CLIMATE-RESILIENT DAMS AND HYDROPOWER INFRASTRUCTURE INTEGRATING ENVIRONMENTAL SUSTAINABILITY IN PLANNING AND DEVELOPMENT

Space Technology for Structural Health Monitoring (SHM) of Dams and Hydropower in a Changing Climate

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Introduction

✓ **Dams and hydropower are essential for water supply, energy, irrigation, and flood control**

✓ **Many dams are aging and were designed for past climate conditions**

✓ **Climate change increases hydrological and environmental stresses such as:**

- Extreme rainfall and droughts
- Reservoir level fluctuations
- Temperature variations

✓ **These extremes increase risks to dam and hydropower safety**

✓ **Continuous, large-scale monitoring is therefore essential**

✓ **Earth Observation and space technologies provide:**

- Non-invasive, long-term monitoring
- Wide spatial coverage
- Frequent revisit observations

✓ **Remote and Periodic Observation**
- Satellites provide frequent, repeatable coverage over large and remote dam sites.
- Enables routine inspection of reservoir areas, and catchment zones without field visits.
- Helps prioritize on-ground inspections based on observed anomaly

✓ **Deformation Monitoring using InSAR**
- Interferometric SAR (InSAR) data to detect ground movement or dam deformation.
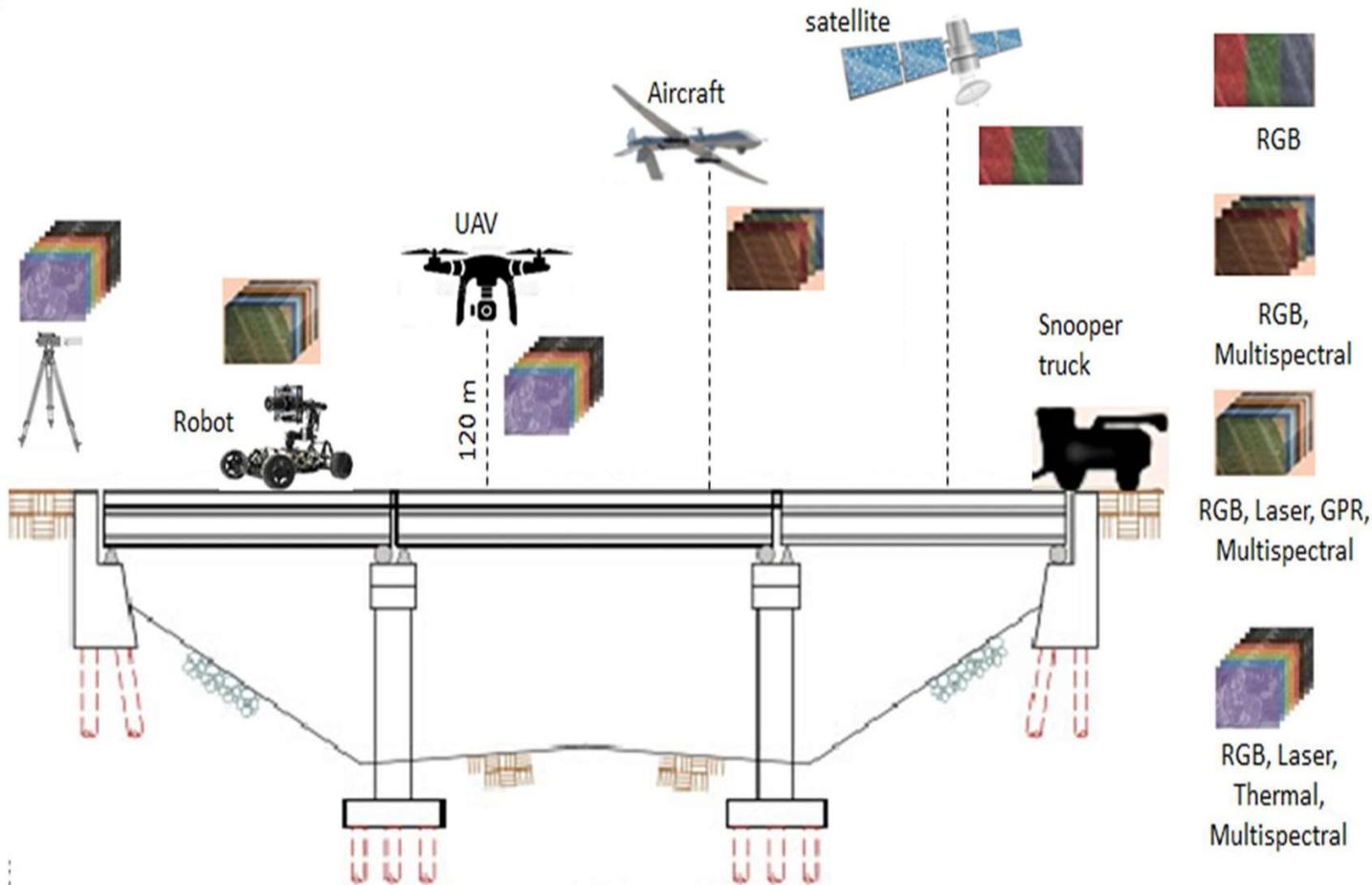- Slope stability monitoring using InSAR

✓ **Water Resources Assessment**
- Support informed decision-making for flood and drought management and surface water dynamics.

