Dam Failure Statistics and AI in Dam Safety

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PRESENTATION OUTLINE

- Statistics of Dam Failures Data
- Koldam: A Safe Dam
- AI in Dam Safety
- Key Implementation Domains
- Miles to Go & Conclusions

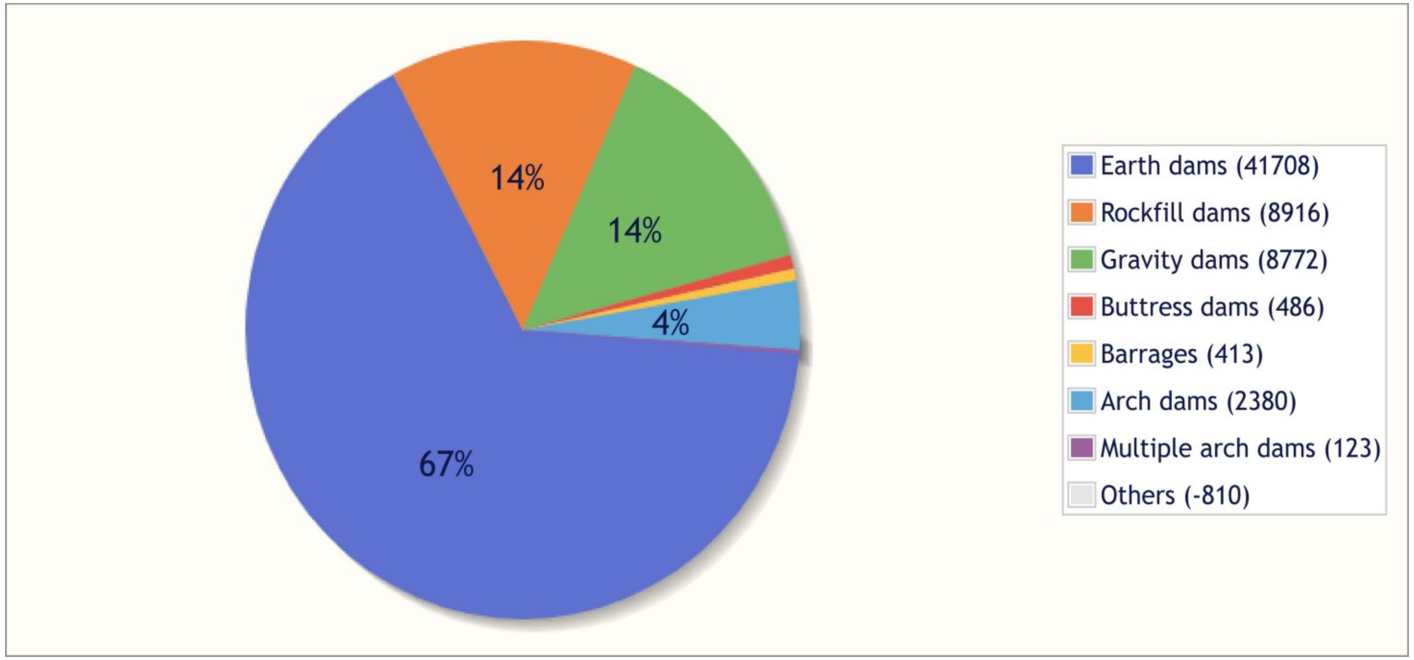
Basic Questions ?

- Why Dam Safety
- Dam Failure Statistics
- How AI can Help

Dams and Data: Need for Dam Safety

- As per ICOLD: more than 62,000 large Dams (World Register of Dams)
- India third ranker after China and USA

Sl No	Country	No. of Dams
1	China	23841
2	United States of America	9263
3	**India**	**6138**
4	Japan	3130
5	Brazil	1365
6	Korea (Republic)	1338
7	South Africa	1266
8	Canada	1156
9	Mexico	1079
10	Spain	1064



Dam Failures: Incident Mechanism

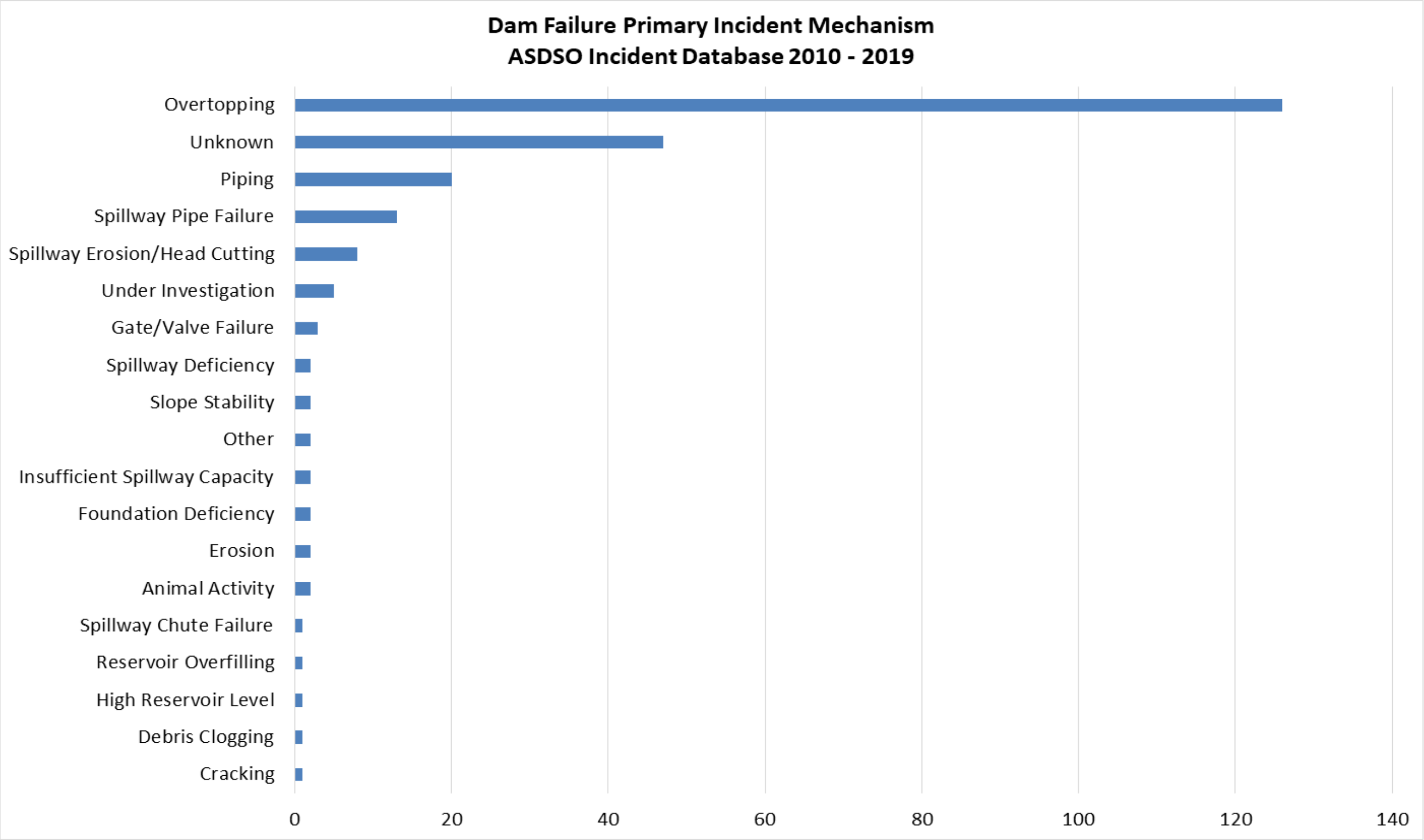
Second largest mechanism triggering dam failure is "Unknown"

As per Association of State Dam Safety Officials (ASDSO)

