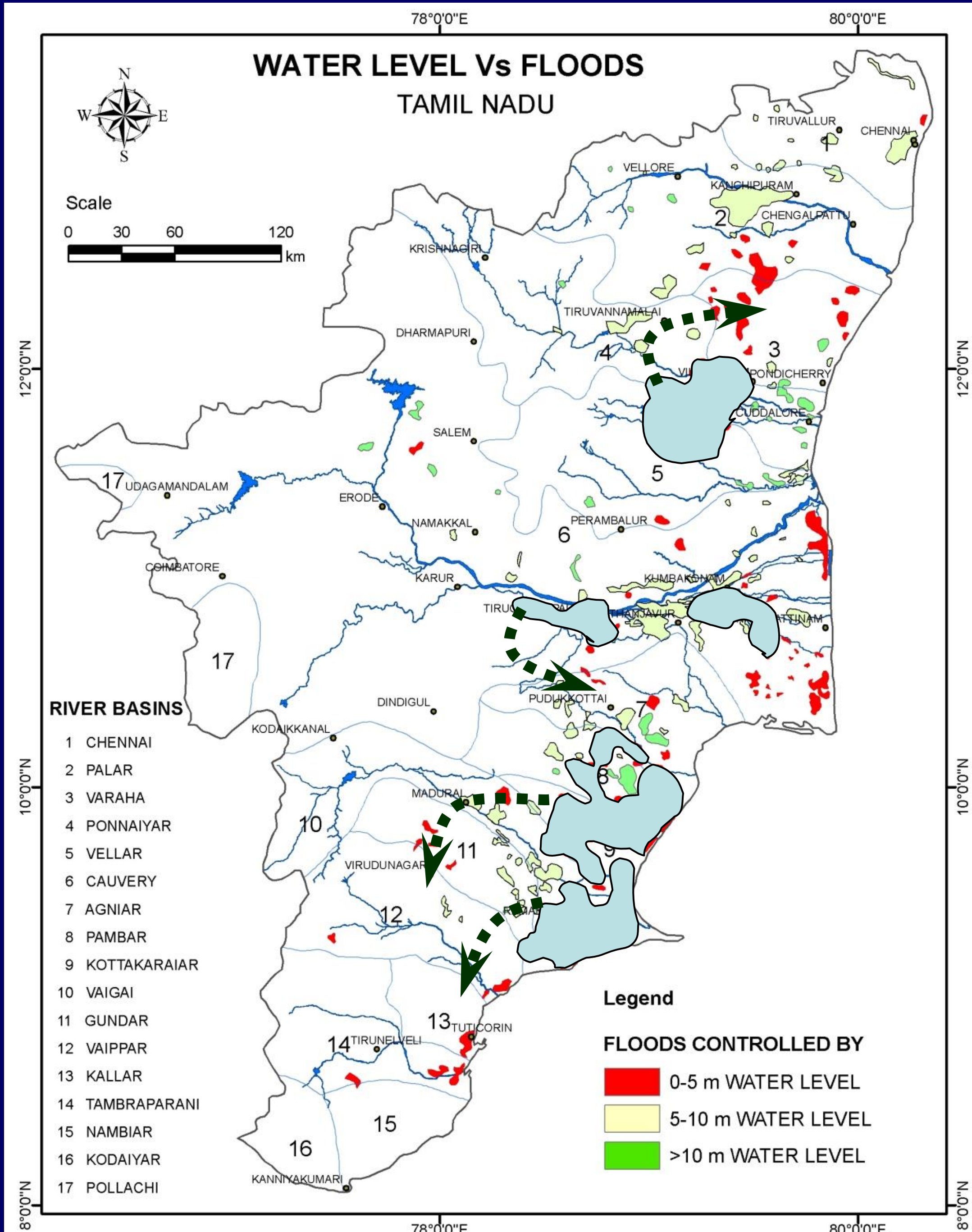
- Transfer to Other basins



FLOOD CONTROLLED BY

DRAINAGE ANOMALIES

- Check dam upper reaches
- Transfer to Other basins



FLOOD CONTROLLED BY

WATER LEVEL

- Depress the water level
- Transfer to other basin

FLOOD WATER HARVESTING TECHNOLOGY

- ♣ Selection of suitable sites for recharge

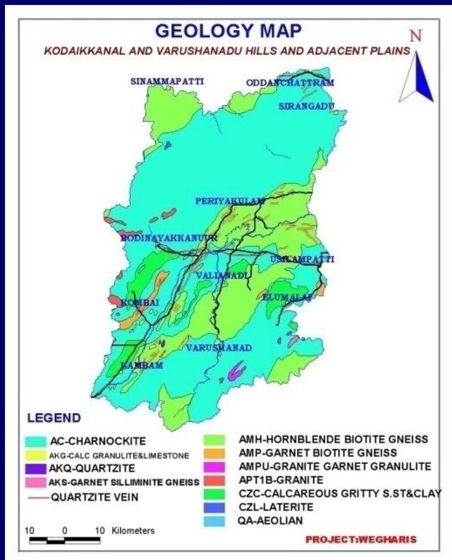
- ♣ Detection of site specific mechanisms (percolation ponds, Check dams , furrowing, flooding, pitting ,induced recharge Hydofracturing etc

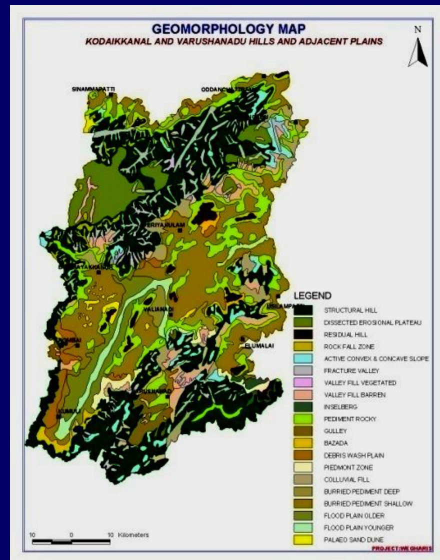
- ♣ estimation of basin wise flood availability, allowable recharge Push such acceptable flood water in the respective basins

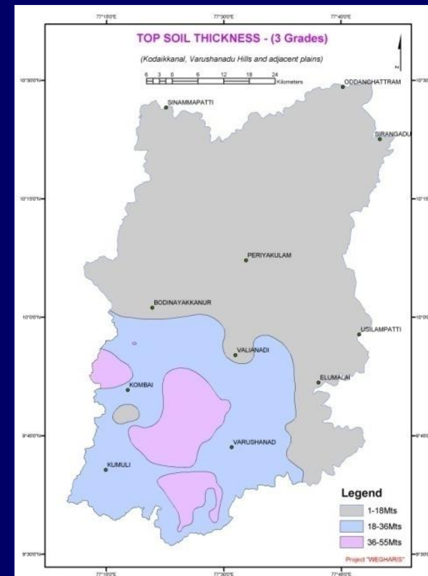
- ♣ Transfer the surplus water to the water deficit basins along optimal routes

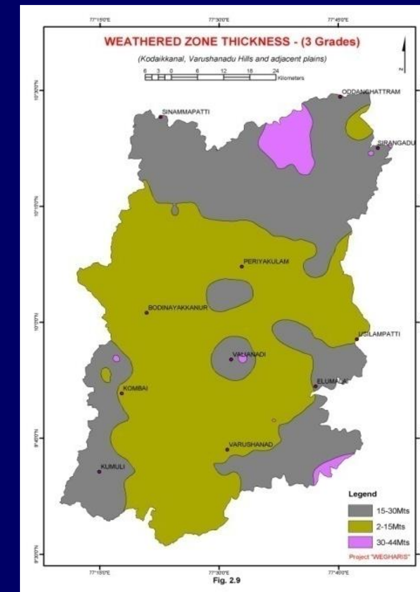
- ♣ All these require in depth geological studies

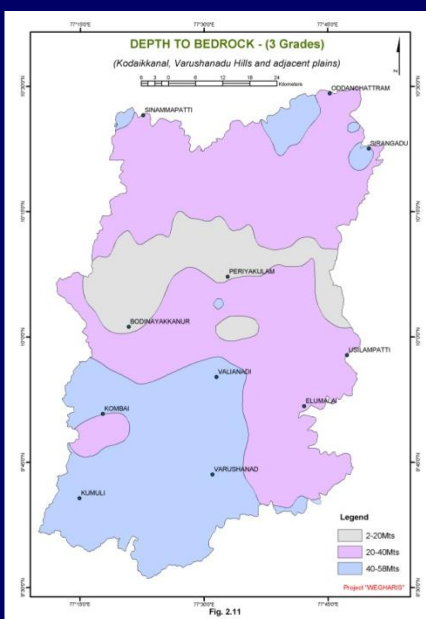
FLOOD WATER HARVESTING TECHNOLOGY – through suitable site selection for Aritificial Recharge