✓ **Land Use and Land Cover Change Analysis**

   Remote sensing tracks changes in land use around reservoirs and downstream areas, helping assess increased risk due to urbanization or deforestation.

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INCOLD

Source: https://doi.org/10.3390/app12136574

(i) High accuracy:
(a)Terrestrial Cameras: terrestrial cameras are mounted on a tripod and they have the capability to continuously acquire the data for longer periods. Different sensors,such as visible range (RGB), laser, thermal and multispectral can be mounted on the same data acquisition platform. Terrestrial cameras and laser scanners to produce 3D models through point clouds can be operated even in varied climatic conditions.

(b) Robot: Robotics can be operated directly on top of the bridge deck to produce high resolution data sets using sensors, such as RGB, laser, ground penetrating radar (GPR) and multispectral. GPR has a unique capability in exploring the internal core condition of the RCC bridge deck to inspect the further serviceability of the structure.

(c) Unmanned Aerial Vehicle (UAV): UAV/drone operational altitude is low and restricted to height of 400 ft (120 m) as per the guidelines issued by the Director General of Civil Aviation (DGCA), so it can be operated very near to the target object. UAV can acquire high resolution digital, multispectral and thermal imaging datasets along with laser point cloud data to inspect the bridge.

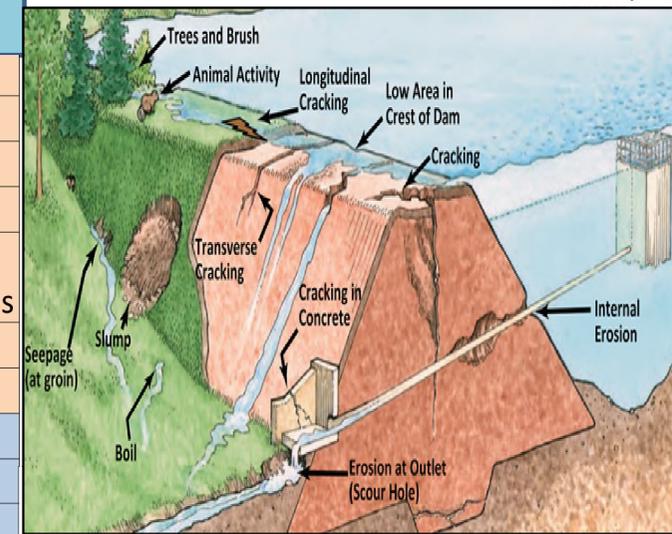**Climate-Resilient Dams and Hydropower Infrastructure: Integrating Environmental Sustainability in Planning and Development**

Dam Distress Influencing Parameters in different types of Dams

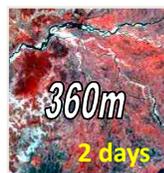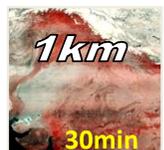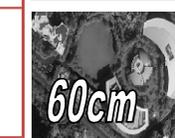| Dam type	Dam Distress Influencing Parameters
Earthen Dam	• Settlement of foundation soil
	• Seepage and internal erosion (piping)
	• Slope instability or sliding (especially during rapid drawdown)
	• Differential settlement causing cracks
	• Upstream/downstream movement due to water level changes or earthquakes
	• Temperature and moisture variations in core materials
	• Poor compaction or construction defects
Concrete Gravity Dam	• Temperature variations (thermal expansion/contraction)
	• Hydrostatic pressure changes with reservoir level
	• Foundation settlement or uplift pressure
	• Creep and shrinkage of concrete
	• Seismic forces (earthquakes)
	• Alkali-aggregate reaction (chemical expansion in concrete)
	• Weak or eroded foundation rock
Arch Dam	• Temperature effects (thermal expansion/contraction)
	• Variation in water pressure (reservoir load)
	• Foundation or abutment movement
	• Seismic activity causing vibrations or cracking
	• Creep of concrete under sustained stress
	• Abutment weakening or rock fracturing

Embankment Dams
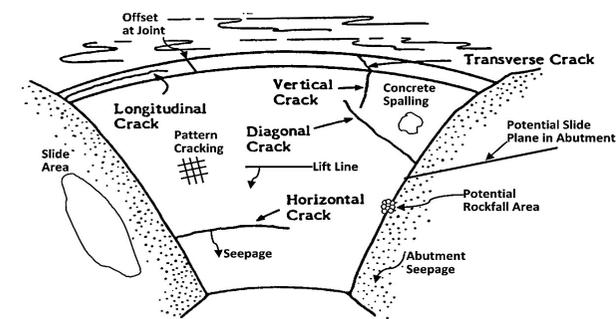
Concrete & Stone Masonry Dams

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Earth Observation Satellites

(1988-2022)

High Resolution	Medium Resolution	Coarse Resolution
Cartosat-3 (0.3m B & W and 1.1m MX)	Resourcesat-1,2 ,2A (LISS-3 23.5m)	Resourcesat-1,2 ,2A (AWiFS 58m)
Cartosat-2s (0.6m B & W and 1.6m MX)	IRS 1C,1D, Resourcesat-1,2,2A (LISS-3 23.5m)	Oceansat-1 & 2 (OCM 360m)
Cartosat-2 (1m B&W)	IRS-1A,1B (LISS-1 72.5m) IRS-1A,1B (LISS-2 36.25m)	IRS-1C,1D (WiFS 188m)
Cartosat-1 (2.5m B&W)	LANDSAT (TM 30m and MSS 80m)	MODIS (AQUA/TERRA)
IRS 1C,1D PAN (5.8m B&W)		NOAA (AVHRR – 1Km)
Resourcesat-1,2,2A (LISS-4MX 5.8m)		

