Satellite Remote Sensing Applications In Water Resources

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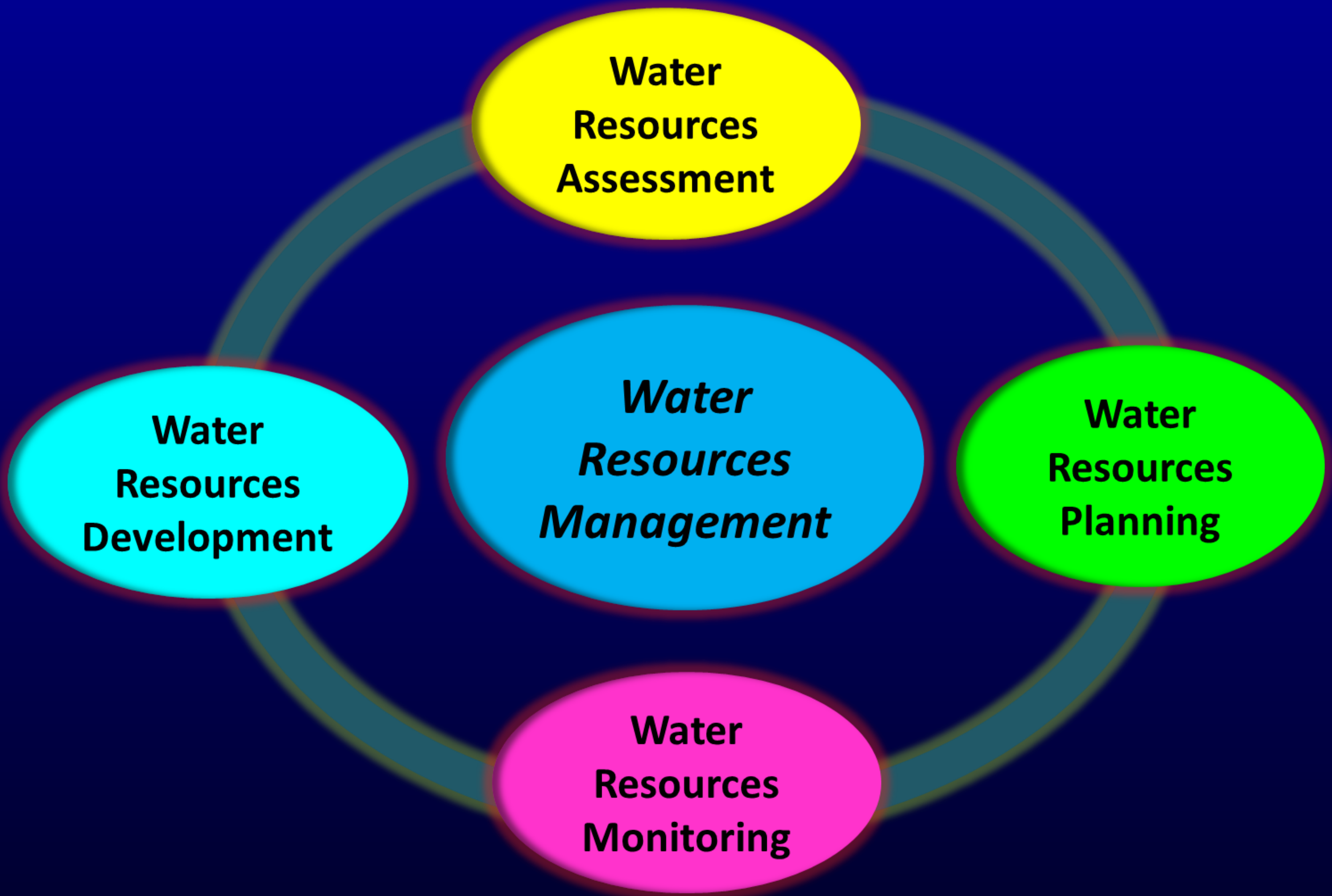
Satellite Remote Sensing Applications in Water Resources



Satellite Remote Sensing Applications in Water Resources

WR Assessment	WR Planning
Surface Runoff Estimation	Inputs for prefeasibility studies of new projects
Snowmelt Runoff Estimation	Identification of suitable sites for Hydropower Projects
Inventory of Glaciers	Reservoir Submergence Analysis
Inventory of Glacial Lakes	Rehabilitation & Relocation Studies
Surface Water Spread Estimation	Canal Alignment Studies
Flood Estimation	Inputs for Interlinking of Rivers
Soil Moisture Estimation	Reservoir Capacity Assessment
WR Assessment	Identification of suitable sites for Check Dams

Satellite Remote Sensing Applications in Water Resources

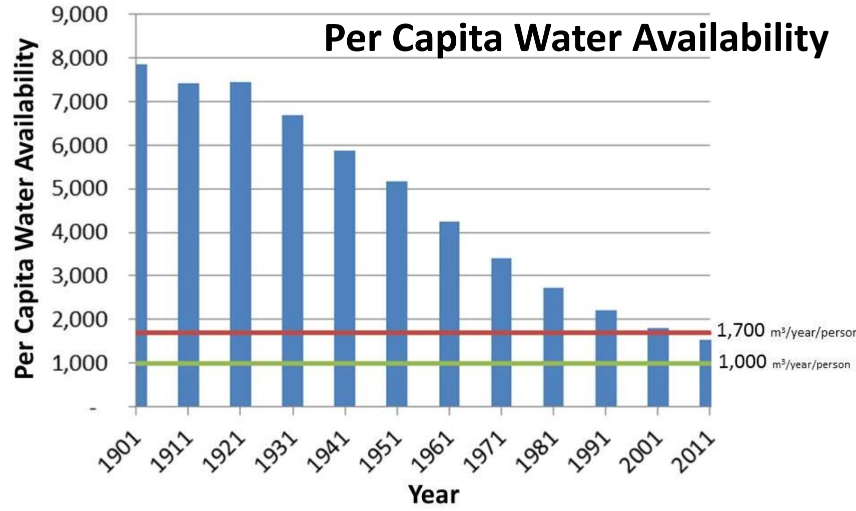
WR Monitoring	WR Development
Inventory of Irrigation Infrastructure	Evaluation of Irrigation System Performance
Irrigation Project Progress Monitoring	Impact Evaluation of Minor Irrigation Tanks
Glacial Lake Monitoring	Spatial Irrigation Utilisation
Glacier Monitoring	Irrigated crop area & productivity assessment
Water Quality Monitoring	Watershed Management
Command Area Monitoring	Inputs for In-season Irrigation Scheduling
Flood Monitoring	Salinity and Water Logging Mapping
Waterspread Monitoring	Irrigation Intervention Schemes

Satellite Remote Sensing Applications in Water Resources

Water Resources of India

Geographical Area = 329 Mha
Population (2018) = 1352.6 millions
Total Cultivable Land = 182.2 Mha
Irrigation Potential created (upto March 2012)=113.5 Mha

Resource	Quantity (BCM)	Precipitation (%)
Average Annual precipitation (1951-2000)(including snowfall)	4,000	100
Average Annual Natural Run-off (1993)	1,869	46.7
Total Utilizable Water Resources	1,122	28.1
Surface water	690	17.3
Replenishable GW	432	10.8
Storage Available (Due to Completed M& M Projects)	253	
Estimated Additional Likely Live Storage Available (Under Construction / Consideration)	155	
Per capita water availability (2001) in m^3	1,820	-



Revised Estimate (2017) by NRSC & CWC:
Mean Annual Rainfall: 3,880 BCM
Avg. Annual Water Resource: 1,999.20 BCM

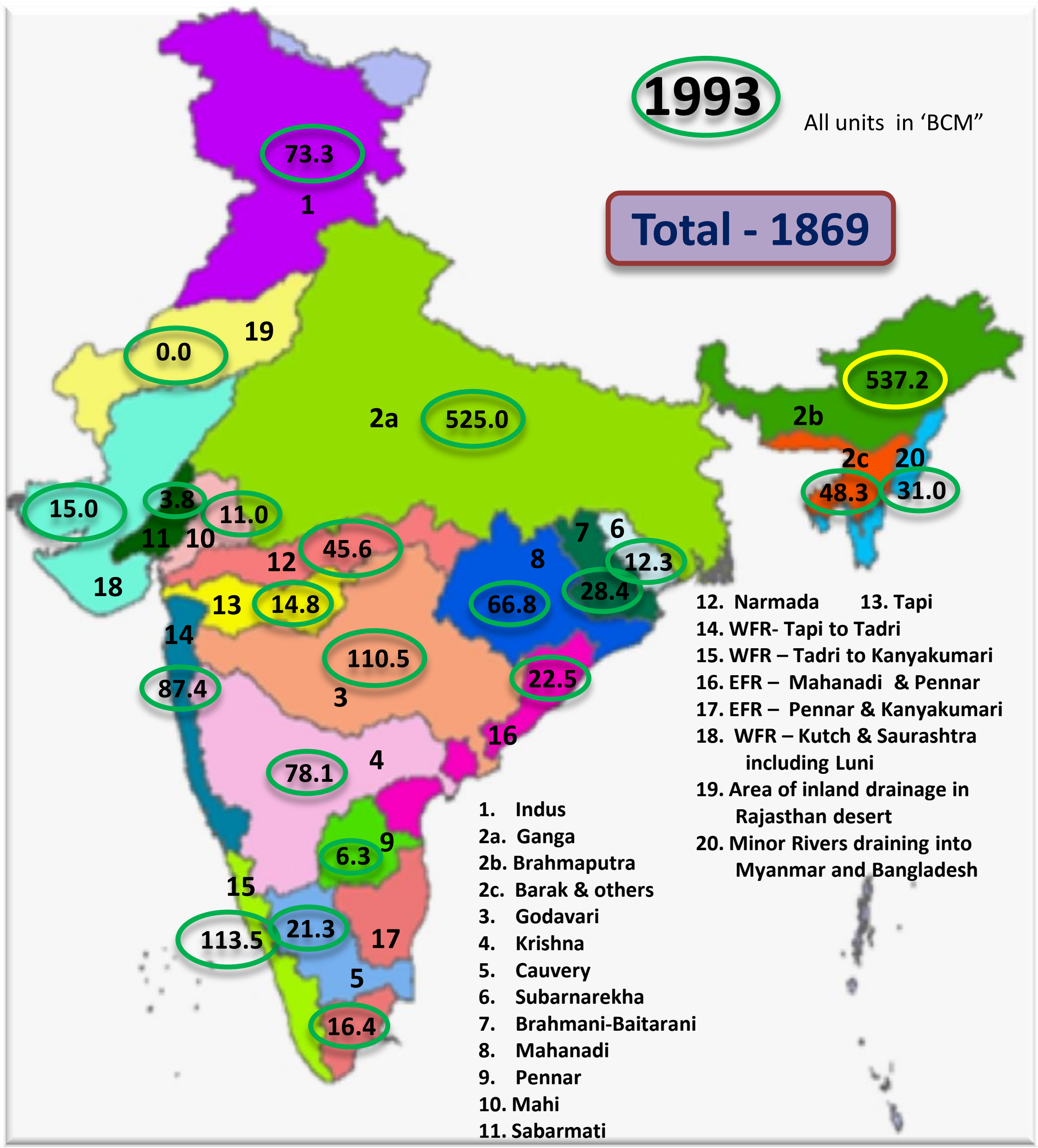
Reassessment of Water Availability in India using Space Inputs

Previous Studies

S. No	Year	Organisation	Methodology Adopted	WR Availability (BCM)
1	1901	Irrigation Commission	• Rainfall data • Estimation of river flows by adopting coefficients of runoff	1,443
2	1946	CW&PC (Dr.A.N.Khosla)	• Empirical relationship between T_{mean} and R_{mean}, based on his studies of the flows of Sutlej, Mahanadi and other river systems	1,673
3	1960	CW&PC	• Statistical analysis of the flow data wherever available • Rainfall runoff relationships wherever data were merge	1,881
4	1988	CWC	• Observed flows corrected for GW abstractions	1,880
5	1993	CWC	• Observed flows corrected for Upstream abstractions	1,869

Reassessment of Water Availability in India using Space Inputs

Central Water Commission (1993)



- The water resources potential was estimated by correcting for upstream abstractions to the observed flows
- Out of total area, assessment done for 35% of area (12 out of 20 basins)
- Average annual flow is computed on pro-rata basis from terminal site
- No uniform procedure for all the basins in computing the upstream abstractions
- Period of assessment varied for each basin based on data availability
- Ground water abstractions are considered for basins only where ground data was available
- Irrigation withdrawals was calculated based on year wise irrigation potential created assuming an average delta
- Irrigation withdrawals of Major and Medium projects were considered, those of minor schemes were not considered

Reassessment of Water Availability in India using Space Inputs

Pilot Study – Godavari & Brahmani-Baitarani River basins

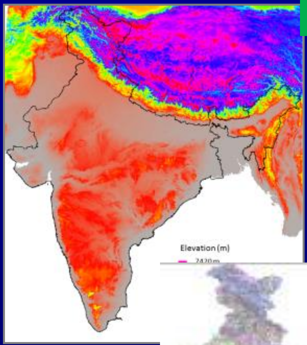
key aspects …

- Water balance approach
- Precipitation, the start point of water budgeting
- Integration of multi-variant terrain parameters in GIS
  (prevailing land use / land cover, elevation, soil, …)
- Spatial interpolation/extrapolation of meteorological data
  (rainfall, hydro-met data, groundwater data, …)
- Hydrological Response Unit (HRU) level water budgeting
- Monthly time-step, with carry over effect
- Calibration and validation with observed runoff
  (CWC recorded, …)
- Basin / sub-basin-wise water resources availability and sectoral utilization

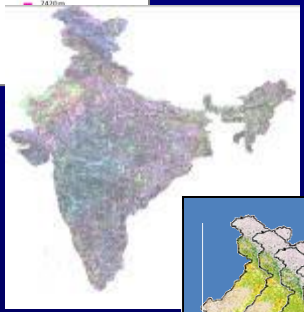
Reassessment of Water Availability in India using Space Inputs

Pilot Study – Godavari & Brahmani-Baitarani River basins

data used…



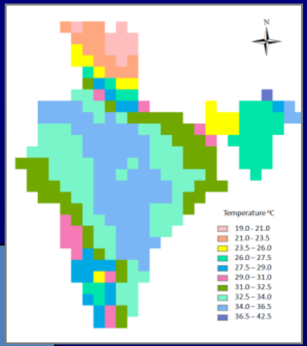
DEM

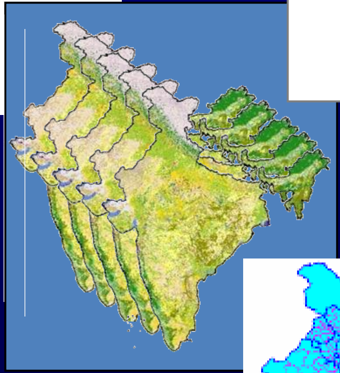


Soil

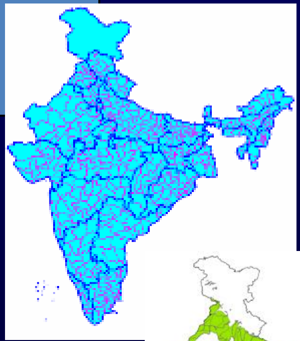
Geo-Spatial Data

Temperature



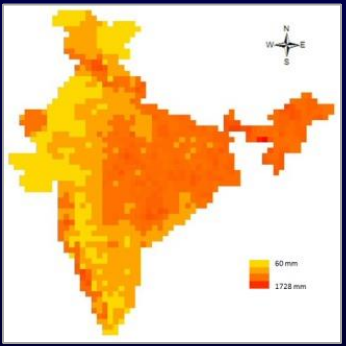


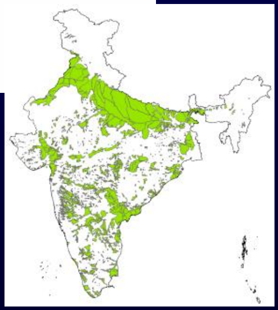
Land use / Land Cover



Administrative

Rainfall





Irrigation Command

Met Data

- 0.5 degree Rainfall Grids
- 1 degree Temperature Grids

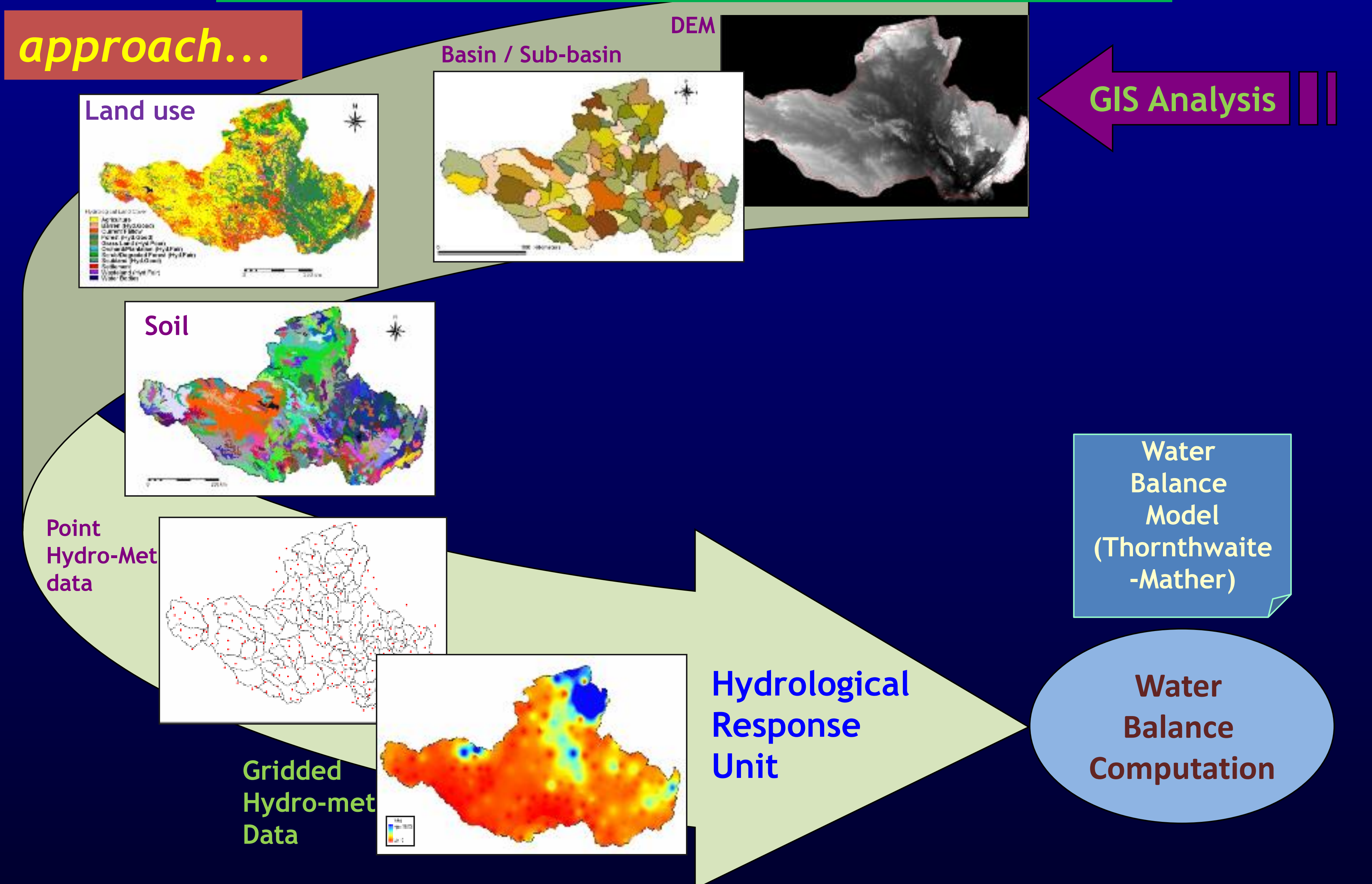
Field Data

- Reservoir data
- Groundwater data
- River Discharge Data
- Demographic data
- Livestock census data

The study period was
1988-89 to 2007-08 (20 years)

Reassessment of Water Availability in India using Space Inputs

Pilot Study – Godavari & Brahmani-Baitarani River basins

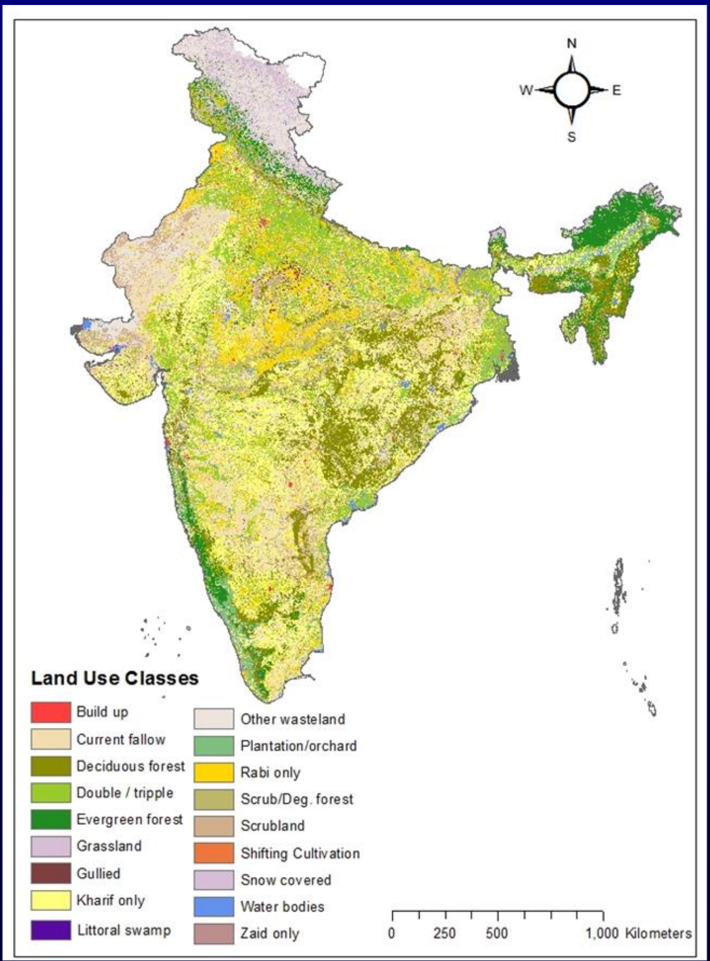


Reassessment of Water Availability in India using Space Inputs

Pilot Study – Godavari & Brahmani-Baitarani River basins

Role of LU/LC

Land Use/Land Cover 2004-05

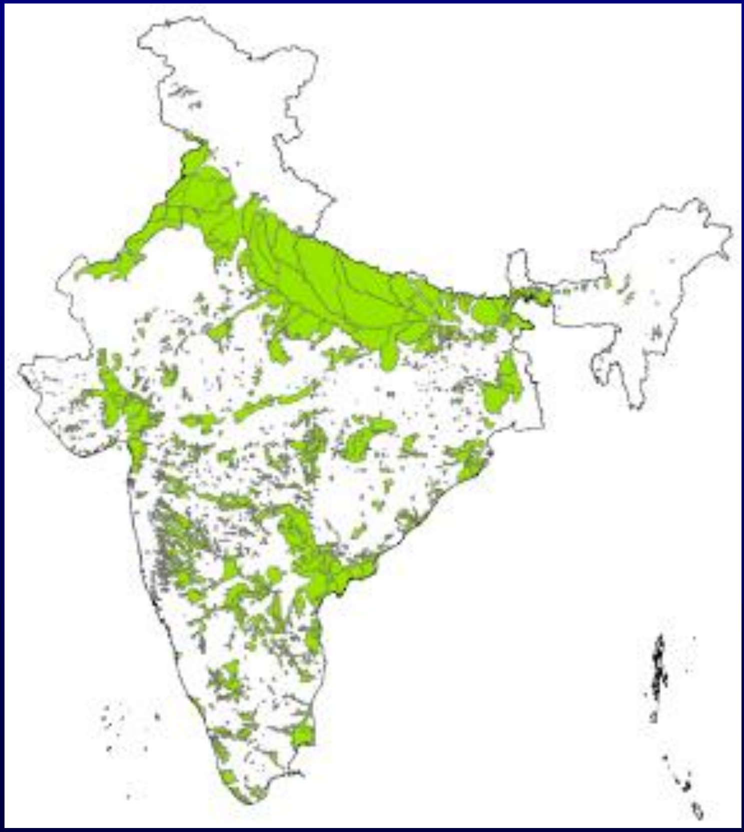


Agriculture

Kharif only
Double/Triple
Rabi only
Zaid only

- Region/District wise crop type variations
- Irrigation support

Irrigation Command Boundaries

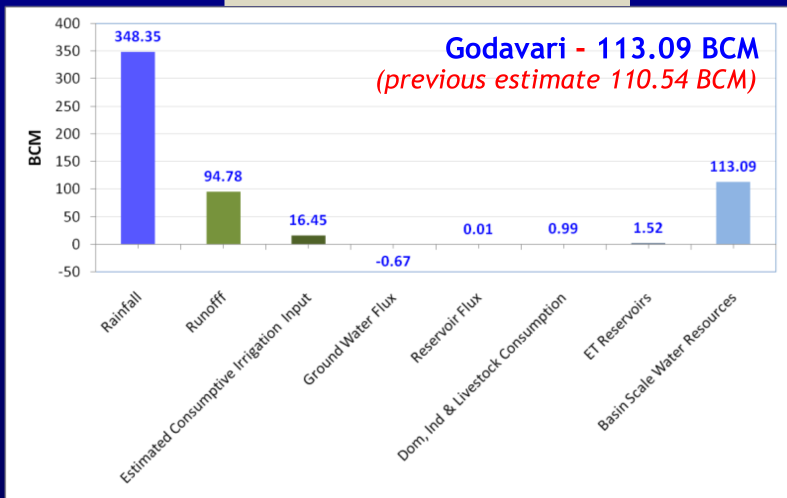


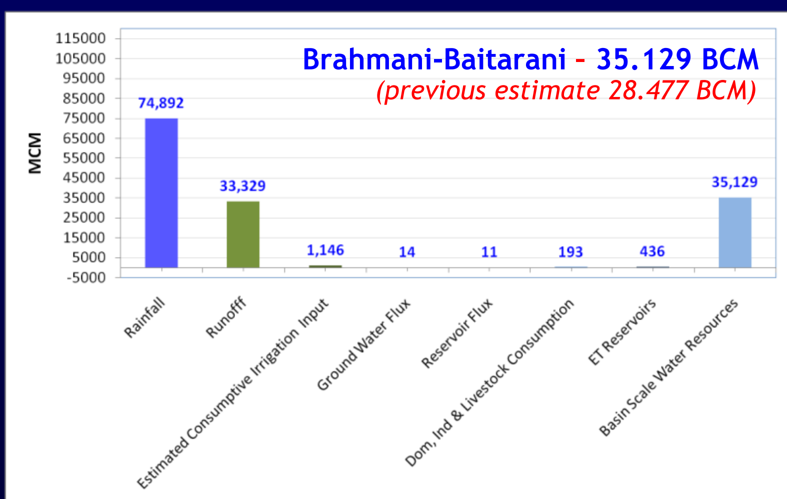
Command Area
Non-Command Area

Reassessment of Water Availability in India using Space Inputs

Pilot Study - Godavari & Brahmani-Baitarani River basins

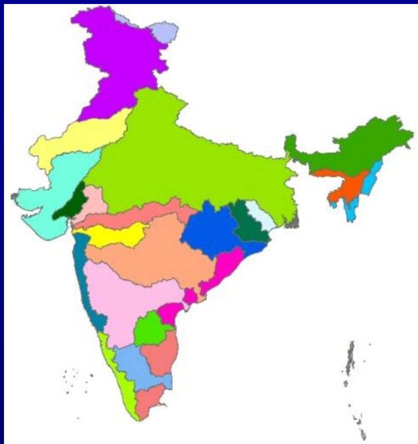
Pilot Study Results

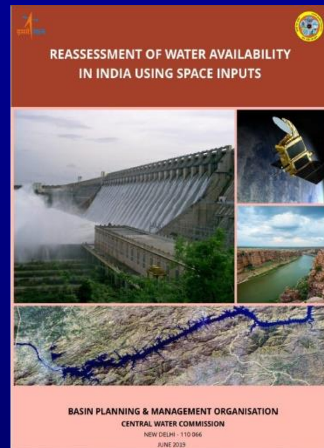




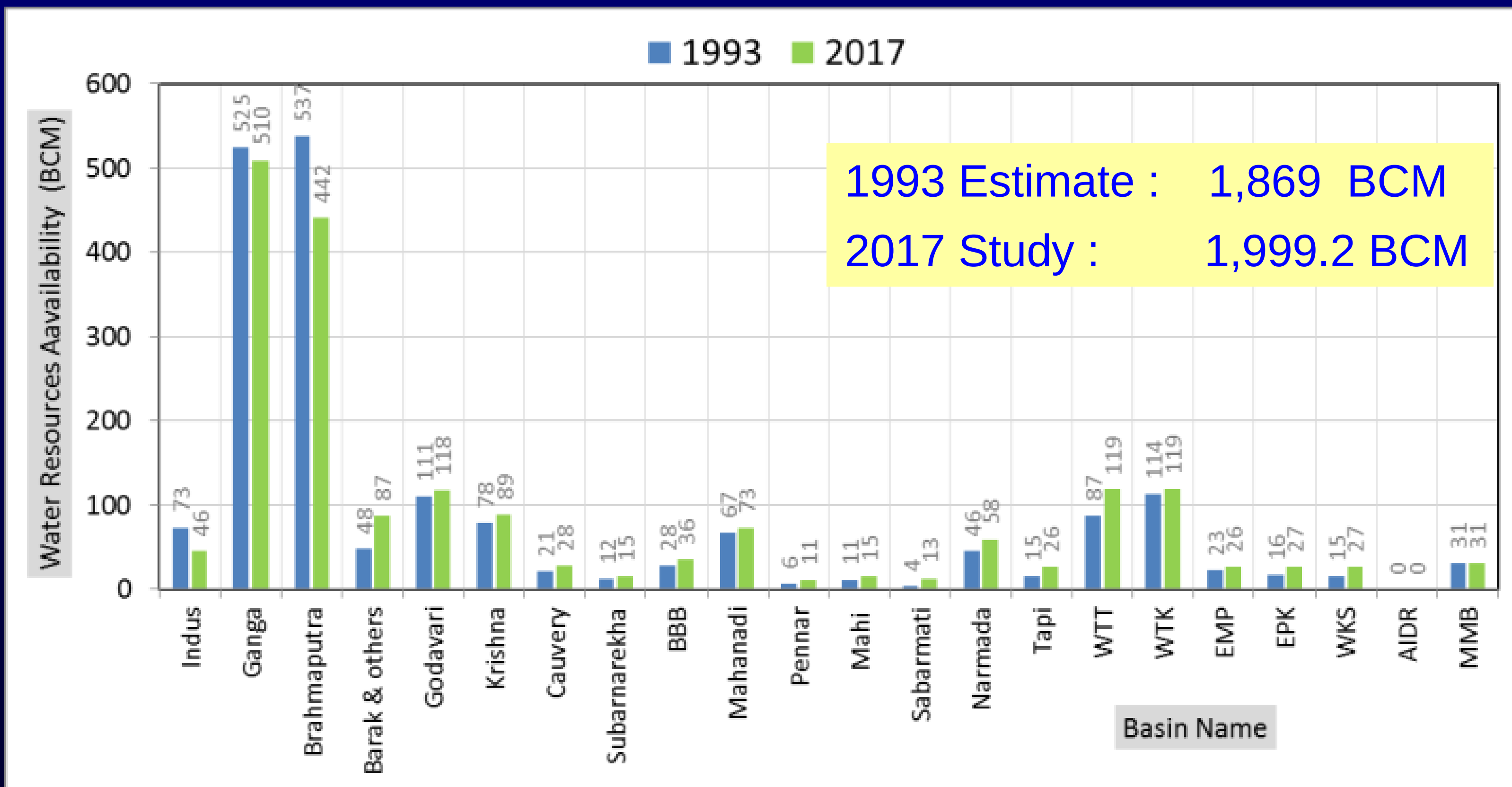
- **Pilot study demonstrated development of geo-spatial data based hydrological modeling approach (in Godavari and Brahmani & Baitarani river basins)**
- **Expert Committee constituted by MoWR reviewed Pilot Studies and Recommended for upscaling to entire Country to obtain latest update**
- **CWC through its 10 Regional Basin Organizations to carryout the study**
- **NRSC/ISRO to provide capacity building through Training and Hand holding**
- **The study to be carried out for a period of 30 years (1985-2015)**