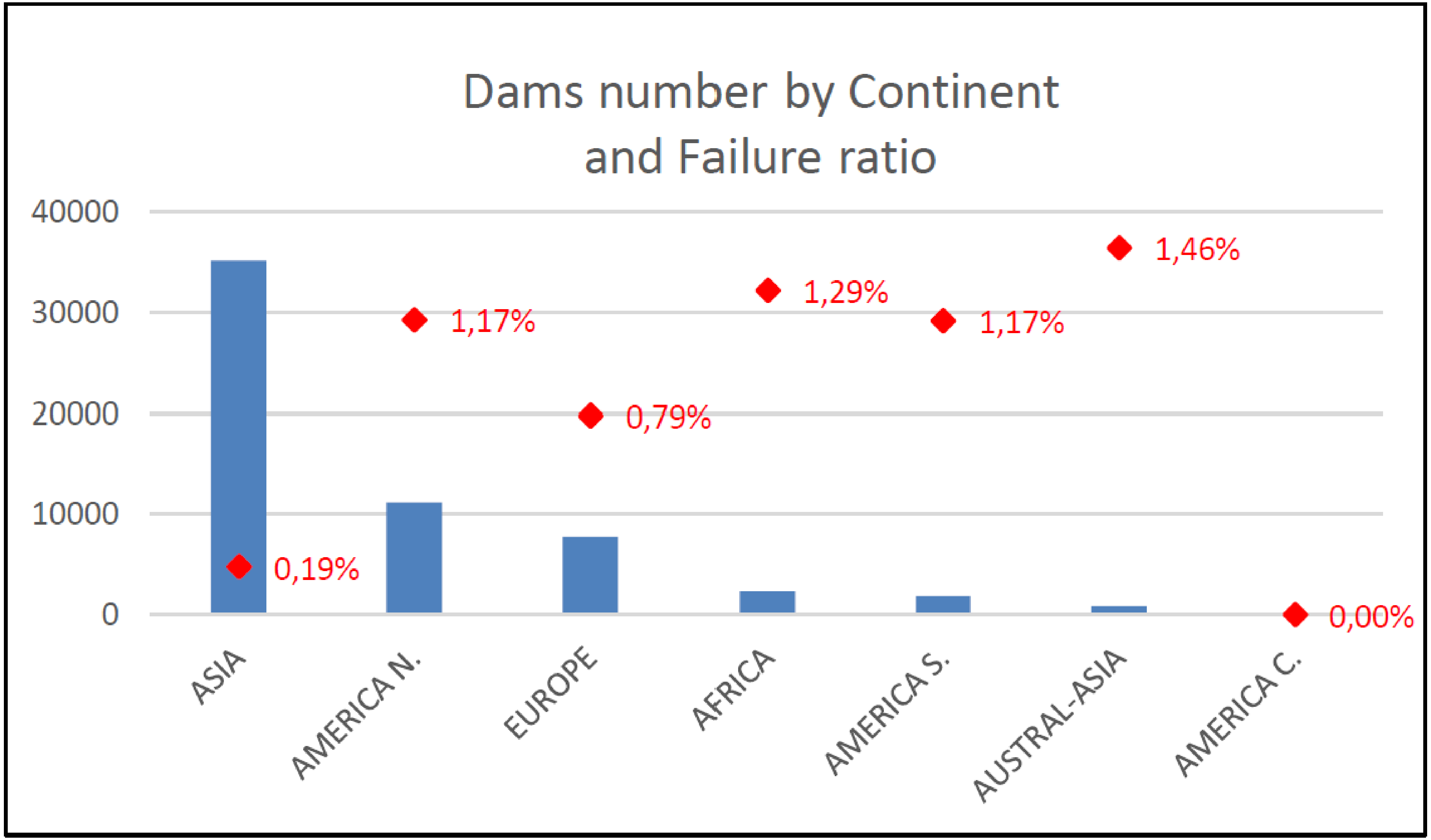
This Uncertainty triggers

The Need to strengthen

dam safety



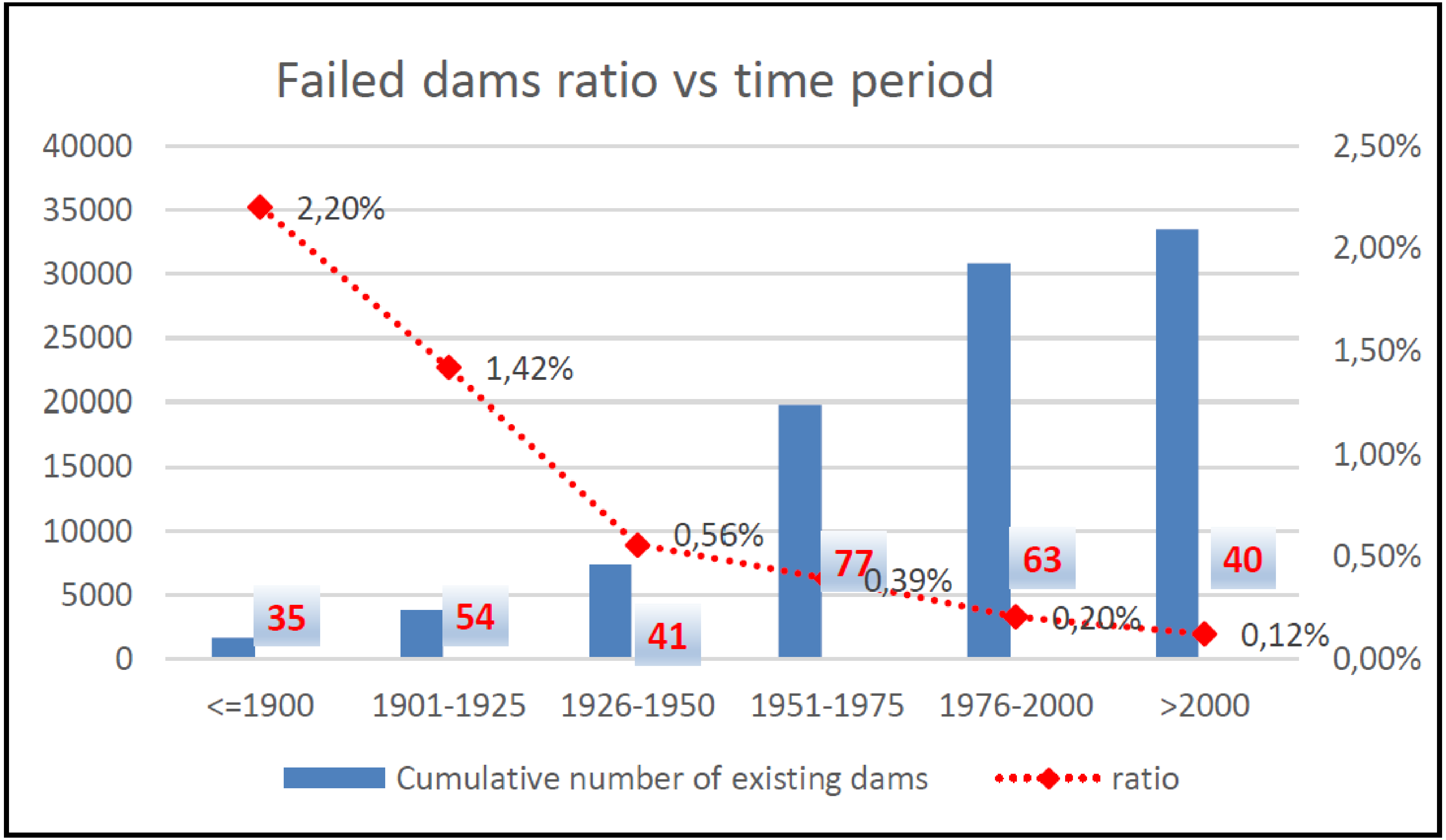
Continent Wise Dam Failures Rates



Despite highest no of Dams, Asia has lowest failure ratio

Australia with lowest no of dams shares the highest dam failure %

Construction Period Vs Dam Failure rates

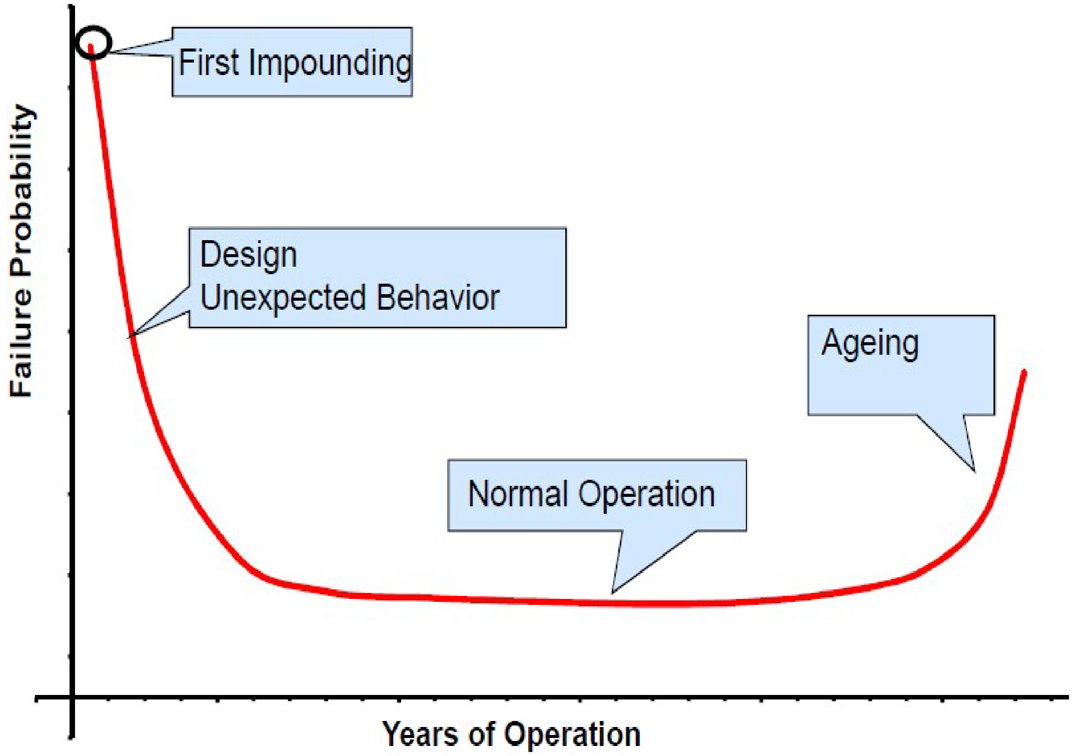


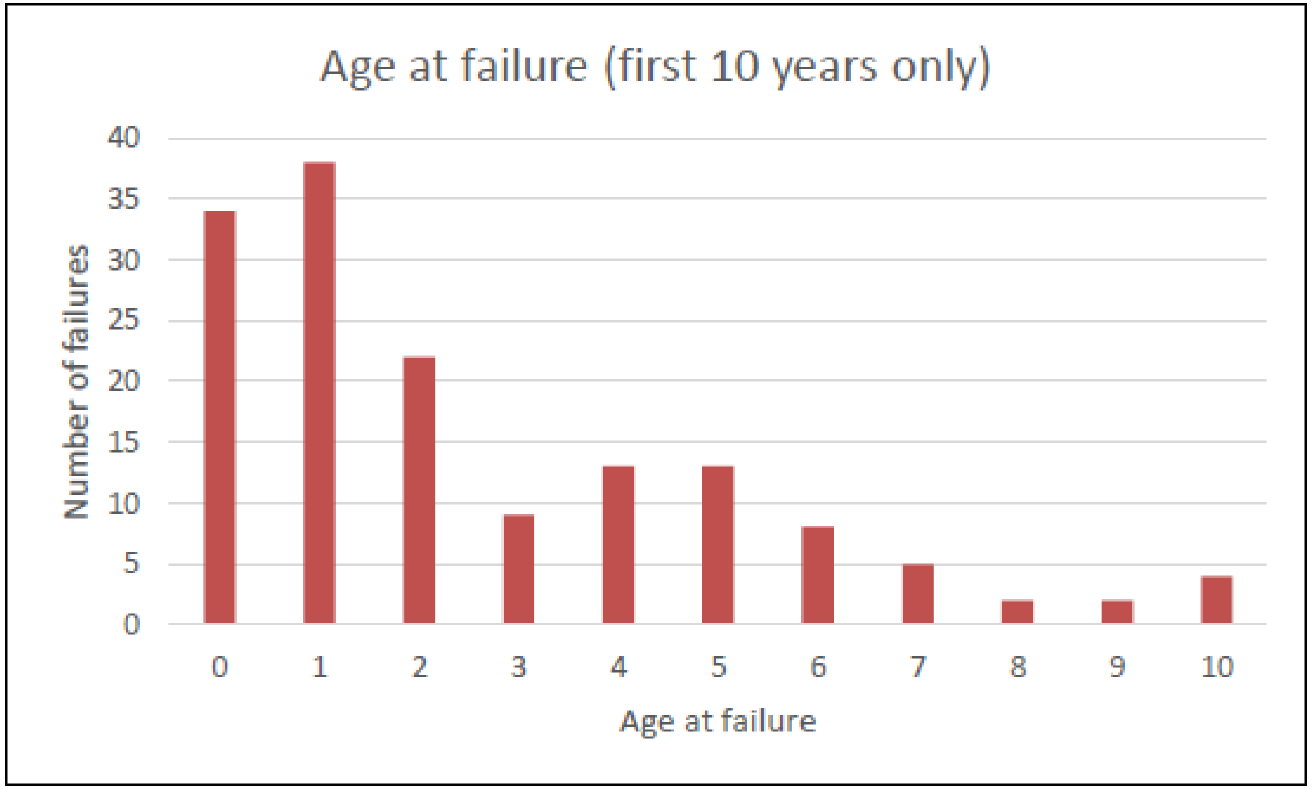