Left margin labels: 1 km / 30min, 360m / 2 days, 188m / 5 days, 72m / 22 days, 55m / 5 days

Right margin labels: 23m, 5.8m, 2.5m, 1m, 60cm

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Geo-Platforms

http://www.bhuvan.nrsc.gov.in

Water Services in Bhuvan :
TWRIS , WBIS, BHUVAN GANGA, Sat-AIBP , Near Real Time hydrological Modeling etc

Multi-sensor, Multi-platform and Multi-temporal satellite imageries , Varieties of thematic maps, Geo Spatial applications for Central and State Governments Departments, Academia and Industry

http://www.mosdac.gov.in

Data related to missions :
SCATSAT-1, INSAT-3DR, INSAT3D, KALPANA-1, INSAT3A, Megha Tropiques, SARAL-AltiKa, Oceansat-2

**Geophysical parameters (for Hydrological Models)**

Satellite based Meteorological & Ocean standard and geophysical products, In-situ data, Weather forecasts data, Cyclone Predictions

https://bhoonidhi.nrsc.gov.in/

Data available on Bhoonidhi:
IRS,CARTOSAT, Landsat 8 Sentinel 1 Sentinel 2 OceanSat 2 etc….

One stop hub which facilitates the dissemination of coarse and medium resolution satellite data products, Data from IRS and NON-IRS sensors

https://vedas.sac.gov.in

Applications on Vedas:
Earth observations , Vegetation and crop monitoring, Snow Cover ,monitoring , Hydrological Science and its applications

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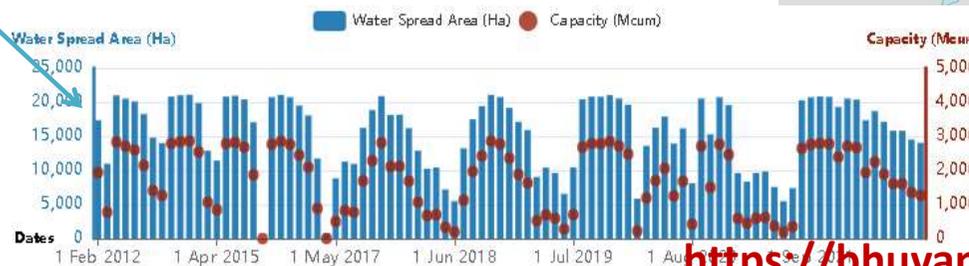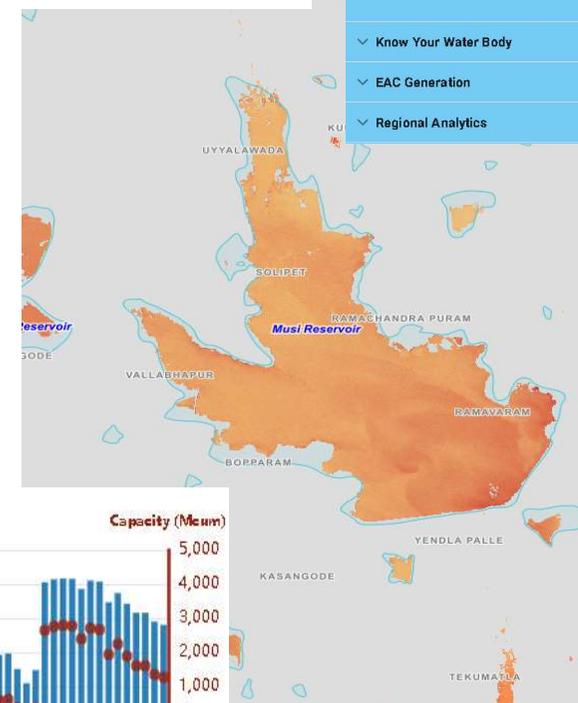
Water Bodies Information System (WBIS)

- Water Bodies Information System (WBIS) provides a dynamic data visualization and helps in analysis surface **water spread information** of water-bodies **from year 2012**.
- Water quality indices such as NDCI and NDTI are generated and monthly composites are made available as spatial layers.
- Elevation-Area-Capacity generation, regional analytics & water spread meter tools are also available to understand the dynamics in water spread changes for all waterbodies at different scales.
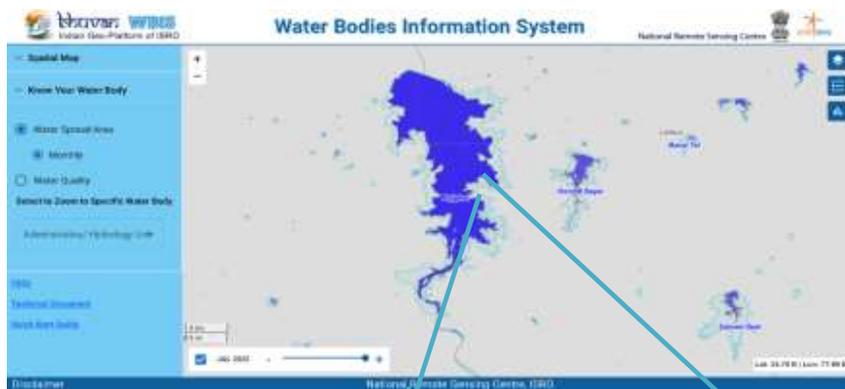
Water bodies	No. of water bodies
> 50 ha	12,831
5- 50 ha	1,25,450
2-5 ha	86,508
1-2 ha	1,57,389
<1 ha	12,51,418+