Reassessment of Water Availability in India using Space Inputs





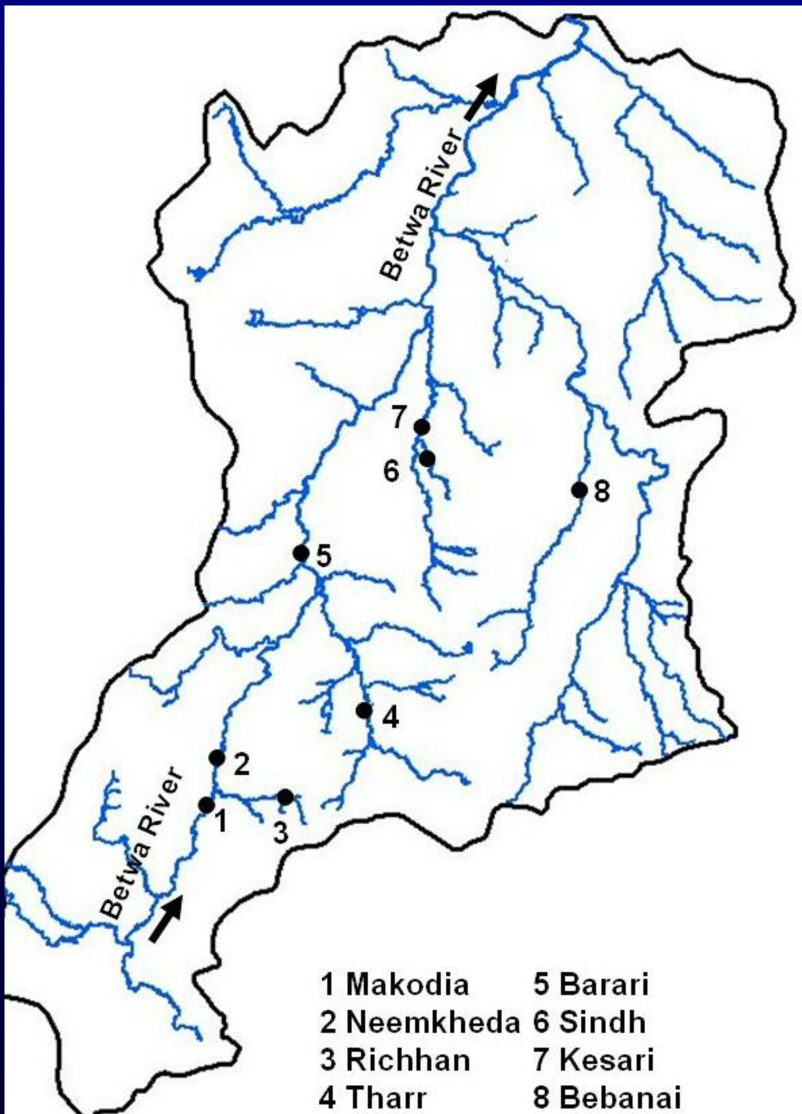
- **The assessment was completed for all 20 river basins for a period of 30 years**
- **The total mean WRA of the country was assessed as 1,999.2 BCM for mean annual rainfall of 3,880 BCM**

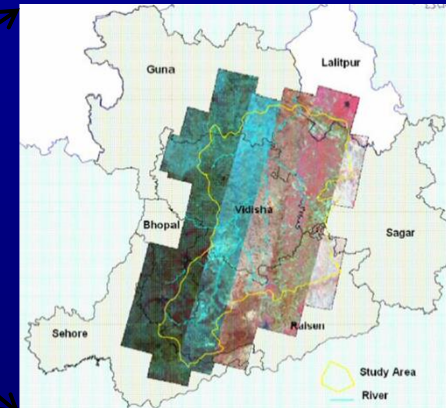


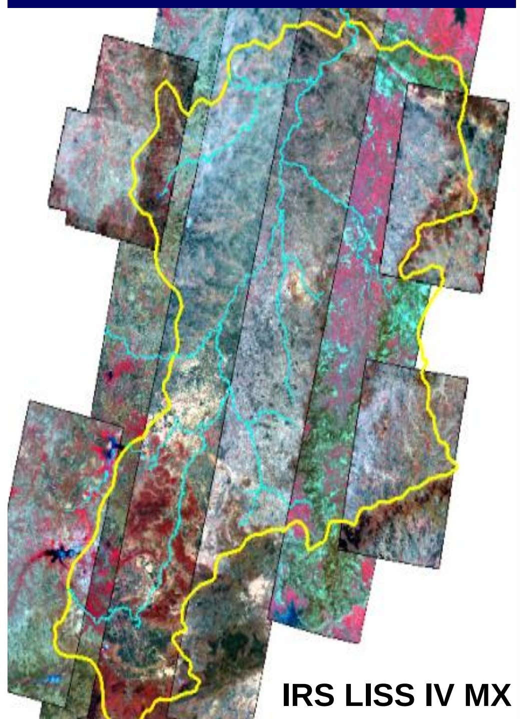
Selection of Suitable Sites for Dams

Feasibility assessment of Proposed Irrigation Projects in upper Betwa basin as a part of Ken-Betwa River Link Project

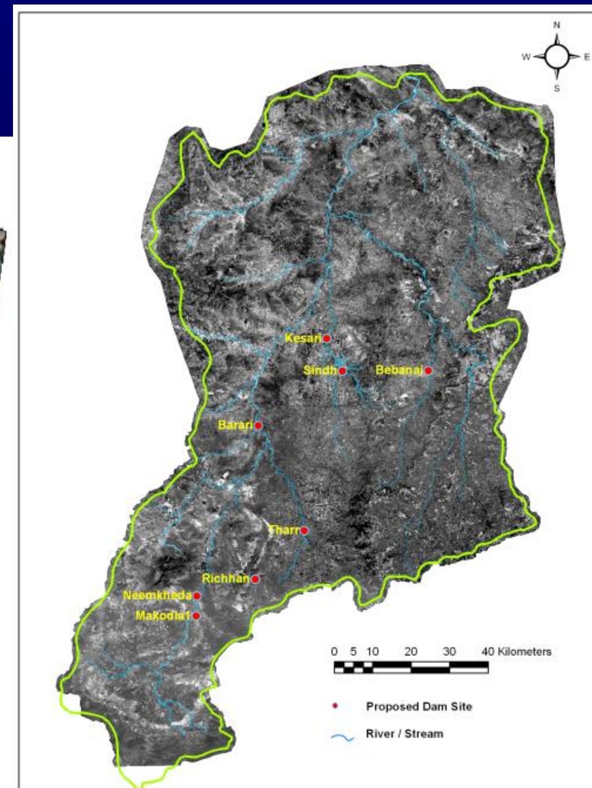
- ❖ 659 MCM of excess water from Ken basin to Betwa basin
- ❖ NWDA proposed eight dam sites







IRS LISS IV MX

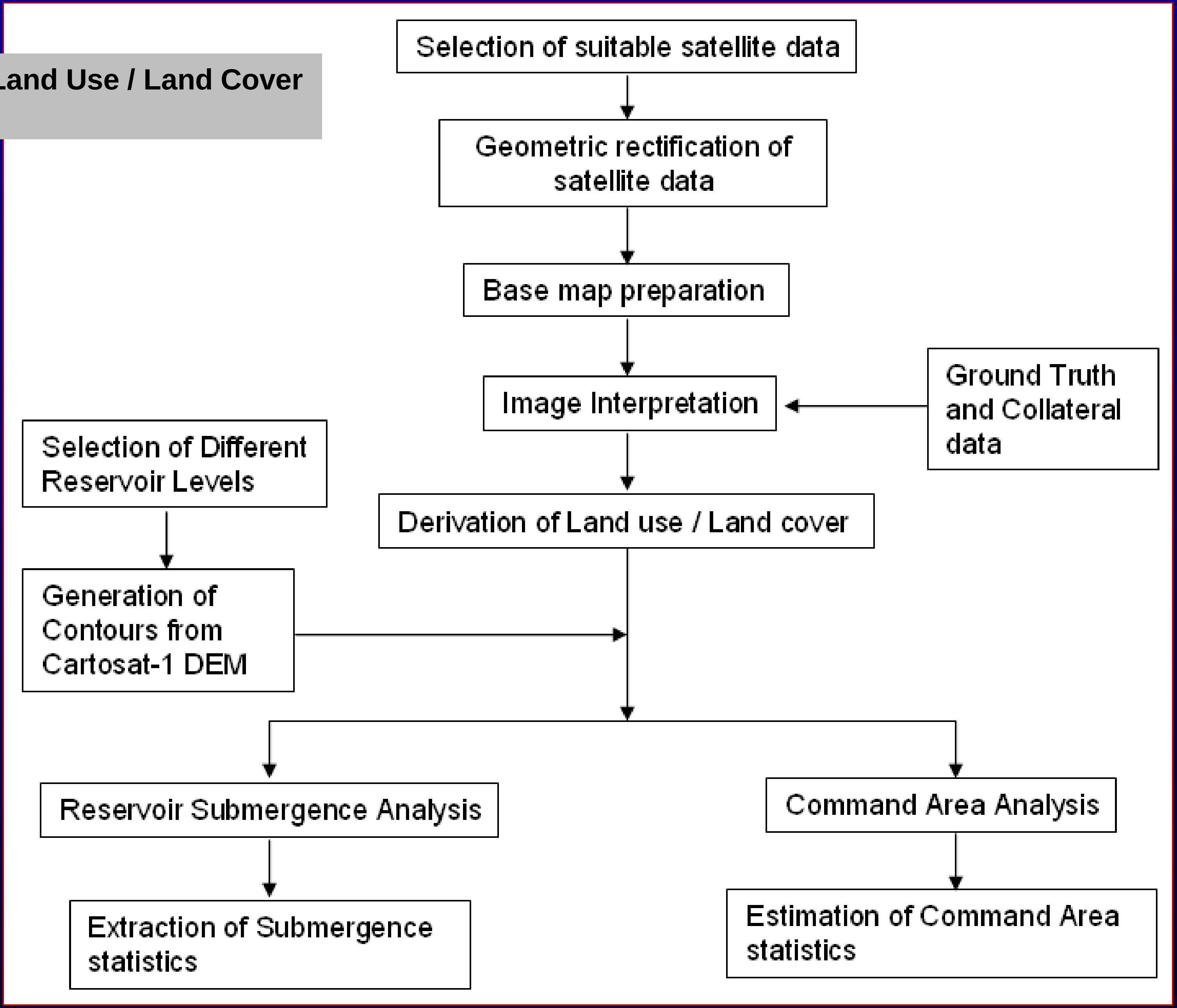


Casrtosat Image

Feasibility assessment of Proposed Irrigation Projects in upper Betwa basin as a part of Ken-Betwa River Link Project

Data Used:

- **IRS LISS-IV MX - Land Use / Land Cover**
- **Cartosat-1 - DEM**



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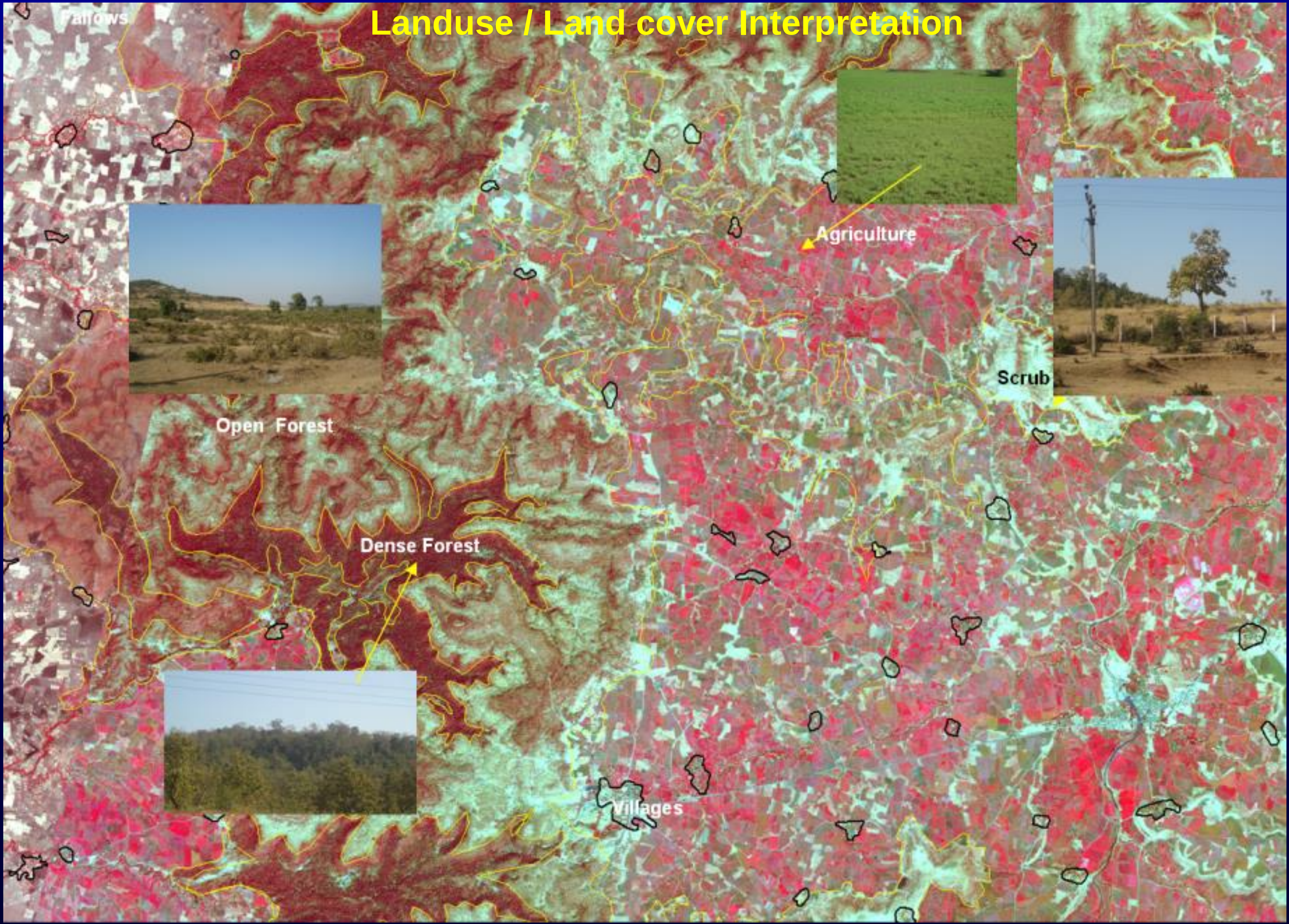

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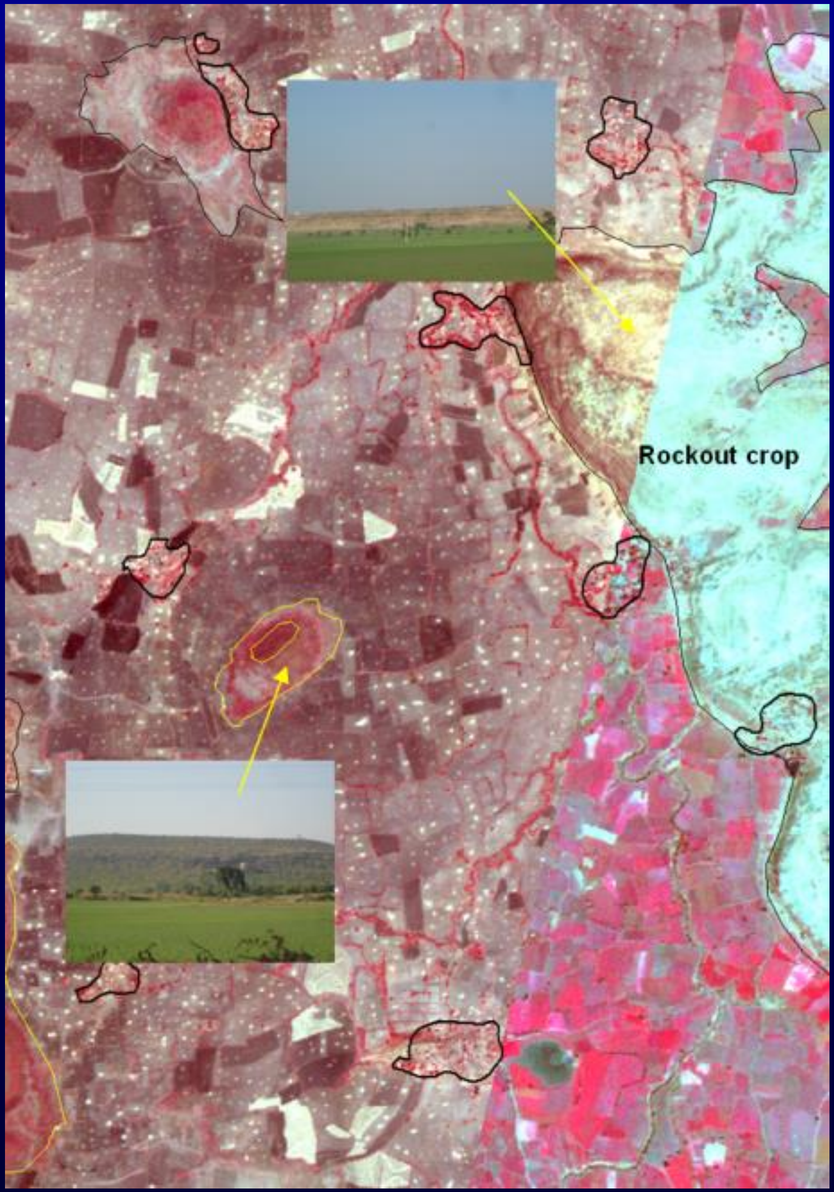
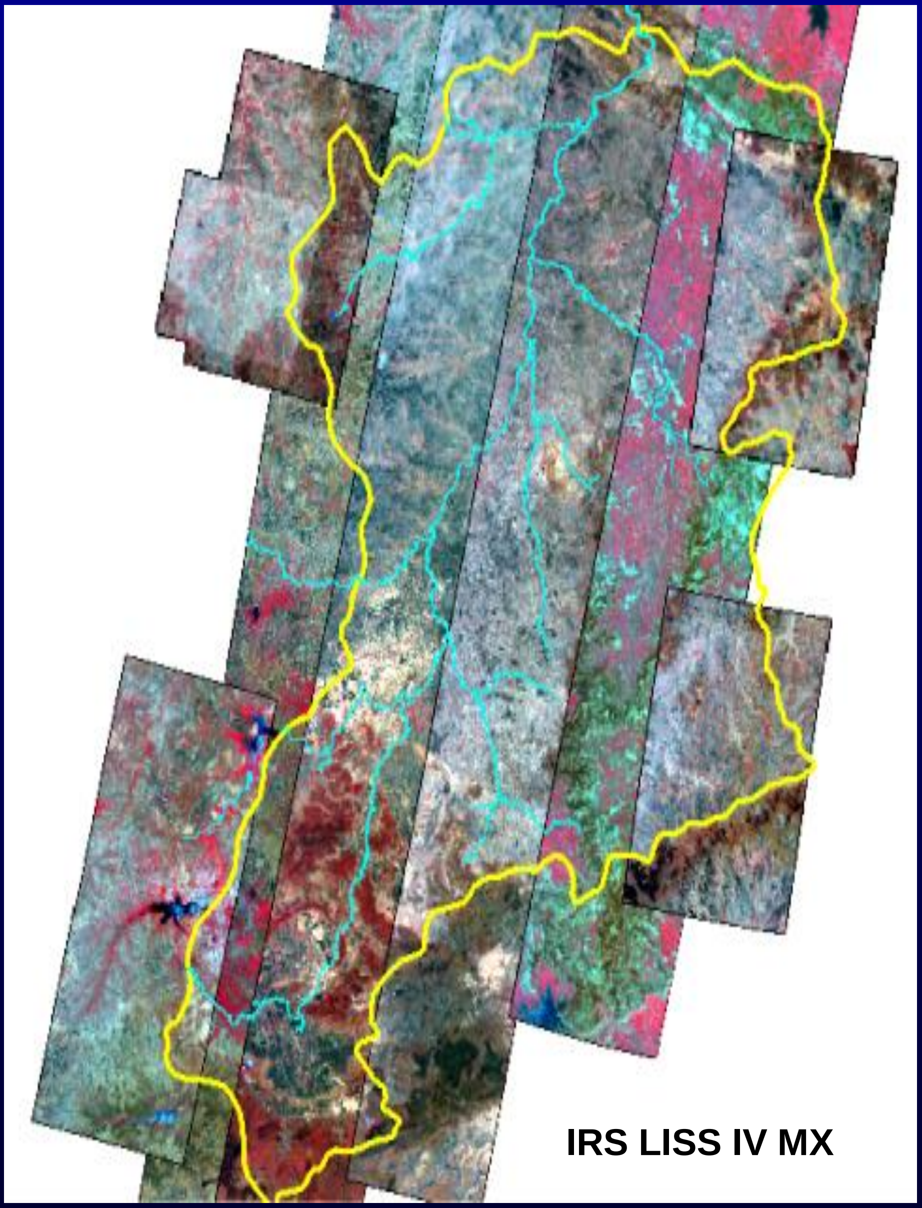
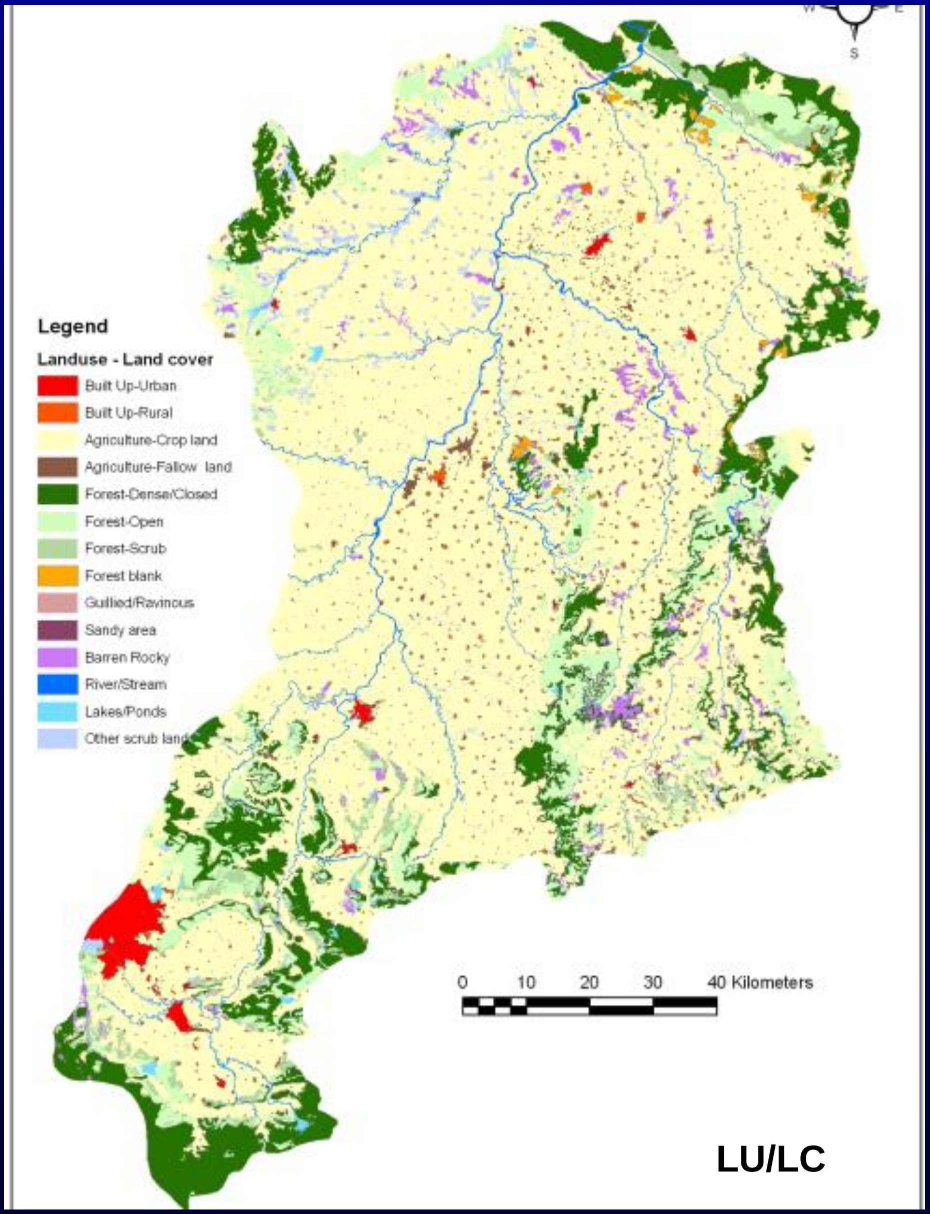


Landuse / Land cover Interpretation

Feasibility assessment of Proposed Irrigation Projects in upper Betwa basin as a part of Ken-Betwa River Link Project





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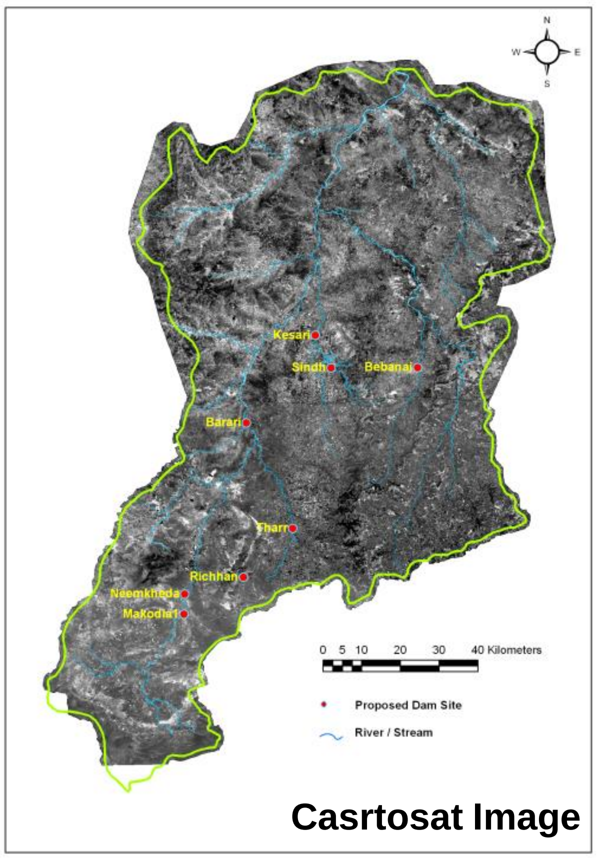
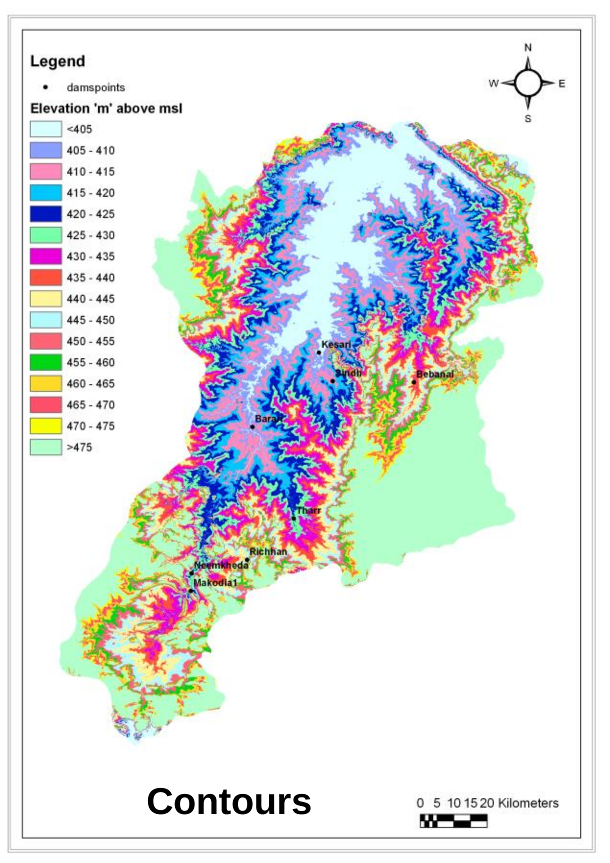
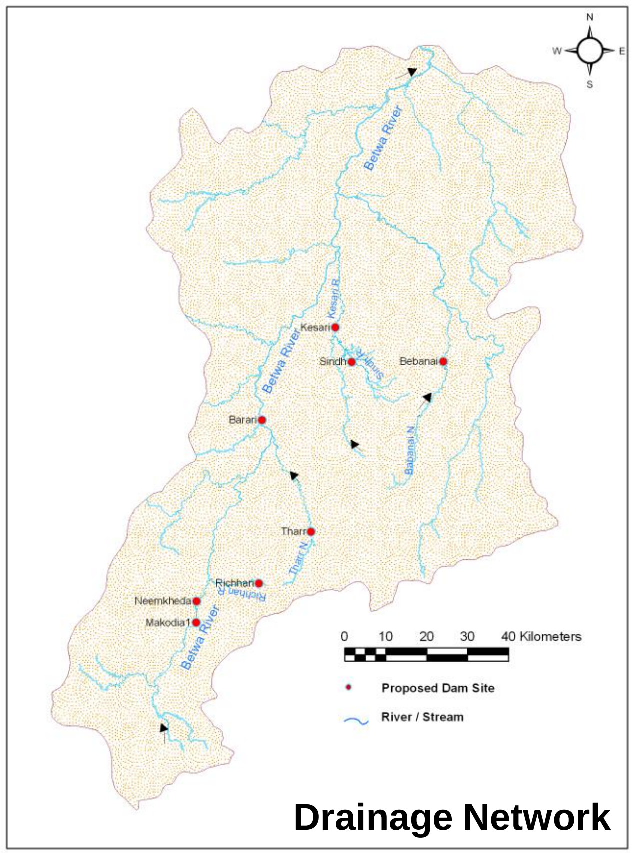
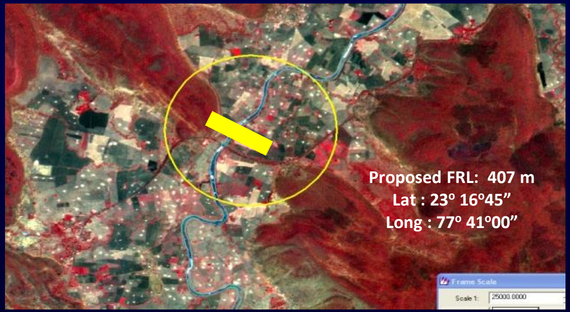






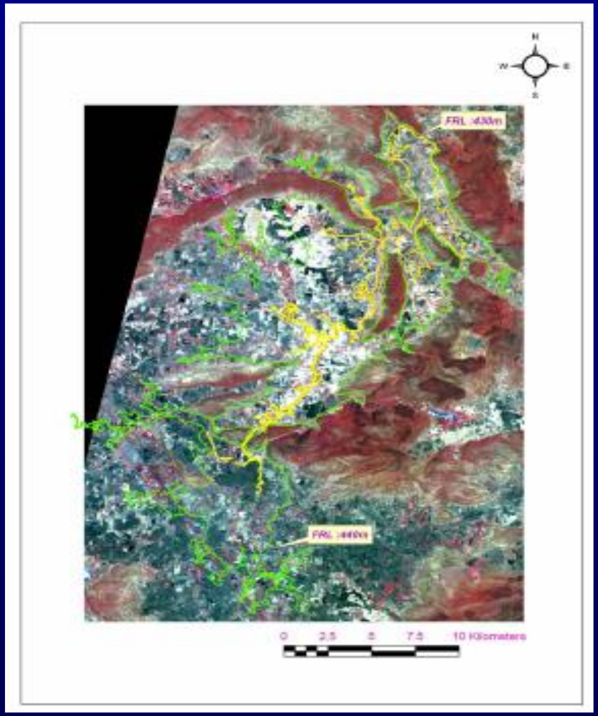
Neemkheda Dam and its Environs



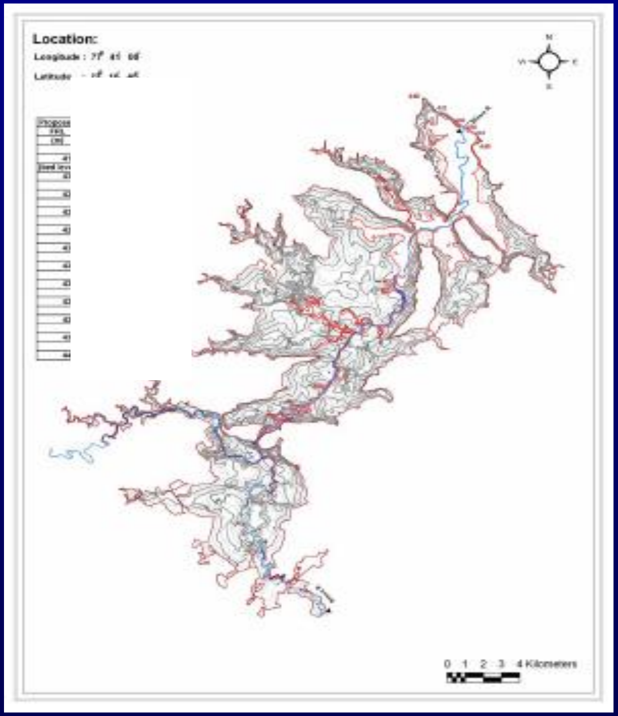
For eight proposed dam sites

- Land use/land cover - 1:25K – IRS P6 LISS IV
- Digital Elevation Model - Cartosat -1 stereo
- Contour maps - derived DEM