Despite increase in no of dams,

The failure rate of dams is continuously decreasing due to technological advancement & strict monitoring

Failure ratio for dam constructed after 2000 is only 0.12%

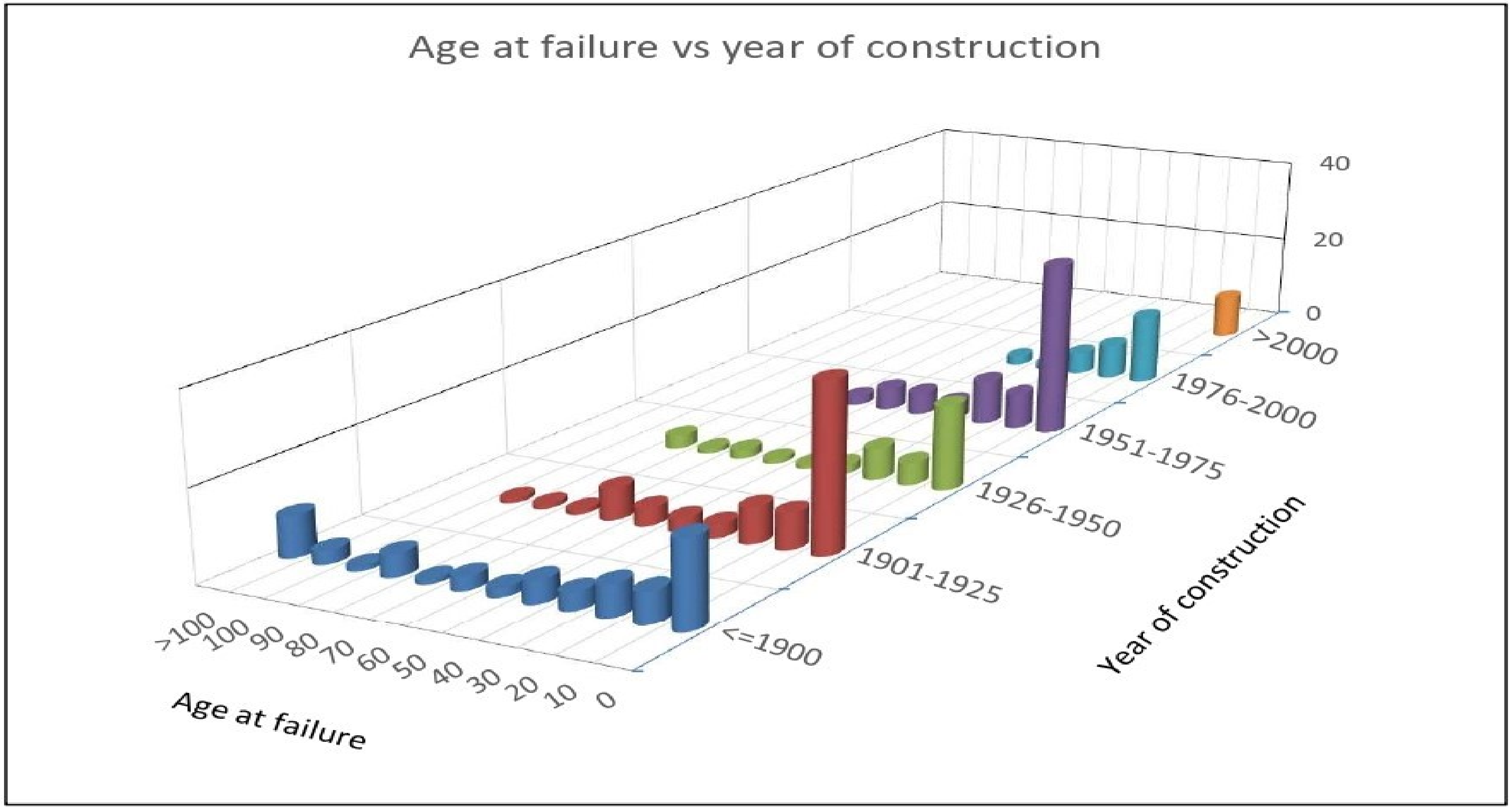
Probability of Dam Failures





- Highest probability of failure : during the first impounding
- Maximum dams fail within the first 10 years
- About 50% of dam failures : within 2 years of age