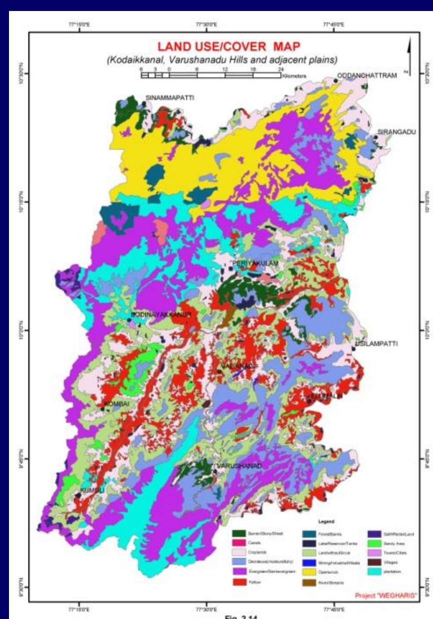


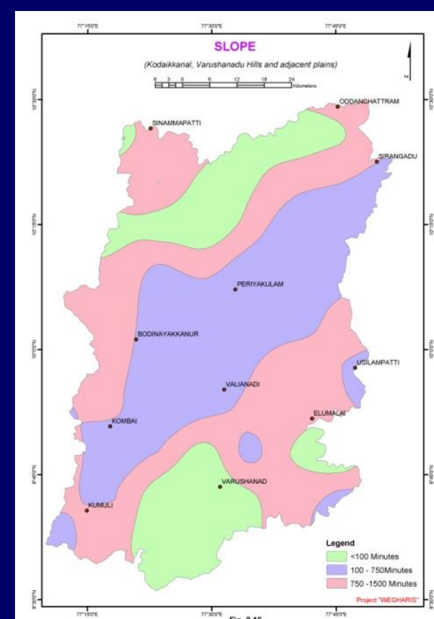


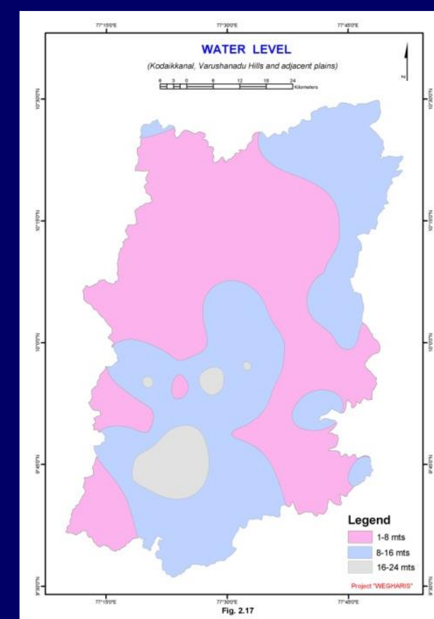




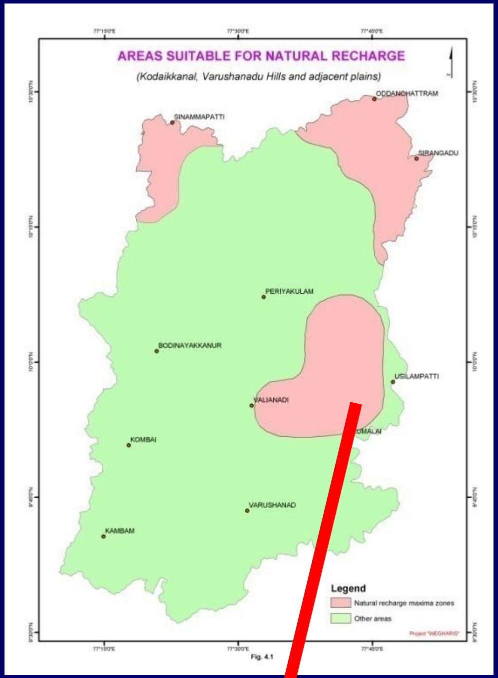






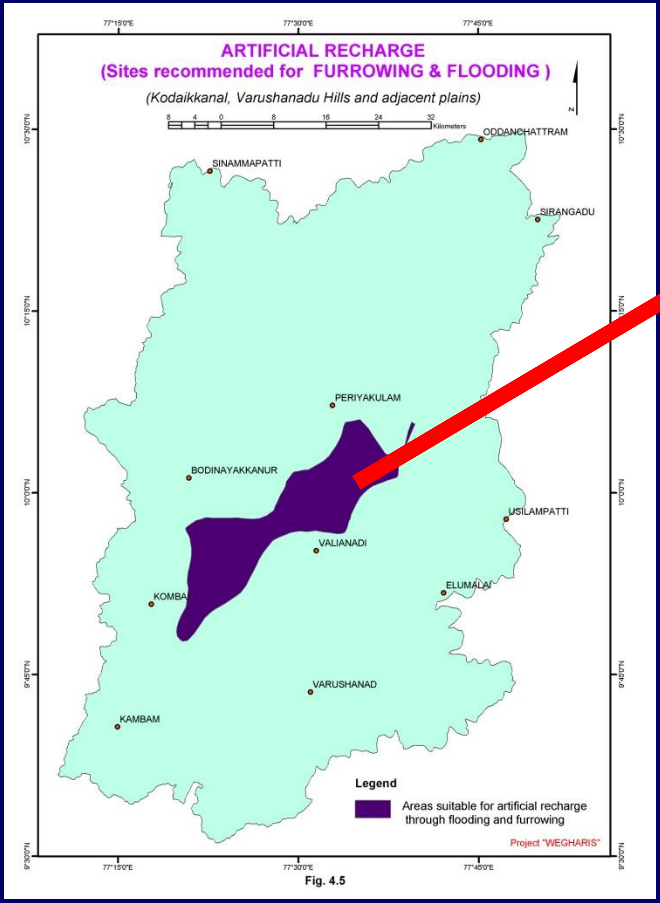


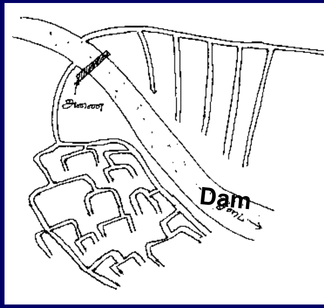
FLOOD WATER HARVESTING TECHNOLOGY – through suitable mechanism identification for Aritificial Recharge



Site favourable for

Artificial Recharge

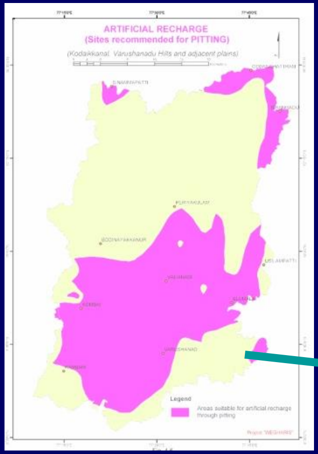




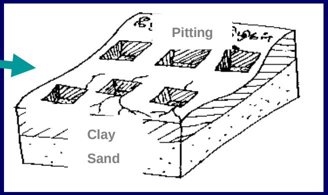
Site suitable for Furrowing & Flooding

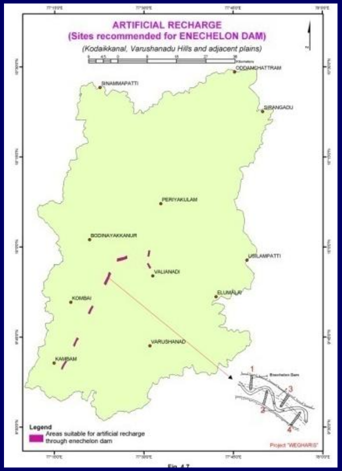
FLOOD WATER HARVESTING TECHNOLOGY – through suitable mechanism identification for Aritificial Recharge

