Tsunami and Storm Surge Early Warning Systems

Dr. T. Srinivasa Kumar

Director

Indian National Centre for Ocean Information Services (INCOIS)

Ministry of Earth Sciences (MoES)

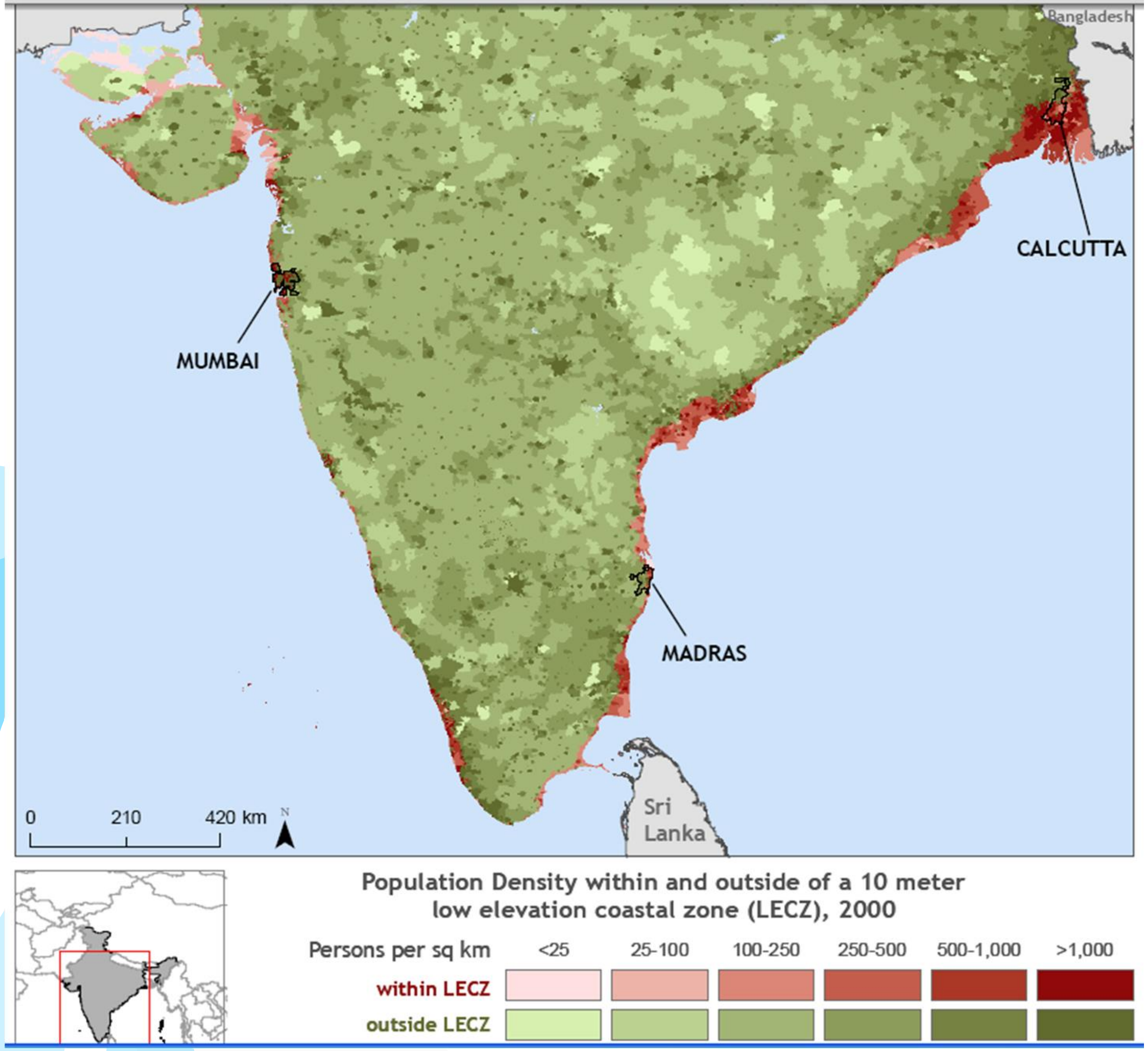
srinivas@incois.gov.in

National Meet on "Disaster Risk Management – Trends and Technologies

HICC, Hyderabad

27 – 28 February 2023

Vulnerability of the Indian Coastline



- **26 % of Indian Population live within 100 Km from the shoreline**
- **Most of the coastal areas are low lying and vulnerable to oceanogenic disasters such as Tsunamis, Storm Surges, Sea-level rise, etc.**
- **Dec 26, 2004 Tsunami resulted in a loss of 18, 045 deaths and 6,47,599 persons displaced**
- **Increased frequency and intensity of the disasters (Uttarkhand flood-2013, etc.)**
- **Frequent Cyclones - 13% of World's cyclones in the Seas around India (recent cyclones: Phailin, Hudhud, Fani, Amphan, Tauktae, Yass, etc.**

Disaster Management Cycle

Risk Assessment and Reduction

Systematically collect data and undertake risk assessments

Detection Warning and Dissemination

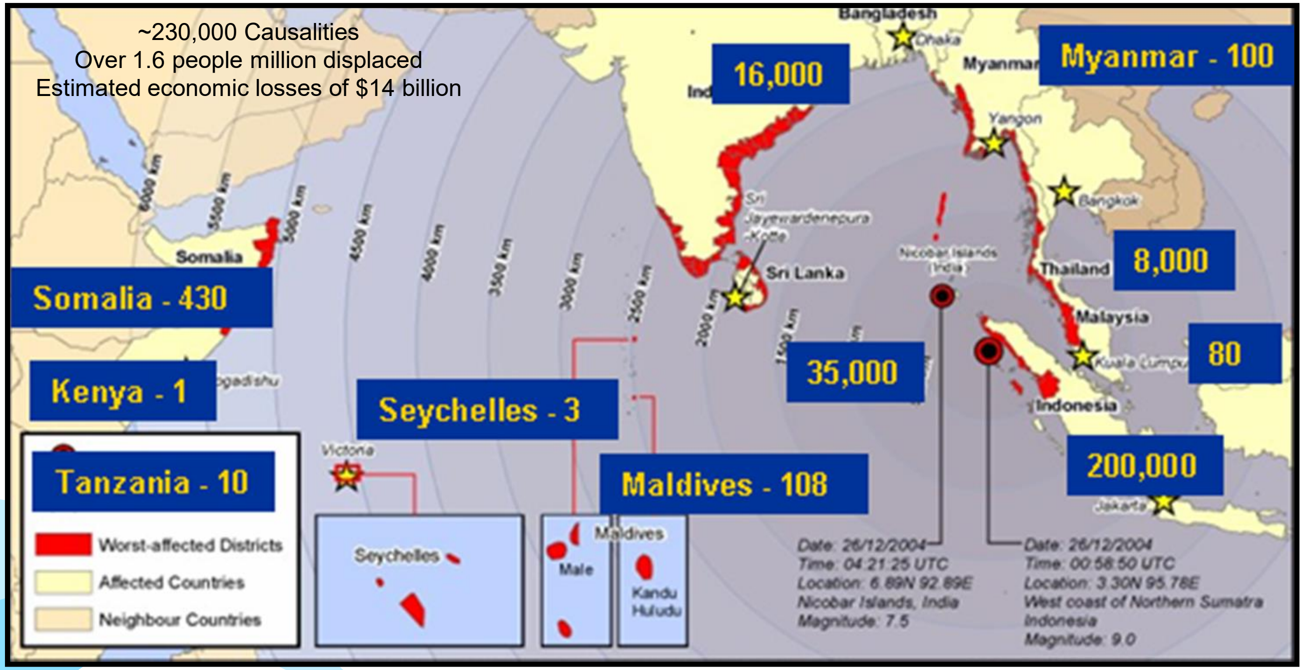
Develop hazard detection, monitoring and early warning services

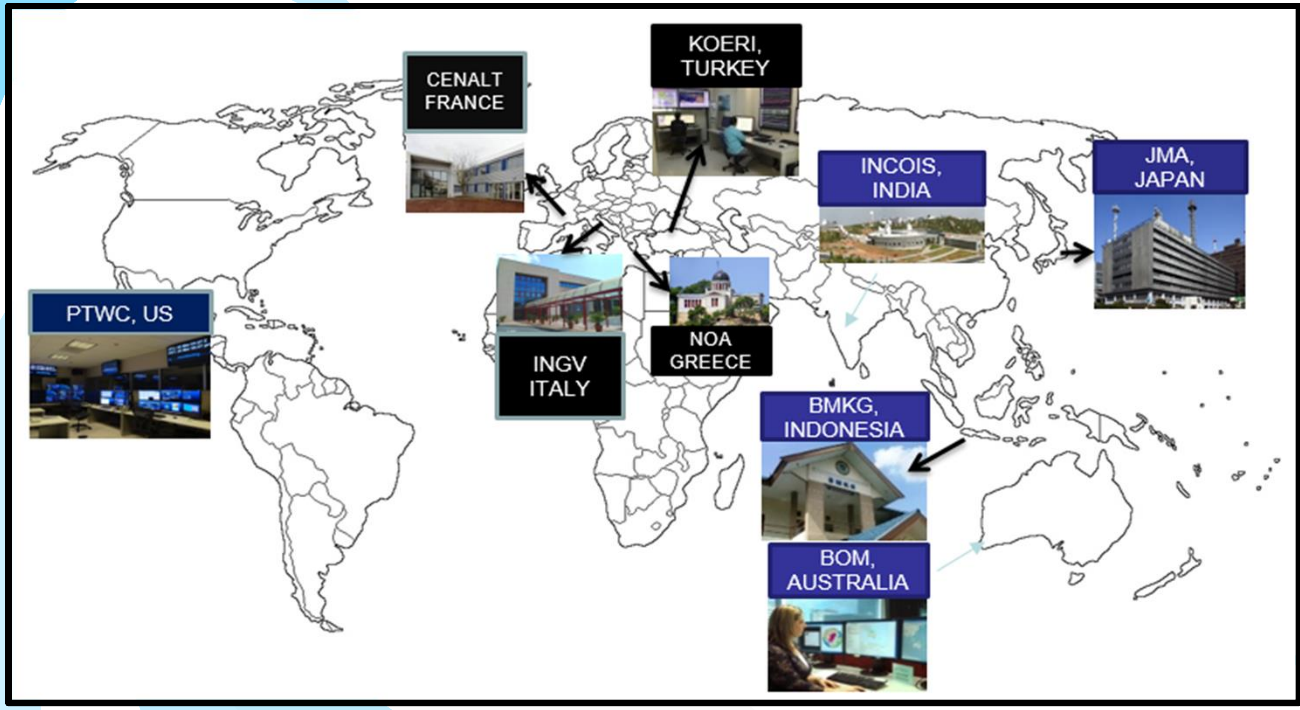
Communicate threat information and early warnings

Awareness and Response

Build national and community response capabilities

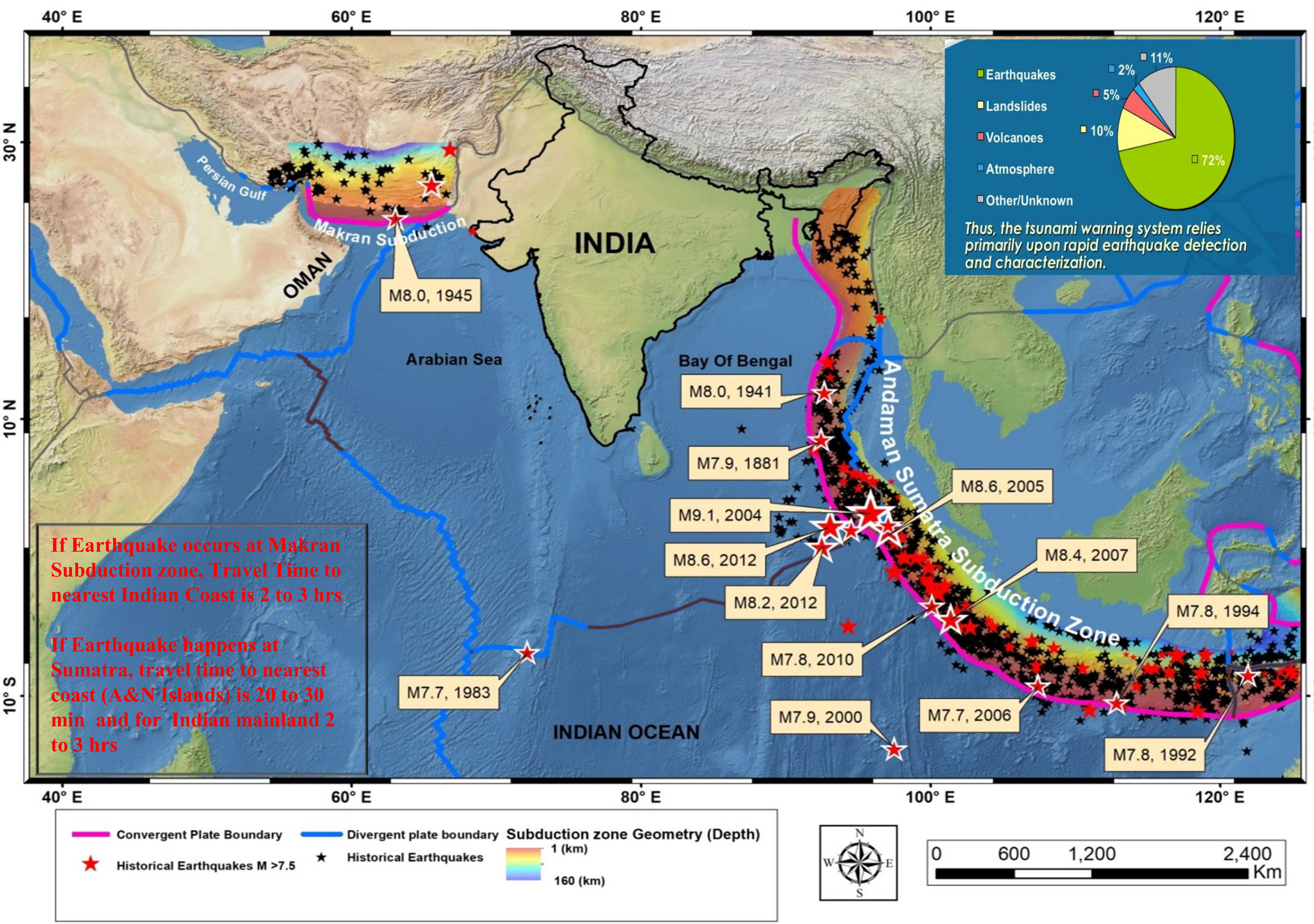
Global Tsunami Warning Systems



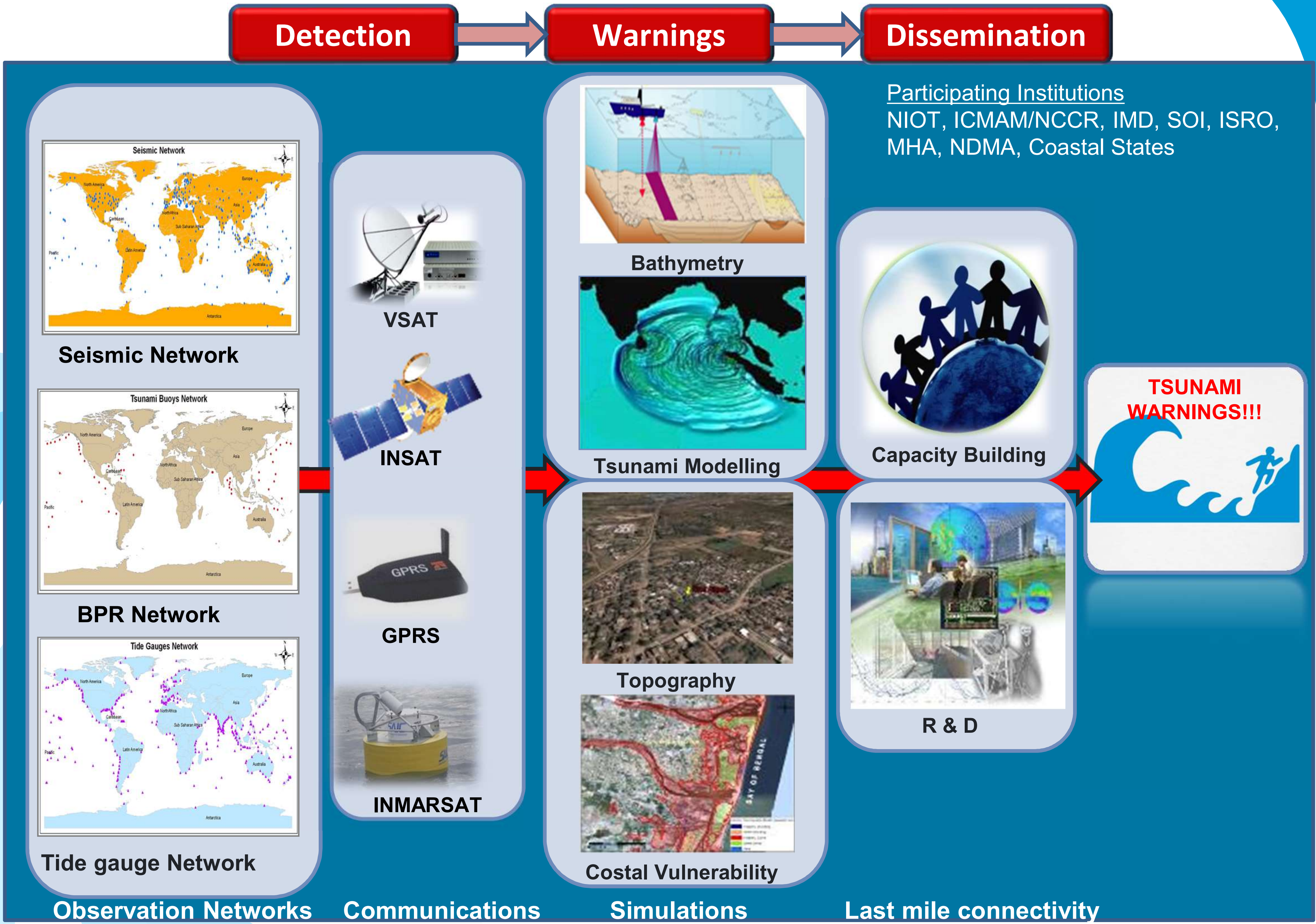


- Pacific System since 1965
- None in the Indian Ocean or other basins
- Many did not even recognize the word "tsunami"
- IOT of December 26, 2004 tsunami illustrated need for more warning systems
- IOC coordinated the establishment of three more TWS
  - ICG IOTWMS
  - ICG CARIBE EWS
  - ICG NEAMTWS
- 8 New Tsunami Service Providers established since 2004
- ITEWC established by the Government of India at INCOIS, ensued national operations in 2007 and regional operations in 2011
- Integral part of the ICG IOTWMS along with Australia and Indonesia serving 25 MS

Potential Tsunamigenic Sources



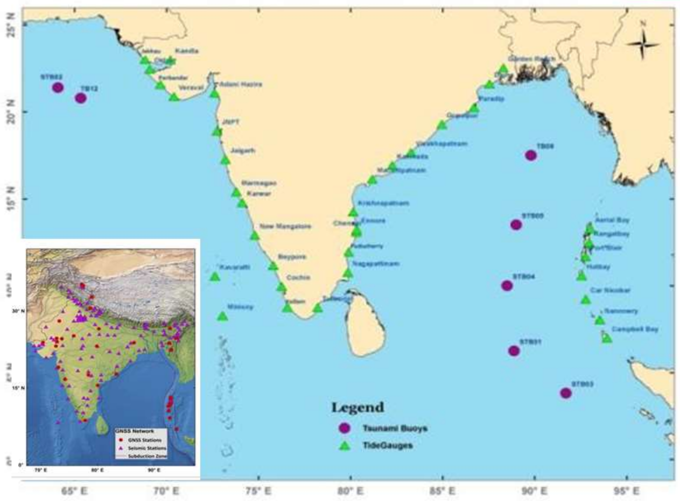
Indian Tsunami Warning System Architecture



Indian Tsunami Warning System - Upstream

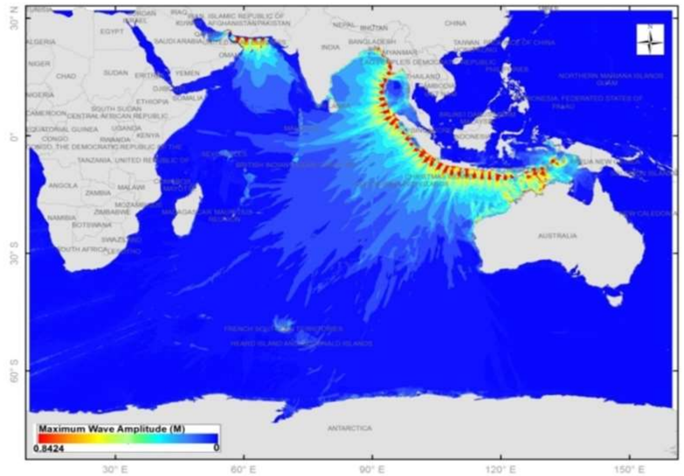
Seismic & GNSS Network:

- Real-Time Seismic Network of 17 stations and ~350 international stations
- Established Indian Seismic & GNSS Network (www.isgn.gov.in) for real-time connectivity to 100's of seismic & GNSS Stations
- Capable of estimating earthquake parameters in less than 10 min
- Shares data from 3 Indian stations
- 35 station GNSS Network in A&N Islands



Tsunami Buoy Network:

- INCOIS-NIOT established real-time network of 7 Tsunami Buoys
- Receives data from ~ 50 international real-time tsunami buoys
- Shares data from 7 Indian stations



Tide gauge Network:

- INCOIS established real-time network of 36 tide-gauge stations
- Receives data from 300 international real-time tide-gauge stations
- Shares data from 8 Indian stations

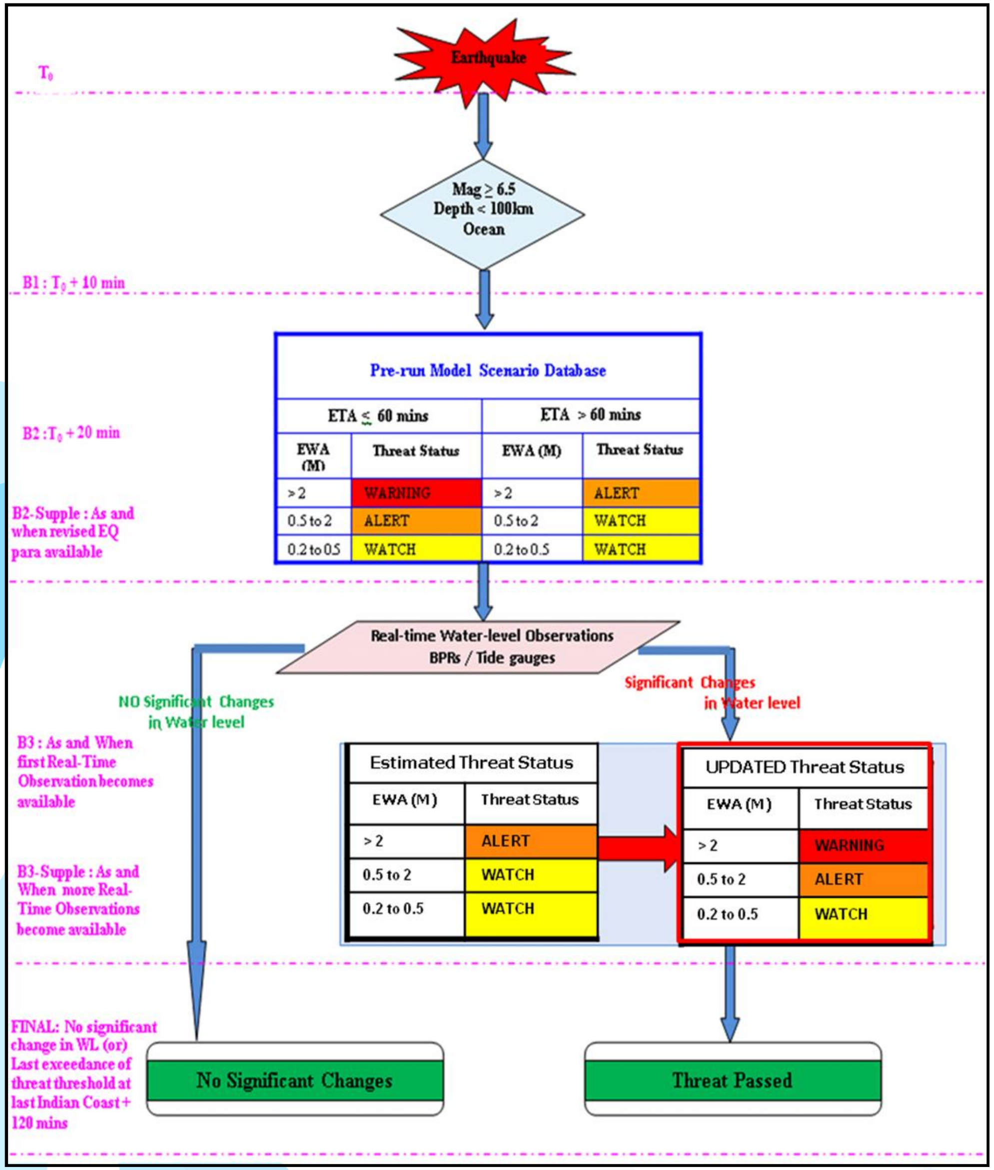
Tsunami Modeling:

- Large Database of open ocean propagation scenarios (oops db)
- ~1400 unit sources each of 100 X 50 km area representing rupture caused by EQ of M 7.5 with slip as 1m . Can scaled up/down
- Expected Wave Arrival & Amplitude forecasts at CFP and CFZs

24 x 7 warning Centre:

- Computation & Communication Infrastructure

Indian Tsunami Warning System - SOP



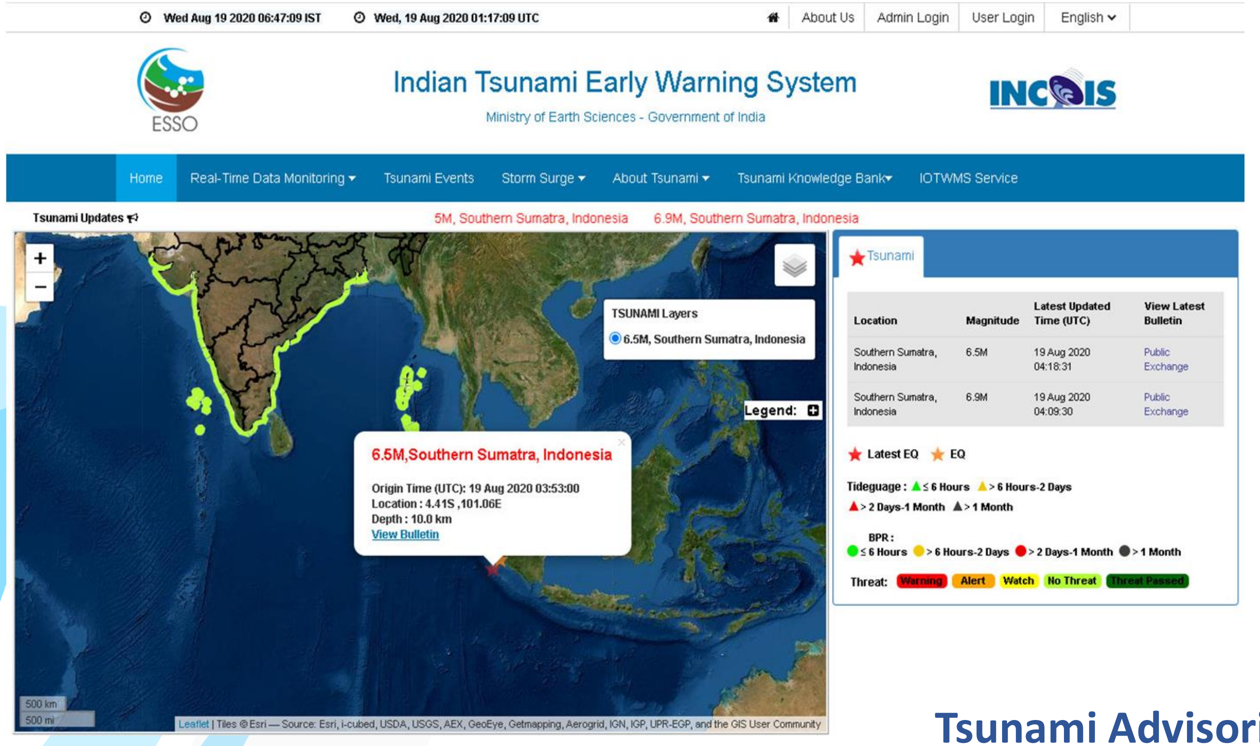
- The Indian Tsunami Early Warning Centre (ITEWC) services for an event commence whenever an earthquake is recorded with M ≥ 6.5 within the Indian Ocean and M ≥ 8.0 outside of the Indian Ocean
- Uniquely designed SOP for generation of timely and accurate tsunami bulletins to handle both near-source and far-source coastal regions
- Based on proximity of a coastal zone to the tsunamigenic earthquake source regions and Expected Wave Heights from Models
- 4 Threat Levels corresponding to different public responses and mapped to NDMA guidelines

SOP – Public Response and Threat Levels in Bulletins

Threat Status	Action to be taken	Dissemination to
WARNING	Public should be advised to move inland towards higher grounds. Vessels should move into deep Ocean	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media
ALERT	Public should be advised to avoid beaches and low-lying coastal areas. Vessels should move into deep Ocean	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media
WATCH	No immediate action is required	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Media
THREAT PASSED	All clear determination to be made by the local authorities	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media

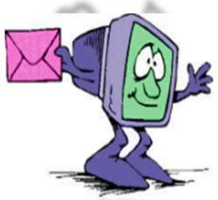
ITEWS Products and Dissemination

- **Notification Messages** are issued in **text** format
- **Bulletins** are generated in both text and **HTML formats** on the websites
- **Graphics** are generated in jpg or png format on the websites
- **Spatial** data is also available in dbf format on the websites



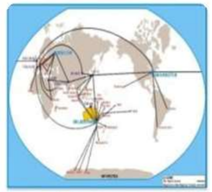
- **Common Alerting Protocol(CAP) सचेत is an Integrated Alerting System by NDMA for Disaster Management to warn the public regarding disasters and emergencies.**
- **CAP being implemented for INCOIS services**


Fax

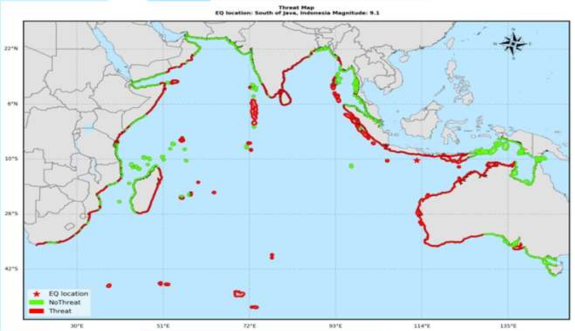

Email

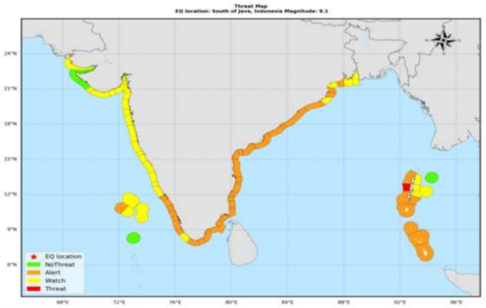

SMS

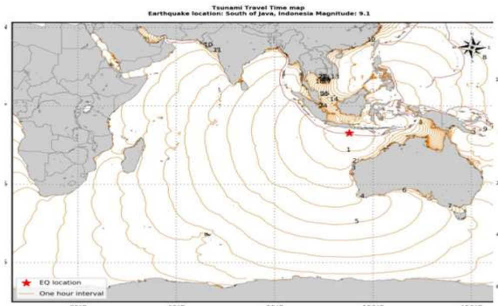
Web

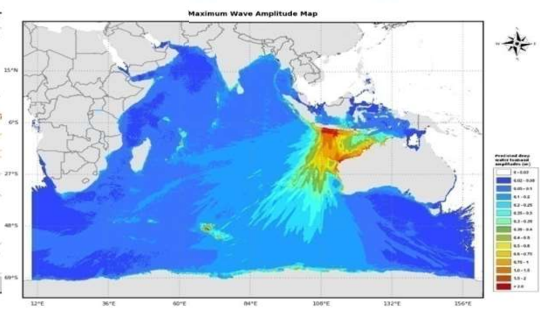

GTS

Tsunami Advisories and bulletins at
https://tsunami.incois.gov.in


Tsunami Threat Map for Indian Ocean


Tsunami Threat Map for India


Tsunami Travel Time Map


Tsunami Amplitude Map

Indian Tsunami Warning System - Downstream

➢ SOP Workshops, Tabletop Exercises & COMMs test

- For DMOs to build their own SOPs detailing actions to be taken upon receipt of bulletins from the warning centre
- To stimulate the development, training, testing and evaluation of Emergency Response Plans, SOPs and assess procedures followed
- ITEWC conducts communication tests every 6 months to validate the dissemination and reception processes of advisories
- Awareness material in vernacular languages

➢ Mock Drills

- INCOIS also conducts IOWave Tsunami mock exercises biannually in coordination with ICG/IOTWMS and conducts at National level mock exercises alternative years in coordination with National/State DMOs to strengthen the readiness to handle the emergency situations with stakeholders.

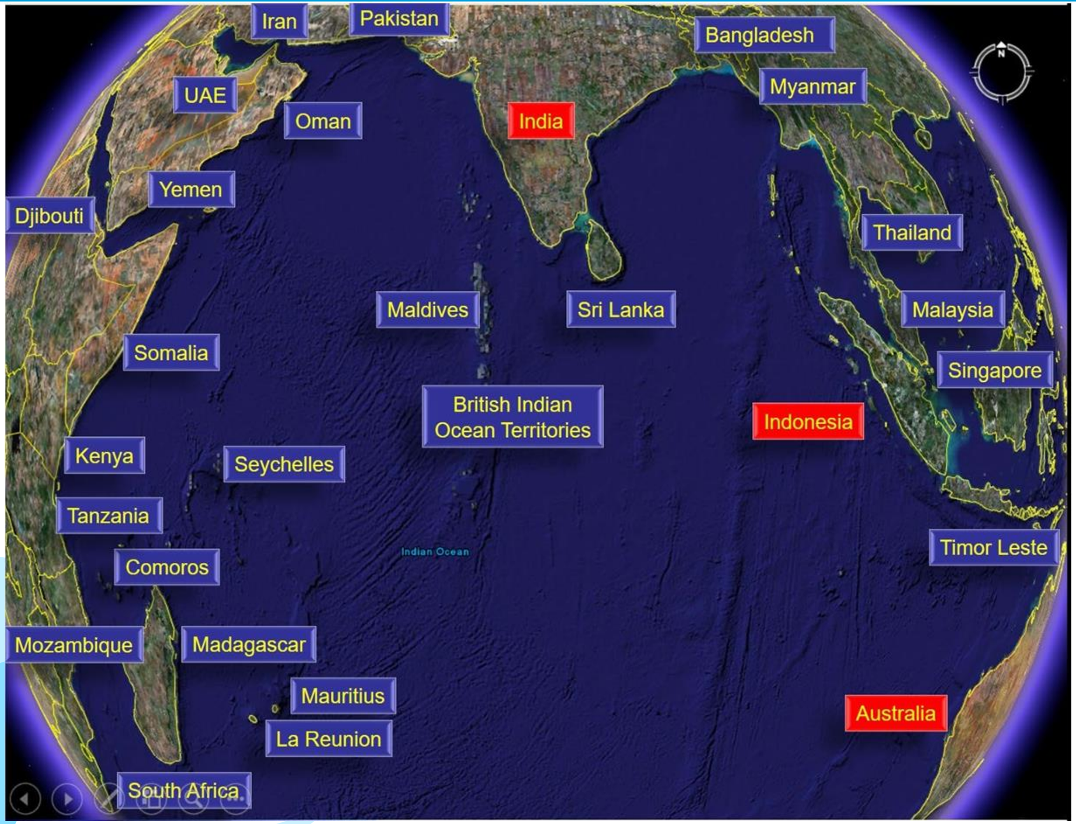
➢ World Tsunami Awareness Day

- Commemorates World Tsunami Awareness Day on 5th November and organized various activities

➢ Tsunami Ready Recognition

- Tsunami Ready is a community performance-based programme by IOC-UNESCO to promote tsunami preparedness – 11 Indicators
- Based on National Board recommendation, IOC-UNESCO recognized Venkatraipur and Noliasahi villages of Odisha as Tsunami Ready communities
- India is the first country that implemented TR in Indian Ocean region.

IOTWMS Services and Performance Indicators



The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) was formed in response to the tragic tsunami on 26 December 2004

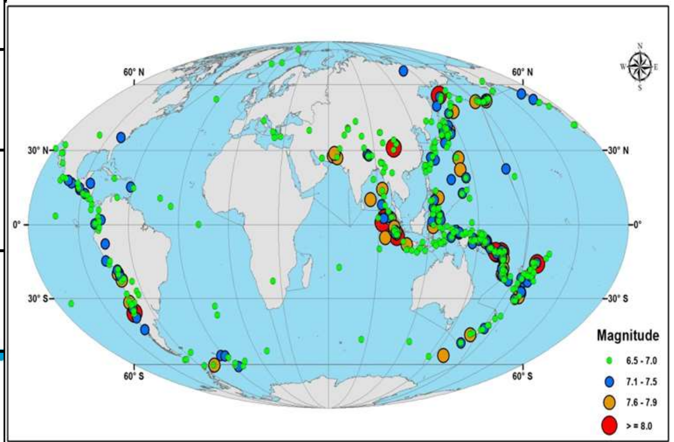
In October 2011, ITEWC recognized as a Tsunami advisory Service Provider (TSP) along with other two TSPs of Australia and Indonesia by IOC-UNESCO. Since then ITEWC providing services to all Indian Ocean member countries.

INCOIS is providing tsunami services to 25 countries in the Indian Ocean Region

Performance

ITEWC monitored 690 earthquakes (M>6.5) since its inception to till date

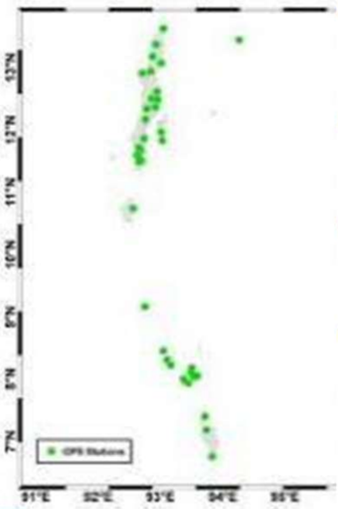
Region	No of Earthquake M≥6.5
Indian Ocean **(IO)**	102
Other than Indian Ocean (GO)	588

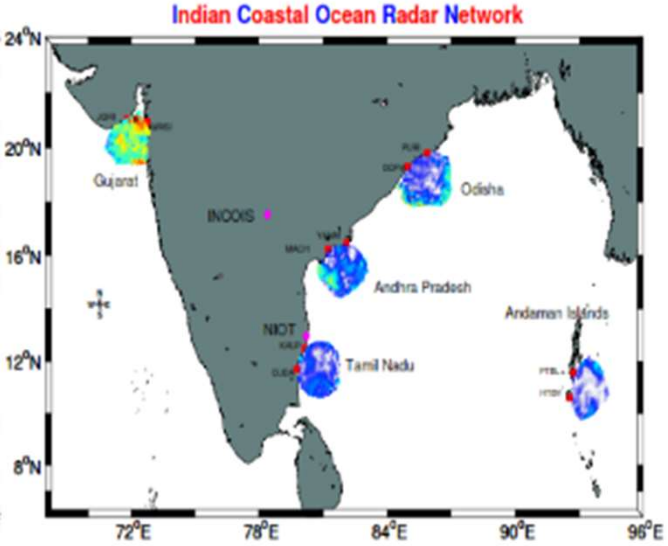


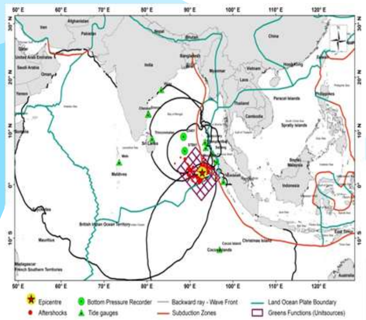
Key Performance Indicators

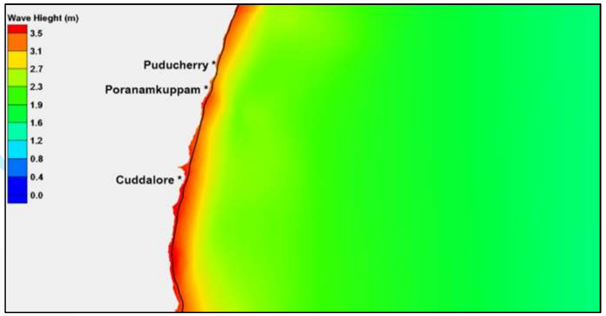
Parameter	Target (local/distant)	Achievement GO	Achievement IO
Elapse time from earthquake origin time to initial earthquake information issuance	10 min	10.0min	7.7 min
Probability of detection of Indian Ocean earthquakes with Mw ≥ 6.5	100%	100%	100%
Accuracy of hypocenter location (with respect to USGS final estimates)	Within 30 km	16.5 Km	14.8 Km
Accuracy of hypocentre depth (with respect to USGS final estimates)	Within 25 km	16.9 Km	13.8Km
Accuracy of earthquake Mw magnitude (with respect to USGS final estimates)	0.3	0.19	0.13

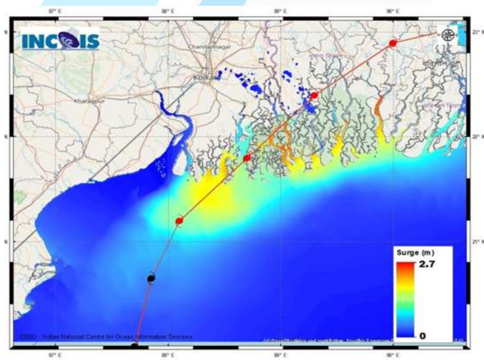
Are We Ready ??

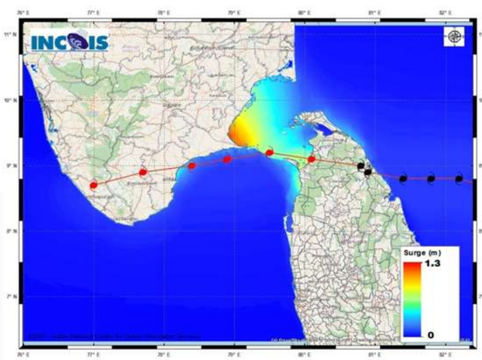












Great progress since 2004

- State-of-the-art warning system with observing, modelling, computational, communication facilities DSS and SOPs
- Successfully monitored 630 EQ of M ≥ 6.5, 101 in the Indian Ocean, Avg time for 1st Bulletin: 7.7 Min, Warning for 7 events
- Preparedness & Response – TR pilot

Recent advances

- W-phase CMT
- Sea-level inversion
- GNSS & HF Radar networks
- Realtime tsunami modeling
- Storm Surge Forecasting

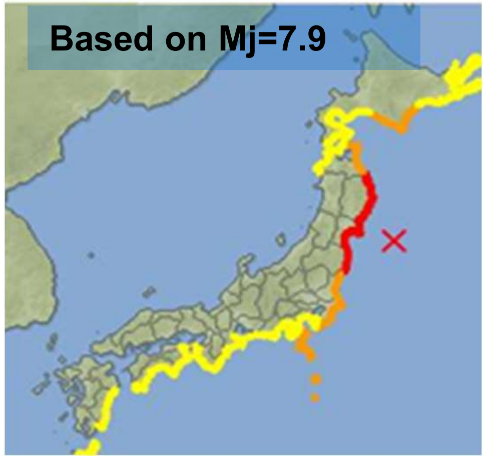
Several challenges evidenced from recent events

- Tsunami warning is race against time - Uncertainties in tsunami warning
- Gaps in Warning and Response capabilities, specially for atypical, near-field sources
- Gaps in SOPs and Early Warning Chains

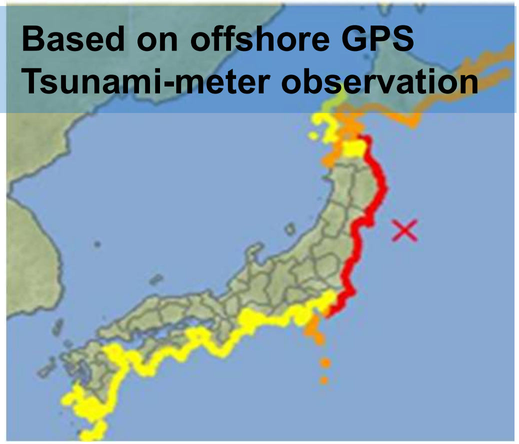
Challenges & Lessons Learnt from Major Events

Japan Earthquake on Mar 11, 2011

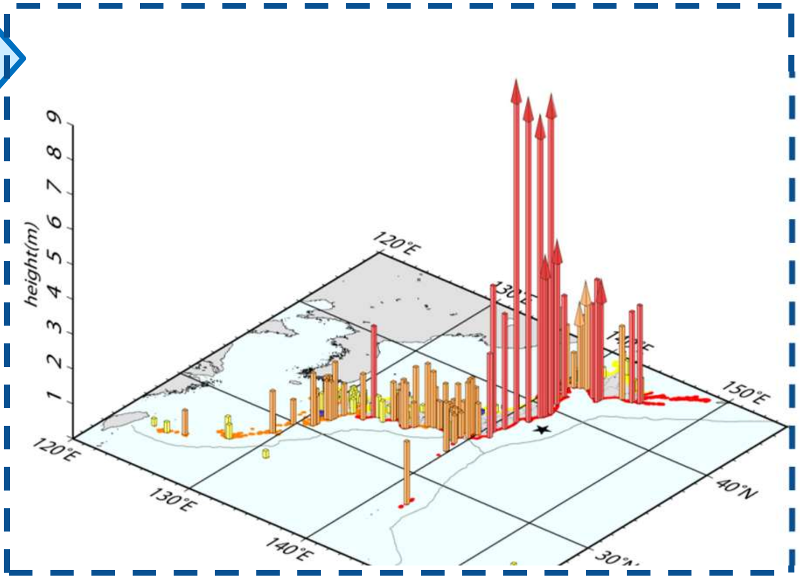
The first Warning in 3 minutes → **Updated warning in 28 minutes**



Iwate : 3m
Miyagi : 6m
Fukushima : 3m



Iwate : 6m
Miyagi : over 10m
Fukushima : 6m



Observed Tsunami Amplitude

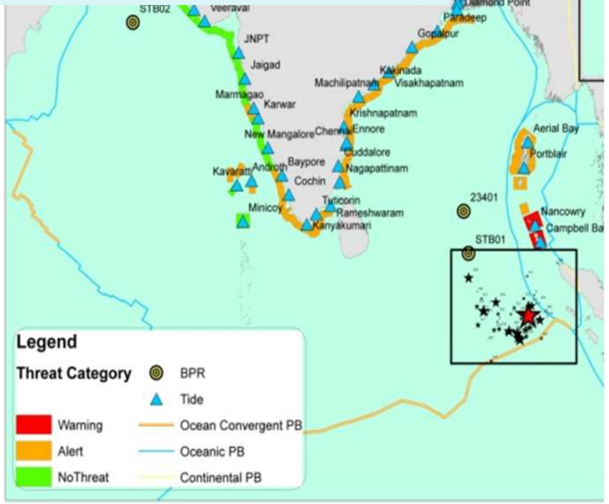
Under-estimation of Magnitude and Tsunami wave heights

- Though the first tsunami warning was given in 3 minutes, it was based on underestimated 7.9 M
- Announced tsunami amplitude estimate "3m" led to delays in evacuation
- Failed to calculate Mw (Moment magnitude) automatically due to waveform data over-scale for most of the domestic broadband seismometers, and consequently, could NOT update the warning
- Collected unsaturated oversea broadband waveform data, and calculated Mw = 8.8 in 54 minutes and that was too late for the warning update based on the seismic data

Challenges and Lessons Learnt from Major Events

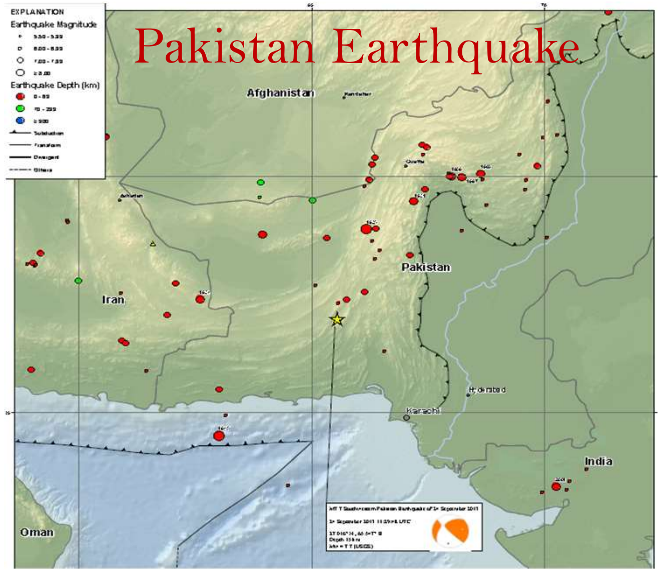
Northern Sumatra Earthquake on Apr 11, 2012
Pakistan Earthquake on September 24, 2013

Northern Sumatra Earthquake



Little Nicobar, Indira Point > 2m

Pakistan Earthquake



Np Tsunami

Over-estimation of Tsunami wave heights and Source of Tsunami

- The first tsunami warning was given in **8 minutes for Northern Sumatra EQ based on magnitude** of 8.7 and Announced **tsunami amplitude estimate " > 2m"** at Andaman & Nicobar Islands
- The actual **displacement was in horizontal** direction and tsunami wave height 30 cm at Campbell bay
- The Pakistan **M 7.7 event was about 200 km inland from the coast**. Earthquake identified by ITEWC and was deemed to be of "No Threat" (About 200 KM inland)
- It **caused a new island** to rise from the sea, just off the Pakistan's southern coast. A **minor Tsunami** was observed near coast of **Oman about 0.5 m.**

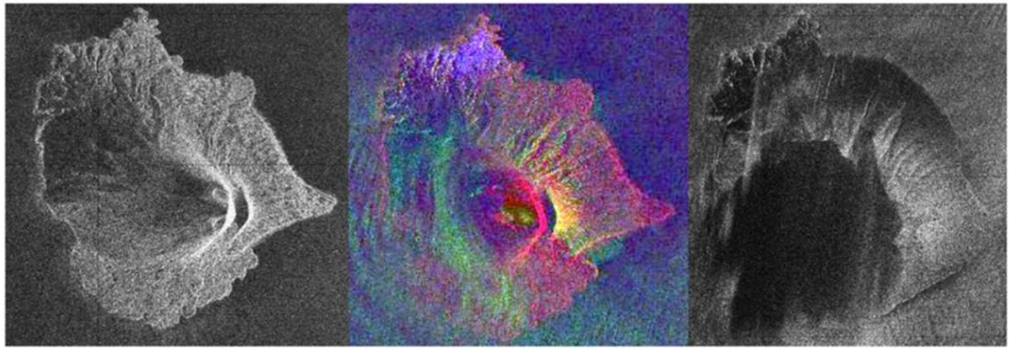
Challenges & Lessons Learnt from Major Events

Palu tsunami on Sep 28, 2018 (Submarine landslide, Liquefication)

Hunga Tonga–Hunga Ha'apai tsunami on Jan 15, 2022 (Volcano eruption)

- Underwater volcano in Tonga erupted and generated tsunami in Pacific Ocean, sea level changes were observed even in Indian Ocean

Sunda Strait tsunami on Dec 22, 2018 (Volcano eruption)



December 11, 2018 At 17:28 WIB | December 23, 2018 | December 27, 2018 At 17:28 WIB

Submarine landslide

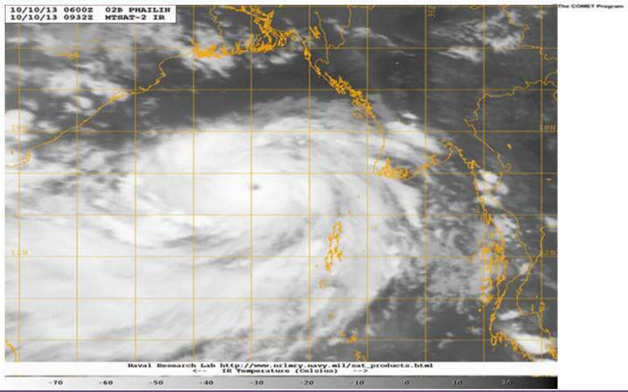
- Deaths - 2,100; Missing 680; Injured 4,612; and Displaced 78,994 **first wave arrived in 3 minutes**, earlier than the warning
- Complex Event – **Strike Slip Earthquake, Extensive Liquefaction,** Coastal / Submarine Landslides, Bay
- **Sirens weren't working ,** Electricity and communication were cut off
- No time for communities to receive official warning
- Lack of capacity in LDMO

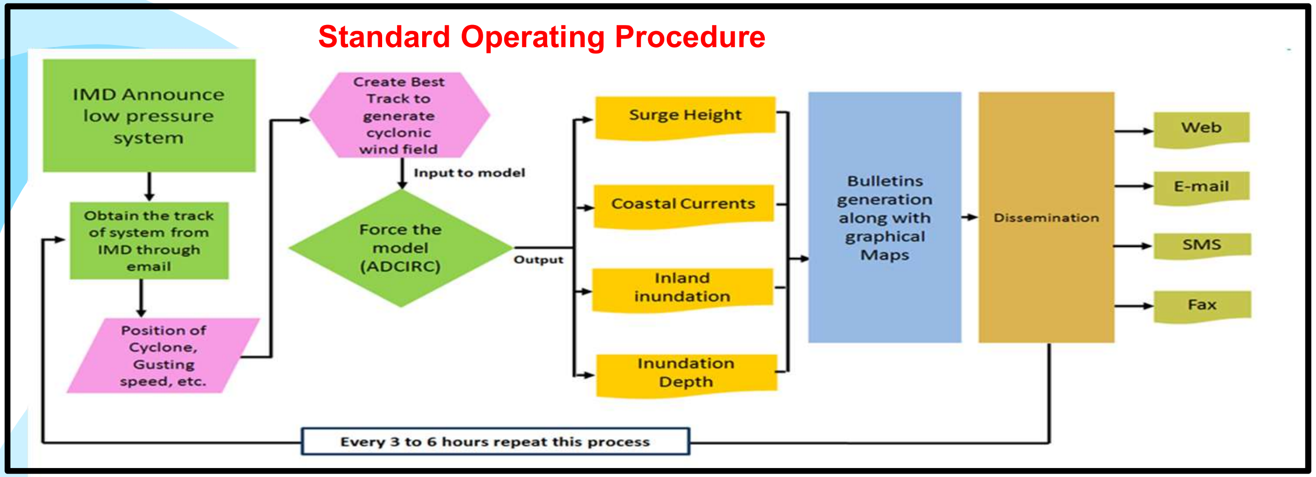
Anak-krakatau Volcano eruption

- Deaths - 430; Missing 128; Injured 1,459; and Displaced 5,695
- **Caused by flank collapse** due to eruption of Anak Krakatau volcano
- No Tsunami Early Warning issued
- Tsunami waves arrived in succession following the eruptions patterns, and avalanches.
- Tsunami confirmed only by recognizing wave anomaly at near-by tide-gauges

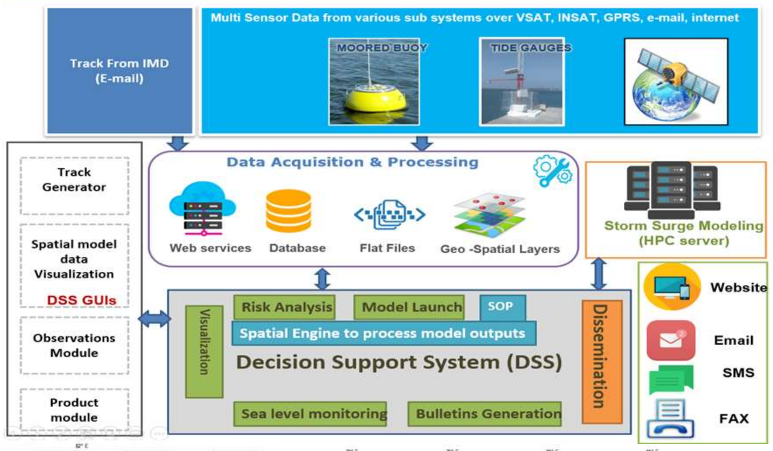
Storm Surge Early Warning System

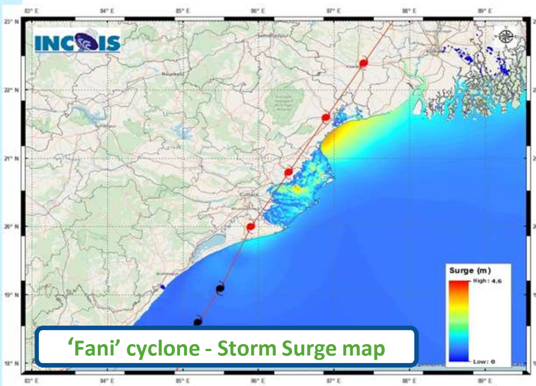
- **Storm surge –** A storm surge is an abnormal raise in sea level at the coast due to the strong winds of an approaching Cyclone/ Hurricane.
- INCOIS is the nodal agency to provide the Storm surge advisories to Indian coast along with IMD. These advisories are useful **to foresee the threat , mitigate and save precious the lives along the Indian Coast.**
- INCOIS has set-up the storm surge early (SSEWS) warning system for the Indian coasts using ADCIRC model.
- SSEWS utilizes an automated Decision Support System (DSS) based on Geographic Information System (GIS) and database technology.
- Till date SSEWS has successfully issued the real-time storm surge warnings for about 55 cyclones.