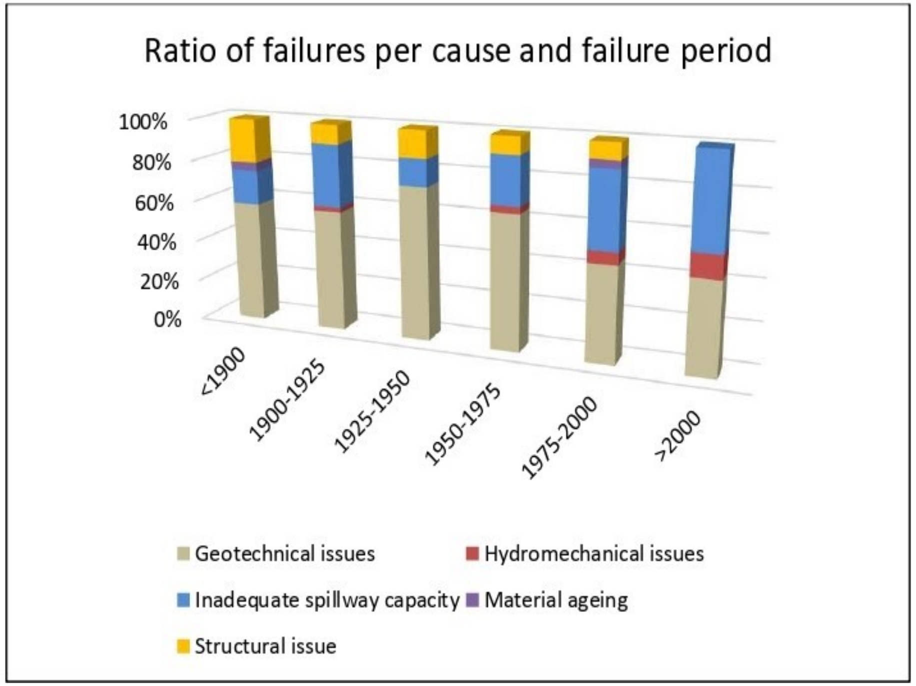
Statistical Data Analysis of Dam Failures: (ICOLD)

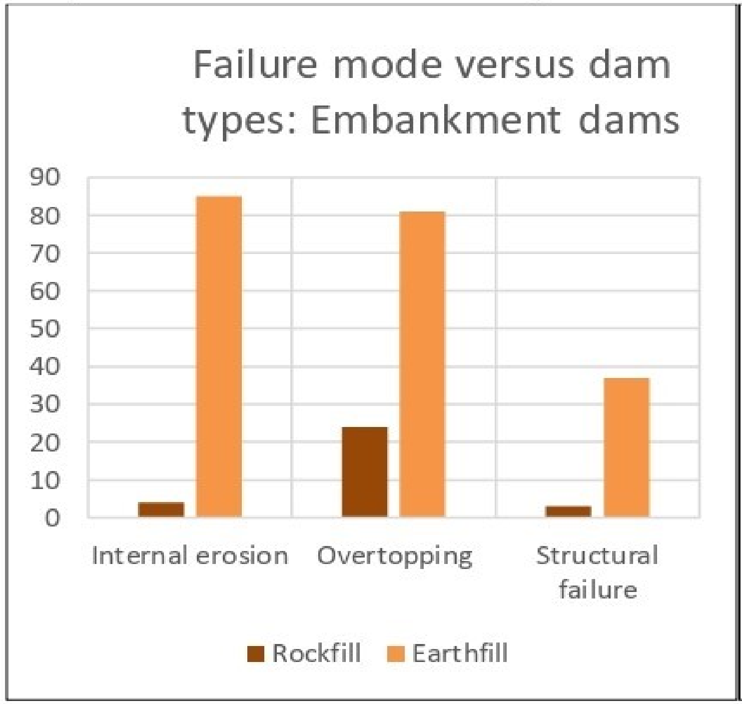


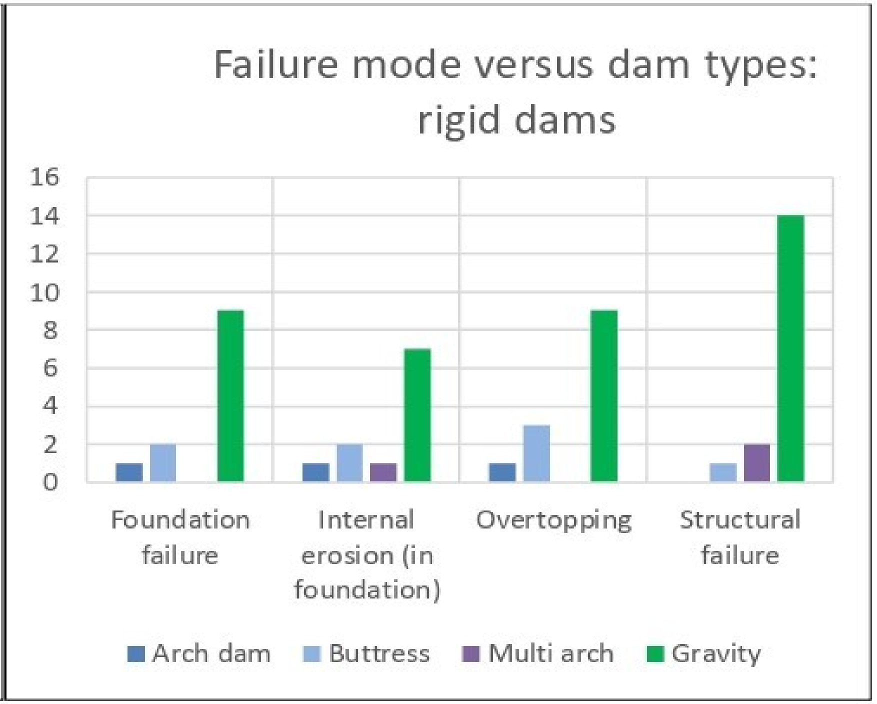
The failure rate of dams is continuously decreasing in latest times