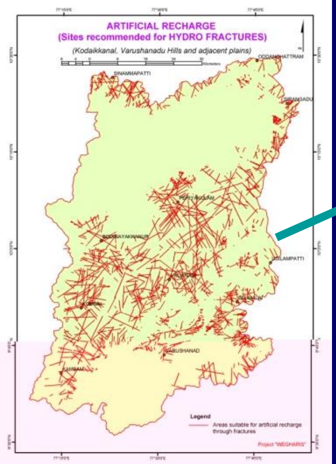
Site suitable for Enechelon Dam



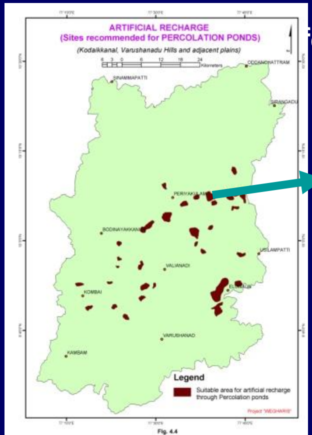
Site suitable for Pitting



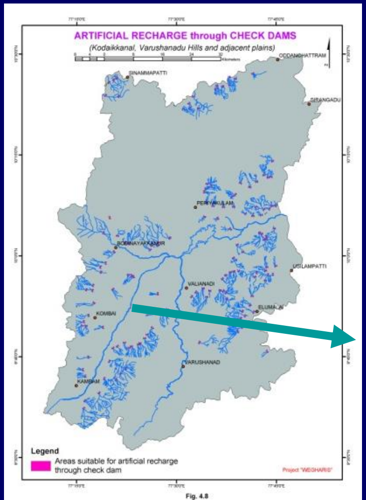




Site suitable for Hydro fractures



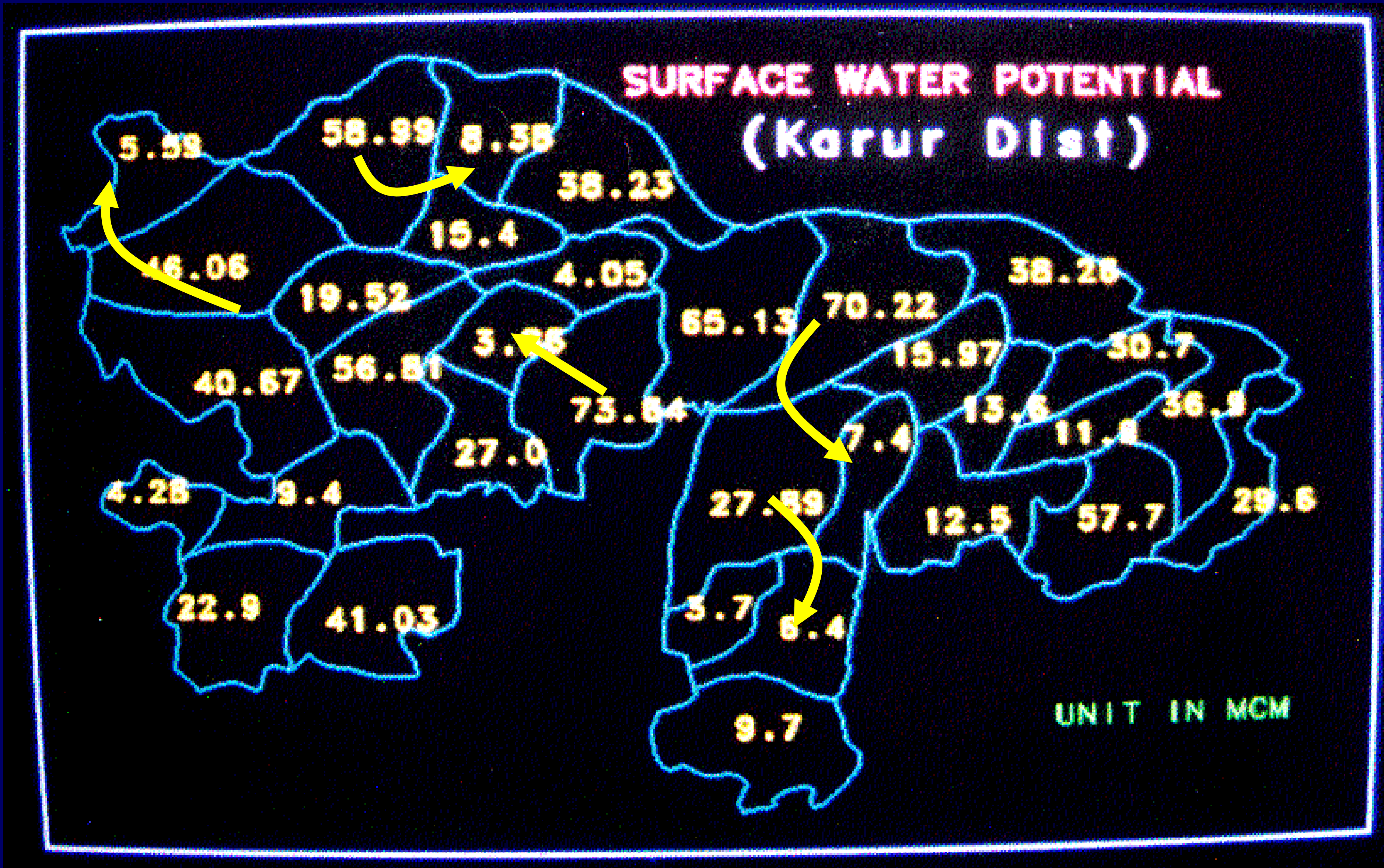
Site suitable for Percolation Pond



Site suitable for Check Dam

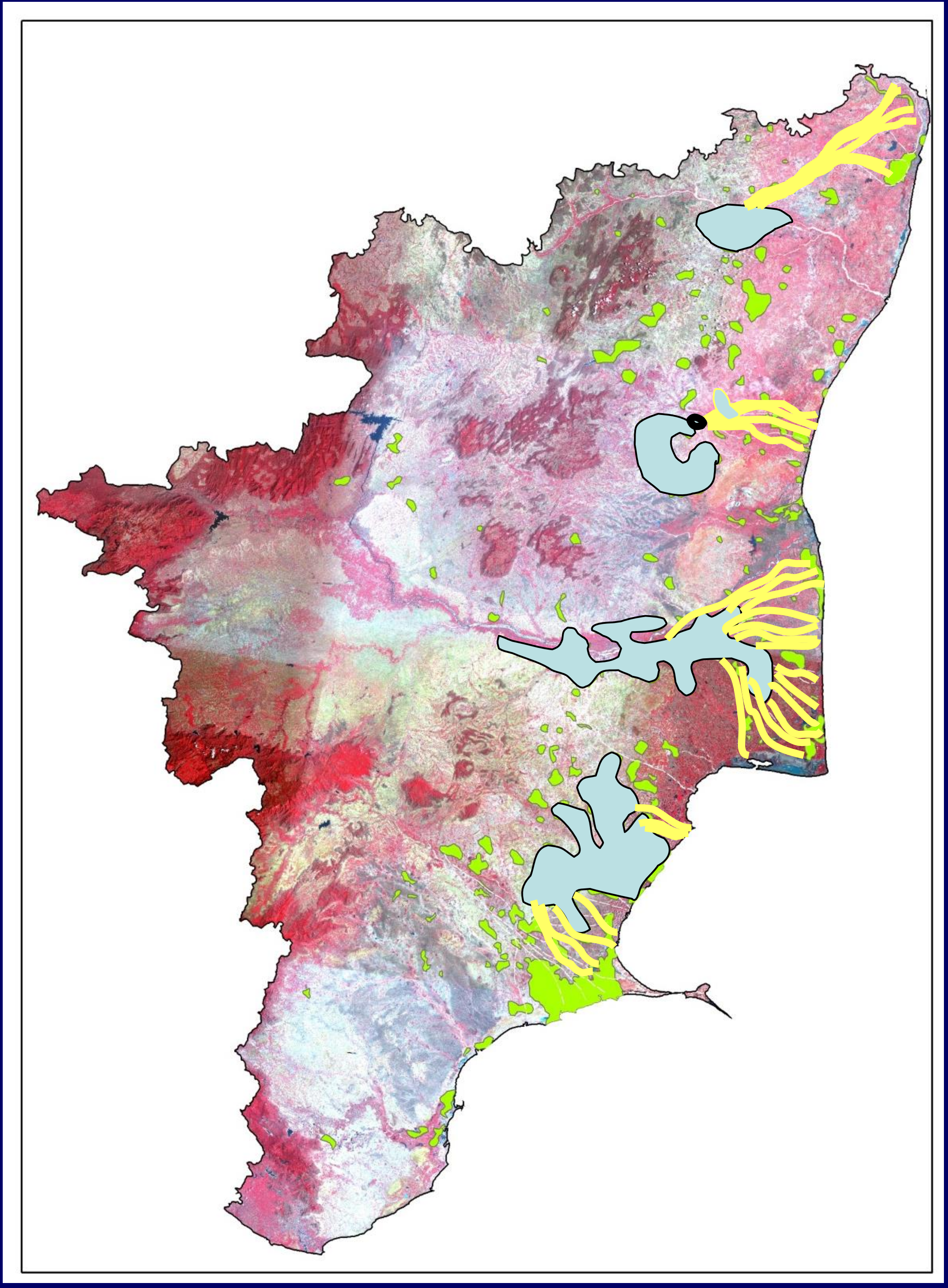
OPTIMAL ROUTES FOR WATER TRANSFER

Water Transfer



DIVERSION OF FLOOD THROUGH

BURIED RIVERS



DROUGHT

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (G.Hagman 1984).

Droughts have no universal definition. As drought definitions are region specific, reflecting differences in climatic characteristics as well as incorporating different physical, biological and socio-economic variables, it is usually difficult to transfer definitions derived for one region to another

However some of the common definitions for drought

The Director of Common Wealth Bureau of Meteorology in 1965 suggested a broad definition of drought as "severe water shortage".

Definition given by Palmer states that "Drought is an interval of time, generally of the order of months of years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply (Palmer, 1965)

According to Mc Mohan and Diaz Arena (1982), "Drought is a period of abnormally dry weather sufficiently for the lack of precipitation to cause a serious hydrological imbalance and carries connotations of a moisture deficiency with respect to man's usage of water

By studying the above definitions it can be understood that drought is mainly concerned with the shortage of water which in turn affects availability of food and fodder thereby leading to displacement and loss to economies as a whole.

Droughts can be classified in four major categories:

- Meteorological drought
- Hydrological drought
- Agricultural drought
- Socio-economic drought

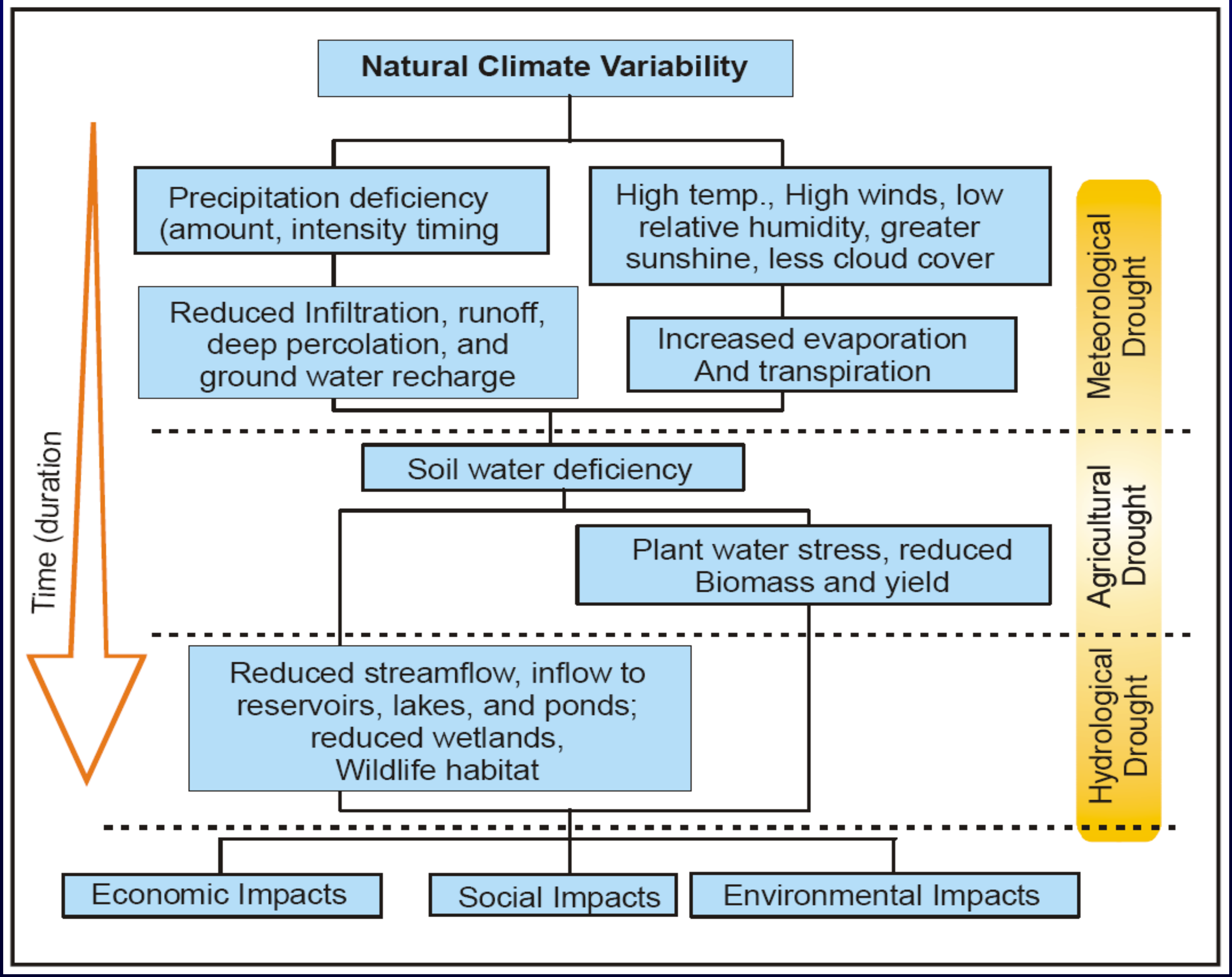
Meteorological drought: it simply implies rainfall deficiency where the precipitation is reduced by more than 25%from normal in any given area. These are region specific, since deficiency of precipitation is highly variable from region to region.