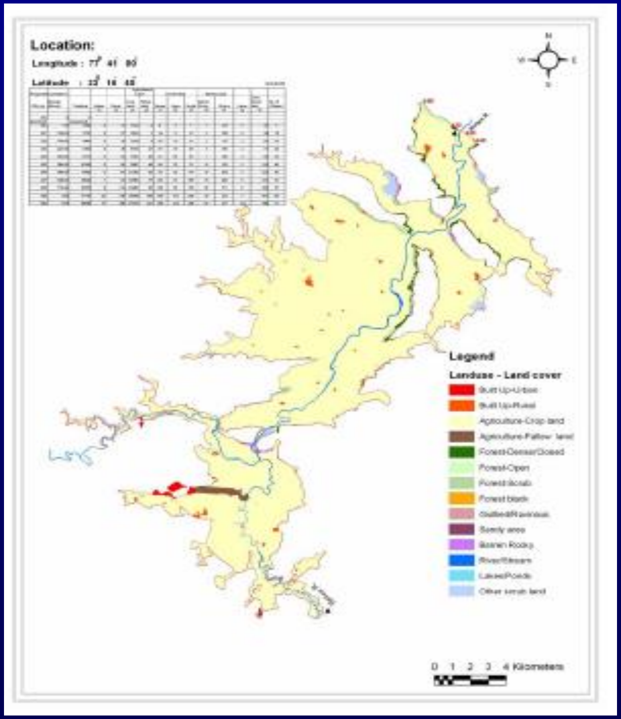
Neemkheda Dam



IRS LISS IV MX Image

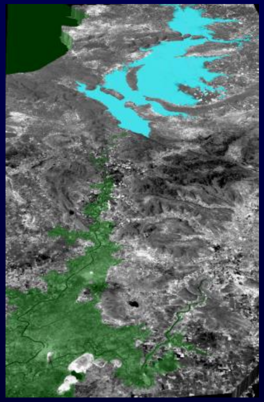


1m contours (430m - 440m)



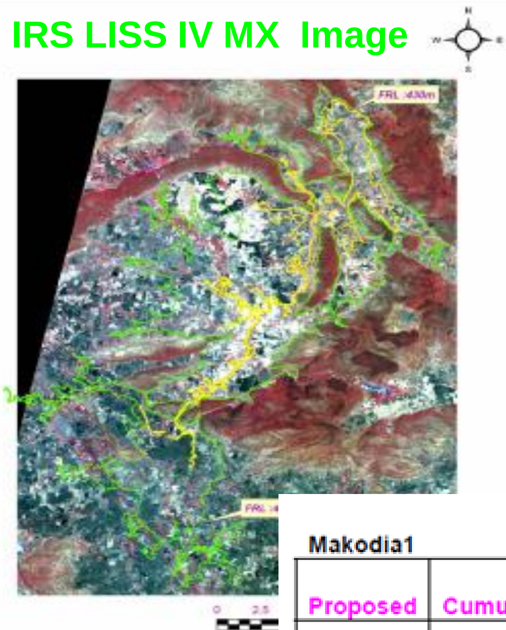
Land use Map (440m)

- Submergence at various reservoir levels
- Determining RL of reservoir



Feasibility assessment of Proposed Irrigation Projects in upper Betwa basin as a part of Ken-Betwa River Link Project

IRS LISS IV MX Image



Neemkheda Dam

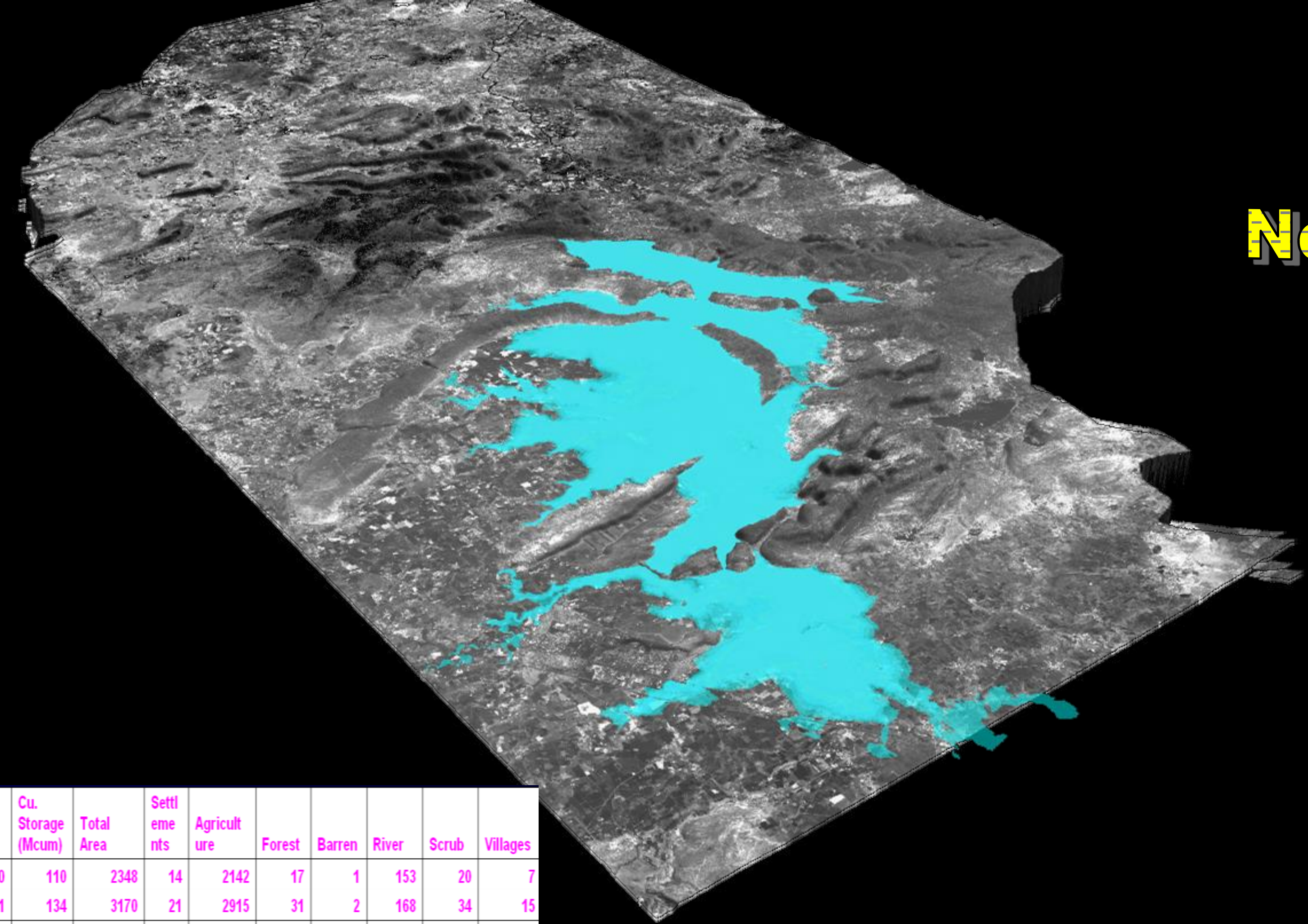
- *Facilitates NWDA for pre-feasibility report preparation*

Makodia1

Area in Ha

Proposed FRL (m)	Cumulative Storage (Mcum)	Total(ha)	Rural	Agricultural Land: Crop Land	Agricultural Land: Fallow Land	Forest Land: Dense	Forest Land: Open	Forest Land: Scrub	Barren Rocky	Rivers	Lakes	Other Scrub land	No. of Villages
			12	21	22	31	32	33	43	51	52	70	
Makodia1													
417 (bed level)													
430	55	1264	3	1112	0	6	0	4	1	124	1	14	5
431	71	1908	5	1724	2	10	0	8	2	134		22	10
432	95	3120	12	2889	10	14	1	15	3	143		34	13
433	134	4608	20	4316	26	17	1	23	5	153	1	46	20
434	189	6475	12	6113	40	22	2	35	7	160	1	63	26
435	264	8486	46	8057	48	26	3	52	10	166	1	76	33

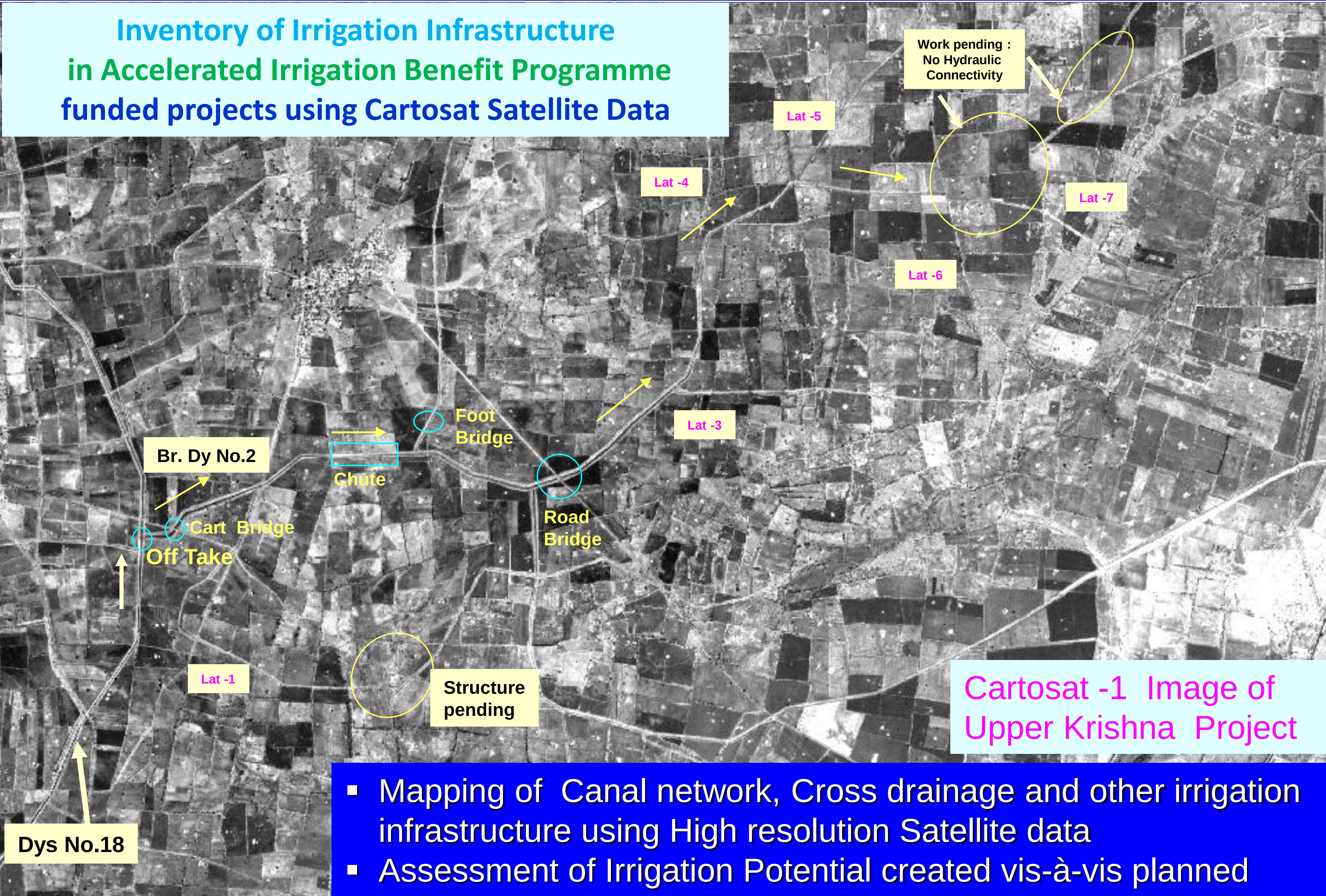
Neemkheda



FRL (m)	Cu. Storage (Mcum)	Total Area	Settlements	Agriculture	Forest	Barren	River	Scrub	Villages
430	110	2348	14	2142	17	1	153	20	7
431	134	3170	21	2915	31	2	168	34	15
432	168	4485	30	4163	59	3	176	52	20
433	221	6150	39	5760	94	5	182	71	25
434	292	8175	54	7697	132	7	193	92	33
435	384	10196	69	9635	176	10	197	110	40
436	494	11982	81	11319	237	14	209	123	45
437	628	13842	94	13060	314	19	214	141	51
438	770	15479	122	14544	403	28	216	166	57
439	933	17115	158	16015	500	39	222	181	60
440	1114	19040	235	17731	601	50	225	198	71

Dam Submeregnce : Simulation

Inventory & Monitoring of Irrigation Infrastructure



- Mapping of Canal network, Cross drainage and other irrigation infrastructure using High resolution Satellite data
- Assessment of Irrigation Potential created vis-à-vis planned

Inventory & Monitoring of Irrigation Infrastructure

Methodology for assessment of Irrigation potential created

- **High Resolution satellite data**

↓

- **Satellite derived irrigation infrastructure map**

↓

Canal network: inventory in terms of No's, Lengths ,status of canals ,Cross Drainage & other structures

- **Comparison with proposed irrigation canal network / infrastructure**

↓

Status of works : completed, ongoing works are reported

- **Assessment of Irrigation potential created – status of I.P created**

↓

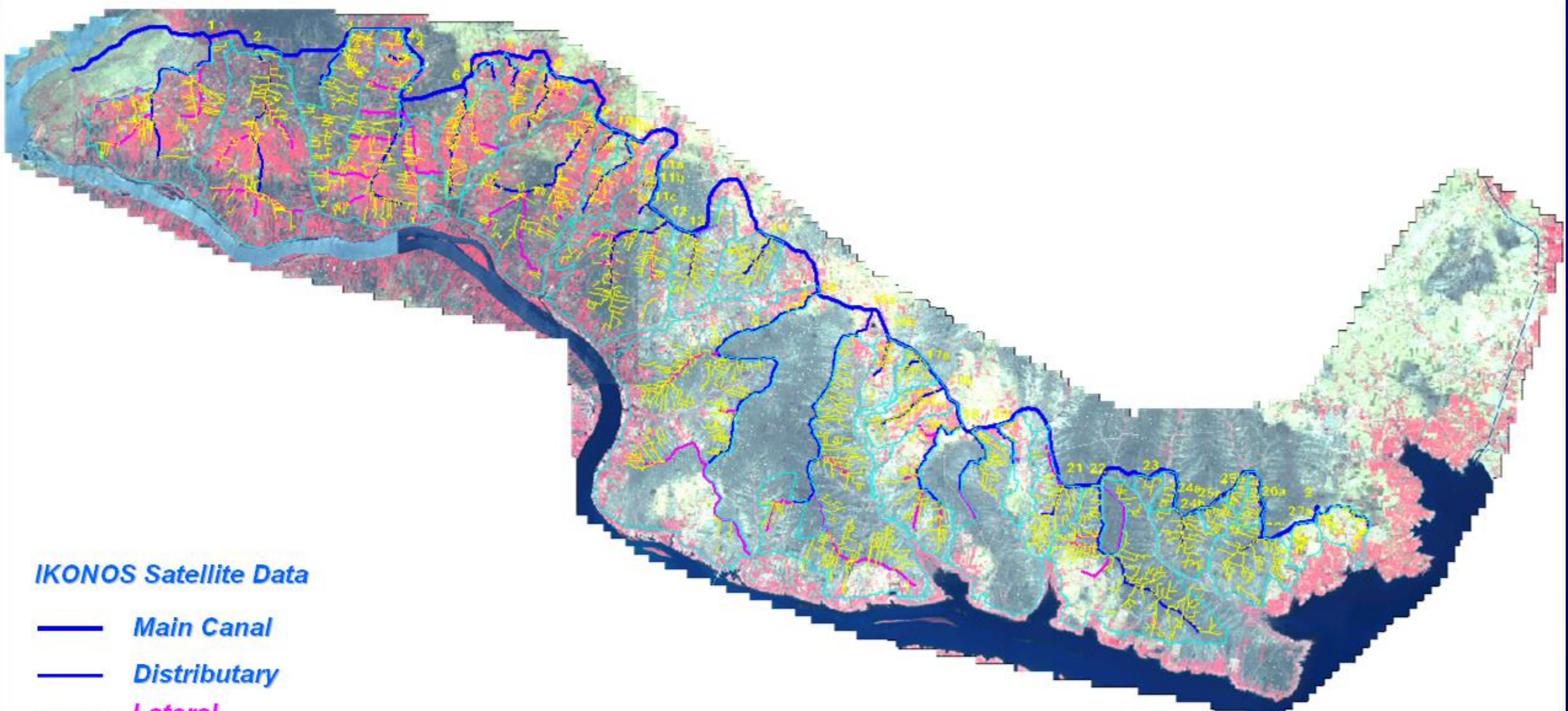
Assessment is based on completed works & percentage progress of infrastructure provided

Potential created	**Percentage progress**	**Critical gap areas**	**Spatial distribution of gap areas**

Delineation of Canal Network

Assessment of Irrigation Potential created Through Irrigation Infrastructure Mapping

Almatti Left Bank Canal Project, UKP

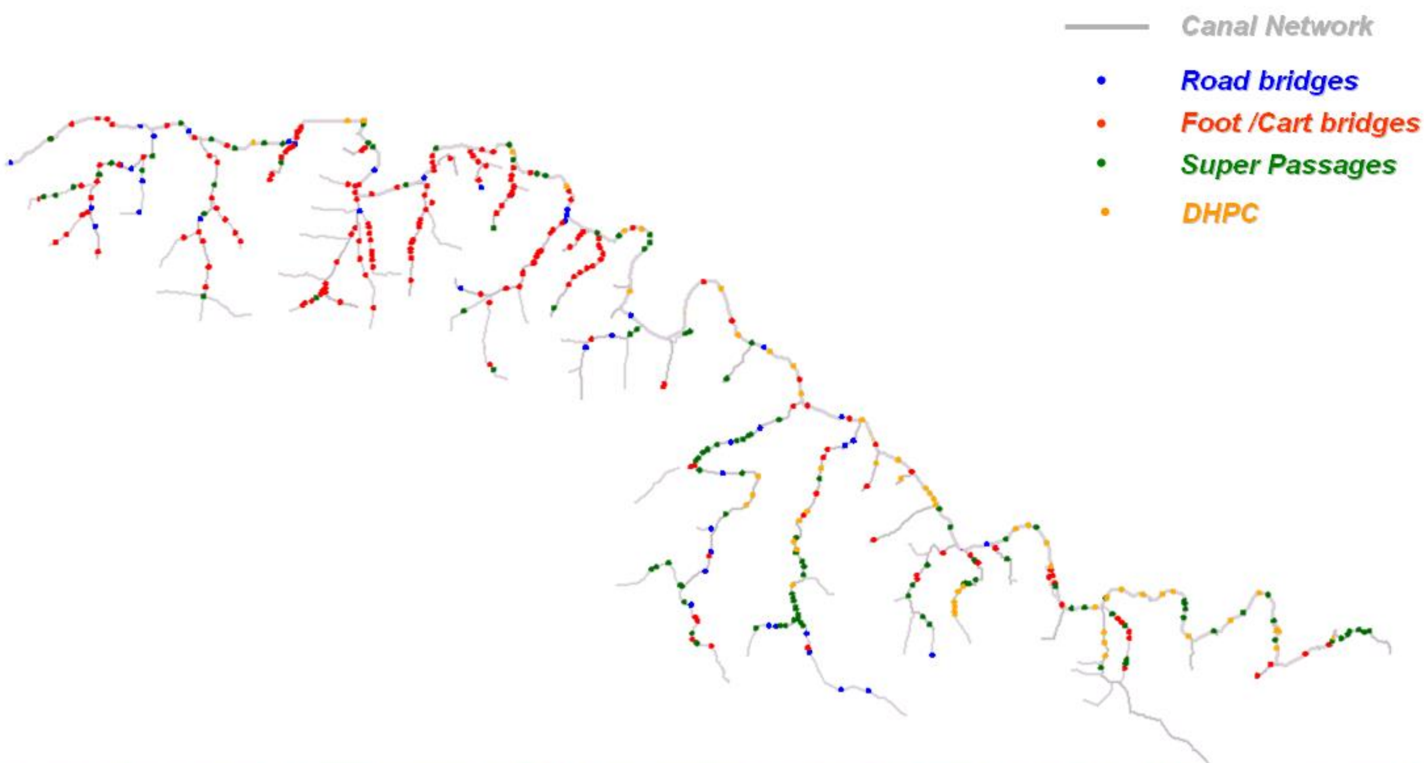


IKONOS Satellite Data

- Main Canal
- Distributary
- Lateral
- Field Channels
- Distributary Boundary

Identification of Structures

Almatti Left Canal Command



Inventory & Monitoring of Irrigation Infrastructure

Canal, including main canal and distribution system

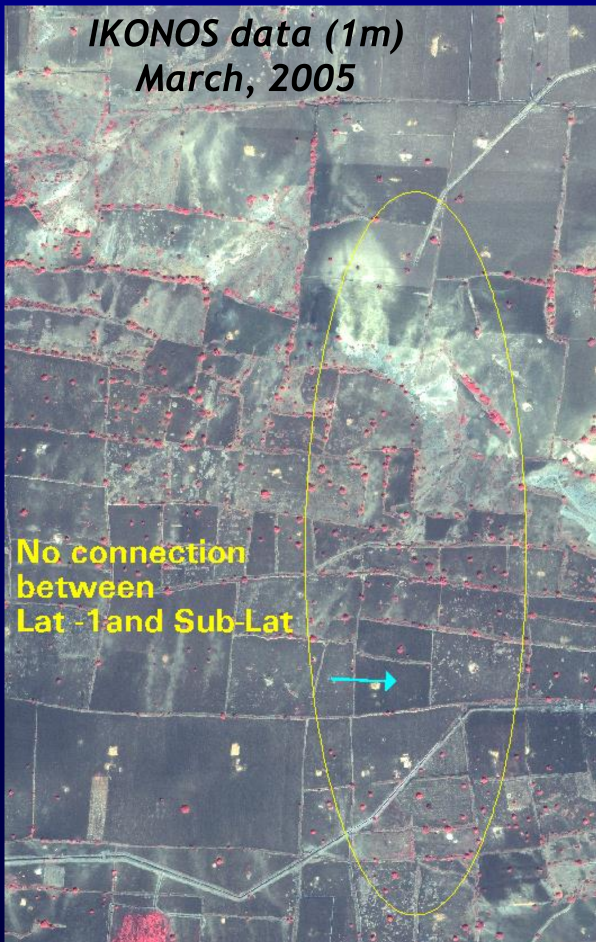
Completed section i.e., canal in place

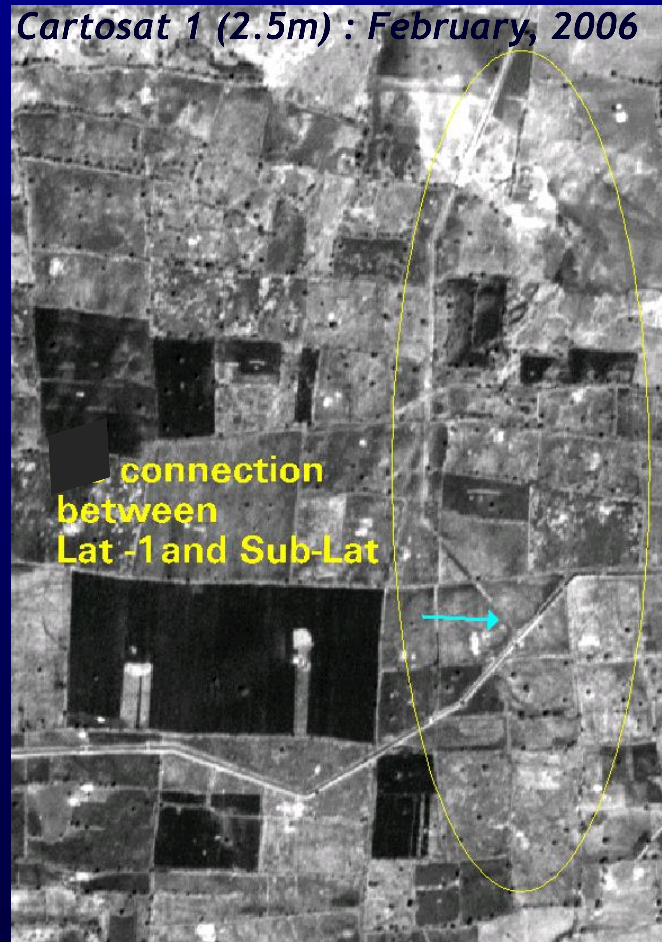
Canal section to be constructed

Canal under construction

Inventory & Monitoring of Irrigation Infrastructure

Connectivity between Lateral and sub-lateral



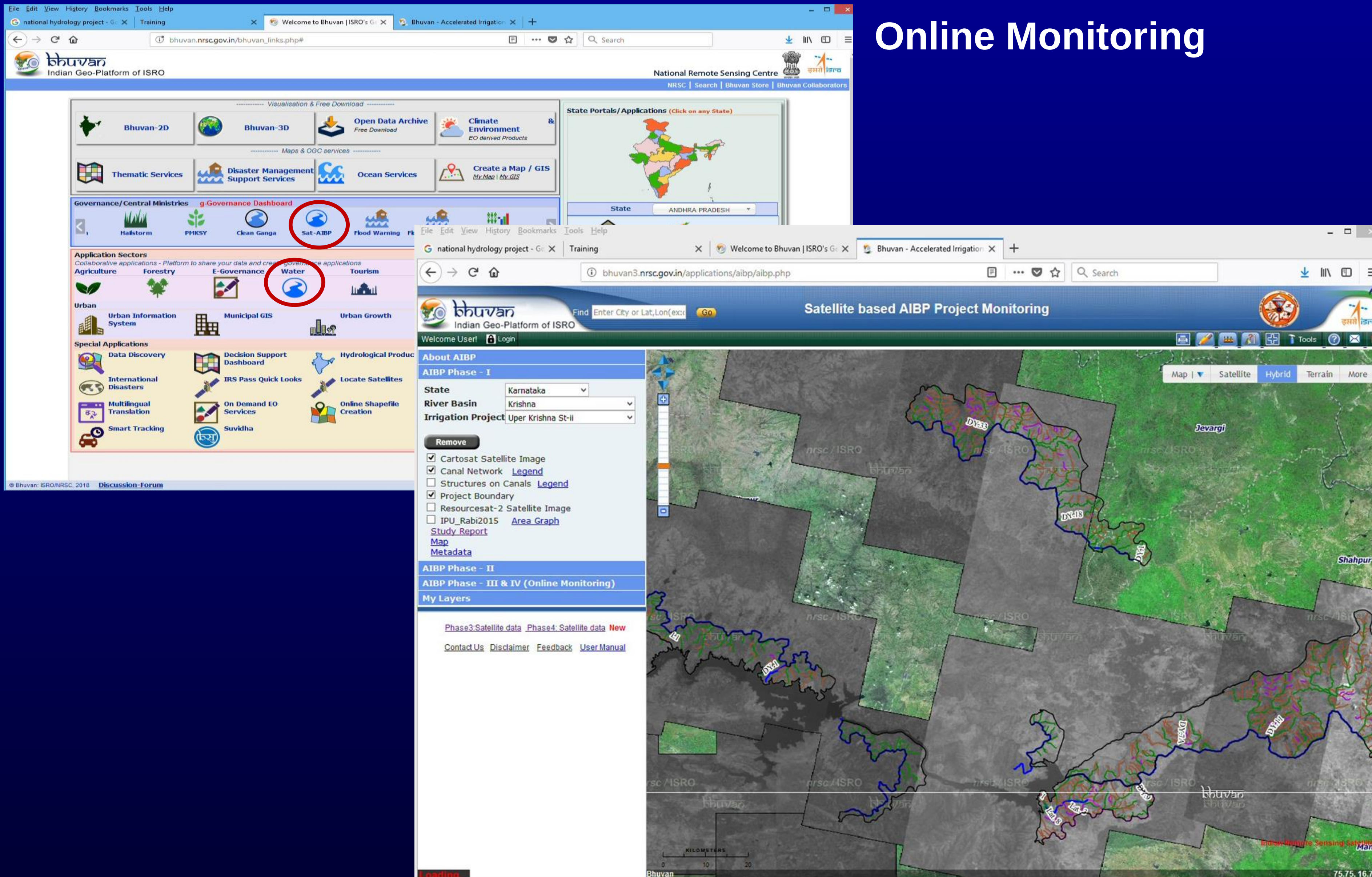


Offtake Connectivity

IKONOS data (1m) March, 2005

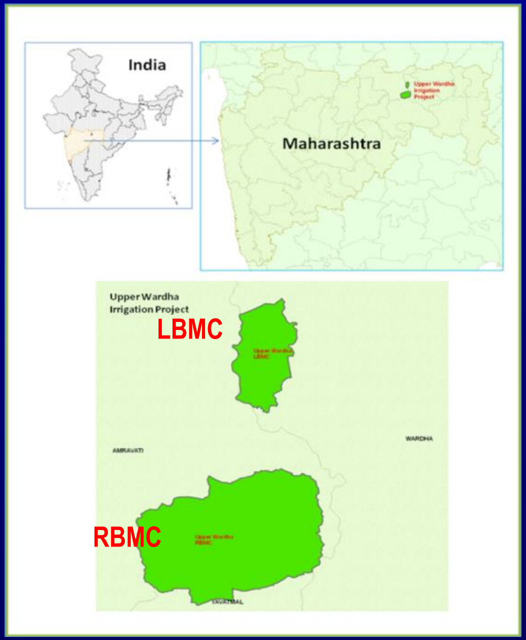
Cartosat1 (2.5m) Feb, 2006

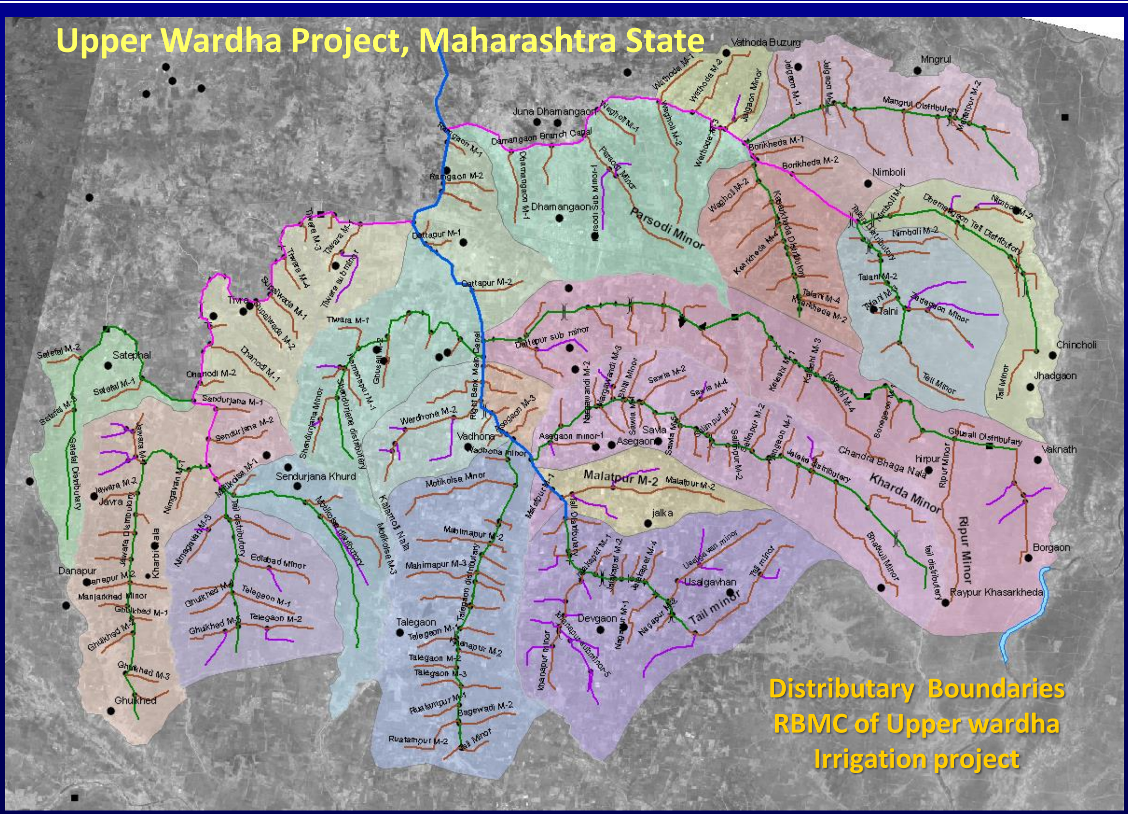
Inventory & Monitoring of Irrigation Infrastructure