Size wise statistics of water-bodies over entire India

https://bhuvan-wbis.nrsc.gov.in/

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Water Bodies Information System (WBIS)

S. No.	Water body size	Sensor	Satellite	Monitoring frequency* (Once in)	Data Availability Period^
1	> 50 ha	AWiFS	Resourcesat2/2A	5 days	Since Oct 2012
		LISS-III		23 days	Since Oct 2012
		C-Band SAR	Sentinel-1	12 days	Since June 2017
		C-Band SAR	RISAT	13 days (CRS mode) & 25 days (MRS mode)	Jul 2014 - Sep 2016
		OLI	Landsat-8	16 days	2018-2020
		MSI	Sentinel-2	5 days	Since Feb 2022
2	> 5 ha	LISS-III	Resourcesat2/2A	23 days	Since Oct 2012
		C-Band SAR	Sentinel-1	12 days	Since June 2017
		C-Band SAR	RISAT	25 days	Jul 2014 - Sep 2016
		OLI	Landsat-8	16 days	2018-2020
		MSI	Sentinel-2	5 days	Since Feb 2022
3	> 2 ha	LISS-III	Resourcesat2/2A	23 days	Since Oct 2012
		OLI	Landsat-8	16 days	2018-2020
		MSI	Sentinel-2	5 days	Since Feb 2022
4	>1 ha	MSI	Sentinel-2	5 days	Since Feb 2022

Application	Description
Reservoir sedimentation analysis	Use of surface water spread area of reservoirs in carrying out reservoir sedimentation studies
Fisheries Development	Identification of sustainable water bodies and monitoring of eutrophication levels
Urban Applications	Identification and prioritization of water bodies for restoration
Water bodies sustainability analysis	Seasonal water spread sustainability for planning developmental activities
Hydrological Drought Assessment	Water spread area is a very good indicator of hydrological drought

Feb 2022

Spatio-Temporal variability in Chlorophyll in water bodies are captured using indices such as Normalized Difference Chlorophyll Index (NDCI) in Kolleru Lake
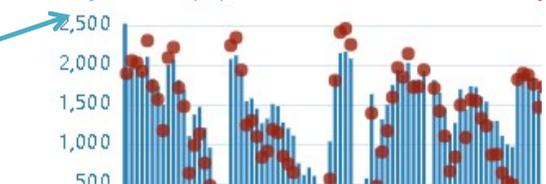
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Surface Water Spread Dynamics
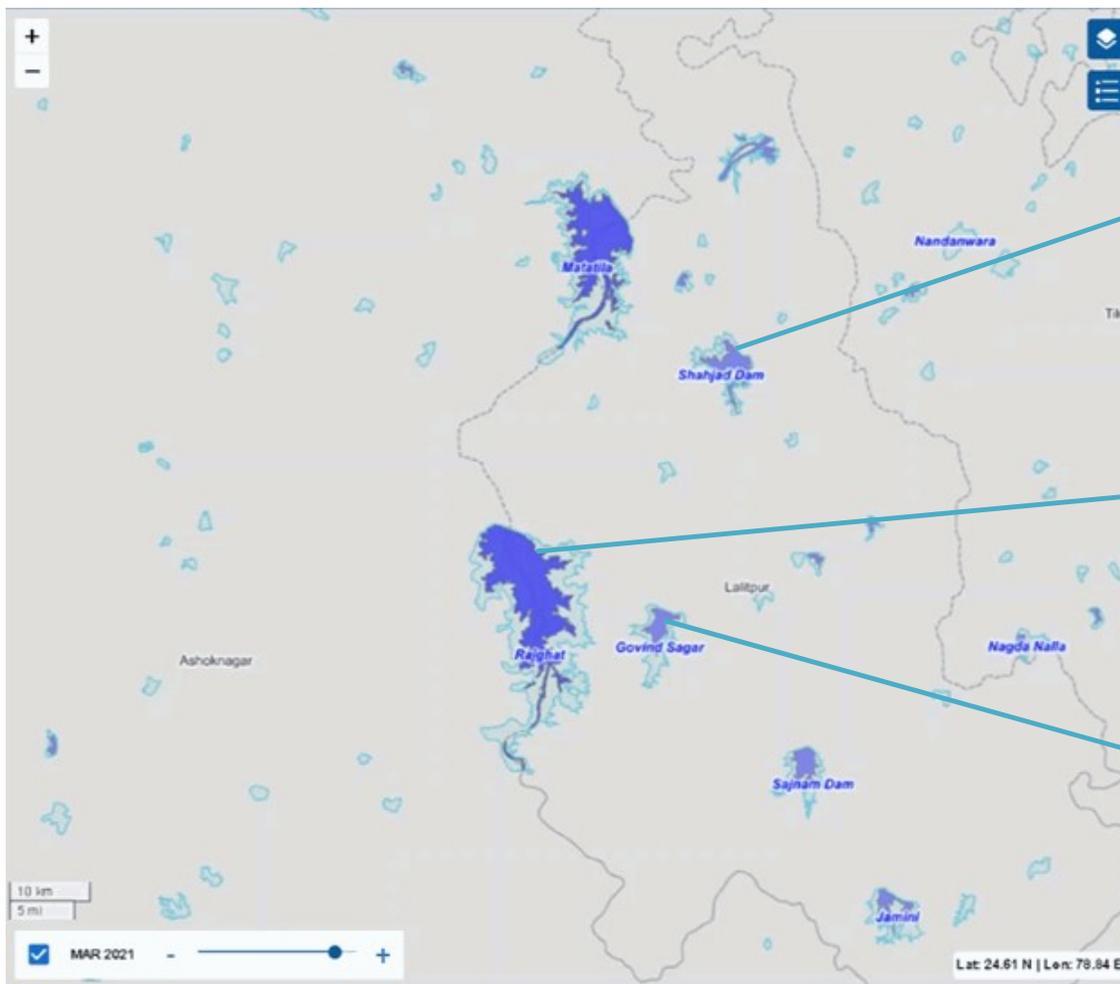
https://bhuvan-wbis.nrsc.gov.in/