Hydrological drought: these are associated with the deficiency of water on surface or subsurface due to shortfall in precipitation. Although all droughts have their origination from deficiency in precipitation, hydrological drought is mainly concerned about how this deficiency affects components of the hydrological system such as soil moisture, stream flow, ground water and reservoir levels etc

Agricultural drought: this links various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual potential evapotranspiration, soil, soil water deficits, and reduced ground water or reservoir levels. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, and its stage of growth and the physical and biological properties of the soil.

Socio-economic drought: it is associated with the demand and supply aspect of economic goods together with elements of meteorological, hydrological and agricultural drought. This type of drought mainly occurs when there the demand for an economic good exceeds its supply due to weather related shortfall in water supply

A relationship between the meteorological, agricultural and hydrological droughts



Economic impacts

Many economic impacts occur in agriculture and related sectors, including forestry and fisheries, because of the dependence of these sectors on surface and subsurface water supplies.

In addition to obvious losses in yields in crop and livestock production, drought is associated with increases in insect infestations, plant disease, and wind erosion. Droughts also bring increased problems with insects and diseases to forests and reduce growth.

The incidence of forest fires increases substantially during extended droughts, which in turn places both human and wildlife populations at higher levels of risk.

Environmental Impacts

Environmental losses are the result of

- ❖ Damages to plant and animal species, wildlife habitat, and air and water quality
- ❖ Forest and range fires
- ❖ Degradation of landscape quality;
- ❖ Loss of biodiversity and
- ❖ Soil erosion

Social Impacts

- Social impacts involve public safety, health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief.
- Population migration is a significant problem in many countries, often stimulated by a greater supply of food and water elsewhere.
- Migration is usually to urban areas within the stressed area, or to regions outside the drought area. Migration may even be to adjacent countries.
- The drought migrants place increasing pressure on the social infrastructure of the urban areas, leading to increased poverty and social unrest.

History of droughts in India and Gujarat

Agriculture in India is often seen as a gamble on summer monsoon rainfall. Summer monsoon rains constitute the greatest climatic resource of the Indian subcontinent as these rains support not only the country's agriculture and food production but substantially contribute to power generation (H.P.Das 2000).

Thus success or failure of the crops and economy are intimately linked with prospects of good or bad monsoon

The Indian subcontinent is predominantly characterized by a tropical monsoon climate, where climatic regimes are governed by the differences in rainfall, rather than temperatures.

There are two monsoon systems operating in the region- the southwest or summer monsoon and the northeast or the winter monsoon.

The summer monsoon accounts for 70 to 90 percent of the annual rainfall over major parts of South Asia (Krishnamurthy and Shukla, 2000).

There is a large variability in the monsoon rainfall on both space and time scales.

some part of the country or the other almost every year during the monsoon period (June-September).

The drought of 1987 was one of the worst in the century. The monsoon rainfall was normal only in 14 out of 35 meteorological sub-divisions in the country. The overall deficiency in rainfall was 19% as compared to 26% in 1918 and 25% in 1972 being worst years.

Agricultural operations were adversely affected in 43% (58.6 million ha) of cropped area in 263 districts in 15 States and 6 Union Territories.

In the two worst affected states of Rajasthan and Gujarat, the rainfall was less than 50% from normal.

In these states, the drought of 1987 was the third or fourth in succession resulting in distress to an unprecedented level. Gujarat is one such state where drought occurs with unfailing regularity

1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000
Gujarat state									
1901	1911	1923	1931	1942	1951	1962	1972	1982	1991
1904	1915	1924	1936	1948	1952	1963	1973	1985	1993
1905	1918	1925	1938		1955	1965	1974	1986	1995
	1920	1927	1939		1957	1966		1987	1998
		1929	1940		1960	1968		1990	1999
									2000
All India									
1901	1911			1941	1951	1965	1972	1982	
1904	1918					1966	1974	1987	
1905	1920					1968	1979		

Table 1-1 All India and Gujarat state Drought Years

(Source: Gore and Ponkshe, 2004)

The monsoon of 2000 was the 13th consecutive normal monsoon considering country as a whole, but on a regional basis, this was the third consecutive drought year in areas covered by the states of Rajasthan, Gujarat and Andhra Pradesh

In 1999, as many as 98 out of a total of 225 blocks in the state received less than 50% of the season's expected rainfall. In 1999, Gujarat faced the worst drought of the past 100 years. Some 7,500 villages spread over 145 blocks in 15 districts were severely affected. The state has been hit by the worst drought in 100 years. More than 25 million people living in 9,000 villages of 17 of the 25 districts have been hit.

Almost all water sources have dried up; there is no food for the people and no fodder for over 7 million cattle. The water table in drought affected Saurashtra, Kutch and northern Gujarat is said to be falling by 10-15 feet each year (Bavadam 2001).

Drought risk evaluation

Risk assessment involves evaluation of the significance of a risk, either quantitatively or qualitatively.

Risk assessment/evaluation according to Kates and Kasperson (1983) comprises of three steps:

- Identification of hazards, which may cause disasters.
- Estimation of risks arising out of such events and
- Estimation of losses

Meteorological drought indices and drought detection

Drought indices have been developed as a means to measure drought. A drought index assimilates thousands of data on rainfall, snow pack, stream flow and other water-supply indicators into a comprehensible picture.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms.

Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), and Surface Water Supply Index (SWSI).

Palmer Drought Severity Index (PDSI)

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply (Palmer,1965).

The Palmer Drought Severity Index (PDSI) is to provide standardized measurements of moisture conditions so that comparison could be made between locations and between months.

The PDSI is a meteorological drought index that is responsive to abnormal weather conditions either on dry or abnormally wet side.

The index was specifically designed to treat the drought problem in semiarid and sub humid climates; with palmer himself cautioning that extrapolation beyond these conditions may lead to unrealistic results.

Crop Moisture Index (CMI).

Three years after the introduction of his drought index, Palmer (1968) introduced a new drought index based on weekly mean temperature and precipitation known as Crop Moisture Index (CMI). It was specifically designed as an agricultural drought index

It measures both evapotranspiration deficits (drought) and excessive wetness (more than enough precipitation to meet evapotranspiration demand and recharge the soil).

CMI is designed to monitor short-term moisture conditions affecting a developing crop; therefore CMI is not a good long-term drought-monitoring tool.

Standardized Precipitation Index (SPI)

Tom Mckee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in

The purpose is to assign a single numeric value to the precipitation that can be compared across

SPI Values	
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

Table 2-1 Standardised Precipitation Index

Surface Water Supply Index (SWSI)

Shafer and Dezman (1982) to complement the Palmer Index for moisture conditions developed the Surface Water Supply Index (SWSI).

This index compliments the Palmer index for moisture condition.

It is dependent on the season; SWSI is computed with only snowpack, precipitation, and reservoir storage in the winter. During the summer months, stream flow replaces snowpack as a component within the SWSI equation.

Satellite based drought indices for drought characterization

Drought indicators assimilate information on rainfall, stored soil moisture or water supply but do not express much local spatial detail. Also, drought indices calculated at one location is only valid for single location. Thus, a major drawback of climate based drought indicators is their lack of spatial detail as well as they are dependent on data collected at weather stations which sometimes are sparsely

distributed affecting the reliability of the drought indices (Brown and Reed et al. 2002)

Satellite derived drought indicators calculated from satellite-derived surface parameters have been widely used to study droughts. Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation indices.

Normalized Difference Vegetation Index (NDVI)

Tucker first suggested NDVI in 1979 as an index of vegetation health and density

NDVI is defined as: **NDVI= (NIR-RED)/ (NIR+RED)**

Where, NIR and RED are the reflectance in the near infrared and red bands.

NDVI is a good indicator of green biomass, leaf area index, and patterns of production (Thenkabail and Gamage et al. 2004, Wang and Wang et al. 2004).

NDVI is the most commonly used vegetation index. It varies from +1 to -1. Since climate is one of the most important factors affecting vegetation condition, AVHRR- NDVI data have been used to evaluate climatic and environmental changes at regional and global scales

It can be used not only for accurate description of continental land cover, vegetation classification and vegetation strength but is also effective for monitoring rainfall and drought, estimating net primary production of vegetation, crop growth conditions and crop yields, detecting weather impacts and other events important for agriculture, ecology and economics (Singh &Roy et al. 2003).

NDVI has been used successfully to identify stressed and damaged crops and pastures but only in homogenous terrain. In more heterogeneous terrain regions their interpretation becomes more difficult (Vogt et al. 1998; Singh et al.2003).