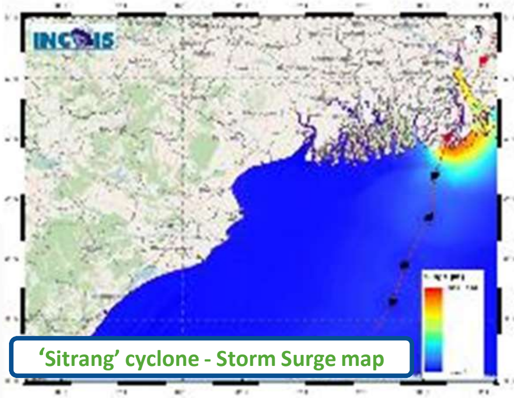


Architecture of Storm Surge Early Warning System

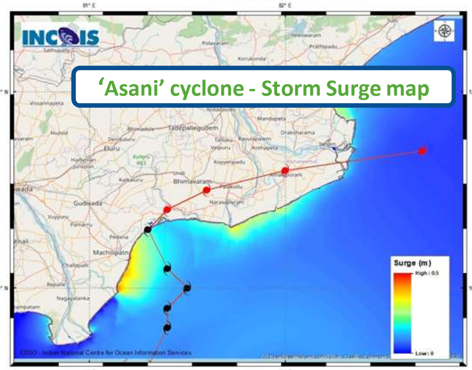




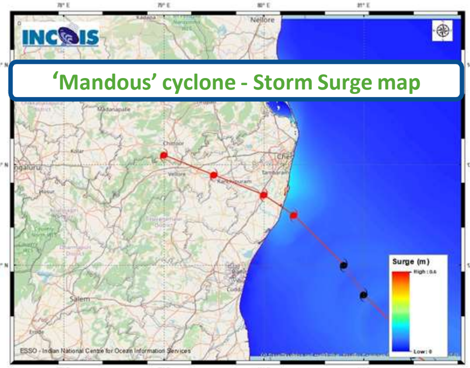
'Fani' cyclone - Storm Surge map



'Sitrang' cyclone - Storm Surge map

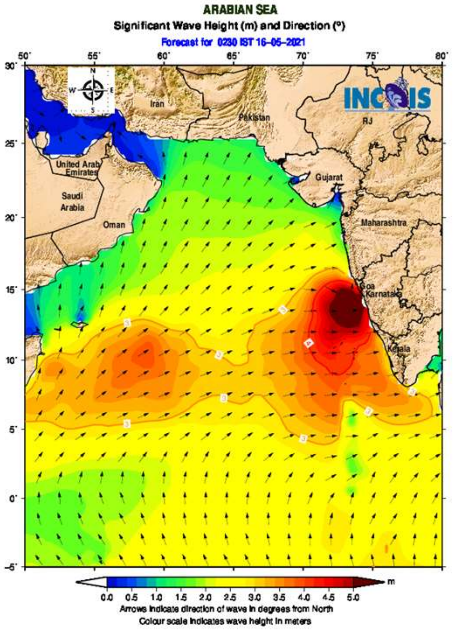


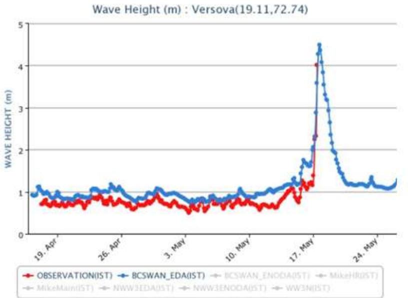
'Asani' cyclone - Storm Surge map

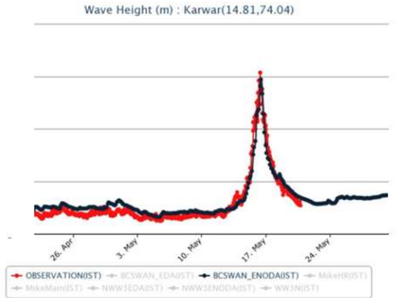


'Mandous' cyclone - Storm Surge map

Marine Safety Services – High Wave, Storm Surge







INCOIS-IMD JOINT BULLETIN

Time of issue: 11:30 hours IST Dated: 17.05.2021, Bulletin No.: INCOIS/17/05/2021/4

Sub: INCOIS-IMD Joint Bulletin - Ocean State Forecast associated with the Extremely Severe Cyclonic Storm "Tauktae" (pronounced as Tau'Te) over Eastcentral Arabian Sea: *Cyclone Warning for Gujarat & Diu coasts & & post landfall outlook for Gujarat & Rajasthan (Red message)*

The **Extremely Severe Cyclonic Storm "Tauktae" (pronounced as Tau'Te)** over eastcentral Arabian Sea moved north-northwestwards with a speed of about 15 kmph during past 06 hours, and lay centred at 0830 hours IST of today, the 17th May, 2021 over eastcentral Arabian Sea near latitude 18.8°N and longitude 71.5°E, about 150 km west of Mumbai, 220 km south-southeast of Diu, 260 km southeast of Veraval (Gujarat), and 490 km east-southeast of Karachi (Pakistan).

It is very likely to move north-northwestwards and reach Gujarat coast in the evening hours of 17th & cross Gujarat coast between Porbandar & Mahuva (Bhavnagar district) during the night (2000 – 2300 hrs IST) of 17th May with a maximum sustained wind speed 155-165 kmph gusting to 185 kmph.

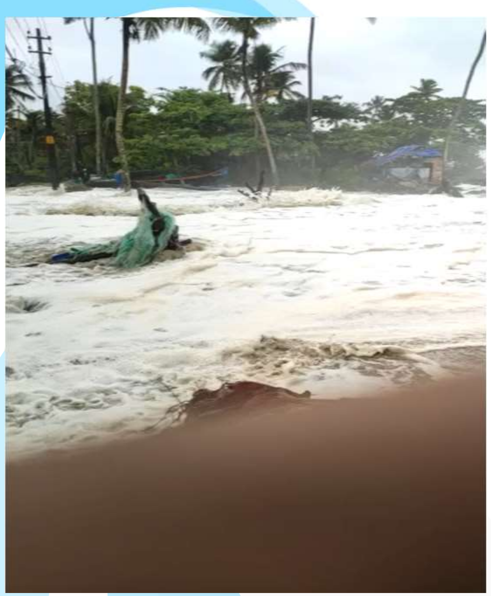
High Wave/Ocean State warning/alert for Maharashtra, Goa, Gujarat, Karnataka, Kerala and Lakshadweep

Maharashtra:

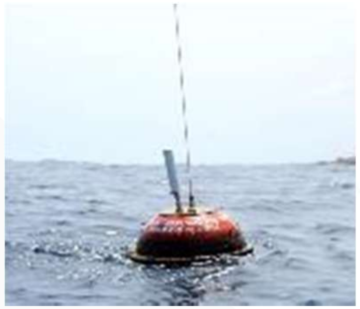
Table: Forecasted Significant wave height and corresponding swell height, for coastal region, into the sea upto 10 km off Maharashtra. There is a possibility that the low lying areas (Malvan, Munage, Phanase, Velas, Colaba, Gateway of India) may be surged (gushing of sea water into these areas) intermittently, because of the waves and tidal conditions.

Location/District	Date/ Time (IST)		Significant Wave Height (m)	Swell height (m)
	From	To		
Greater Mumbai	11:30 hrs, 17-05-2021	23:30 hrs, 18-05-2021	3.0-5.5	1.5-3.0
Raigarh	11:30 hrs, 17-05-2021	23:30 hrs, 18-05-2021	3.0-5.6	1.5-3.2
Ratnagiri	11:30 hrs, 17-05-2021	23:30 hrs, 18-05-2021	3.2-6.5	1.4-3.7
Sindhudurg	11:30 hrs, 17-05-2021	23:30 hrs, 18-05-2021	3.5-6.7	1.5-3.0

Mode	Number
SMS Alerts	1253449
NO. of INCOIS-IMD Joint Bulletins Issued	38
Bulletins sent to emails	13964
No. of High Wave Alerts/Warnings bulletins issued	44
No. of NAVIC messages	30
IMD hourly bulletins in INCOIS website	33



Coastal Inundation (Storm)



ESCS Tauktae
May 13 – 18, 2021

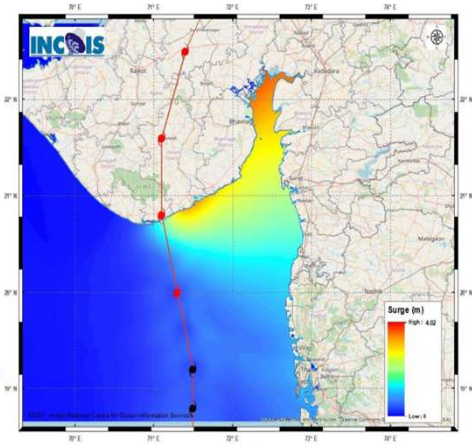
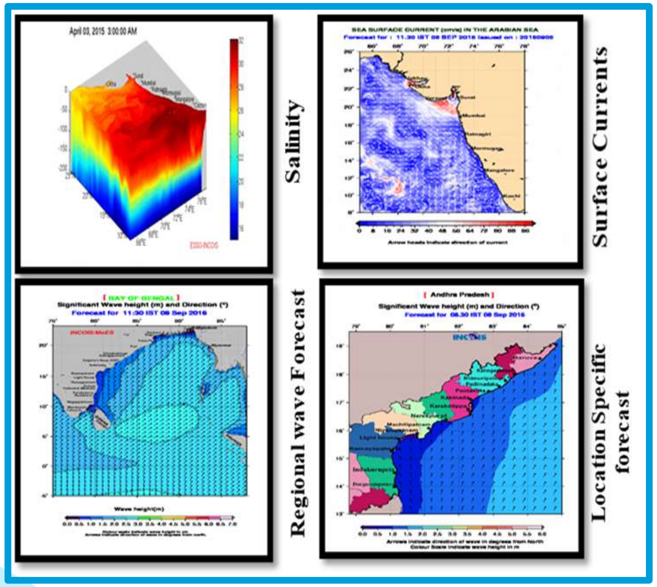


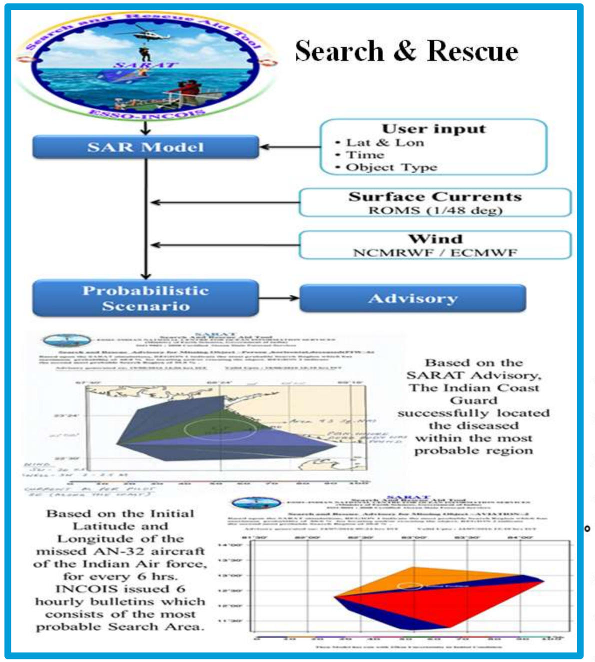
Figure:Storm Surge Map

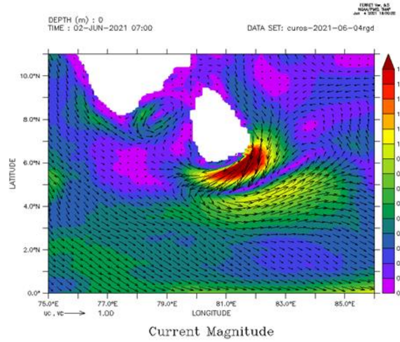
Marine Safety Services – OSF, SAR, SVAS, Oil Spill

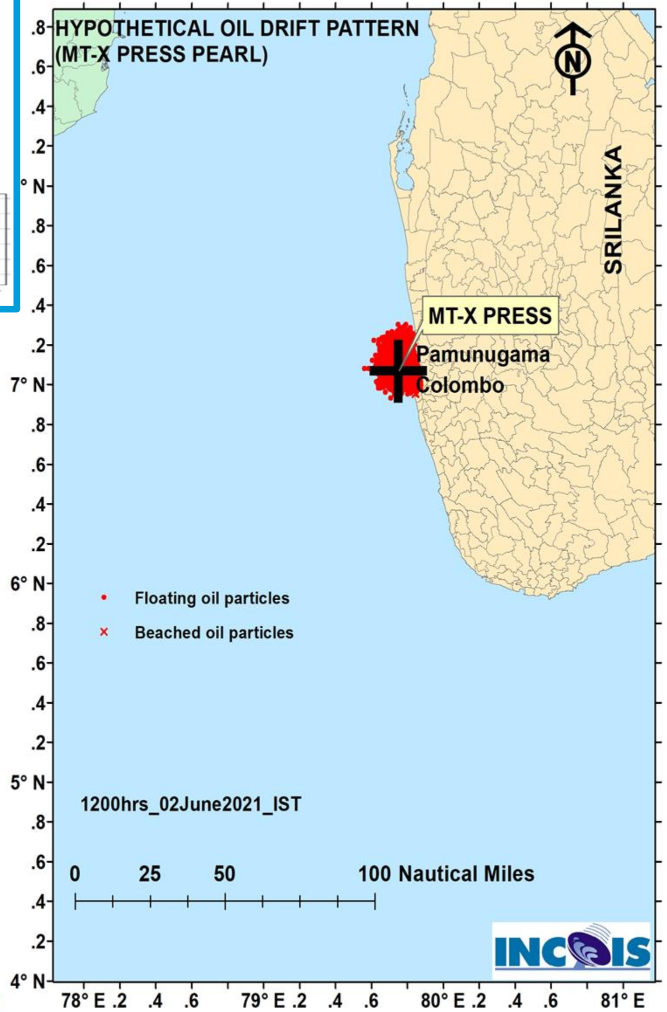
Ocean State Forecasts

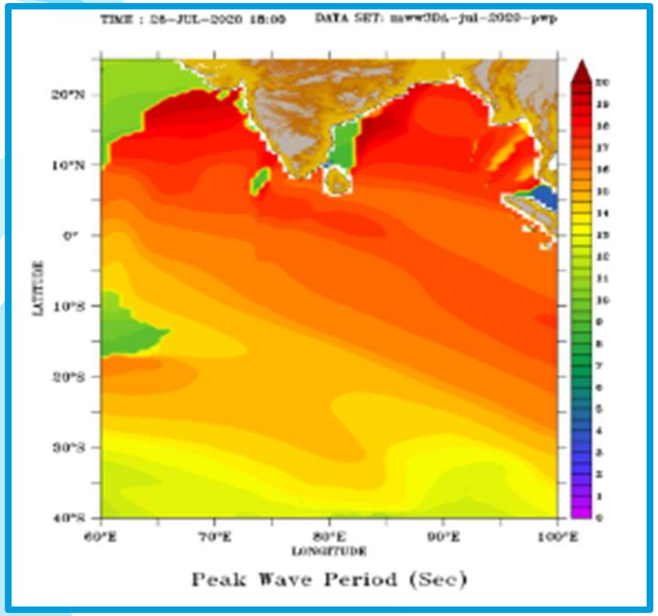
45 User specified daily forecast products for India and 06 Neighbouring Countries

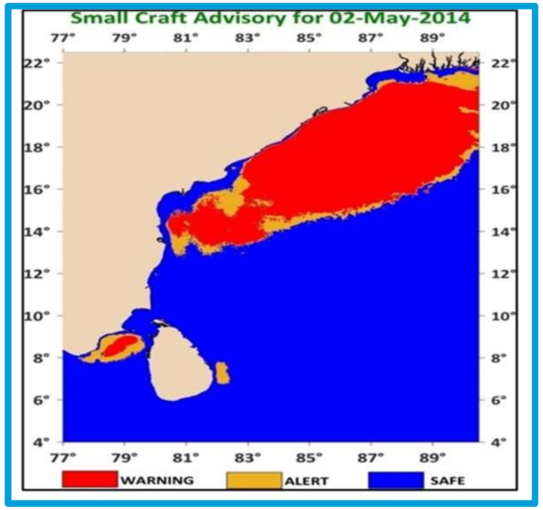








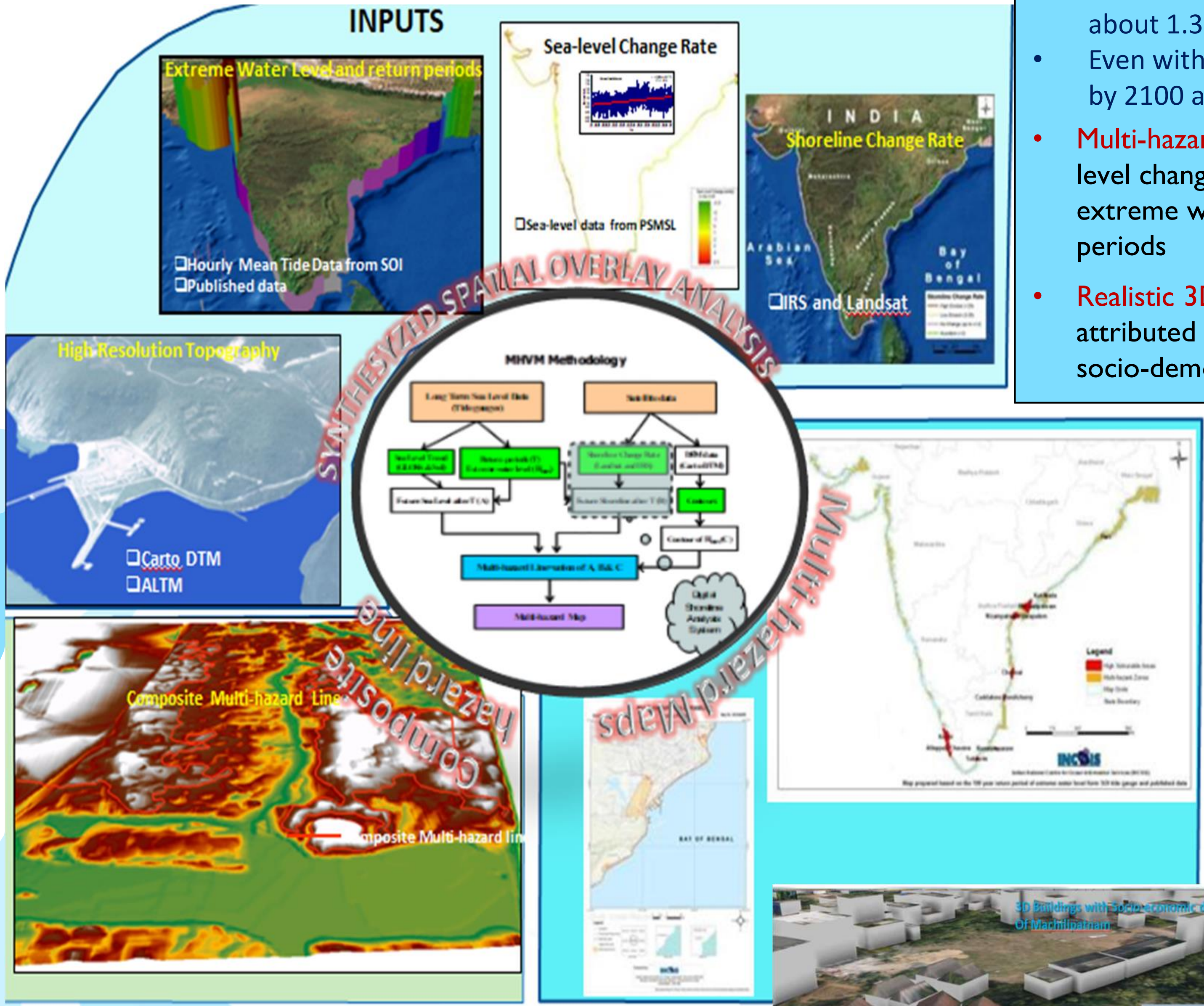




Swell Surge Forecast

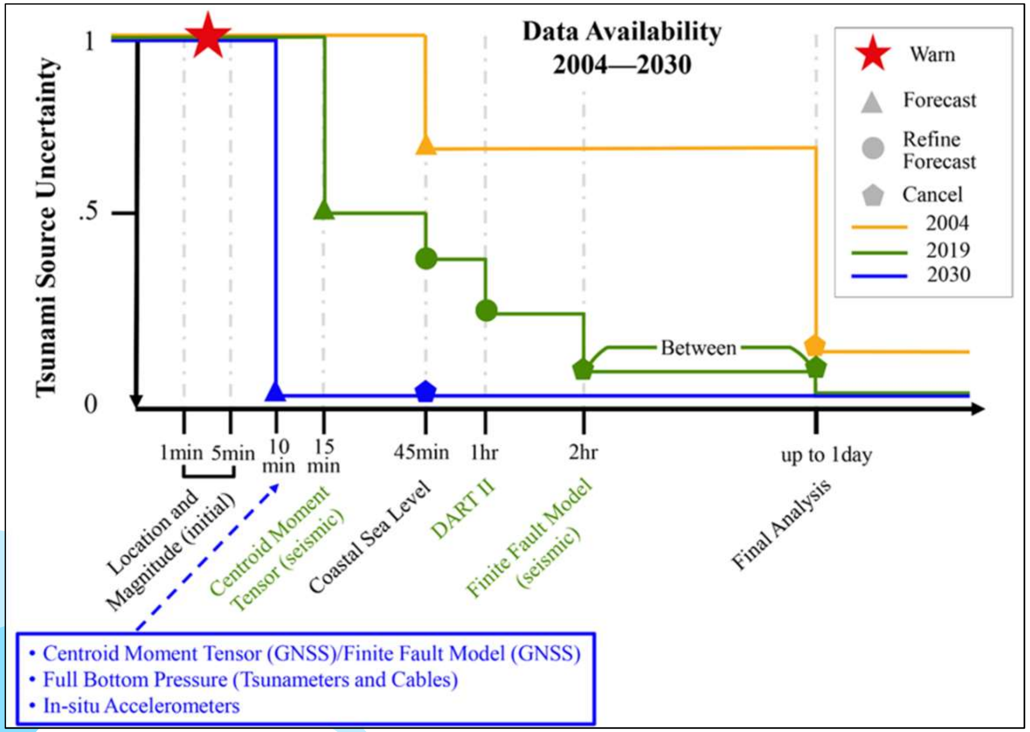
Coastal Multi-hazard Early Warning Services

- Mean sea-level-rise trends along the Indian coasts are about 1.30 mm/y based on past tide gauge records
- Even with the same rate expected SLR of about 13 cm by 2100 along the Indian coast
- Multi-hazard mapping has been carried out using sea level change, shoreline change rate, elevation contours, extreme water level from tide gauges and the return periods
- Realistic 3D models of the buildings along with the attributed details of the owner, address and other socio-demographic details.

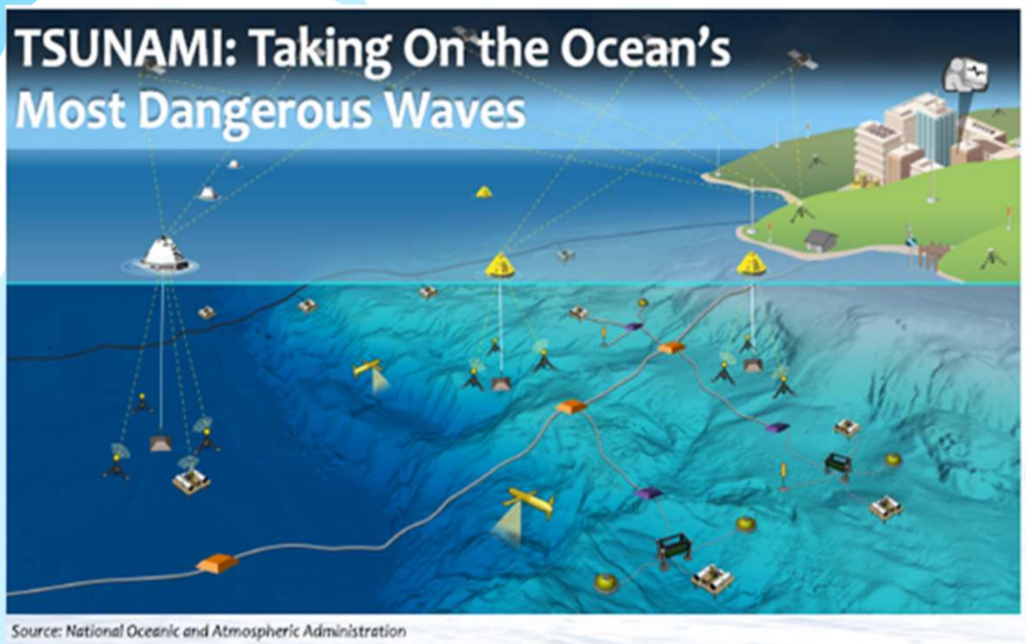


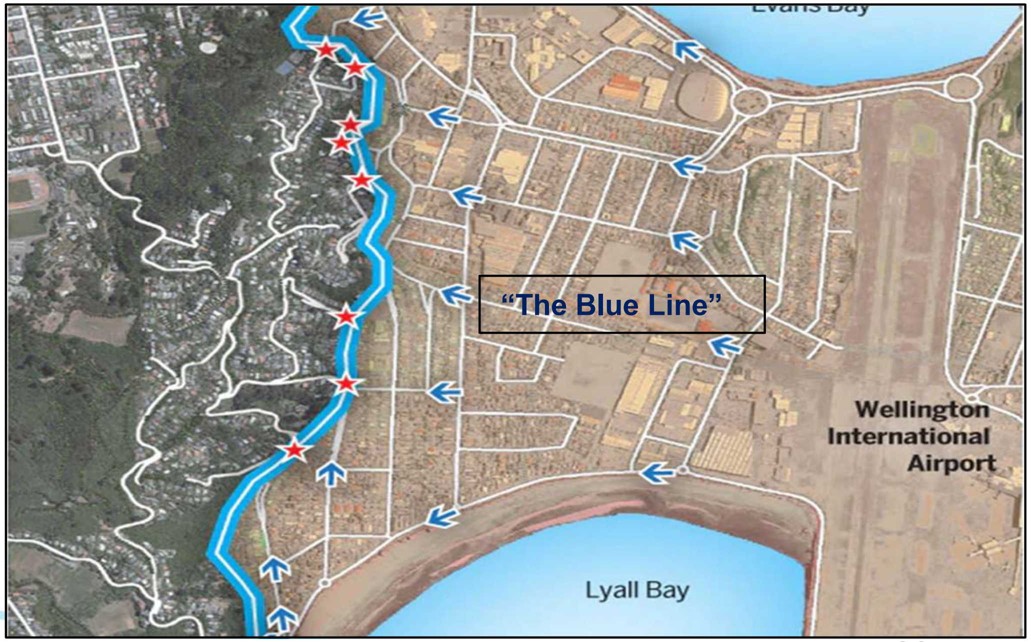
Coastal Inundation – 3D Mapping

Way Forward – UN Ocean Decade



- Enhance Hazard Assessments – "All Sources"
- Detect, Model, Monitor and Warn – "All Sources"
- **Reduce Uncertainties in Warning Products – Data is the KEY**
  - **Enhance Observations – from Ocean, Land, Space**
    - **Seismic, GNSS, Tsunameters, Smart Cables, Tide Gauges**
    - **Altimetry, Ionosperic obs., Infrasound, Coastal Radars, etc.**
  - Bathymetry & Topography Mapping
  - HPC capabilities for real-time modelling
- **Enhance Community Awareness & Preparedness**
  - **Near-field response capabilities**
  - **"Tsunami Ready" Communities**
- Multi Hazard Warning Framework
- **Grand Coalition – Tsunami Scientists, Emergency Managers, Broader Ocean Science Enterprise, Industry, Foundations, UN Partners as part of UN Ocean Decade 2021 - 2020**





Angove M, et. Al. (2019) Ocean Observations Required to Minimize Uncertainty in Global Tsunami Forecasts, Warnings, and Emergency Response. Front. Mar. Sci. 6:350.doi: 10.3389/fmars.2019.00350 0 - Oceanobs


Thank You

nrsc

Hydrological Disasters

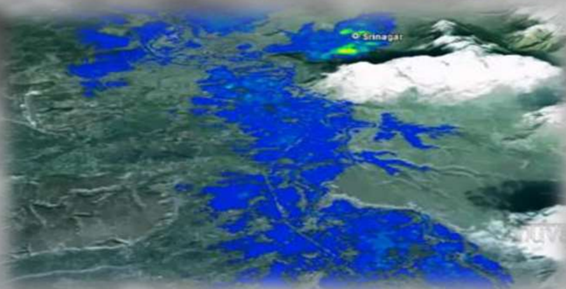
Early Warning : Response : Mitigation

Dr. K H V Durga Rao

Group Director

Disaster Management Support Group

National Remote Sensing Centre, ISRO



The Vision: To provide space based information during all phases of natural disasters in preparedness, response, mitigation, and reconstruction phases for DRR in the country

- **Spatial flood early warning systems**
- **NRT activities and damage assessment**
- **State level flood hazard zonation atlases**

End user: MHA, NDMA, SDMAs, NDRF, etc..

These are used by the State and central authorities in relief & rescue operations, damage assessment and in DRR activities

Spatial Flood Early Warning Systems Development

nrsc

- Web-enabled fully automated operational spatial flood early warning systems for Godavari and Tapi Rivers are developed (under NHP)
- Spatial flood advisories to nodal organisations with 2 days lead time to aid in DRR
- Apart from flood affected areas, it provided information on flood depth and velocity which are vital input in risk assessment

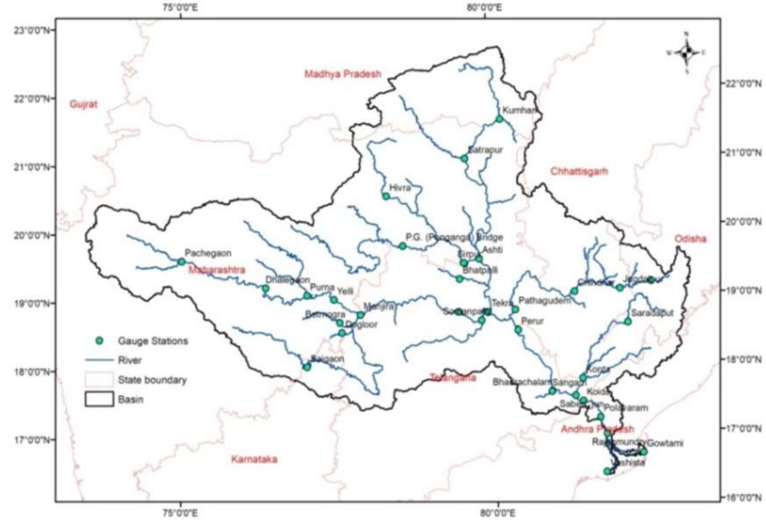
Study Basins

- **Length of the Godavari river** is approximately around **1,465 km**. Basin Area is **312,812 km²**. It drains through six states.
- 2006, 2010, 2013, 2016, and 2020 are major floods year in the Godavari basin.
- Reservoirs: Jayakwadi, SRS, Gosi Kurd, Bailmela, Isapur etc

Year	Discharge (cumec)
1981	51496
1983	43879
1986	62889
1990	62800
1994	41042
1995	40205
2000	40942
2006	51916
2010	44200
2013	57244
2019	38070
2020	44988
2022	70000

Major floods (discharge at Perur, CWC)

The Godavari Basin

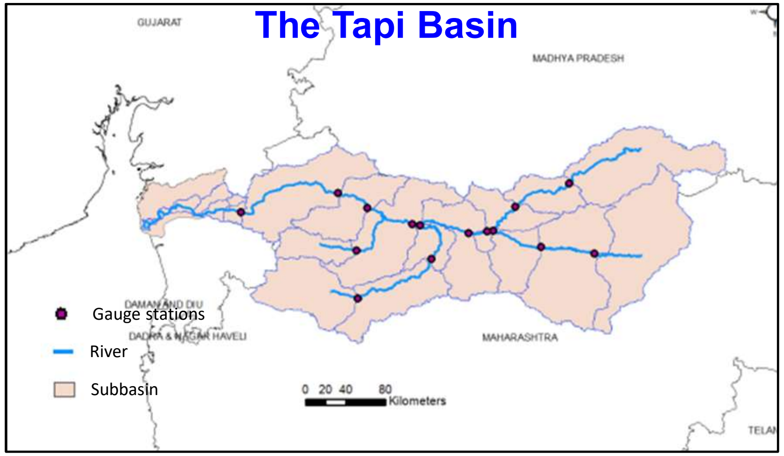


Hydrological setting of Godavari basin

- **Length of the Tapi river** is approximately around **724 km**. It drains through three states.
- 2006, 2012, 2013 are major floods year in the Tapi basin.
- Reservoirs: Hathnur, Ukai etc

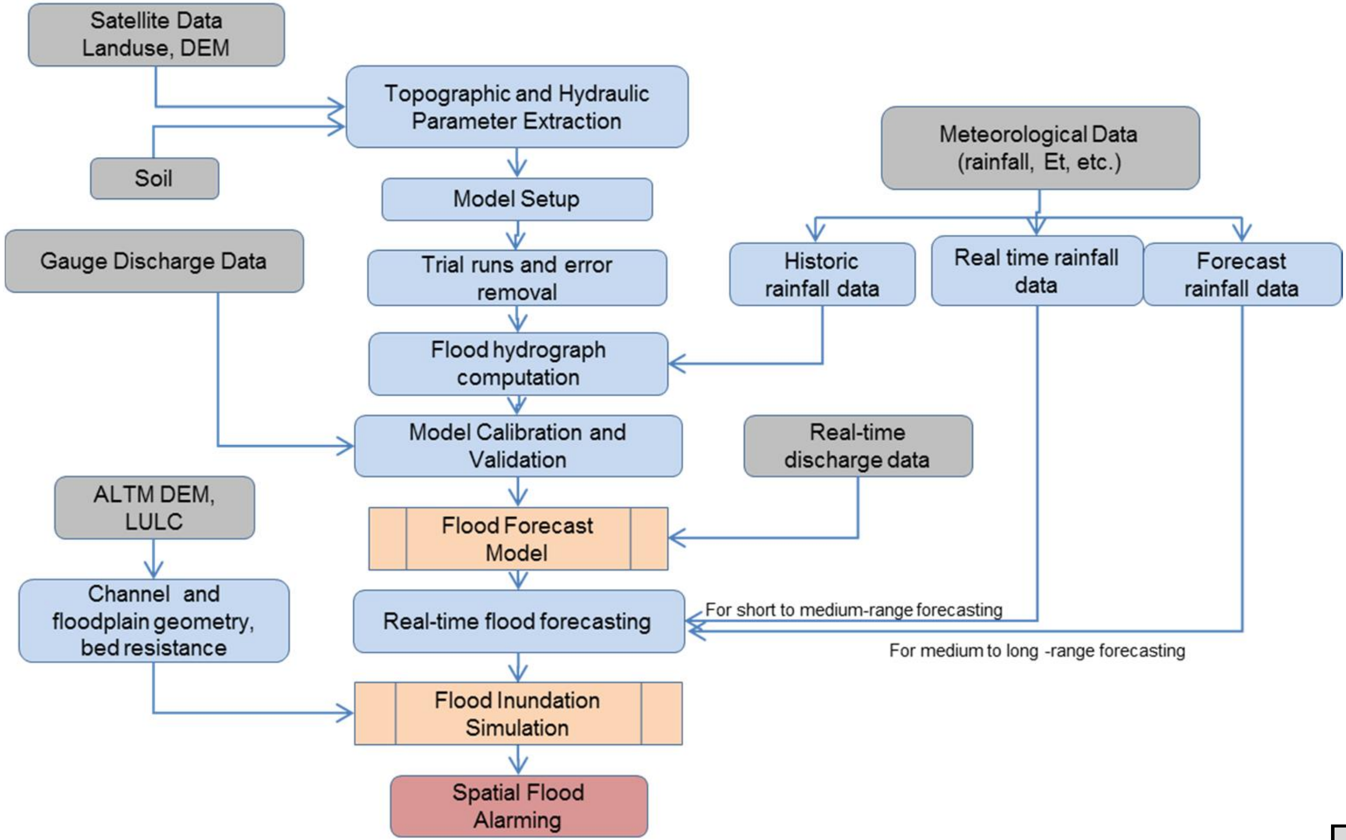
Year	Discharge (cumec)
1944	33527
1945	28996
1949	23843
1959	36642
1968	44174
1998	19057
2006	25768
2012	9508
2013	12146

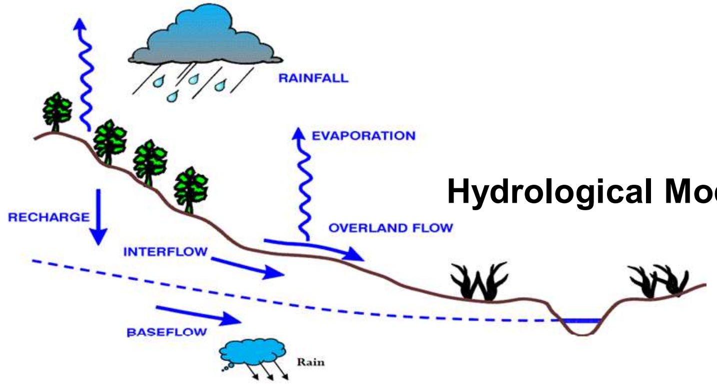
Major floods at Surat (CWC)



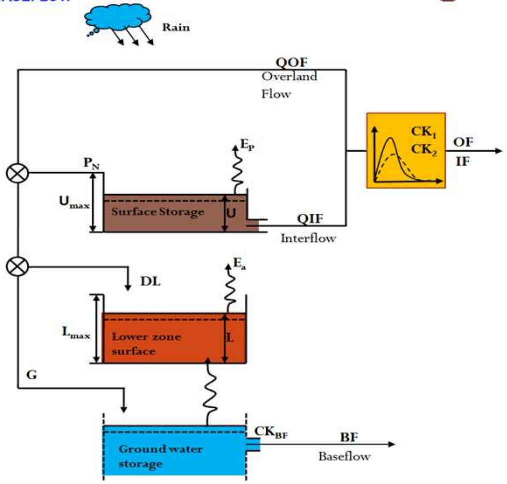
Hydrological setting of Tapi basin

The Modeling Environment





Hydrological Model (NAM)



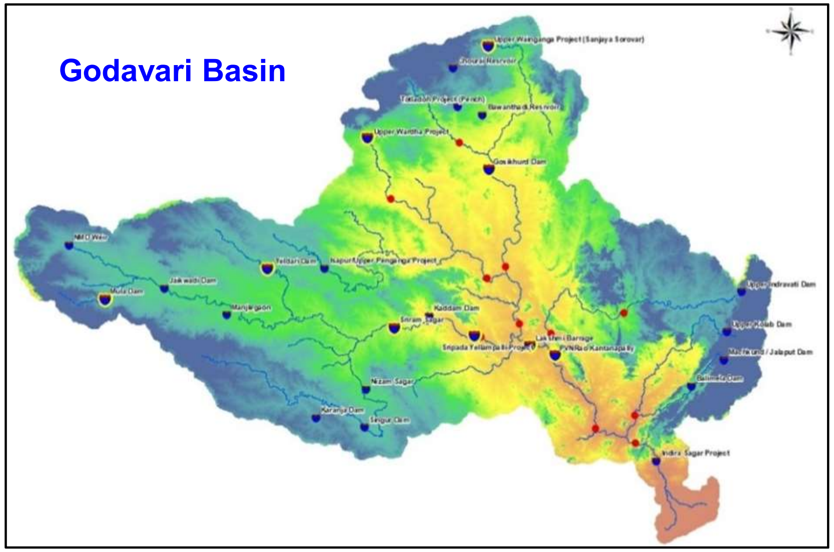
Input Data:

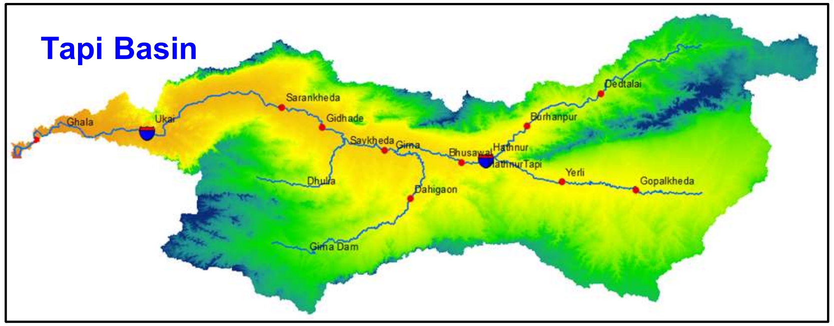
Data Requirement
• Meteorological data (rainfall and potential evaporation)
• Hydrological data (discharge at the outlet of the catchments for model calibration and validation)
• Model parameters (time constants and threshold values for routing surface storage, rootzone storage and groundwater storage)

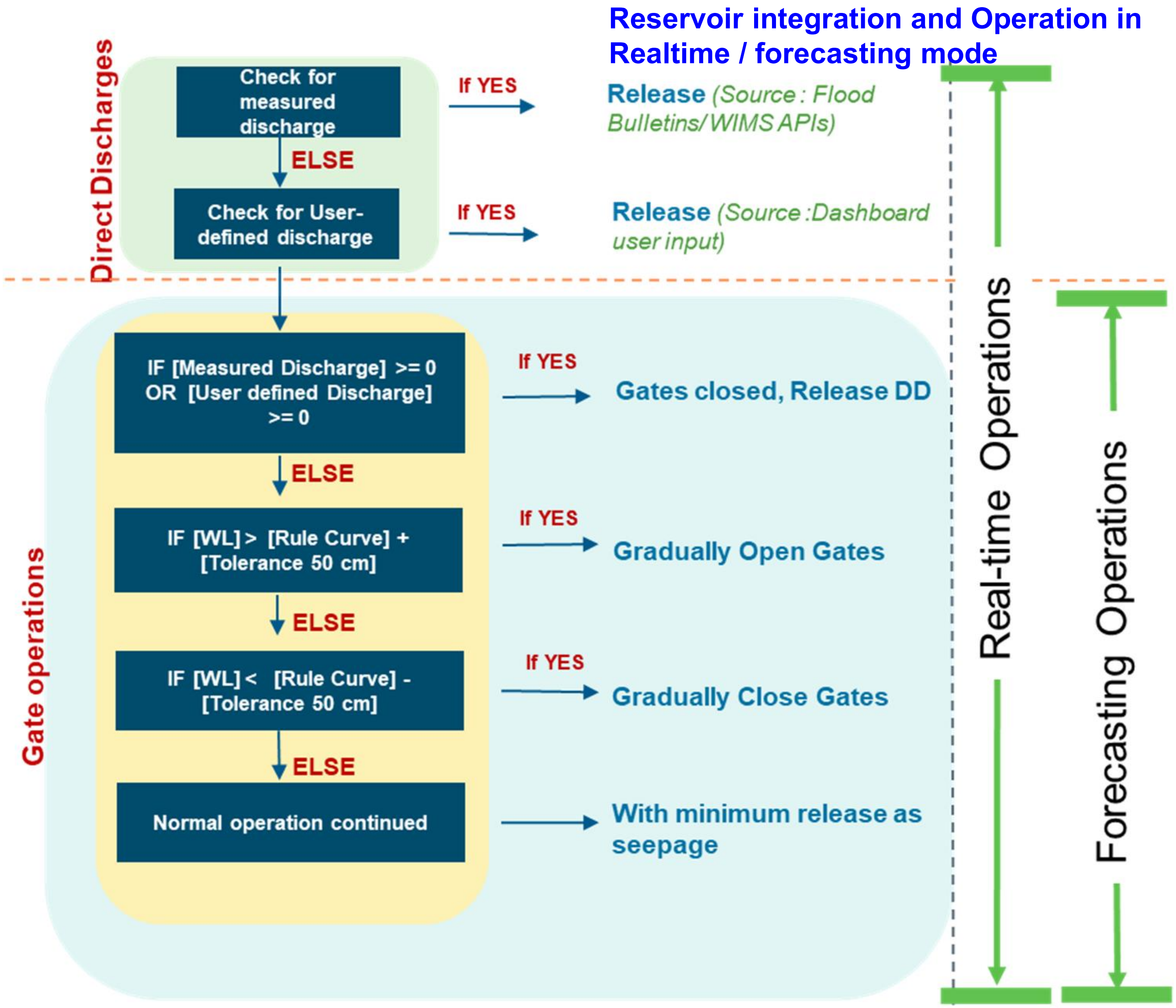
Model Parameter:

Parameter	Description	Unit
Umax (mm)	Maximum water content in surface storage	mm
Lmax (mm)	Maximum water content in root zone storage	mm
CQOF	Overland flow runoff coefficient	-
CKIF (h)	Time constant for interflow	h
TOF	Root zone threshold value for overland flow	-
CK1,2 (h)	Time constant for routing overland flow	H
TIF	Root zone threshold value for interflow	-
TG	Root zone threshold value for groundwater recharge	-
CKBF (h)	Time constant for routing base flow	h

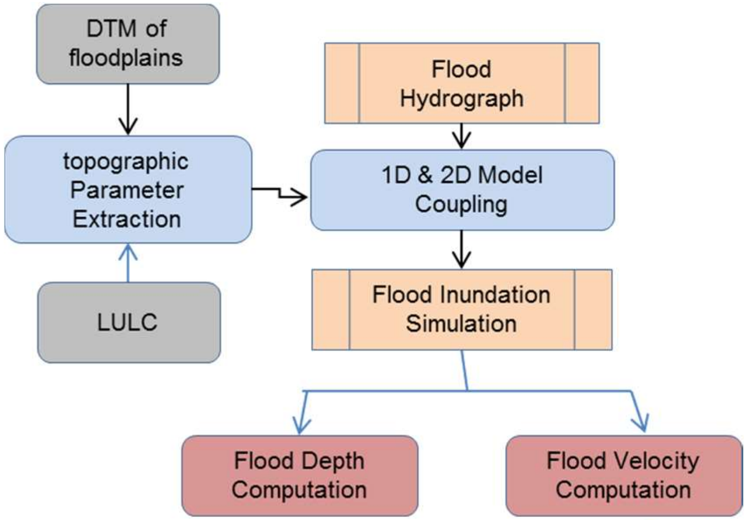
Control Rules for Reservoir Operations

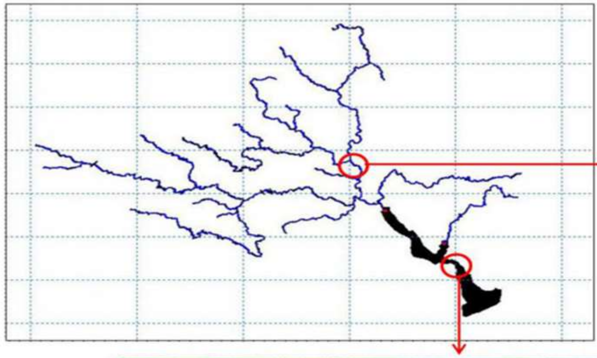


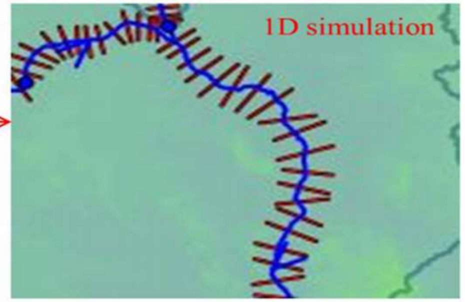


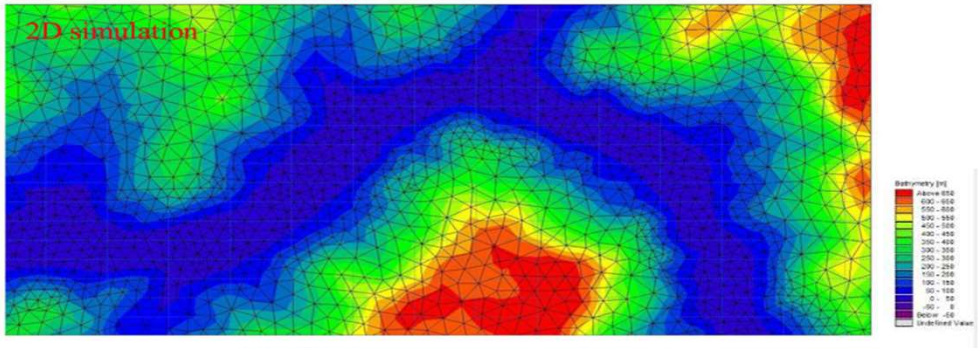


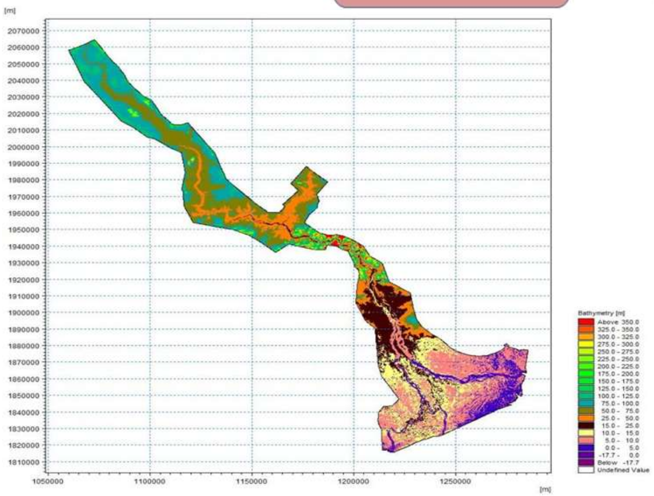
1D-2D model coupling for spatial flood inundation simulation