High Failure chances at age of 100 years or more

Dams Failures: Different construction periods and failure modes

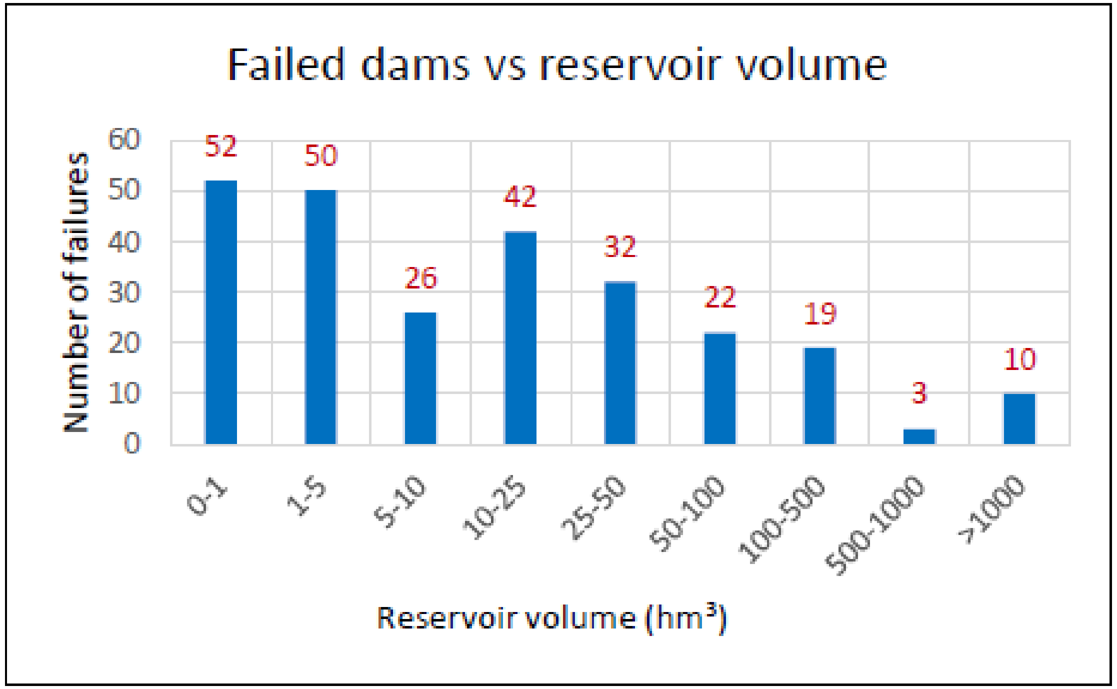


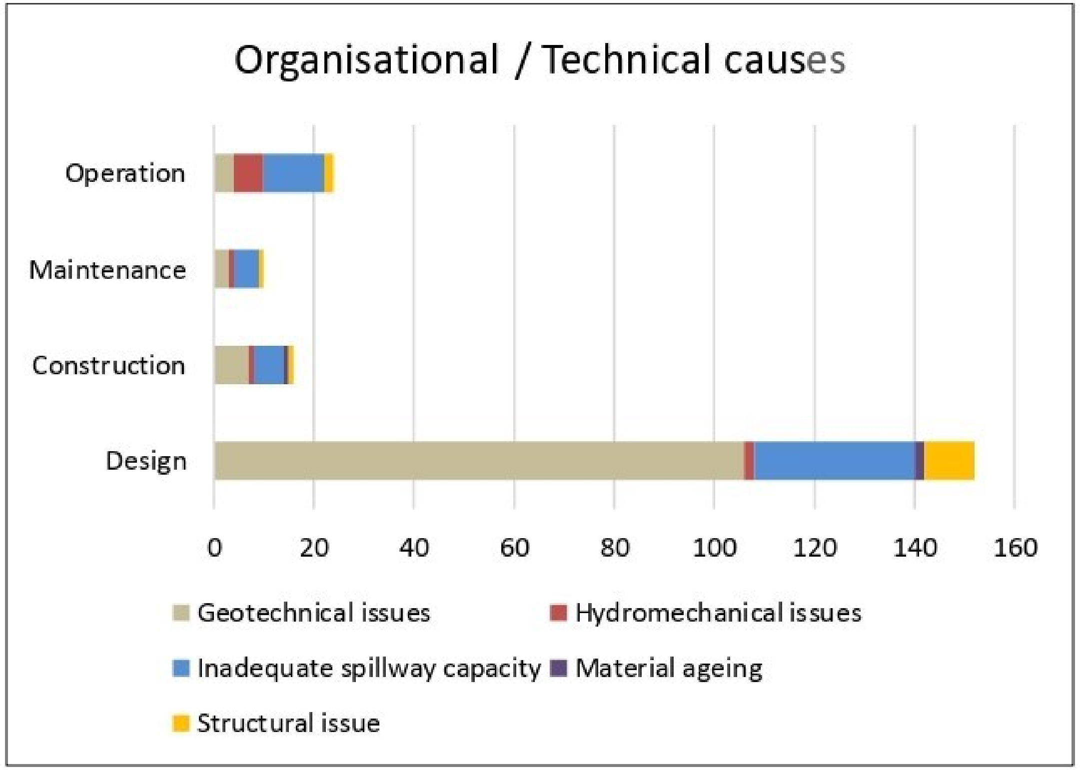




- Most of the dam failures after 2000 due to inadequate spillway capacity
- Failure rate of rock fill dams is about 10 to 20% of earthfill dams

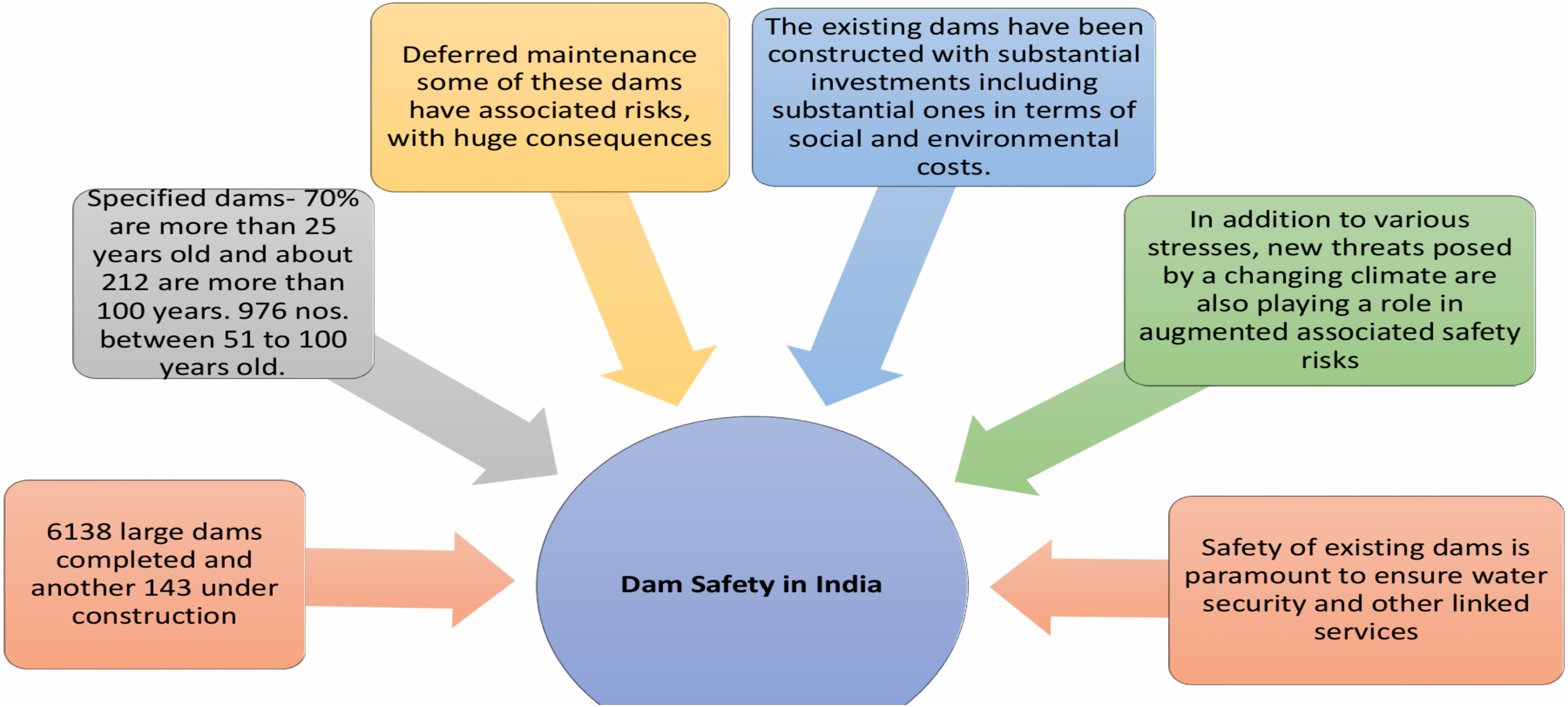
Failed dams Vs Reservoir volume & Technical reasons of failures