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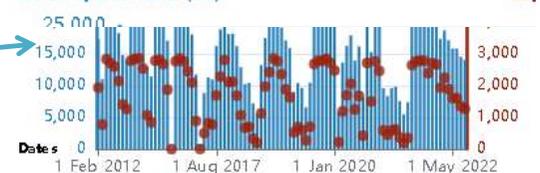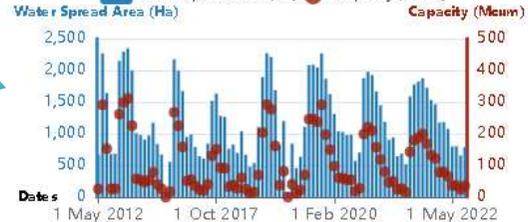
Using UAV Technology

1)Structural health monitoring and inspection of dams based on UAV photogrammetry with image 3D reconstruction Sizeng Zhao a, Fei Kang a,**, Junjie Li a,b,*, Chuanbo Ma c a *School of Hydraulic Engineering, Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian*
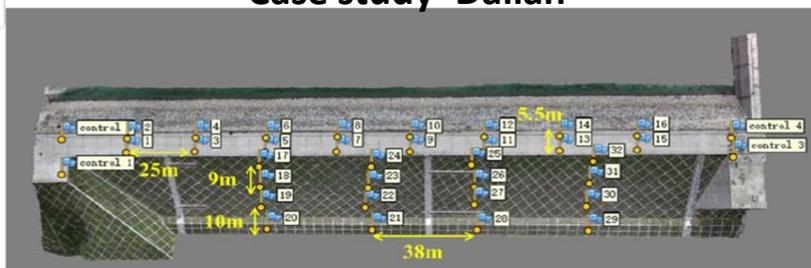
Case study -Dalian

Fig. 7. 3D model and GCP distribution on sand-gravel fill dam. Points No. 1 to No. 16 are placed on the dam crest, points No. 17 to No. 32 are placed on the dam downstream surface, points control 1 to control 4 are placed on the edge of dam crest.
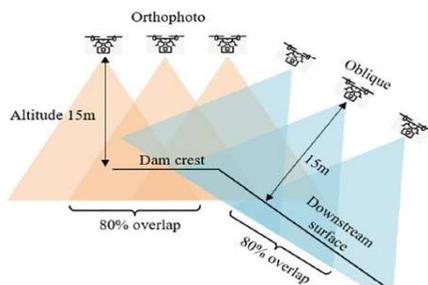

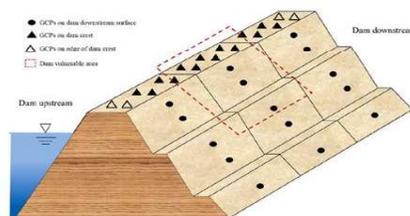**Fig. 3.** The aerial photography altitude and route of the dam using UAV.