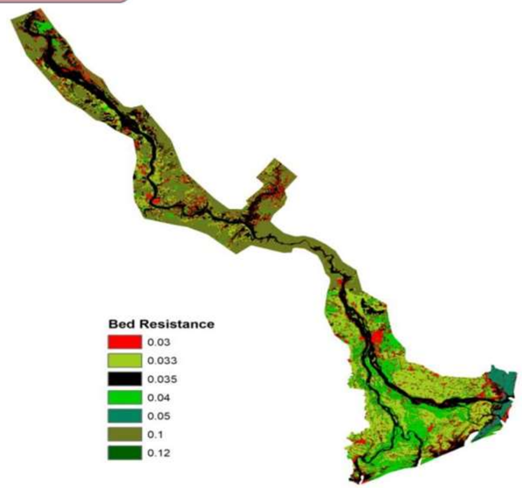




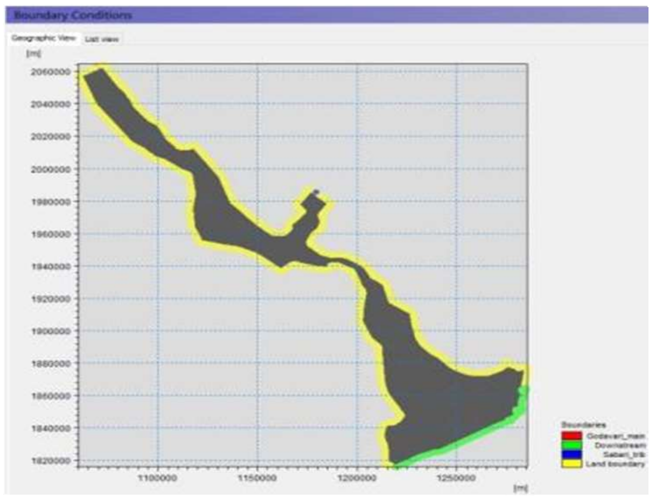




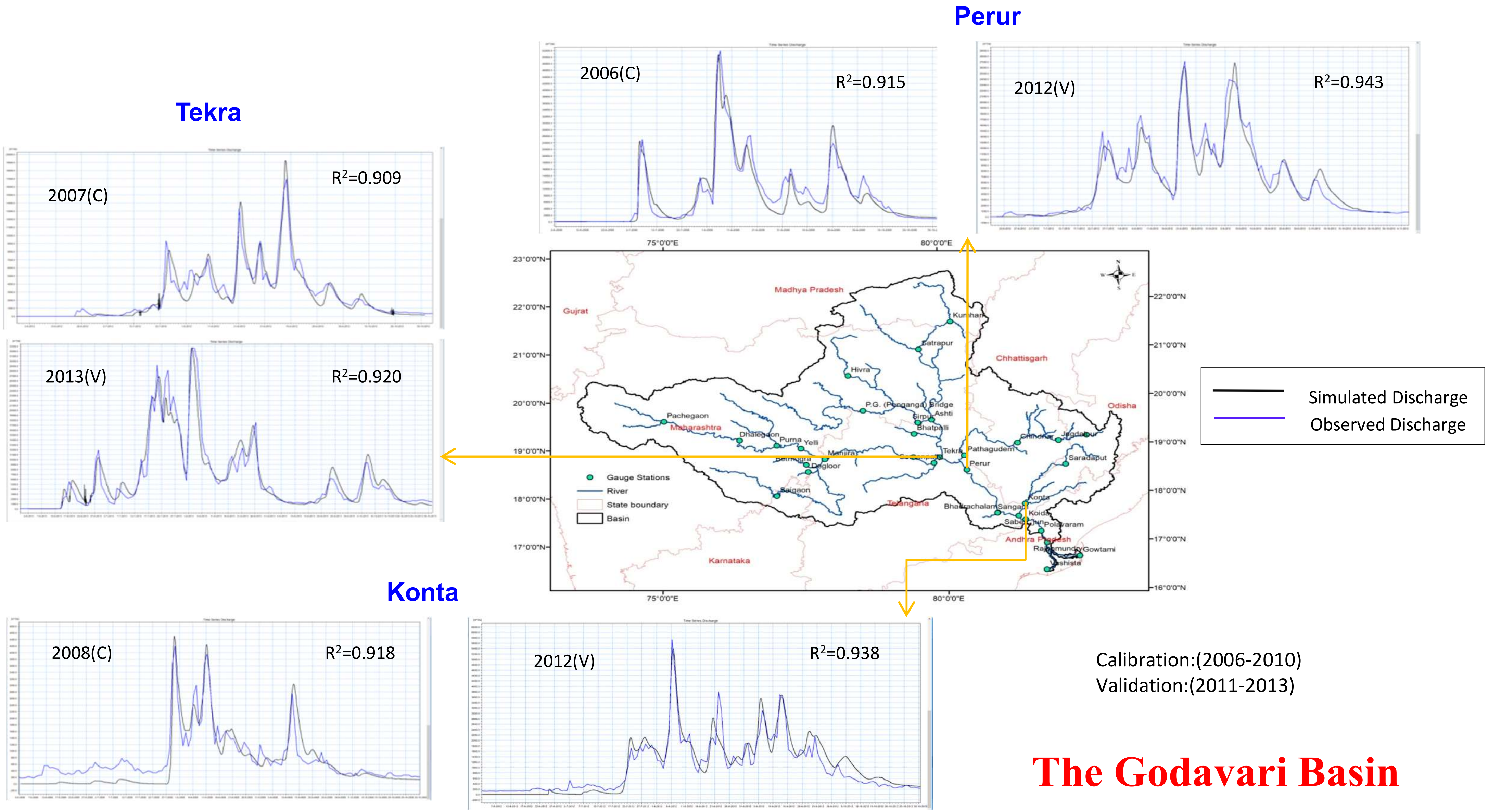
Bathymetry



Bed resistance



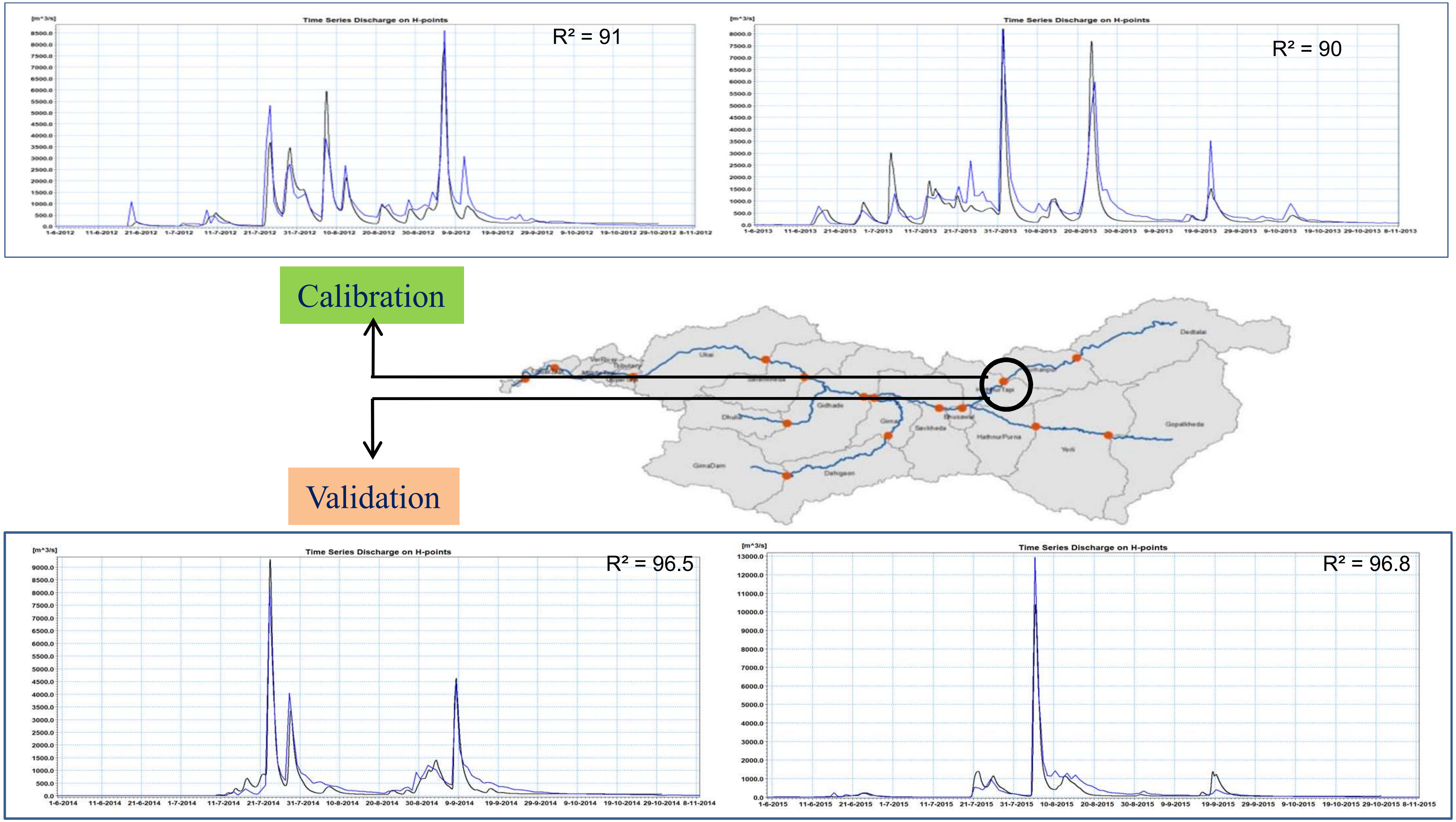
Boundary Conditions



Perur
2006(C)
R²=0.915
2012(V)
R²=0.943
Tekra
2007(C)
R²=0.909
2013(V)
R²=0.920
Konta
2008(C)
R²=0.918
2012(V)
R²=0.938
Madhya Pradesh
Gujrat
Chhattisgarh
Odisha
Maharashtra
Telangana
Andhra Pradesh
Karnataka
Gauge Stations
River
State boundary
Basin
Simulated Discharge
Observed Discharge
Calibration:(2006-2010)
Validation:(2011-2013)
The Godavari Basin

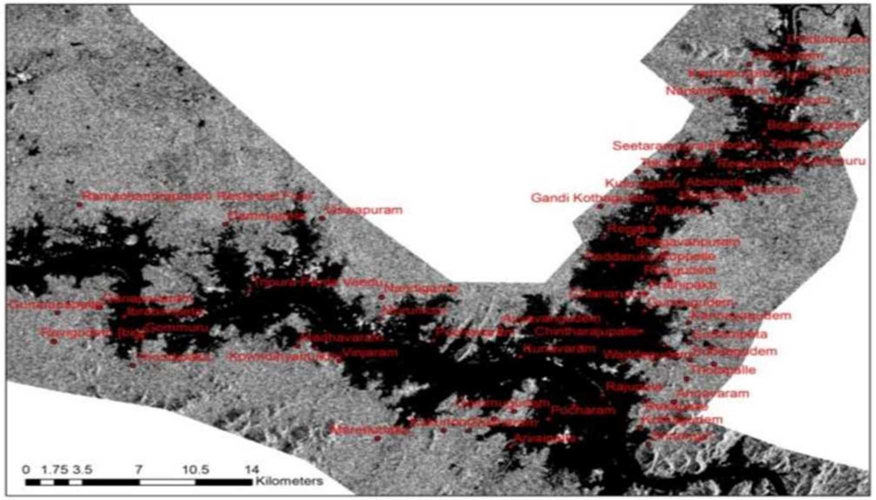
The Tapi Basin

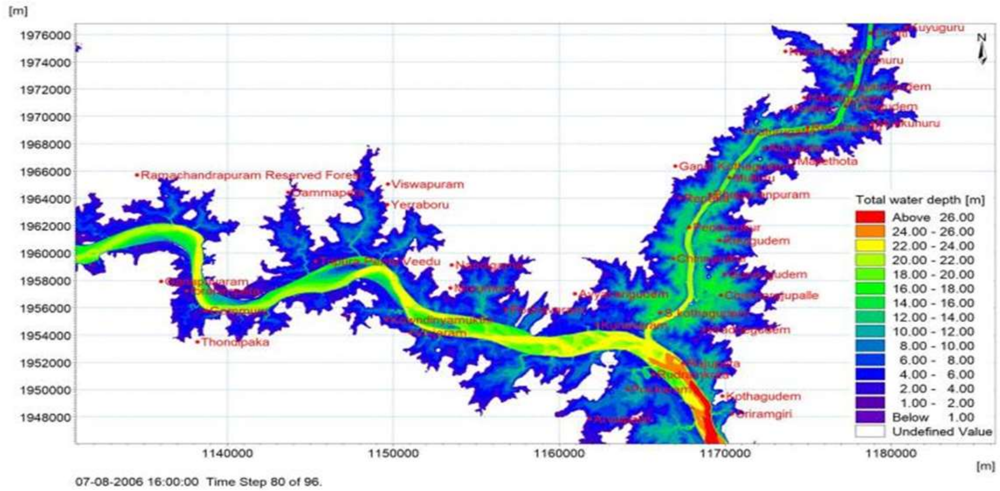
Calibration – 2006, 2007, 2012, 2013 **Validation** – 2014, 2015



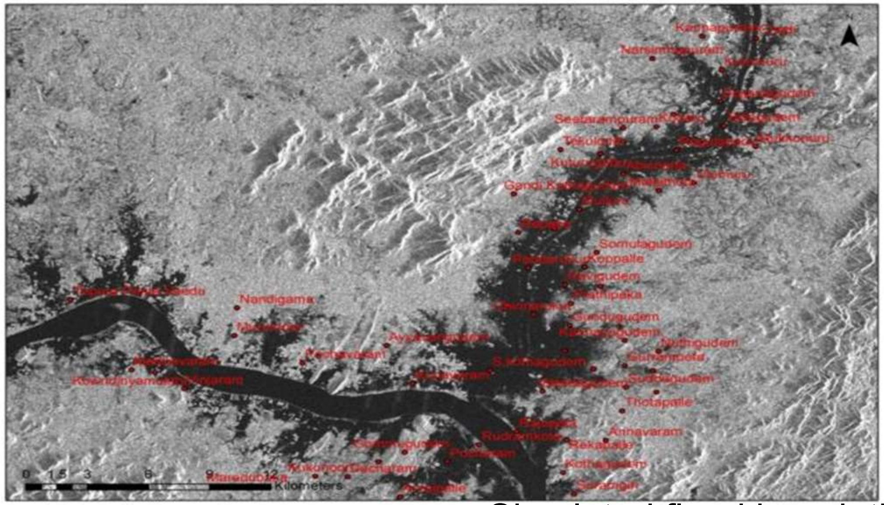
Barhanpur

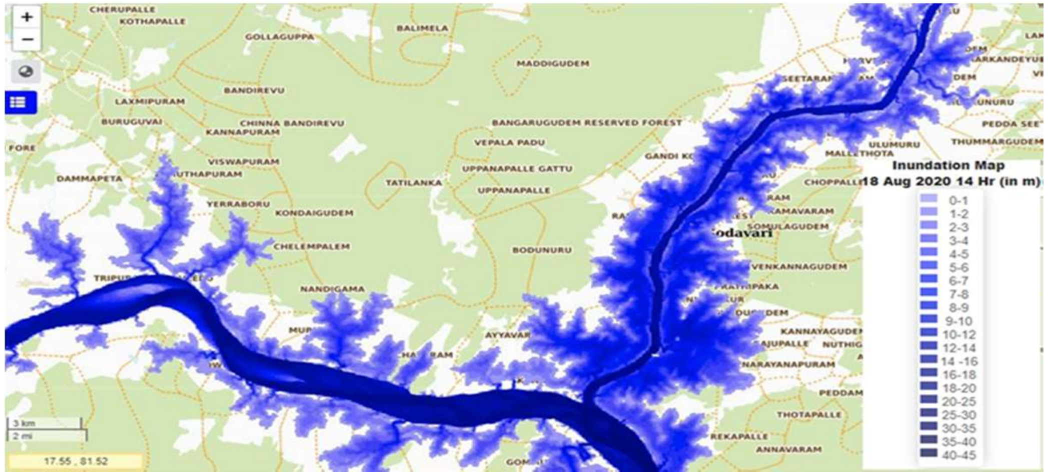
Spatial Flood Inundation Simulations (Observed Vs Simulated)





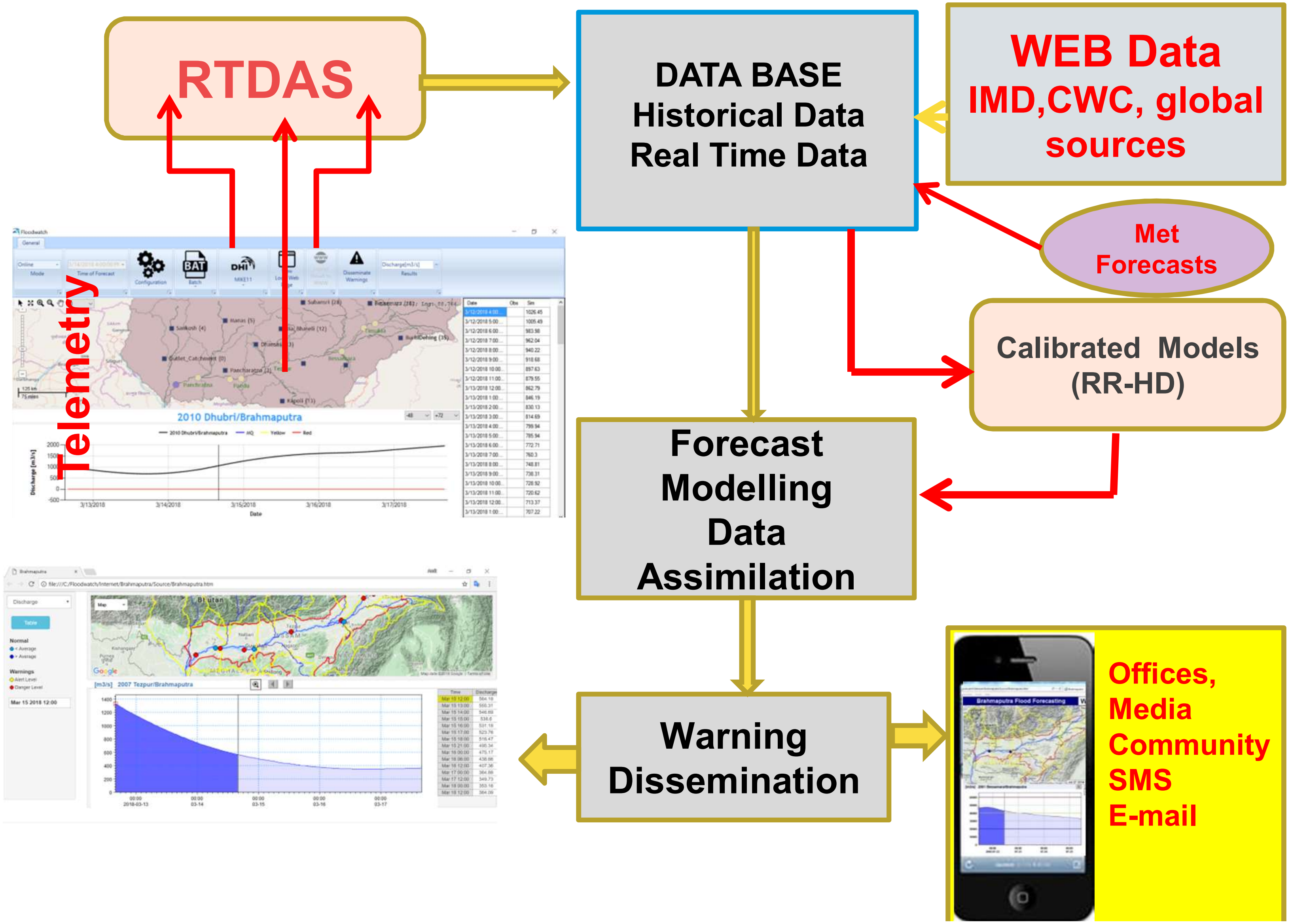
Simulated flood inundation during 2006 flood at Sabari confluence (calibrated)





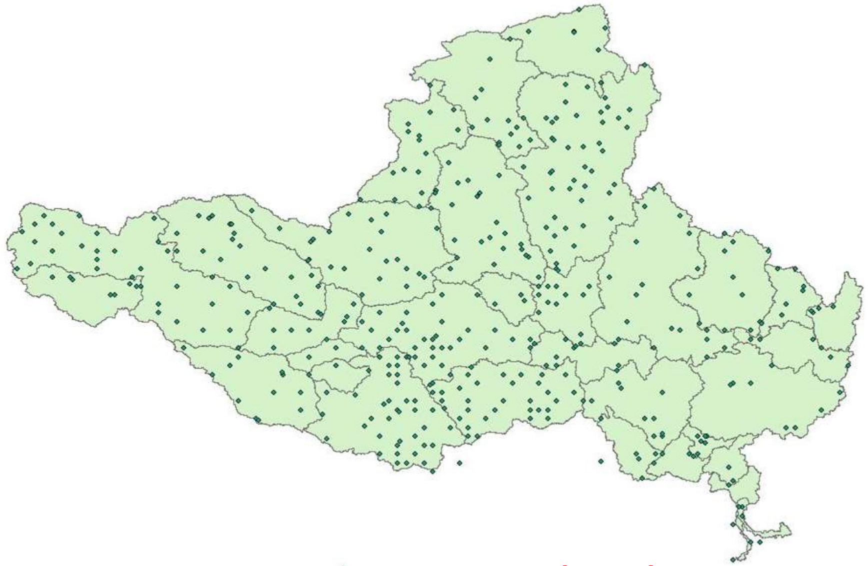
Simulated flood inundation during 2020 flood at Sabari confluence

The Integrated Spatial Flood Early Warning System

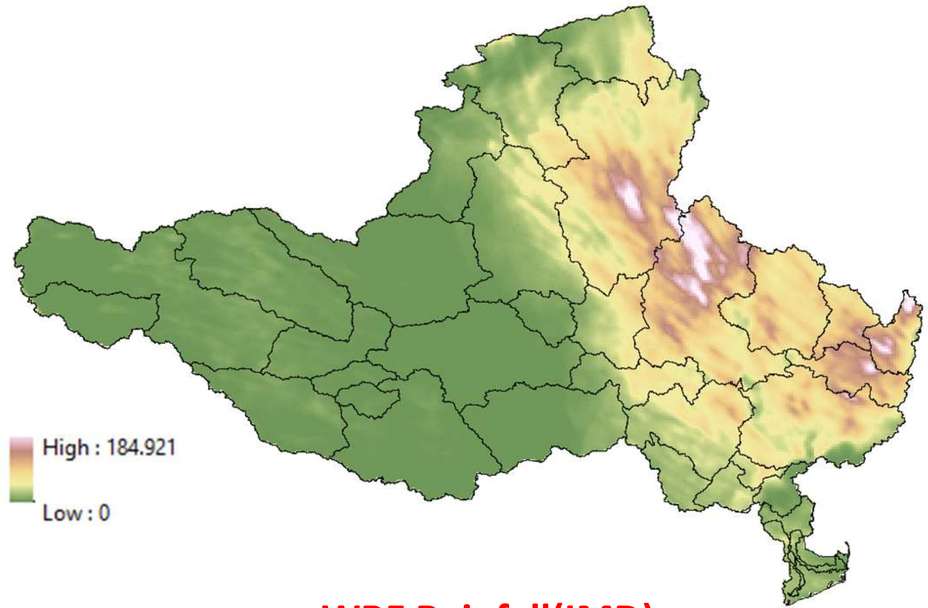


Real time operations

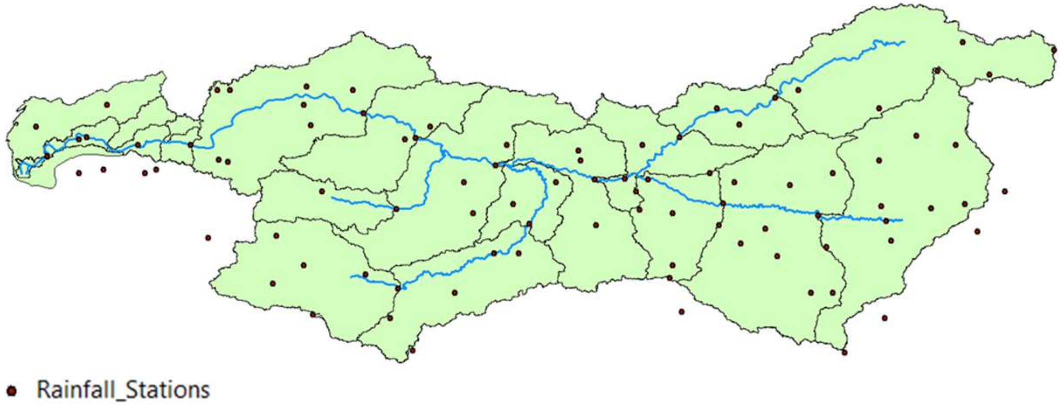
nrsc

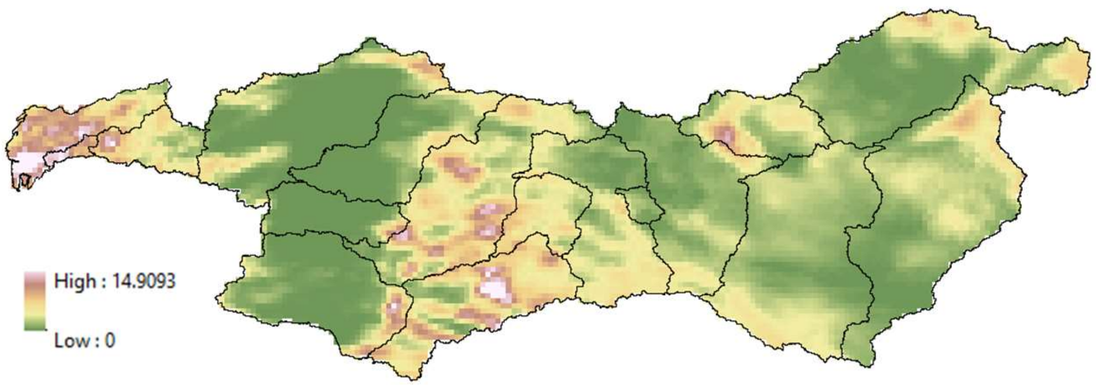


Rainfall Stations (IMD)



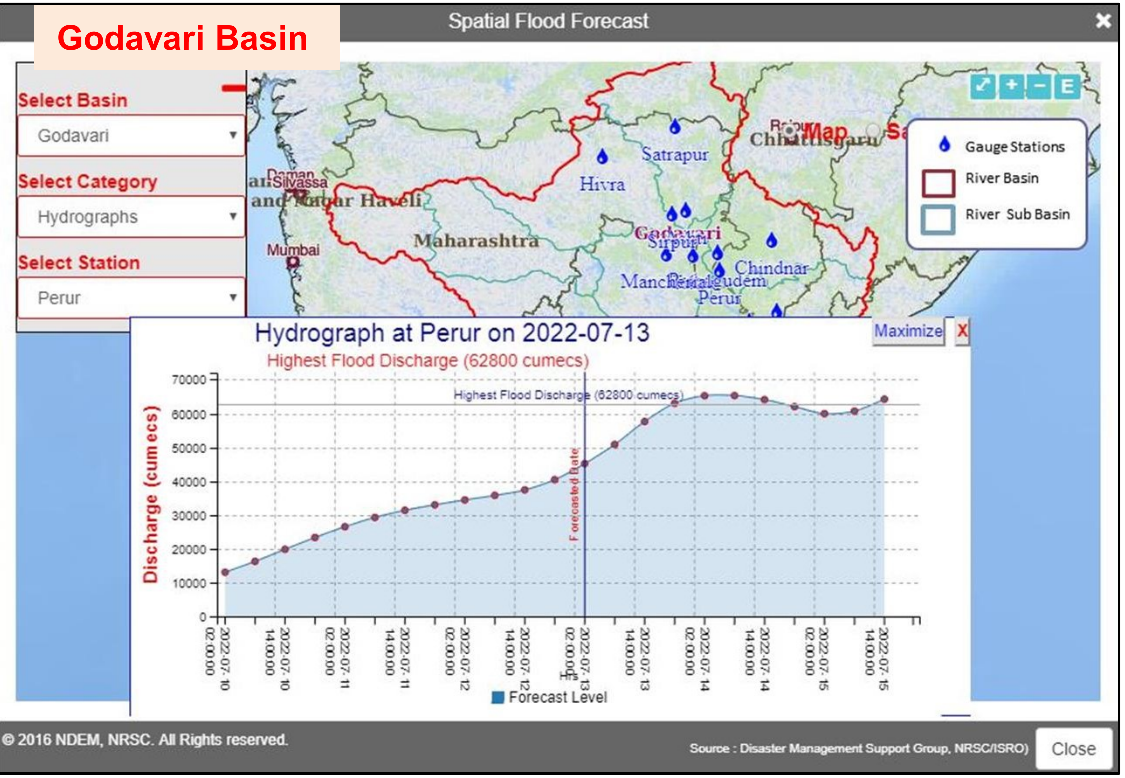
WRF Rainfall(IMD)



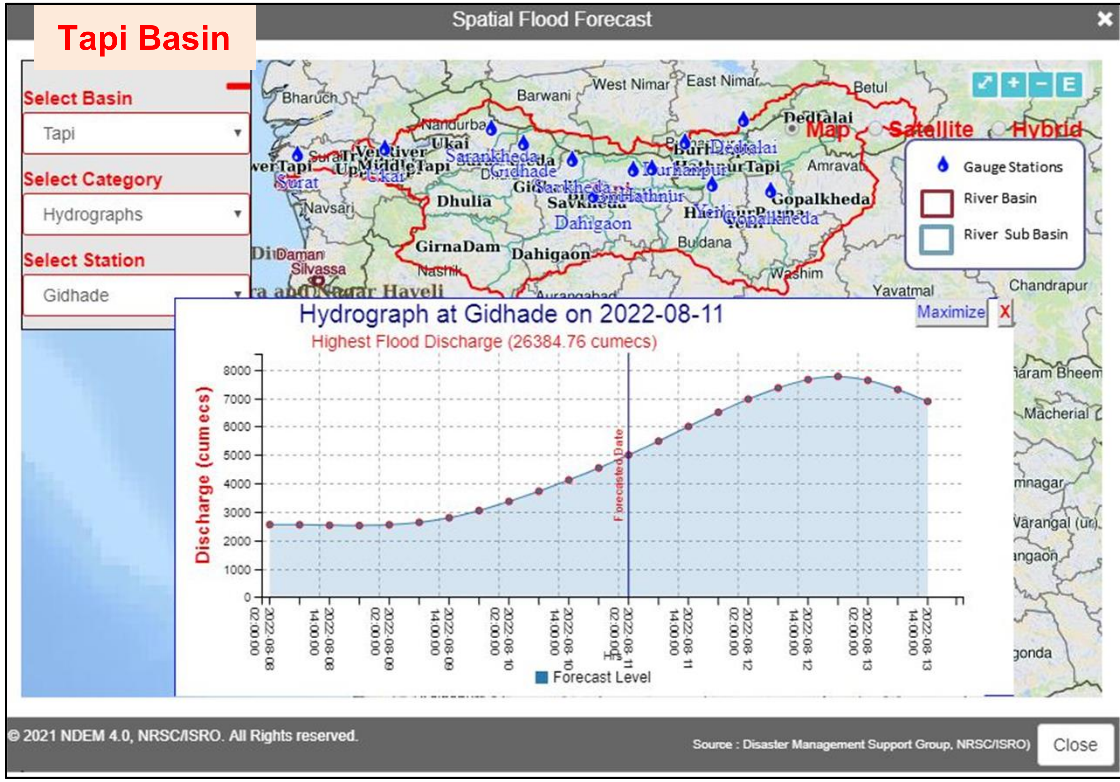


nrsc

Flood Early Warning in 2022



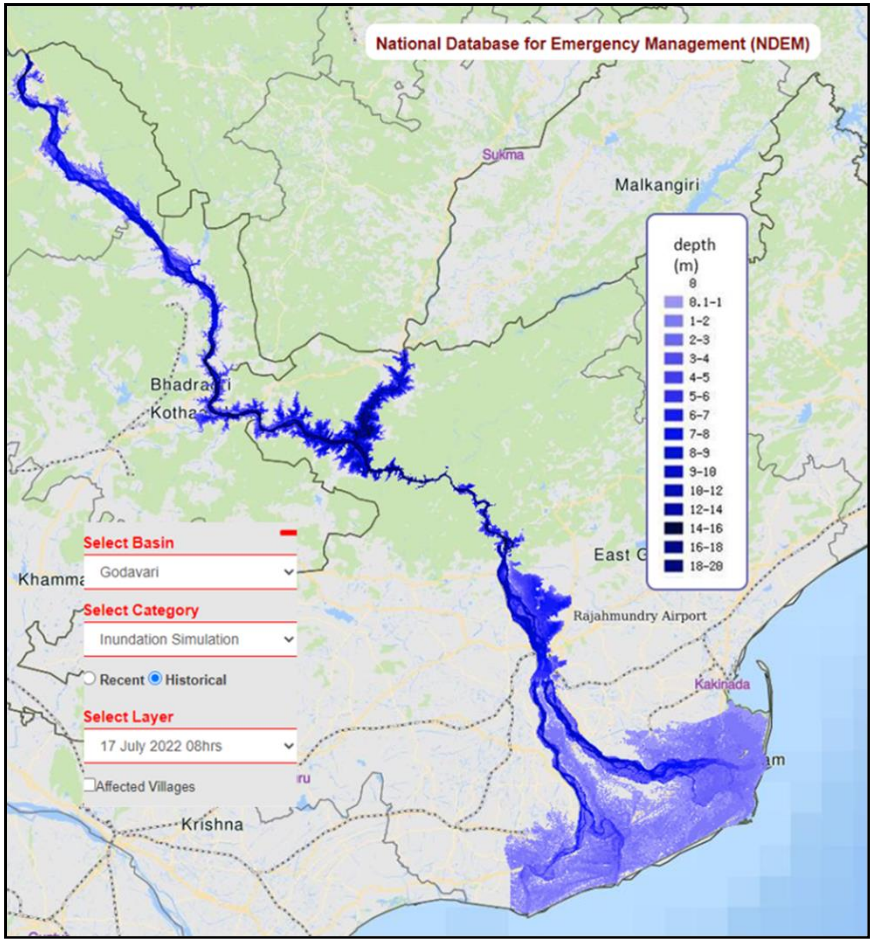
Flood Hydrograph at Perur in Godavari River



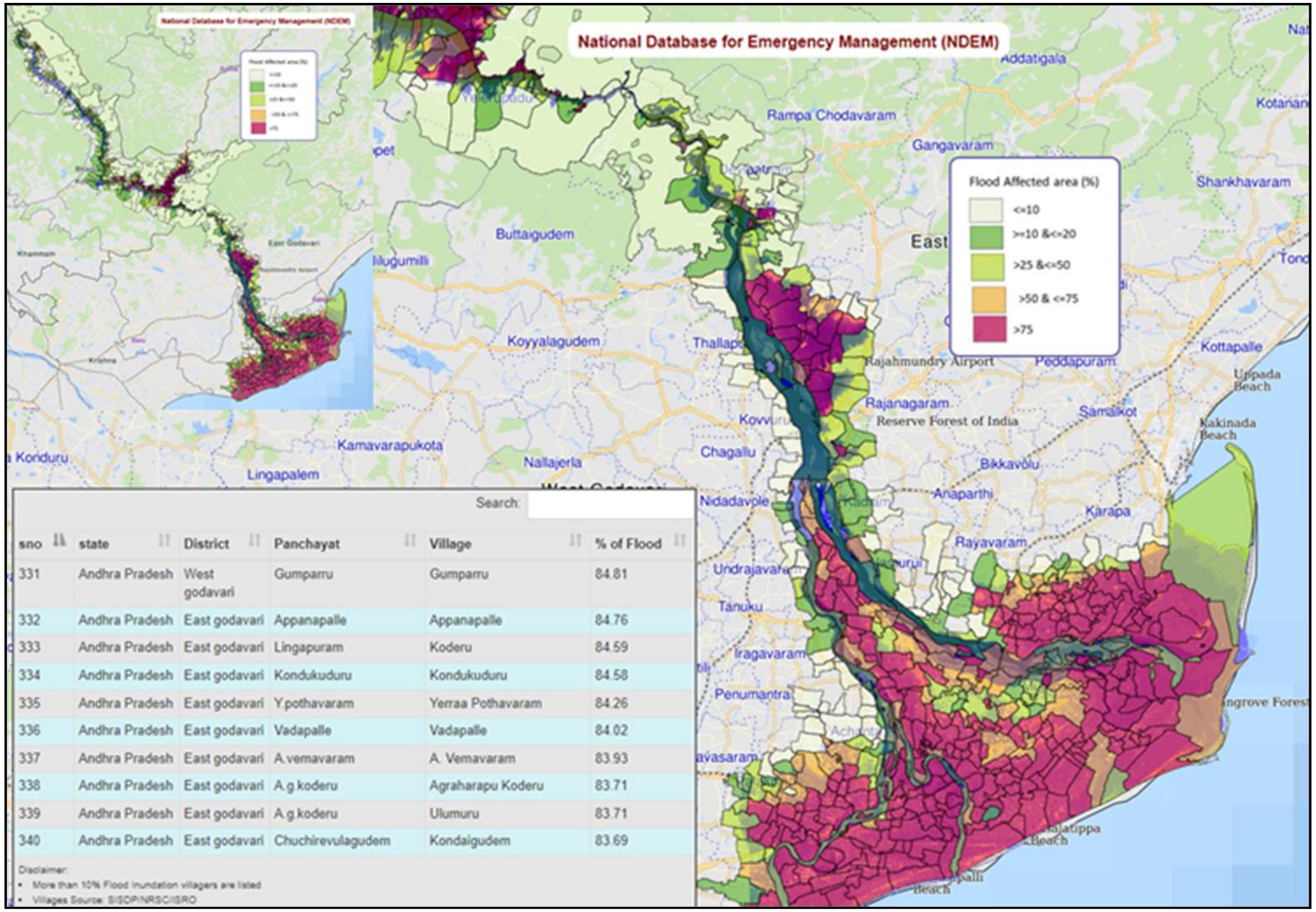
Flood Hydrograph at Gidhade in Tapi River

Spatial Flood Early Warning in 2022 and Risk Assessment

nrsc

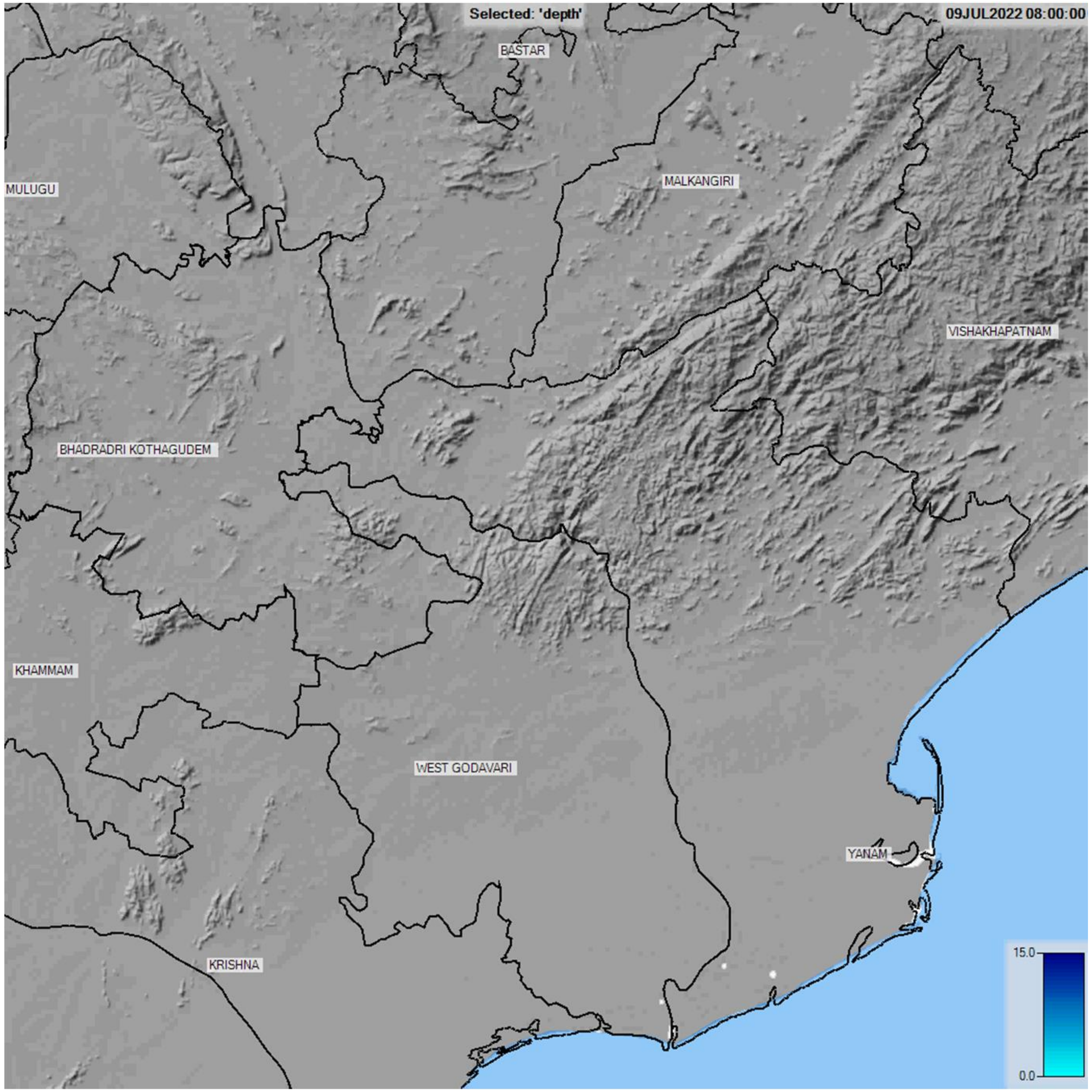


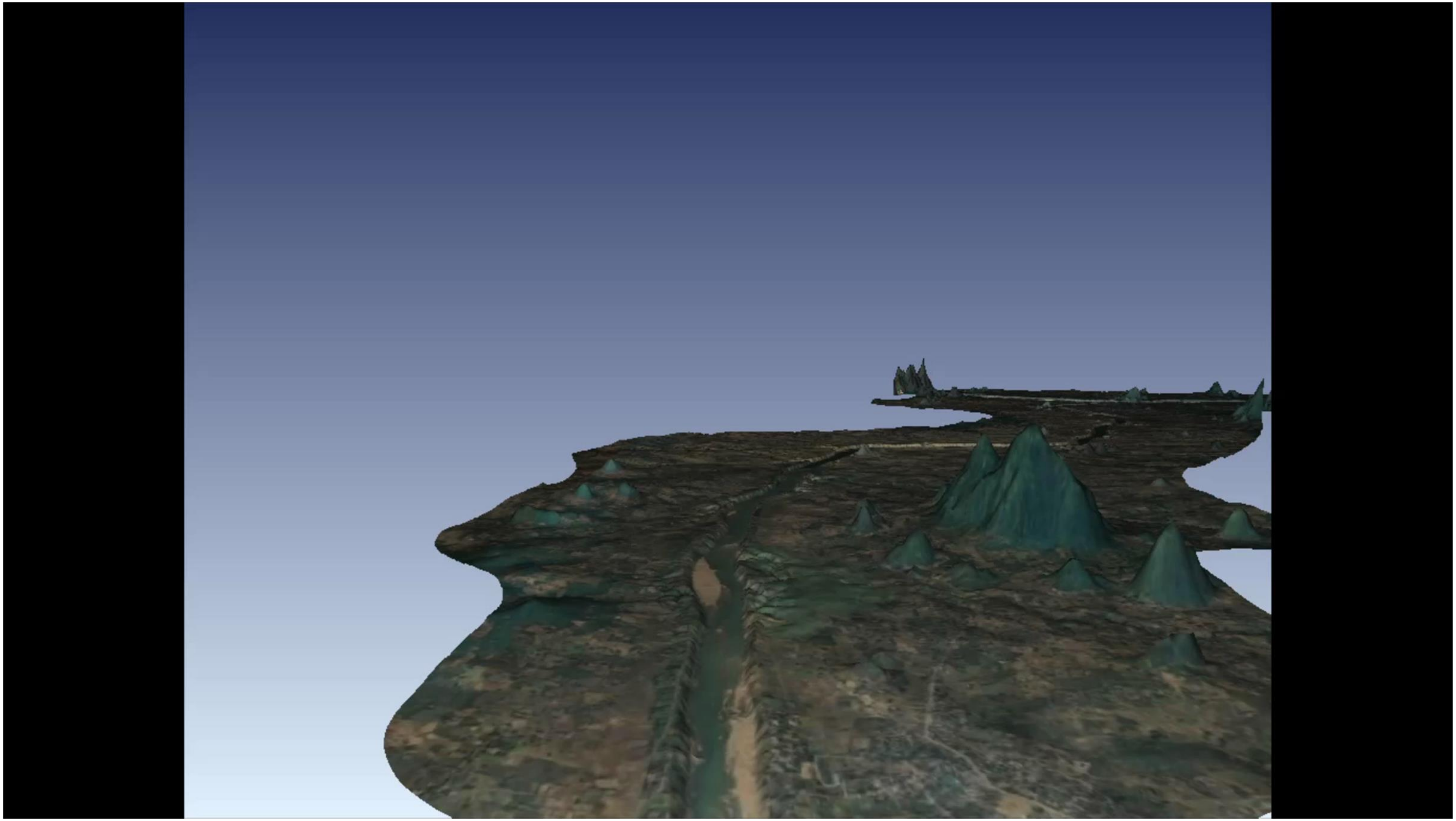
Spatial flood inundation simulation (17 Jul 2022)



sno	state	District	Panchayat	Village	% of Flood
331	Andhra Pradesh	West godavari	Gumparru	Gumparru	84.81
332	Andhra Pradesh	East godavari	Appanapalle	Appanapalle	84.76
333	Andhra Pradesh	East godavari	Lingapuram	Koderu	84.59
334	Andhra Pradesh	East godavari	Kondukuduru	Kondukuduru	84.58
335	Andhra Pradesh	East godavari	Y.pothavaram	Yerraa Pothavaram	84.26
336	Andhra Pradesh	East godavari	Vadapalle	Vadapalle	84.02
337	Andhra Pradesh	East godavari	A.vemavaram	A. Vemavaram	83.93
338	Andhra Pradesh	East godavari	A.g.koderu	Agraharapu Koderu	83.71
339	Andhra Pradesh	East godavari	A.g.koderu	Ulumuru	83.71
340	Andhra Pradesh	East godavari	Chuchirevulagudem	Kondaigudem	83.69

Spatial flood early warning and villages affected (17 Jul 2022)


Selected: 'depth'
09JUL2022 08:00:00
BASTAR
MULUGU
MALKANGIRI
VISHAKHAPATNAM
BHADRADRI KOTHAGUDEM
KHAMMAM
WEST GODAVARI
YANAM
KRISHNA
15.0
0.0



Major Highlights & End use

Accuracy

Flood discharge computation accuracy is > 85 % with Improved Forecast lead time (36 to 50 hours) at multiple locations.

Application

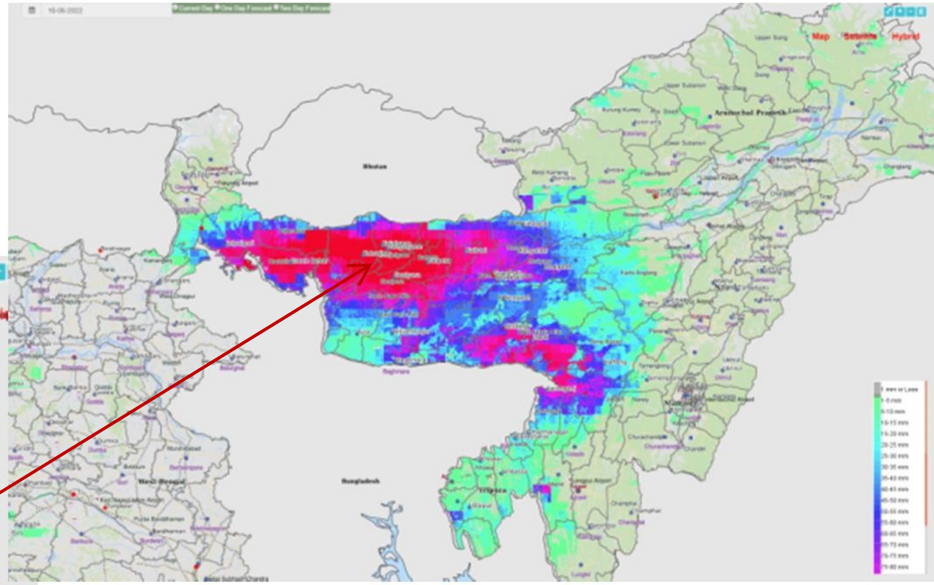
Spatial flood advisories on flood extent & depth to all the stake holders through automated sms services.

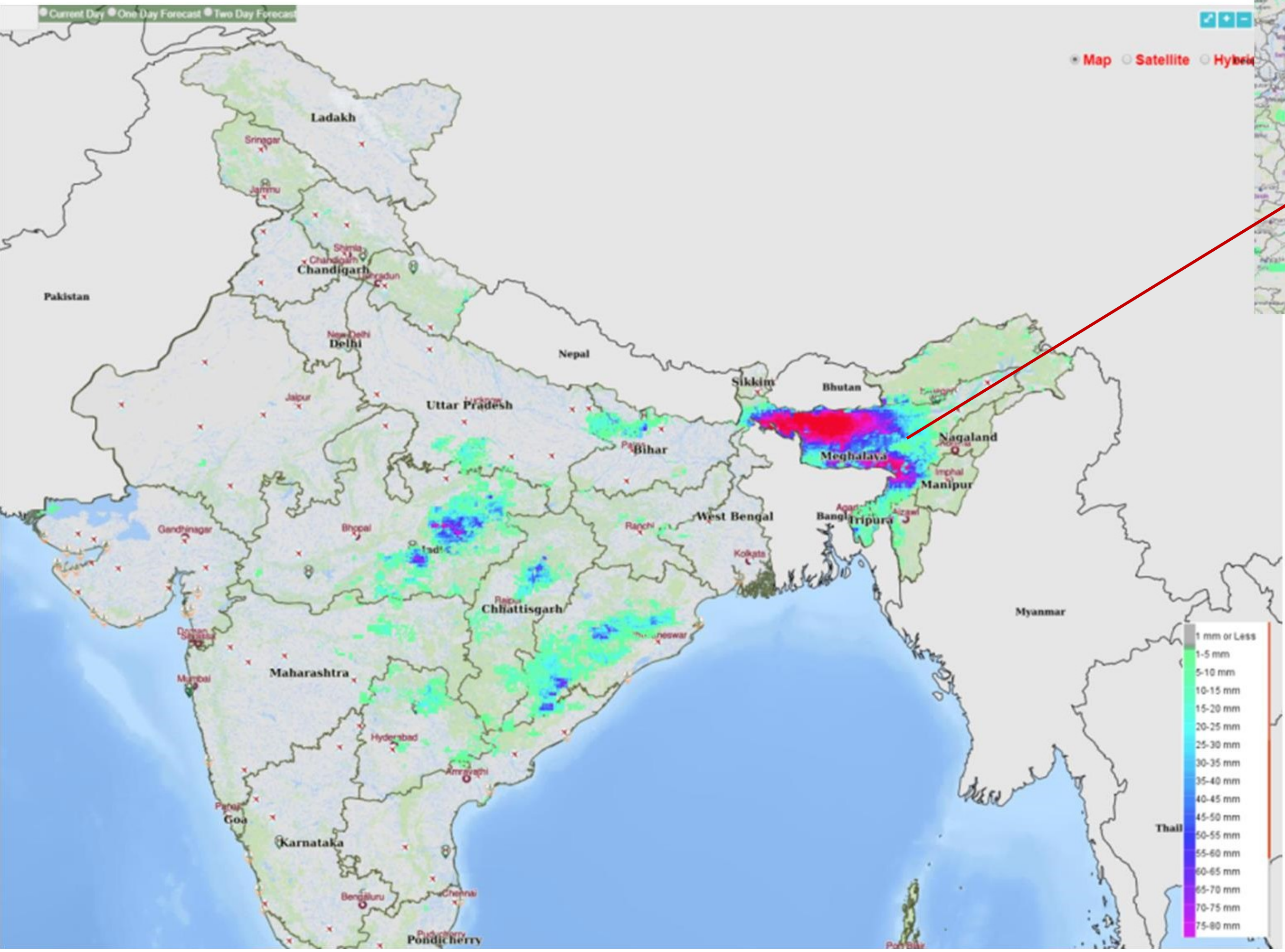
End use

Vital input in relief & rescue operations, and in preparing Basin level DM plans for DRR.