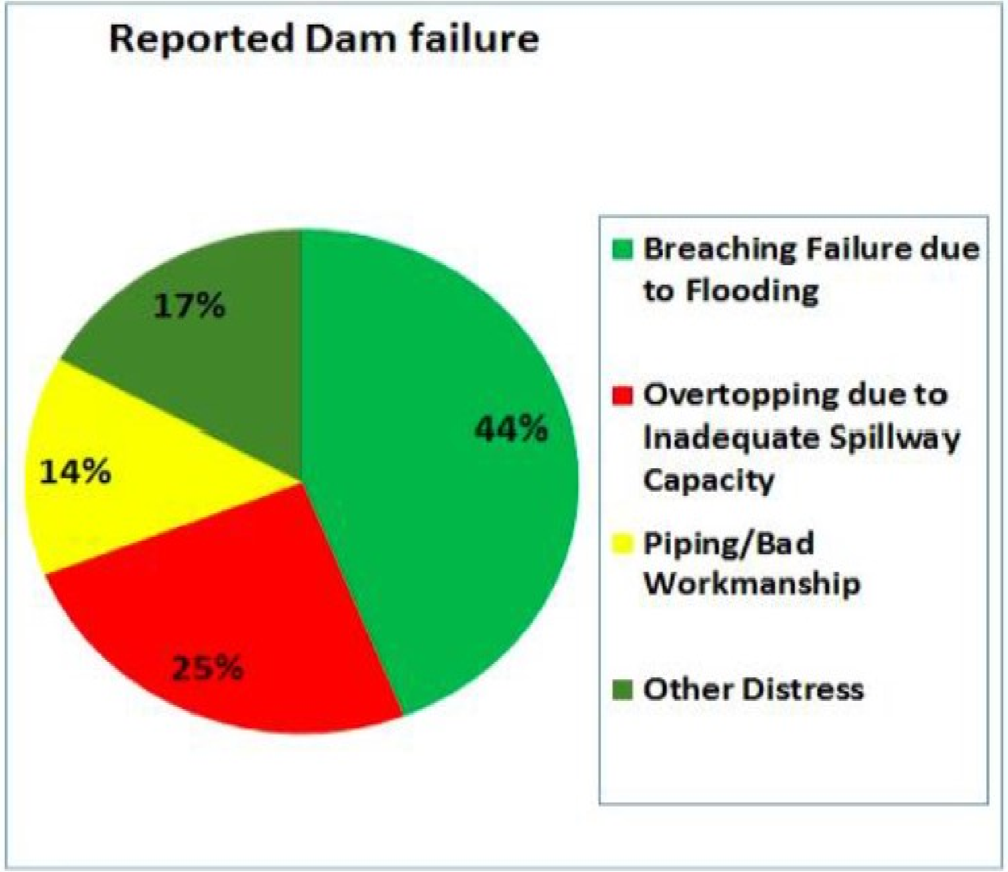


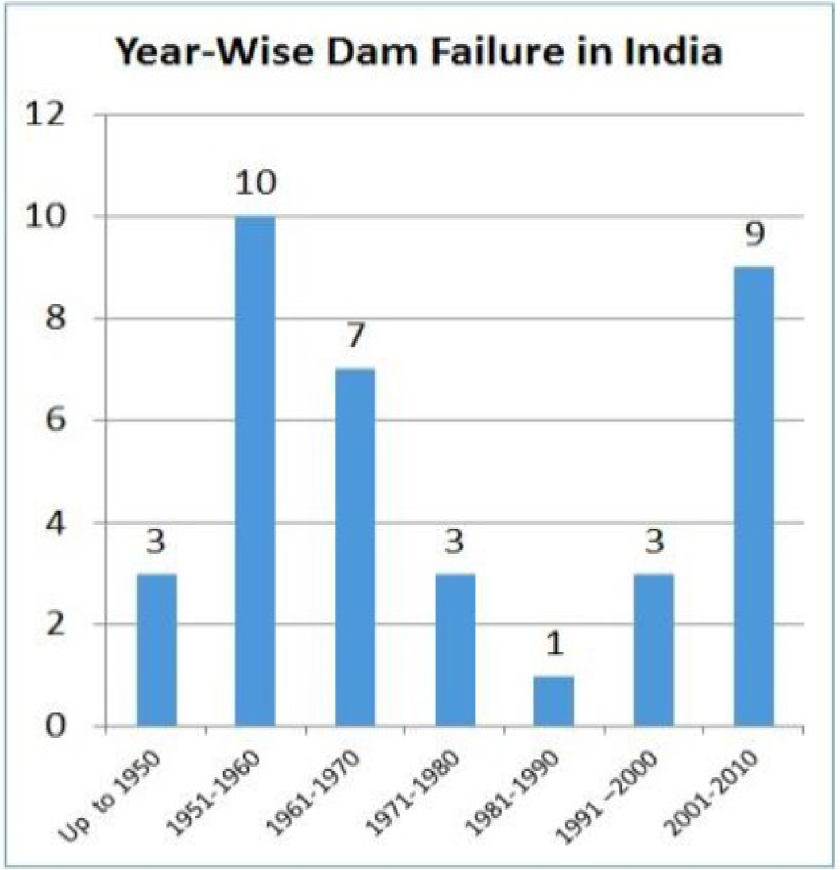
- Large Gross reservoir capacity Dams have failed very less
- Geotechnical issues are the largest cause of Dam failures

Dam Safety: Indian Perspective



Dam failure data in India





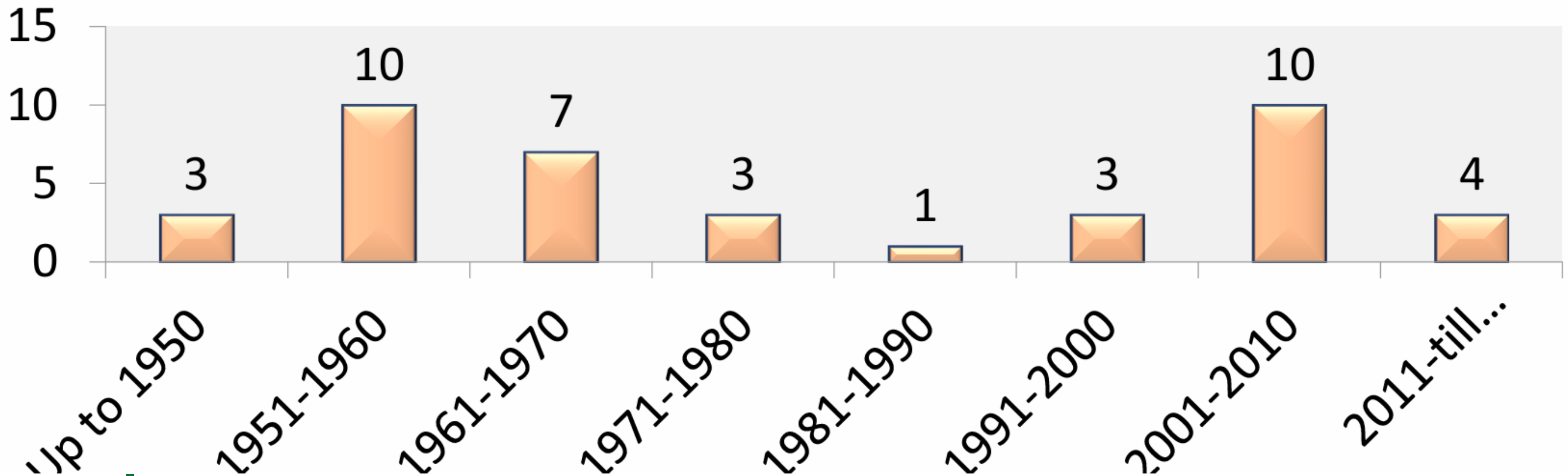
- Breaching failure due to High floods: biggest reason of dam failures in India
- Secondly 25% failure : Inadequate spillway capacity

Dam Failures in India

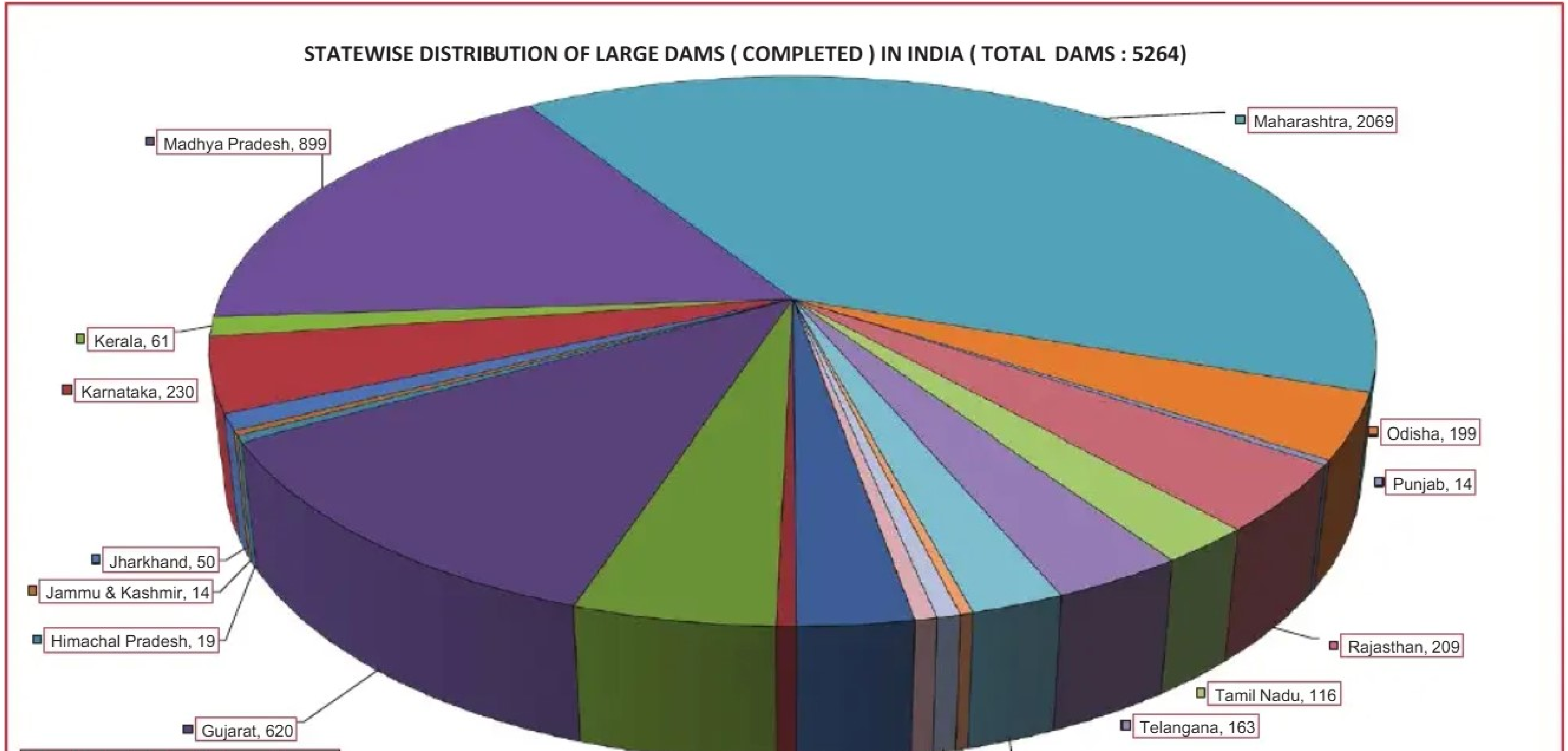
There are 42 reported dam failures in India. The first dam failure was recorded in Madhya Pradesh in 1917 when the Tigra dam failed due to overtopping.