Many studies in the Sahel Zone (Tucker et al 2005), Argentina (Sullivan et al.1998), SouthAfrica (Unganani & Kogan, 2004) and Mediterranean (Vogt et al., 1998), and Senegal (Li. et al.,2004) indicate meaningful direct relationships between NDVI derived from NOAA AVHRR satellites, rainfall and vegetation cover and biomass.

Vegetation Condition Index (VCI)

It was first suggested by Kogan (1997) (Thenkabail et al.2004; Vogt et al. 1998).

VCI is an indicator of the status of the vegetation cover as a function of the NDVI minimum and maxima encountered for a given ecosystem over many years.

VCI is defined as:

$$VCI_j = (NDVI_j - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) * 100$$

Where, NDVImax NDVImin is calculated from long-term record for a particular month and j is the index of the current month. The condition of the ground vegetation presented by VCI is measured in percent.

The VCI values between 50% to 100% indicate optimal or above normal conditions whereas VCI values close to zero percent reflects an extreme dry month.

VCI has been used by (Kogan and Unganani) for estimation of corn yield in South Africa; drought detection in Argentina (Sullivan et al 1998); drought monitoring over India (Singh et al.2002); monitoring droughts in the southern Great Plains, USA (Wan et al.2004); drought detection and monitoring in the Mediterranean region (Vogt et al.2000) and drought assessment and monitoring in Southwest Asia (Thenkabail et al. 2004).

These studies suggest that VCI captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas. Also, VCI values indicate how much the vegetation has advanced or deteriorated in response to weather.

It was concluded from the above studies that VCI has provided an assessment of spatial characteristics of drought, as well as its duration and severity and were in good agreement with precipitation patterns.

Temperature Condition Index (TCI)

TCI was also suggested by Kogan (1997), (Thenkabail et al. 2004). It was developed to reflect vegetation response to temperature i.e. higher the temperature the more extreme the drought.

TCI is based on brightness temperature and represents the deviation of the current month's value from the recorded maximum. TCI is defined as:

$$TCIj= (BT\ max- BTj)/ (BTmax- Btmin) *100$$

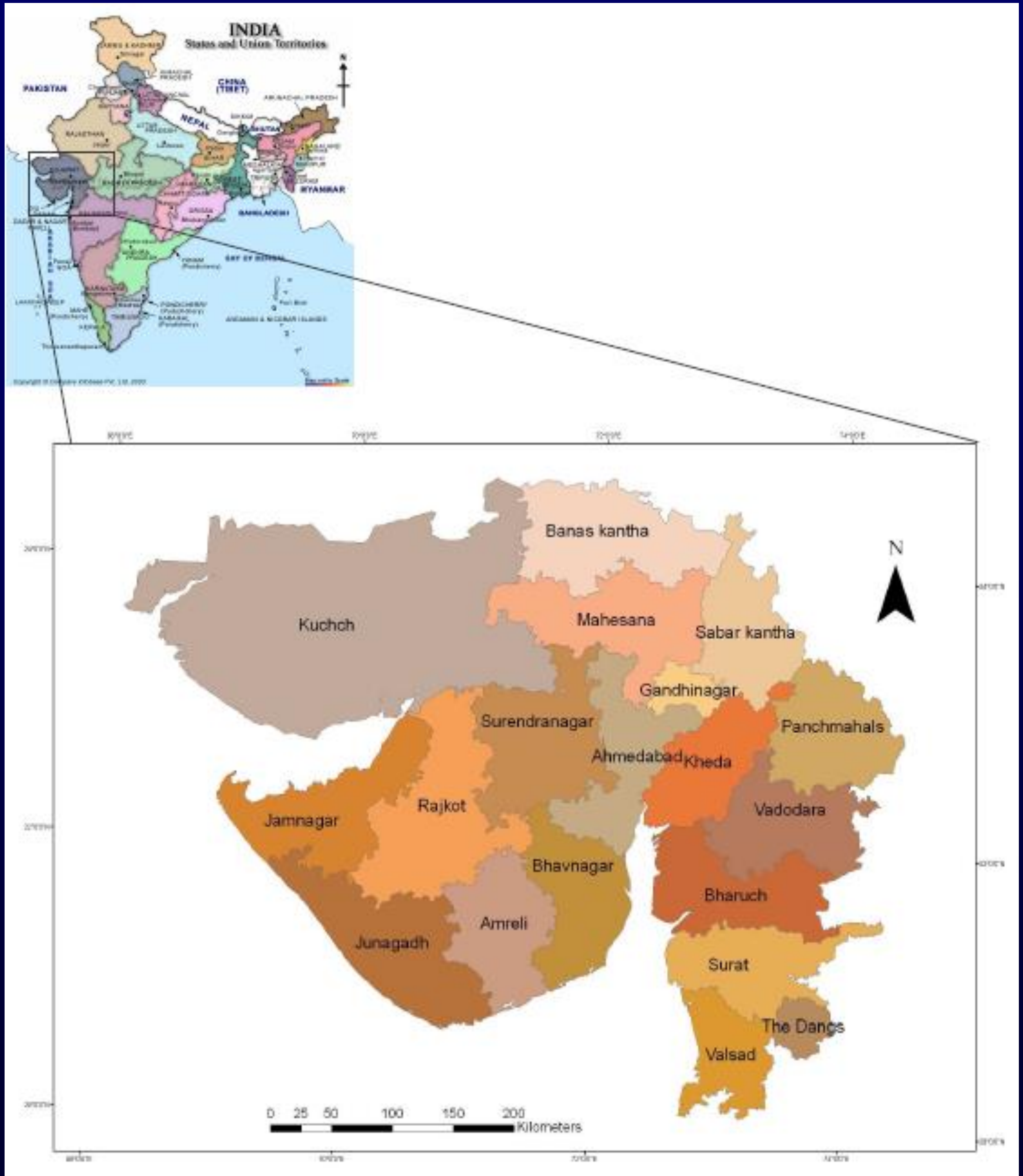
Where BT is brightness temperature. Maximum and minimum BT values are calculated from the long-term record of remote sensing images for a particular period j

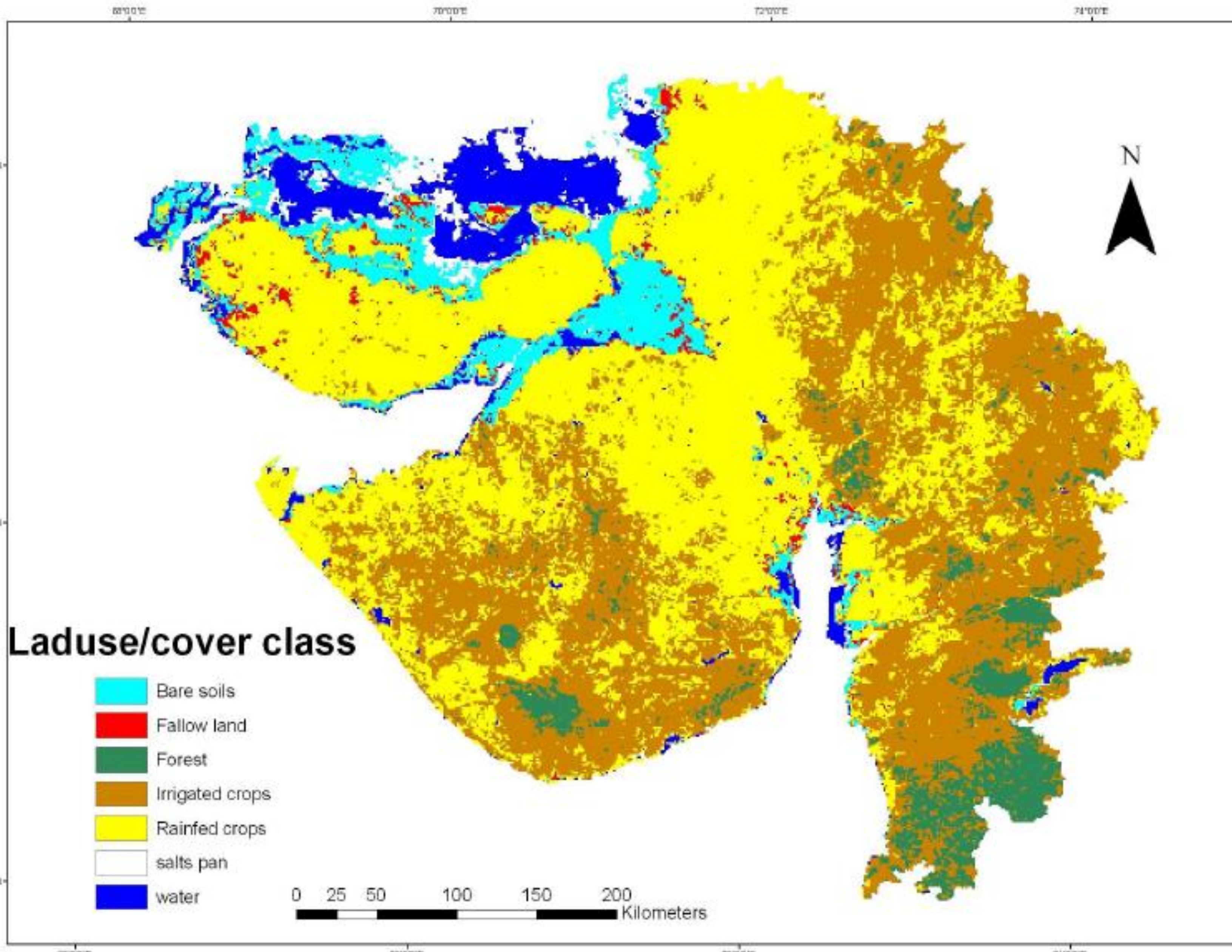
Low TCI values indicate very hot weather.

TCI has been used for drought monitoring in the USA, China, Zimbabwe and the Former Soviet Union.