Scientific assessment of flood-prone area in the Basins

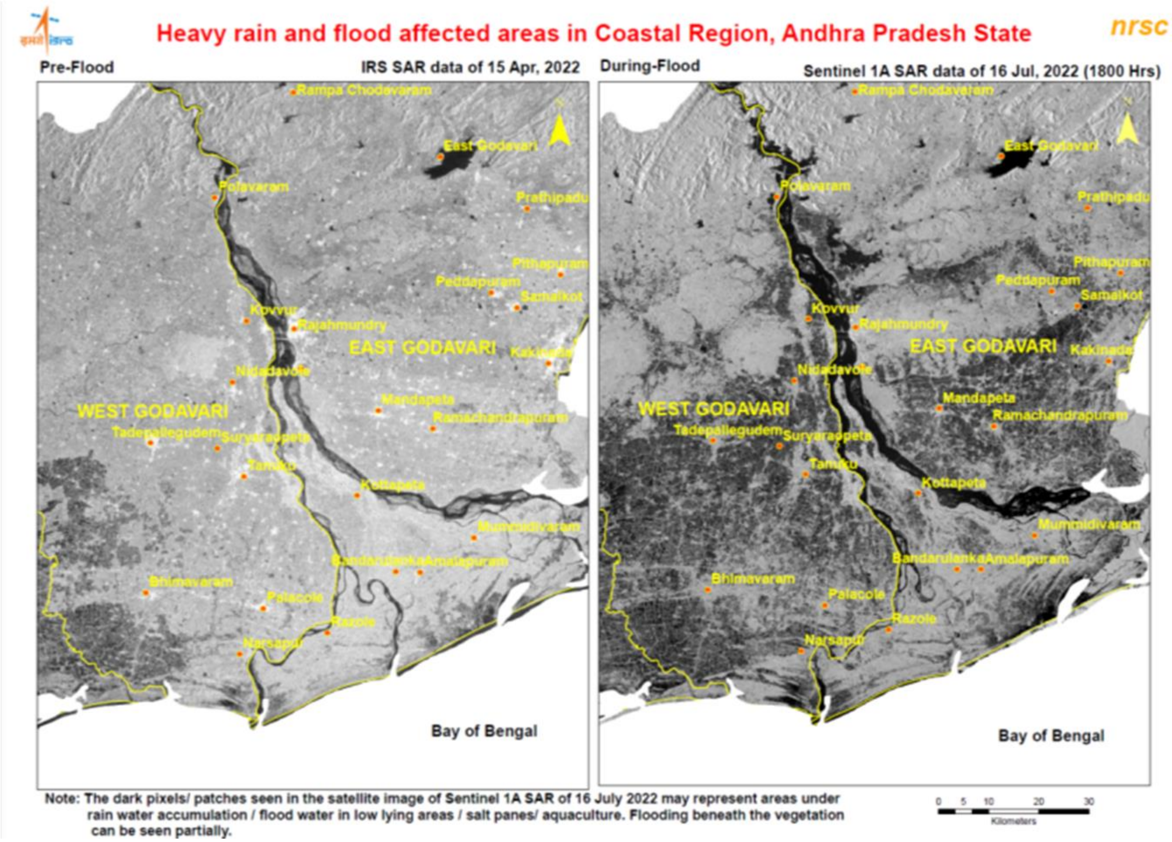
PAN India Runoff in mm
(as on 17 June 2022)





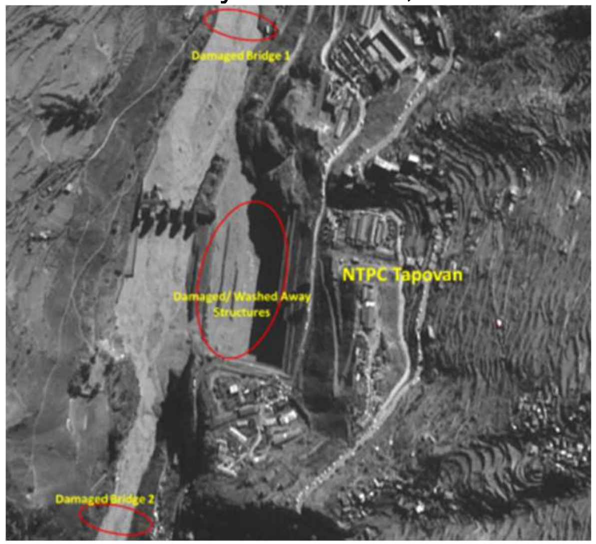
- Model computation is automated
- Current day runoff using GPM data
- 2 day forecast using IMD WRF data

Response Phase: Near Real-time Flood & Cyclone Monitoring and Mapping



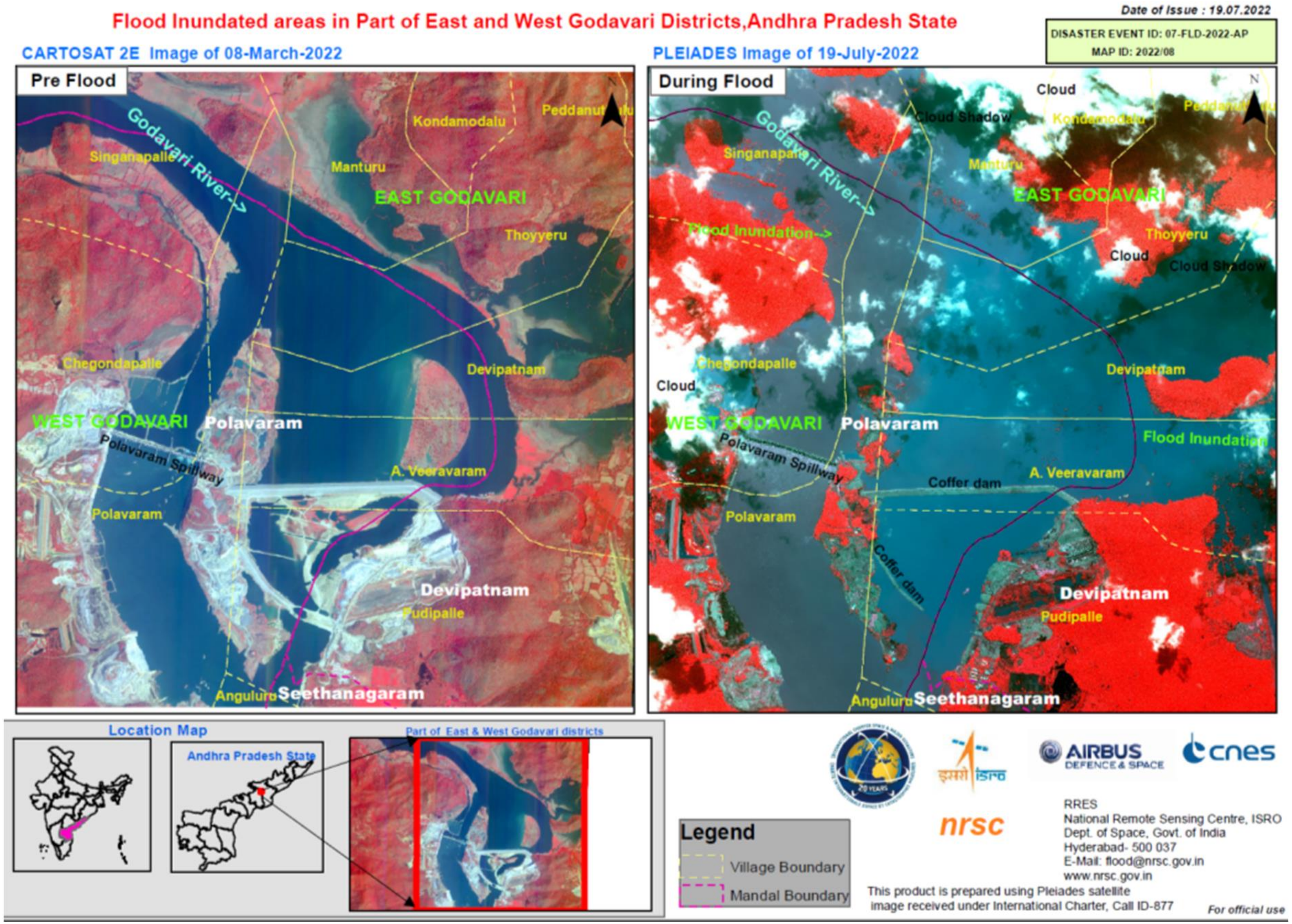
- Flood/cyclone monitoring, mapping of PAN India with TAT of 3 to 4 hours
- Damage assessment and Value Added Products
- Being disseminated to MHA, NDMA, State DMS, etc
- It is used in relief and rescue operations, and damage assessment

Damage to Urban Infrastructure due to Phani Cyclone 2019, Odisha

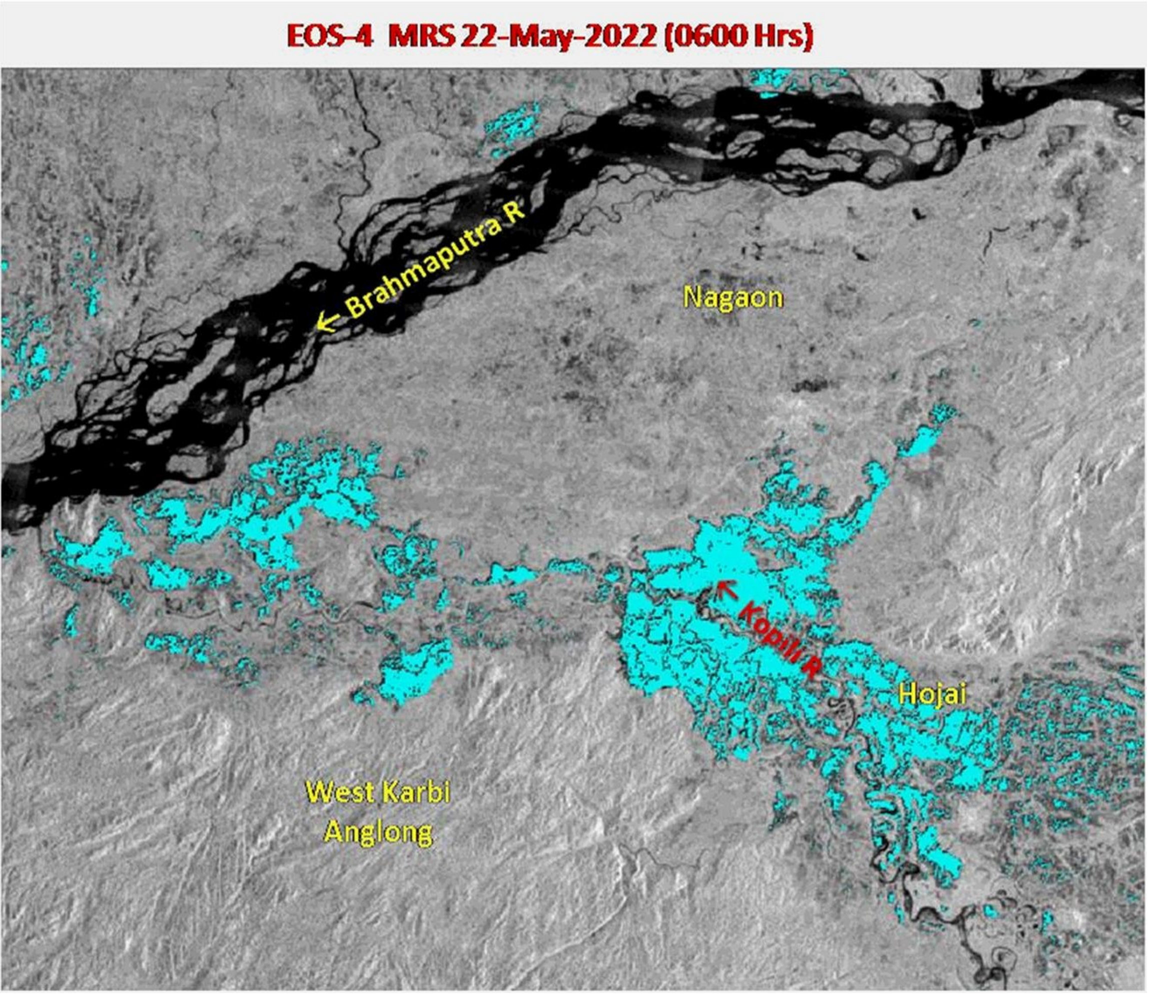


Damage to Tapovan Project due to flash flood in Rishi Ganga River, Feb 2021

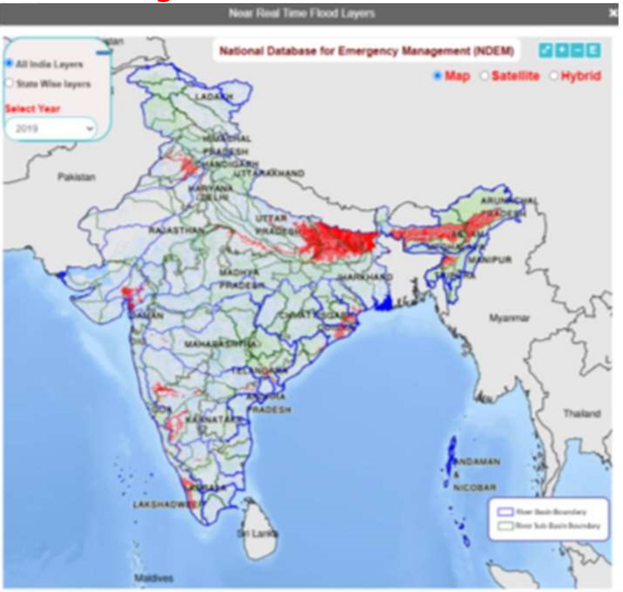
Polavaram Project Before and During Flood Event



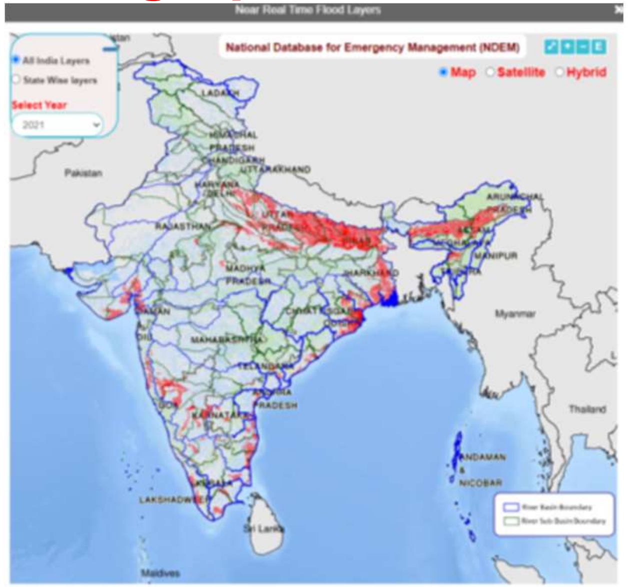
Assam Floods – 2022



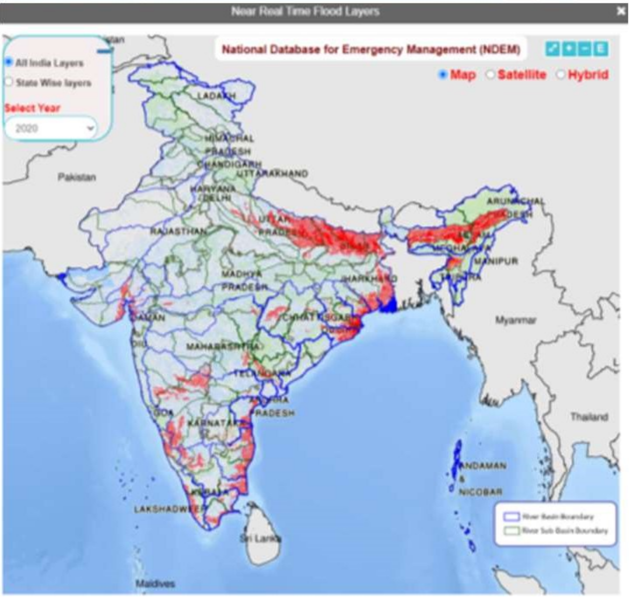
Major Floods in the Country as Mapped using Space Data in Recent Years



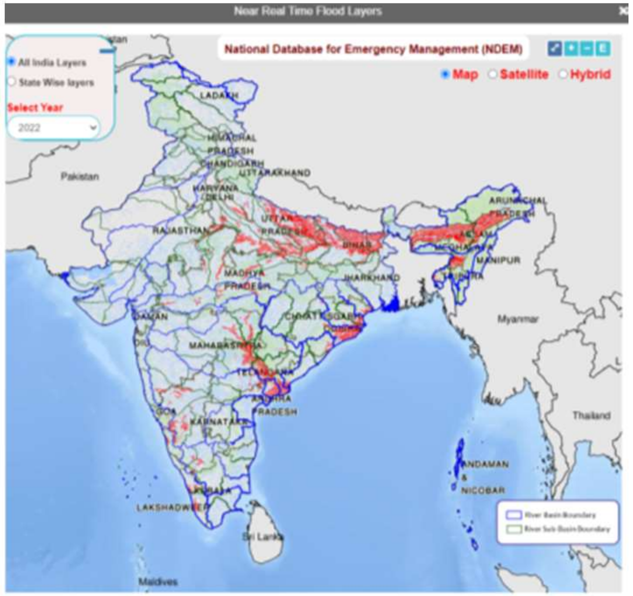
Year: 2019
States : 14
Districts: 186
Maps/VAPs: 254



Year: 2021
States : 15
Flood events: 24
Districts: 181
Maps/VAPs: 277



Year: 2020
States : 15
Flood events: 21
Districts: 183
Maps/VAPs: 308



Year: 2022
States : 13
Flood events: 21
Districts: 192
Maps/VAPs: 47

Mitigation Phase: State Level Flood Hazard Zonation Atlases

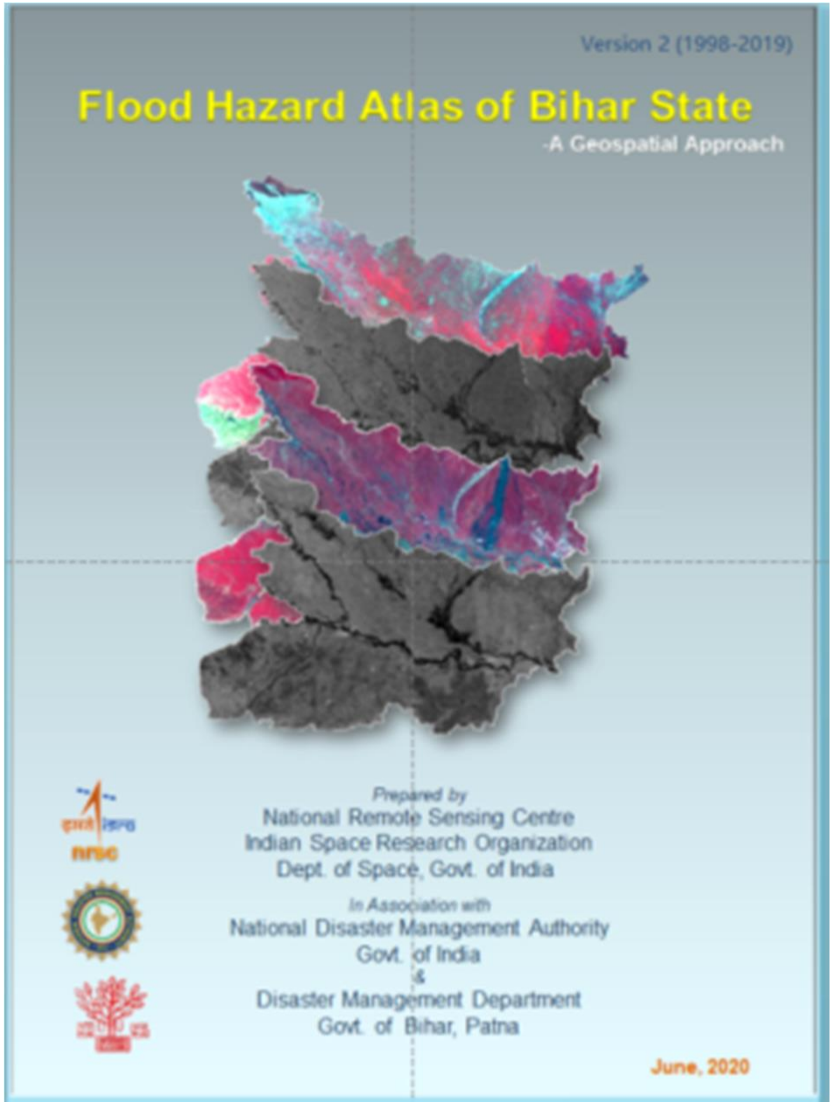
nrsc

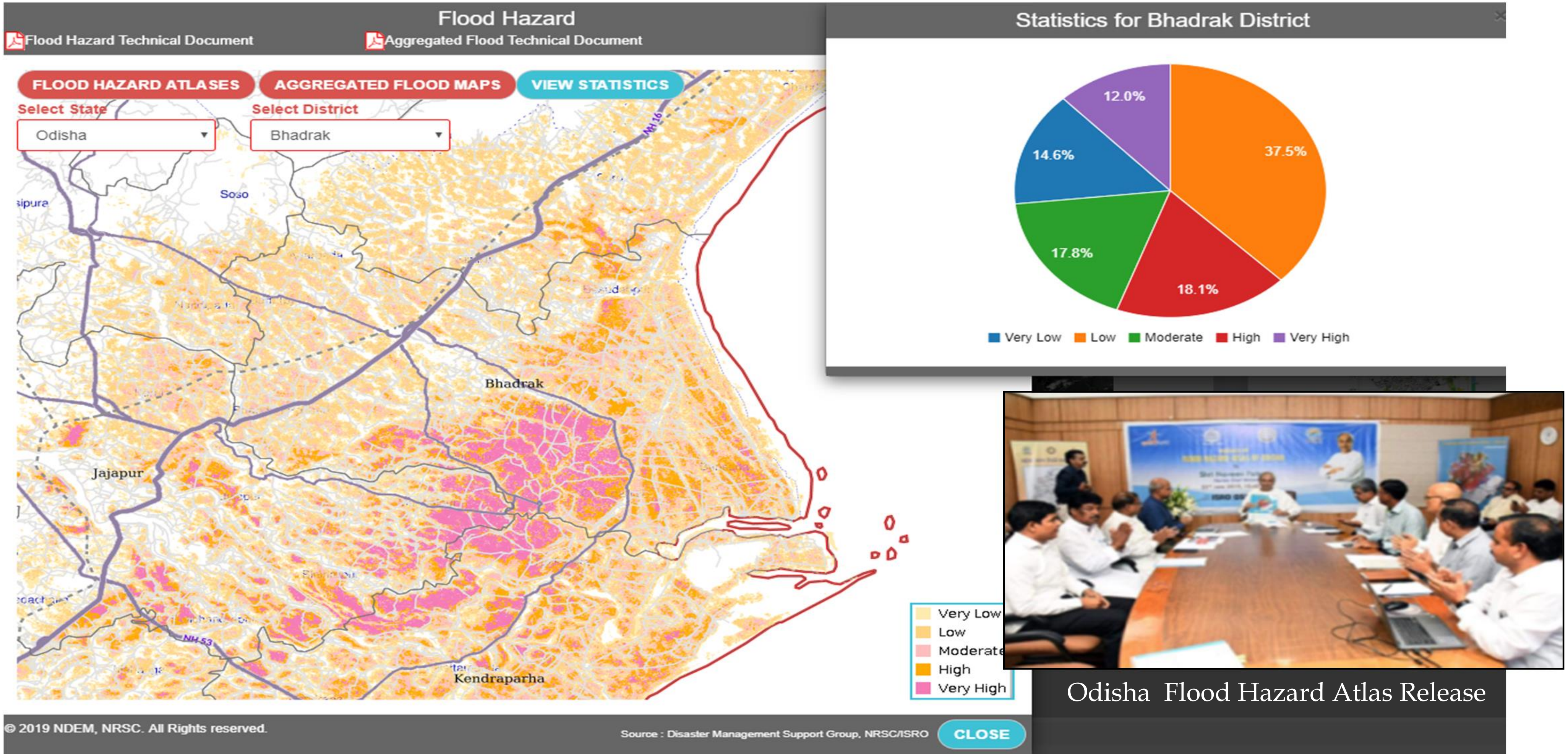
Advantages

- Flood Hazard Maps are one of most important non-structural flood disaster risk reduction methods
- It is useful for controlling developmental activities
- Useful in planning of relief, rescue, and health centers
- Useful input in growing flood tolerant crops
- Important parameter in flood insurance

Input Data

- Historic flood maps of about 20 years
- CWC discharge data of 20 years
- Large scale geo-spatial data
- Ground validation





Odisha Flood Hazard Atlas Release

- Flood hazard atlases of most flood-prone states like Assam, Bihar, Odisha, Andhra Pradesh, West Bengal, and UP are completed using satellite data of 2000 to 2020
- Aggregated flood maps for 11 more states using satellite data of 2003 to 2020

Project Team

Flood Modelling:

Sri Amanpreet Singh

Sri Abhinav Kumar

Flood Mapping & Hazard:

Flood Mapping & Hazard

Assessment Team

For details, please contact at

durgarao_khv@nrsc.gov.in

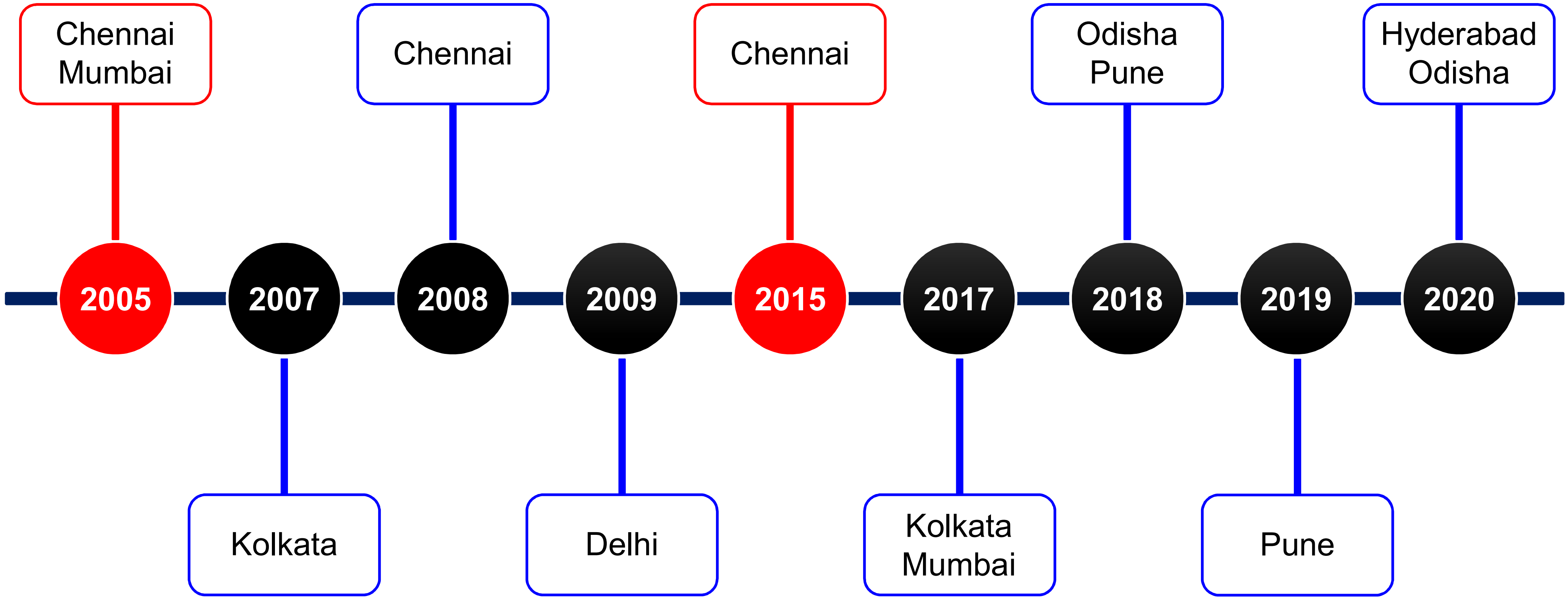
Urban Flood Modelling

Balaji Narasimhan
Professor
Dept of Civil Engineering
Indian Institution of Technology - Madras

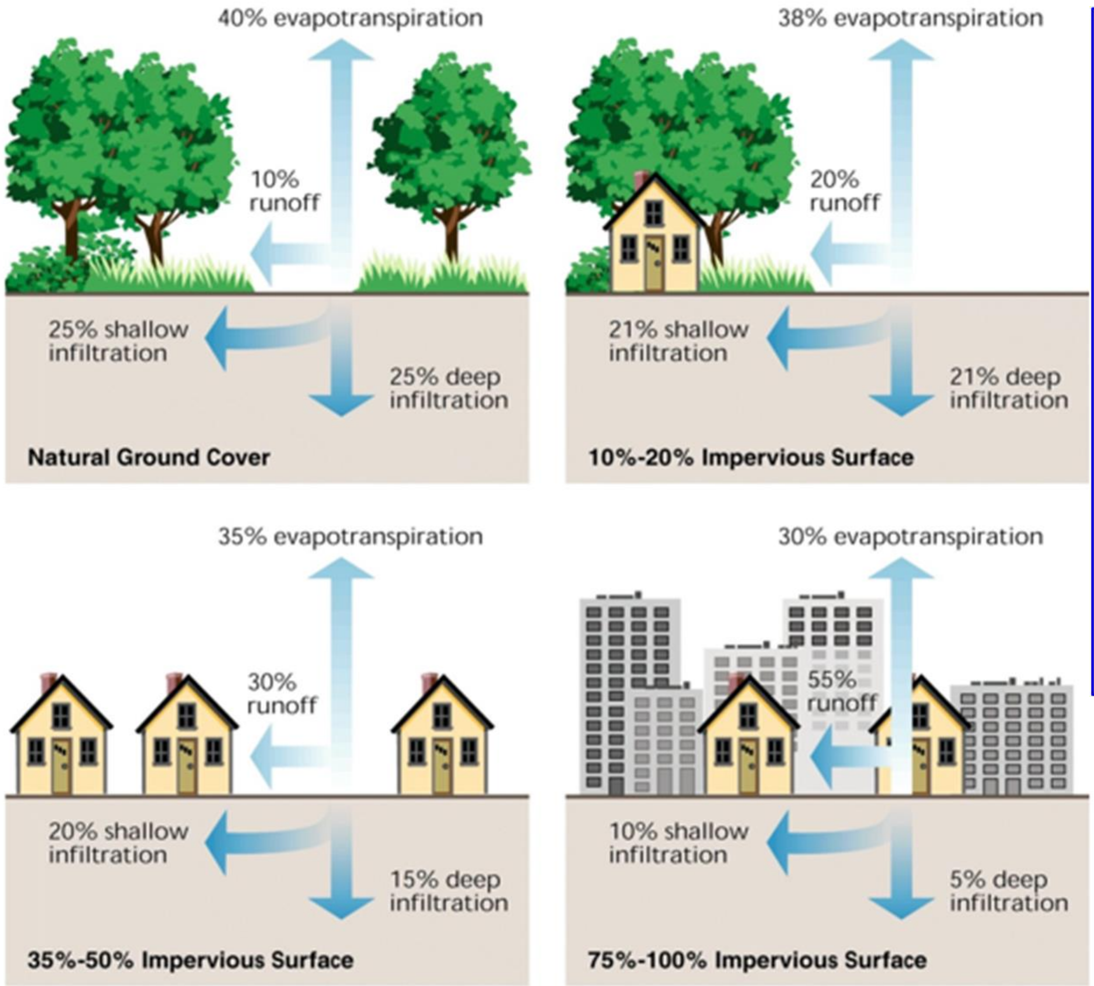
Overview

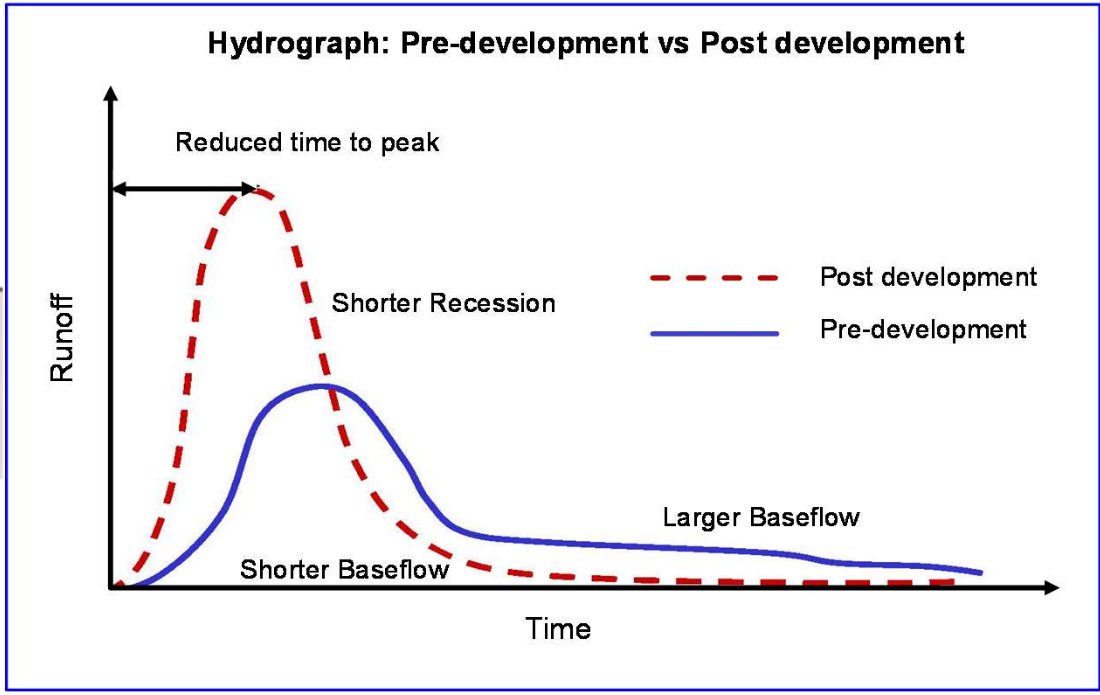
- Urban Flooding
- Causes
- Modelling Approaches
- Spatial variability of rainfall data – Satellite and RADAR
- Case Study: Chennai Floods
- Flood forecasting systems
- Challenges
- Way Forward

Major Urban Flood Events



Characteristics of Urban Flooding





- Rapid urbanization and resulting **urban sprawl**
- Heavy precipitation
- **Vulnerable to hydrologic extremes**.

Source: www.landscouncil.org

Causes of urban flooding

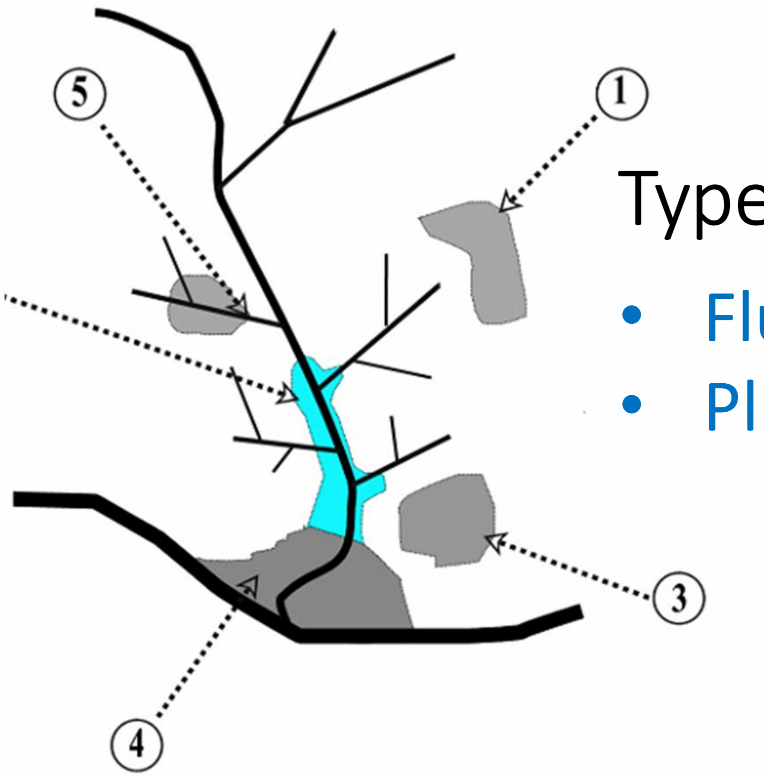
(1) Lack of drainage infrastructure

(2) Backup due to elevated downstream water levels

(3) Flooding in low-lying areas

(4) Innundation caused by high river water levels

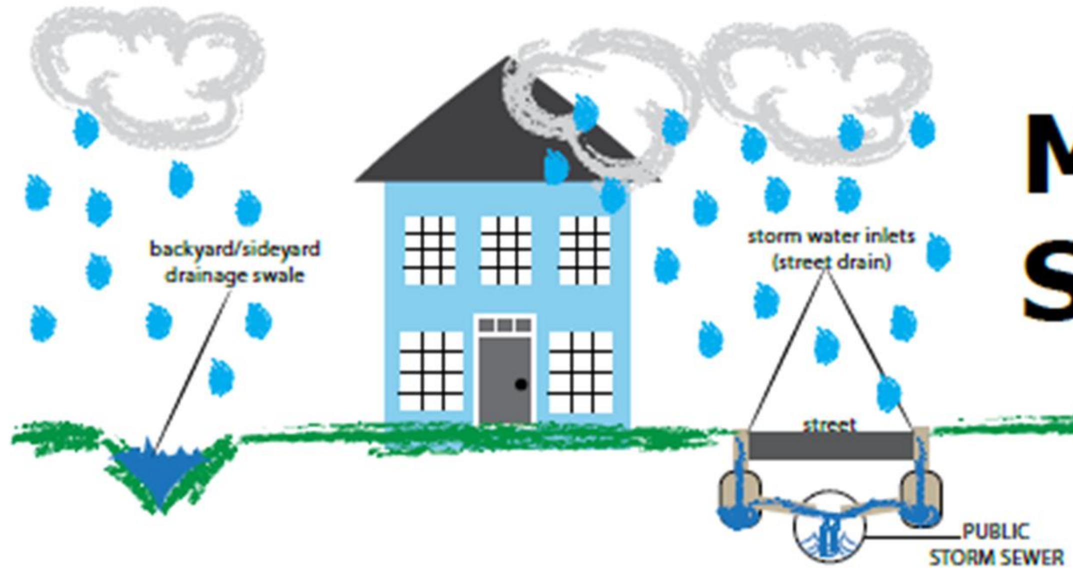
(5) Blockage of the drainage system



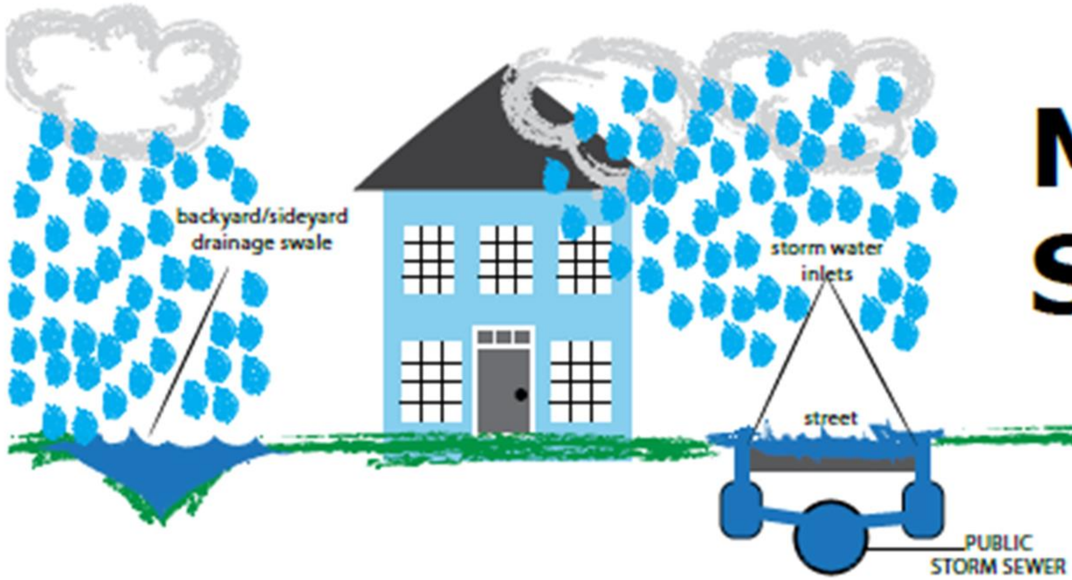
Source: Urban Stormwater Management in Developing Countrie

Types of flooding

- Fluvial Flooding
- Pluvial Flooding



MINOR STORM



MAJOR STORM

Purpose for urban flood modelling

- Designing Storm Water Drainage System
  - Identifying lacuna in the urban drainage of an area
  - Designing a network of drains with appropriate sizes and appurtenances to safely and effectively convey excess storm water
  - Design storm of specific return period
- Designing Blue-Green / Nature Based infrastructure to improve the resilience of SWD
- Identifying vulnerable areas to flooding
  - Flood Plain modelling for different flood return periods
- Flood Forecasting and Early Warning Systems

Modelling Approaches

- Drainage Network model → Stormwater Drainage and simulation of surface runoff by hydrological methods

Storm Water Management Model (SWMM)
Dynamic, Distributed, Physically-based, Continuous, and Deterministic Model

- Shallow Water based model → Simplified and Full 2D – Shallow water models
- Shallow Water based model → Drainage Network Coupled to urban surface model
- Shallow Water based model → Hydrological model coupled to Hydrodynamic flood model

HEC HMS & HEC RAS
Watershed Scale Hydrologic and Hydraulic Modelling

- Hydrogeomorphic Approaches → Inundation area recognized using terrain data analysis

- Other Methods → Cellular Automata (CN) and Artificial Neural Network (ANN) based methods

Source: Guo et al. (2021)

Case Study: Seethammal Colony (Stormwater Drainage Design)

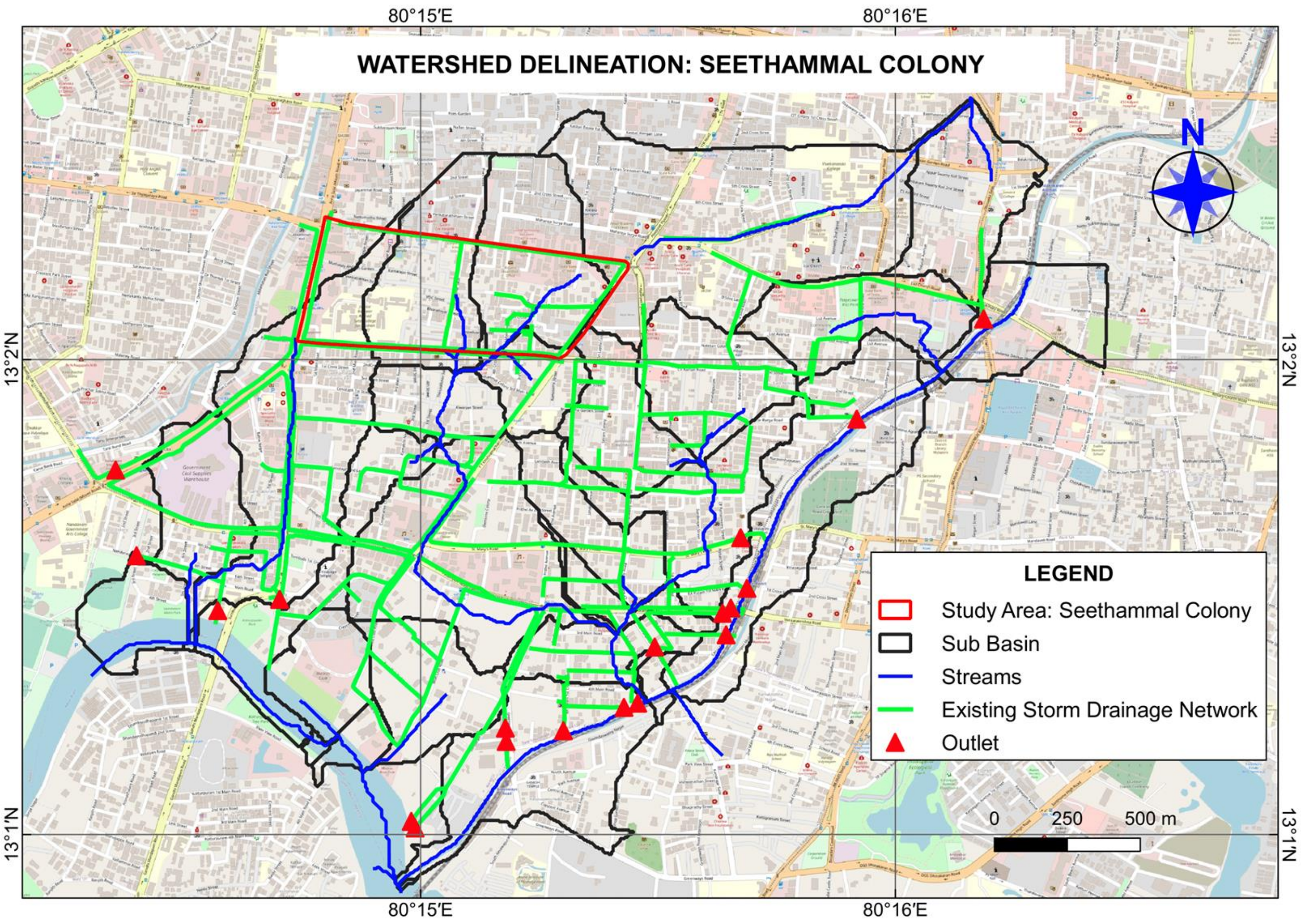
ISSUES: November 2021

- Inundation for several days
- Power and Water supply Outrage
- No reduction in inundated water even after deploying Pumps.
- Mixing of Sewage into inundated water.

CAUSES:

- Inadequate SWD capacity.
- Poor Maintenance of SWDs
- SWD Alignment – not based on the natural topography.
- Adverse Slope

Case Study: Seethammal Colony (Stormwater Drainage Design)

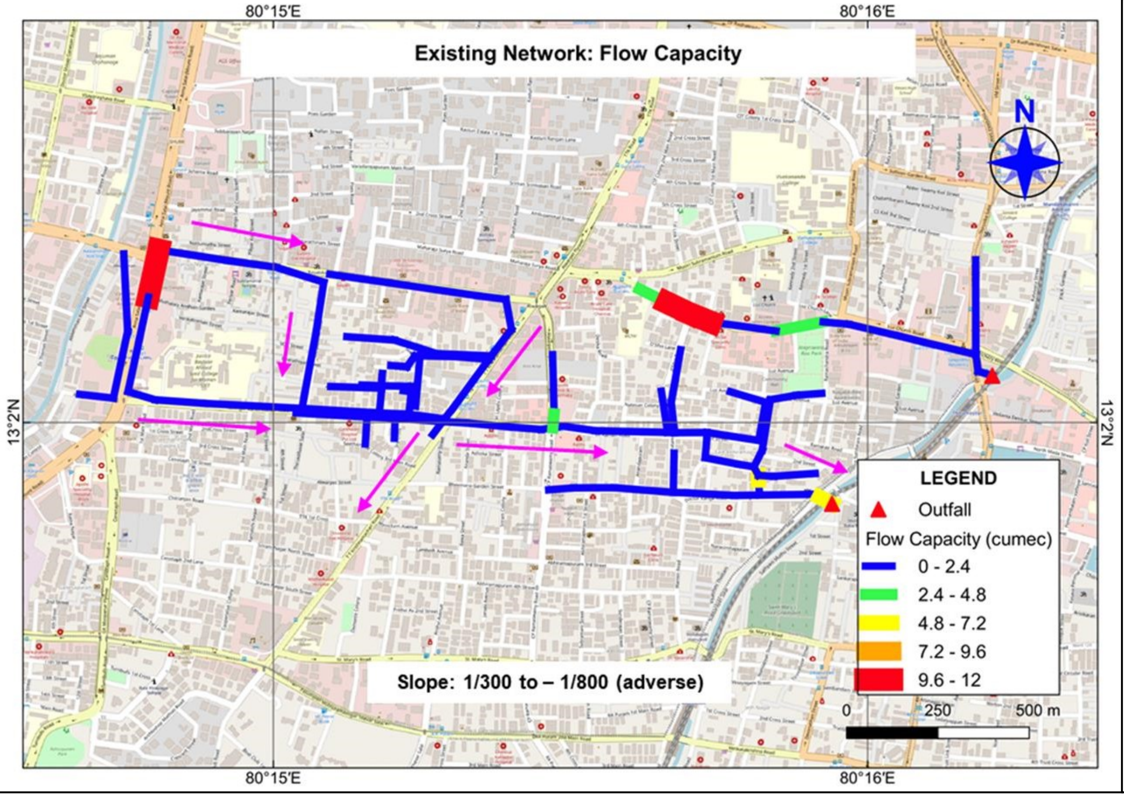


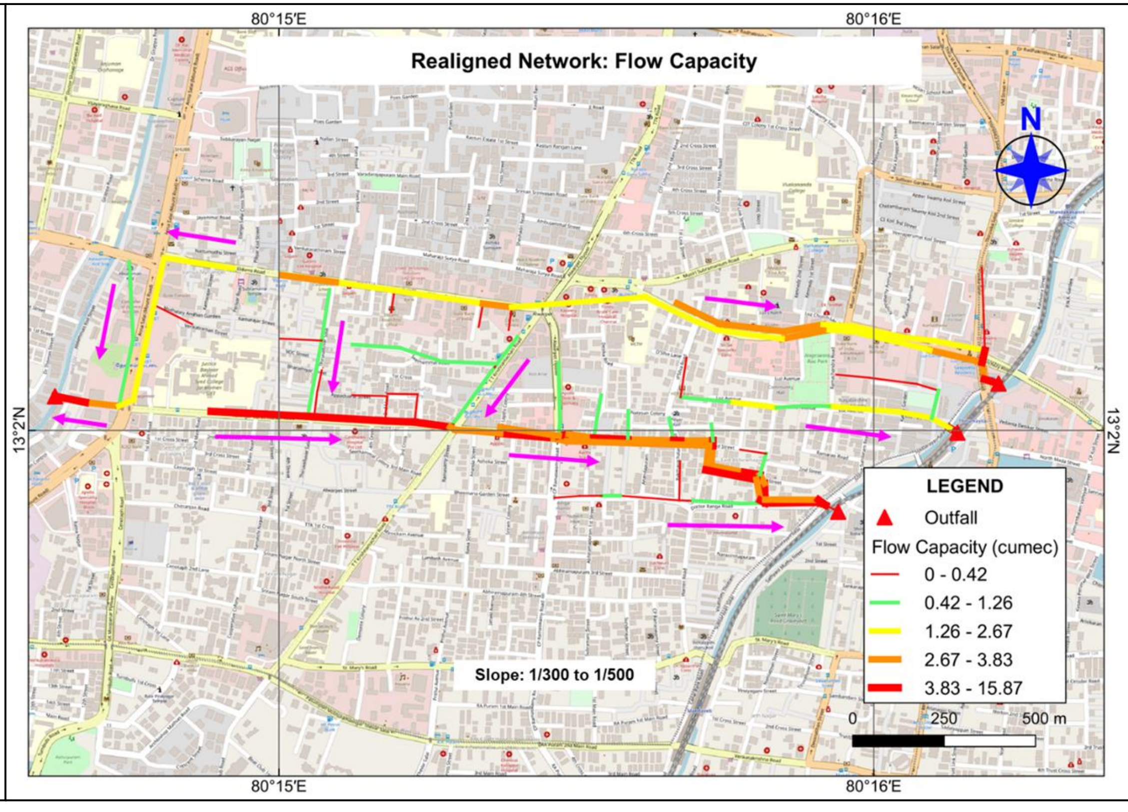
Modelling Approach:

- Realignment of SWDs.
- Adequate carrying capacity of drains.