The worst dam disaster was the Machu dam (Gujarat) failure in 1979, in which about 2,000 people were reported dead.

Most failures involved newly built dams, chiefly in the first ten years.

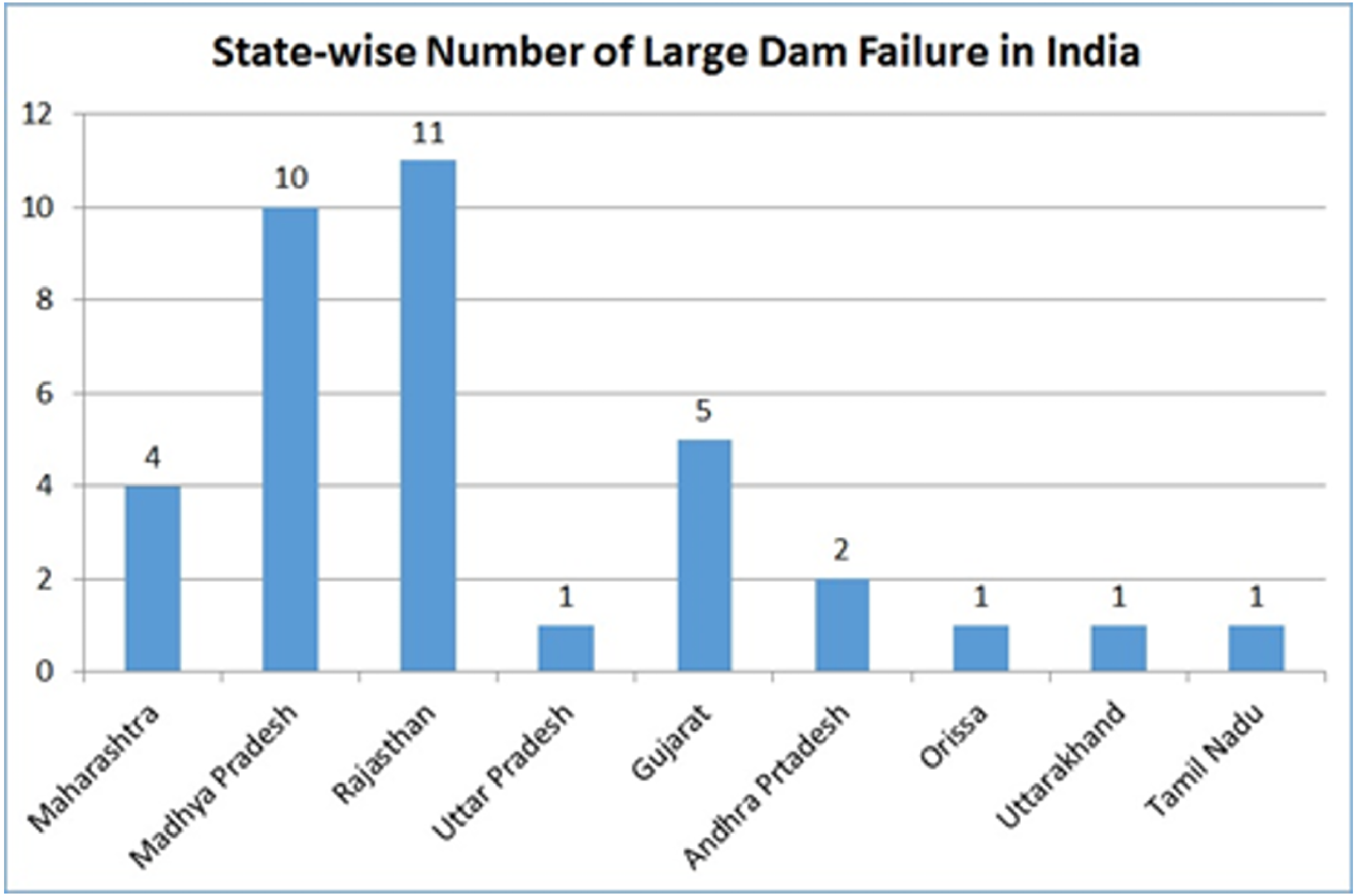


State-wise Distribution of Large Dams



Other States includes: Andaman & Nicobar Islands(2), Arunachal Pradesh(1), Assam(3), Goa(5), Haryana(1), Manipur(3), Meghalaya(8), Nagaland(1), Sikkim(2) & Tripura(1)

State-wise Dam Failures in India



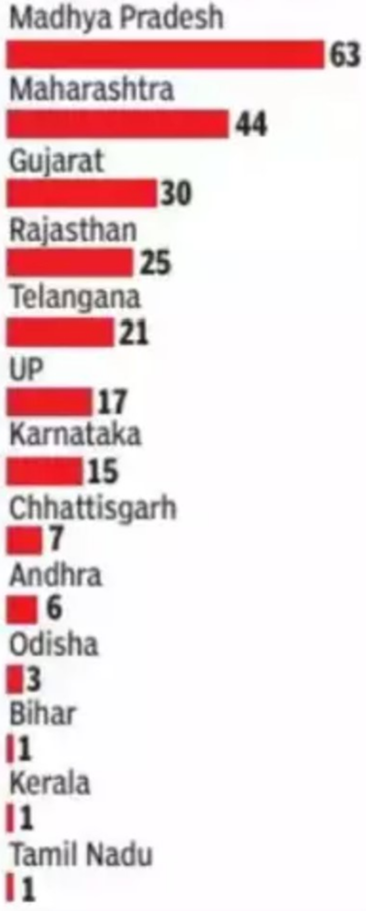
Old Dams and failures in India

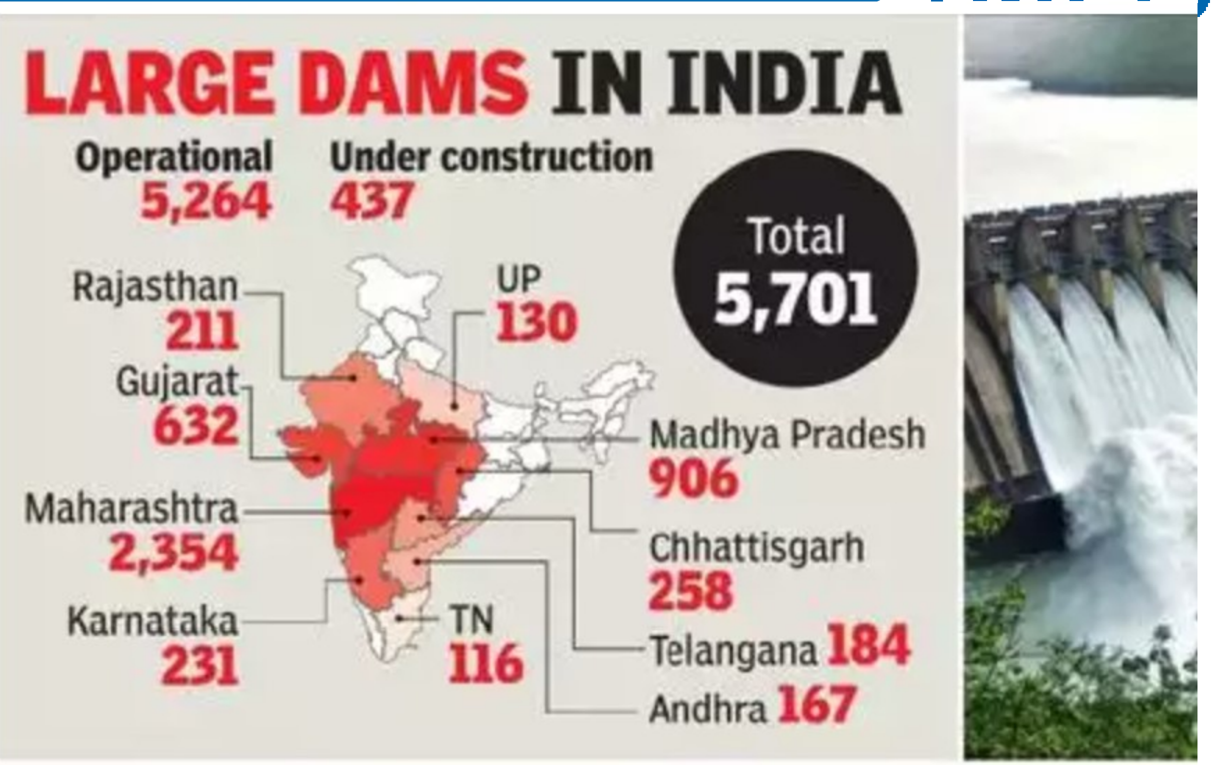
No. of functional large dams which are more than 100 years old **234**