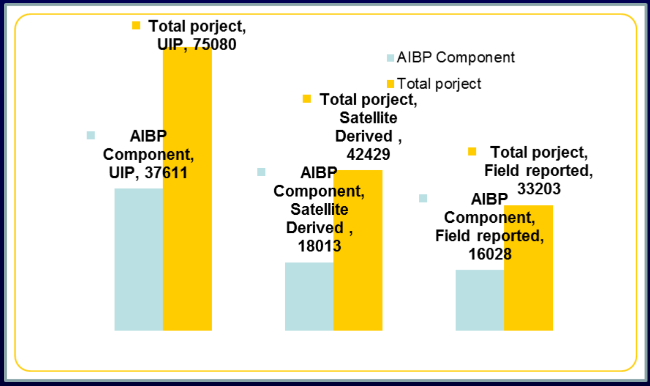
Online Monitoring

Spatial Irrigation Potential Utilization





	AIBP component	Total project
	(Ha)	(Ha)
GCA	**57,802**	**1,04,400**
CCA	45,900	**83,300**
ICA	**35,154**	**70,169**
Irrigation Potential	**37,611**	**75,080**

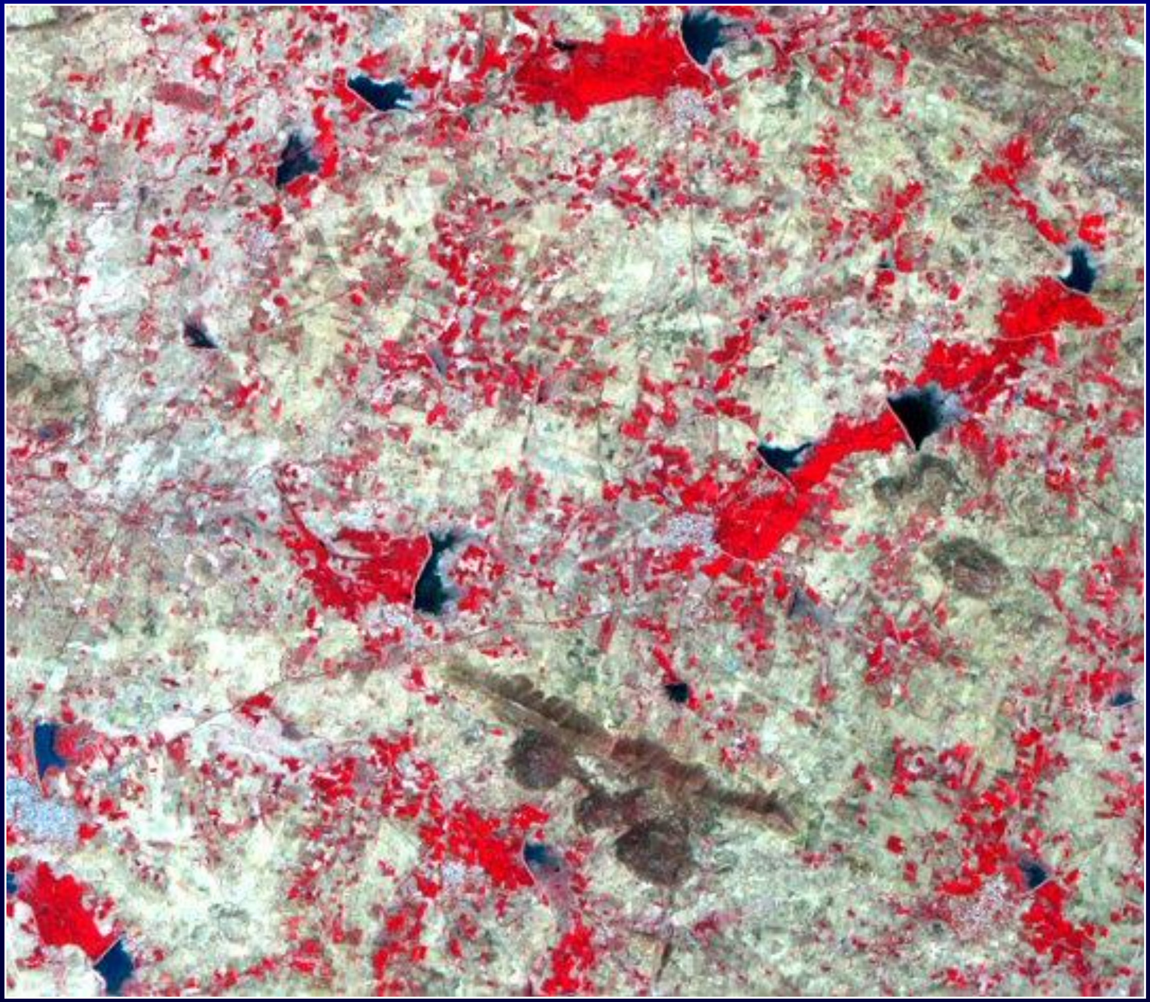


48% of Irrigation potential is utilized in the AIBP Area

67% of Irrigation potential is utilized at the project level

Monitoring & Evaluation of Minor Irrigation Systems (Tanks)

National Project for Repair, Renovation and Restoration of Water Bodies directly linked to Agriculture



- About 5,00,000 water bodies/tanks used for irrigation
- Storage capacity coming down due to improper maintenance, Silting, etc.
- Area under tank irrigation 4.78 Million ha in 1962-63; 3.07 Million ha in 1985-86

Monitoring & Evaluation of Minor Irrigation Systems (Tanks)

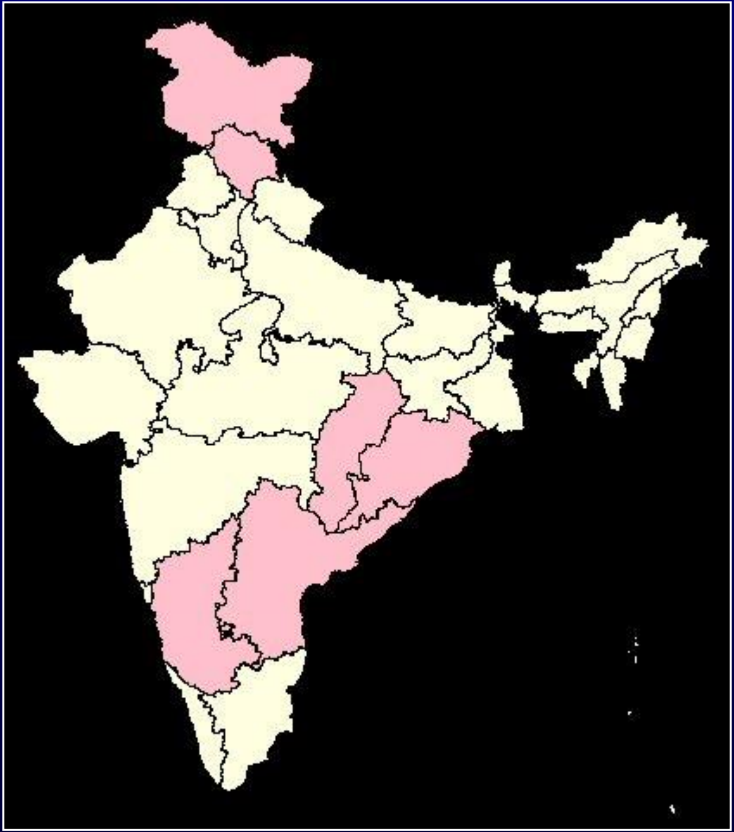
Objectives:

- Inventory of WSA, crop area and cropping pattern in 2 years (pre-2004-05) and post-2007-08 NPRRR scheme
- Study the crop condition within each tank command area for two seasons

Study area:

742 tanks spread in 9 Districts of 6 States

State	Districts
Andhra Pradesh	2
Chattisgarh	1
Himachal Pradesh	1
Jammu&Kashmir	1
Karnataka	2
Orissa	2



Monitoring & Evaluation of Minor Irrigation Systems (Tanks)


Tank Bund repairs and strengthening


Weir construction


Weir repairs


Sluice repairs

Works undertaken in NPRRR Programme


Jungle cutting


Irrigation channel construction

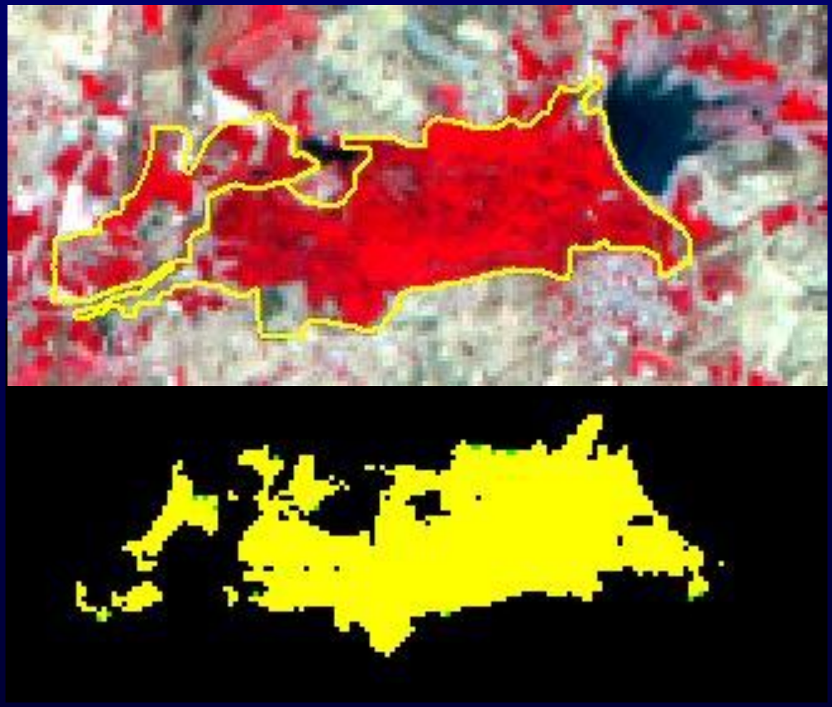

IC repairs

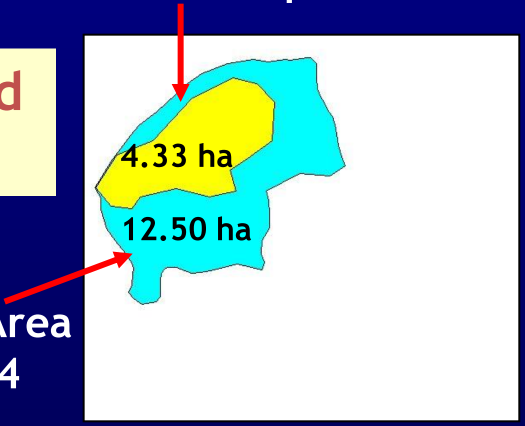
Monitoring & Evaluation of Minor Irrigation Systems (Tanks)

The changes in performance of NPRRR tanks from 2004-05 to 2007-08 are assessed through the parameters

- Water spread area
- Season-wise crop area
- Cropping pattern
- Season-wise crop condition
- Irrigation utilisation

Water Spread Area



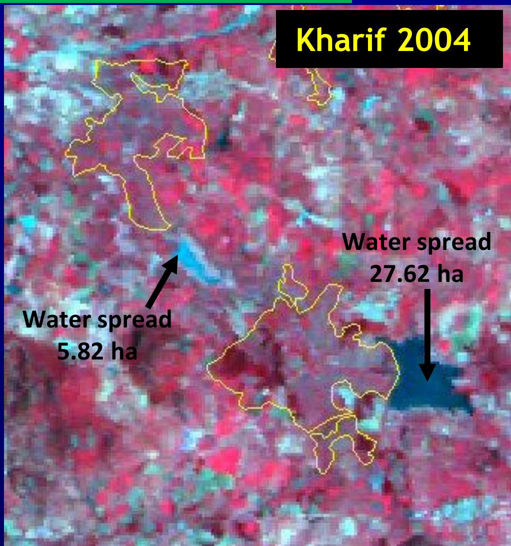


Name of State	Name of District	No. of tanks	CCA (in ha)
Andhra Pradesh	Mahabub Nagar	226	20,000
	Anantapur	49	9,060
Chhattisgarh	Kabir Dham	10	2,039
Himachal Pradesh	Mandi	13	1,165
Jammu & Kashmir	Kupwara	21	1,126
Karnataka	Gulbarga	116	22,744
	Bangalore Rural	180	22,551
Orissa	Ganjam	68	14,247
	Gajapati	59	9,010
	Total	**742**	**1,01,942**

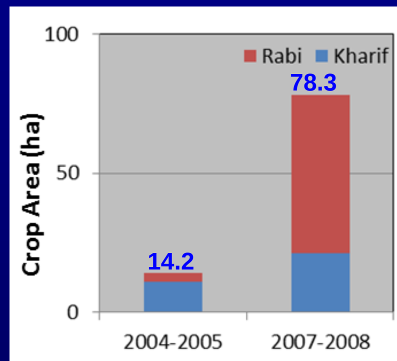
Monitoring & Evaluation of Minor Irrigation Systems (Tanks)

Jagpalsamudram cheru and Amma cheru Command Area Mahabub Nagar District, Telangana State

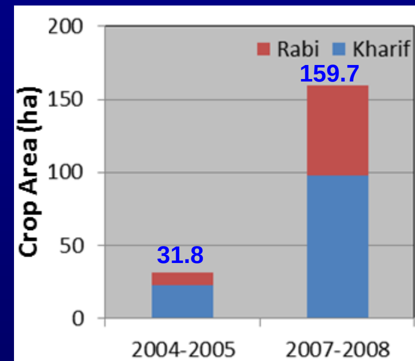
Pre-Improvement



Increase in Crop Area

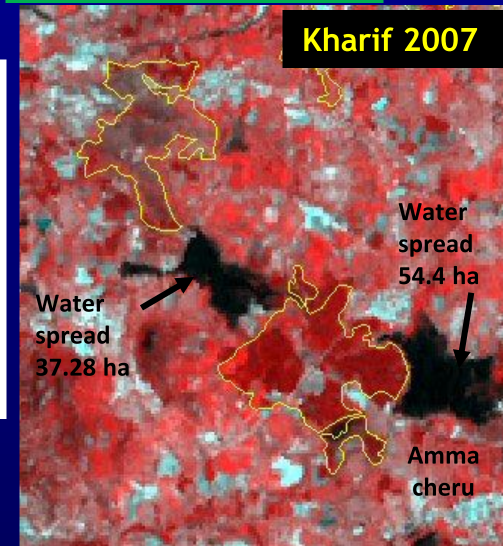


Jagpalsamudram cheru

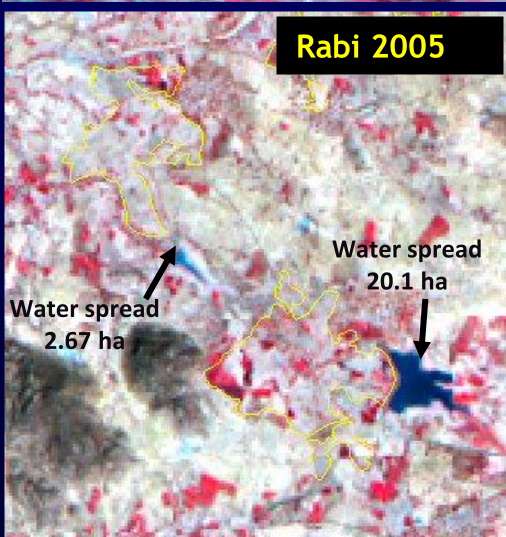


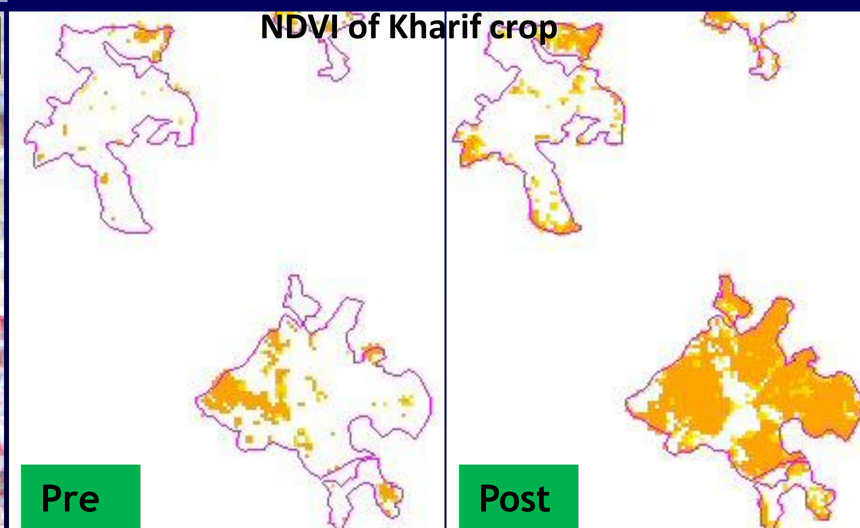
Amma cheru

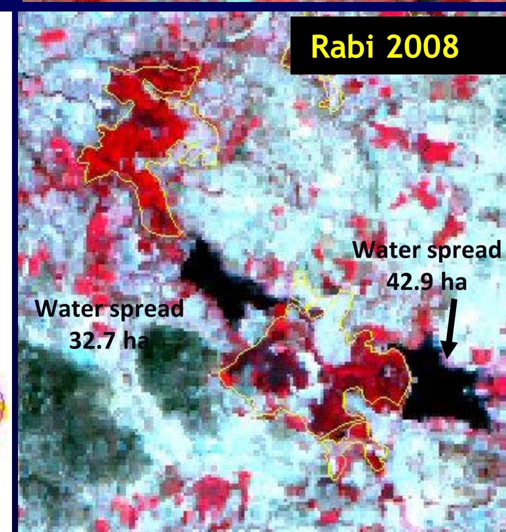
Post-Improvement



Improvement in Crop Condition





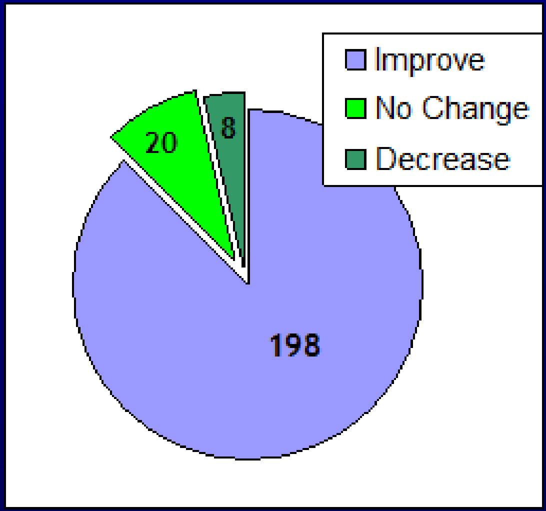


Monitoring & Evaluation of Minor Irrigation Systems (Tanks)

Mahabub Nagar District, Telangana State

Impact Evaluation: Observations

Overall Performance of tanks



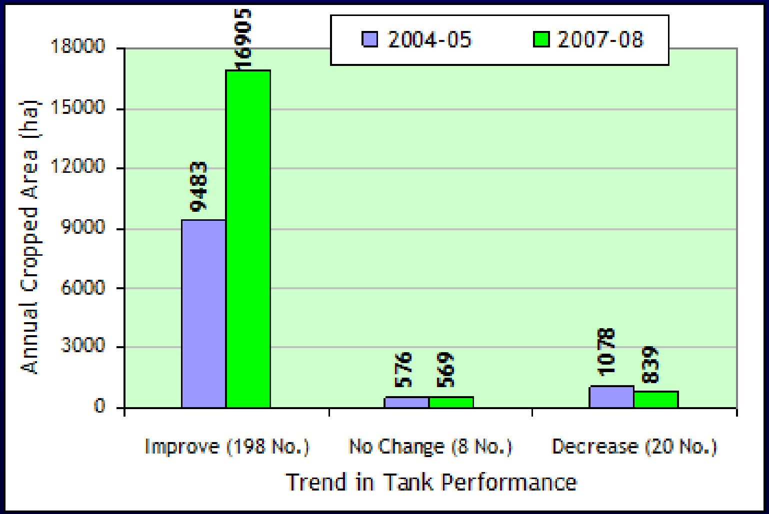
Out of 226 selected tanks in the district

- 198 tanks (87%) showed improvement
- 20 tanks (9%) showed no significant improvement and
- 8 tanks (4%) showed decrease in performance

Crop area (Irrigation utilisation) increase registered

- Annual crop area during 2004-05 was 11,136 ha
- Annual crop area during 2007-08 was 18,312 ha

Annual Irrigation Utilisation

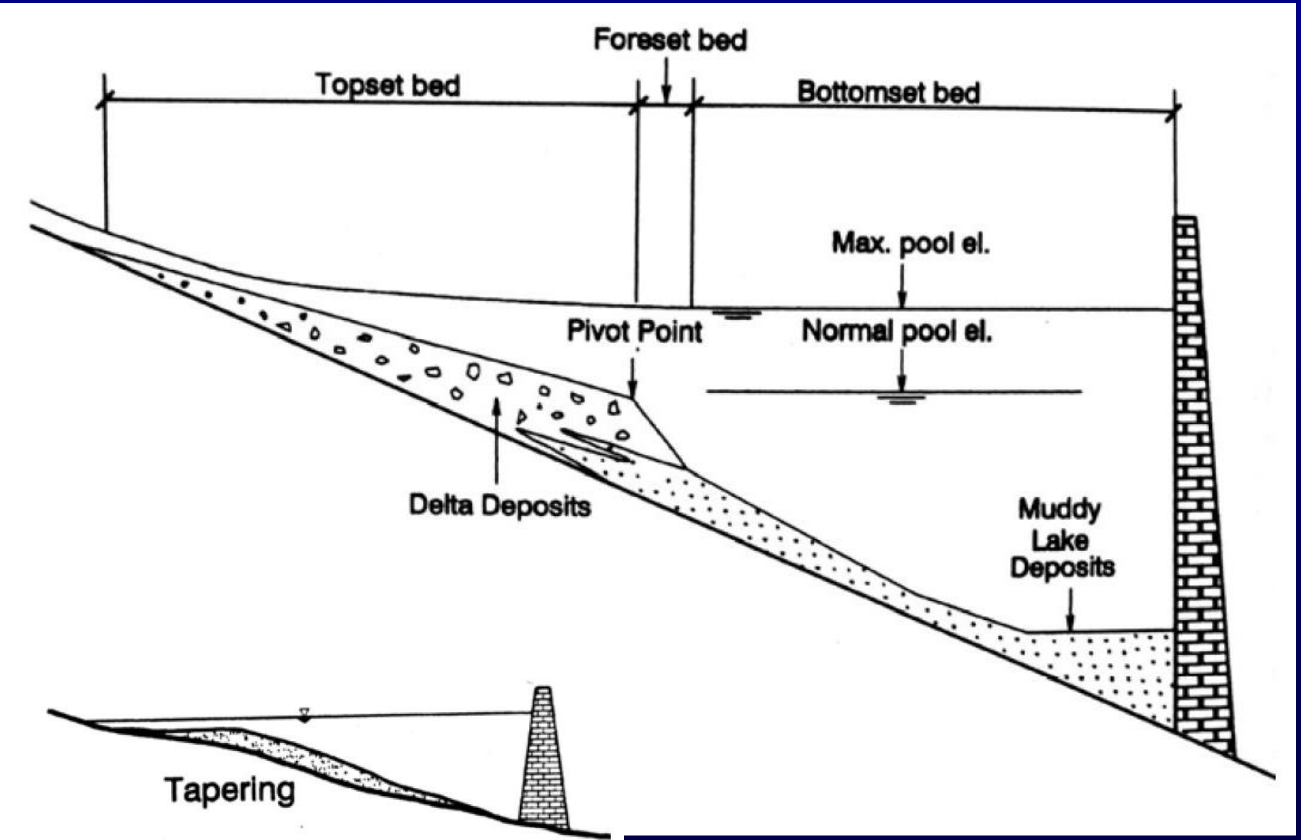


Increase in annual irrigation utilisation in 198 tanks

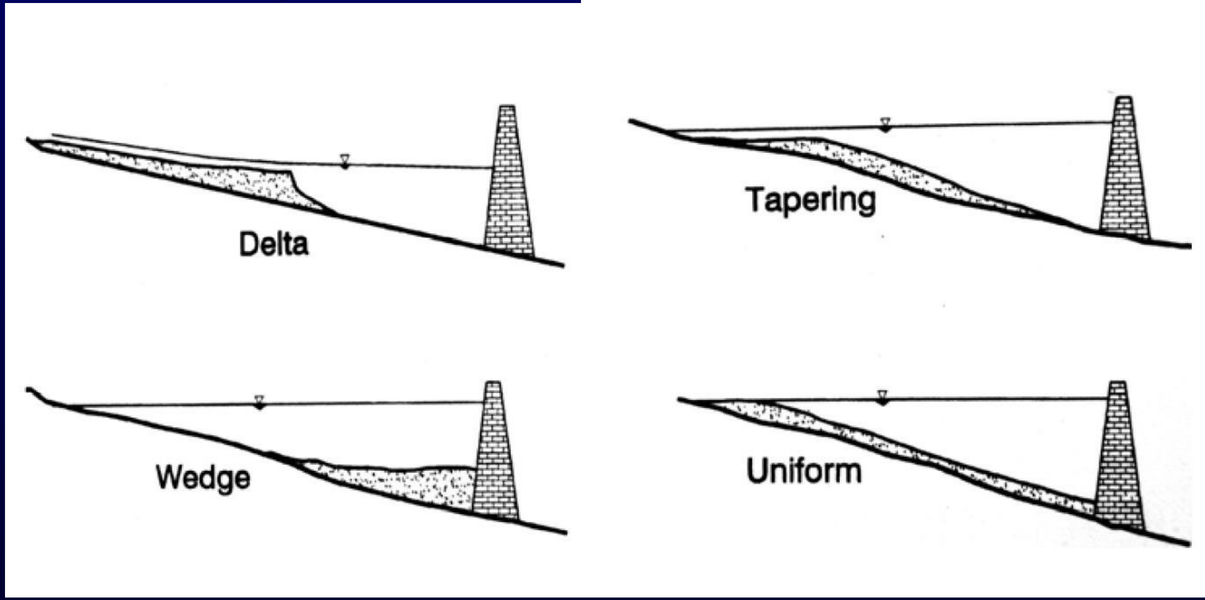
- Annual crop area during 2004-05 was 9,483 ha
- Annual crop area during 2007-08 was 16,905 ha

Reservoir Sedimentation

Longitudinal profile of sedimentation in reservoir

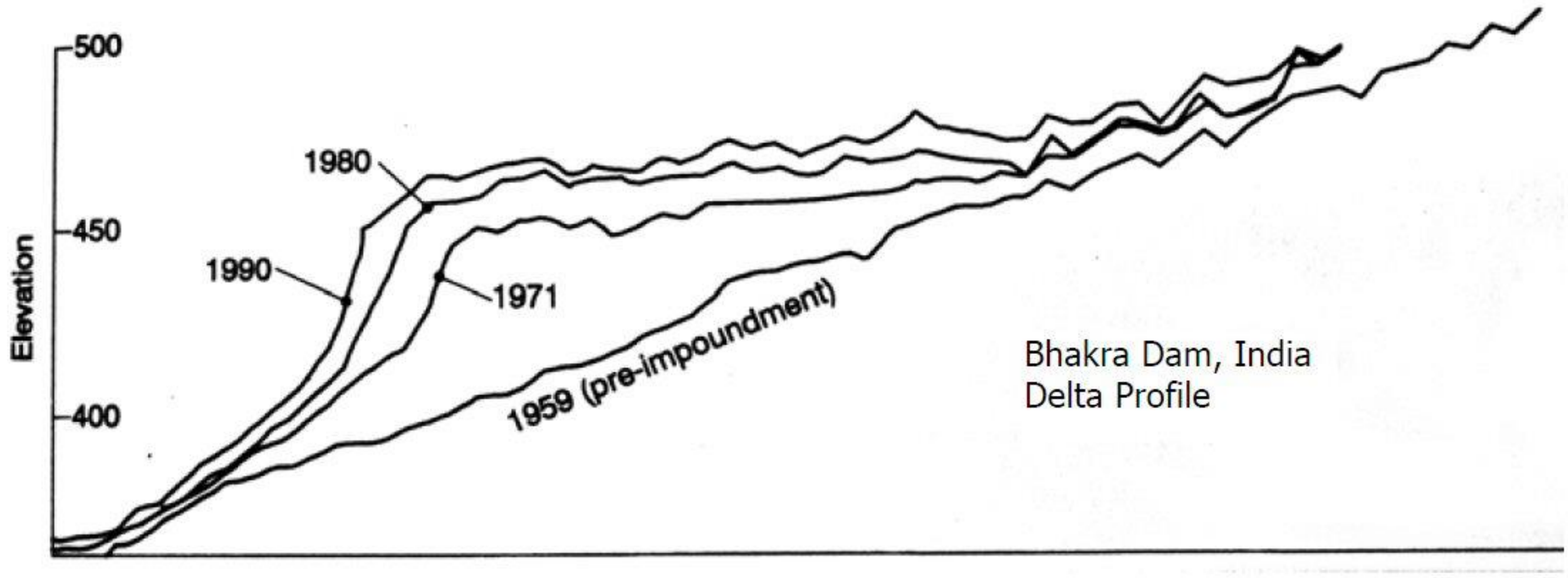


Types of Sediment Deposits



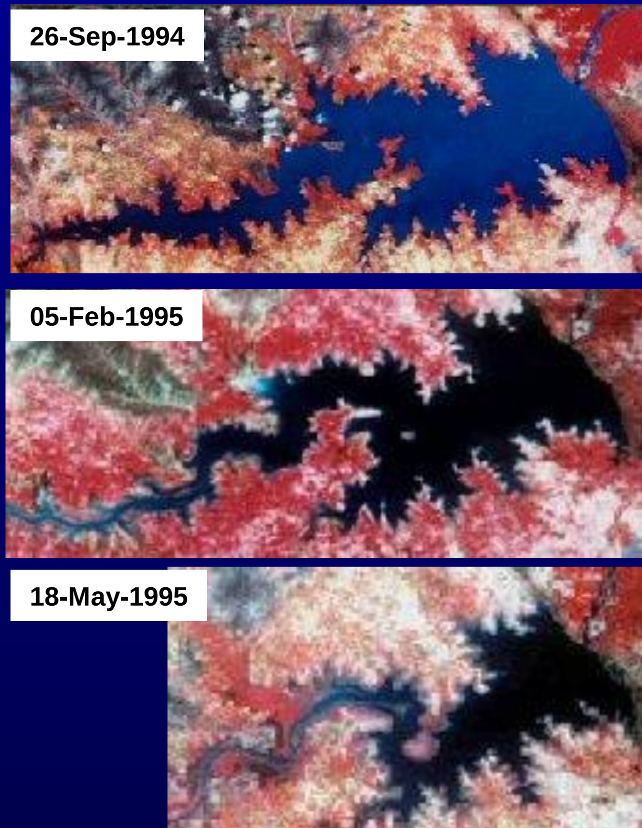
Reservoir Sedimentation

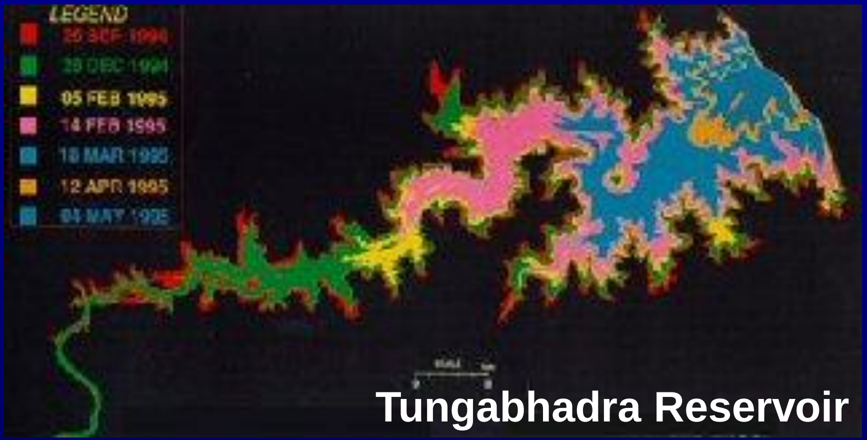
Delta profile Upstream of Bhakra Dam

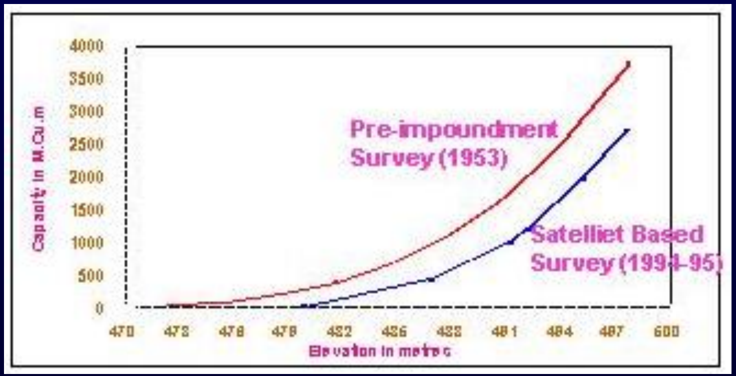


Timewise pattern of delta growth upstream of Bhakra Dam, India. The rate of delta advance slows with time because of reservoir geometry, which deepens and broadens in the downstream direction.