Case Study: Seethammal Colony (Stormwater Drainage Design)

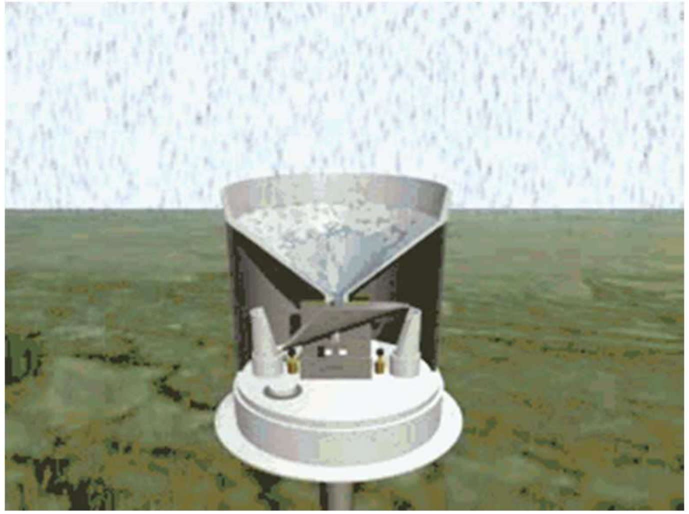
Existing Layout vs Proposed Layout (Realignment) of SWD

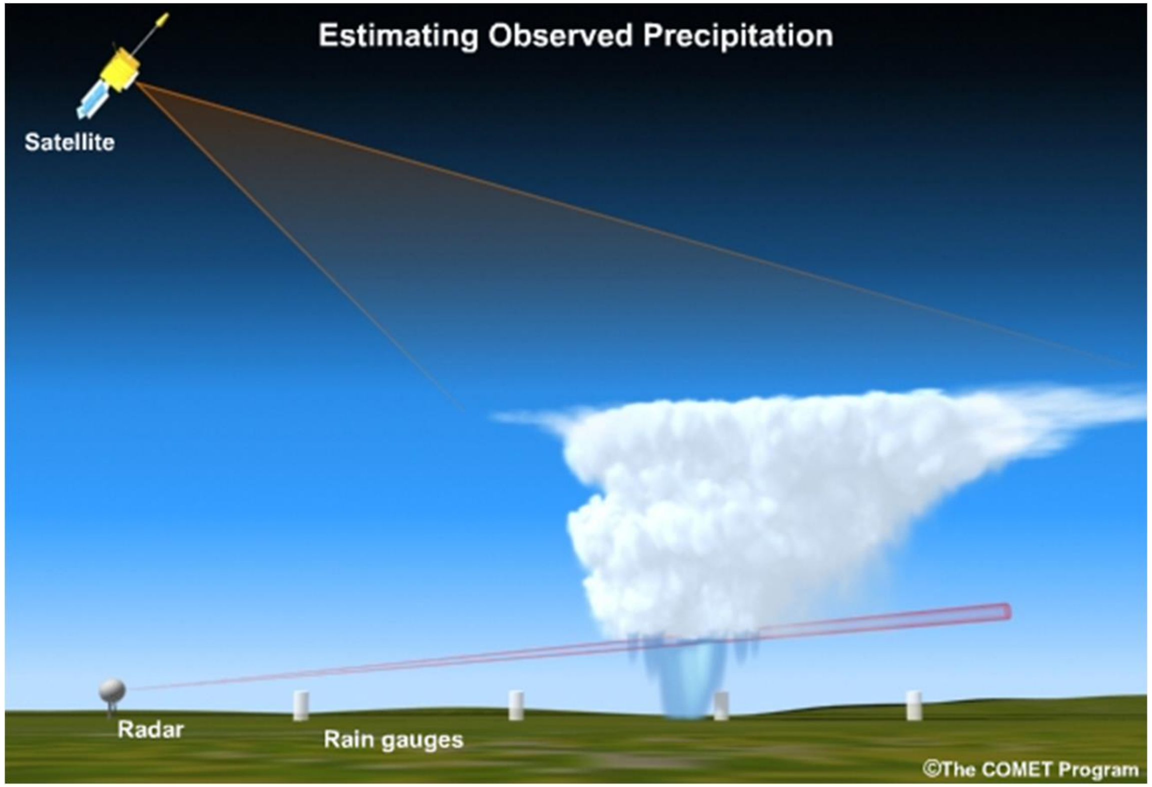


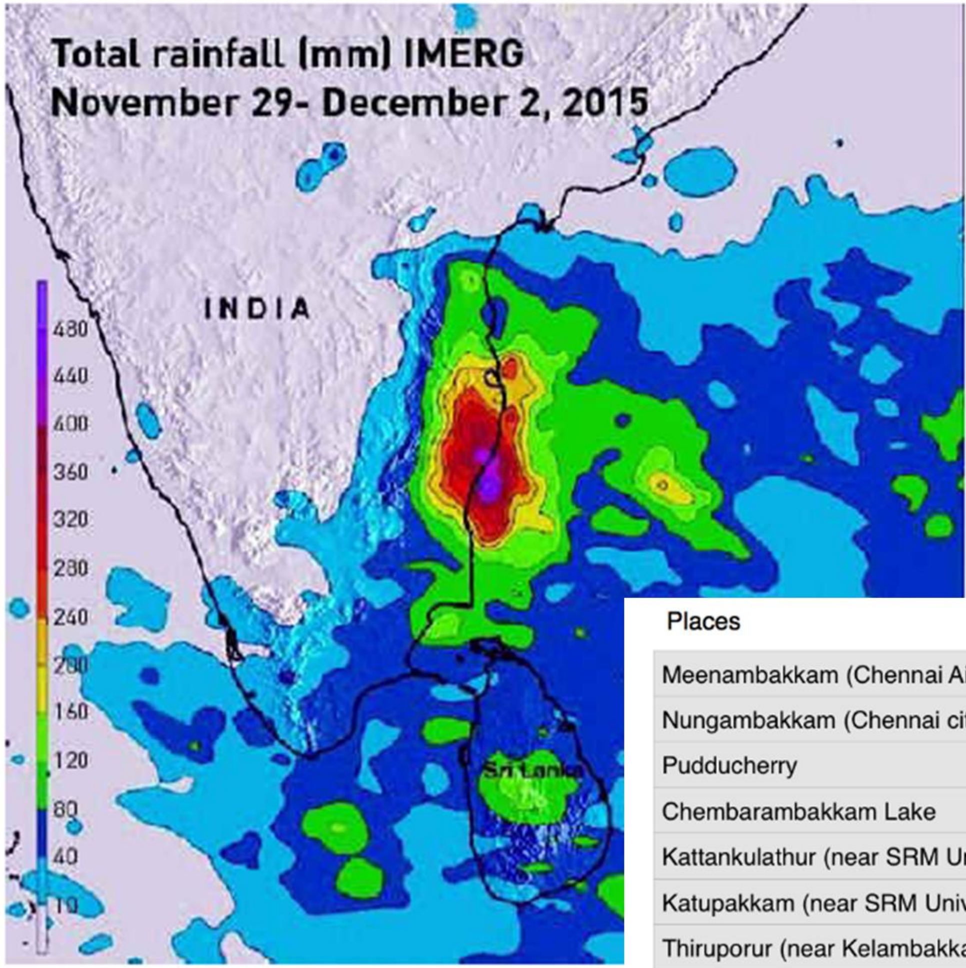


Rainfall spatial distribution

- Rainfall is the single most uncertain variable in hydrologic modelling
- Very critical in urban flood modelling and flood forecasting







Dec.1-Dec.2, 2015: 24hr rainfall

Places	Rainfall in millimetre
Meenambakkam (Chennai Airport)	345
Nungambakkam (Chennai city)	294
Pudducherry	218
Chembarambakkam Lake	475
Kattankulathur (near SRM University)	445
Katupakkam (near SRM University)	429
Thiruporur (near Kelambakkam)	348
Korattur Anaicut (Poonamalle)	336
Puzhal Agro	325
Redhills Lake	320
Anna University	319
Kolapakkam (near Chennai Airport)	310
Taramani	300

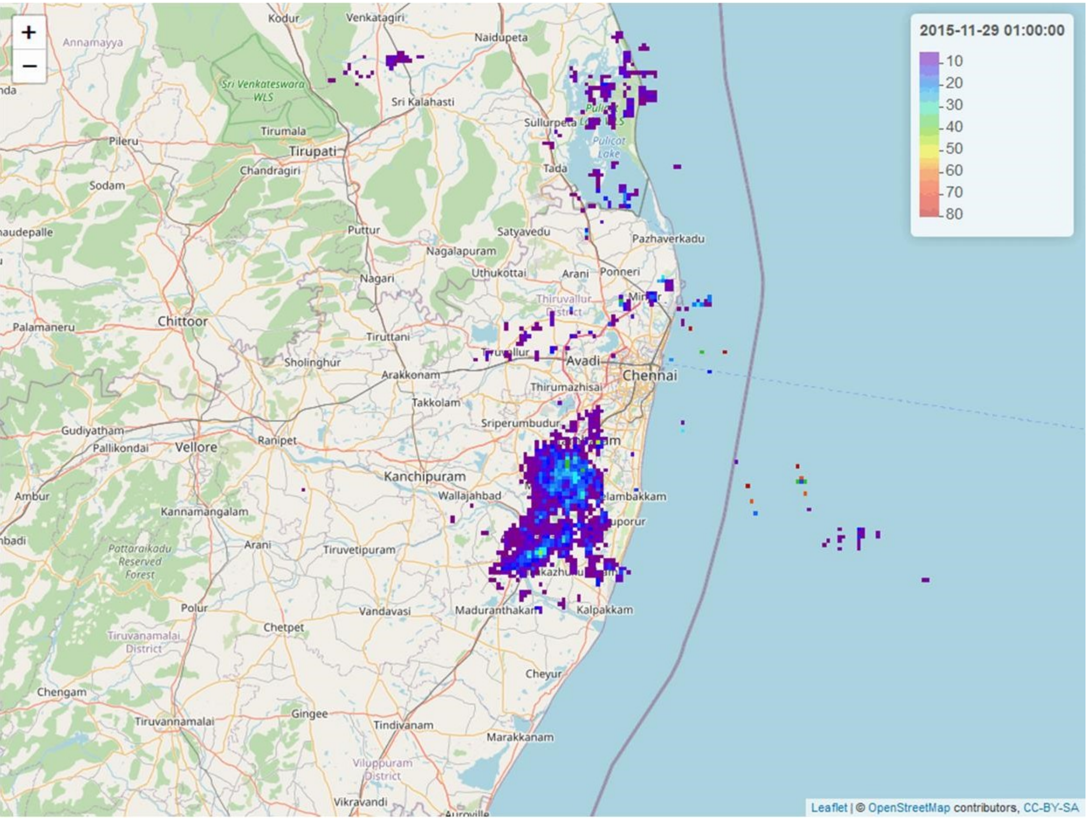
Consequence of Urban Flooding

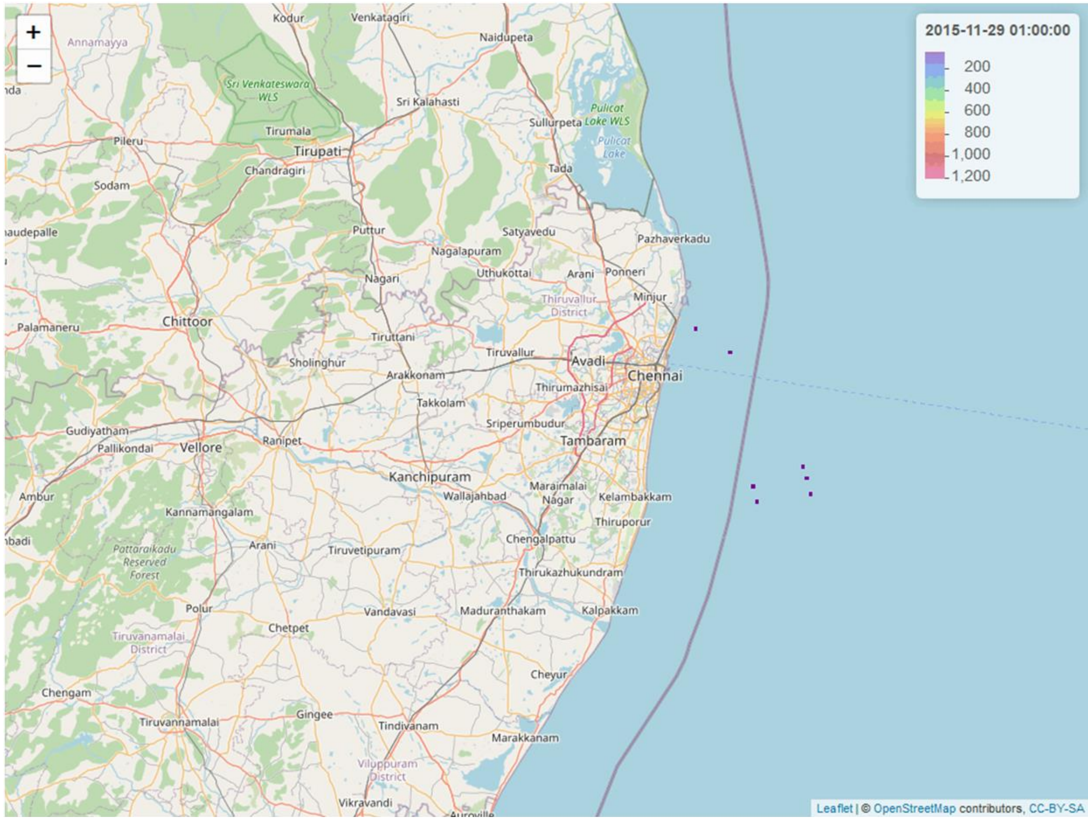
Maraimalaiadigal Bridge, Saidapet

Left: Kotturpuram
Right: Jafferkhanpet

Source: The Hindu News Article - December 2, 2015 Chennai floods

2015 Cumulative Rainfall
Chennai DWR

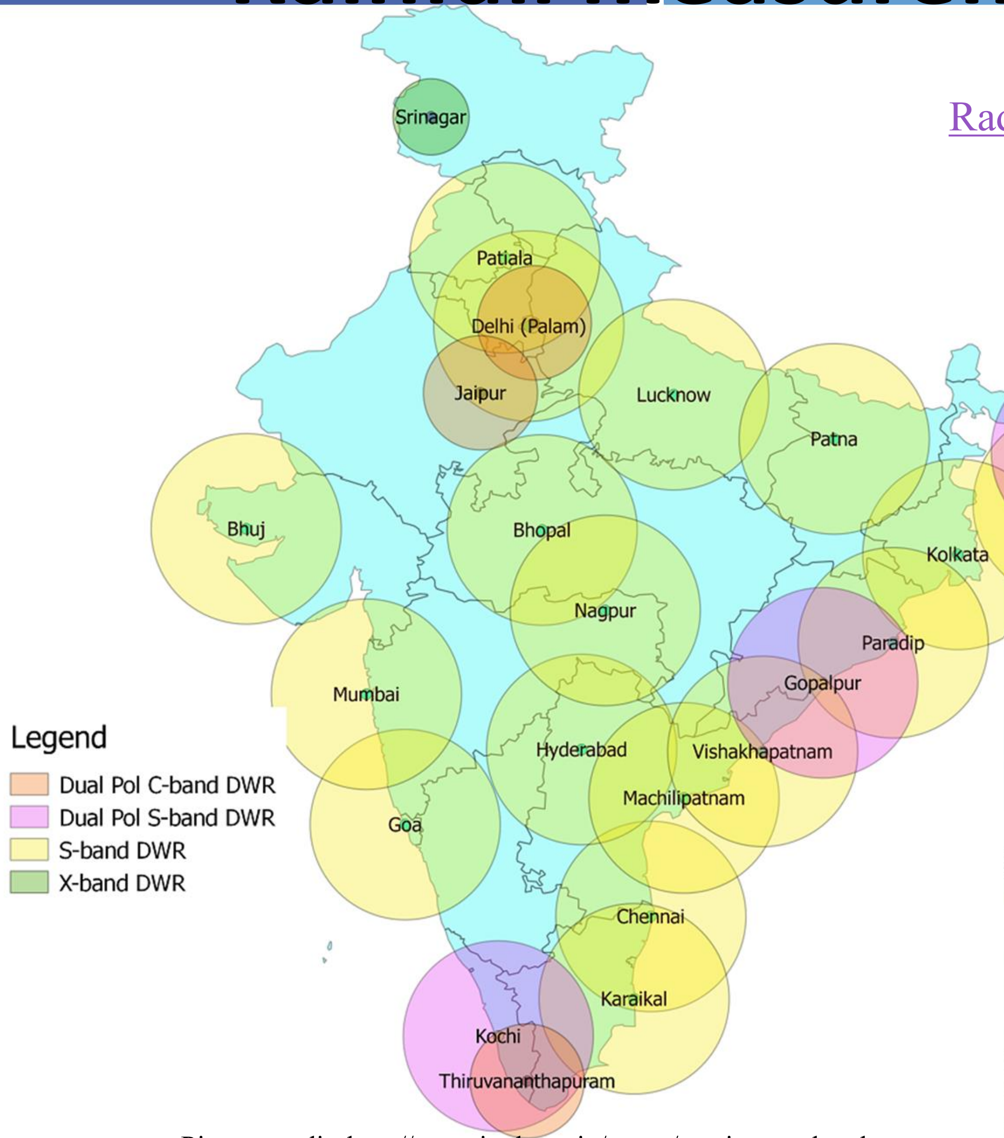




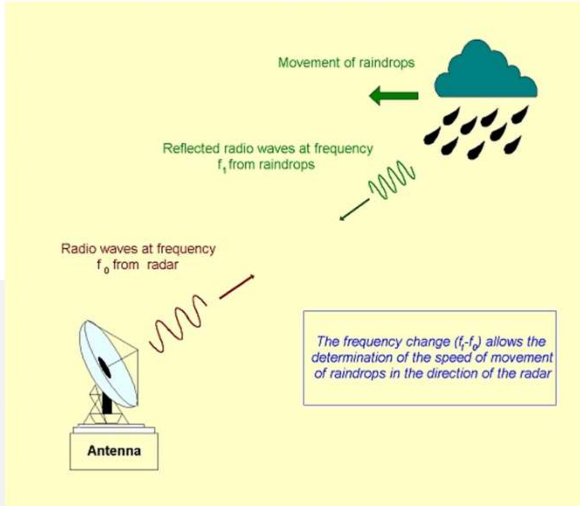
Spatial Resolution: 450 m×450 m
Temporal Resolution: 15 minutes

Rainfall measurement: Radar based

[Radar rainfall data in India]



Picture credit: http://www.imd.gov.in/pages/services_radar.php



Dual Pol X-band radar at NIOT, Chennai

Satellite Based Rainfall Products

- Global Precipitation Mission (GPM)
  - NASA and JAXA
  - 0.1° spatial resolution and half-hour temporal resolution
- Global Satellite Mapping of Precipitation (GsMAP)
  - Japan Aerospace Exploration Agency (JAXA)
  - 0.1° spatial resolution and at one-hour temporal resolution
- Precipitation Dynamic Infrared Rain Rate near real-time (PDIR)
  - Centre for Hydrometeorology and Remote Sensing (CHRS), University of California Irvine
  - 0.04° spatial resolution and at 15 minutes to 60 minutes temporal resolution

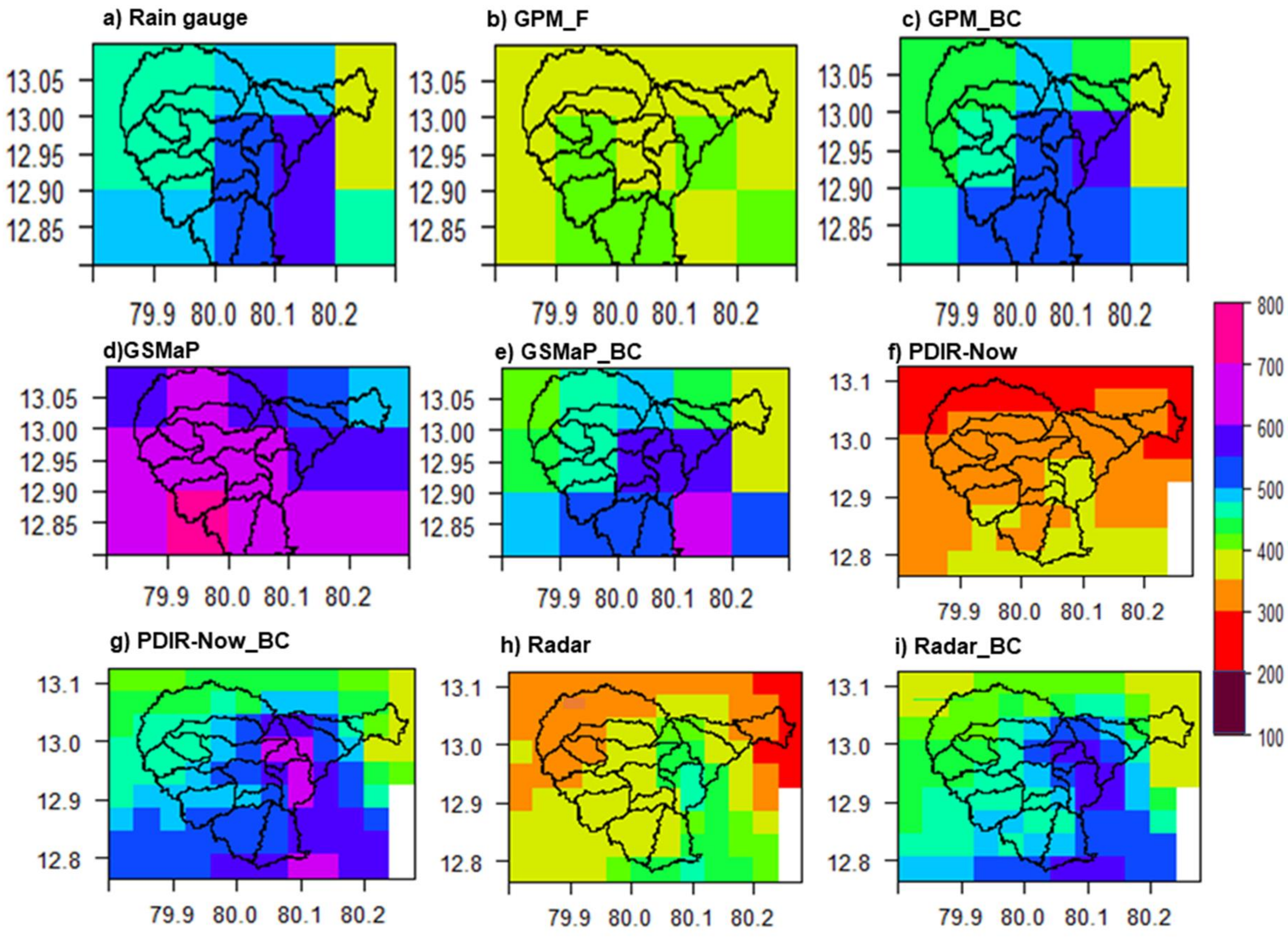
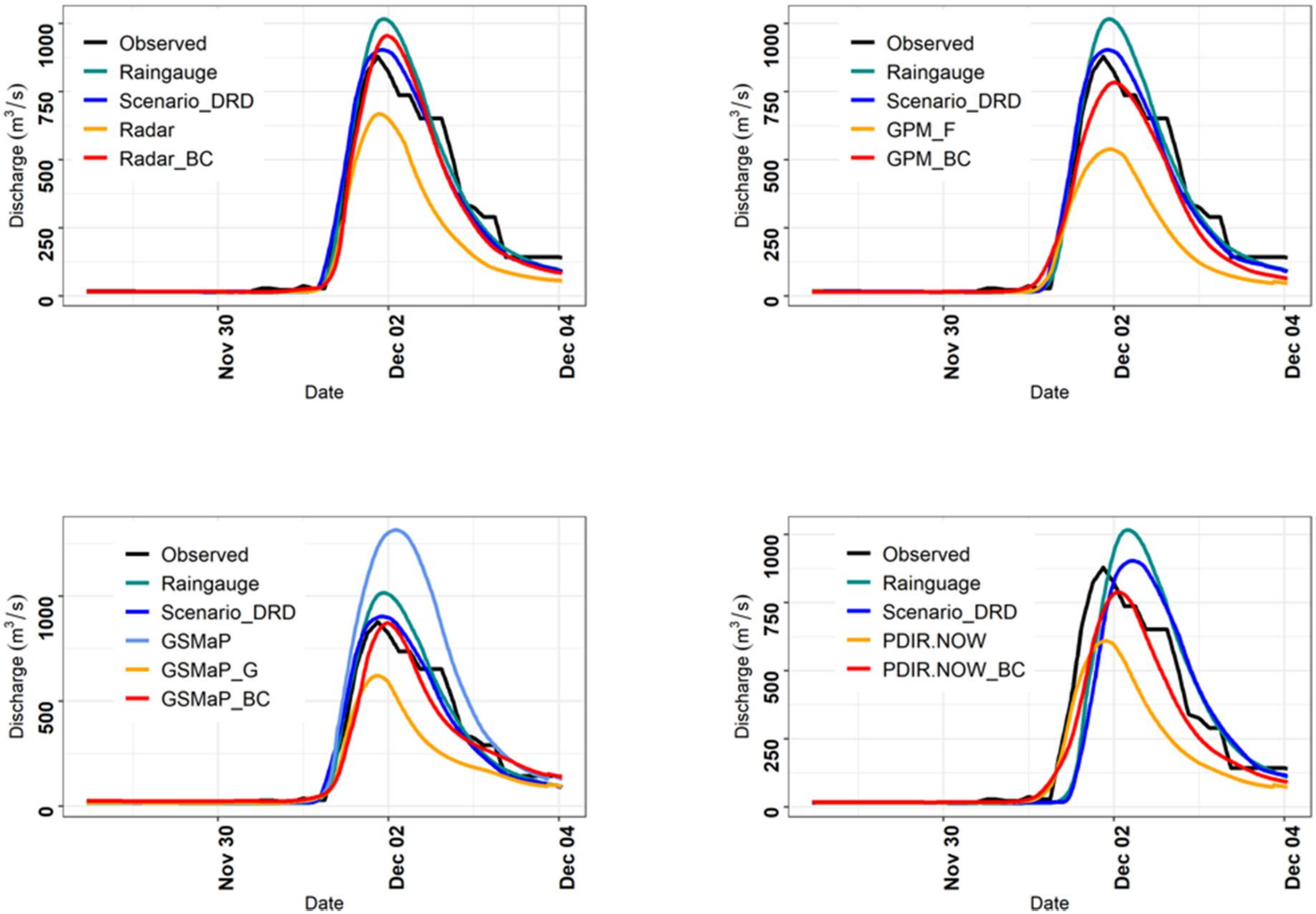
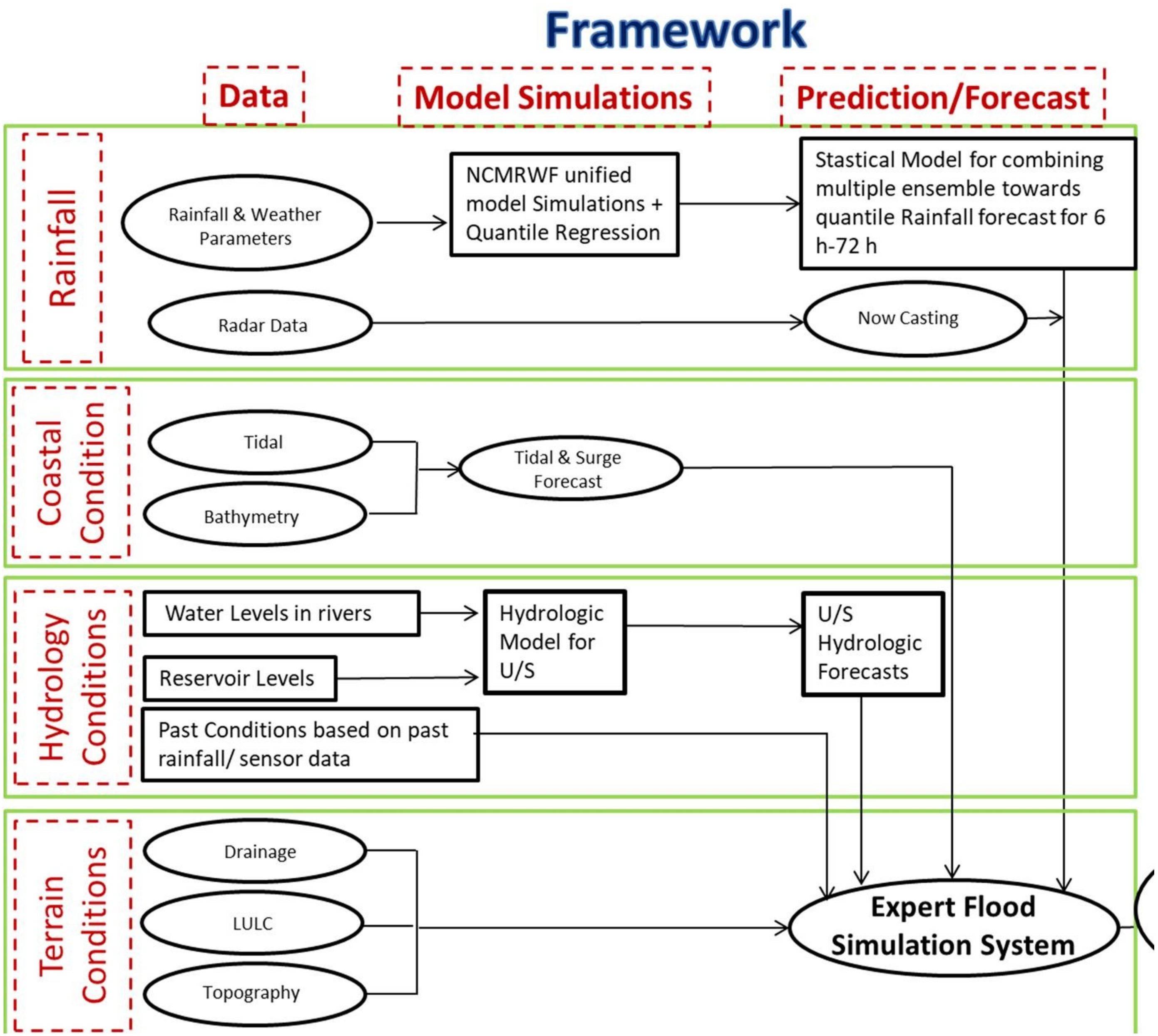


Fig. Spatial map of total accumulated rainfall (in mm) for 2015 Event before and after bias adjustment.



Yaswanth et al. (2023) Water Resources Management



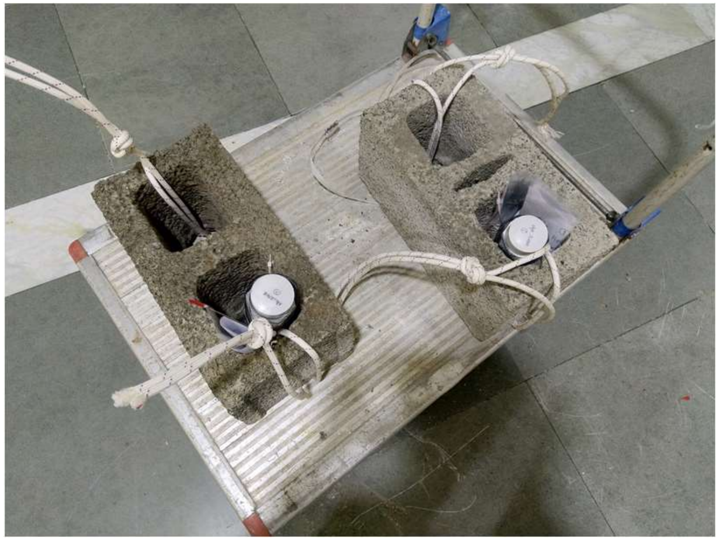
Design of an Expert System for Flood Forecasting and Management for the city of Chennai

Funding support
Principal Scientific Advisor
Govt. of India

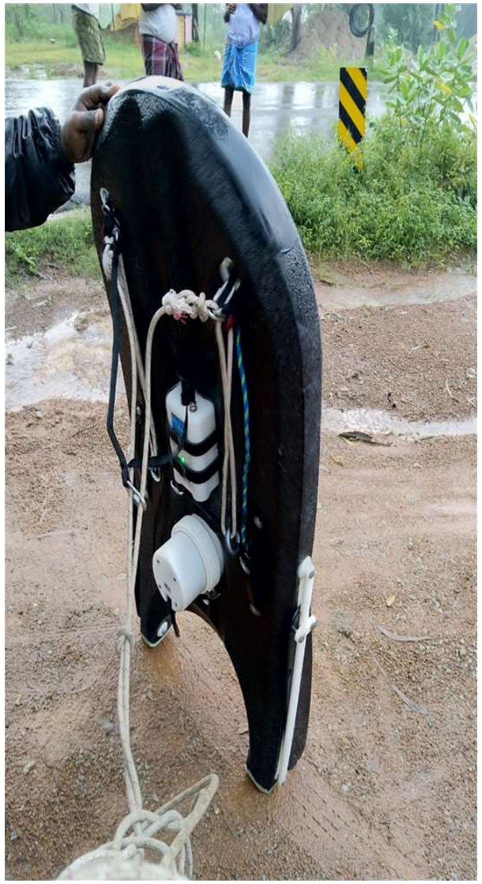
IIT Bombay, IIT Madras, Anna University, IISc Bangalore, NCCR

Field Campaign – November - December 2020 and 2021

Depth Logging Sensors



Acoustic Doppler Velocity Profiler (ADCP)



Automatic Water Level Logger

Government of Tamil Nadu
தமிழ்நாடு அரசு

Chennai RTFF & SDSS - Project Scope

Bathymetry / Topography Survey
- 125 WRD Lakes/Tanks
- 74 Waterways,
- Hydraulic Particulars

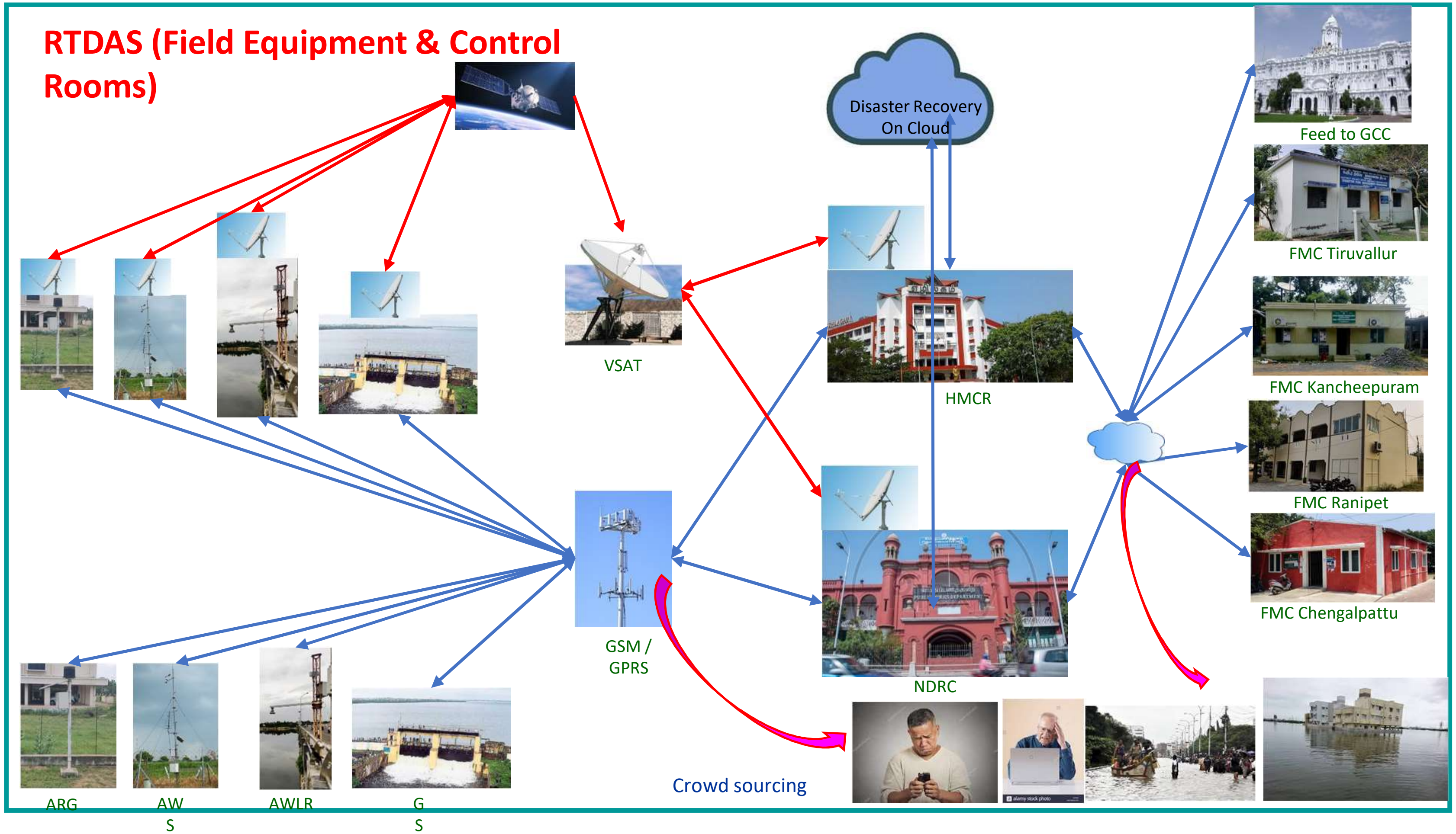
Rainfall, Hydro Models
- Realtime Data Acquisition System (RTDAS)
- NWP based Rainfall Forecasting, Now casting using DWR
- Multi-tier Hydro modelling in 1D / 2D Coupled Models
- Storm Water Drain & Street level flood mapping
- Lake Operation Guidance System (LoGS)
- Flood Preventive and Mitigation Measures

Aerial Survey
over ~5,000 sq.km
Now in SoI Scope

Control Rooms , Web-DSS
- Dissemination of information - Web DSS
- Hydro Modelling Control Room at SEOC
- NDRC (Backup) at WRD HQ and Cloud
- Flood Monitoring Centres (FMC), Triuvallur, Kancheepuram, Changalpattu and Ranipet

Handholding (36 months)
- Institutional Arrangements
- Capacity Building
- Training

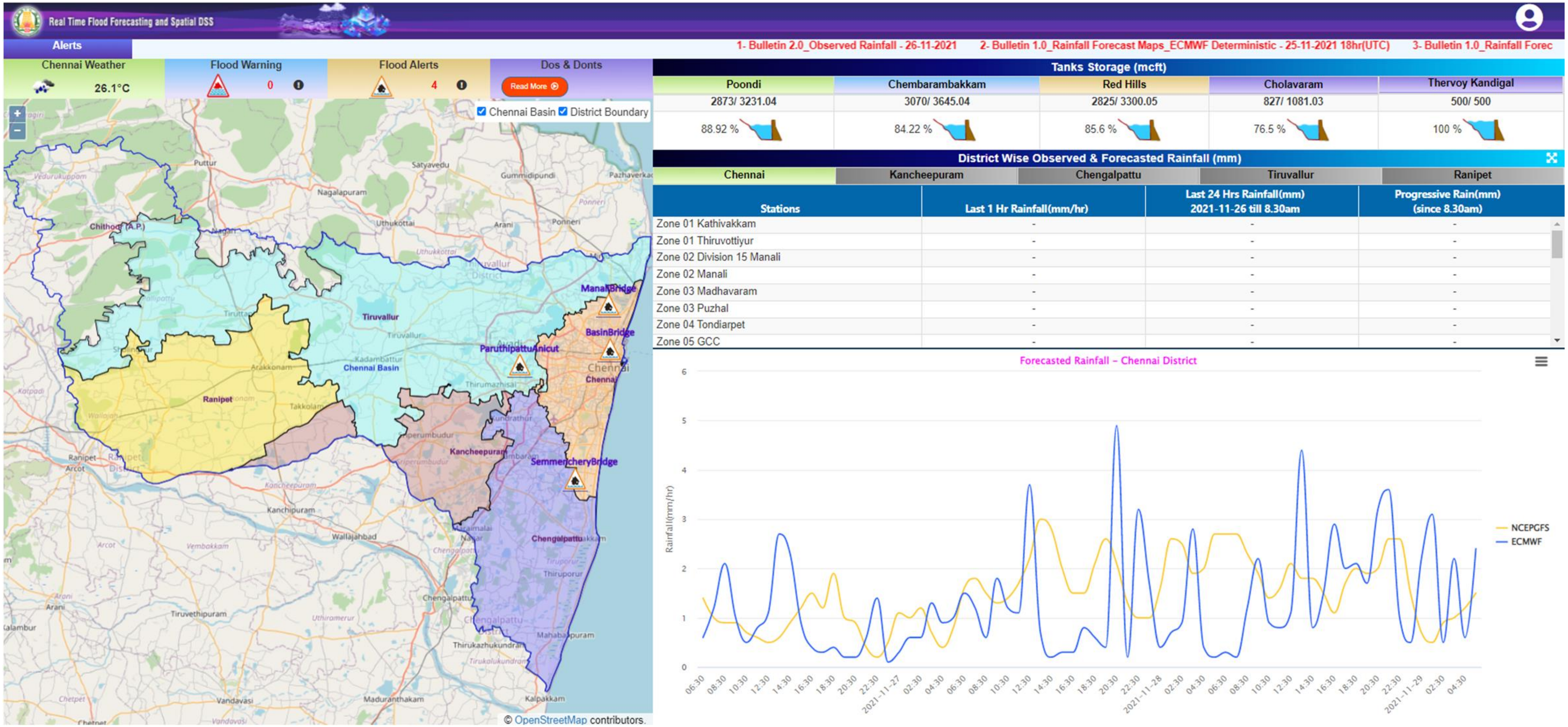
SECON™ TNUIFSL INDIAN INSTITUTE OF TECHNOLOGY MADRAS


RTDAS (Field Equipment & Control Rooms)
Disaster Recovery On Cloud
Feed to GCC
FMC Tiruvallur
FMC Kancheepuram
FMC Ranipet
FMC Chengalpattu
VSAT
HMCR
NDRC
GSM / GPRS
Crowd sourcing
ARG
AW S
AWLR
G S

Web DSS

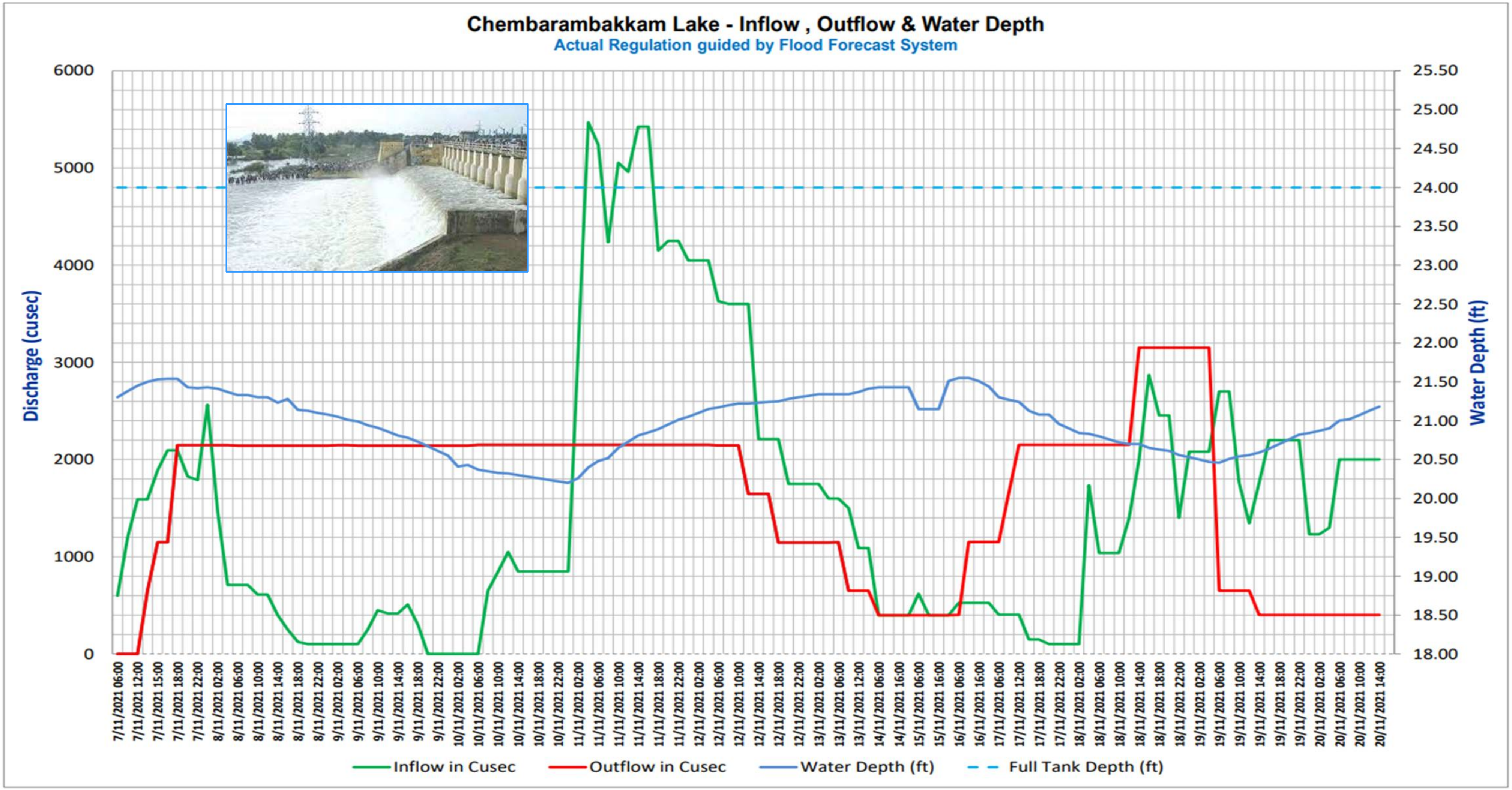
Interface for Stakeholders

URL: https://www.chennaifloodsdss.in



Demonstration of Utility of Flood Forecast System in Lake Operation

Chembarambakkam Lake – Inflow, Outflow, Water level in 2021



Challenges for Urban Flood Modelling

- Data Availability → Spatial and Temporal data of high resolution
  - Terrain
  - Precipitation
  - Land use
- Climate Change Impacts → Intensity – Duration – Frequency (IDF) Curves
- Reliable Forecasts → High-resolution urban weather prediction model
- Infrastructure Management
  - → Proper construction & maintenance of SWD Networks
  - → Encroachments and Haphazard Urban Development
- Field Data Collection → Use of Crowdsourcing data, Deploying Sensors for depth measurements, etc.

Challenges in Urban Flood Management

- Man-made alterations to topography
  - Roads and plot development
- Faster response of the catchment
  - Less lead time (< few hours)
- Clogging of the drainage network
- Limited Engineering Control
  - Flood detention structures

Way Forward

- Expanding the sensor / gauging network
- Expanding the X-Band & C-Band Dual pole radar network
- Improving the lead-time of weather forecasts
  - Multi-physics ensembles at convection allowing scales (< 4km) – with assimilation of satellite / radar data
  - Weather forecast at 1-day to 3-day lead time is needed for proper response measures
- Nowcasting with data from satellite based rainfall products
  - High spatial variability in rainfall Nowcasting with data from weather radar
- High resolution terrain data
- Hazar – Risk – Vulnerability and capacity analysis (HRVCA)

Hydrological Disasters – FLOOD – Early Warning

R. GIRIDHAR

DIRECTOR
Indian National Committee of Irrigation and Drainage (INCID), India and
CONVENER
Indo - European Union Water Partnership (IEWP), India

DIRECTOR
Central Water Commission
Ministry of Jal Shakti
Govt. of India
E-mail: incid-cwc@gov.in
incidindia@gmail.com

Hydrological Disasters - Global

Primary

Floods

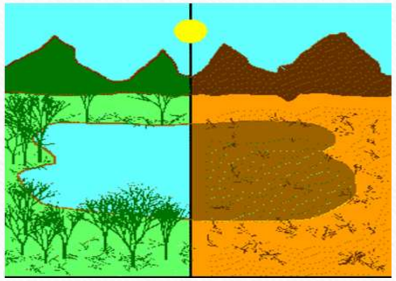
Droughts

Extreme Storms

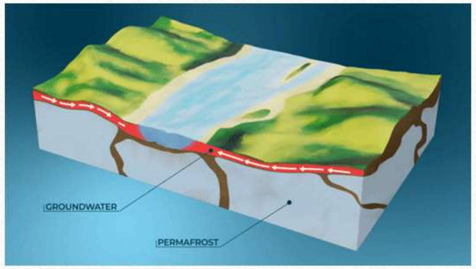
Secondary

Landslides

Avalanches



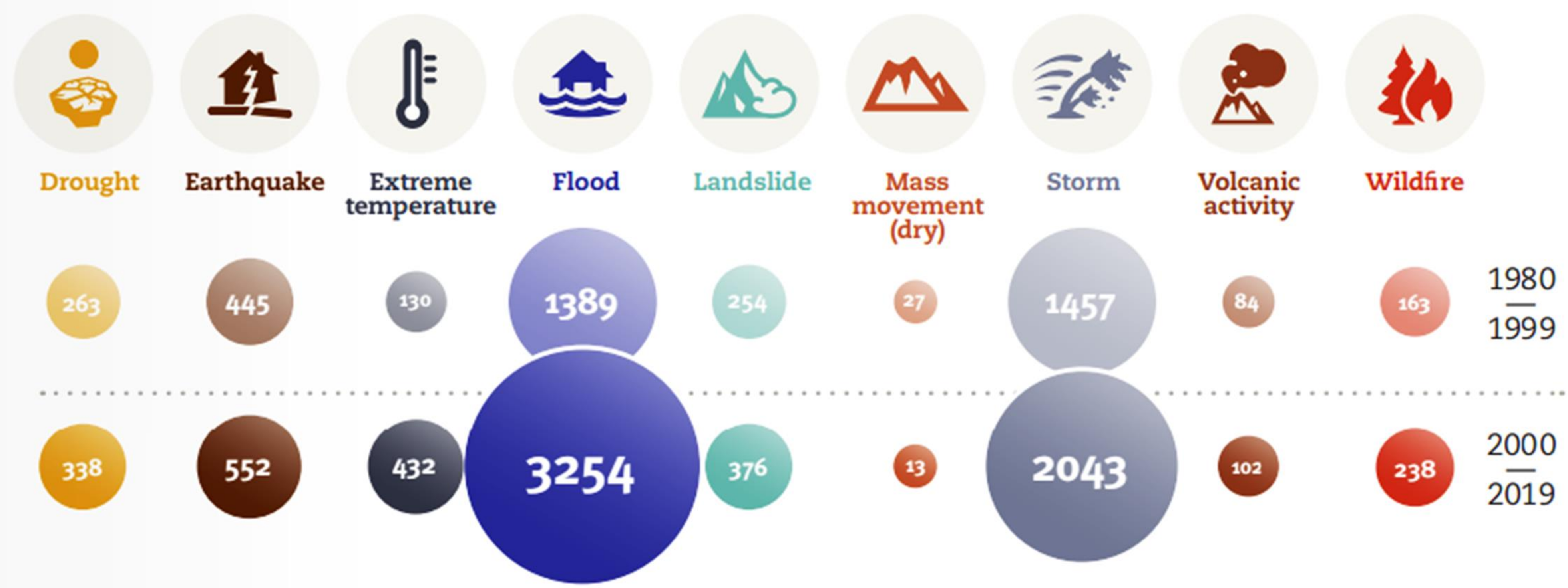
Desertification in steep area



Permafrost melt

Also,
Heat waves,
Wildfires,
Extreme cold etc

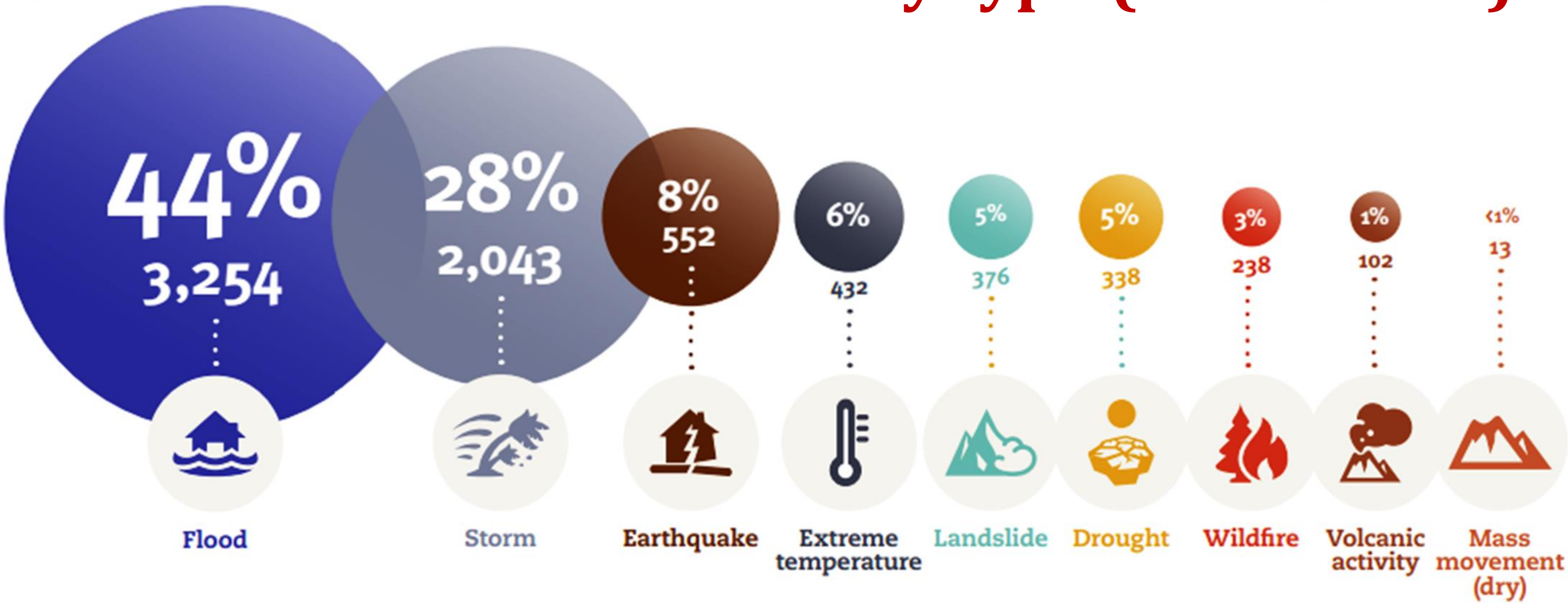
Global disaster events by type:



Noteworthy surge in the number of water related disasters

Source: UNDRR, The human cost of disasters: an overview of the last 20 years (2000-2019)

Occurrences of Disasters by type (2000-2019)



Floods - most common type of disaster, accounting for 44% of total events (riverine floods 24%, general floods 14% and 17% have been associated with tropical cyclones), affecting 1.6 billion people worldwide.

Source: UNDRR, The human cost of disasters: an overview of the last 20 years (2000-2019)

Increasing number of Major floods in past years

India is the 2nd most affected country by floods: it experienced an average of 17 flood events per year and had a total of approximately 345 million people affected.

2022 Maharashtra

2022 Gujarat

2022 Assam

2021 South India

2018 Kerala

2019 Narmada

2017 Gujarat

2017 Mumbai

2017 Bihar

2017 West Bengal

2017 North-East

2016 Brahma putra

2015 Chennai

2015 Gujarat

2015 Assam

2014 Kashmir

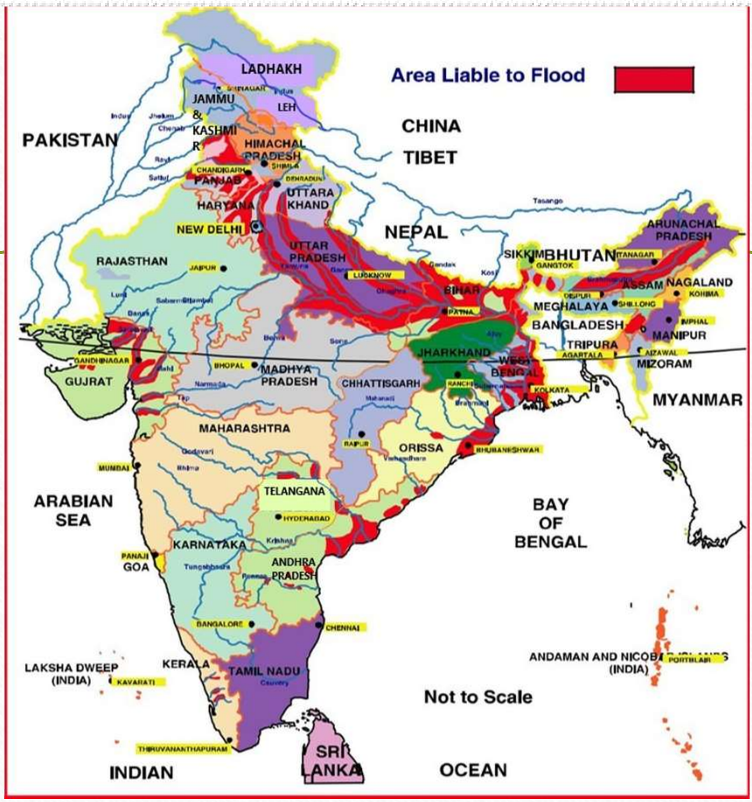
2013 Uttara khand

2012 Brahma putra

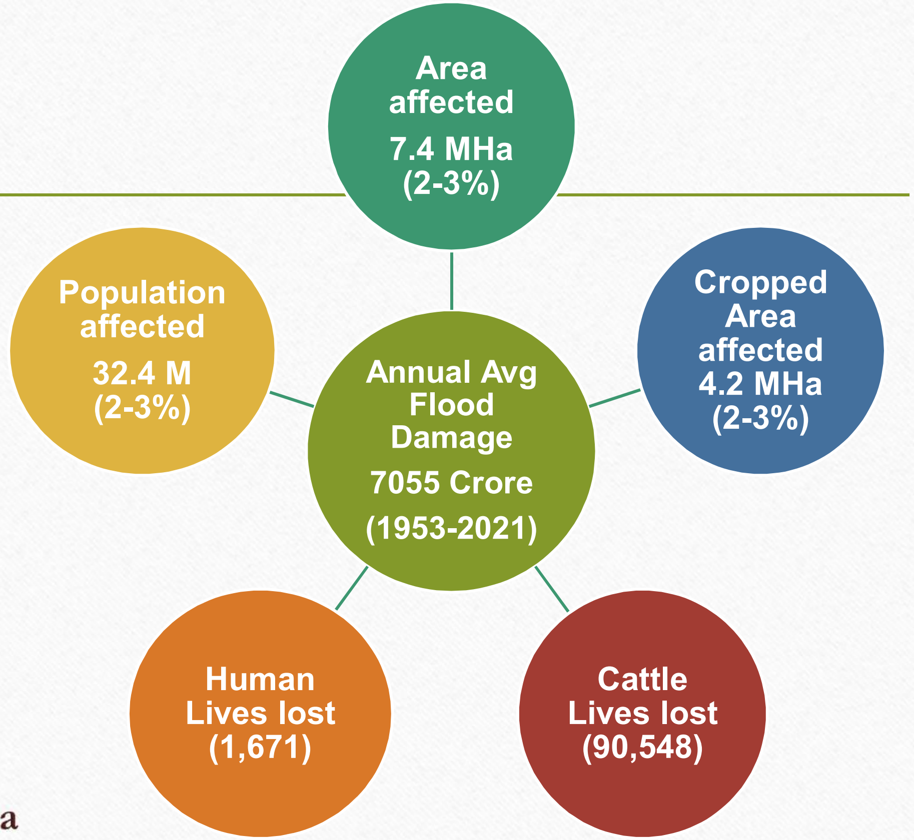
2008 Bihar

2007 Bihar

Flood Prone Area and Annual Damages



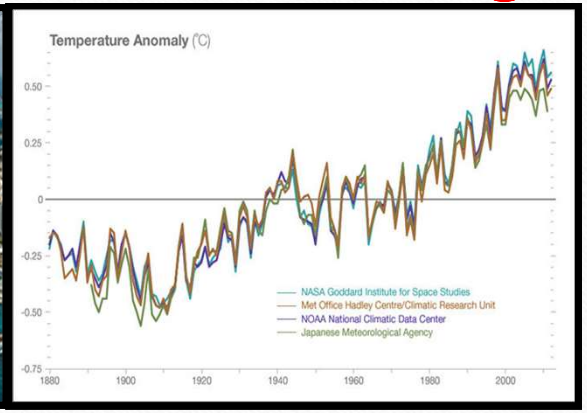
- **Flood Prone Area:** 40 Mha
- **Main Flood Prone Basins:** Ganga, Brahmaputra
- **Main Flood Prone States:** UP, Bihar, WB, Assam



Evidence of Climate Change

Heavier Precipitation

Rising Sea Levels



Global Temperature Rise

Warming & Acidifying Oceans

Increased Flood Risk

Shrinking Ice Sheets

Retracting Glaciers

Extreme Events

Source: http://climate.nasa.gov/evidence/

Direct Impacts of Climate Change on Water Resources

Intense Hydrological Cycle	Increase in extreme rainfall	Increase in daily rainfall intensity
Decrease in the number of rainy days	Unevenness in water availability may increase	Unscheduled Dam regulation & Flash Floods
No clear evidence of substantial change in the year-to-year rainfall variability	Surface air temperature shows increasing trends by 3 to 4° C by 2100	Warming is more pronounced over North India

Source: Impact assessment study of climate change on Krishna, Ganga, and Godavari River Basins by IITM

Integrated Flood Management Approach

Structural Measures

- Aims at keeping flood water away from people
  - Embankments
  - Dams & Reservoirs
  - Interlinking of Rivers
  - Channel Drainage Improvements

Reduce Flood Magnitude

Non Structural Measures

- Aims at keeping people away from flood water
- Risk can be reduced through
  - Early Warning
  - Flood Plain Zoning
  - Awareness
  - Capacity Building

Reduce Susceptibility to Flood Damages

Journey of Flood Forecasting in CWC

1958

Manual Flood Forecast with lead time of upto 24 hours

2016

Mathematical Modelling based 3-Day Advisory Flood Forecast

2017

Inundation Forecast using return periods

2021

Lead time of Advisory increased to 5 days.