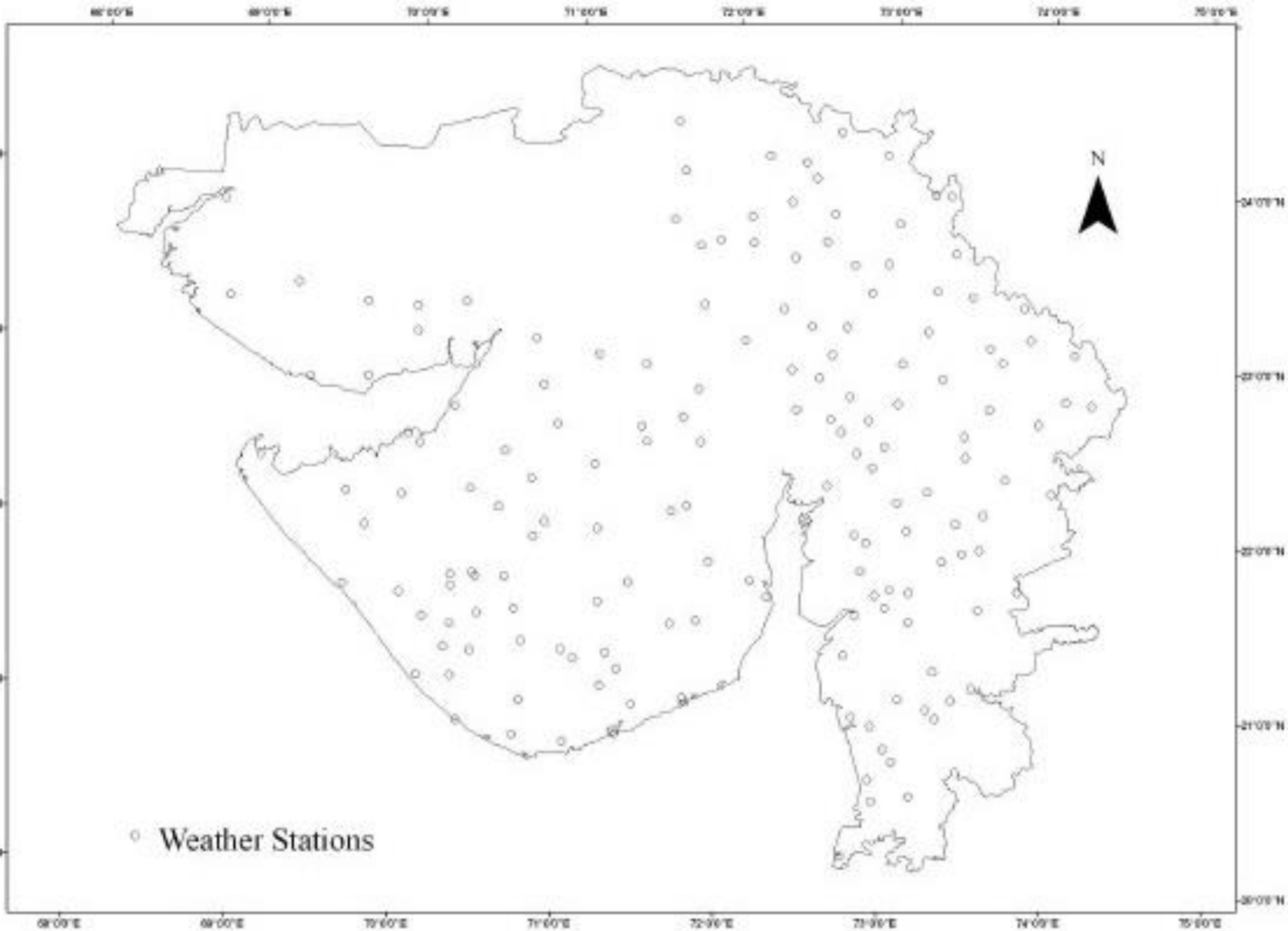
A study in Argentina for drought detection revealed that TCI was useful to assess the spatial characteristics, the duration and severity of droughts, and were in good agreement in precipitation patterns (Seiler et al.1998).

TCI has been related to recent regional scale drought patterns in South Africa (Kogan, 1998).


INDIA
States and Union Territories
PAKISTAN
CHINA (TIBET)
NEPAL
MYANMAR
BANGLADESH
N
Banas kantha
Kuchch
Mahesana
Sabar kantha
Gandhinagar
Surendranagar
Panchmahals
Ahmedabad
Kheda
Rajkot
Jamnagar
Vadodara
Bhavnagar
Bharuch
Amreli
Junagadh
Surat
The Dangs
Valsad
0 25 50 100 150 200
Kilometers

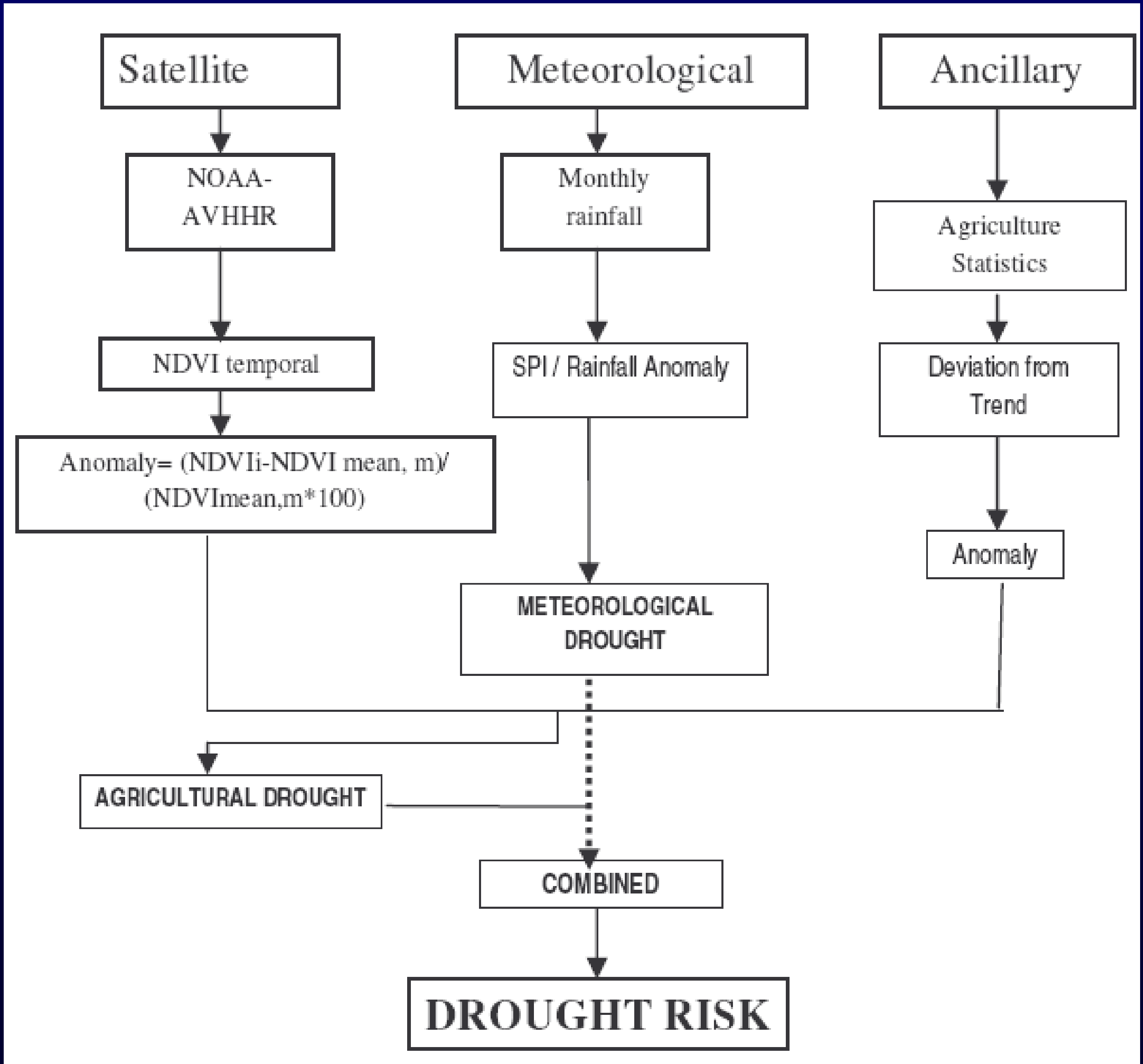


Generalised Landuse/cover map of Gujarat



Location of 164 weather stations in Gujarat

METHODOLOGY



RAINFALL vs NDVI (1981-2000)