Reservoir Sedimentation

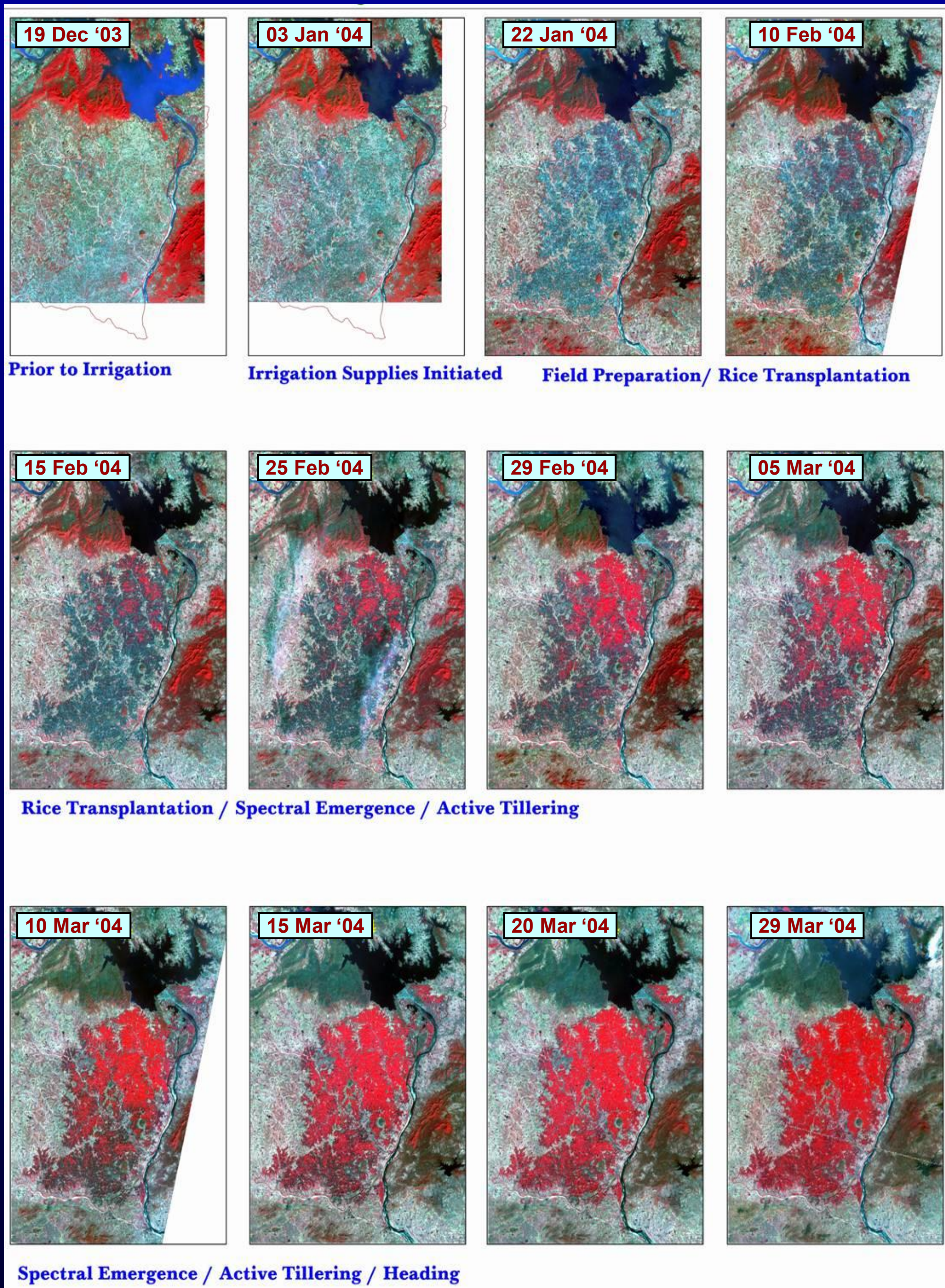






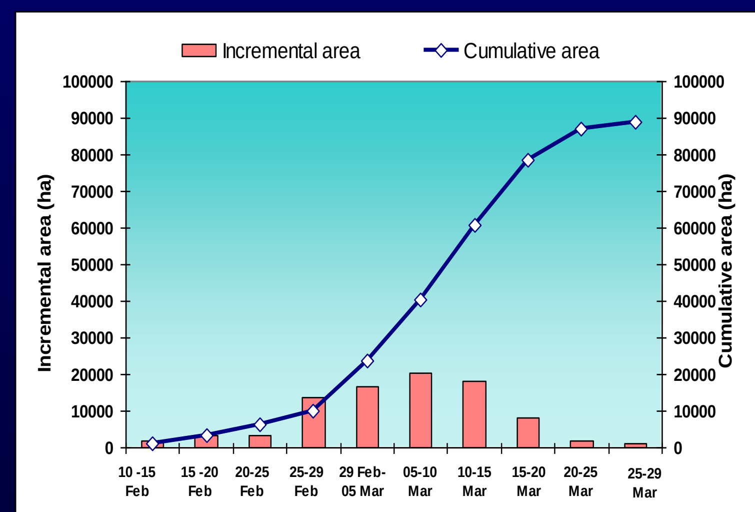
- **Multi-temporal satellite images at different water levels of reservoir**
- **Use of Satellite data to estimate reduction in the "Live Storage capacity" whereas conventional hydrographic surveys used for the "Dead Storage capacity"**

Irrigation Command Area Monitoring



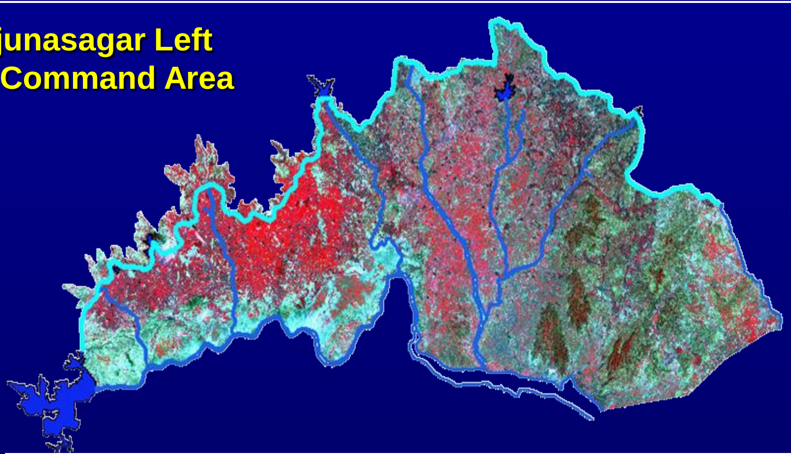
Progression of 2003-04 Rabi Season Crop Area in Hirakud Command

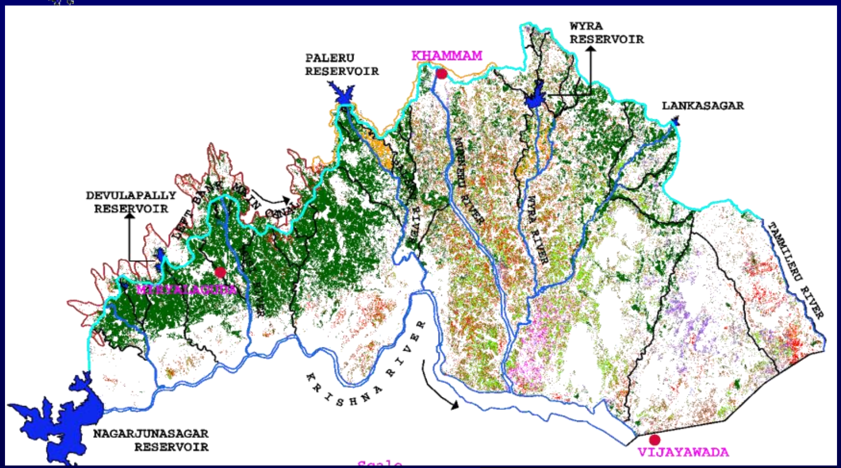
As captured by multi-date AWiFS data

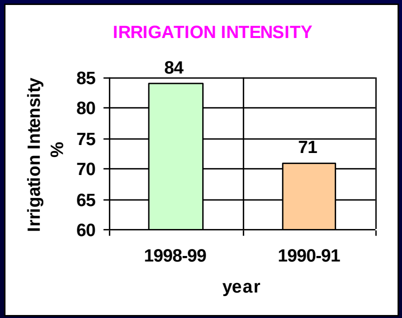


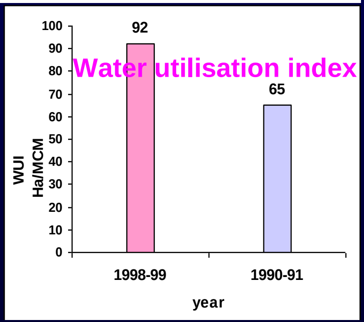
Evaluation of Irrigation System Performance

Nagarjunasagar Left Canal Command Area









Irrigation potential created to the tune of 100 Mha. But Water use efficiency (~ 35%) needs to be improved

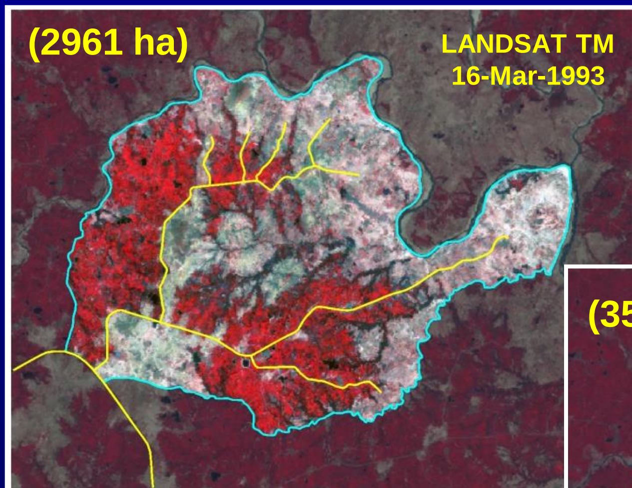
Performance indicators

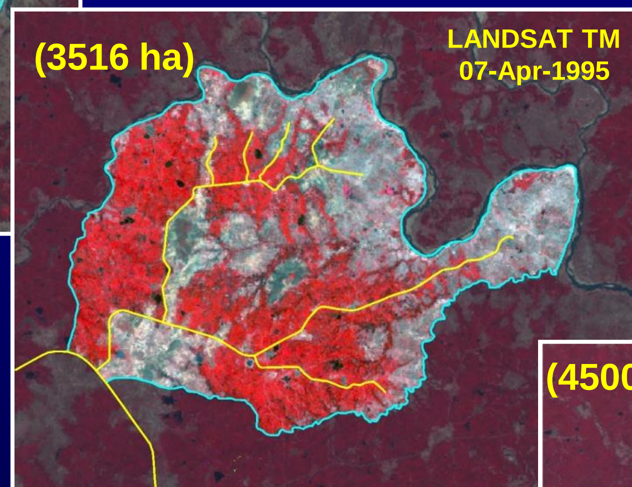
- Cropping Pattern
- Area under crop
- Irrigation potential utilized
- Irrigation Intensity
- Crop Production
- Water Utilization Index

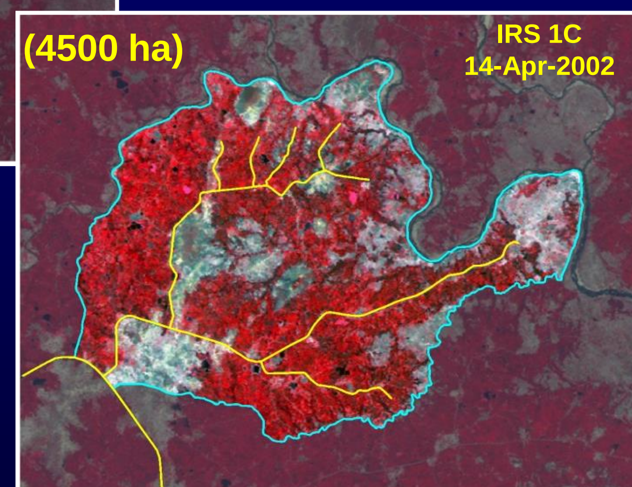
Identification of Canals with Differential / Poor Performance over Space and Time

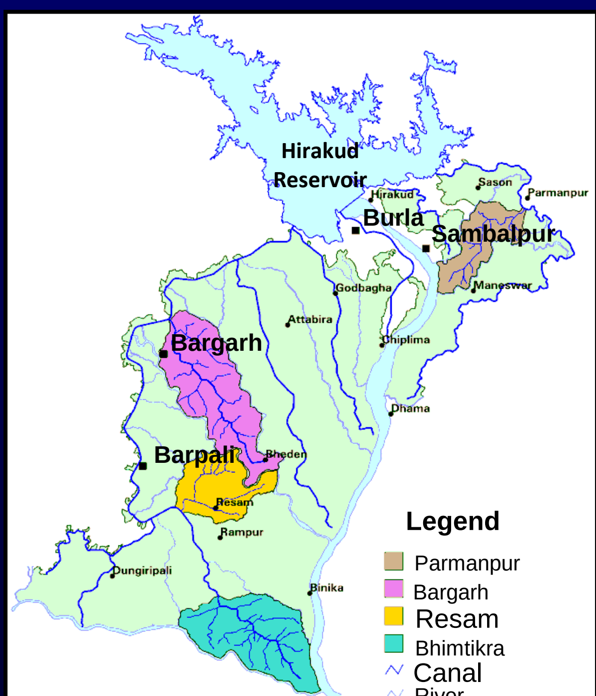
Decision Support For Intervention / Rehabilitation

Performance of Resam Distributary under *NWMP/WRCP*





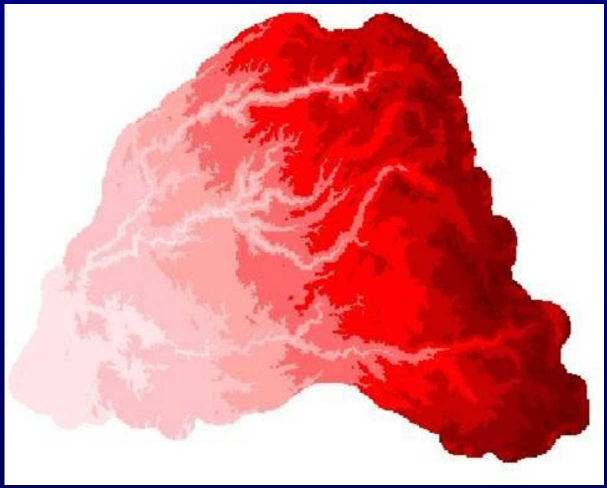




Hydrological & Hydraulic Modelling

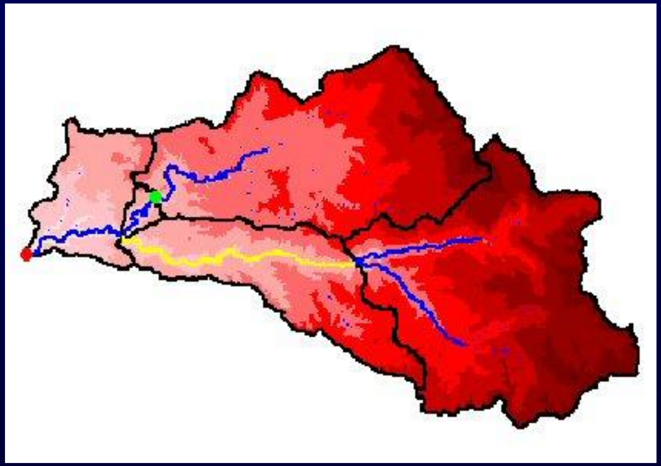
Various inputs required for runoff estimation can be derived from satellite remote sensing.

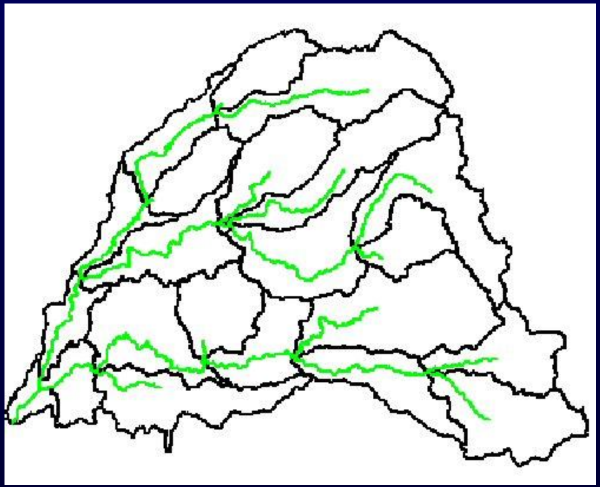
- Digital Elevation Model
- Drainage network
- Catchments boundaries derived from DEM
- Land use / Land cover
- Soils



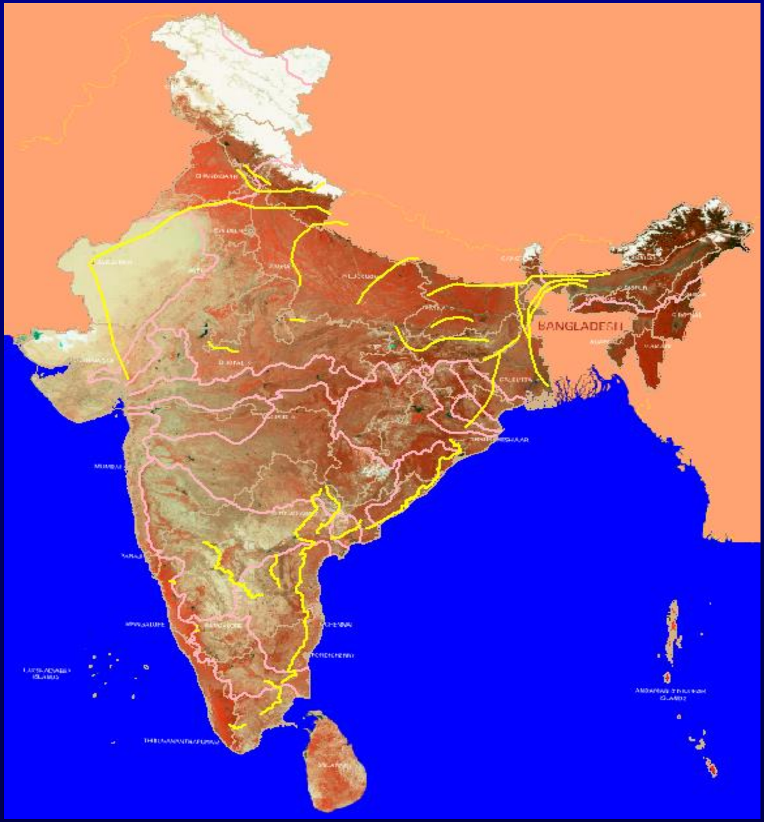
Stream and catchment characteristics:

- River length
- River slope
- Basin centriod
- Longest flow path
- Centriodal flow path





Inter-Basin Transfer

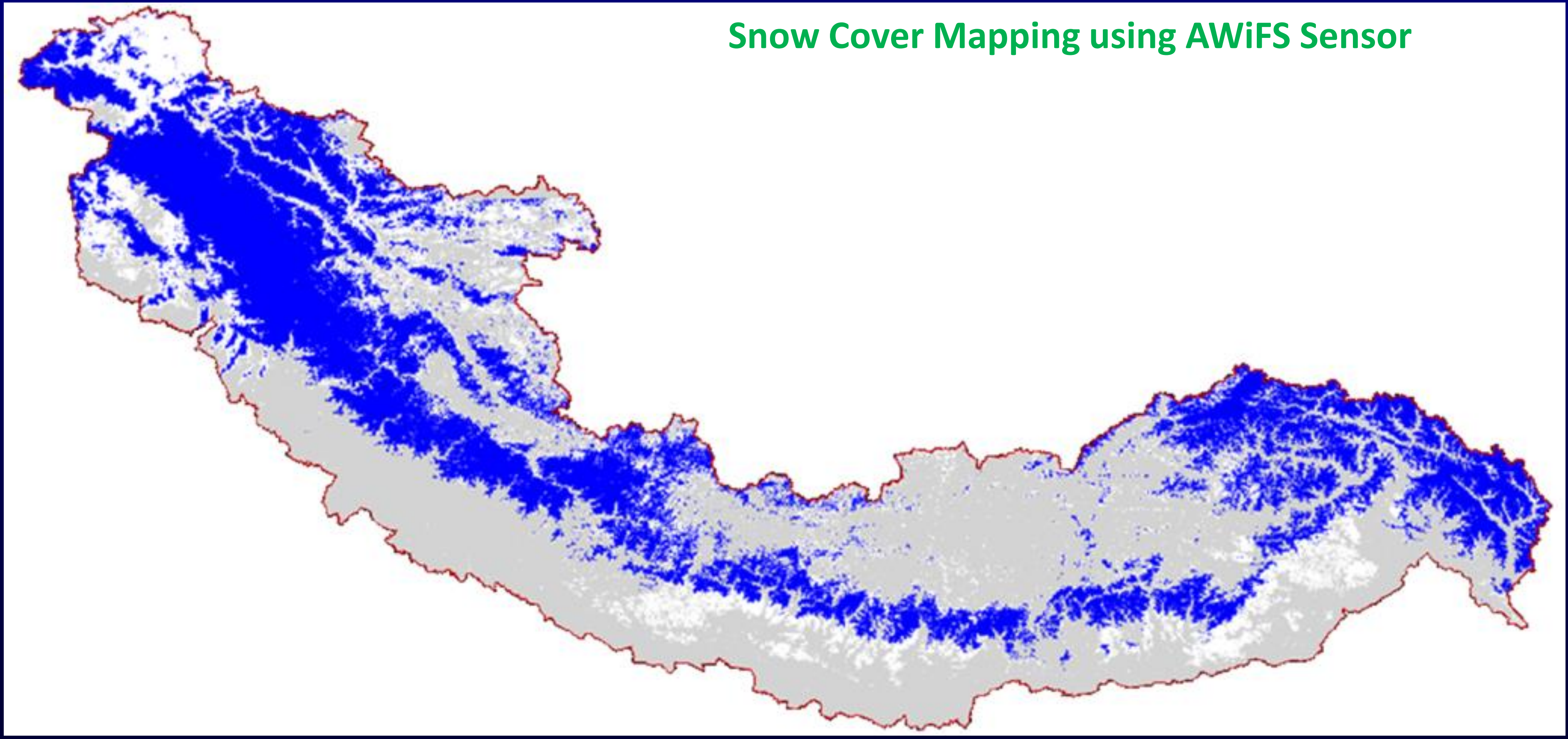


- **12 major river basins and 46 medium river basins with ultimate irrigation potential of 140 Mha**
- **Episodic deficits and excesses; floods and droughts in several parts**
- **Feasibility studies on interlinking of river basins**

- Space remote sensing inputs used Feasibility studies – Topographical Surveys, Hydrological Surveys, Geo-technical / Geological, Environmental & Ecological, Command Area Surveys, Base line information, Water balance studies, Run-off estimation in un-gauged basins

Snow Cover Mapping and Monitoring in Himalayas

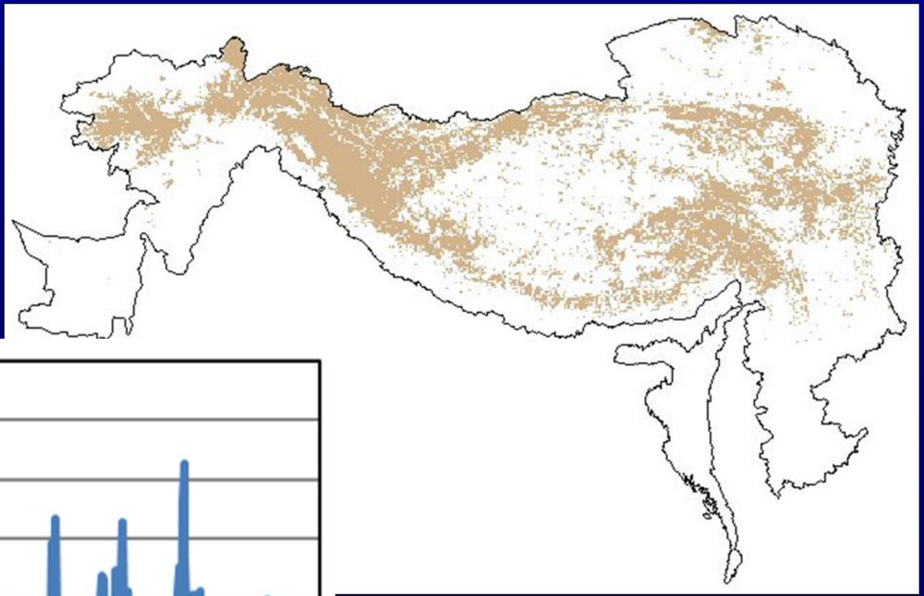
- Snow plays a major role in the hydrology, as it is the major source of water for the many perennial river systems of India.
- Snow accumulation period in the Himalayan region starts from October to March and starting melting during summer months

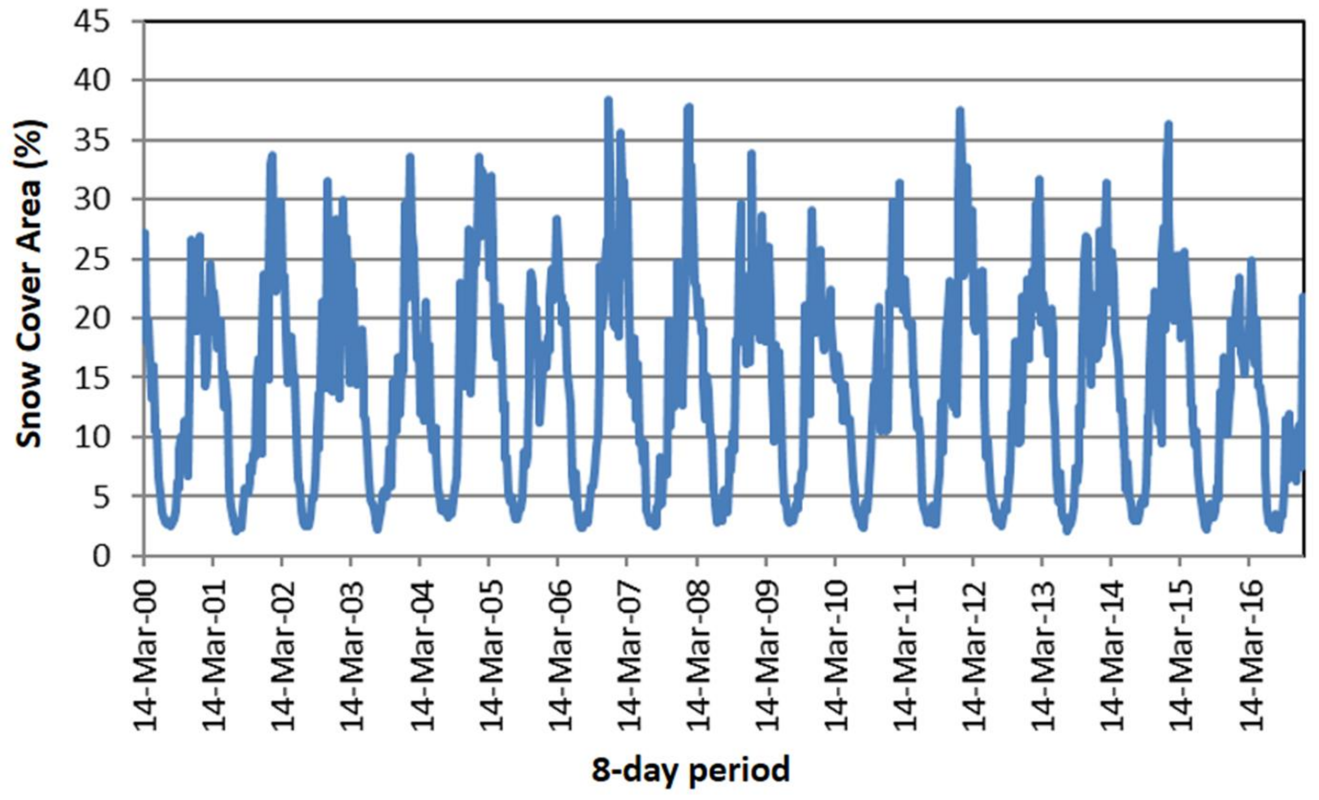


Snow Cover Mapping and Monitoring in Himalayas

Modis Snow Cover Variations from 2000 to 2016

Hindu-Kush Himalayan region with area of 41,93,210 sq.km.