2022

Ensemble Flood Forecasting using NCMWRF Rainfall product

Currently working on Near Real time Inundation Flood Forecasting

Nodal Ministry for Management/Mitigation of Riverine Flood

- **Ministry of Jal Shakti - Nodal Department: Central Water Commission**

Flood Mitigation Activities of CWC

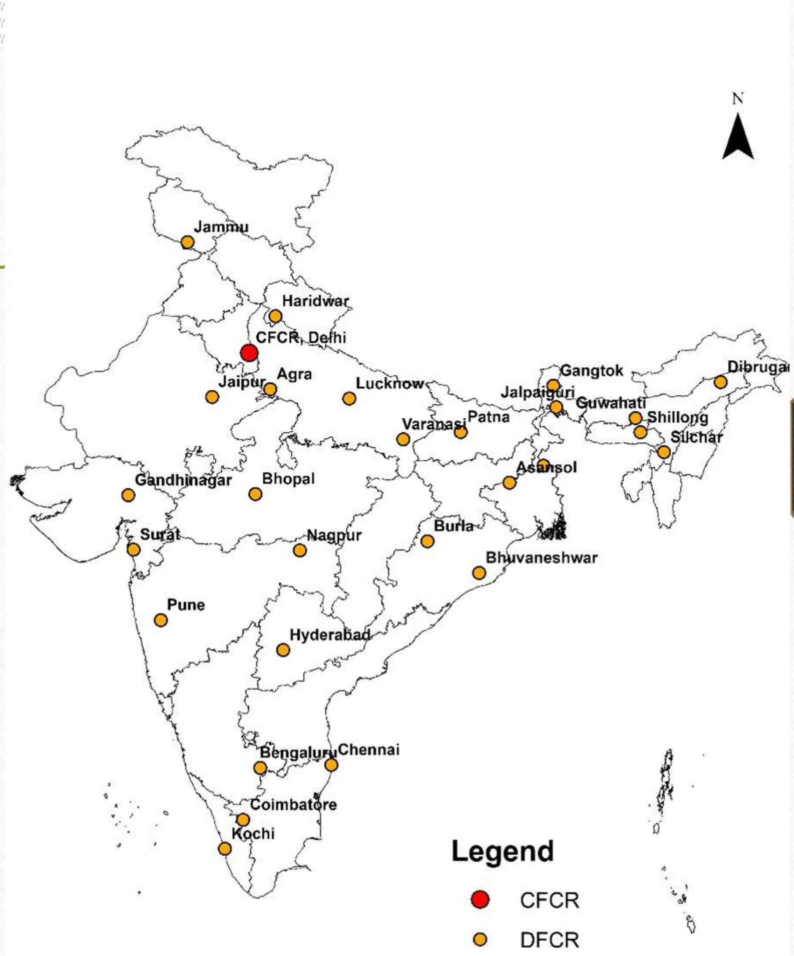
- Running and maintenance of 24x7 Flood Control Rooms in Divisional and National Headquarters during the notified flood period
- Issue of flood forecasts whenever situation demands
- Issue of inflow forecast to majority of the dams
- Issue of flood advisories in association with heavy rainfall warnings and status of various dams in affected basins
- Monitoring of glacial lakes
- Integrated Reservoir Operation (IRO)
- Advisory role in preparation of Emergency Action Plan (EAP) & reservoir operation protocols for majority of the dams

Institutional Mechanism

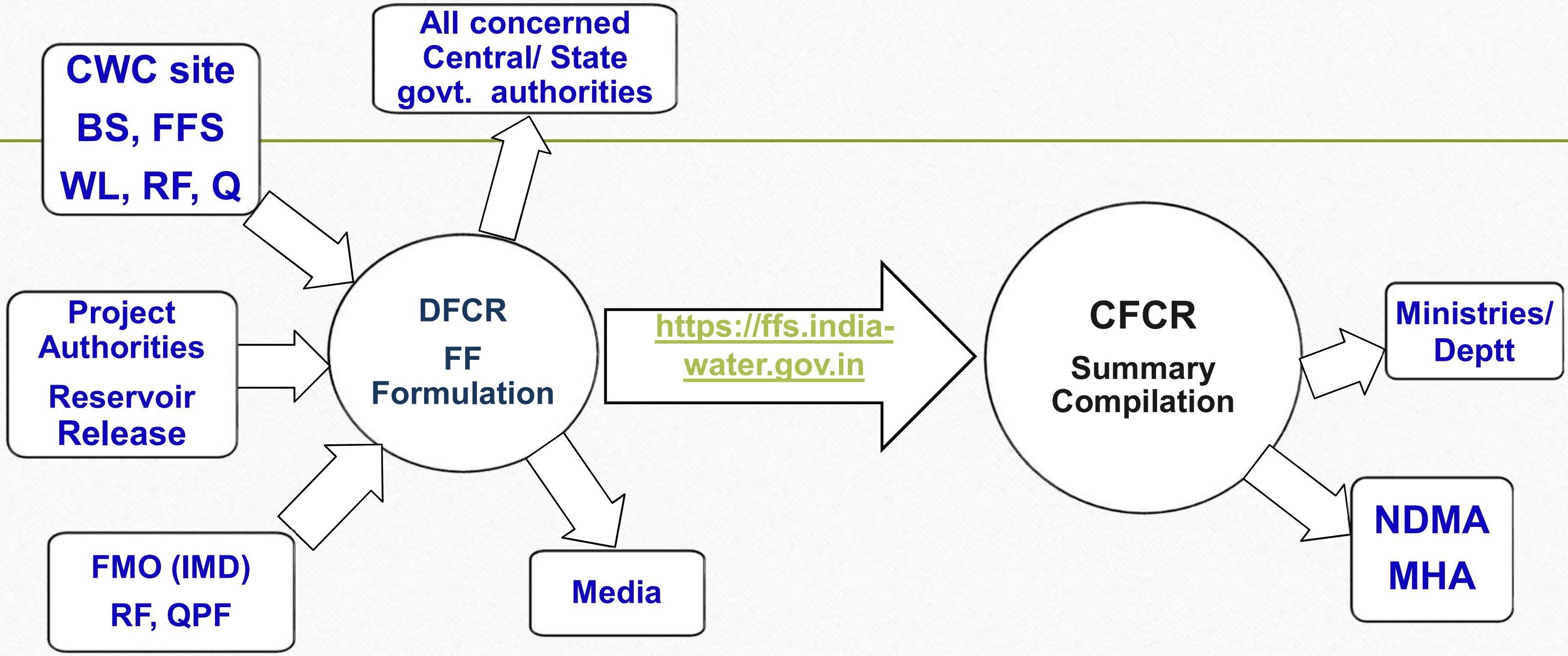
- CWC operates 29 Divisional Flood Control Rooms (DFCRs) located in various field Divisions of CWC across India and a Central Flood Control Room (CFCR) at CWC (HQ), New Delhi.

	Basin	Designated Flood Period
1	Brahmaputra, Barak, Teesta, Jhelum	1st May to 31st Oct
2	All other Basins upto Krishna	1st June to 31st Oct
3	South of Krishna (Pennar, Cauvery & Southern Rivers)	1st June to 31st Dec

Location of Central Flood Control Rooms and Divisional Flood Control Rooms of CWC



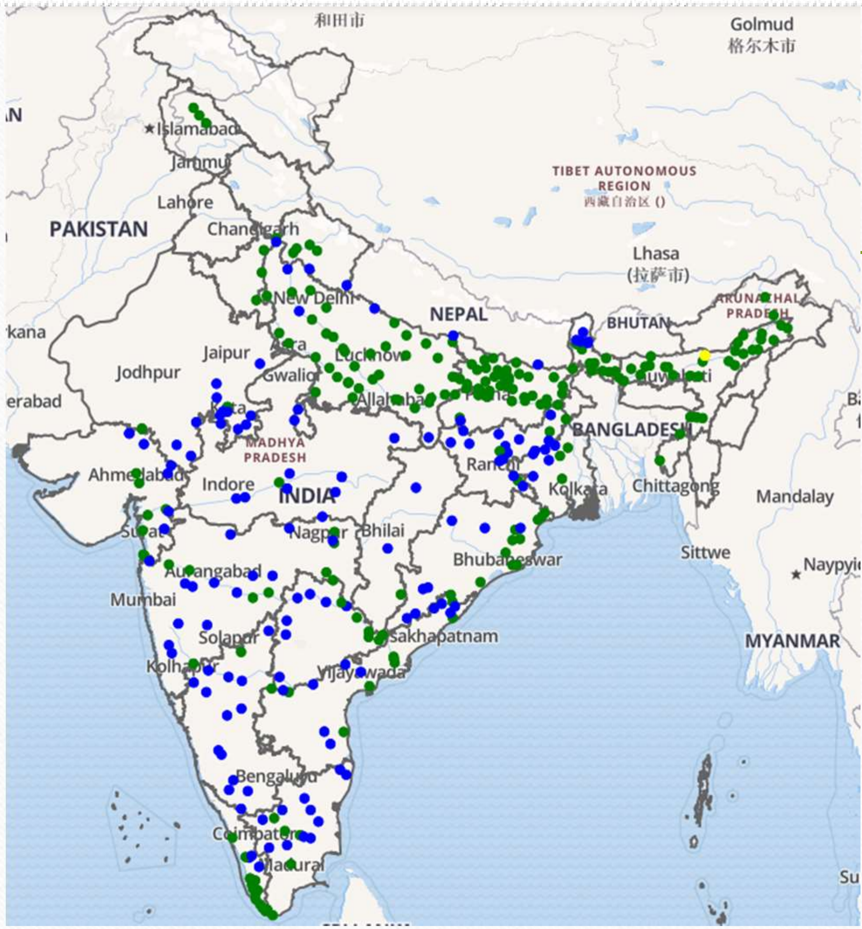
Setup of Flood Forecasting



Coordination with other Agencies at Regional Level

24X7 Control Room in CWC

Flood Forecasting Network of CWC



Hydro-meteorological Stations- **1730 (Gauge, Discharge, Sediment and WQ)**

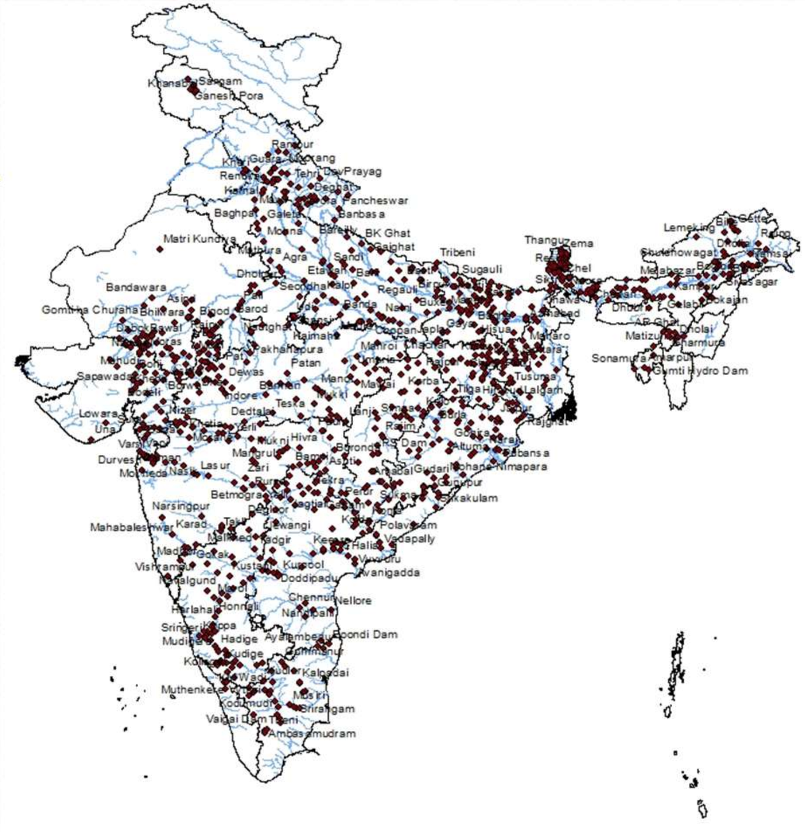
Flood Forecasting Stations increased from 175 in 2014 to 333 in 2022

- **Level - 199**
- **Inflow - 134**

Types of Forecasts

- **Short Range forecast lead time upto 1 day**
- **5 days advisory forecast**
- **10-15 days ensemble Forecast**
- **Inundation Forecast**

Telemetry System in CWC



- 1100 Telemetry sites
- Water level
  - ❑ Bubbler
  - ❑ Radar
- Rainfall
  - ❑ Tipping bucket

India – Nepal, China & Bhutan Co-operation

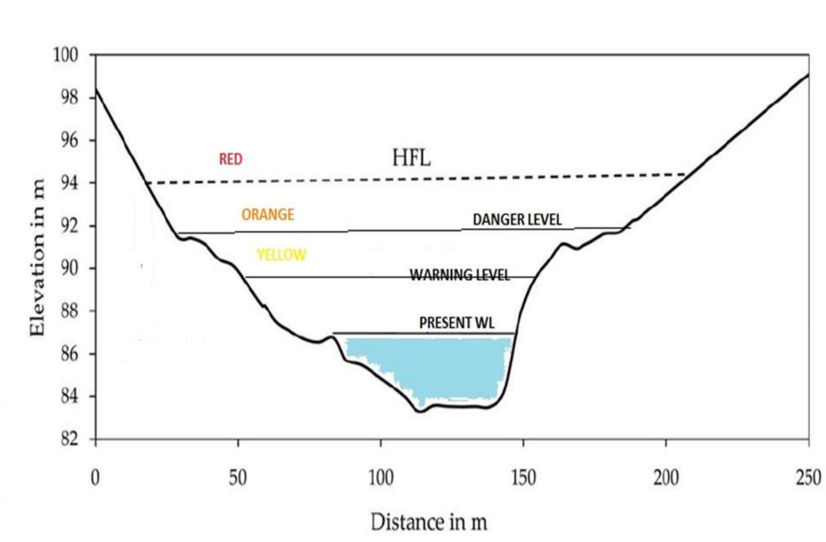
Nepal: Mahakali (Sarada in India), Karnali (Ghaghra in India), Narayani (Gandak in India) and Kosi (157 hydro-meteorological stations data being shared) (https://hydrology.gov.np)

Bhutan: Wangchu (Raidak-I in India), Amo Chhu (Torsa in India), Puna Tsang Chhu (Sankosh in India), Jaldakha (35 hydro-meteorological stations data being shared)

China: Sharing of HO data on rivers Brahmaputra and Sutlej during monsoon season

Level Forecast by CWC

- **Red Stage alerts communicated with 3 hourly updates or at more frequent intervals as warranted by the situation**
- **Orange stage alerts communicated with 6 hourly updates**
- **Yellow stage alerts communicated daily**

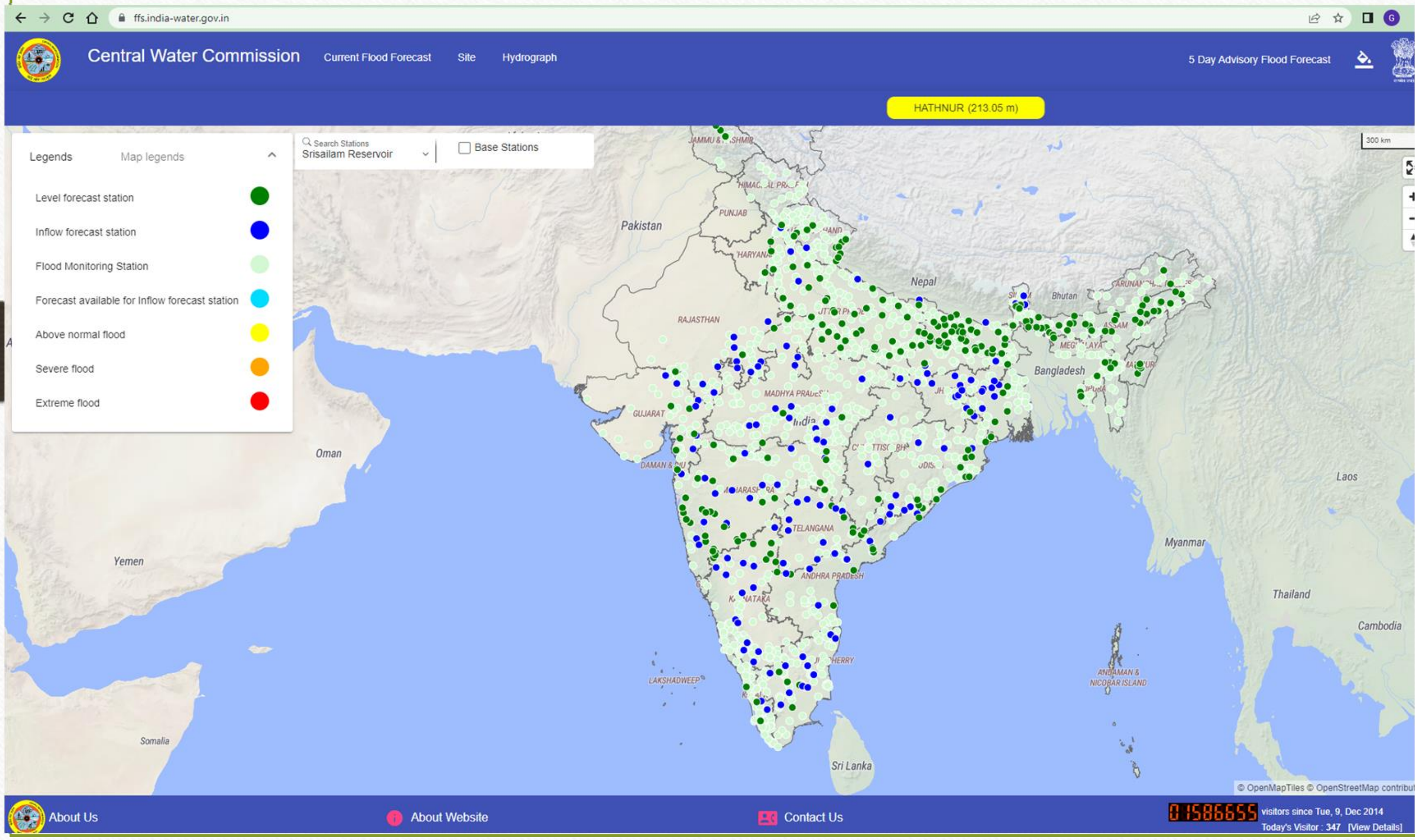


Forecast Dissemination

- Email, SMS, Websites, WhatsApp, Social media
- Flood Monitoring & short range Forecast: https://ffs.india-water.gov.in/
- 5 days Advisory Flood Forecast: https://aff.india-water.gov.in/
- Flood Messages
- CWCOfficial.FF
- CWCOfficial_FF

Short Range Forecast upto 1 day

https://ffs.india-water.gov.in



Nellore CWC (Level) station

District / Town	NELLORE
Basin	Pennar
River	Pennar
Division	Hydrology Division(HD),Chennai
RL of Zero gauge	7.23
Warning Level (WL)	15.91
Danger Level (DL)	17.28
Highest Flood Level (HFL)	18.7
HFL Attained Date	1982-11-30
Present Water Level	7.59 mtrs on Thu, 23, Feb 2023, 1:00 PM
Cumulative Daily Rainfall	0 mm on Thu, 23, Feb 2023, 8:30 AM

Hydrograph

Srisailam Reservoir (Inflow) station

District / Town	KURNOOL
Basin	Krishna
River	Krishna
Division	Lower Krishna Division(LKD), Hyderabad
RL of Zero gauge	0
Full Reservoir Level (FRL) / Pond Level (PL)	269.75
Maximum Water Level (MWL)	269.75
Highest Flood Level (HFL)	
HFL Attained Date	2009-10-03
Present Water Level	251.856 mtrs on Thu, 23, Feb 2023, 1:00 PM
Cumulative Daily Rainfall	0 mm on Thu, 23, Feb 2023, 8:30 AM

Hydrograph

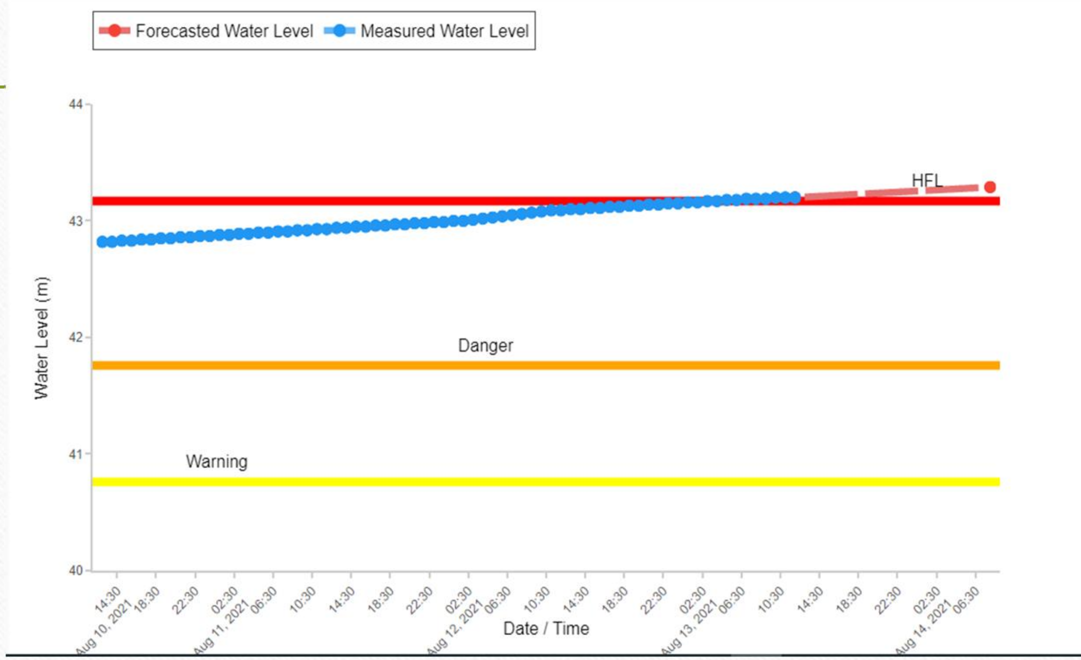
Flood Forecasting Website https://ffs.india-water.gov.in

District	Basin	River	Division
PATNA	Ganga	Ganga	Lower Ganga Division-II(LGD-II), Patna

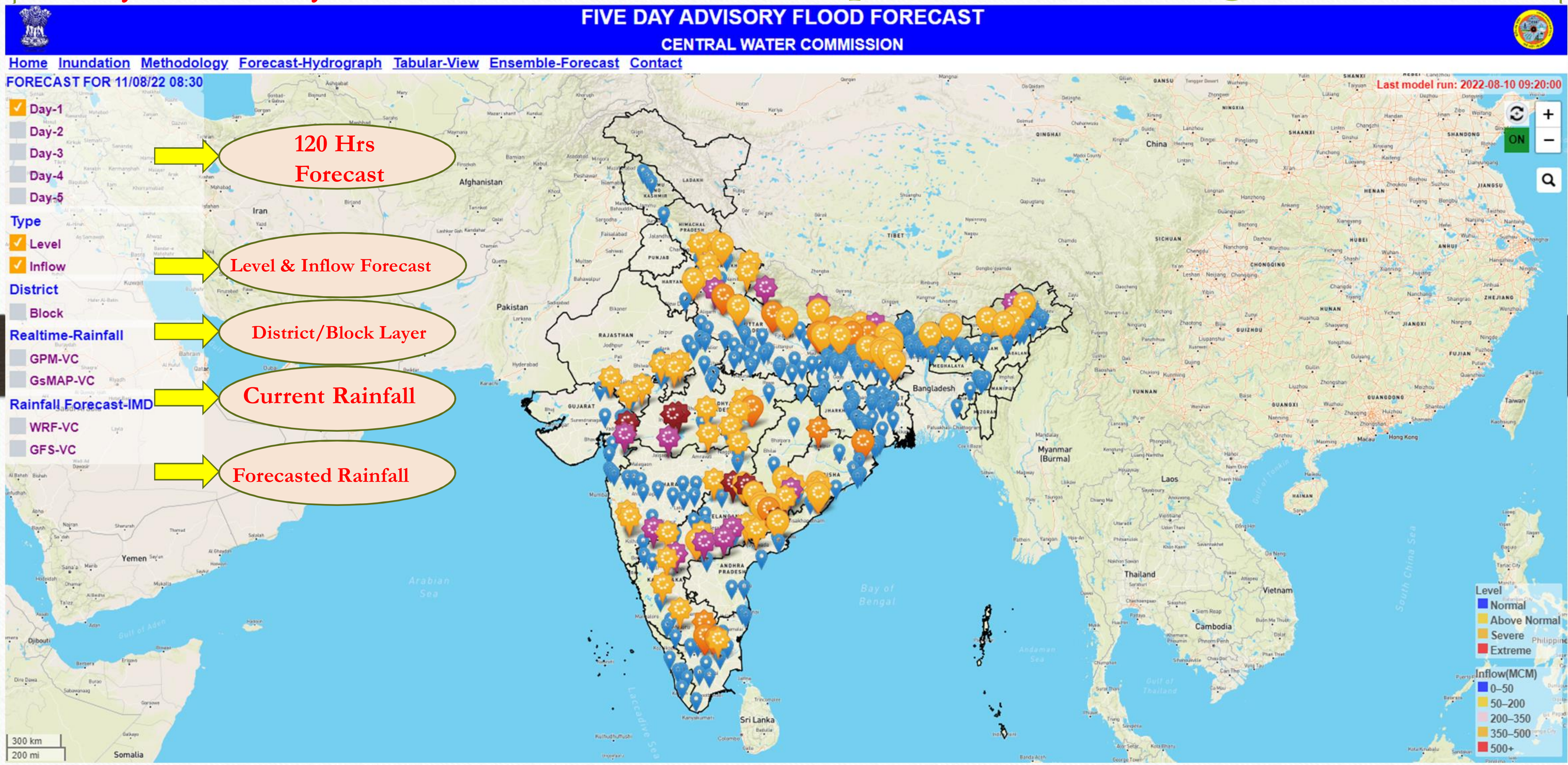
Hathidah (Level) station

District / Town	PATNA
Basin	Ganga
River	Ganga
Division	Lower Ganga Division-II(LGD-II), Patna
Warning Level (WL)	40.76
Danger Level (DL)	41.76
Highest Flood Level (HFL)	43.17
HFL Attained Date	2016-08-21
Present Water Level	43.2 mtrs on Fri, 13, Aug 2021, 12:00 PM
Cumulative Daily Rainfall	0 mm on Fri, 13, Aug 2021, 8:30 AM
Level Forecast (12)	43.29 mtrs ↑ on Sat, 14, Aug 2021, 8:00 AM

Hydrograph

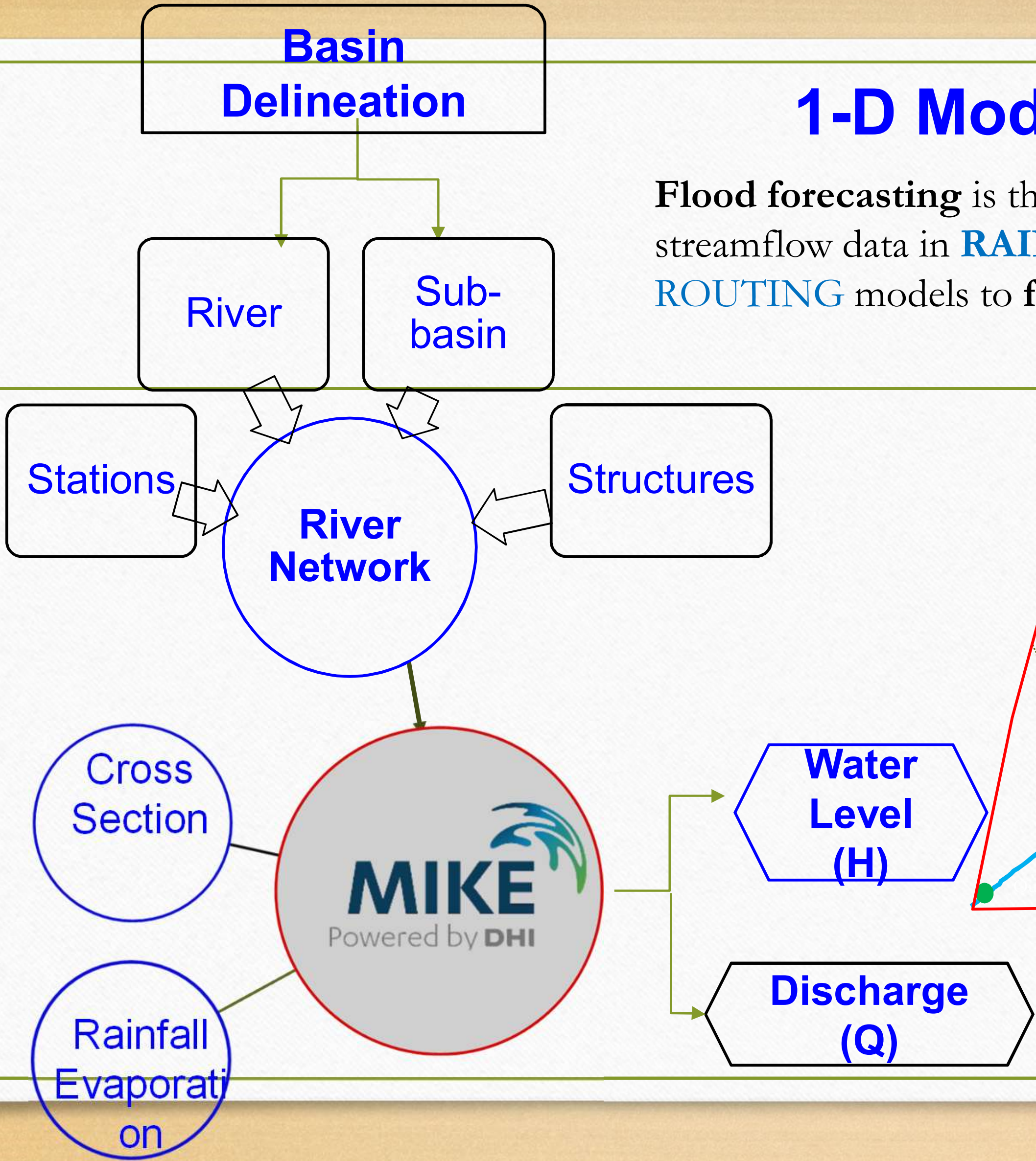


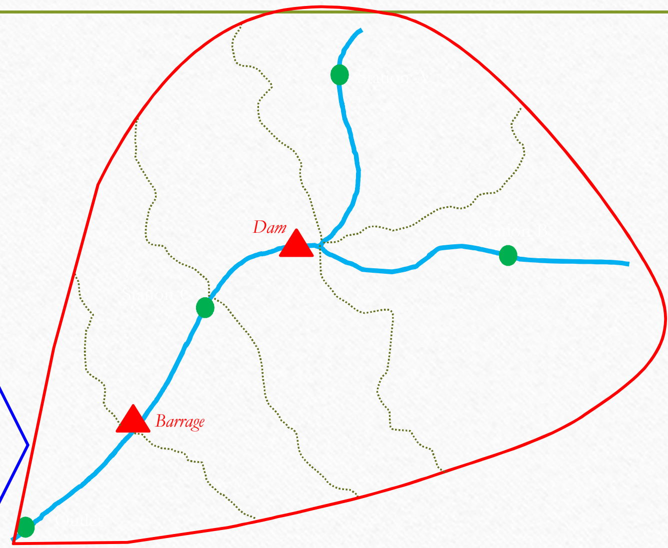
5 Day Advisory Flood Forecast Website https://aff.india-water.gov.in/



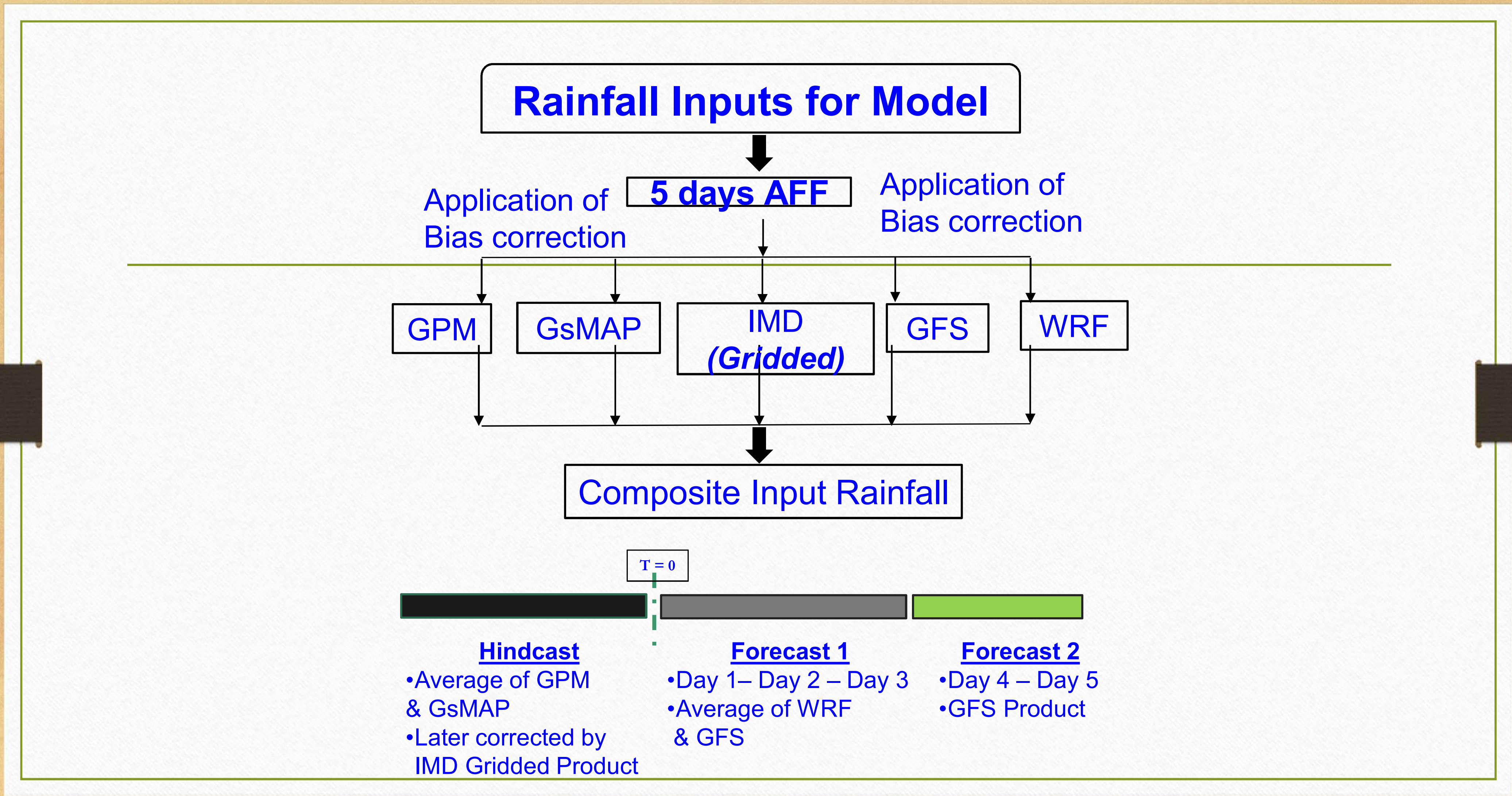
1-D Modelling Approach

Flood forecasting is the use of **forecasted** precipitation and streamflow data in **RAINFALL-RUNOFF** and STREAMFLOW ROUTING models to **forecast** flow rates and water levels

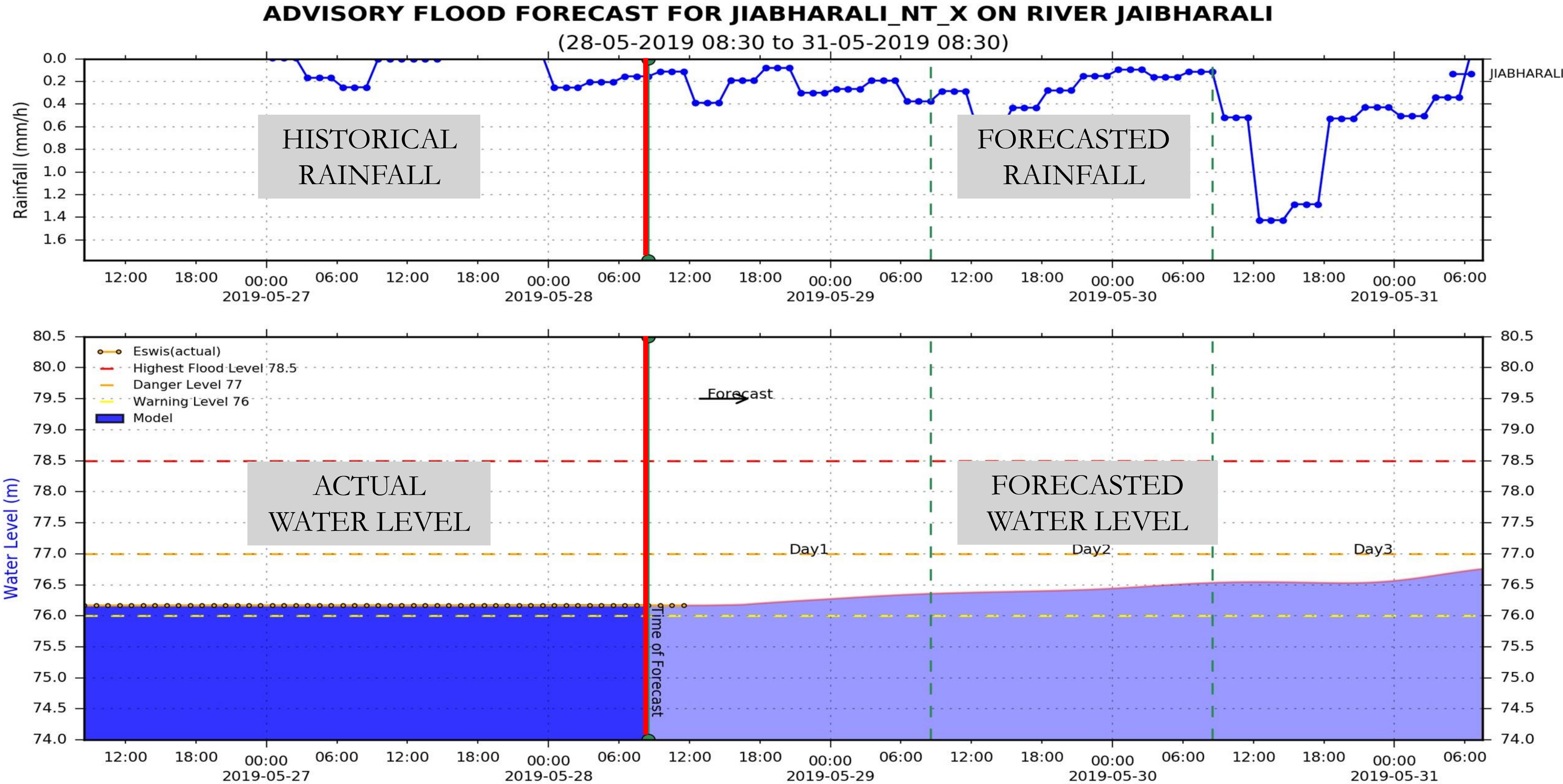




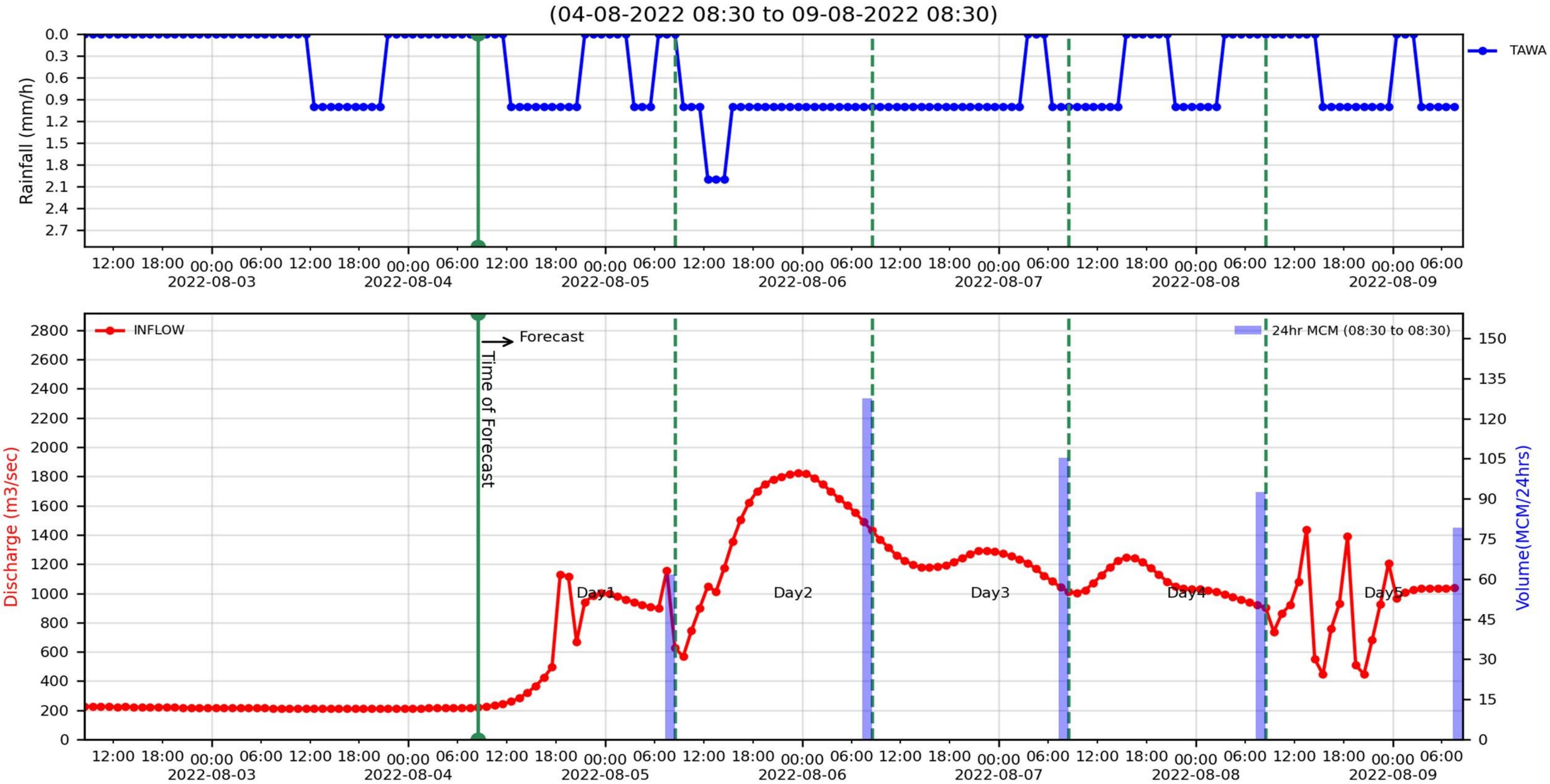
Sub Basin


Rainfall Inputs for Model
5 days AFF
Application of Bias correction
Application of Bias correction
GPM
GsMAP
IMD (Gridded)
GFS
WRF
Composite Input Rainfall
T = 0
Hindcast
•Average of GPM & GsMAP
•Later corrected by IMD Gridded Product
Forecast 1
•Day 1– Day 2 – Day 3
•Average of WRF & GFS
Forecast 2
•Day 4 – Day 5
•GFS Product

FORECAST SAMPLE

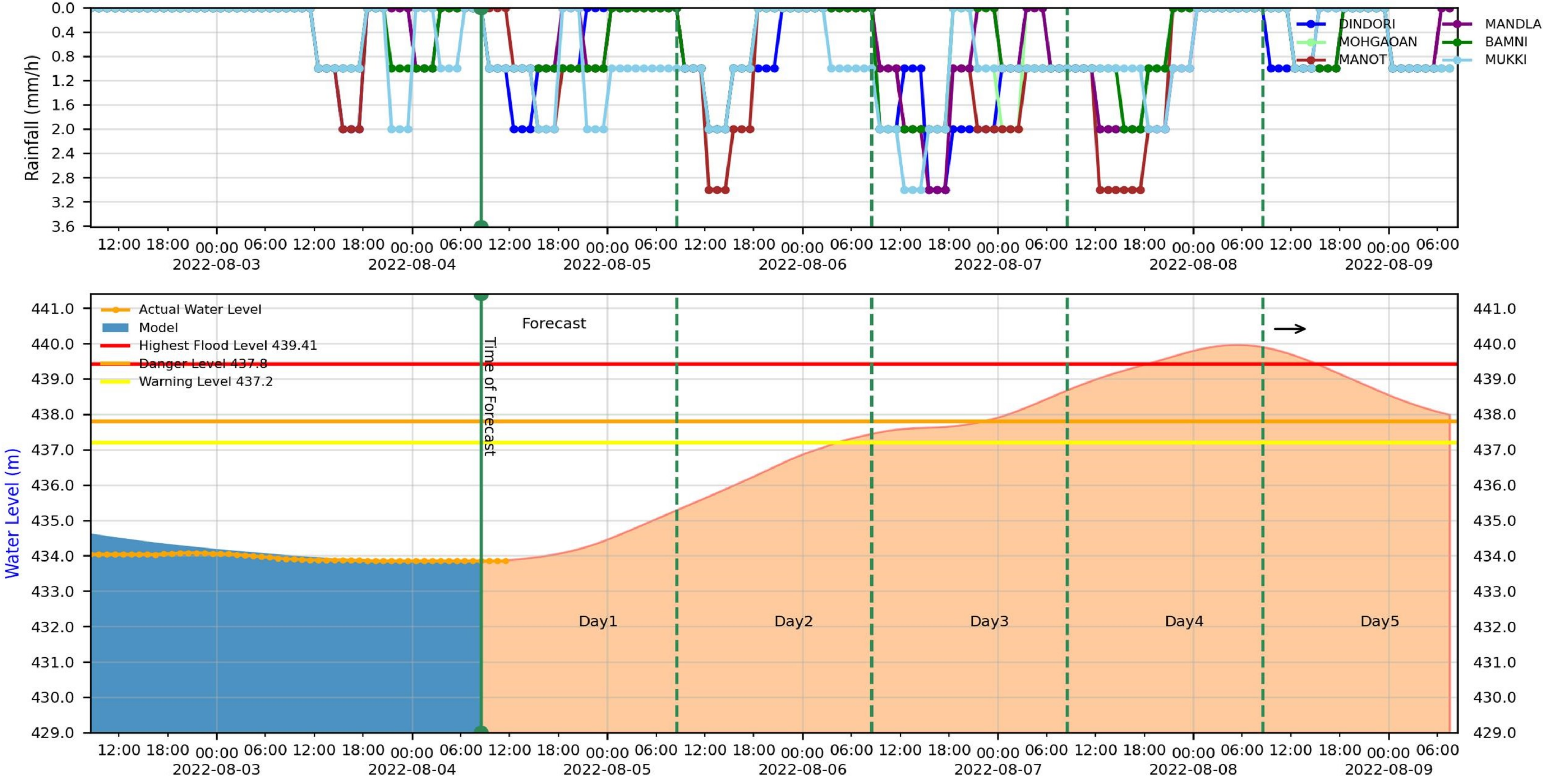


ADVISORY INFLOW FORECAST FOR TAWA_DAM ON RIVER TAWA



ADVISORY FLOOD FORECAST FOR MANDLA ON RIVER NARMADA

(04-08-2022 08:30 to 09-08-2022 08:30)



Tabular View

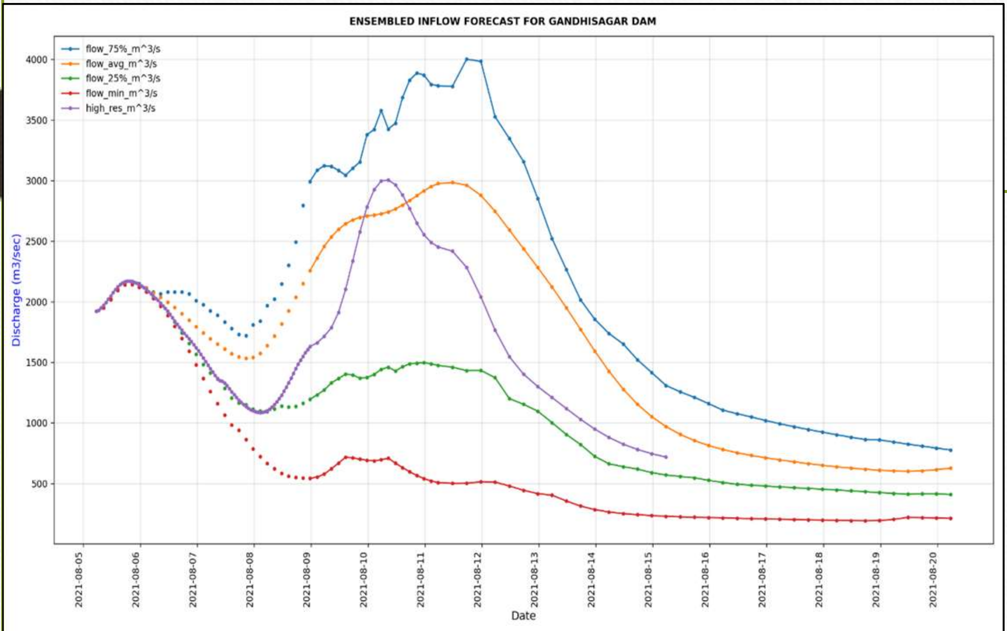
Details of likely Inflows to various reservoirs

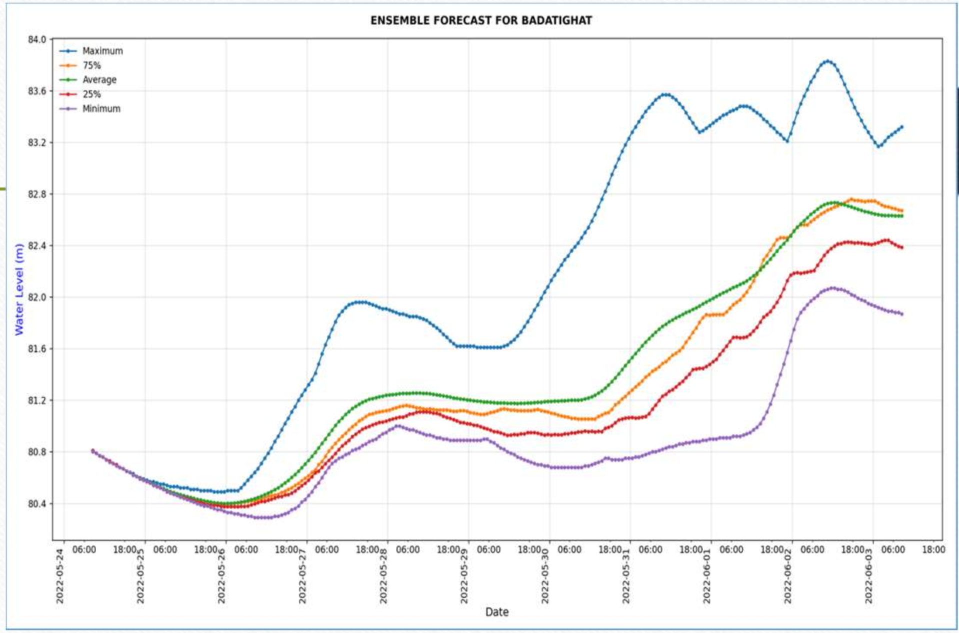
CWC Inflow stations			Reservoir charecteristics		Day-1 Forecast		Day-2 Forecast		Day-3 Forecast		Day-4 Forecast		Day-5 Forecast	
S.No	Reservoir name	GS (MCM)	MDDL (m)	FRL (m)	Date	Inflow(MCM)	Date	Inflow(MCM)	Date	Inflow(MCM)	Date	Inflow(MCM)	Date	Inflow(MCM)
1	LAXMI_BARRAGE	458.0	89.0	100.0	11/08/22 08:30	3020.38	12/08/22 08:30	2883.52	13/08/22 08:30	2047.64	14/08/22 08:30	1639.78	15/08/22 08:30	1871.69
2	P_R_KANTAPALLY	-1.0	-1.0	-1.0	11/08/22 08:30	2718.9	12/08/22 08:30	3064.68	13/08/22 08:30	2254.5	14/08/22 08:30	1726.63	15/08/22 08:30	1774.13
3	POLAVARAM_PRJ	5511.0	6.44	45.72	11/08/22 08:30	1883.46	12/08/22 08:30	3117.56	13/08/22 08:30	3040.89	14/08/22 08:30	2353.75	15/08/22 08:30	2235.14
4	SSD	9501.8	110.64	138.68	11/08/22 08:30	996.94	12/08/22 08:30	1143.3	13/08/22 08:30	952.11	14/08/22 08:30	931.89	15/08/22 08:30	806.9
5	OMKARESHWAR	1500.0	193.5	201.2	11/08/22 08:30	971.07	12/08/22 08:30	865.07	13/08/22 08:30	817.15	14/08/22 08:30	810.8	15/08/22 08:30	694.95
6	INDIRA_SAGAR_DA	12200.0	245.06	263.13	11/08/22 08:30	911.89	12/08/22 08:30	784.88	13/08/22 08:30	768.44	14/08/22 08:30	760.87	15/08/22 08:30	654.69
7	S_YELLAMPALLI	571.0	121.7	148.0	11/08/22 08:30	853.09	12/08/22 08:30	814.43	13/08/22 08:30	578.34	14/08/22 08:30	463.15	15/08/22 08:30	528.65
8	HIRAKUD_DAM	8105.0	182.0	192.0	11/08/22 08:30	455.89	12/08/22 08:30	460.17	13/08/22 08:30	321.64	14/08/22 08:30	242.08	15/08/22 08:30	228.49
9	METTUR_DAM	2640.0	219.0	240.73	11/08/22 08:30	380.19	12/08/22 08:30	290.26	13/08/22 08:30	248.63	14/08/22 08:30	228.63	15/08/22 08:30	214.38
10	KATERNIAGHAT_DAM	-1.0	-1.0	136.8	11/08/22 08:30	346.0	12/08/22 08:30	350.67	13/08/22 08:30	343.39	14/08/22 08:30	284.47	15/08/22 08:30	242.53
11	B_K_GHAT	-1.0	-1.0	-1.0	11/08/22 08:30	338.14	12/08/22 08:30	342.68	13/08/22 08:30	350.12	14/08/22 08:30	301.69	15/08/22 08:30	249.4
12	L_SUBANSIRI_HE	1370.0	-1.0	-1.0	11/08/22 08:30	327.58	12/08/22 08:30	285.38	13/08/22 08:30	244.53	14/08/22 08:30	237.71	15/08/22 08:30	285.86
13	TUNGABHADRA_DAM	2860.0	474.0	498.0	11/08/22 08:30	316.22	12/08/22 08:30	212.49	13/08/22 08:30	172.21	14/08/22 08:30	161.31	15/08/22 08:30	143.11
14	HATHNUR_DAM	388.0	209.0	215.0	11/08/22 08:30	309.12	12/08/22 08:30	281.39	13/08/22 08:30	255.5	14/08/22 08:30	196.25	15/08/22 08:30	150.27
15	KOSI_BRG	-1.0	-1.0	79.26	11/08/22 08:30	303.25	12/08/22 08:30	289.91	13/08/22 08:30	279.02	14/08/22 08:30	267.01	15/08/22 08:30	253.92
16	UKAI_DAM	7414.0	90.0	106.0	11/08/22 08:30	288.26	12/08/22 08:30	380.35	13/08/22 08:30	360.6	14/08/22 08:30	325.13	15/08/22 08:30	259.58
17	NSDAM	11492.6	100.0	162.0	11/08/22 08:30	260.55	12/08/22 08:30	333.19	13/08/22 08:30	377.53	14/08/22 08:30	374.66	15/08/22 08:30	348.01
18	SRISAILAM_DAM	5060.0	243.84	269.75	11/08/22 08:30	259.39	12/08/22 08:30	256.61	13/08/22 08:30	267.72	14/08/22 08:30	270.77	15/08/22 08:30	245.43
19	HIPPARGI	169.9	516.0	531.0	11/08/22 08:30	248.39	12/08/22 08:30	161.16	13/08/22 08:30	138.27	14/08/22 08:30	127.95	15/08/22 08:30	115.38
20	GANDAK_BRG	-1.0	-1.0	110.3	11/08/22 08:30	245.16	12/08/22 08:30	241.83	13/08/22 08:30	205.38	14/08/22 08:30	171.75	15/08/22 08:30	156.54