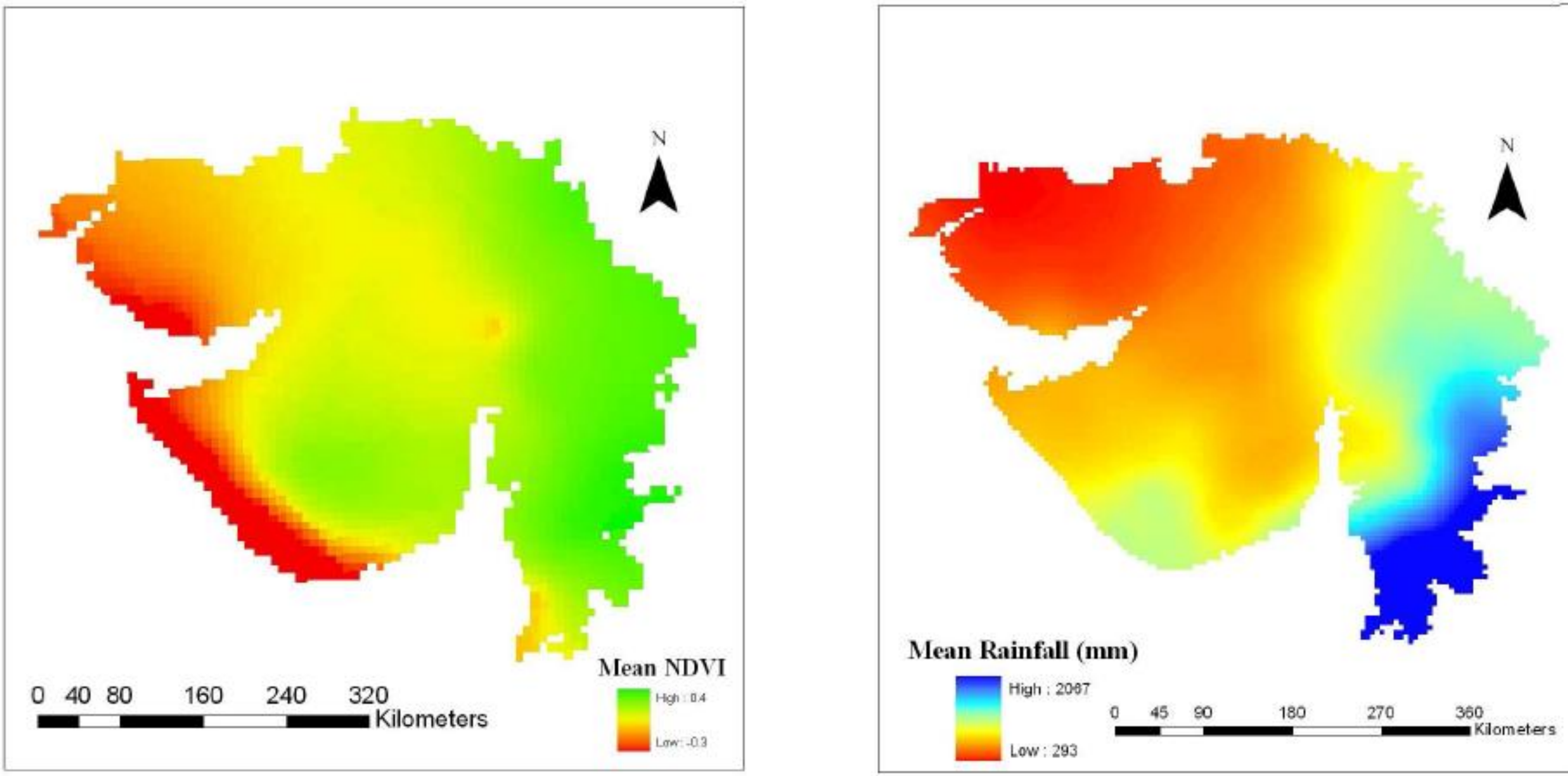


Figure 5-2 Average rainfall and Average NDVI (1981-2000)

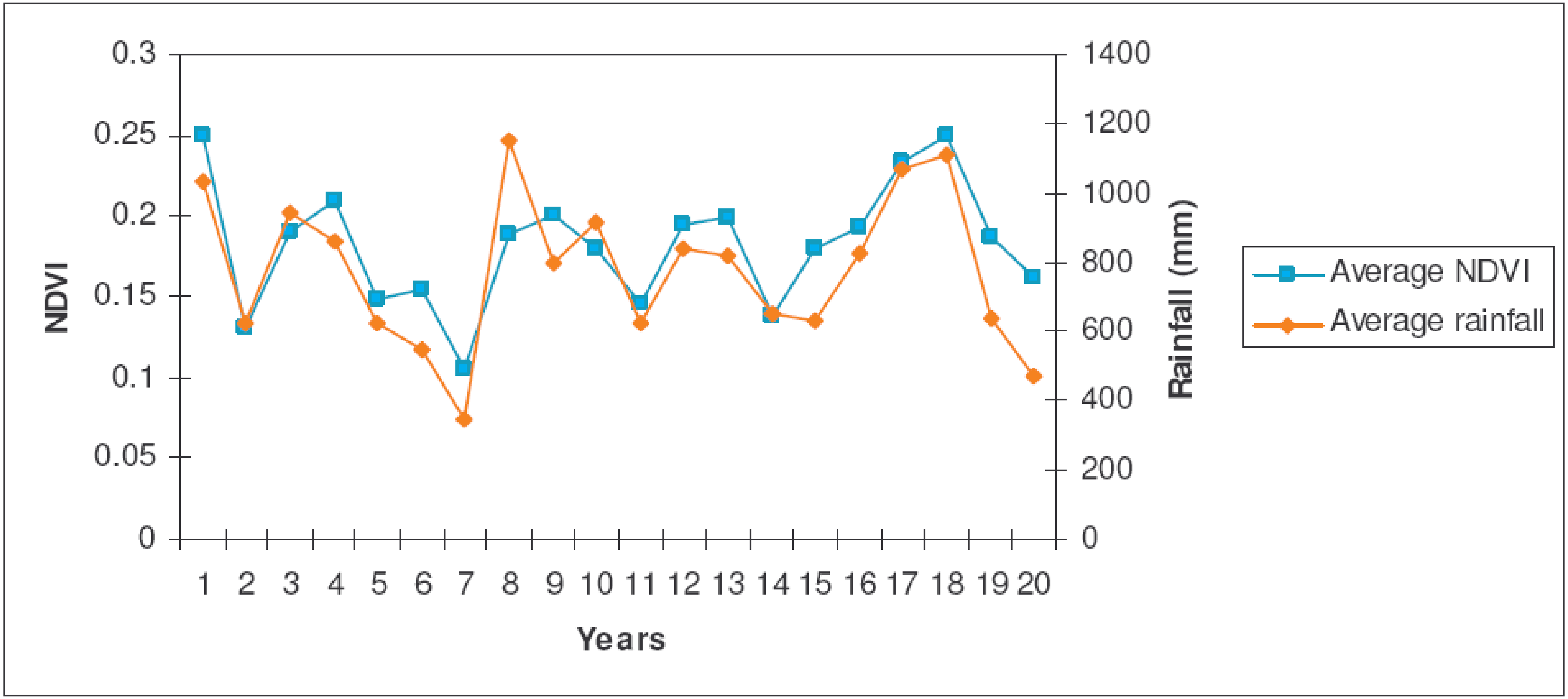
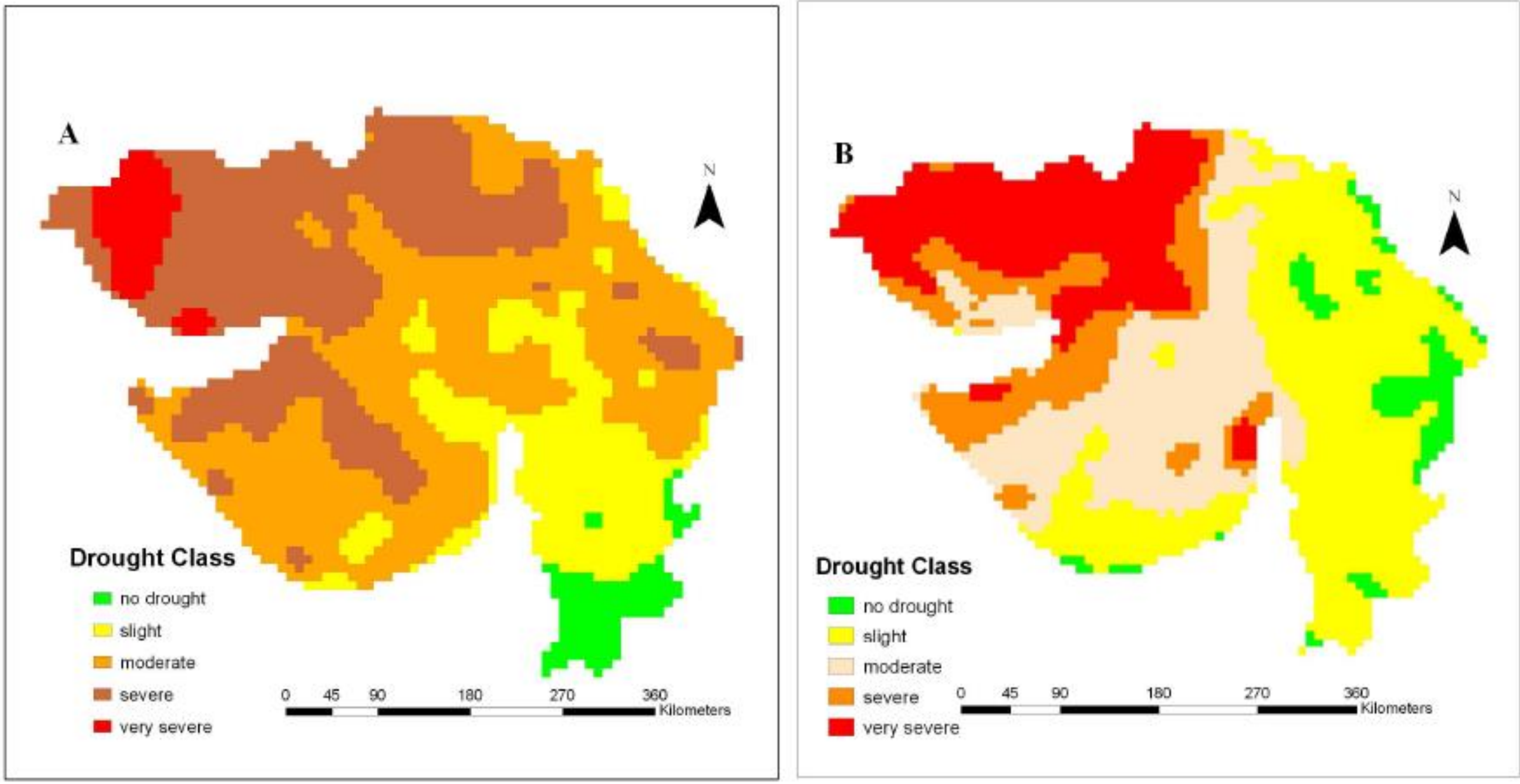


Figure 5-3 Temporal trends of NDVI and Rainfall (1981-2000)