Fig. 4. GCP distribution on dam and vulnerable area: ● represents the GCP arranged on the dam downstream, which are hard to measure for concrete dams; ▲ represents the GCPs arranged on the dam crest, which are convenient for placement and measurement on most types of dams; △ represents the GCP arranged on the edges of dam crest, which usually would not move even if the dam is damaged.
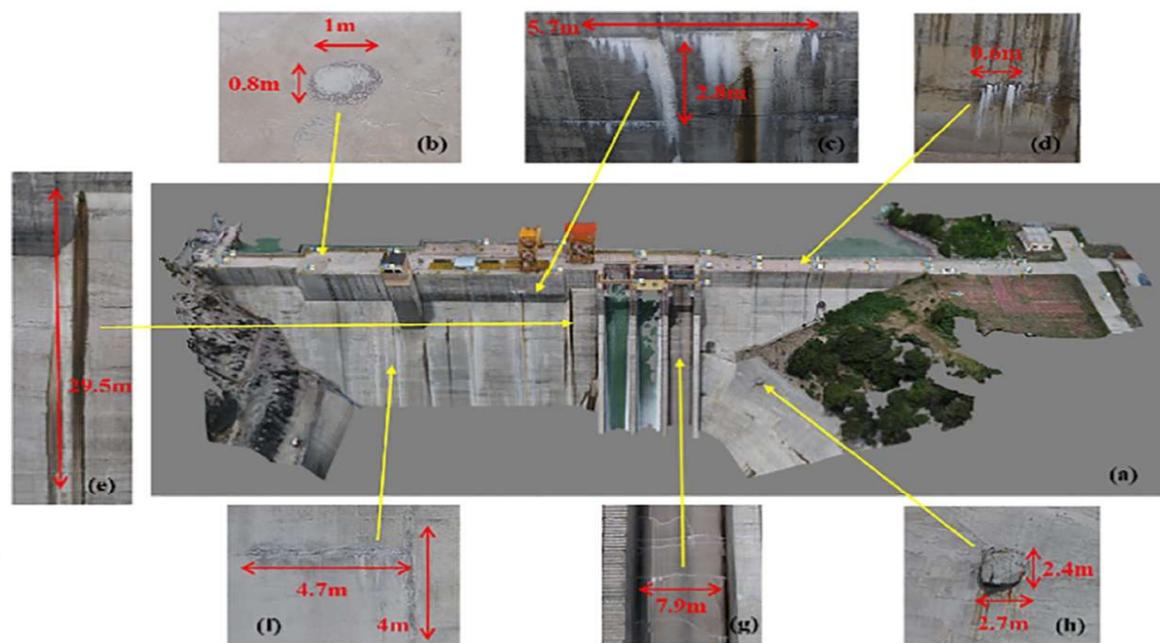

Fig. 23. Dam model and several different measured damages: (a) dam 3D model with GCPs; (b) collapse on dam crest; (c) calcified precipitate on downstream surface; (d) calcified precipitate on upstream surface; (e) penetration and water stains on downstream surface; (f) crack on downstream surface; (g) crack on spillway surface; (h) concrete block on slope protection.

Source: https://doi.org/10.1016/j.autcon.2021.103832

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Dam Deformation Studies using Interferometry

Case studies using Interferometry :

- SAR interferometry is a imaging technique in which two or more SAR images over same region is used to examine surface motion and surface topography.

- **SBAS:** SBAS technique is used to detect and monitor surface deformations over time, particularly for studying slow-moving ground movements, such as subsidence, landslides or structural deformation.

- **PSI:** PSI, or PSInSAR, focuses on persistent scatterers (PS). These are pixels in SAR images that maintain a strong and stable reflection over a long period. They act as reliable point targets for deformation measurement.

SBAS Technique

Aswan High dam in Egypt (Earthern dam) and Benínar,La Viñuela (concrete *dam)*
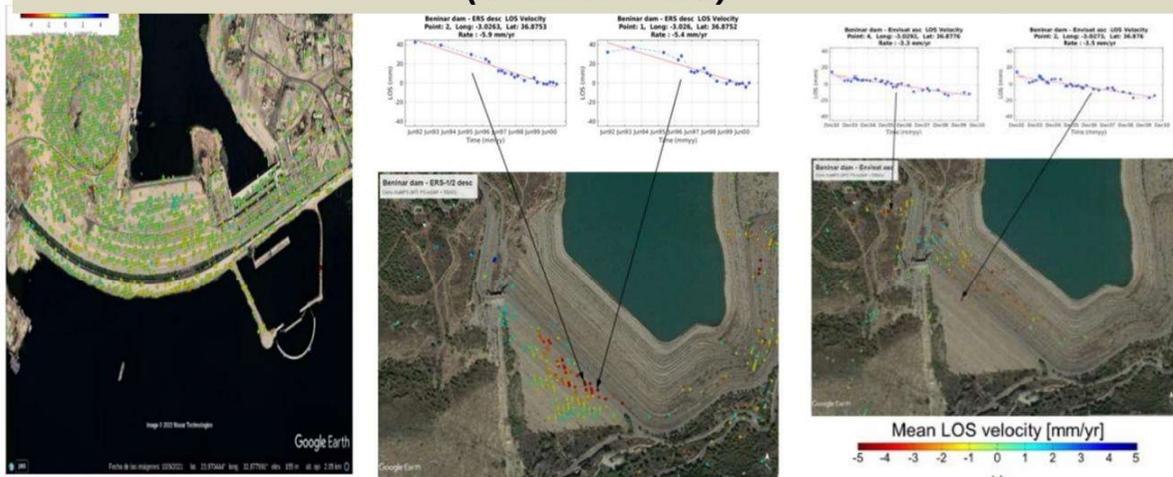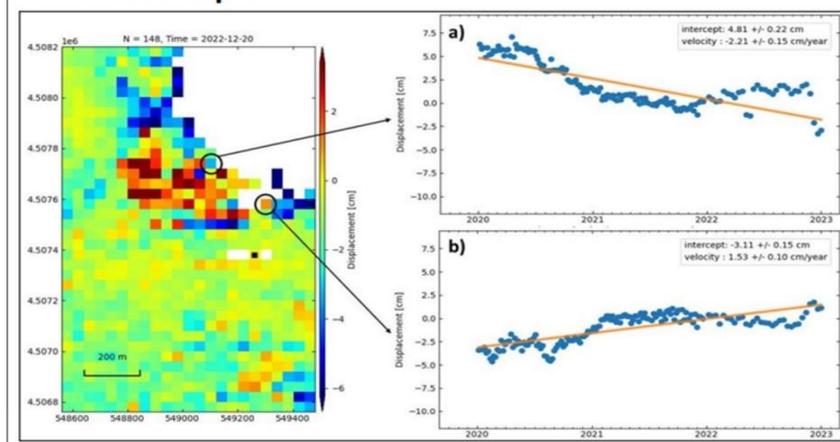