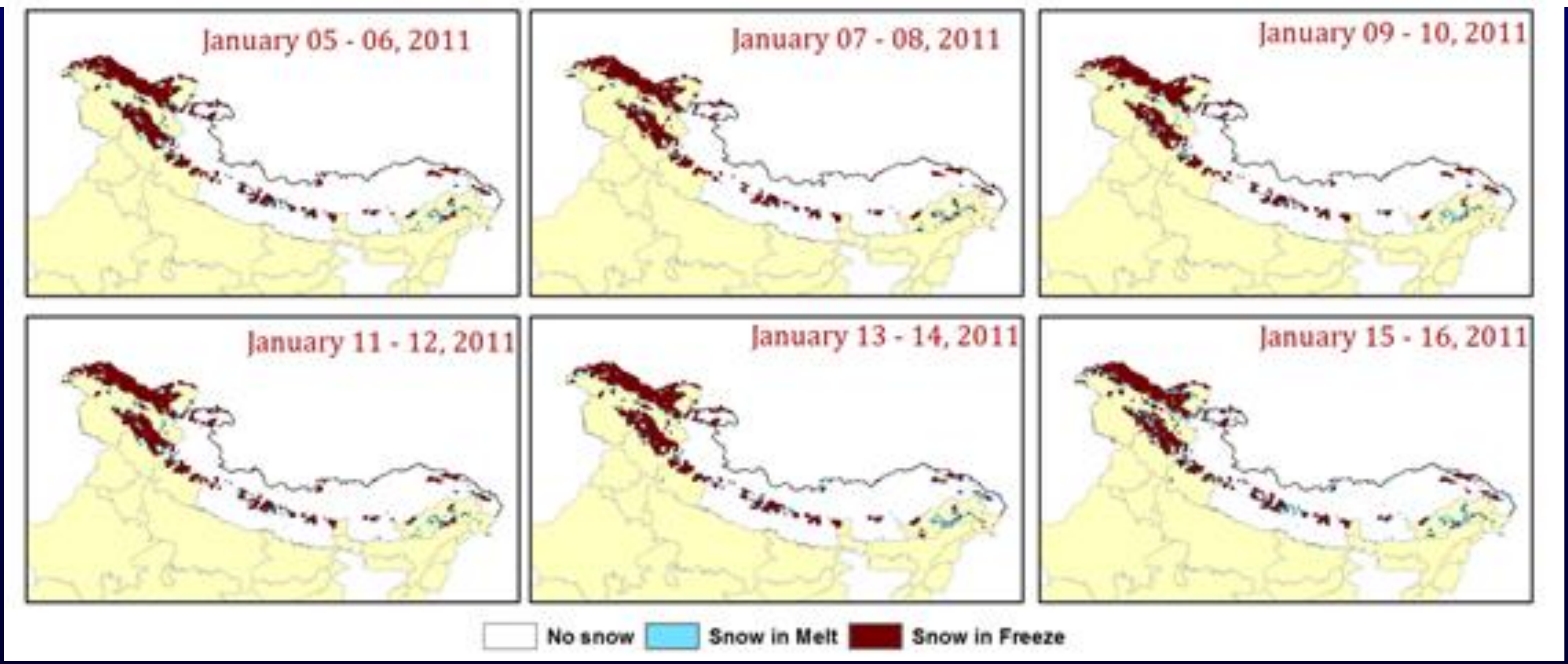


	Area (sq.km)	Area (%)
Maximum	16,07,318	38
Minimum	84,609	2
Mean	6,09,901	15

Satellite Remote Sensing Applications in Water Resources

Snow Melt / Freeze

- Indian Himalayas (J&K to Arunachal Pradesh), 0.9 M sq km (covering Nepal, Bhutan, Tibet and India)
- 4 zones – Upper, Western, Central and Eastern Himalaya
- OSCAT data enhanced resolution images available at 2.225 km resolution
- Oceansat2 satellite, Ku band (13.73 GHz) pencil beam scatterometer, HH and VV polarizations, once in two days, 57^0 (VV), 49^0 (HH)
- SRTM DEM
- AWS data from CEOP (Coordinated energy and water cycle observation project)

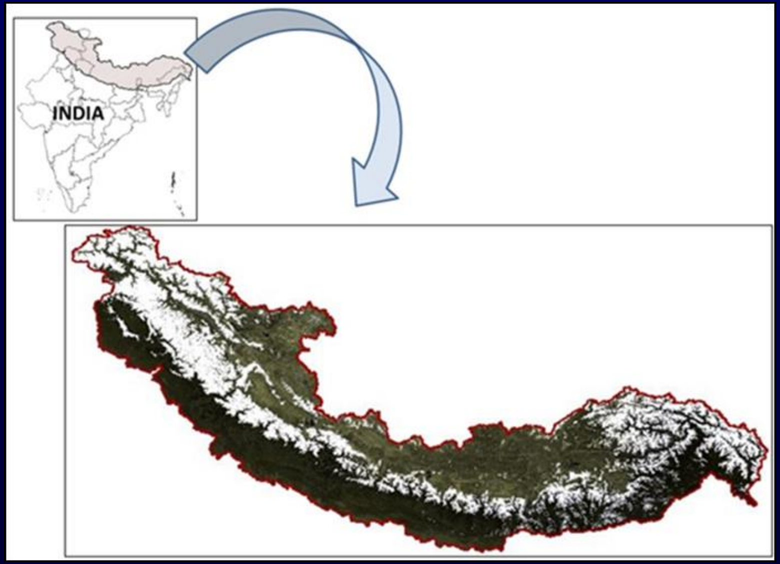


Snowmelt Runoff Modelling

- Snowmelt runoff forecast is critical input for reservoir managers in allocating the water resources for drinking water supply, irrigation and industrial purposes particularly during summer months
- NRSC has been involved in snowmelt runoff modelling and forecasting for the past 2 decades
- Improved snowmelt runoff methodologies from empirical approach to energy Balance approach
- Snowmelt runoff forecasting has been extend from 5 to 16 basins covering entire Indian Himalayas
- Improvement in short-term snowmelt forecasting period from 16-days to 3-days during April-June months

Study Area

- **Indian Himalayas covering Major river systems (Indus, Ganga and Brahmaputra) including outside Indian boundary**



Snowmelt Runoff Modelling

Input Data Used	Source
Snow Cover Area	Suomi-NPP derived daily data
Snow Albedo	Suomi-NPP derived daily data
Snow Surface Temperature	Suomi-NPP derived daily data
Incoming Solar Radiation	f(Julian day, lat, long, elevation, slope, aspect)
Aerosol Optical Depth	INSAT-3D Imager Half-hourly data
Cloud Cover	INSAT-3D Imager Half-hourly data
Water Vapour, Ozone	INSAT-3D Sounder Hourly data
Land Cover	AWiFS satellite data
DEM	Cartosat / SRTM data
Discharge, Rainfall	CWC- Field data

Snowmelt Runoff Modelling

DEM
f(Elevation, slope, aspect, Julian day)

Incoming Surface Shortwave Radiation
(without considering atmospheric and land cover effects)

Incoming Surface Shortwave Radiation
(atmospheric transmission effects)

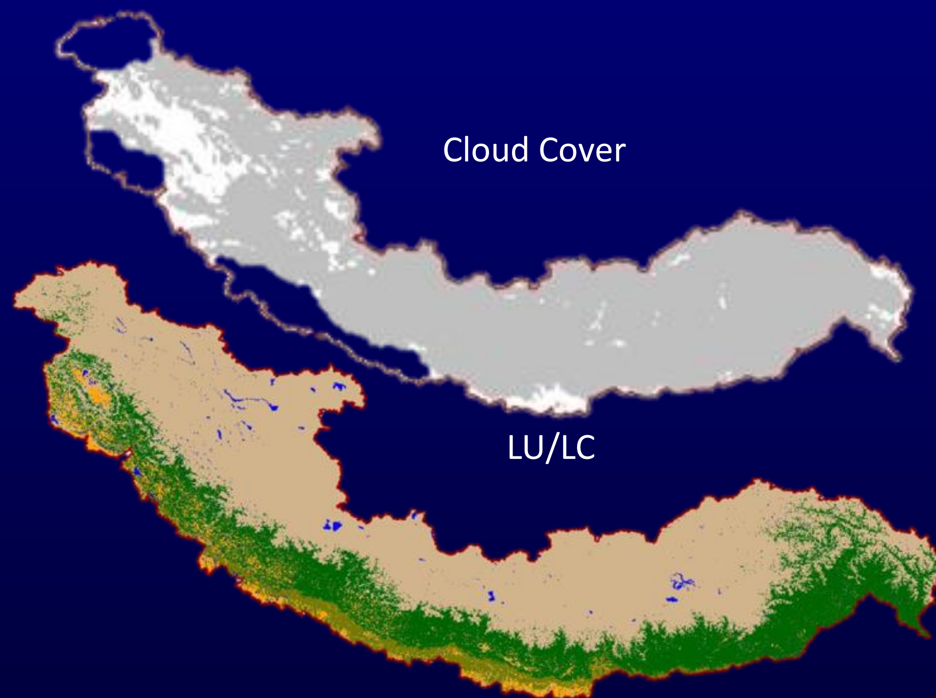
Incoming Surface Shortwave Radiation
(Cloud cover effect)

Incoming Surface Shortwave Radiation
(Land cover effect)

Outgoing Shortwave Radiation
(Snow albedo)

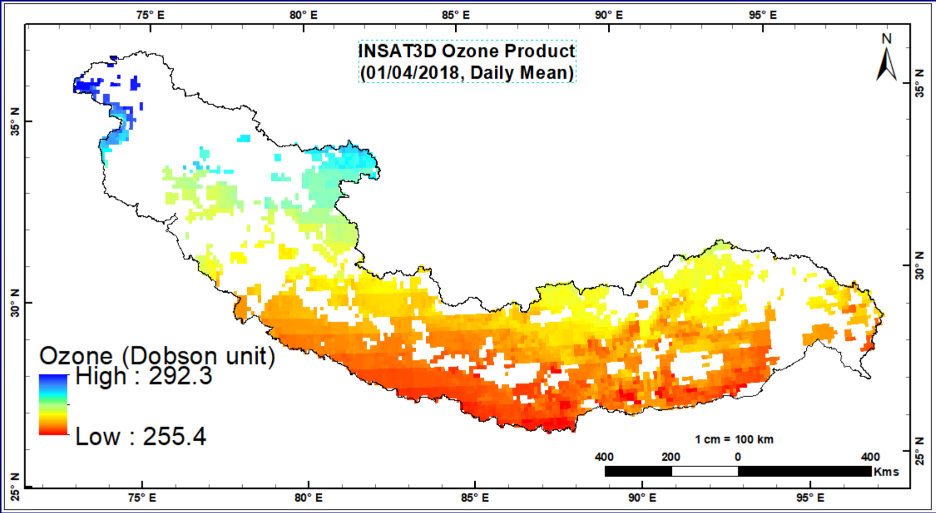
Net Surface Shortwave Radiation

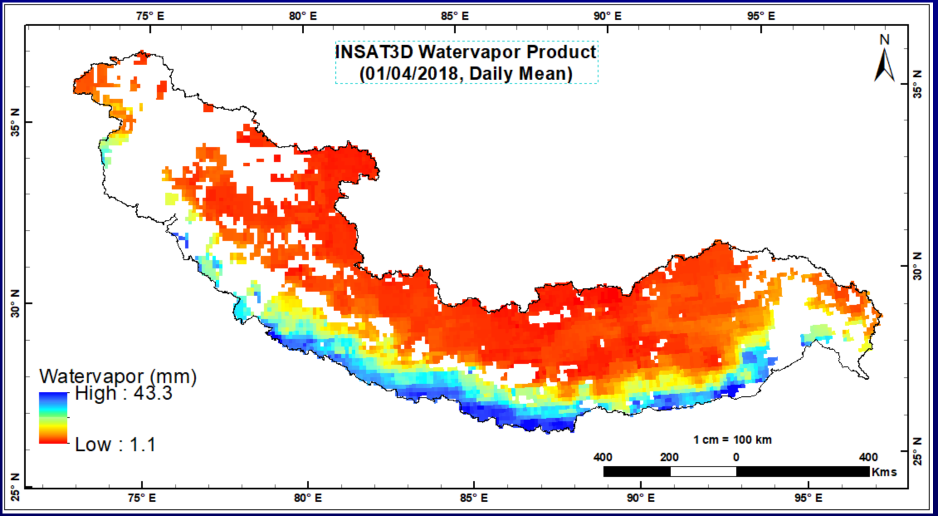
Shortwave Radiation

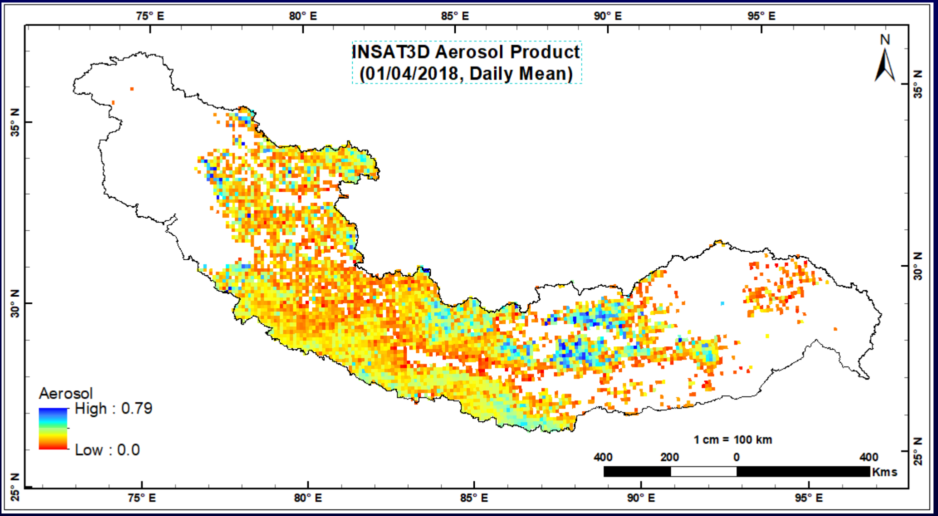


Snowmelt Runoff Modelling

Atmospheric Constituents – Effects on incoming Solar Radiation

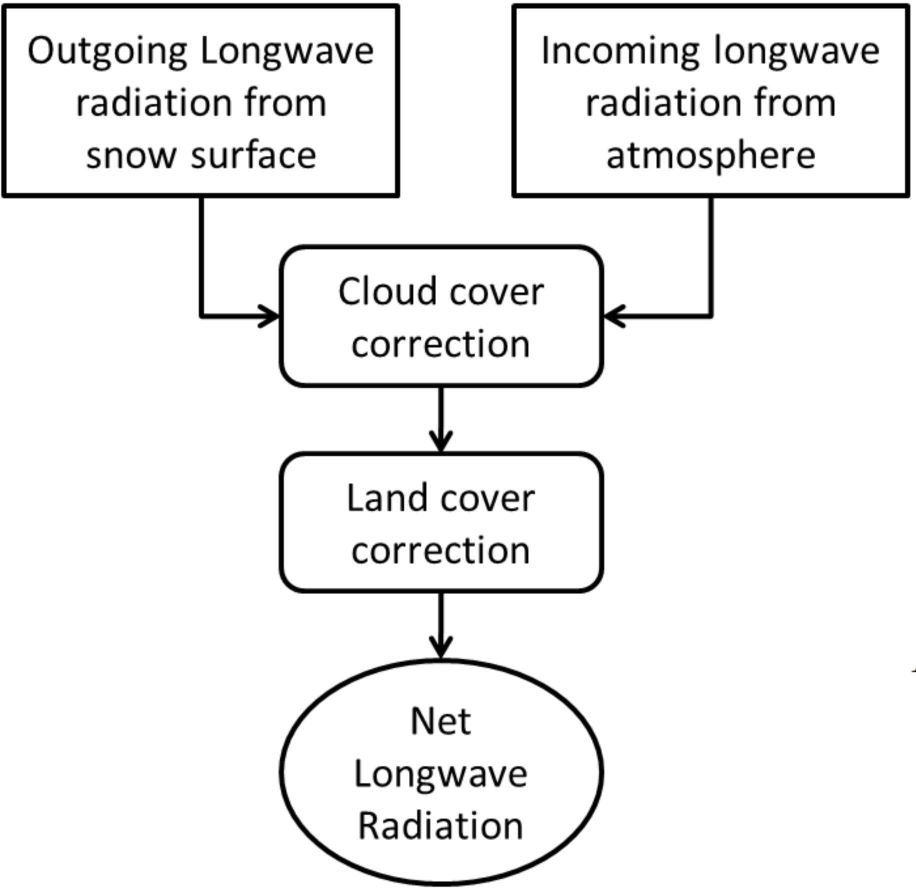






Snowmelt Runoff Modelling

Longwave Radiation



Incoming Longwave Radiation

$$LW_{in} = \sigma * \varepsilon_{air} * T_{air}^{4}$$

σ Stefan Boltzmann Constant ($5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$)

ε_{air} Emissivity of air

T_{air} Air Temperature

Outgoing Longwave Radiation

$$LW_{out} = \sigma * \varepsilon_{snow} * T_{lst}^{4} + LW_{in}(1 - \varepsilon_{snow})$$

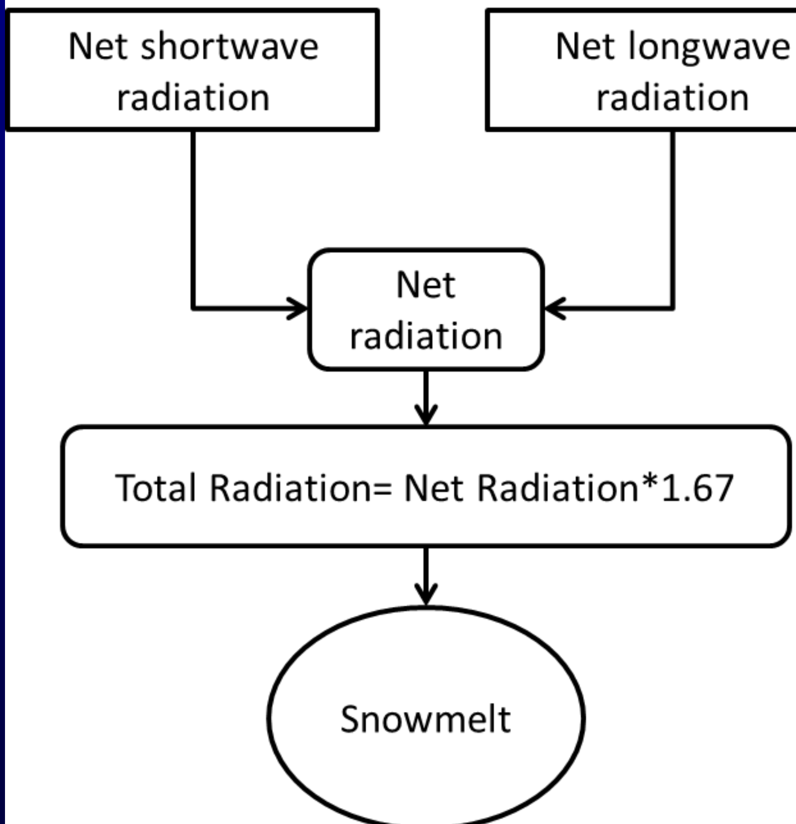
σ Stefan Boltzmann Constant ($5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$)

ε_{snow} Emissivity of snow

T_{lst} Snow Surface Temperature

Snowmelt Runoff Modelling

Methodology for Snowmelt Calculation

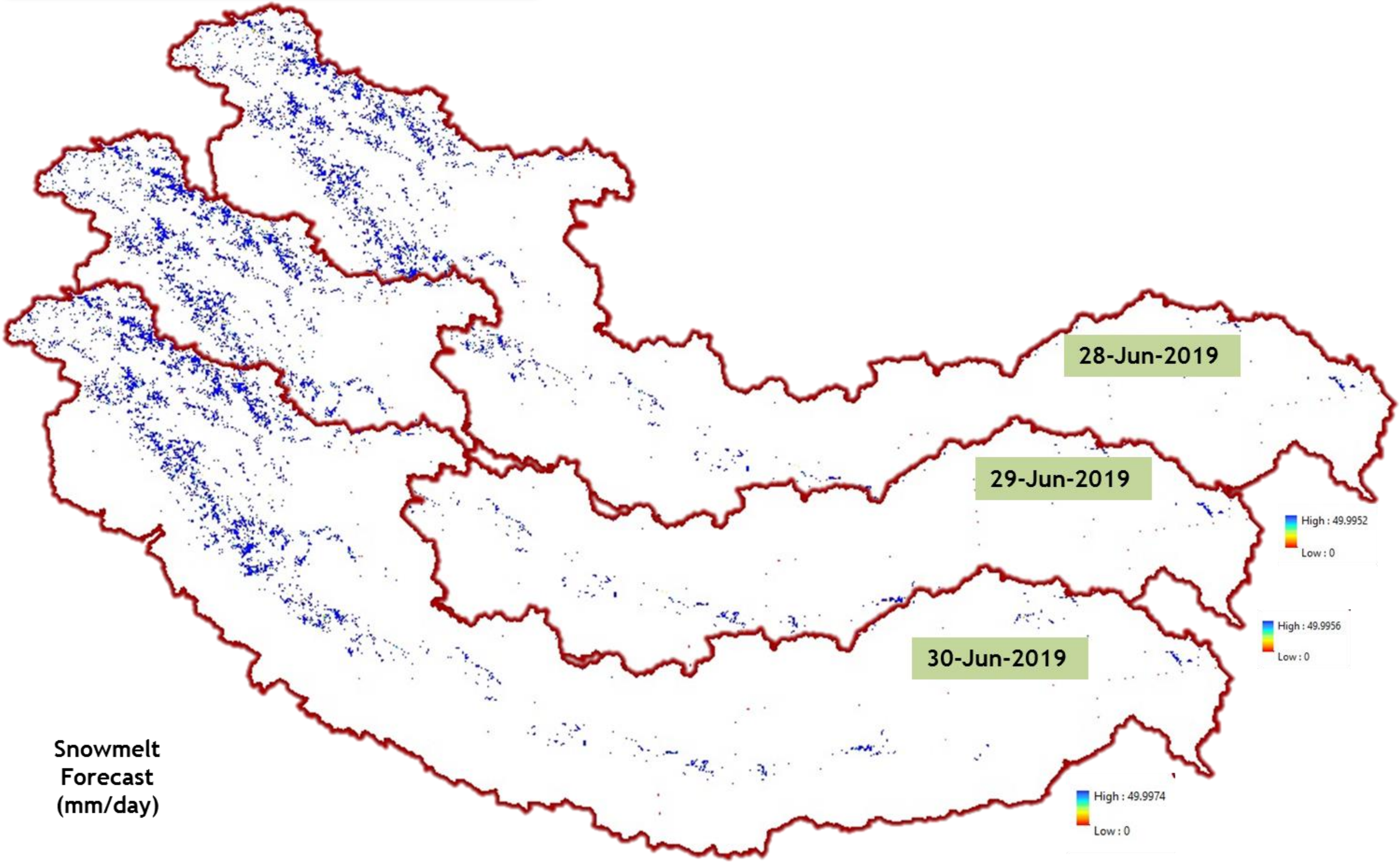


$$M = \frac{Q_m}{334.9 * \rho_w * B}$$

M	Depth of Snowmelt (mm)
Q_m	Total Energy available at snowpack for snowmelt (kJ/m2)
B	thermal quality of the snow (ratio of heat required to melt a unit weight of the snow to that of ice at 0 degree Celsius).
ρ_w	Density of water kg/m3.
334.9	Latent heat of fusion of ice kJ/Kg

Snowmelt Runoff Modelling

Snowmelt Runoff Forecast



Glacial Lake Monitoring

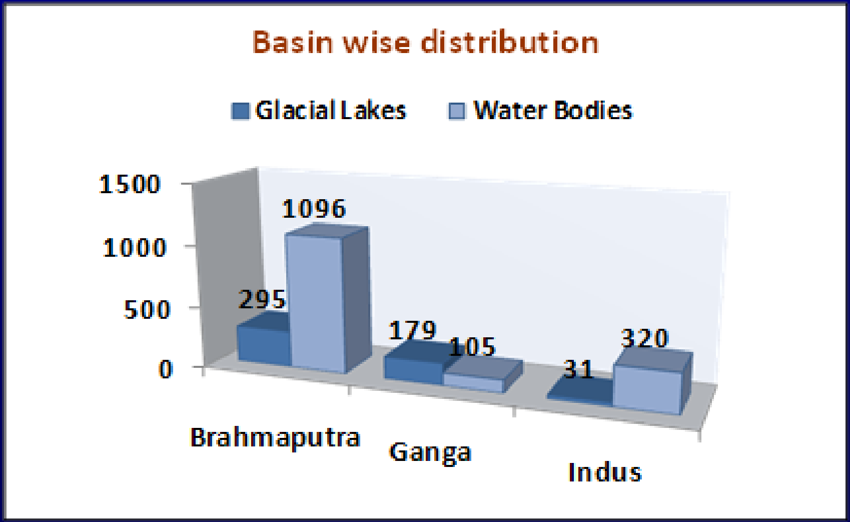
Glacial Lake

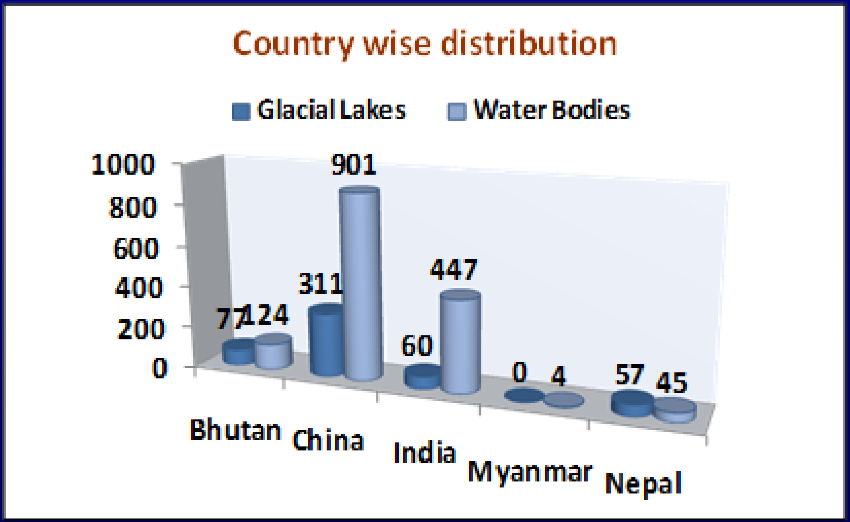
A glacial lake is defined as a water mass existing in a sufficient amount and extending with a free surface beside and/or in front of a glacier and originated by glacier activities and/or retreating processes of a glacier.

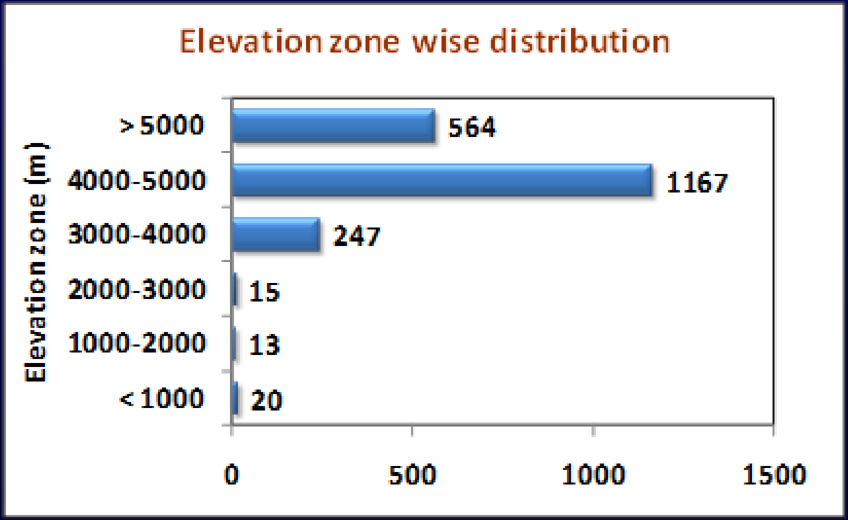
Periodic or occasional release of large amounts of stored water in a catastrophic outburst flood is widely referred to as a Glacial Lake Outburst Flood (GLOF)

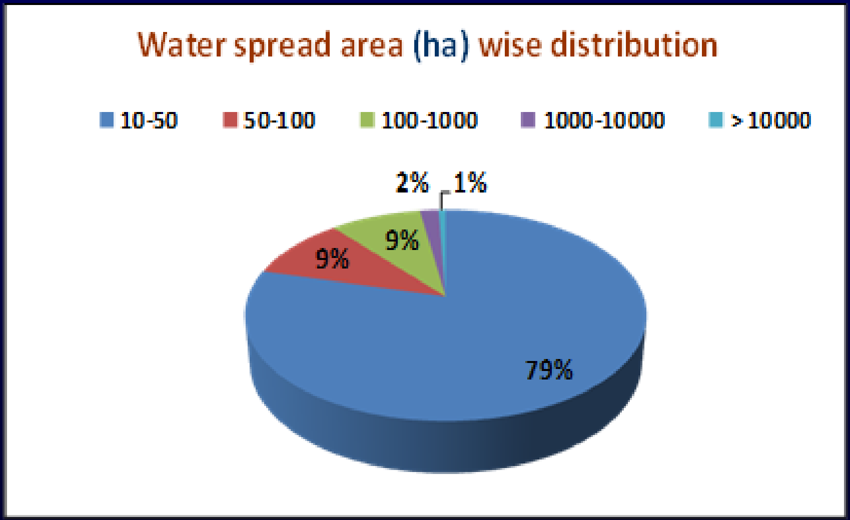
Inventory and Monitoring of Glacial Lakes in Indian Himalayas

- Prepared inventory of glacial lakes & water bodies > 10 Ha during 2009
- Monitoring of the glacial lakes & water bodies > 50 Ha on monthly basis during June to October months for 2011 to 2015 (5 years) completed and being continued by CWC





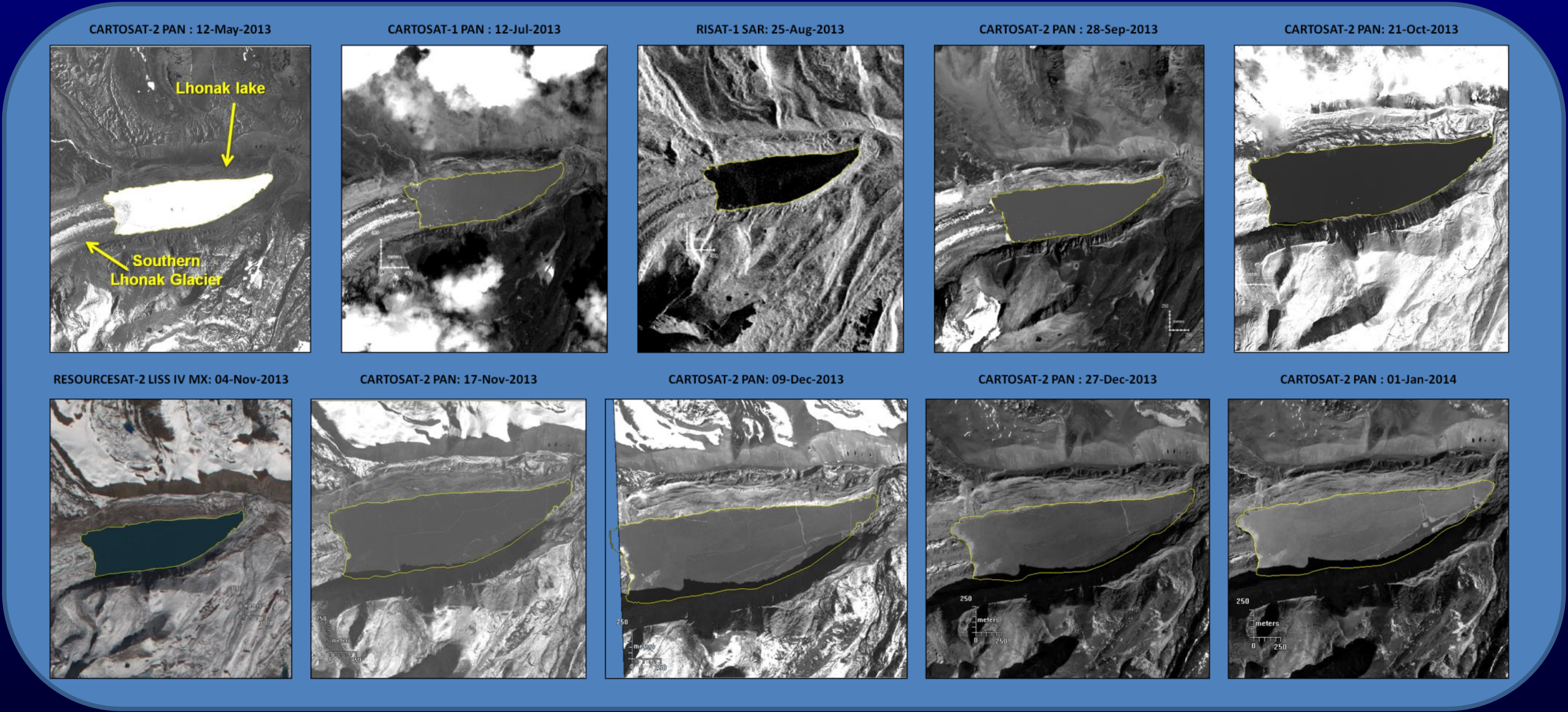




Glacial Lake Monitoring

- Monitoring the spatial extent of the glacial lakes
- Monthly basis (June to October) for 5 years (2011-15)
- Close monitoring with high resolution images

Lhonak lake in Sikkim



GLOF Risk Assessment of Glacial Lakes in Indian Himalayas

Background

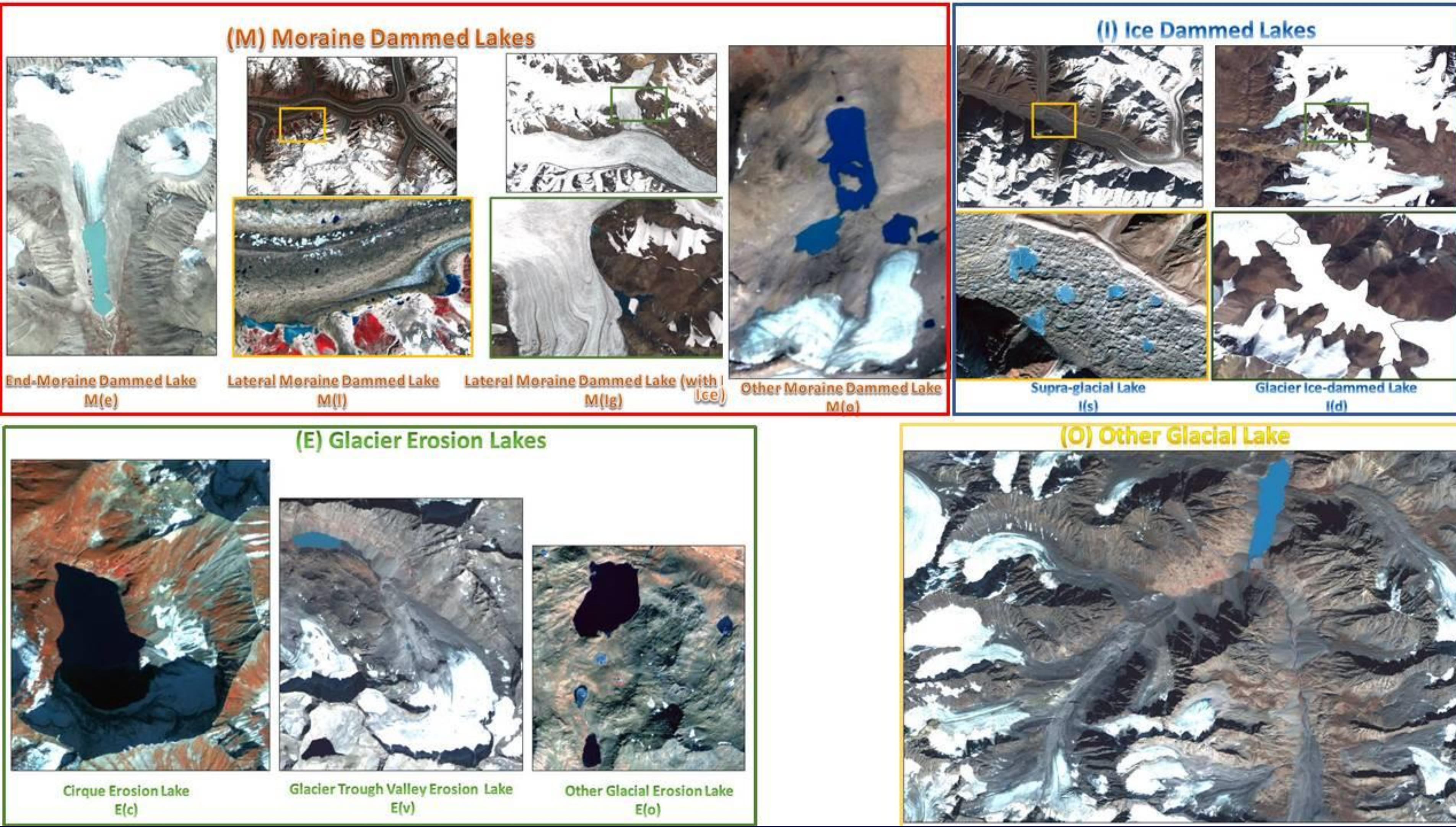
- Glacial Lake Outburst Flood (GLOF) is a type of outburst flood that occurs when the moraines blocking a glacial lake fails due to its unstable nature of the material
- Information on glacial lakes in Indian Himalayas is important for identifying the critical lakes which are prone to GLOF for disaster risk reduction