Ensembled Flood Forecast

- Outputs of **15-days GEOGLOWS ECMWF Streamflow Forecast** taken as service (https://geoglows.ecmwf.int/)
- At **selected** inflow forecasting of reservoirs of India

- **10 days** ensemble level forecast
- Based on **NCMRWF 23 members ensemble** rainfall forecast



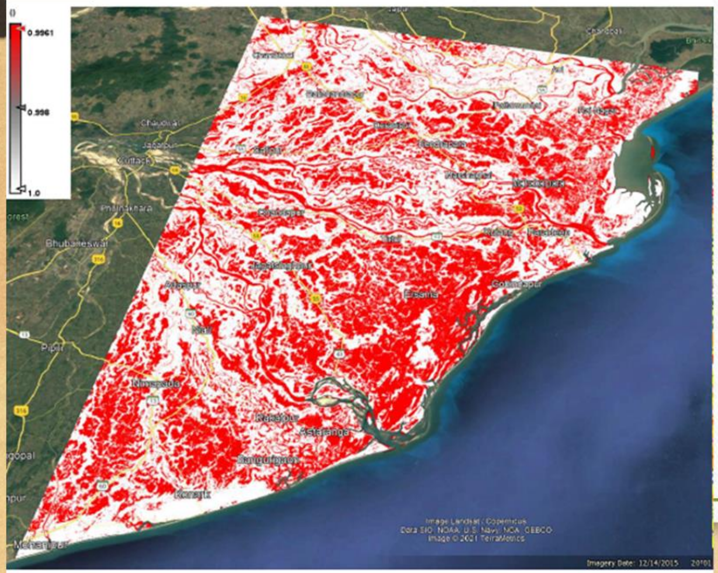


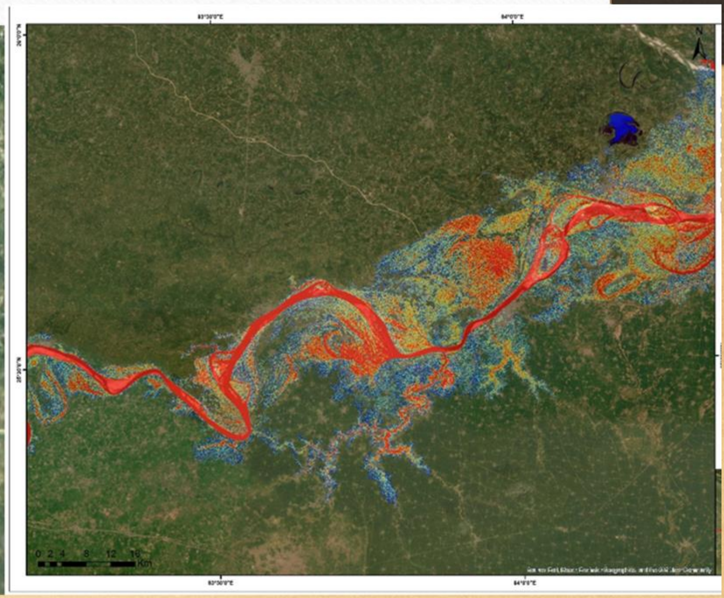
Inundation Forecast

Near real-time Inundation Forecast Model for Mahanadi delta

Inundation maps for Yamuna, Tapi, Brahmaputra

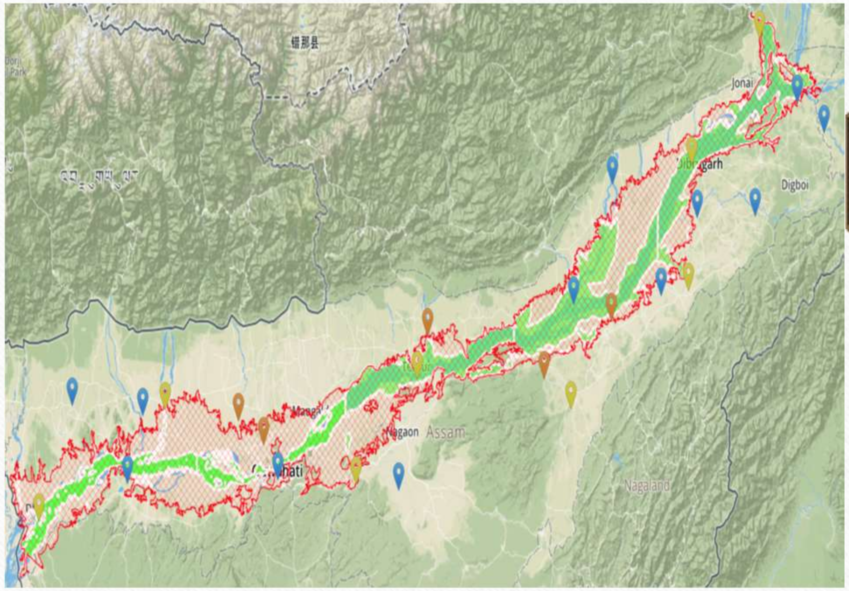
Inundation Forecast model for Ganga Basin under development





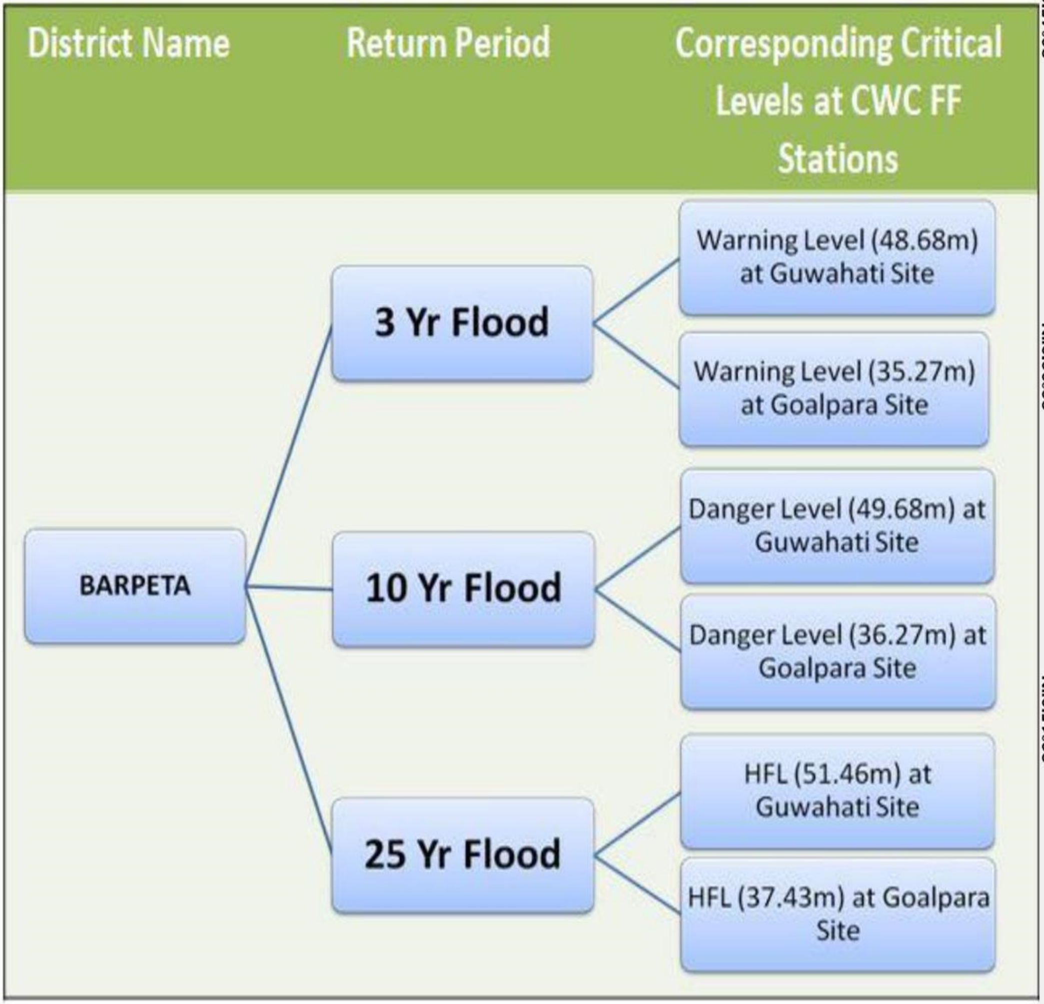
Flood Inundation Atlas for Brahmaputra River

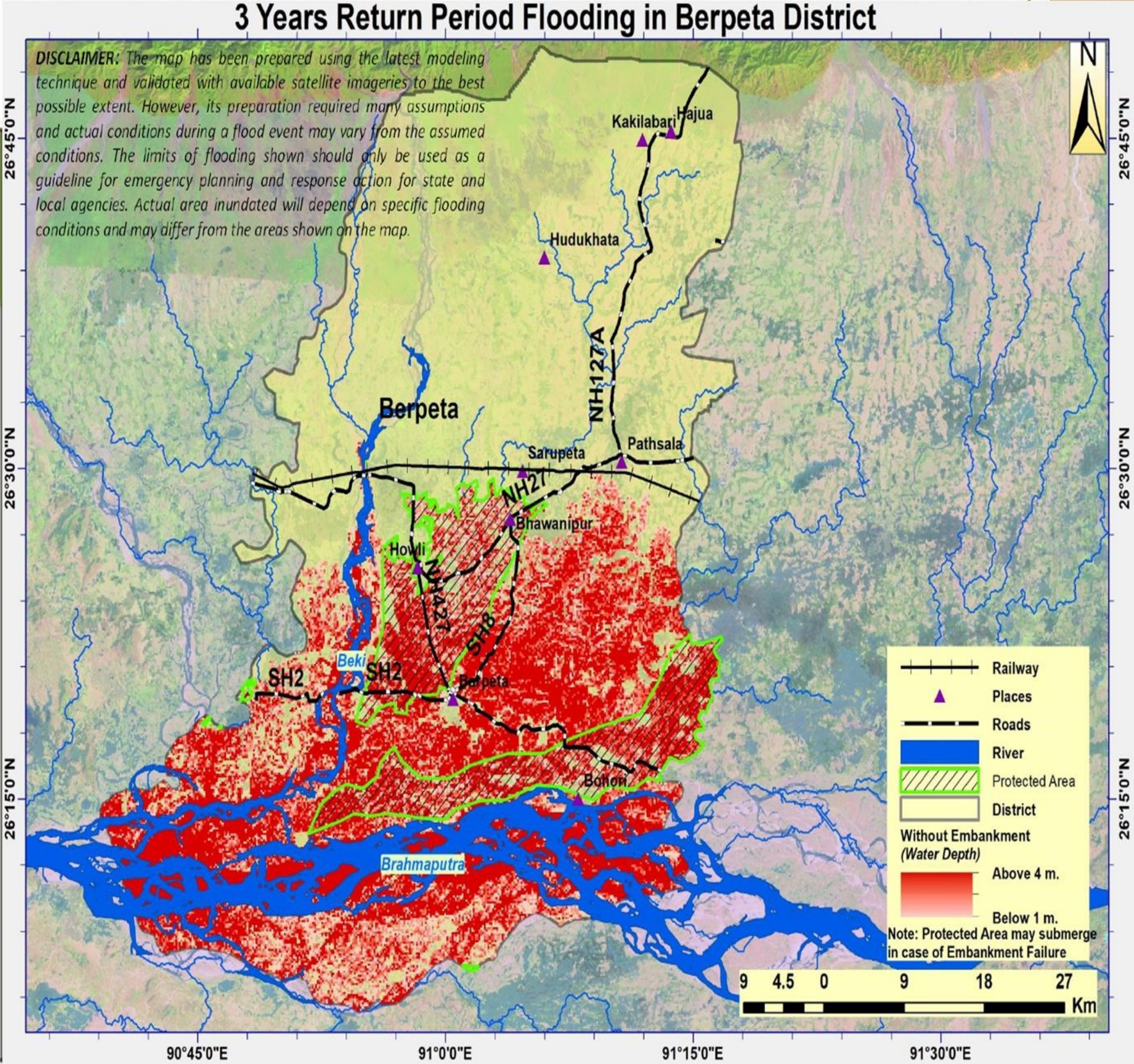
- Brahmaputra River Inundation Atlas and maps were prepared
- Based on **2, 3, 5, 10 & 25** year return period flood
- CWC Station and district maps were incorporated
- Layers of rail, road and important places were incorporated
- Already **running** on CWC 5-Days Advisory website on real-time basis



Brahmaputra Inundation Model: *Library based approach*

BARPETA





Monitoring of Glacial Lake & Water Body through Remote Sensing

2009
- MOU was signed with NRSC for preparation of an Inventory

2011
- Inventory of 2028 GL& WB having size above 10 Ha was prepared and published by NRSC

2011 -15
- Remote sensing based monitoring was taken up
- 477 GL&WB was selected having size greater than 50 ha out of 2028
- Monitoring carried in association with NRSC till 2015

2016 -21
- Monitoring of 477 GL & WB was being carried out by CWC

2022
- **Monthly Monitoring of 902 Glacial Lakes & Water bodies (up to 10 Ha as per NRSC inventory 2009) started**
- Critical Glacial Lakes Identified by Swiss Development Agency (SDC) for Indian Himalayan region have also been included

2023 onwards
- ***frequency to be increased from monthly to fortnightly***

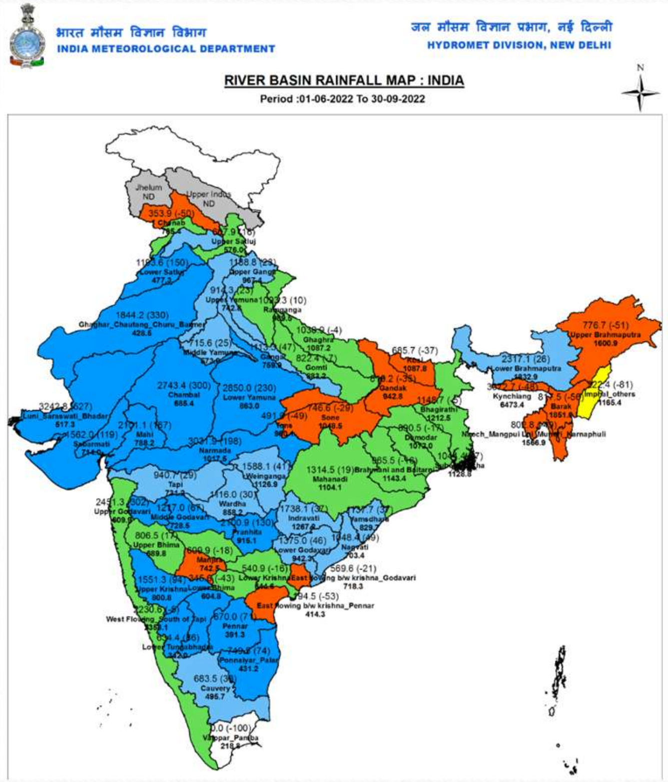
Monthly Reports from June to October are prepared and published

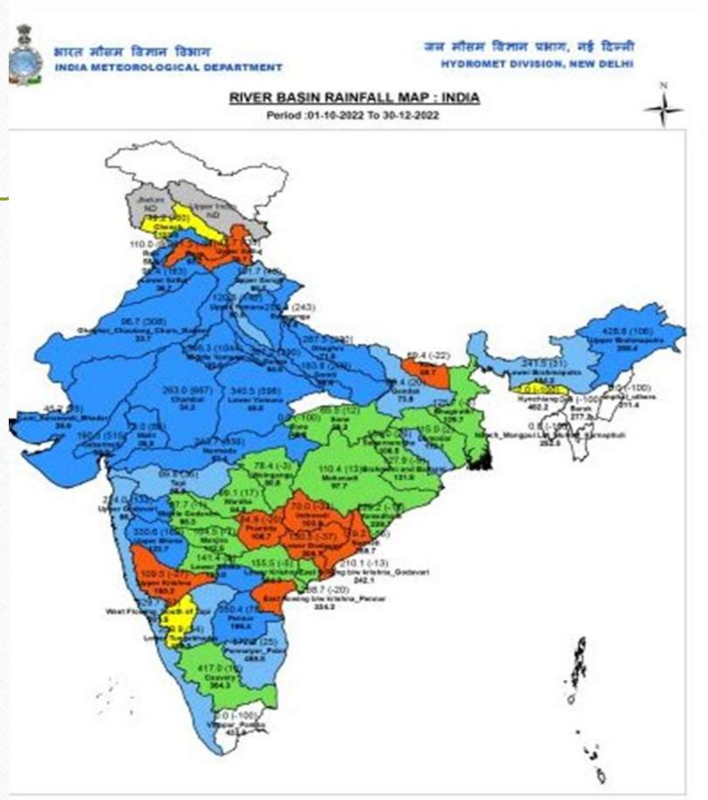
Annual Report is prepared and published

Shared with all stake holders including NDMA, concerned states

Flood Early Warning during May to December 2022

Rainfall Situation - Monsoon and Post Monsoon 2022





Large Excess [60% or more]

Excess [20% to 59%]

Normal [-19% to 19%]

Deficient [-59% to -20%]

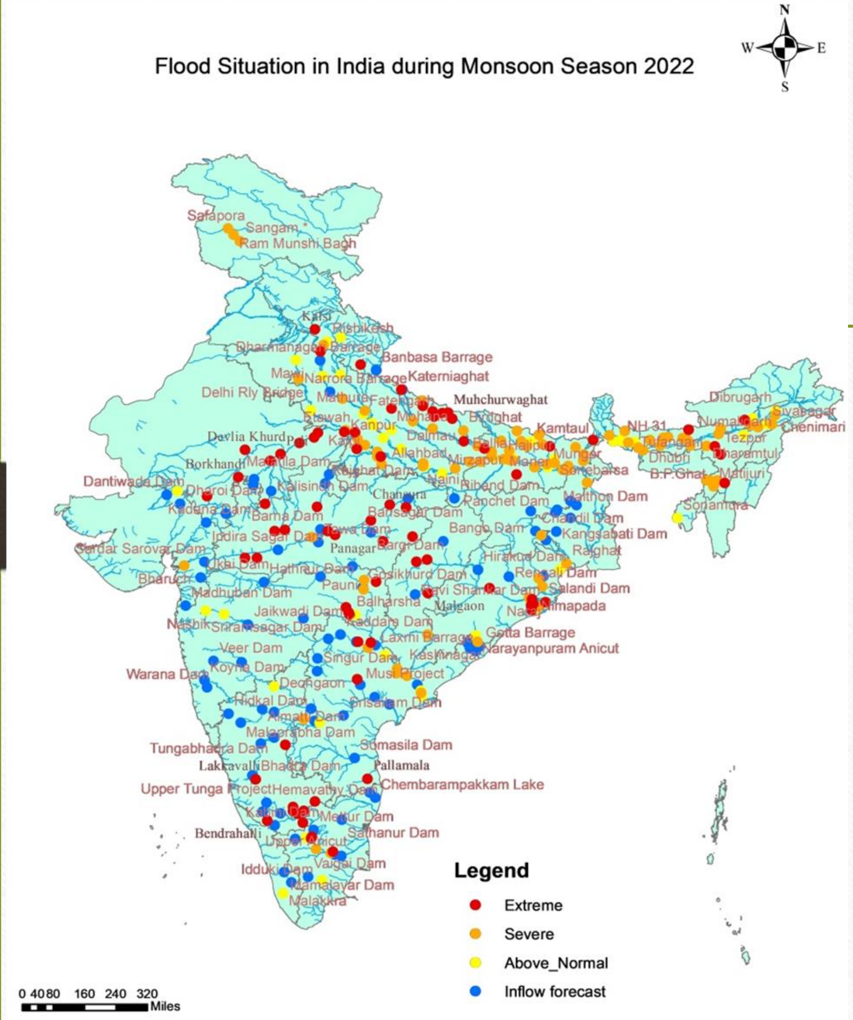
Large Deficient [-99% to -60%]

No Data [-100%]

No Rain

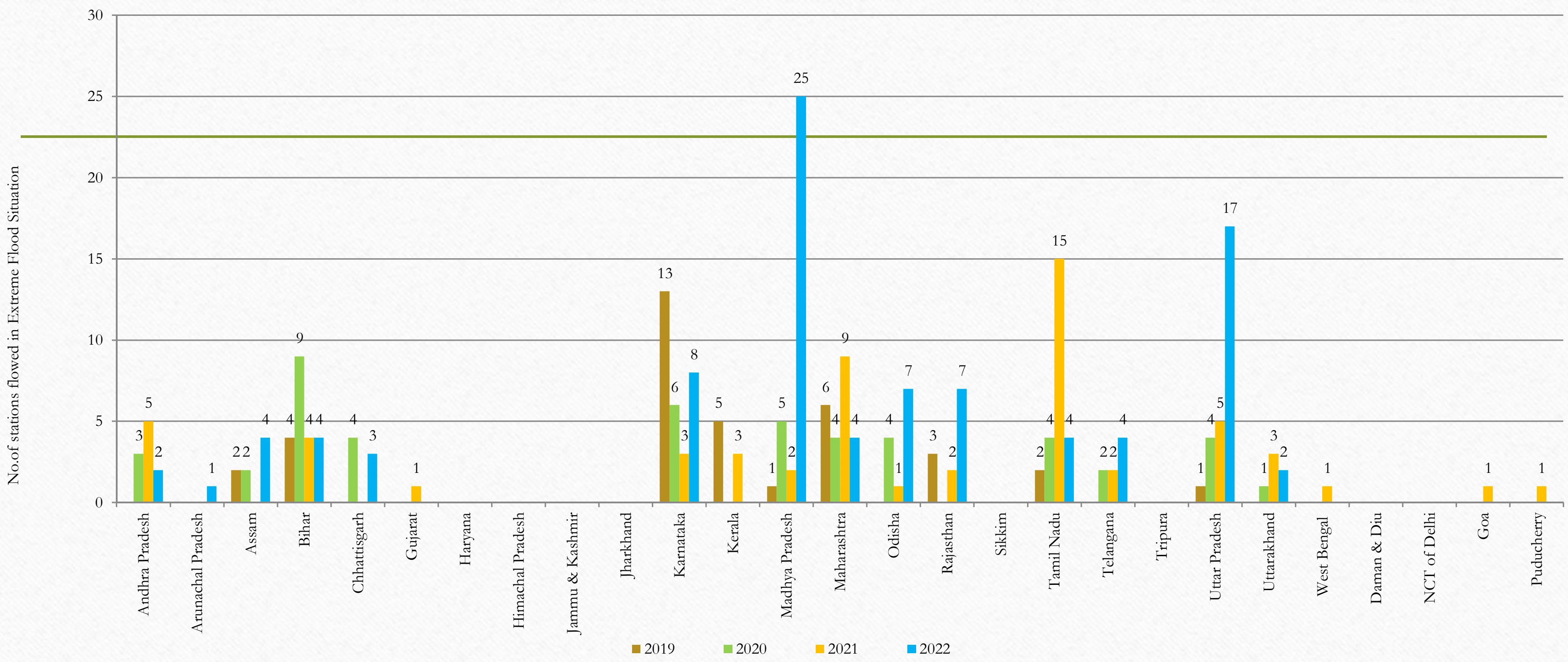
FF Dissemination - May to December 2022

- 11558 flood forecasts (6779 Level and 4779 Inflow) were issued from CFCRs all over India
- out of which 10845 (6476 Level and 4369 Inflow) forecasts were within limit of accuracy with a percentage accuracy of 93.83%.
- 555 nos. of Red Bulletin (for Extreme flood situation)
- 621 nos. of Orange Bulletin (for Severe flood situation) were issued from Central Flood Control Room.



Flood Situation - Monsoon 2022

Extreme Flood Situation State wise – 2019-22



Present Satellite data utilization in CWC

Use of Indian Satellite data from ISRO as well as from foreign Satellite

- Monitoring of Glacial Lakes / Water Bodies (GL&WBs) in Himalayan Region
  - ➢Earlier by using ISRO satellite Resourcesat-2
  - ➢currently by using Sentinel 2A & 2B MSI (Optical) and Sentinel-1A SAR (Microwave) data

- Scientific Assessment of Flood Prone areas
  - ➢Optical and microwave Satellite data of Landsat & Sentinel series, SRTM & Carto DEM

- Sedimentation assessment of reservoirs
  - ➢Microwave data from Sentinel 1A

- Reassessment of Water Resources Availability in India using Space Inputs
  - ➢Study completed, report published in June, 2019
  - ➢Satellite data used:
    - ✓DEM- SRTM DEM 90m
    - ✓Annual LULC data derived from Indian Remote Sensing (IRS)AWiFS) 56m resolution

- Inundation mapping for flood events and verification of inundation forecast.
- Development / validation of inundation maps
  - ➢Optical and microwave Satellite data of Landsat & Sentinel series, SRTM & Carto DEM

- Water Accounting (+)
  - ➢Open source remote sensing datasets e.g. Evapotranspiration, Rainfall, LULC, Soil Moisture, Biomass etc. used

Satellite data utilization plan for future

In addition to the use of existing satellite data,

- Data from RISAT-1A is attempted to be used in various activities in CWC
- Data from RISAT-1B, Resourcesat-3/3A and Resourcesat-3S/3SA will be used when it will be available.

Working Groups for utilization of data from Indian Satellites

- **WG- A (Flood & Disaster Management)**
- **WG-B (Water Resources Planning)**
- **WG-C (Mapping related activities)**

In addition to the use of satellite data, other potential areas for exploration on pilot basis

Depth-Area Duration Studies of the flood

Performance evaluation of irrigation command projects

- Morphological Studies of Rivers
  - ✓ River Bank erosion and Deposition
  - ✓ Shifting of river banks
  - ✓ River control/training works mapping/monitoring

Flood damage assessment

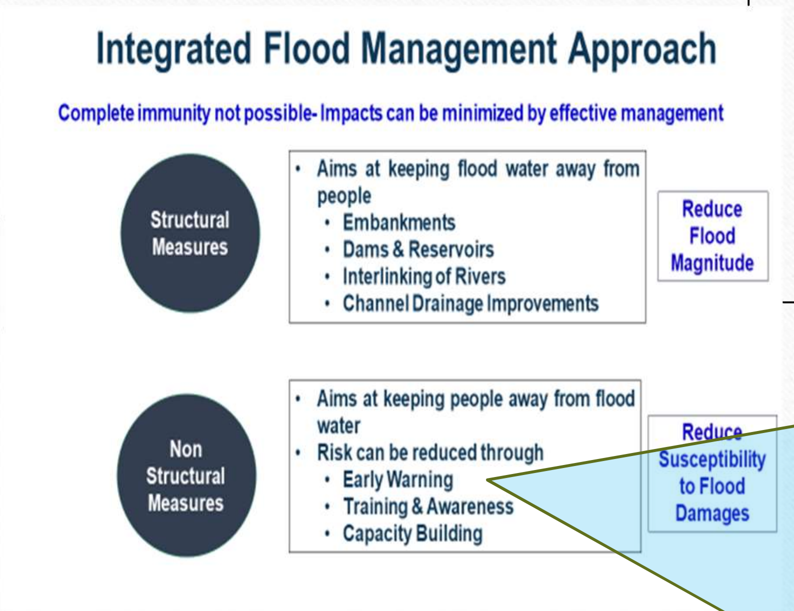
Irrigation efficiency assessment

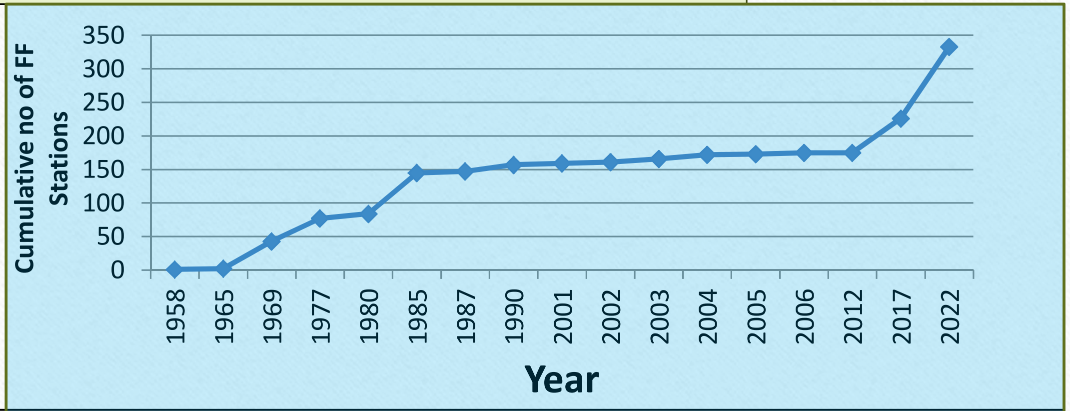
- Minor Irrigation Census
- Impact Evaluation of Minor Irrigation Tanks
- Impact monitoring of Water harvesting interventionsIrrigation Infrastructure Inventory and Monitoring

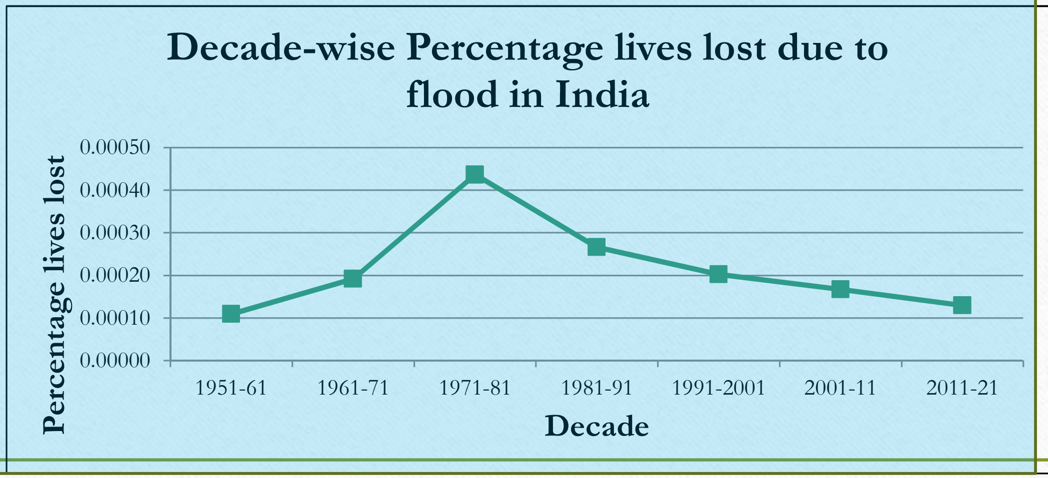
- Mapping and Monitoring of Coastline
- Mapping and Monitoring of salinity intruded areas along the coast
- Mapping and Monitoring of Coastal protection works along the coast

- Surface Water Logging, Soil Salinity/Alkalinity mapping & monitoring
- Mapping of artificial recharge structures
- Mapping of Ground Water

Impact of Flood Forecasting







News · Articles · Ecosystem · Resources · Skills and Jobs · Sectors · Govt. of India

Flood Prediction • 7 Min Read • Dec 16, 2020

Cover Story: **Saving 3.5 billion dollars annually through flood forecasting systems**

By Soumitra Dasgupta

THANK YOU

Highlights

The Central Water Commission has been engaging with Google to send out alerts to people which helped save lives. These alerts provide critical information and are updated regularly that enable Android smartphone users to make informed choices about where they want to be. Particularly this year, when many parts of the country have grappled with flood situations.

25TH CONGRESS &
74TH IEC OF ICID

जल शक्ति मंत्रालय
MINISTRY OF
JAL SHAKTI

25th International Congress & 75th IEC of ICID

- **ICID Congress** - Flagship triennial event - deliberate & develop solutions for concurrent global issues pertaining to agricultural water management

1st Congress in India - 1951	→	6^{th} Congress in India in 1966	→	25^{th} Congress scheduled in India in **2023**

Proud moment for India - Congress after **57 years**

Being organised by INCID & **State Government of Andhra Pradesh**, in collaboration with:

- *ICID,*
- *Central Water Commission (Ministry of Jal Shakti, Government of India)*

Expected footfall of **1000+** delegates

Vishakhapatnam Andhra Pradesh, India

1- 7 November 2023

Theme

Tackling Water Scarcity in Agriculture

Congress Thematic Questions

Theme: **Tackling Water Scarcity In Agriculture**

Ques 64: What alternative water resources could be tapped for irrigation agriculture?

64.1 Reinforcing conventional sources of irrigation water

64.2 Tapping non-conventional sources of water

64.3 Empowerment of farmers

Ques 65: Which on-farm techniques can increase water productivity?

65.1 Improving management of existing facilities

65.2 Improved Agronomics practices

65.3 Efficient application of irrigation water

Seminar: National policies for safe re-use of wastewater in irrigation

Symposium: Tackling Climate Change - Role of Storages for Irrigation

https://congress.icidevents.org/

Call for Papers Timeline:

Abstracts/ papers invited from policy makers, professionals, academicians, researchers, experts, & scientists from private and government sectors through **ICID Technical Management Portal:**

- Submission of 'Extended Abstracts' (500-600 words): **28 Feb, 2023**
- Notification of Acceptance of Extended Abstracts: **31 March, 2023**
- Submission of Full papers: **30 April, 2023**
- Notification to Authors (oral/poster/presentation): **31 May, 2023**

Radisson Blue Resort, Vishakhapatnam, AP

Glacial Lake Outburst Flood (GLOF)

Sanjay K Jain, Scientist G

National Institute of Hydrology

Roorkee

Glacial Lake Outburst Flood (GLOF)

The Indian Himalayan Region (IHR) is facing critical challenges while coping with the adverse effects of climate change. Physically, the disappearance of mountain glaciers, expansion of large glacial lakes and the formation of new glacial lakes are amongst the most recognizable and dynamic impacts of global warming in this environment.

Due to the faster rate of melting from the glaciers, possibly due to global warming, water is accumulating at an increasing rate in these lakes. Sudden outburst results in Glacial Lake Outburst Flood (GLOF) downstream causing destruction of life and property

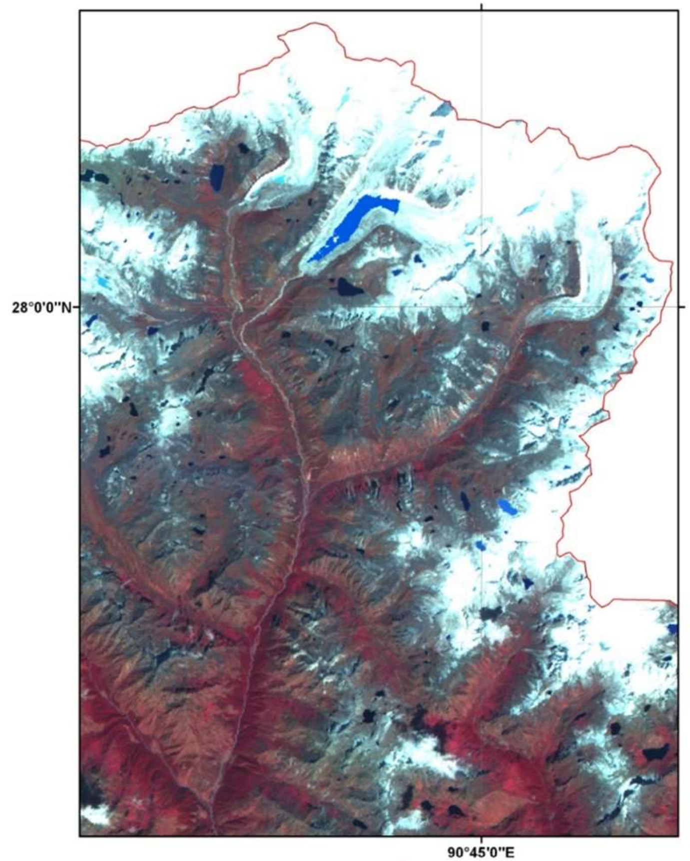
NDMA guidelines envisage specific recommendations for the concerned nodal agency, ministries/ departments, states and other stakeholders, so as to avert or reduce the impact of future calamities. In addition to the Guidelines, 'Summary of Guidelines on GLOFs/ LLOFs for Policy & Decision Makers' and a detailed version i.e., the compendium have been prepared. These guidelines have been released by NDMA on October 11, 2020.

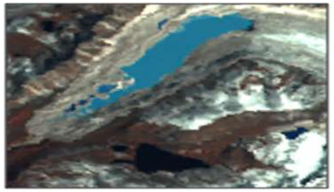
GLACIAL LAKE INVENTORY

For GLOF study, preparation of glacial lake inventory is the first step. The lake inventory has to be prepared at an interval to see the changes in the lakes.

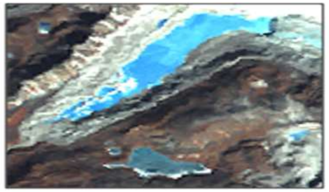
The basic materials used for the compilation of an inventory of glacial lakes are different type of satellite images, topographic maps and published maps, field report and available literatures.

Medium to high resolution satellite images of different dates are more useful in the inventory of glaciers and glacial lakes.

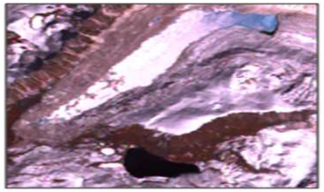




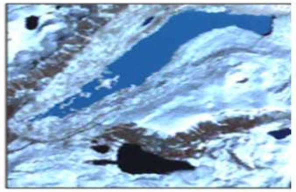
LANDSAT_TM Bands R G B 4 3 2 (1990)



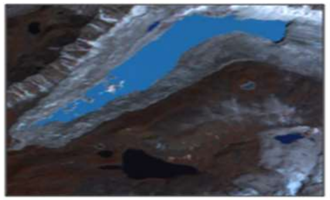
LANDSAT_ETM+ Bands R G B 4 3 2 (2000)



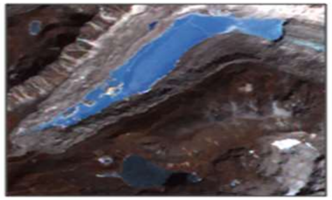
ASTER Bands R G B 3 2 1 (2004)



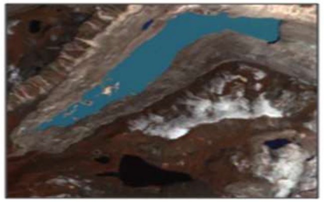
ASTER Bands R G B 3 2 1 (2005)



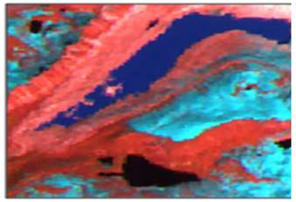
ASTER Bands R G B 3 2 1 (2007)



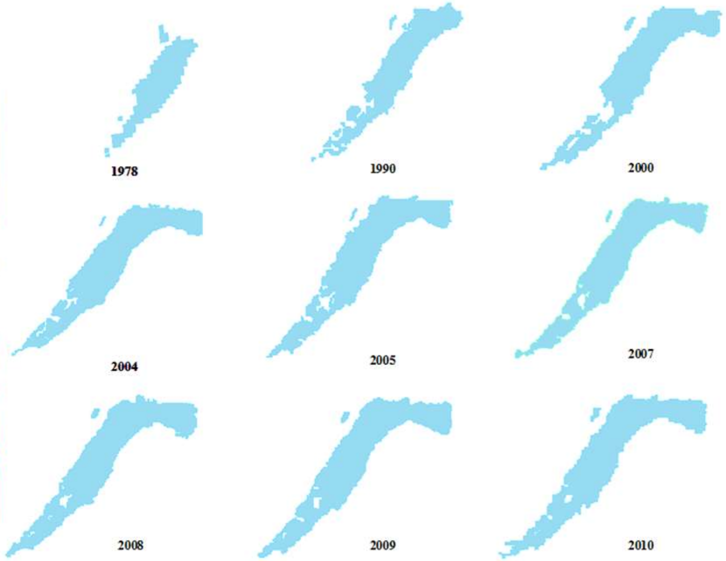
ASTER Bands R G B 3 2 1 (2008)



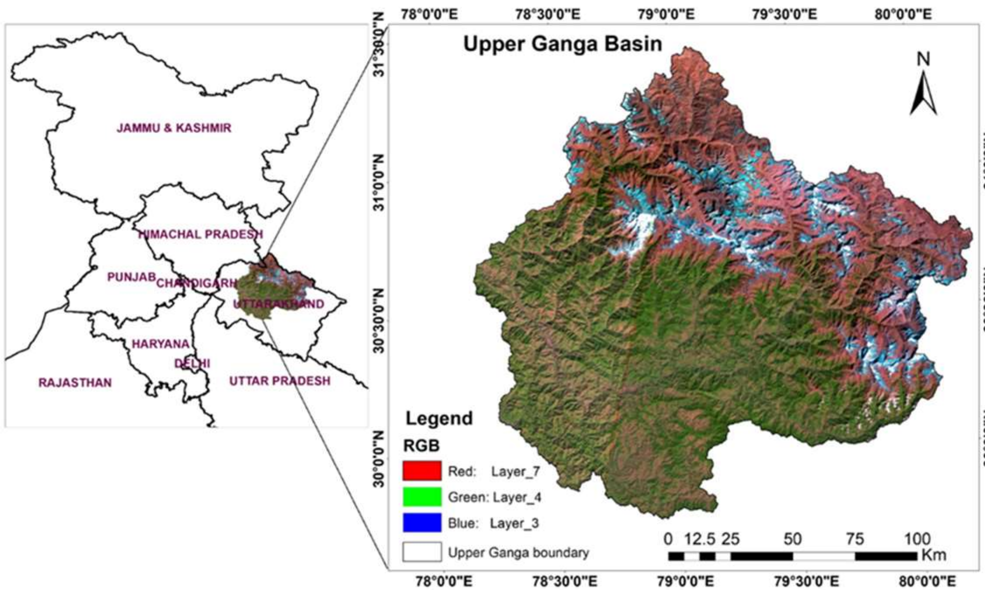
ASTER Bands R G B 3 2 1 (2009)

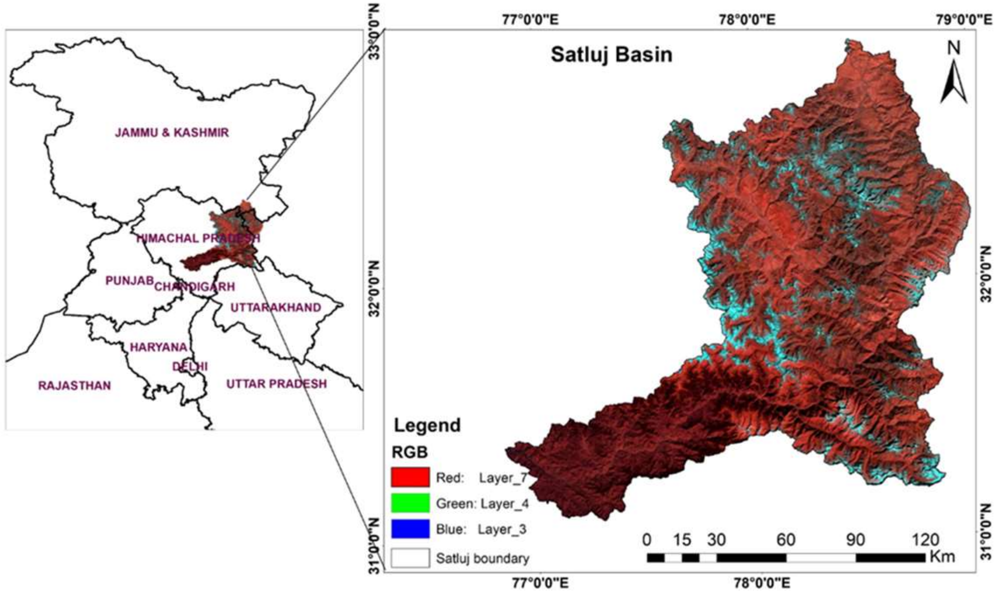


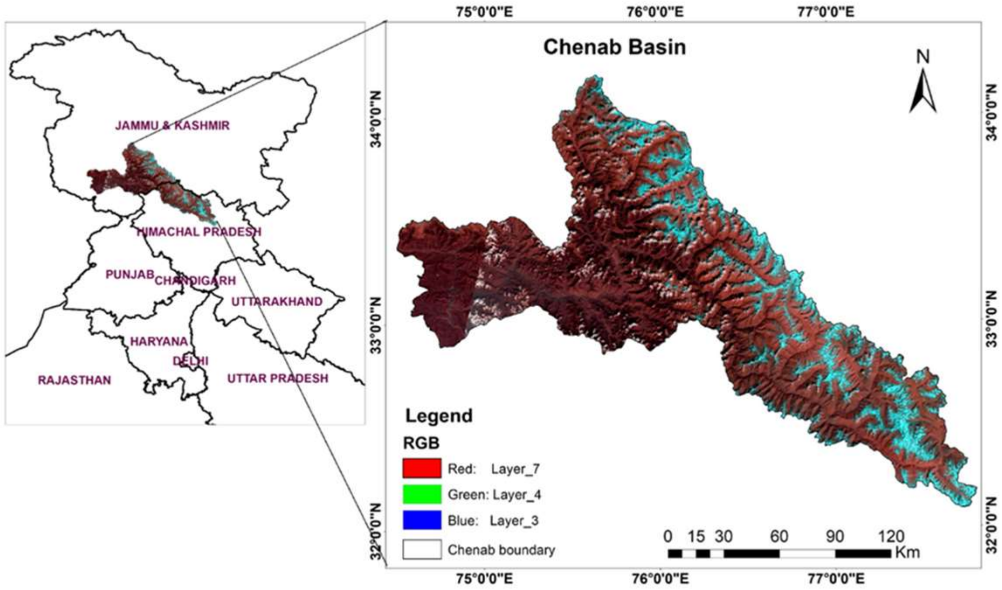
ASTER Bands R G B 3 2 1 (2010)

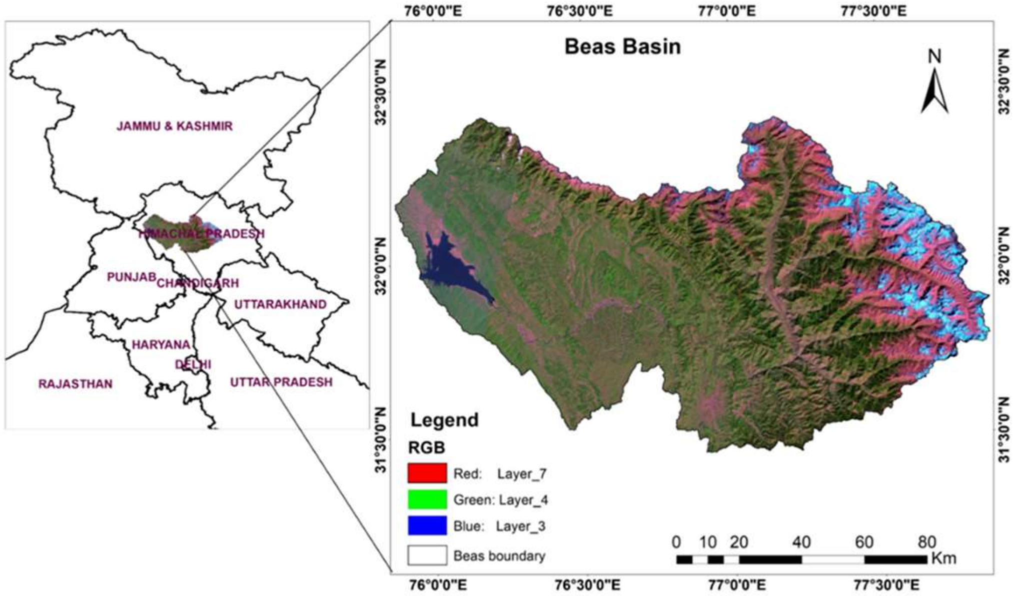


Glacial Lakes in Western Himalayan Region

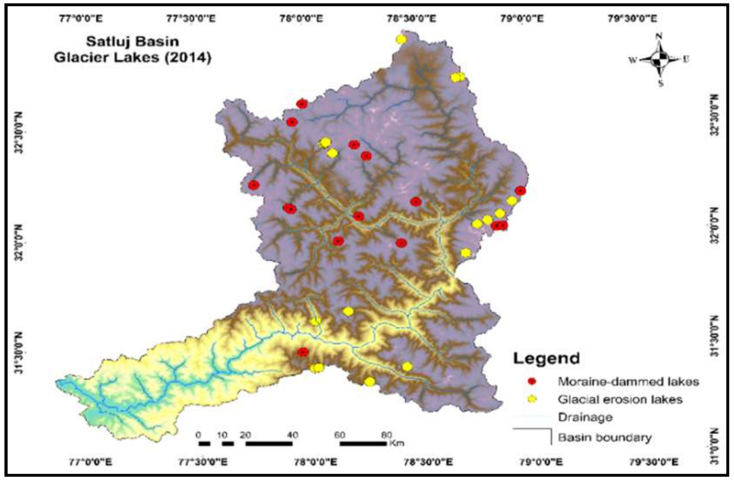


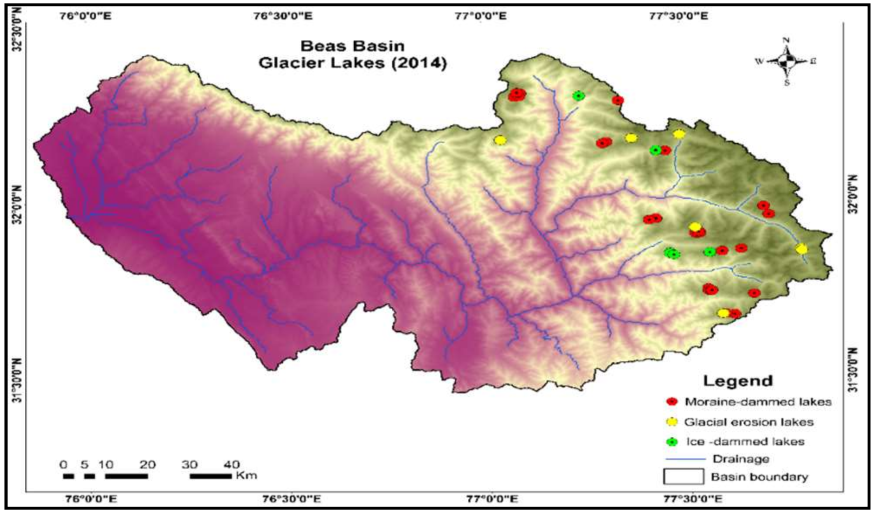


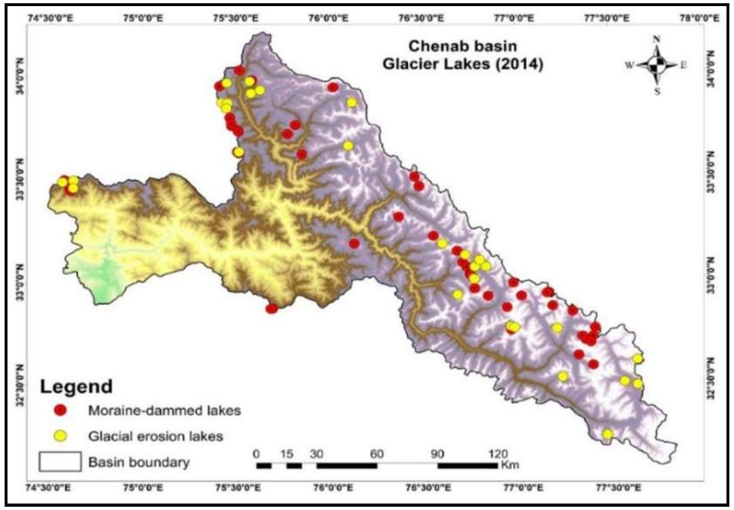


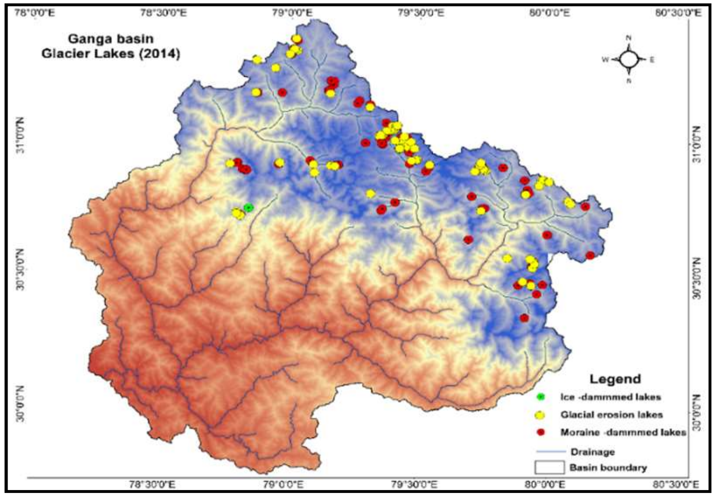


Glacial Lake Inventory Maps of Four Basins









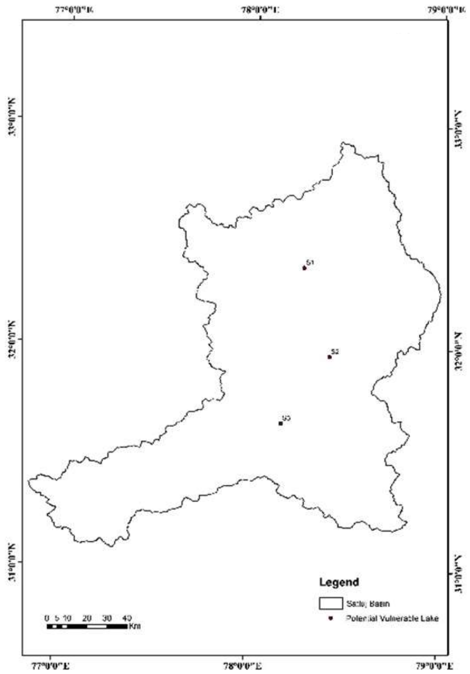
Year	Beas Basin	Satluj Basin	Chenab Basin	Ganga Basin
1990	12	30	57	139
2000	47	41	89	168
2008	32	25	86	182
2014	40	36	89	187

Criteria for identification of dangerous Lake

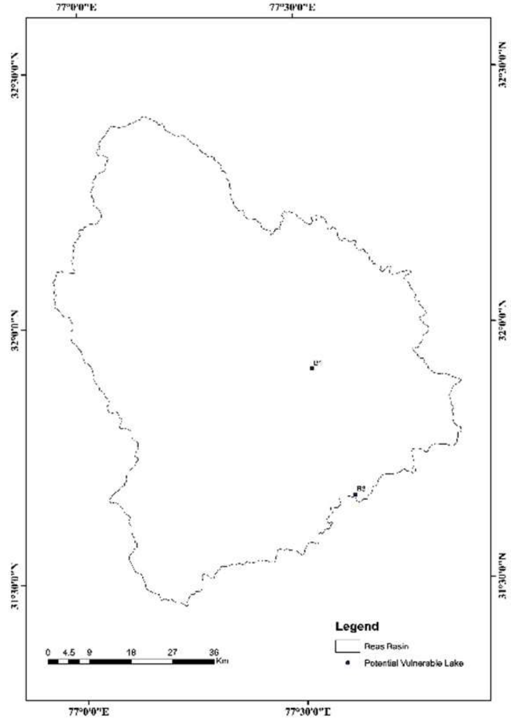
Identification of vulnerable lakes and classification of glacial lakes on the basis of vulnerability (High, moderate and Low)

- **RISE IN LAKE WATER LEVEL**
- **ACTIVITY OF SUPRAGLACIAL LAKES**
- **POSITION OF LAKES**
- **CONDITION OF ASSOCIATED MOTHER GLACIER**
- **PHYSICAL CONDITIONS OF SURROUNDINGS**

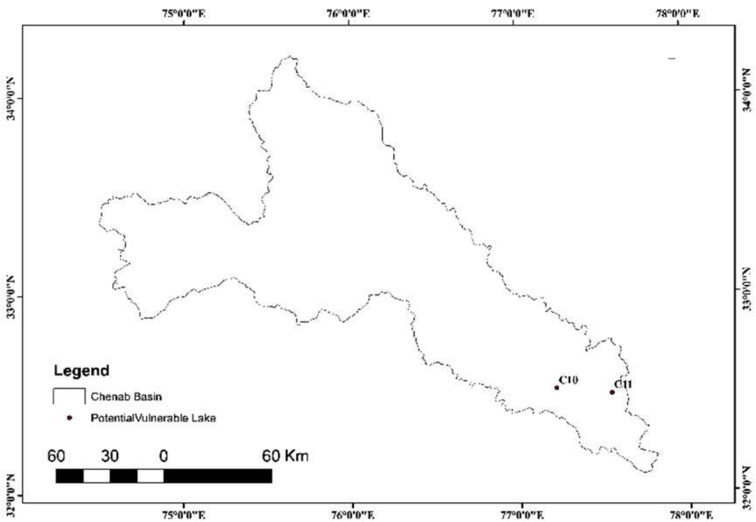
VURNERABLE LAKES



Satluj Basin



Beas Basin



Chenab Basin

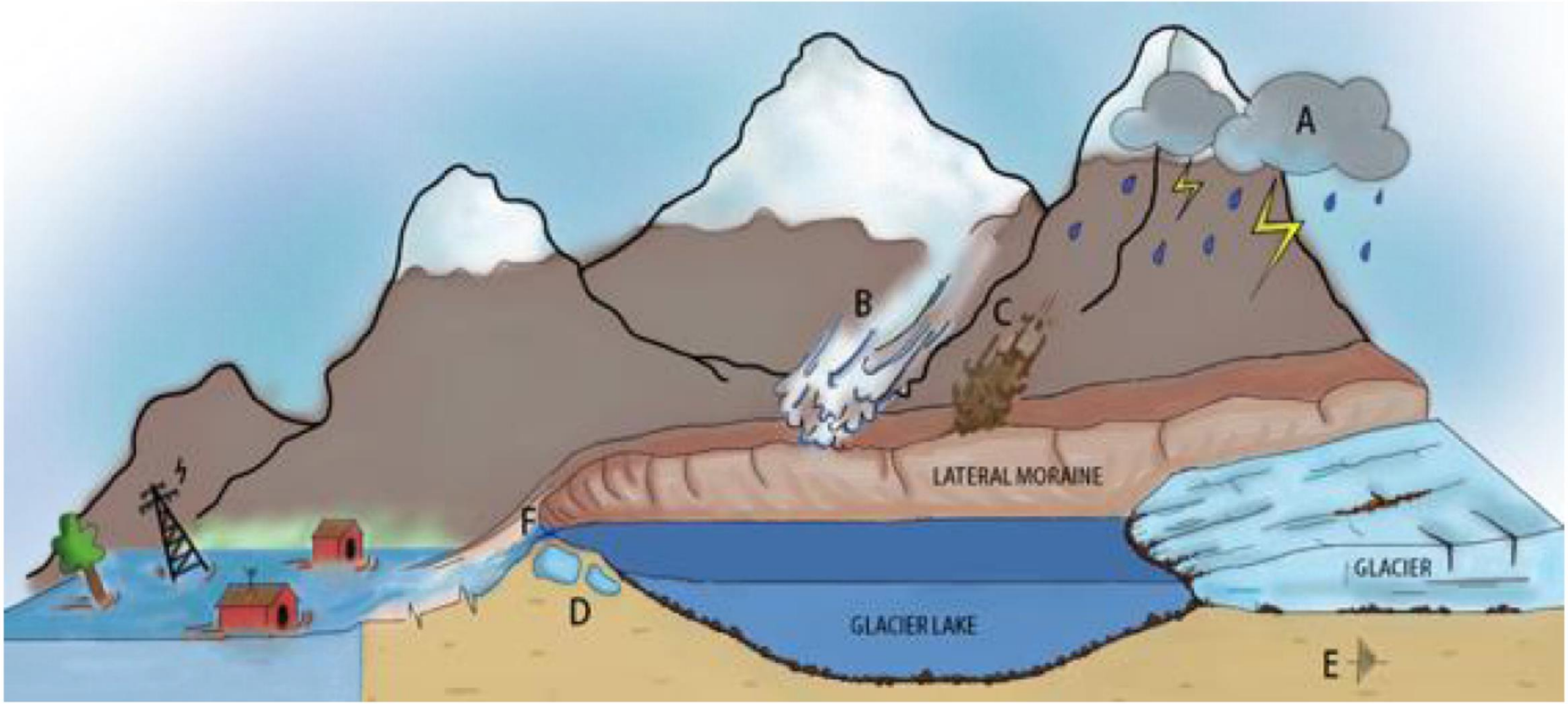
Vulnerable Lakes Satluj 03, Beas 02 and Chenab 02

Area of these lakes computed in 2019 and GLOF modelling has been carried out.