Figure 4. Mean LOS velocity derived from Sentinel-1A/B ascending data over The Aswan High dam (2015-2021).
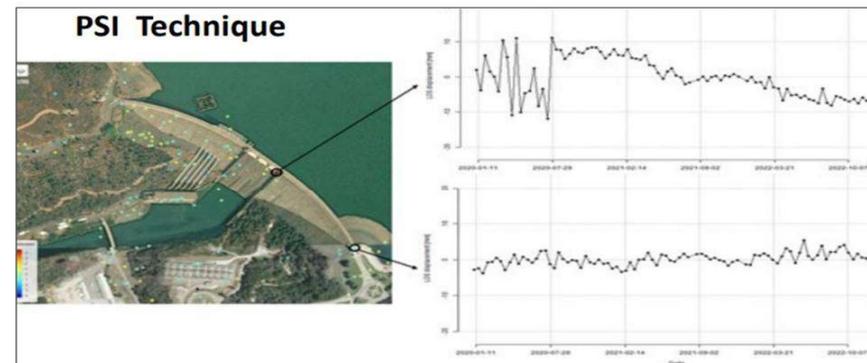
Mean LOS velocity [mm/yr]
-5 -4 -3 -2 -1 0 1 2 3 4 5

Figure 5. Mean LOS velocity maps over the Benínar dam: a) ERS-1/2 desc (1992-2000); b) Envisat asc (2000-2010).

Mean LOS velocity [mm/yr]
-5 -4 -3 -2 -1 0 1 2 3 4 5
b)

PSI Technique

Study Area: Shasta Dam in California, Northern California, USA (Concrete arch-gravity dam)

Source: Antonio Miguel Ruiz-Armenteros et al.   Source : https://doi.org/10.1109/IGARSS.2018.8517276   Source: Rejoice Thomas et al.

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Hydrological Disaster Support

- ✓ **Hazard & risk assessment (Flood, GLOF …)**
- ✓ **Hydrological forecasting and modelling**
- ✓ **Mitigation Planning**
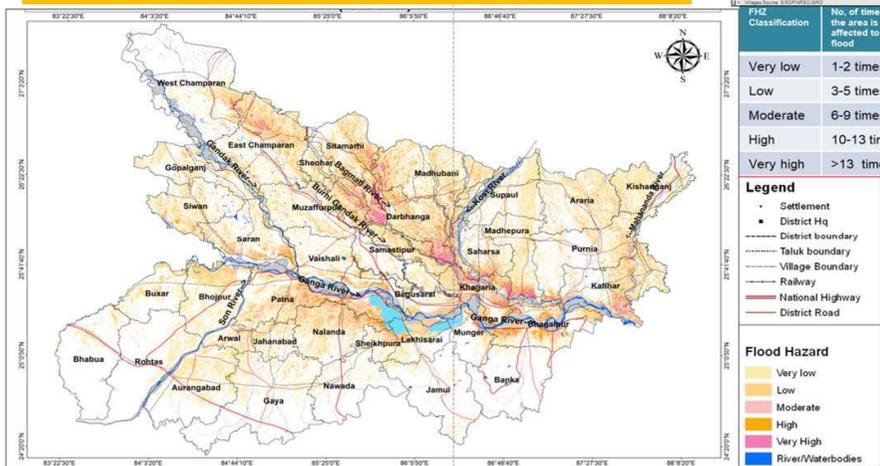- ✓ **National Database for Emergency Management**

Spatial Flood Early Warning - Godavari
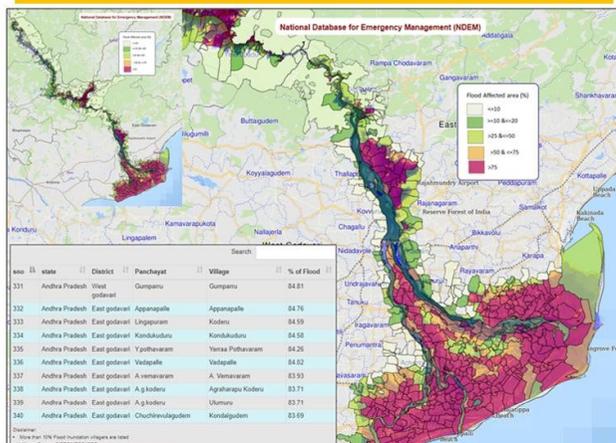
UTILISATION/END USE