Inventory of Glacial Lakes

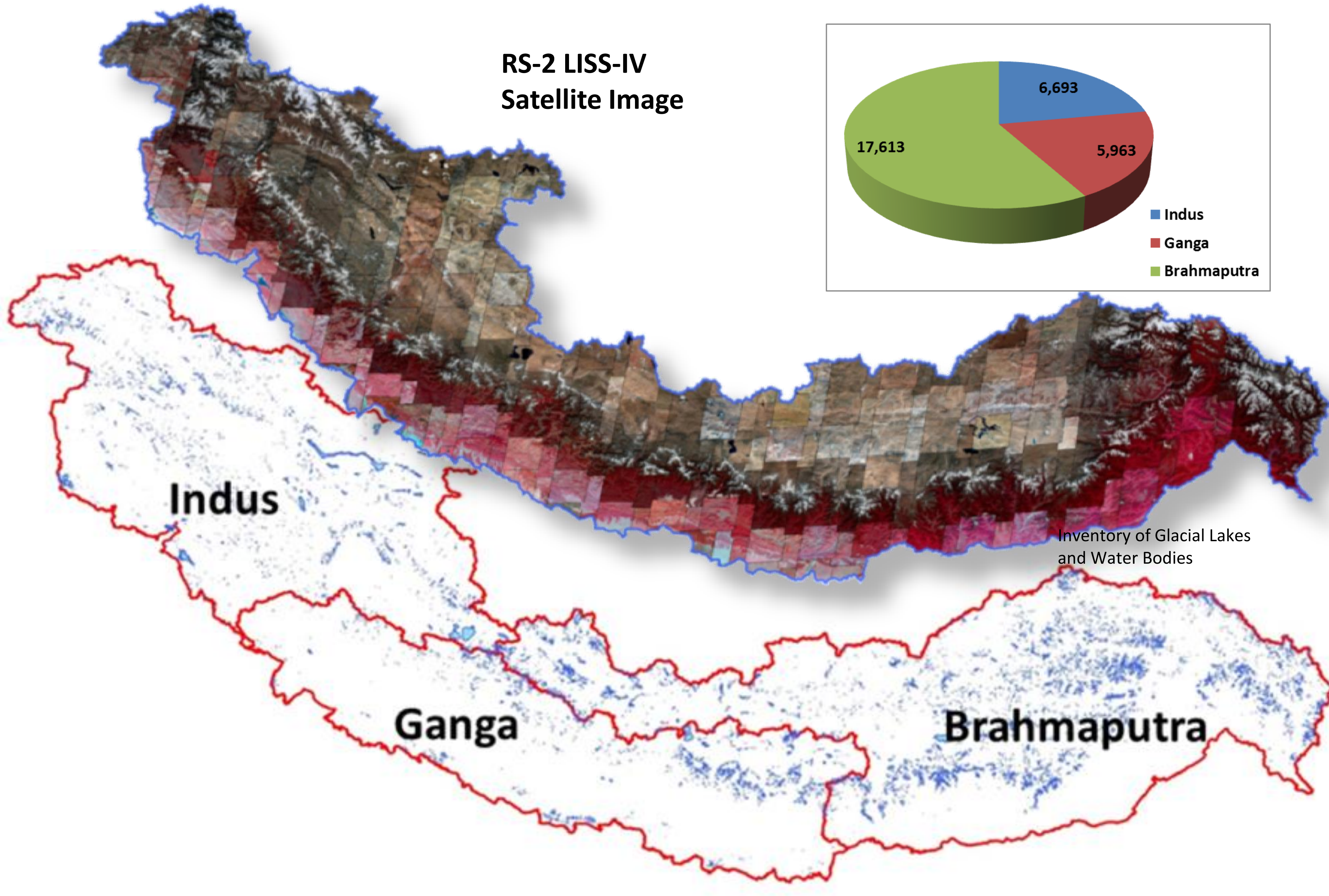
- Inventory of glacial lakes (> 0.25 ha) are prepared using RS-2 LISS-IV satellite data covering catchment areas of rivers originating from Indian Himalayas
- Generated about 21 hydrological, topographical and other attributes of glacial lakes
- Glacial lakes of 4 types (10 sub-types) were identified from the satellite image

GLOF Risk Assessment of Glacial Lakes in Indian Himalayas

Type of Glacial Lakes

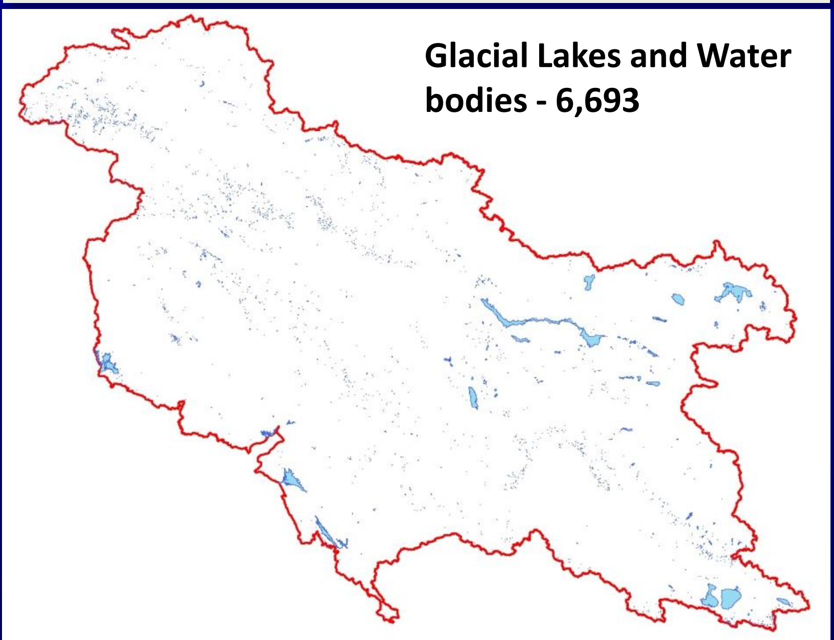


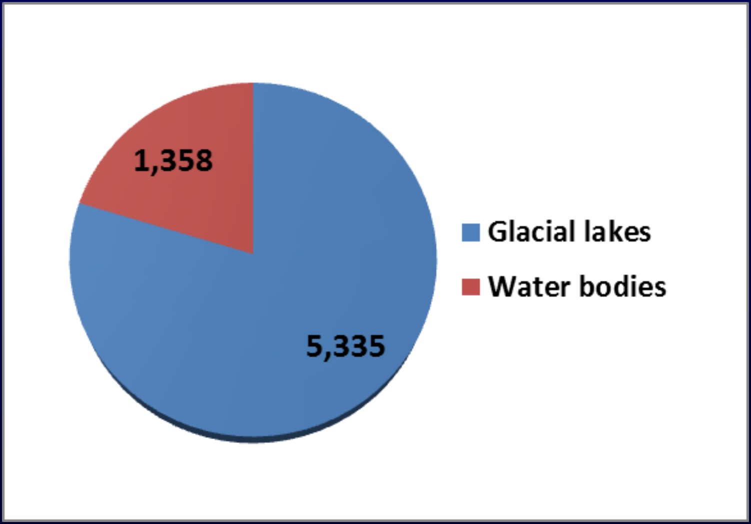
GLOF Risk Assessment of Glacial Lakes in Indian Himalayas



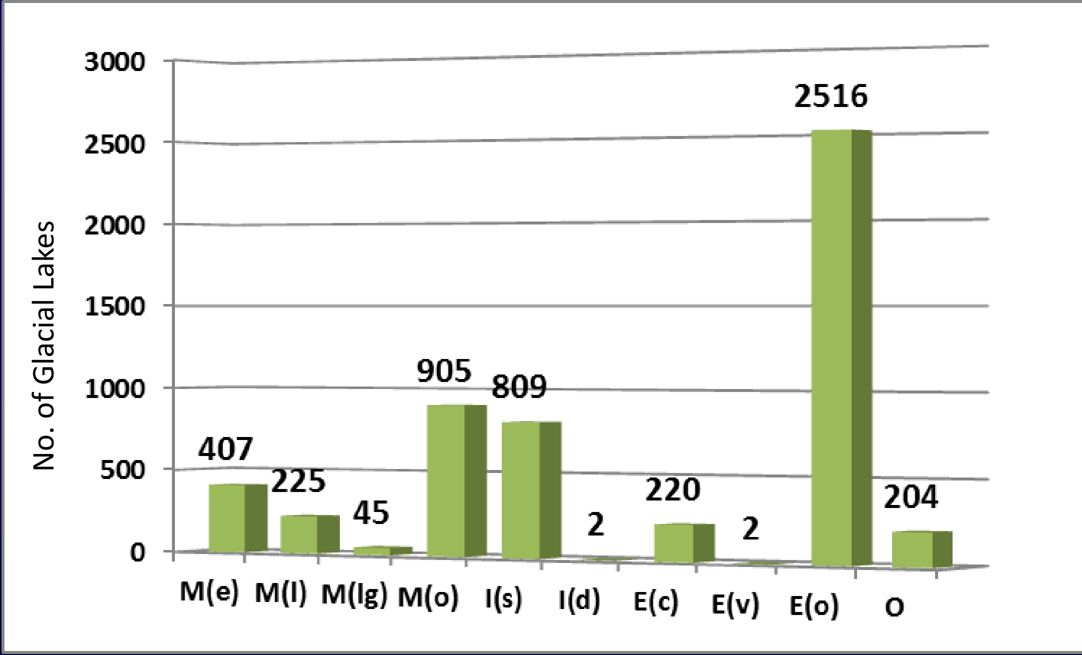
GLOF Risk Assessment of Glacial Lakes in Indian Himalayas

Glacial Lakes in Indus Basin





M(e): End-moraine
M(l): Lateral-moraine
M(lg): Lateral-moraine(ice)
M(o): Other-moraine
I(s): Supra-glacial
I(d): Ice-dammed
E(c): Cirque-erosion
E(v): Erosion trough valley
E(o): Other erosion
O: Other glacial



GLOF Risk Assessment of Glacial Lakes in Indian Himalayas

Step 1: Preliminary Screening

1. **Lake Type**
2. **Lake Area > 1 ha**
3. **Glacier Association**
4. **Contributing to WB (w/o Sett.)**

Screening:

1. Based on **Type: (Moraine, Supra, Cirque**)
   - **M(e):** End-moraine Dammed Lake
   - **M(l):** Lateral-moraine Dammed Lake
   - **M(lg):** Lateral-moraine Dammed Lake (with ice)
   - **M(o):** Other-moraine Dammed Lake
   - **I(s):** Supra-glacial Lake
   - **I(d):** Ice-dammed Lake
   - **E(c):** Cirque-erosion Lake
2. Based on **Area > 1ha**
3. Based on **Glacier Association**:
   - M(e), M(lg) – Already associated
   - M(l), M(o) – Check glacier association
   - I(s) – Closely-spaced in Valley Glacier (>2 nos. within 500m from upstream of snout)
   - E(c) – Glacier Association + Steep Hanging Glacier (> 15^{o} or > 33.3%)

Step 2: Ranking

1. **Lake Type**
2. **Lake Area**
3. **Lake distance from associated Glacier Snout**
4. **Slope between Glacier Snout and Lake**
5. **Distance of Lake from Settlement/Infrastructure**
6. **Slope b/w Glacial Lake and Settlement/Infrastructure**

GLOF Risk Assessment of Glacial Lakes in Indian Himalayas

Preliminary Screening and Prioritization of Glacial Lakes

Indus Basin

Total no. of Glacial Lakes	Based on Type	Based on Area (> 1 ha)	Based on Glacier Association	Based on Contribution to WB (w/o sett.)
5,335	2,613	1,049	652	614

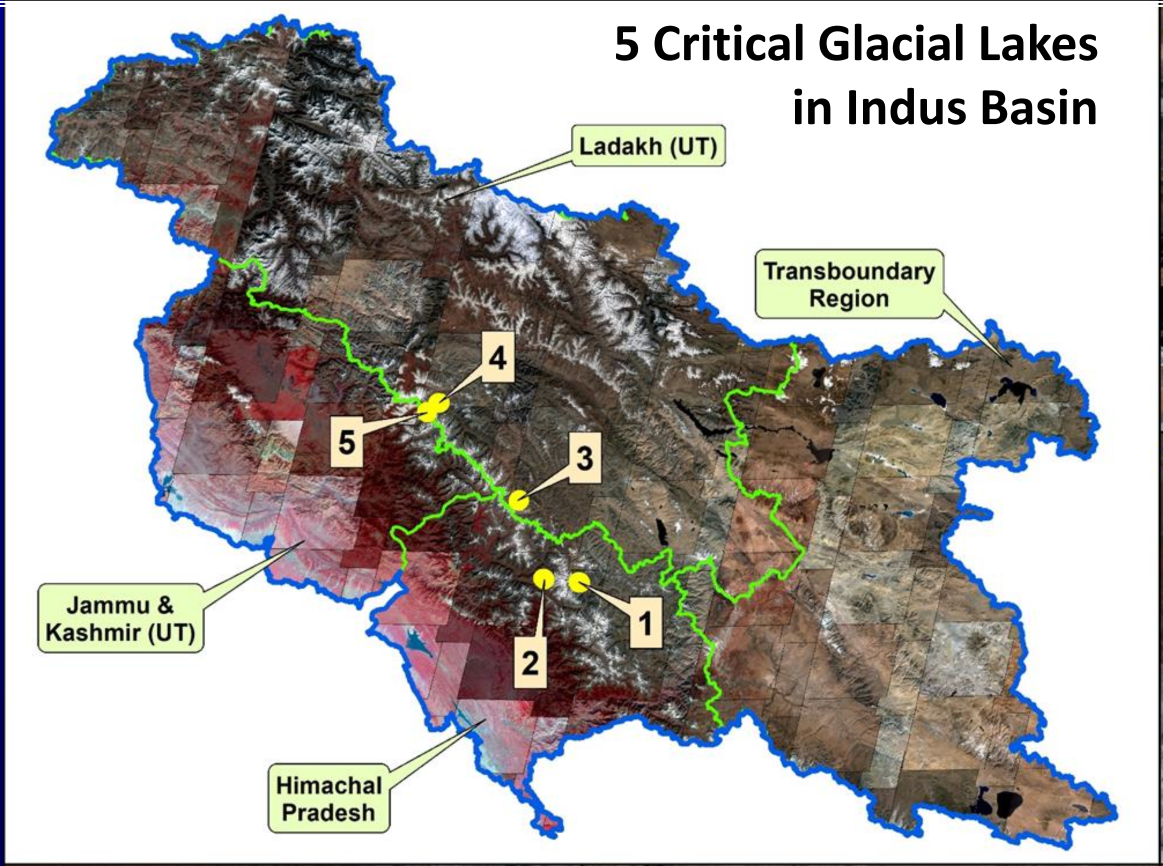
Ganga Basin

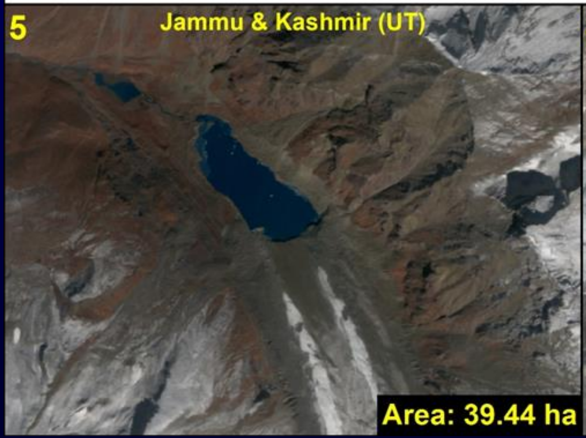
Total no. of Glacial Lakes	Based on Type	Based on Area (> 1 ha)	Based on Glacier Association	Based on Contribution to WB (w/o sett.)
4,707	2,933	1,339	942	784

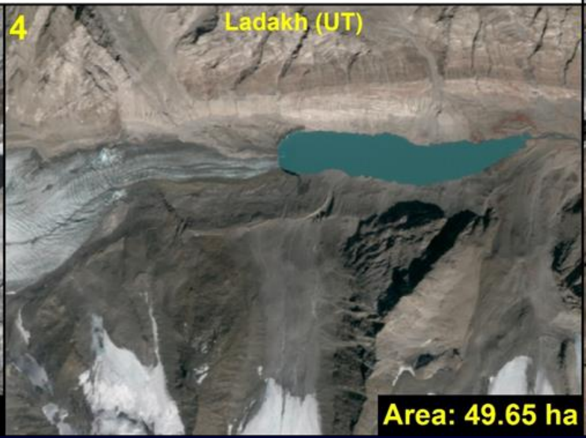
Assessment of Potentiality for Ranking of Glacial Lakes: Results

- Index Approach
  - Equal Weight Method
  - Unequal Weight Method
- Analytical Hierarchy Process
- Qualitative Analysis

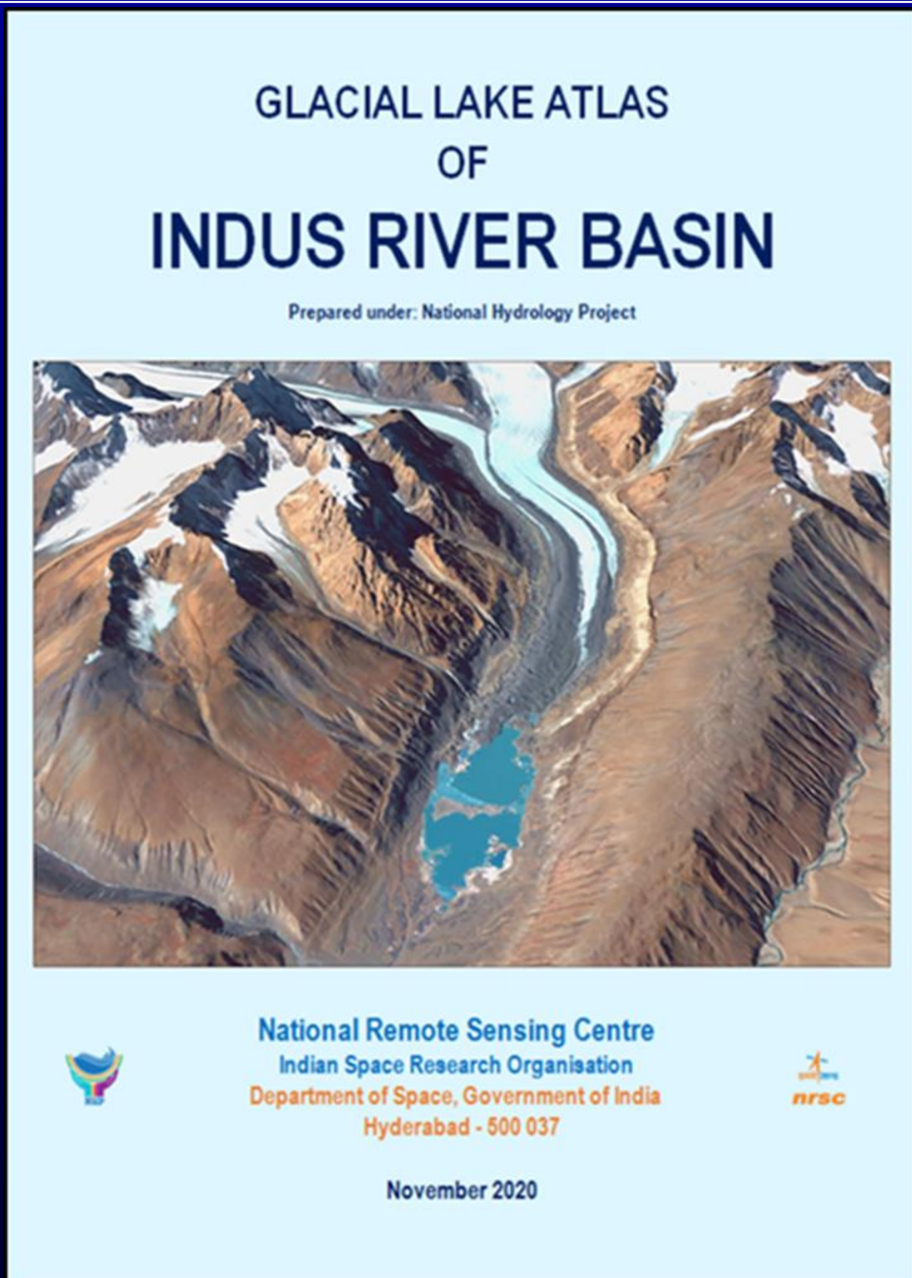
GLOF Risk Assessment of Glacial Lakes in Indian Himalayas

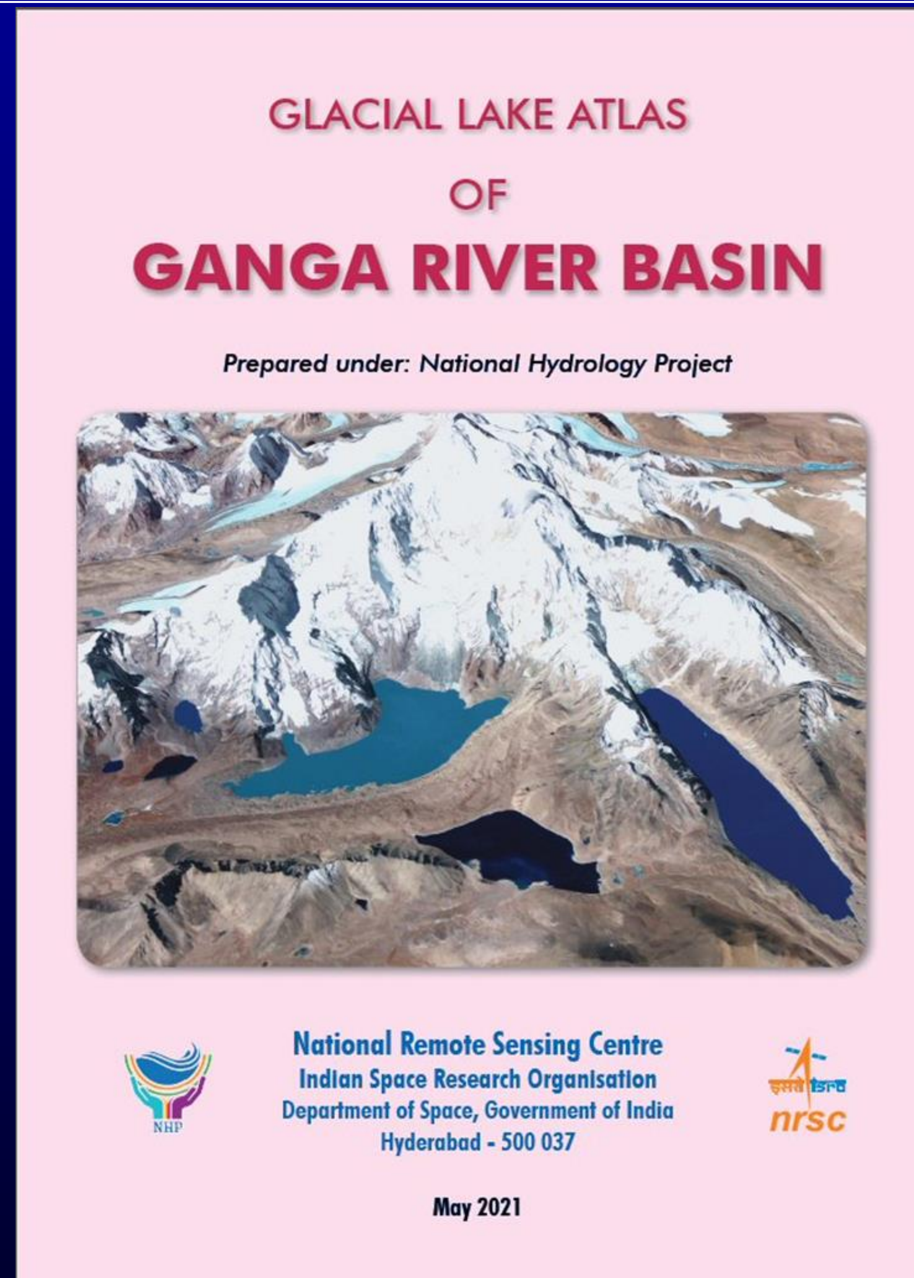






GLOF Risk Assessment of Glacial Lakes in Indian Himalayas



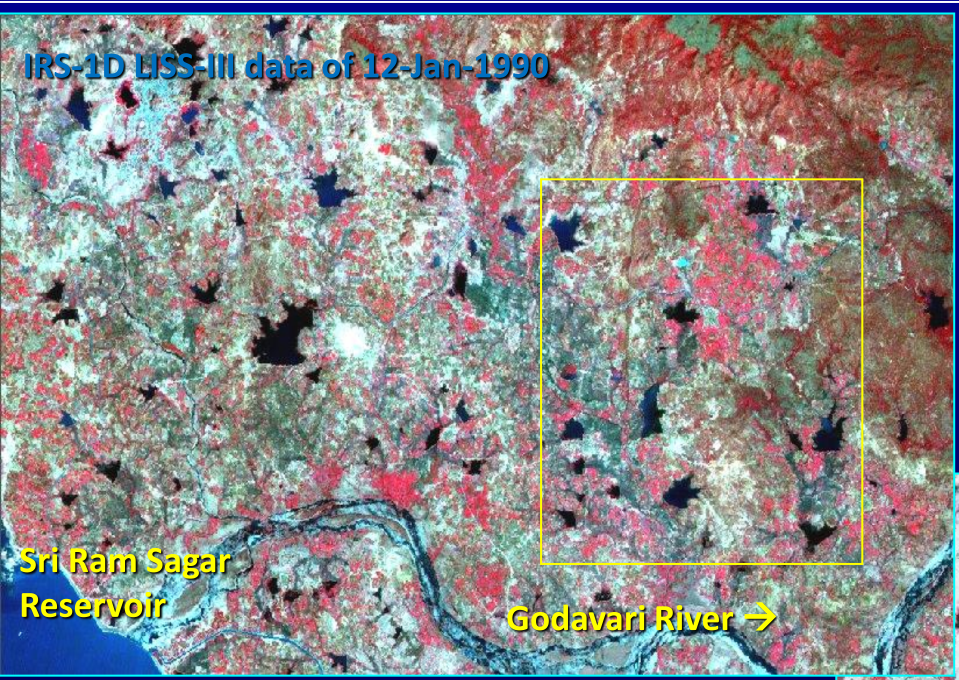


GLOF Risk Assessment of Glacial Lakes in Indian Himalayas

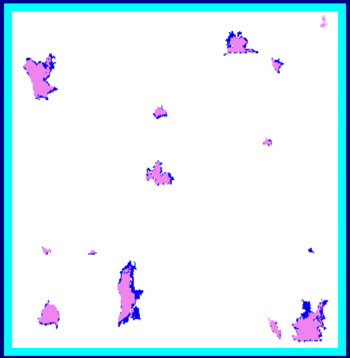
Risk Assessment of Glacial lakes

- Inventory of glacial lakes using satellite data
- Preliminary screening and Ranking of critical lakes
- Selection of Critical glacial lakes
- GLOF Modeling
  - Dam-breach analysis and flood simulation
  - Flood Inundation Maps
- Vulnerability Assessment
  - Economic Vulnerability
  - Social Vulnerability
- Risk Assessment
  - Estimation of Hazard
  - Vulnerability assessment

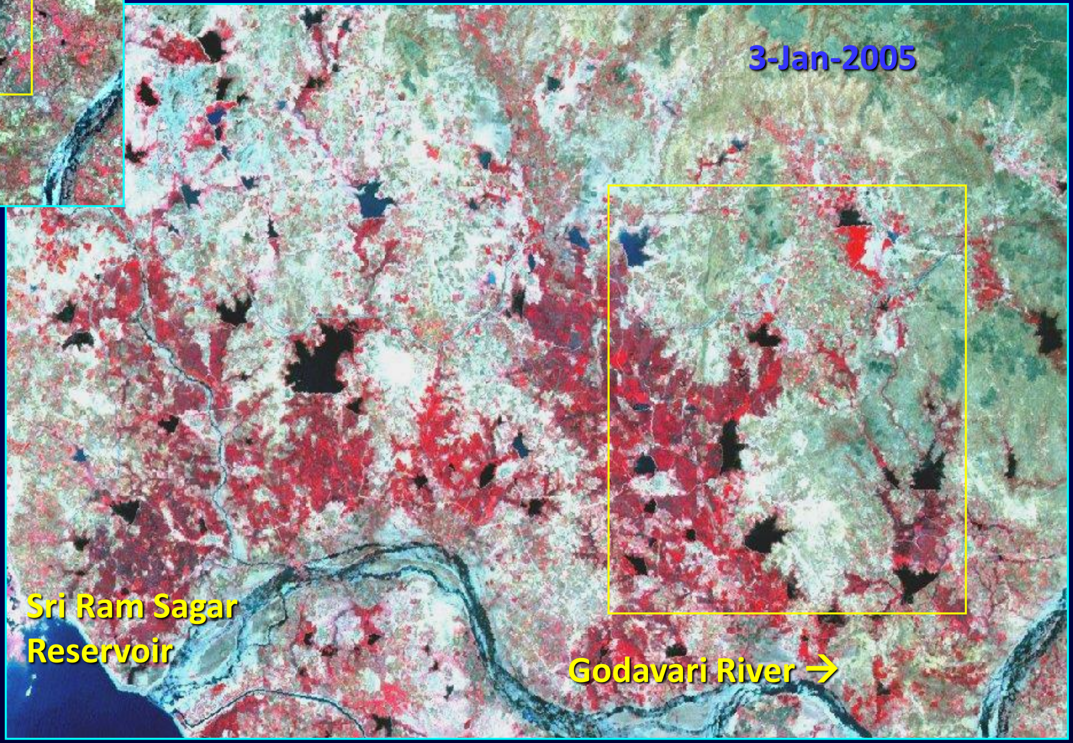
Water Bodies Mapping and Monitoring



Water Spread Area



Tank No	Water Spread (Area in hectares) 1990	2005
1	54.25	42.75
2	25.07	15.88
3	21.56	17.69
4	60.00	36.00
5	58.18	41.25