GLOF Triggering mechanism

A GLOF typically requires a trigger event.

Given an appropriate trigger, the natural moraine dams that impound these proglacial lakes are breached, producing catastrophic Glacial Lake Outburst Floods (GLOFs).



(A) Torrential rainfall (B) Snow/rock avalanche © Landslide/rock fall (D) Melting of ice in moraine (E) Seismic movement (F) Dam overtopping

GLOF MODELLING

Dam-breach models can be categorised as being empirical, analytical or numerical in nature, with each method having significant advantages and shortcomings.

These models are not process-based and comprise a single or series of regression relationships derived from test case studies or observed historical dam failures Input parameters typically include a combination of the following: dam width, height, lake area and volume.

Model output typically comprises a single ndiscrete value, such as peak discharge (*Qp*) or time to peak (*Tp*)

$$Q_p = 0.607V^{0.295} * h_w^{1.24}$$

$$T_p = 0.002546V^{0.53} * h_b^{-0.9}$$

V is Volume, h_w is the depth of the water above the breach invert at the time of failure and h_b is the breach height

Empirical models neglect the inclusion of basic hydraulic principles that describe the mechanics of breach formation.

Fully physically based numerical models

Complex numerical models are based predominantly on the physical processes observed during failure, including breach flow hydraulics and sediment transport, as well as soil erodibility relationships and structural models to simulate breach widening

GLOF Modelling : INPUT REQUIRED

- Glacier and Glacier lake mapping
- Drainage network and Length of stream d/s lake
- DEM of the basin
- Cross Section at regular interval downstream of lake
- Area and Volume of the lake
- Breach width and Depth
- 100 year return flood if available

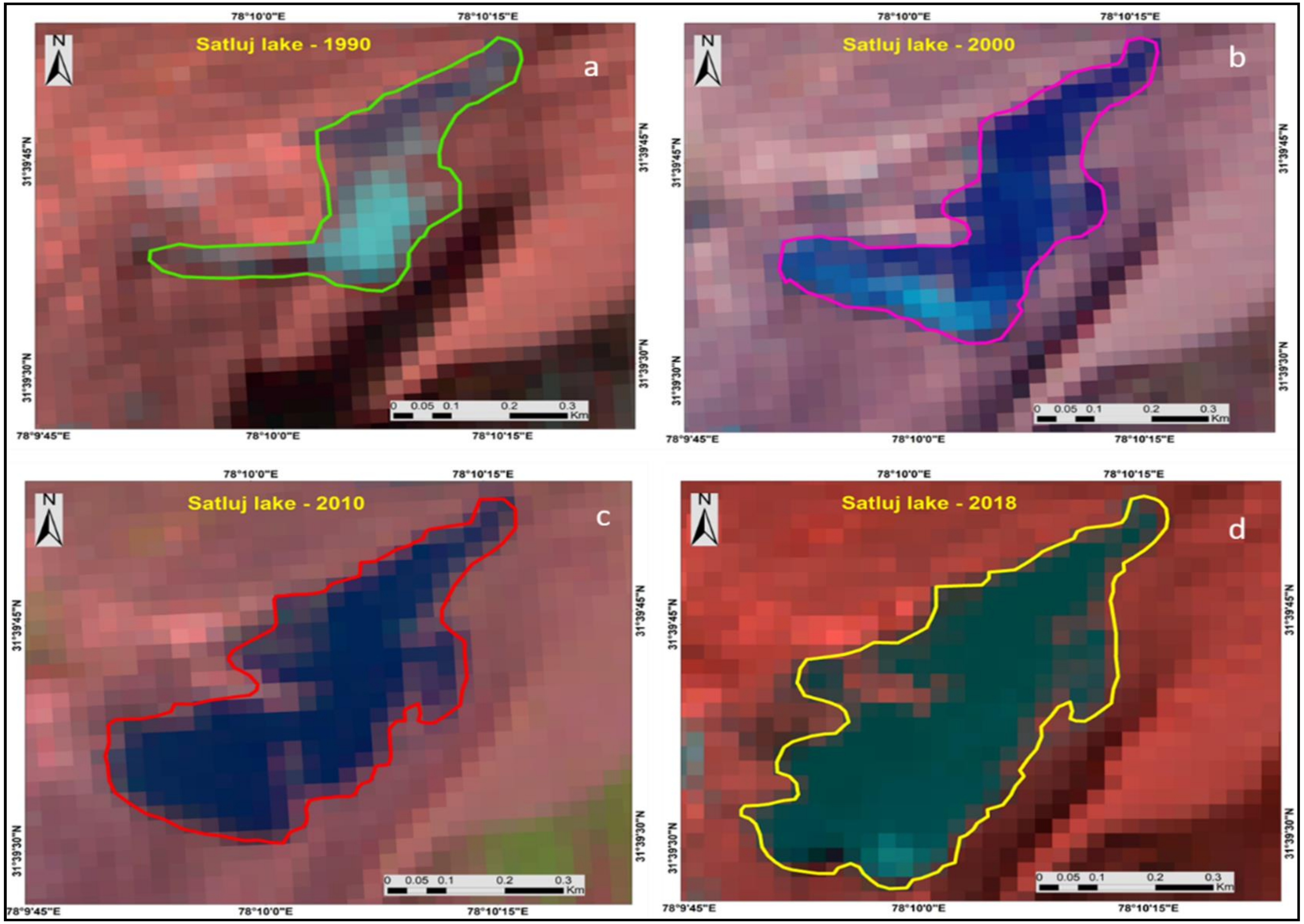
GLOF Modelling : INPUT REQUIRED

Model parameters	
Lake area	Satellite data
Volume	$V = 0.104A^{1.42}$
Depth	$D = 0.104\ A^{0.42}$
Cross sections	-
Breach invert level	2/3 of lake depth
Average breach width	$B = 0.1803\ V_w^{0.32}\ h_b^{0.19}$
Time of failure	$t_f = 0.00254\ V_w^{0.53}\ h_b^{-0.90}$
Time step for dam break simulations	0.5 to 5 minutes
Breach widths	Florich Formula
Side slope	1H: 1V
Roughness coefficient	0.040
Breach timing of a moraine dam	30 minutes

EXPANSION OF GLACIAL LAKES IN SATLUJ BASIN

Glacial lake area changes

Year	Area (Sq.km)
1990	0.112
2000	0.146
2010	0.216
2018	0.262



GLOF Modelling –Satluj Basin

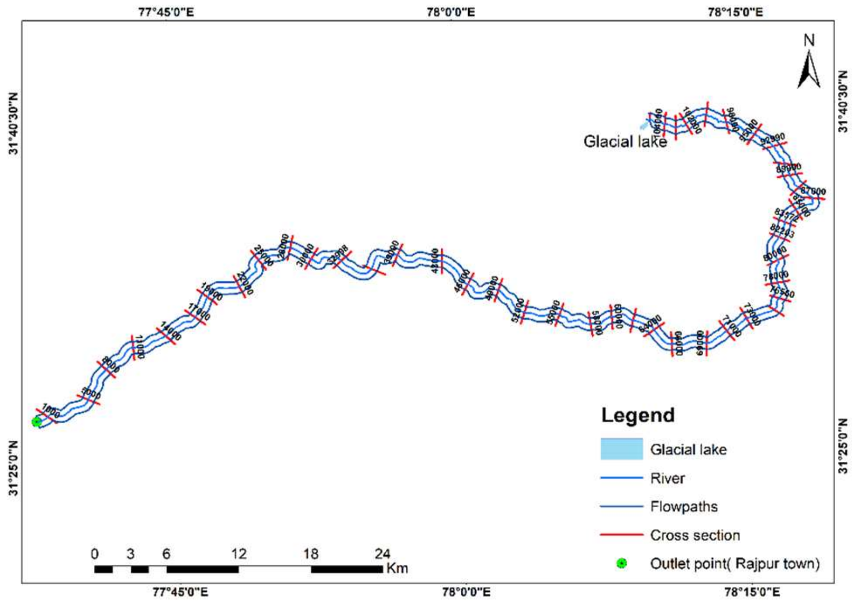
- **The total length from lake to outlet point is 102 km.**

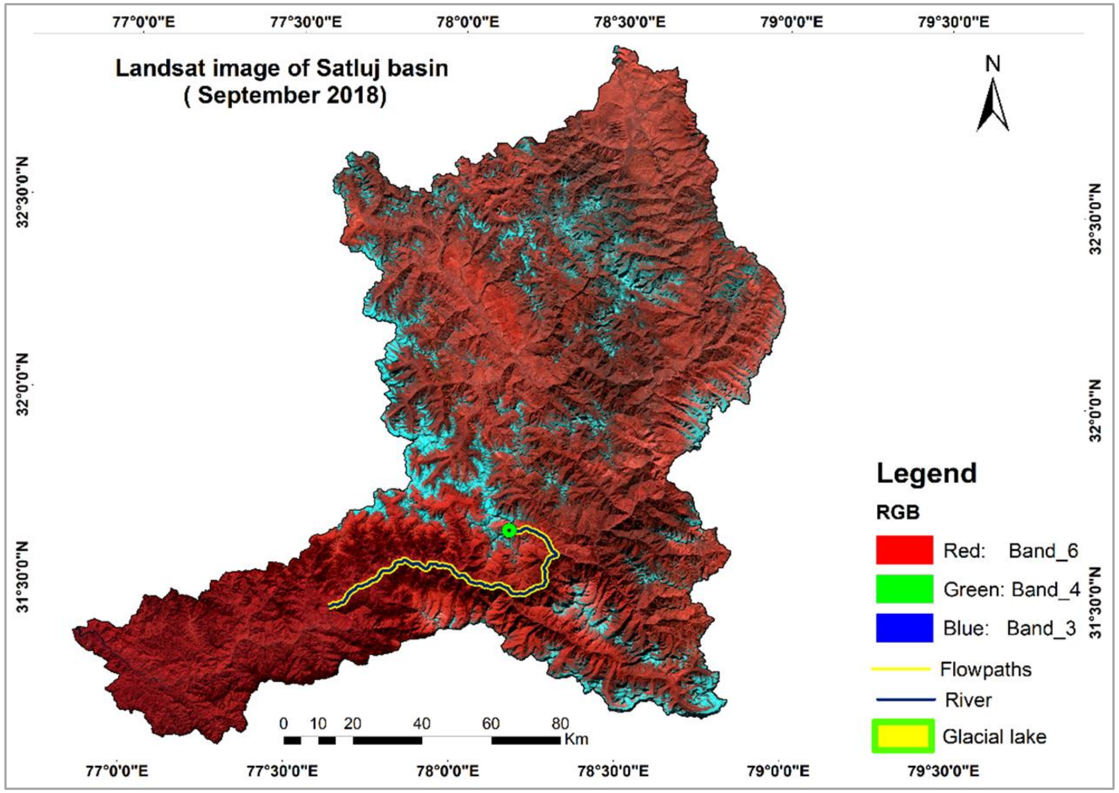
Lake Parameter	Value
Latitude	31° 39' 36.47" N
Longitude	78° 09' 59.85" E
Area (sq. km)	0.262
Depth (m)	20
Breach Width (m)	75
Volume (1000 cubic. m)	5749
Altitude (m)	4267

Calculating Volume and Depth using Huggel’s formulae:

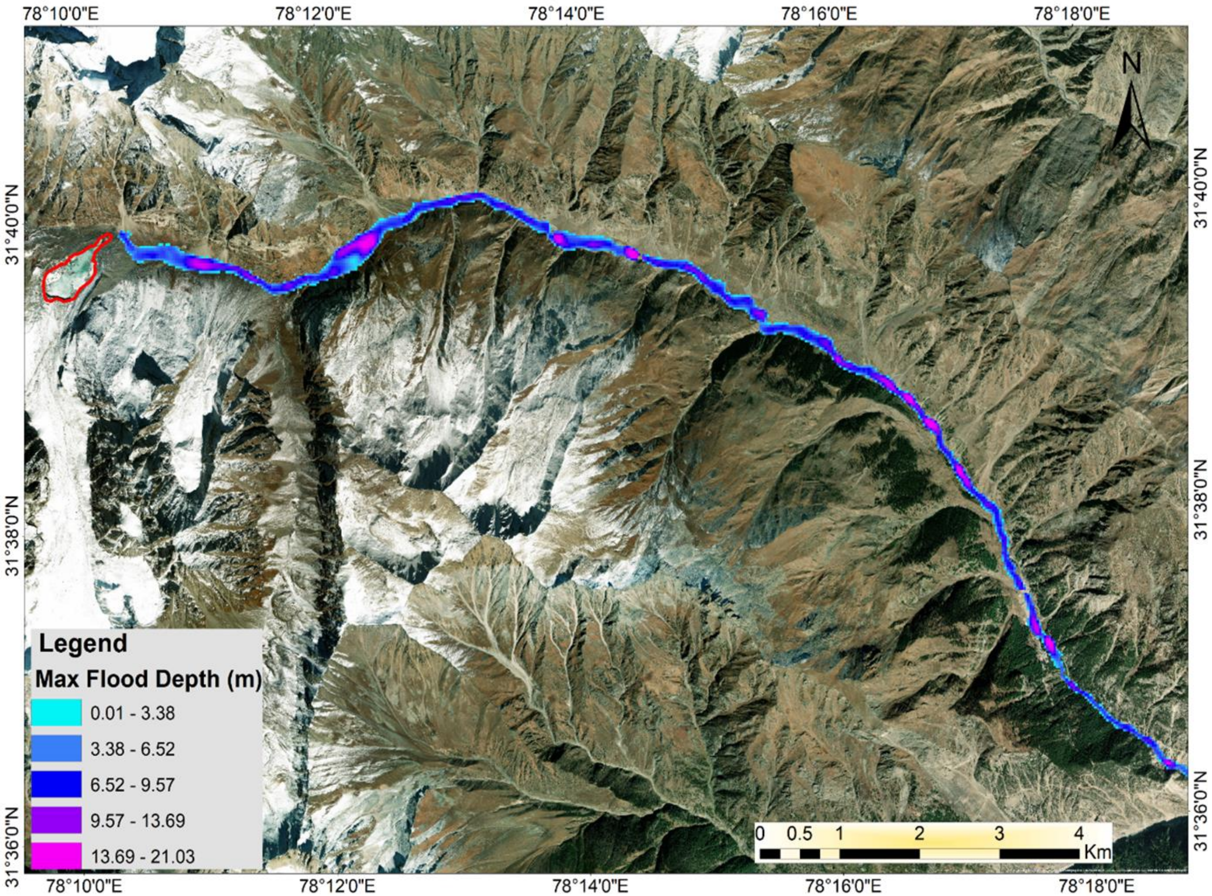
Volume= $0.104A^{1.42}$ and

D= $0.104A^{0.42}$





Inundation due to breaching of Lake



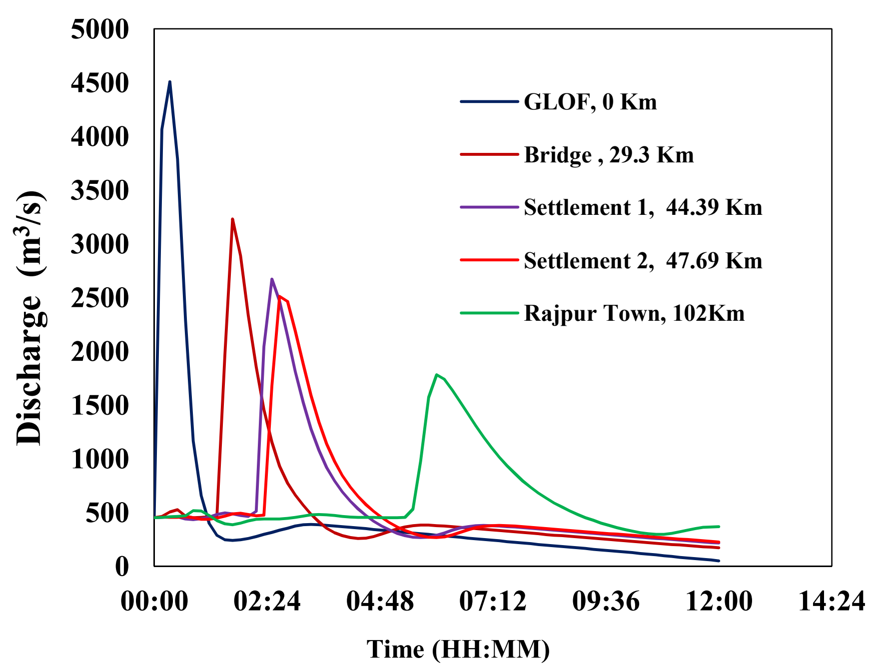
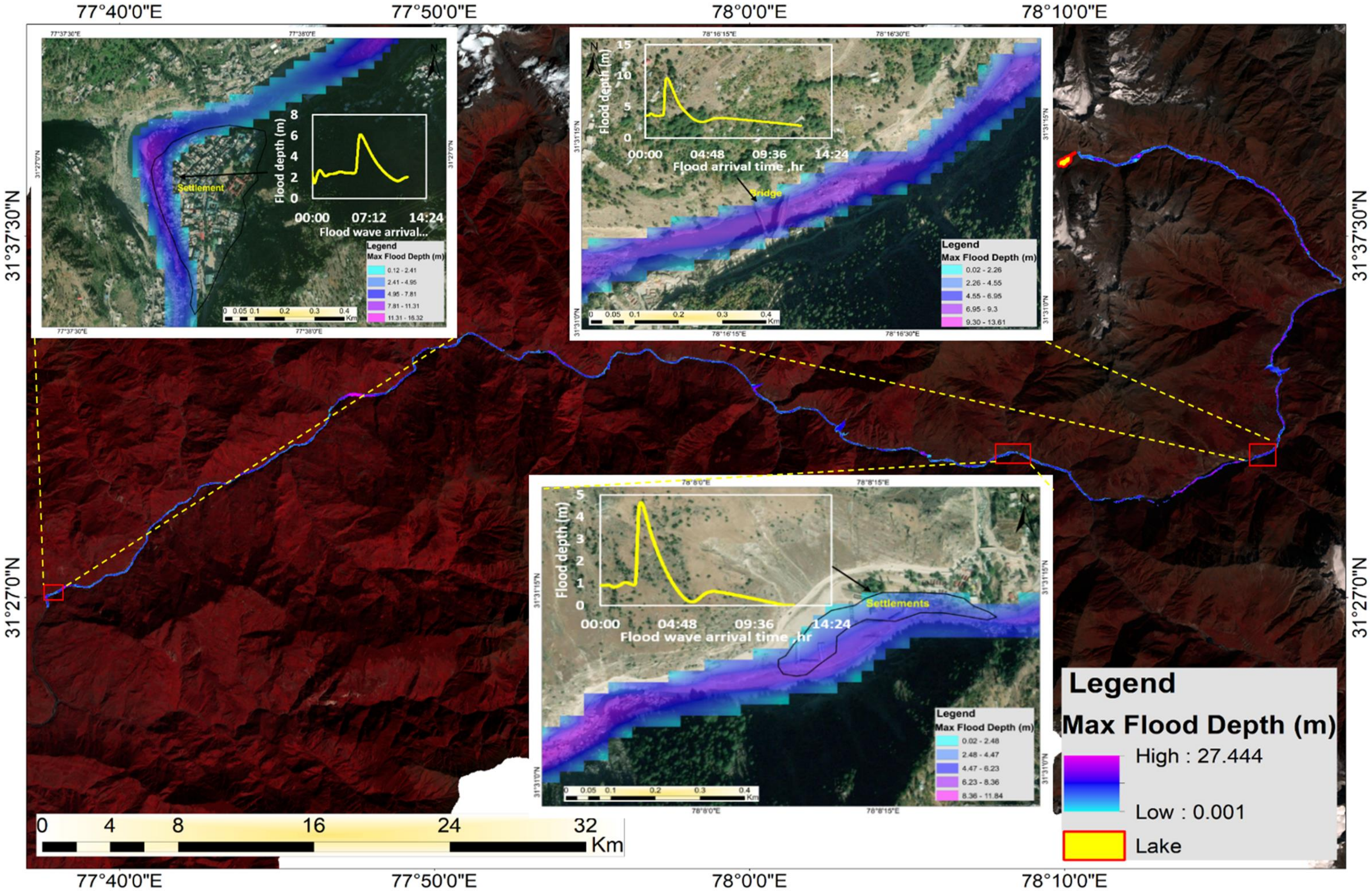


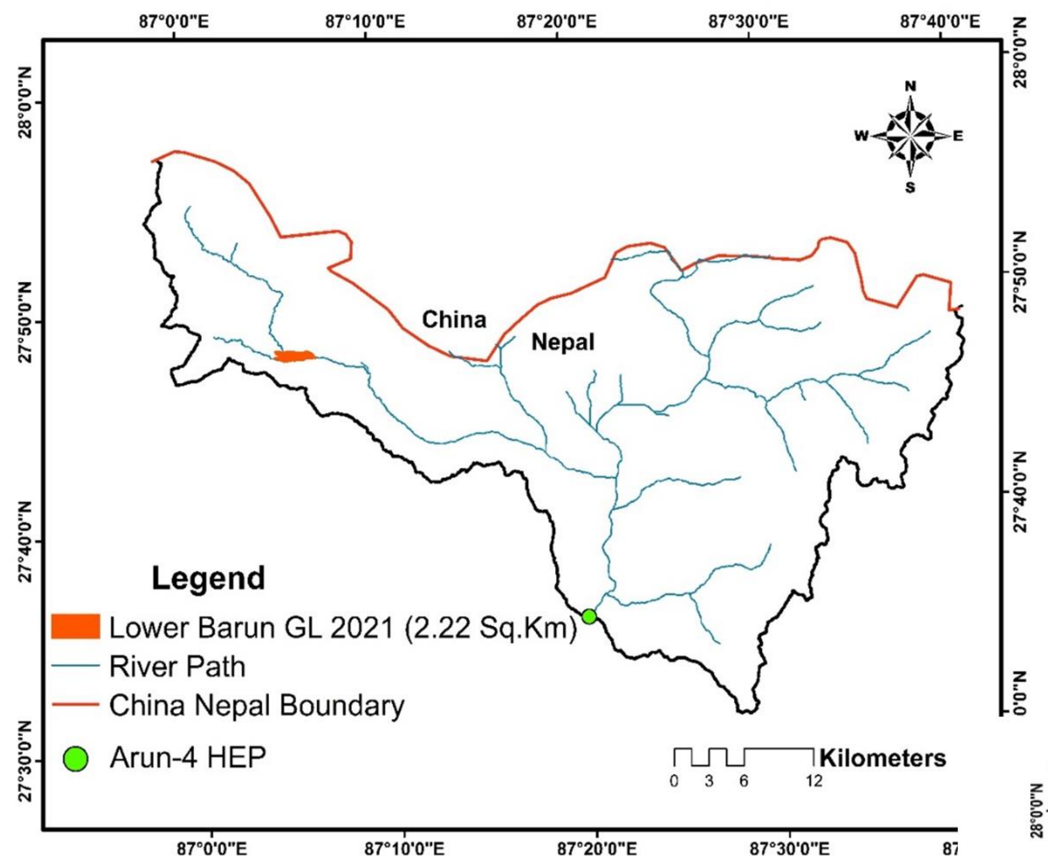
Table 1. Peak flood and time of peak at different sites along the flow routing due to GLOF

Sites	Distance from Lake (km)	Peak flood (m^3/s)	Maximum Depth (m)	Maximum Velocity (m/s)	Flood peak arrival time (HH:MM)
Just d/s of lake	0	4507.01	8.13	8.35	00:20
Bridge	29.3	3229.07	9.71	4.28	01:40
Settlement 1	44.39	2672.12	4.160	4.464	02:30
Settlement 2	47.69	2510.09	3.932	5.498	02:40
Rajpur town	102	481.05	3.320	1.525	06:05

Maximum Flood inundation map showing from glacial lake to the Outlet



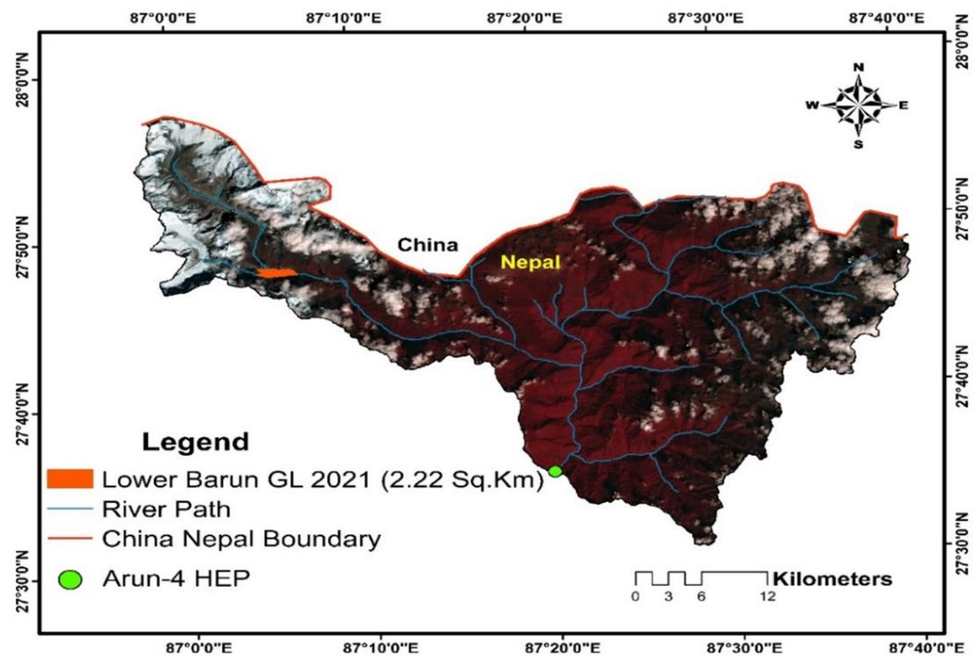
GLOF Studies for Arun Hydro Power Project

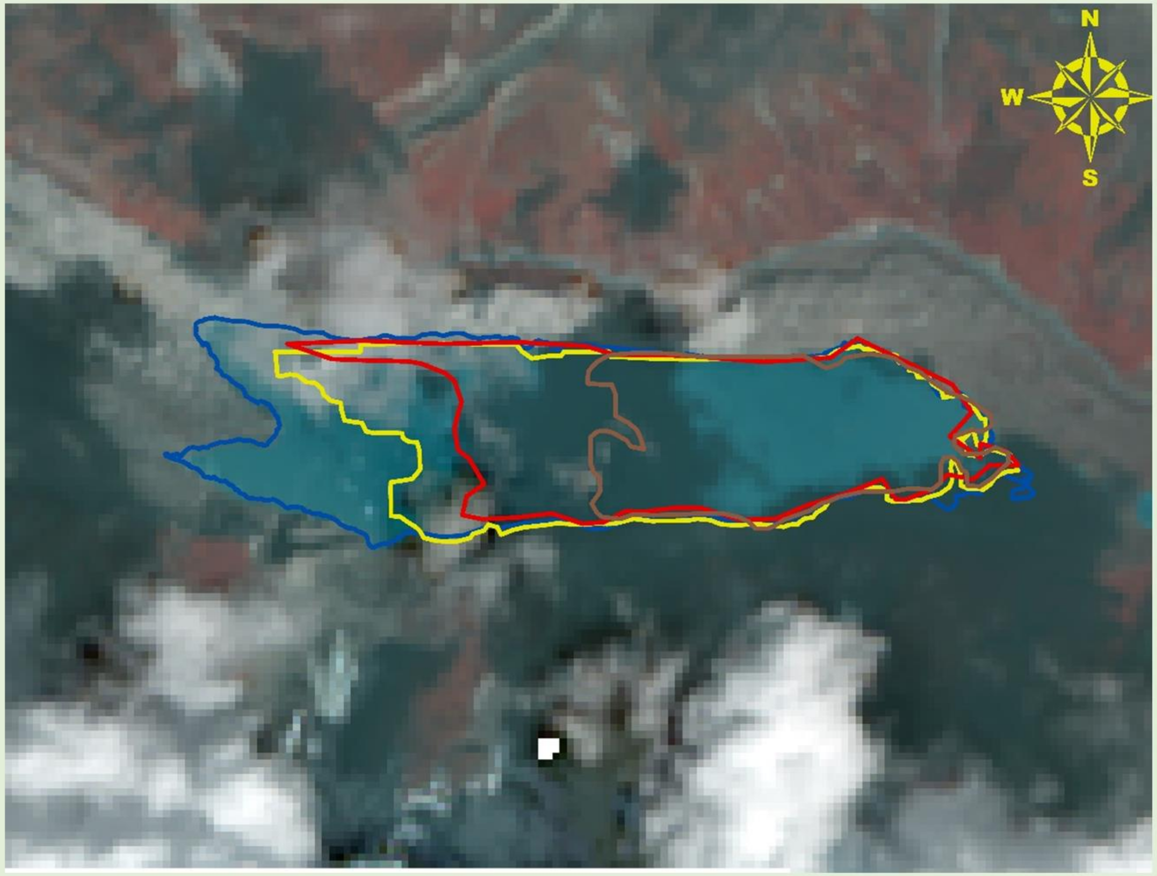


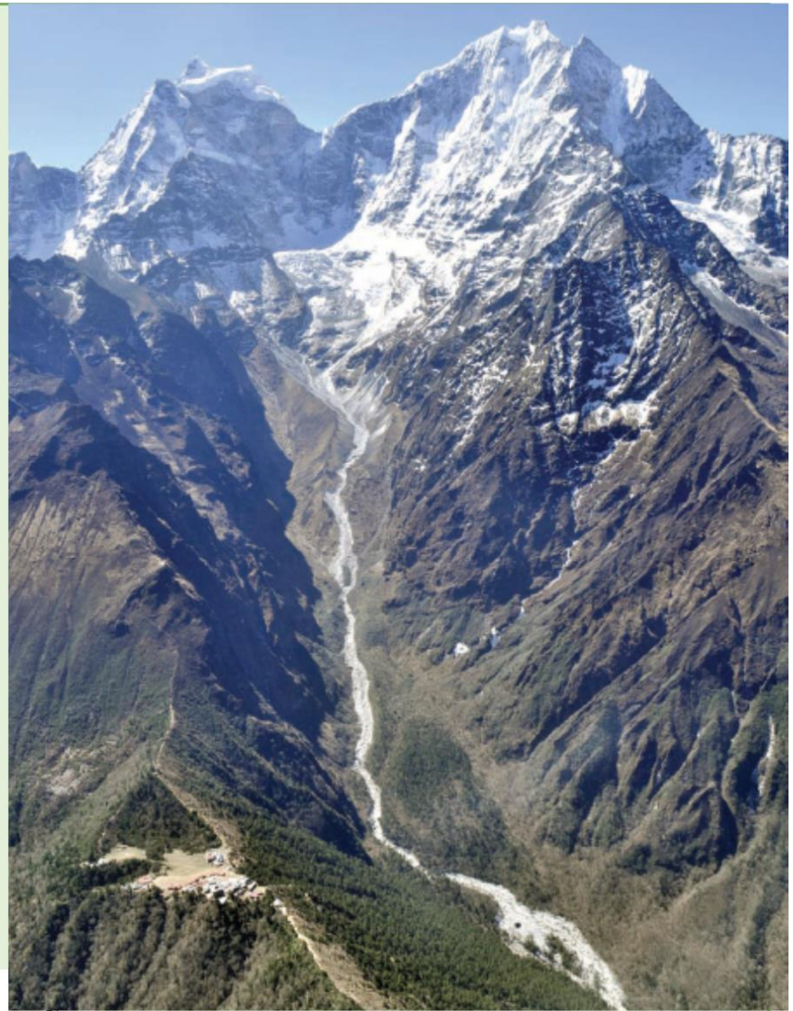
Based on the analysis of the inventory of lakes, 20 glacial lakes are identified as potentially dangerous lakes in Arun River Basin Nepal.

Out of these, there are three glacial lakes (i.e., Nagma, Tam Pokhari, and Dig Tsho) with past outburst events and 17 glacial lakes without a record of past GLOF events.

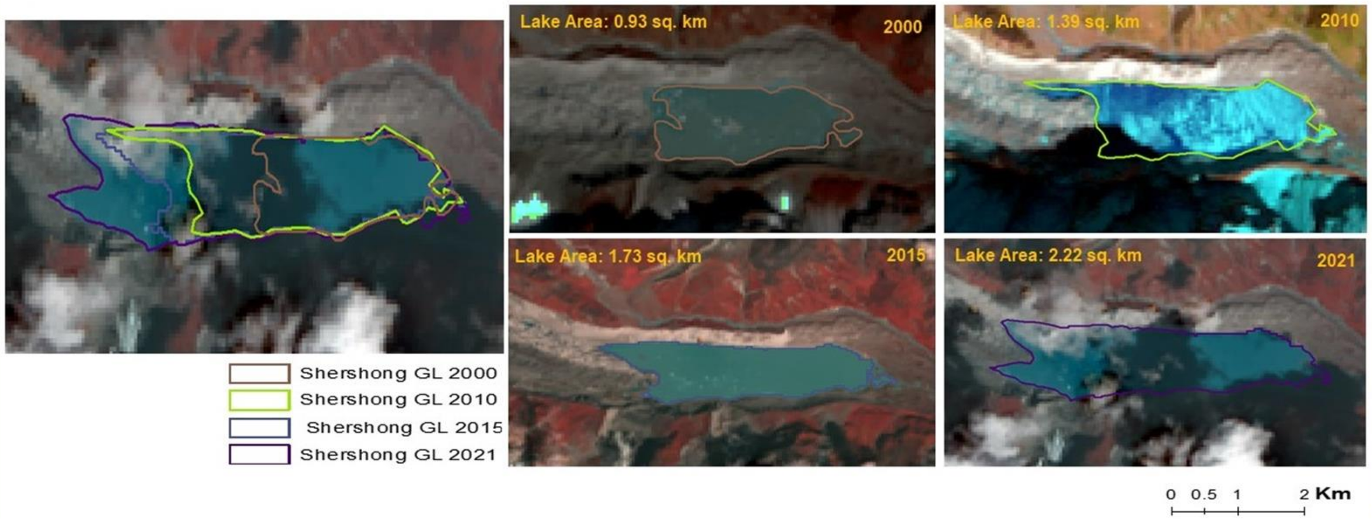
The Lower Barun Glacial Lake, at the toe of the Lower Barun Glacier is potentially dangerous lake identified in the Arun sub-basin of the Koshi River Basin in Nepal.





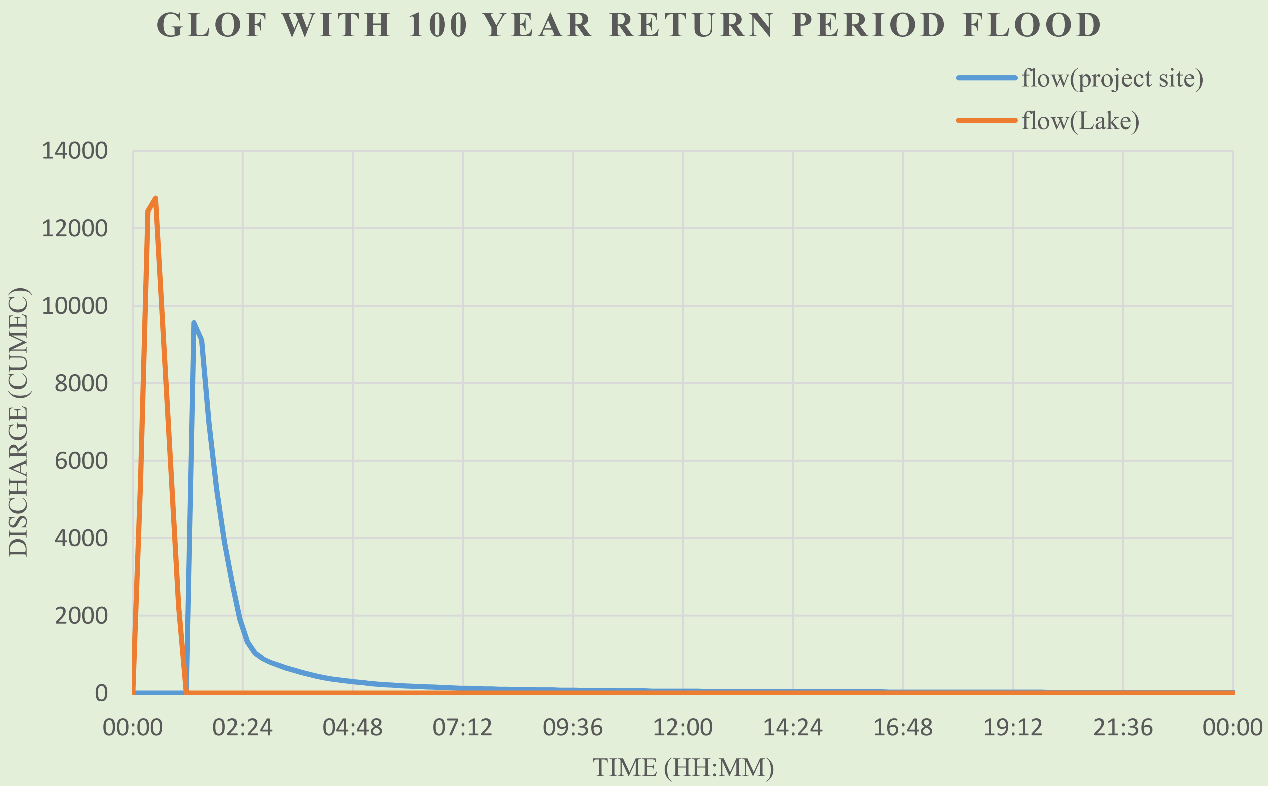


Lower Barun Glacial Lake Expansion 2000-2021

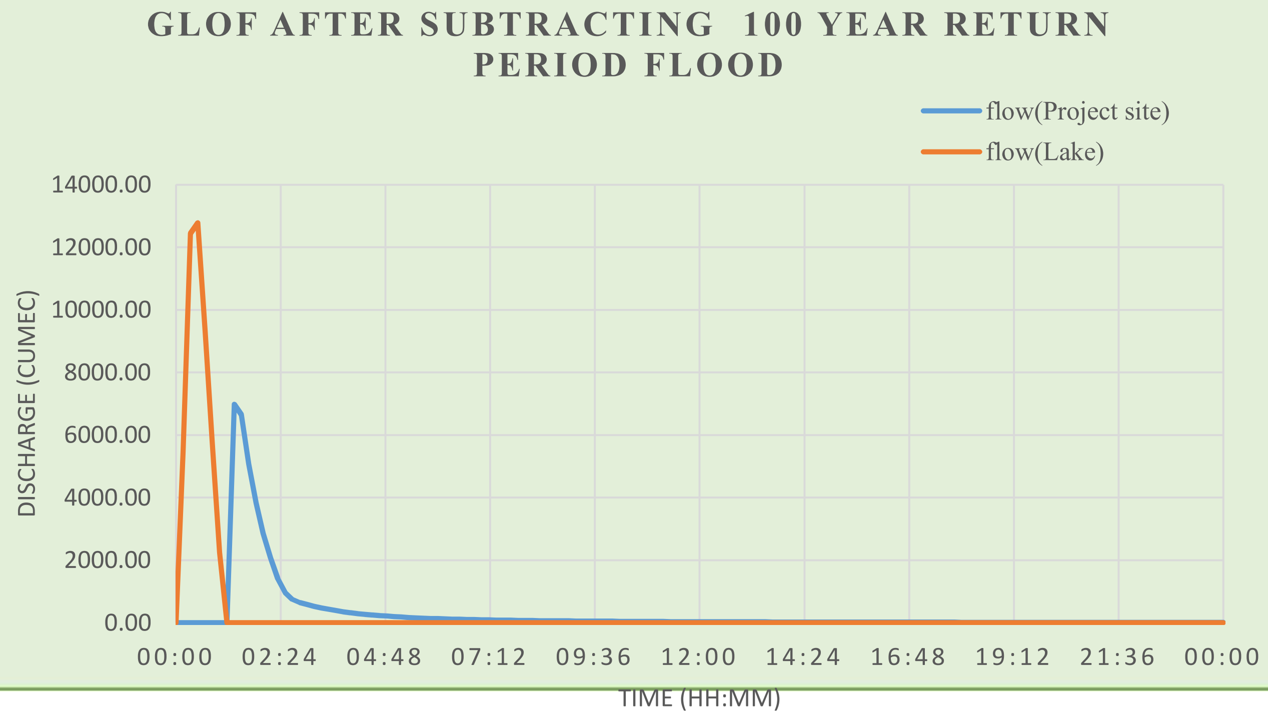


Lateral inflow considered corresponding to 100-year return period flood

Sl. No.	Location	100-year flood m^3/s	Adopted Lateral inflow m^3/s
1	1 Km downstream from lake in the river Arun	341	341
2	15 Km downstream from lake in the river Arun	910	569
3	30 Km downstream from lake in the river Arun	1861	951
4	32.5 Km downstream from lake in the river Arun	2029	168
5	40.0 Km downstream from lake in the river Arun	2295	266
6	**42.0 Km downstream from lake in the river Arun**	**2338**	**43**

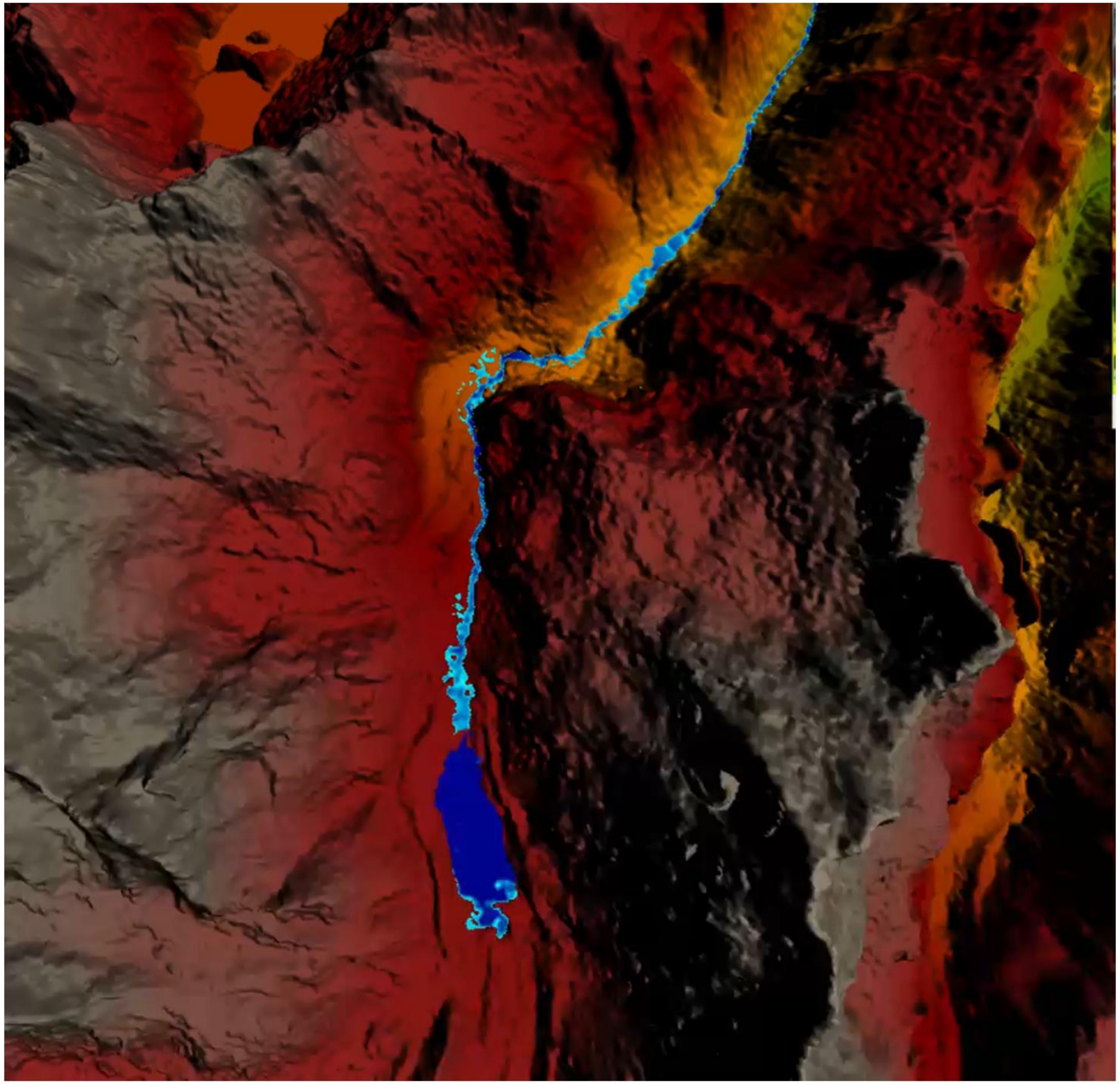


GLOF Hydrograph at lake and Outlet (with 100-year Return Period Flood).



GLOF Hydrograph at lake and Outlet (After subtracting 100-year Return Period Flood).

Shershong lake GLOF analysis(HEC-RAS 3D viewer)

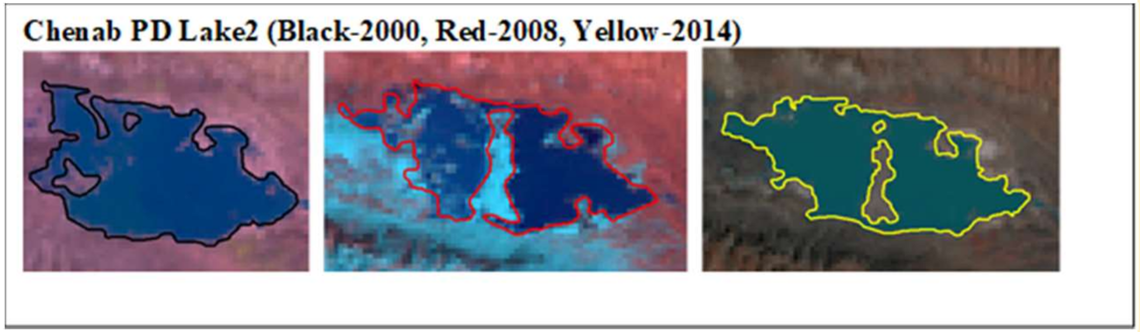


GLOF Studies for Hydro Power Projects (NIH)

For the safety of HE projects in the basin it is necessary to account for GLOF apart from design flood while fixing the spillway capacity

Studies have been carried out for vulnerable lakes in Eastern and Western Himalayas.

The flood values at lake site as well as Hydropower project sites located in the downstream areas have been computed for various projects for the use of the power companies.



GLOF studies carried out so far:

THDC

- Bokang-Bailing (UK),
- Vishnu Prayag (UK),

NHPC

- Twang (Arunachal),
- Chamkarchu (Bhutan),
- Kuri- Gongri (Bhutan)

SJVNL & JSW hydro Energy

- Baspa (Satluj) & Chenab

UJVNL : Maneri

Others :Lachung (Sikkim)

THANKS