(A) Meteorological Drought Risk and (B) Agriculture Drought Risk

Figure 5-18 Meteorological & Agriculture drought risk

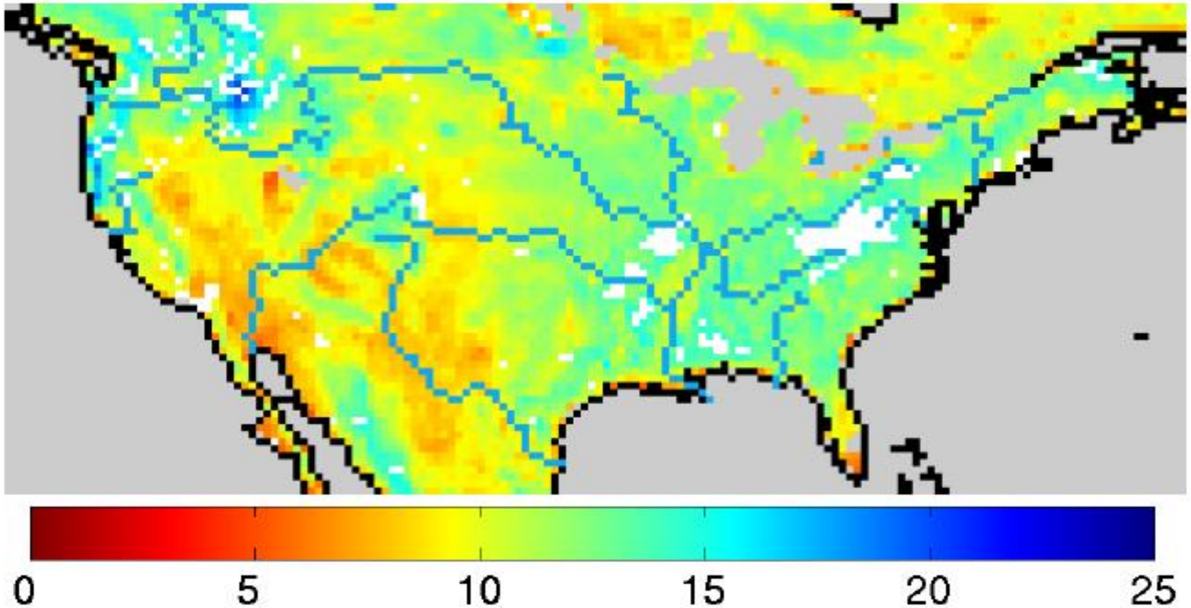


Figure 1. *AMSR-E monthly averaged soil moisture (volumetric %) for August 2002 showing dry conditions over the western U.S.*

Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)

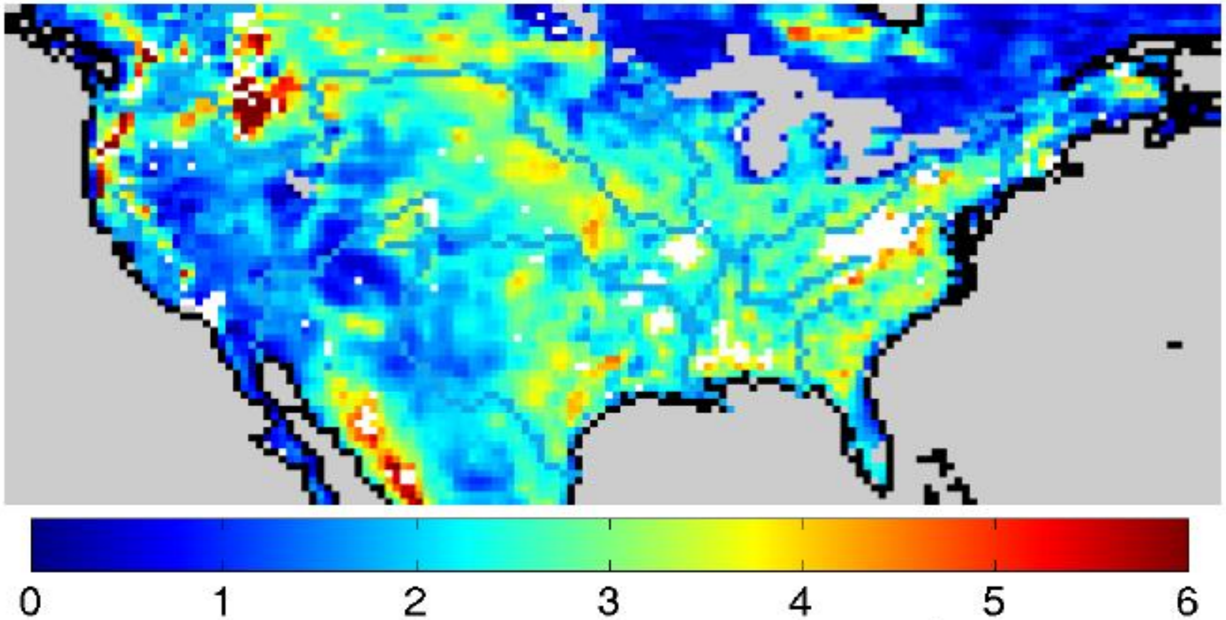
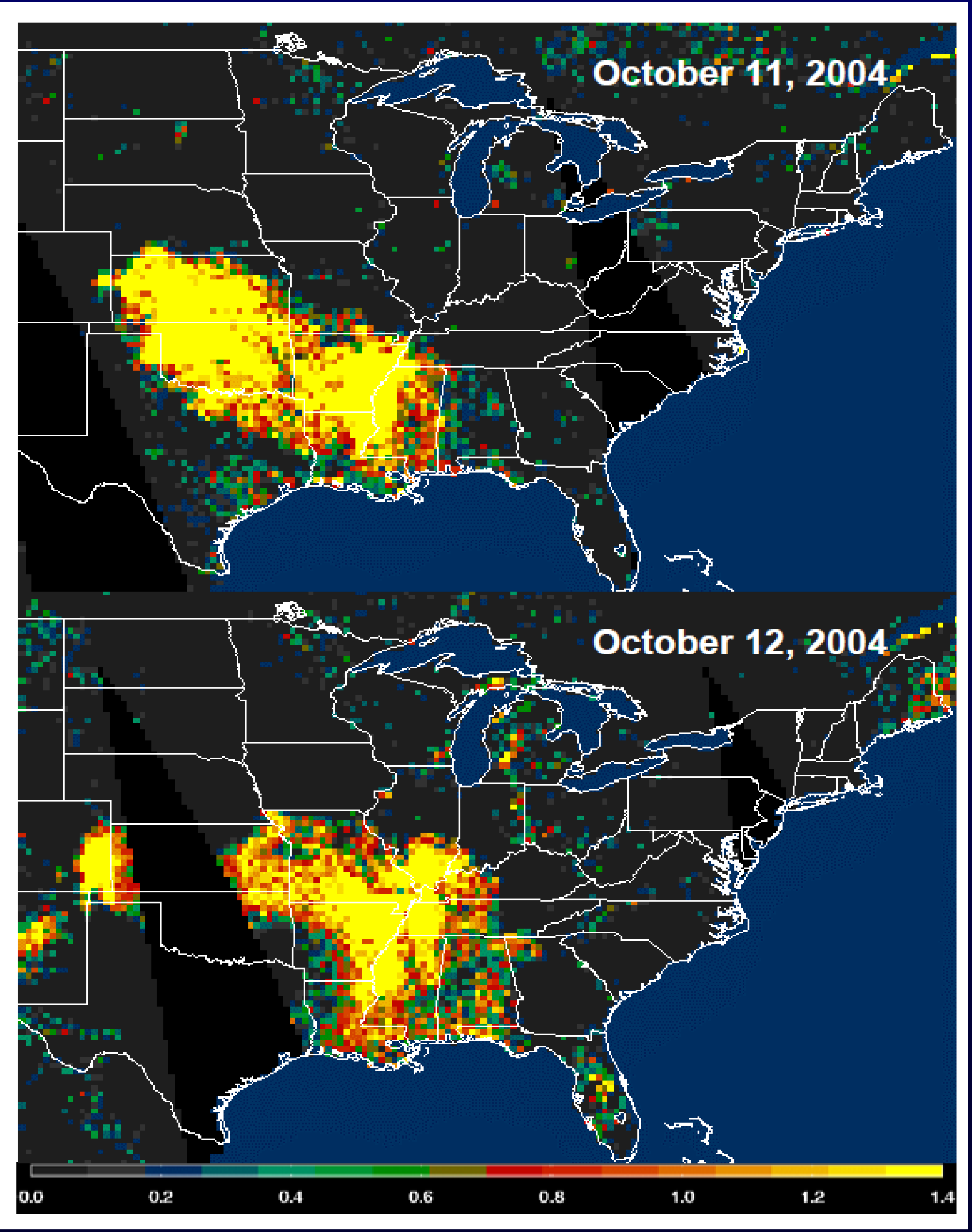


Figure 2. *AMSR-E monthly averaged vegetation water content (kg·m^{-2}) for August 2002 showing moist vegetation over the eastern U.S.*



QSCAT daily maps of surface water increase due to precipitation

the SeaWinds scatterometer aboard the QuikSCAT satellite (QSCAT).

Global scenario on Remote Sensing use for Drought

The normalised difference vegetation index (NDVI) and temperature condition index (TCI) derived from the satellite data are accepted world-wide for regional monitoring.

The ongoing program on Africa Real-Time Environmental Monitoring using Imaging Satellites (ARTEMIS) is operational at FAO and uses METEOSAT rainfall estimates and AVHRR NDVI values for Africa.

The USDA/NOAA Joint Agricultural Weather Facility (JAWF) uses Global OLR anomaly maps, rainfall map, vegetation and temperature condition maps from GOES, METEOSAT, GMS and NOAA satellites.

Canada issues weekly crop condition reports based on NOAA AVHRR based NDVI along with agro meteorological statistics

National Remote Sensing Agency, Department of Space issues biweekly drought bulletin and monthly reports at smaller administrative units for India under National Agricultural Drought Assessment and Monitoring System (NADAMS) which uses NOAA AVHRR and IRS WiFS based NDVI with ground based weather reports.