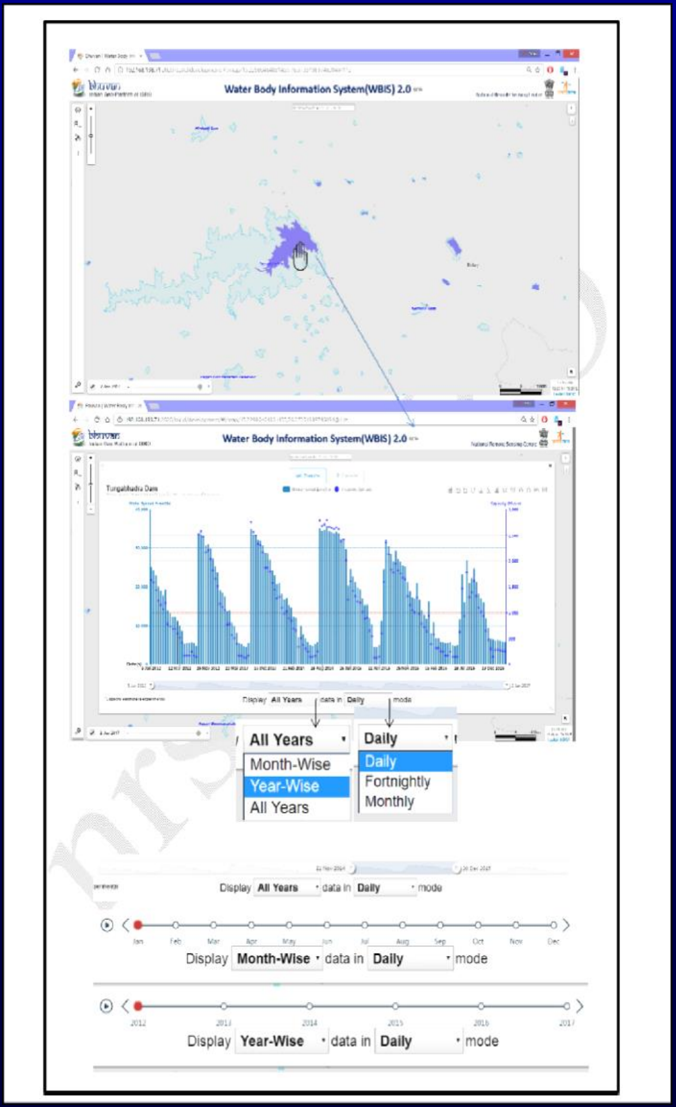


Water Bodies Information System - Bhuvan

- Water Bodies Information System (WBIS) provides a dynamic data visualization and helps in analysis surface **water spread information** of water-bodies **from year 2012**.
- Surface water bodies dynamic water spread information is available at 15 day interval (WB>2ha. in size, ~2.05 lakhs)
- Useful in **water assessment, inland fisheries potential, hydrological drought, sedimentation survey etc.**

Water bodies	No. of water bodies
> 50 ha	12,831
5- 50 ha	1,25,450
2-5 ha	86,508
1-2 ha	1,57,389
<1 ha	12,51,418+

Size wise statistics of water-bodies over entire India



Water Bodies Information System

Water Bodies Information System - Bhuvan

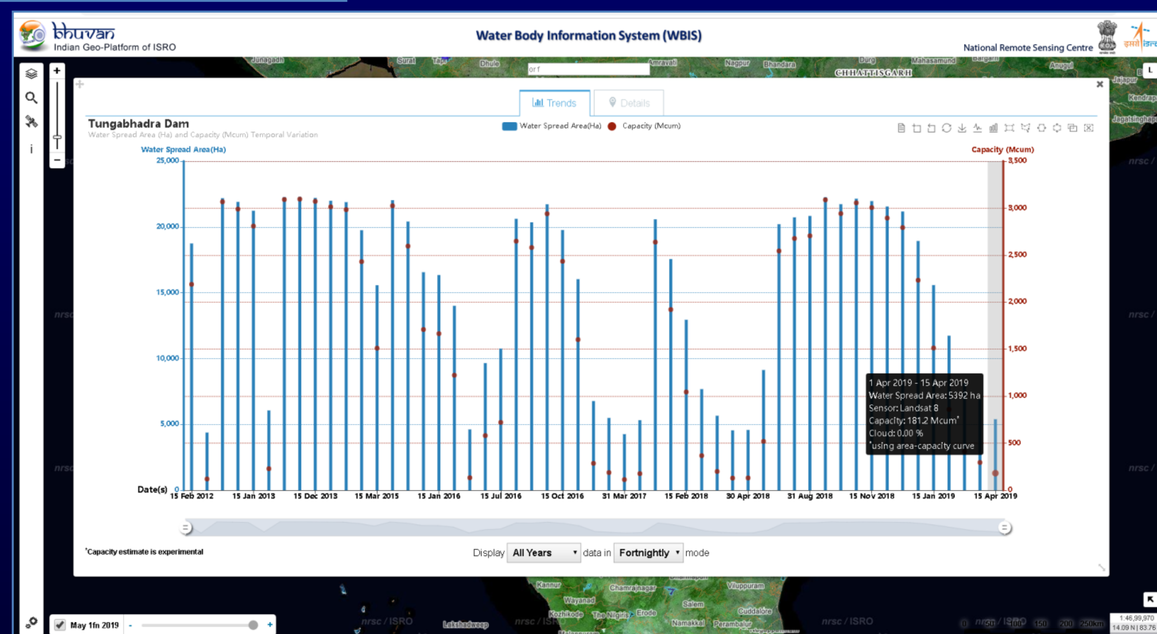
Monthly : (April 2019)

Sriram Sagar Dam:

WSA : 7692 ha

Sensor : LISS III

Capacity : 244.0 Mcum



Fortnightly: (April 1fn 2019)

Tungabhadra Dam:

WSA : 5392 ha

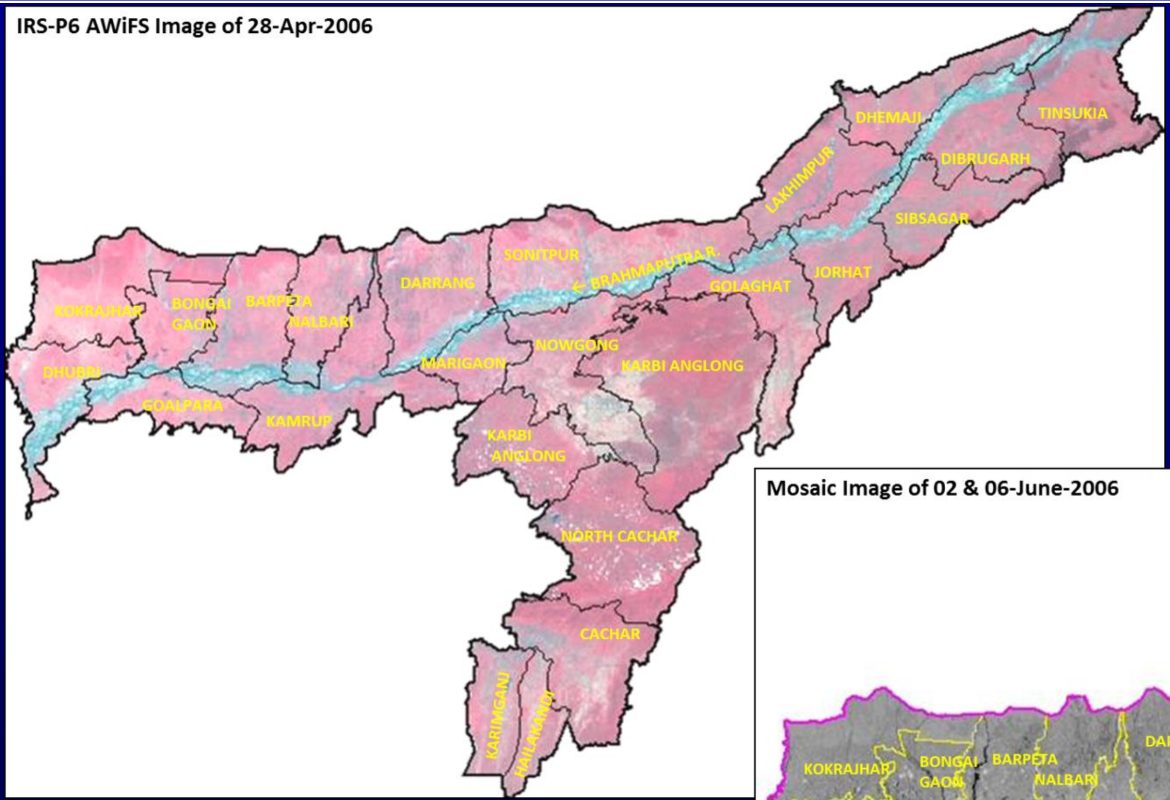
Sensor : LANDSAT 8 OLI

Capacity : 181.2 Mcum

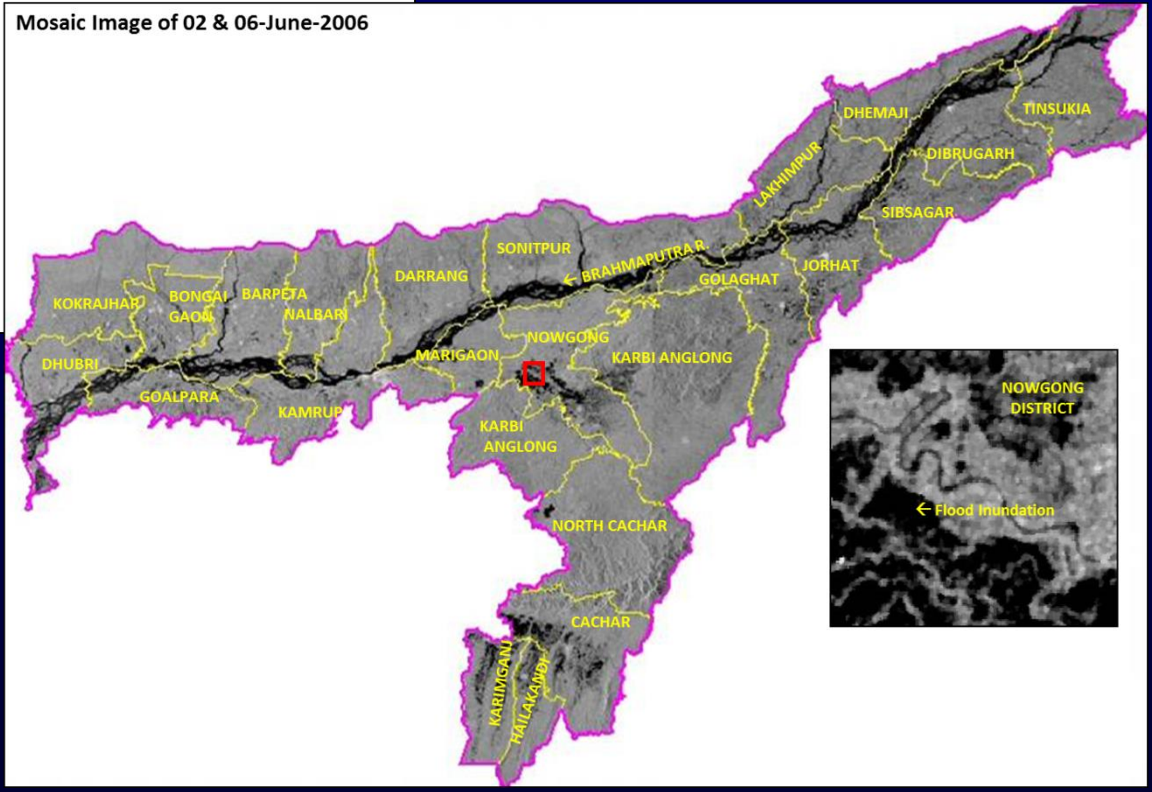
Satellite Remote Sensing Applications in Flood Management

- Flood Inundation mapping and monitoring
- Rapid and scientific based Damage Assessment
- Mapping of river configuration & flood control structures
- Detecting changes in the river course
- Identification of River Bank erosion
- Identification of chronic flood prone areas
- Flood hazard & risk assessment
- Flood Inundation Modelling
- Flood Forecasting & Spatial flood warning

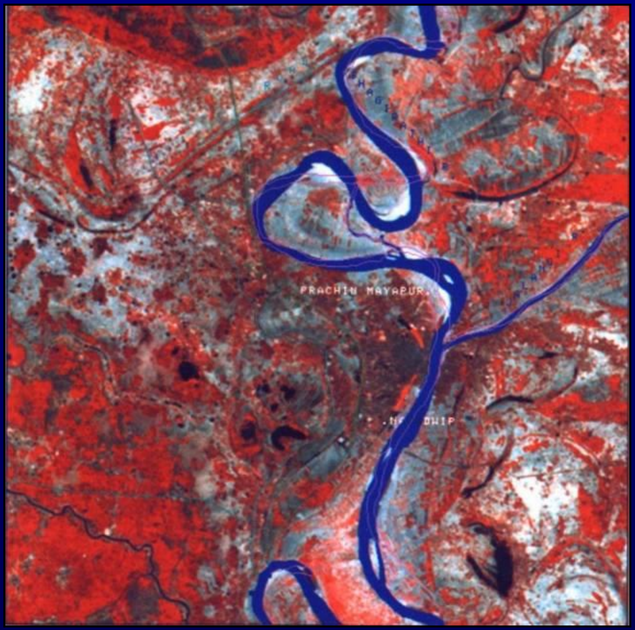
Satellite Remote Sensing Applications in Flood Management



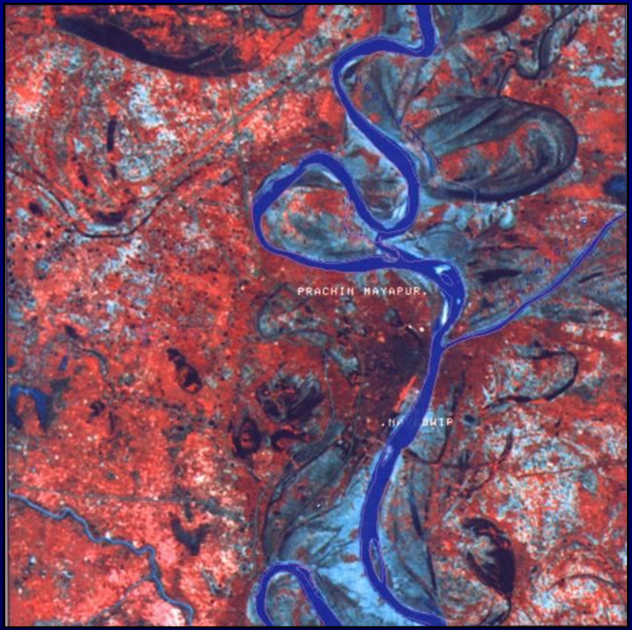
Flood Map of Assam State



Change of Bhagirathi river course near Prachin Mayapur during April 1989 and October 1990



05 Apr, 1989



11 Nov, 1989

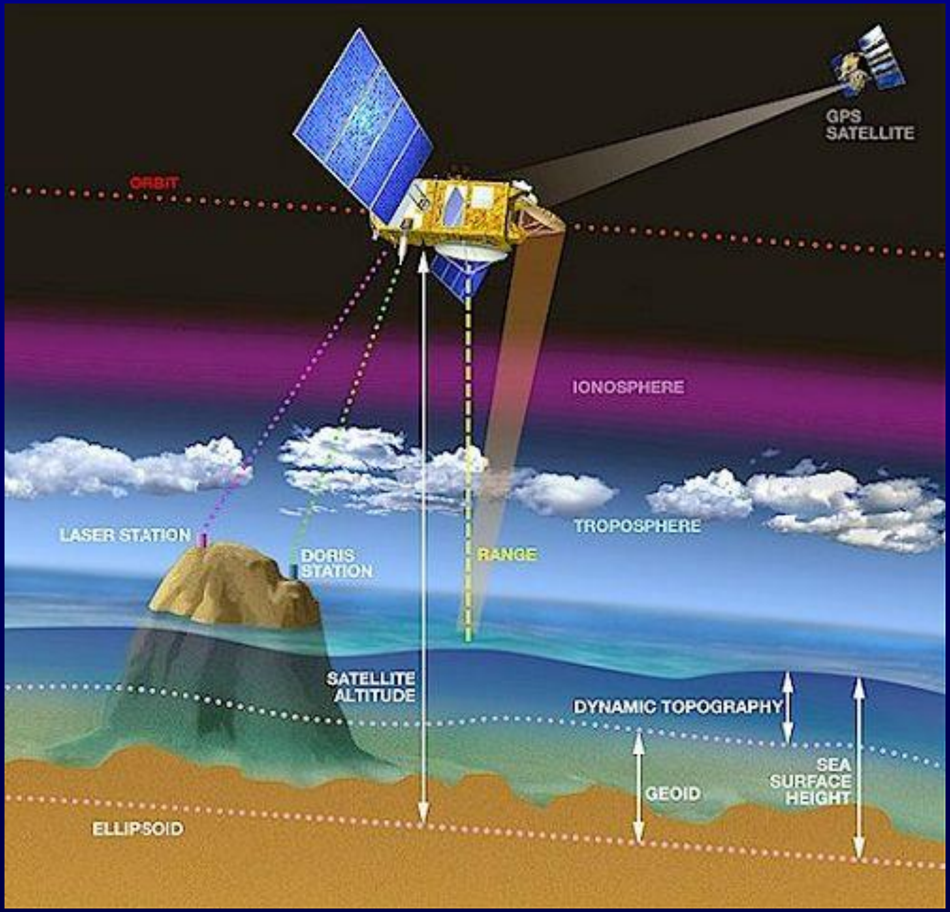
29 Oct, 1990

Satellite Remote Sensing Applications in Water Resources

Water Level Estimation

Altimeter

- **Radar altimeters on board the satellites transmit signals at high frequencies (over 1,700 pulses per second) to Earth and receive the echoes from the surface (the 'waveform').**
- **The precise measurement of the time taken to make the round trip between the satellite and the surface.**
- **EM waves travel through the atmosphere, they can be decelerated by water vapour or ionisation. Once these phenomena have been corrected for, the final range can be estimated with great accuracy.**
- **The ultimate aim is to measure surface height relative to a terrestrial reference frame. This requires independent measurements of the satellite's orbital trajectory, i.e. exact latitude, longitude and altitude coordinates.**

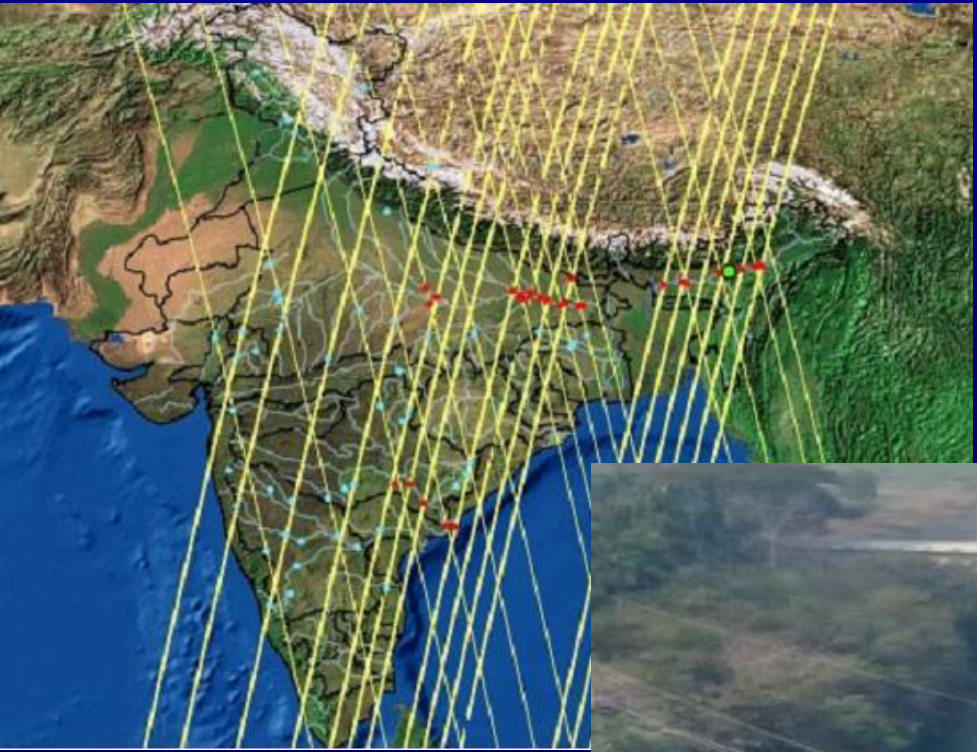


Source: http://www.altimetry.info/radar-altimetry-tutorial/how-altimetry-works/basic-principle/

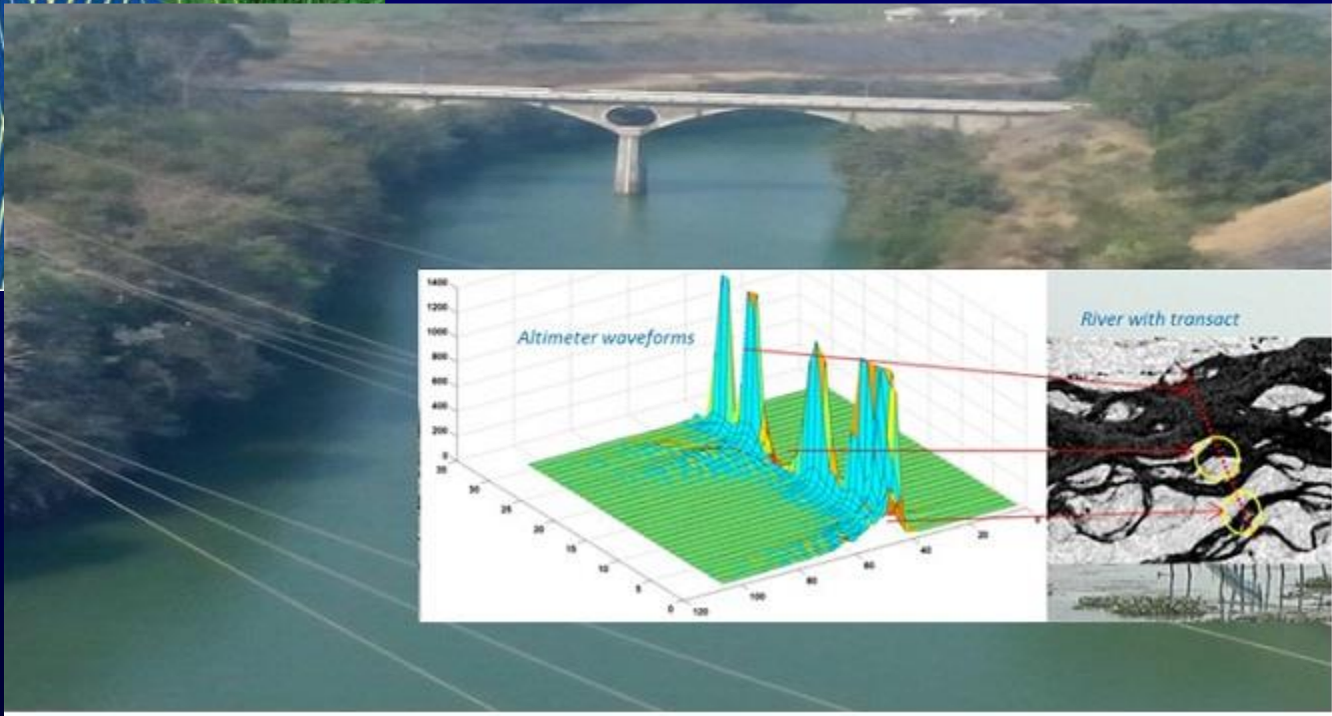
Satellite Remote Sensing Applications in Water Resources

Water Level Estimation

Altimeter



River and Reservoir Water Level Retrieval Locations along with Altimeter Tracks

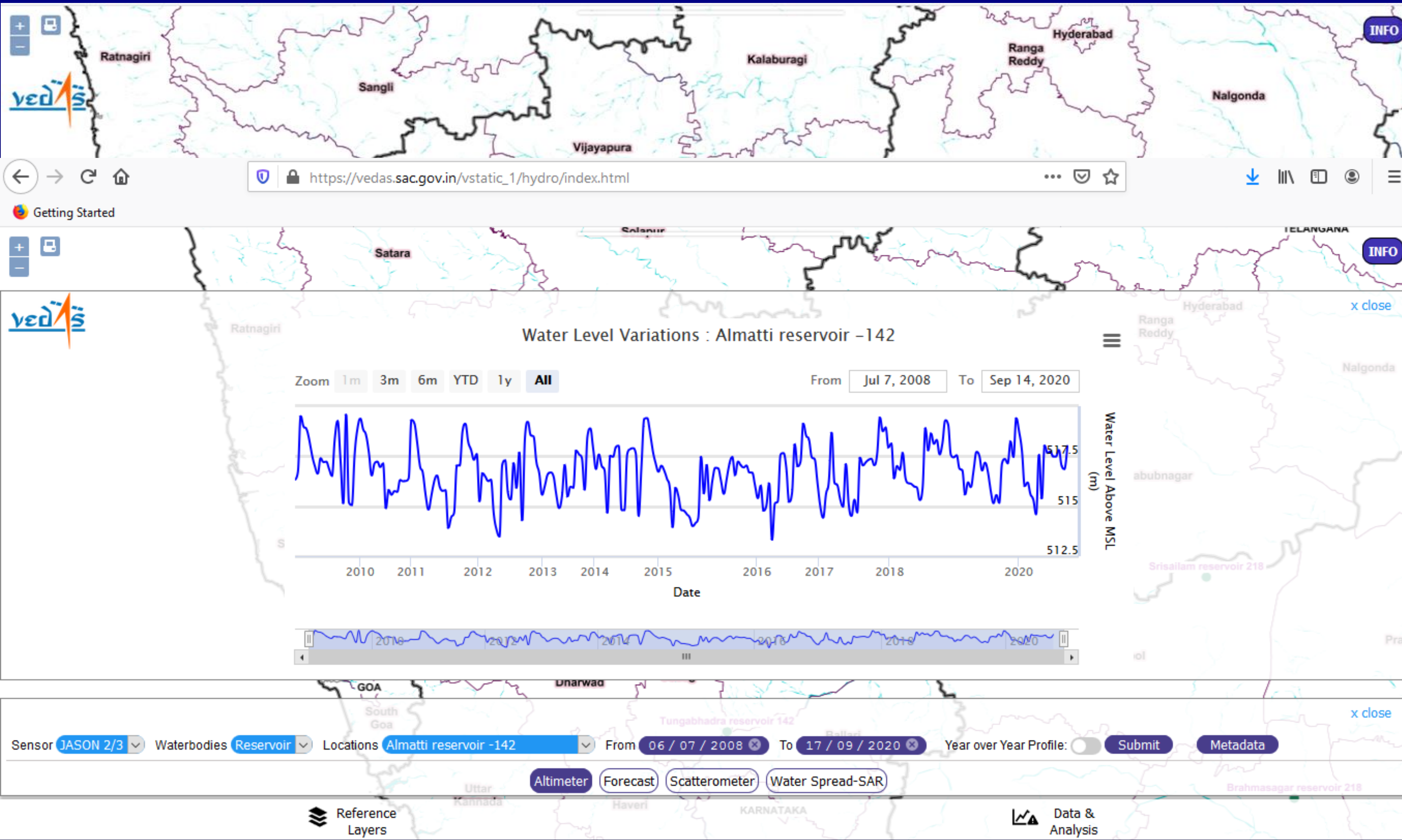


Altimeter Waveforms in a River Transact

Satellite Remote Sensing Applications in Water Resources

Water Level Estimation

Altimeter



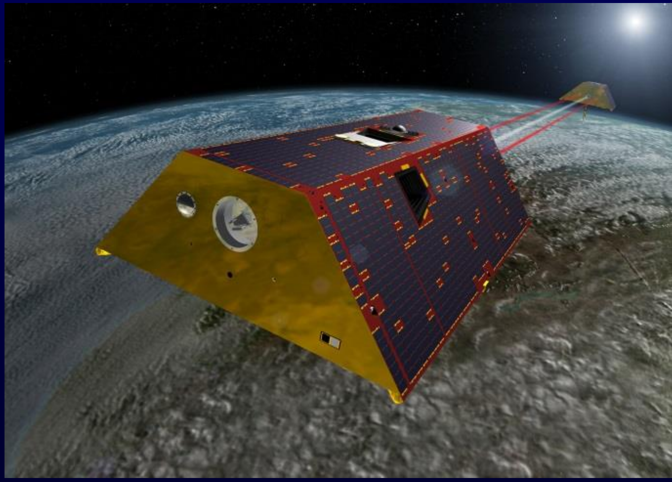
Satellite Remote Sensing Applications in Water Resources

Ground Water Estimation

Gravity Recovery and Climate Experiment(GRACE)

- The GRACE twin satellites (launched 2002) follow each other in orbit around the Earth, separated by about 137 miles (220 km).
- GRACE data will be a series of measurements showing how far apart two satellites are from each other. They will constantly send microwave signals to each other to measure the distance between them.
- As the pair circles the Earth, areas of slightly stronger gravity (greater mass concentration) affect the lead satellite first, pulling it away from the trailing satellite.
- As the satellites continue, the trailing satellite is pulled toward the lead satellite as it passes over the gravity anomaly.
- All this information from the satellites will be used to construct monthly maps of the Earth's average gravity field, offering details of how mass, in most cases water, is moving around the planet.

GRACE-FO, (2018) will continue the work of tracking Earth's water movement to monitor changes in underground water storage, the amount of water in large lakes and rivers, soil moisture, ice sheets and glaciers, and sea level caused by the addition of water to the ocean.



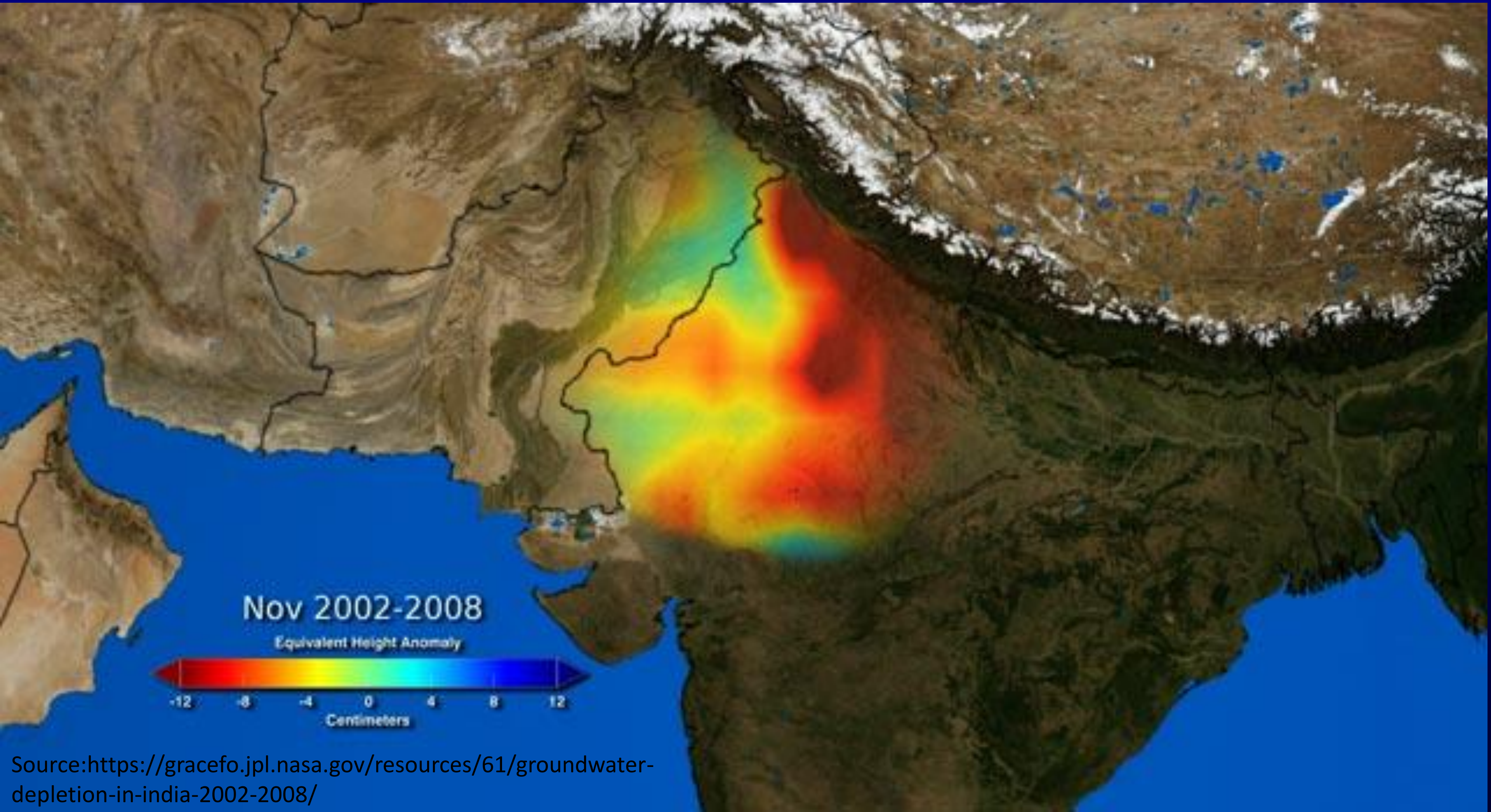
Instruments
- K-band Ranging System (KBR)
- Ultra Stable Oscillator (USO)
- SuperSTAR Accelerometers (ACC)

Satellite Remote Sensing Applications in Water Resources

Ground Water Estimation

Gravity Recovery and Climate Experiment(GRACE)

Groundwater Depletion in India, 2002-2008



Source:https://gracefo.jpl.nasa.gov/resources/61/groundwater-depletion-in-india-2002-2008/

THANK YOU