Flood Forecast Hydrograph and Flood Inundation is disseminated through Bhuvan NHP and NDEM portals and Alerts were given to Central and State Disaster Management Authority with two days forecast during monsoon season.
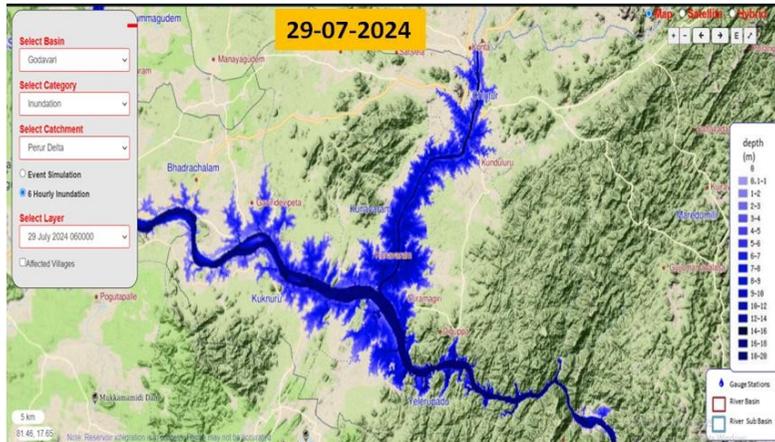
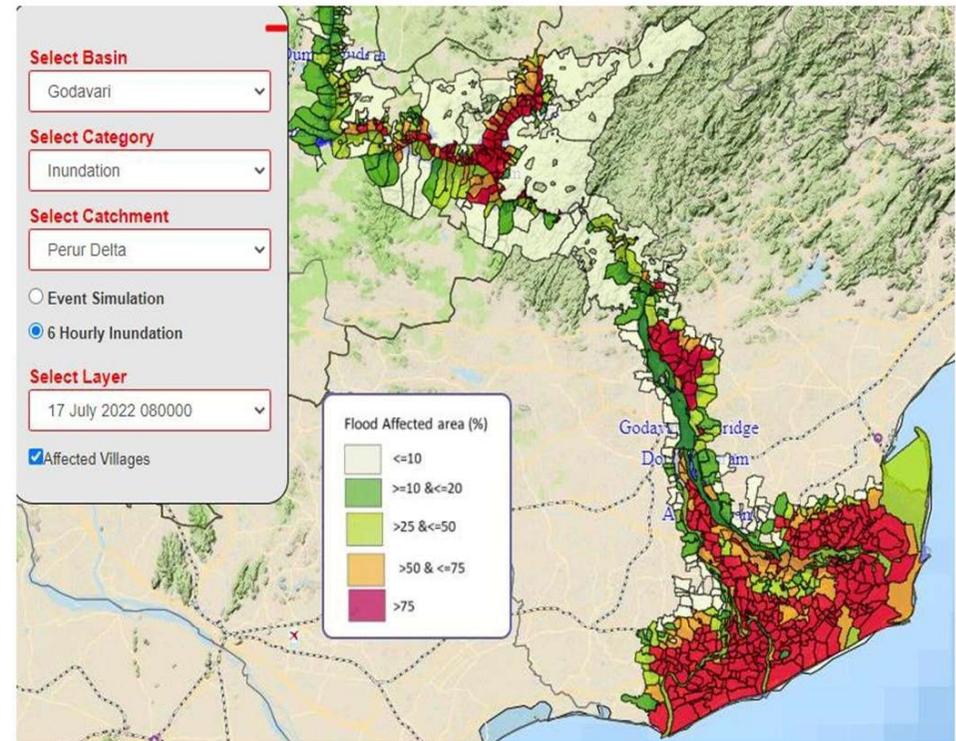## Flood hazard Zonation – Bihar State

FHZ Classification	No. of times the area is affected to flood
Very low	1-2 times
Low	3-5 times
Moderate	6-9 times
High	10-13 times
Very high	>13 times

Legend
- ■ Settlement
- ■ District Hq
- District boundary
- Taluk boundary
- Village Boundary
- Railway
- National Highway
- District Road

Flood Hazard
- Very low
- Low
- Moderate
- High
- Very High
- River/Waterbodies

National database for Emergency Management (NDEM)

https://ndem.nrsc.gov.in/#/

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Spatial Flood Early Warning System Development for Godavari & Tapi Basins

29-07-2024

50 yrs Return flood
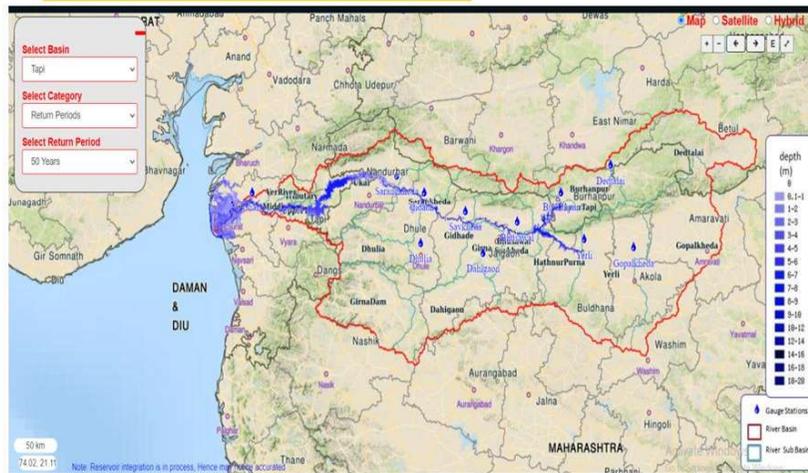
Affected Villages

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

Source: https://ndem.nrsc.gov.in/#/

Climate-Resilient Dams and Hydropower Infrastructure: Integrating Environmental Sustainability in Planning and Development

Godavari River - Cartodem -10m Simulation

	Discharge (Q) in Cumecs			
DATE	TIME	PERUR	KUNAWARAM	KONTA
04-08-2006	00:00	7655	11085	6860

Background Image -Radarsat-7th August,2006

Thank You