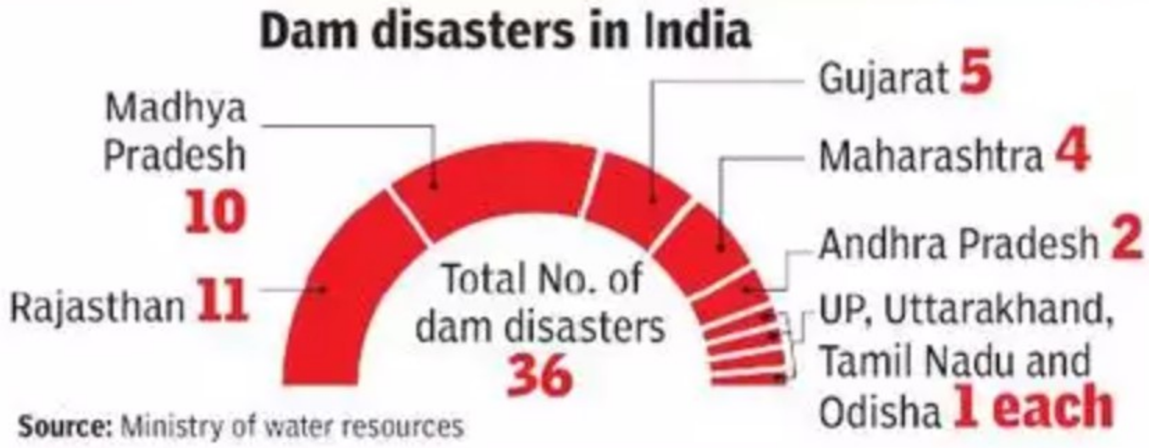
15 OLDEST DAMS

Dams	Year*	State
Thonnur Tank	1000	Karnataka
Cumbhum	1500	Andhra Pradesh
Swarup Sagar	1560	Rajasthan
Udai Sagar	1585	Rajasthan
Dhamapur	1600	Maharashtra
Rajsamand	1676	Rajasthan
Barwa Sagar	1694	Uttar Pradesh
Magar Pur	1694	Uttar Pradesh
Pachwara Lake	1694	Uttar Pradesh
Jai Samand	1730	Rajasthan
Jagannathasagar	1781	Odisha
Kalapvihir	1800	Maharashtra
Mudana	1800	Maharashtra
Rushi	1800	Maharashtra
Vihar	1860	Maharashtra

*Year of completion
Source: National Register of Large Dams-2019







Koldam Vs Dam Failure Data (Safety Evaluation)

1. Age of Dam: Koldam has completed smooth operation of more than 10 years

Max dam fail withing 10 years, 50% withing 2 years

Lowest probability during smooth operation : **Hence Safe**

2. Type of Dam: Rockfill dam

10 to 20% chances of failure w.r.t. Embankment dams

Failures probability due to overtopping and internal erosion is very less: **Hence Safe**

3. Spillway Capacity: 16500 cumecs (PMF)

Max dam failures after 2000: due to inadequate spillway capacity

Spillway discharge has not crossed 3500 cumecs: **Hence Safe**

Koldam Vs Dam Failure Data

4. Construction Period: 2004 to 2014

(very less failures in dams constructed after 2000): **hence Safe**

5. Reservoir Capacity: 576 MCM

Very less failures of large reservoirs (1000 hm2) reported

6. Height of Dam: 167 m

Very less failures of dams of more than 100 m high observed

- **So Koldam is safe in all statistical failures criterion.**

Conclusions about safety of Koldam

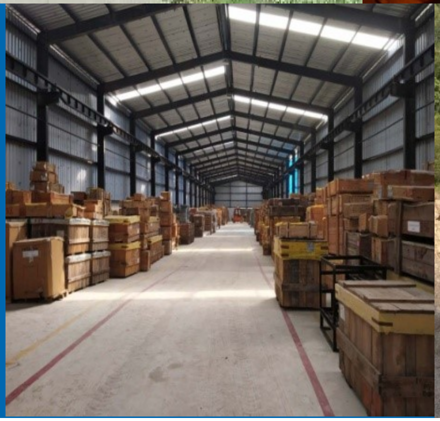
Sl. no.	Criteria of failure	Values	Koldam parameter	Status
1.	Age of dam	50% within 2 years	10 years	Safe
2.	Height of dam	≥100 m, 0.13%	167 m	Safe
3.	Tenure	Safe in normal operation	Normal operation	safe
4.	Dam type	Rock fill 1.39 %	Rockfill	Safe
5.	Storage	≥ 1000 $hm^{2,}$ 0.87%	576 MCM	Safe
6	Spillway capacity	Inadequate	Adequate for PMF (16500 cumec)	safe

Different historical data related to dam failures, like type of dam, age, construction period, height, storage etc. are analyzed and compared with reference to Koldam which indicates that dam is completely safe. It is supported by well planned maintenance practices.

Further, as per the safety inspections carried out in line with CWC / Dam safety Act, the parameters of Dam and appurtenant structures are well within safe limits.




Need of Dam Safety



Dam Safety: Threat Vs Opportunity

- Case 1. In 1975, the Banqiao Dam in China collapsed, and an estimated 1,71,000 lives were lost, the worst dam failure in history.

- Case 2. When Spillway collapse threatened the Oroville Dam in California in 2017, it was holding back 4.3 BCM water. More than 180,000 people were evacuated due to timely dam safety measures.

Dam Failures: Media/Society View

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Libya dam collapse: engineering expert raises questions about management

PREMIUM

September 19, 2023 06:01 pm | Updated 06:21 pm IST

NADHIR AL-ANSARI

COMMENTS SHARE READ LATER

Rescuers and relatives of victims set up tents in front of collapsed buildings in Derna, Libya, Monday, Sept. 18, 2023. Some 11,300 people died when two dams collapsed during Mediterranean storm Daniel last week sending a wall of water gushing through the city, according to the Red Crescent aid group. A further 10,000 people are missing, and presumed dead. | Photo Credit: AP

More than 11,000 people have been killed and tens of thousands are missing following the catastrophic collapse of two dams in the eastern Libyan city of Derna. The dam collapse came after an extreme storm, Storm Daniel, slammed into the north African country. The Conversation Africa's Moina Spooner asked water resources and engineering expert Nadhir Al-Ansari, who has researched the design and safety of dams, to provide insights into the disaster.

Also Read | Libya investigates dams' collapse after flood killed over 11,000

ENVIRONMENT

Sikkim Disaster: Dam Site 'Completely Devastated', Full Extent of Loss Will Take Days To Assess

Local activists called for unity in demanding no more dams be built in the Himalaya. If an early warning system had been in place, some of the destruction could have been avoided, experts said.

The "completely devastated" damsite area of Teesta-III. Photo: X/ @shubhamtorres09

Dam Failures: Media/Society View

Dam safety act was enacted, as a response to deficient surveillance and maintenance practices causing dam failure related disasters.

HOME / SCI-TECH / ENVIRONMENT

Does India need to relook the Dam Safety Act? | Explained

PREMIUM

Do the frequency and scale of disasters like in Sikkim and Himachal Pradesh reveal a pattern of neglect?

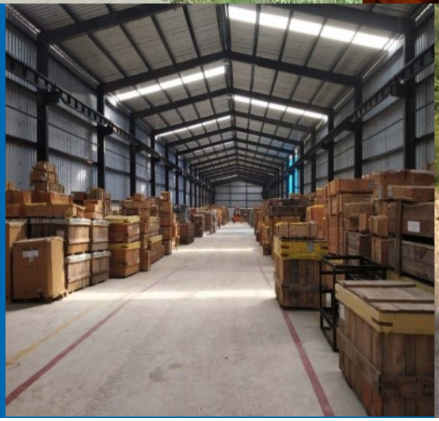
October 22, 2023 02:45 am | Updated 11:55 am IST

SAUMYA KALIA

COMMENTS SHARE READ LATER

The Dam Safety Act was tabled in the Rajya Sabha in December 2021, as a response to deficient surveillance and maintenance causing dam failure-related disasters. File | Photo Credit: PTI

AI in Dam Safety



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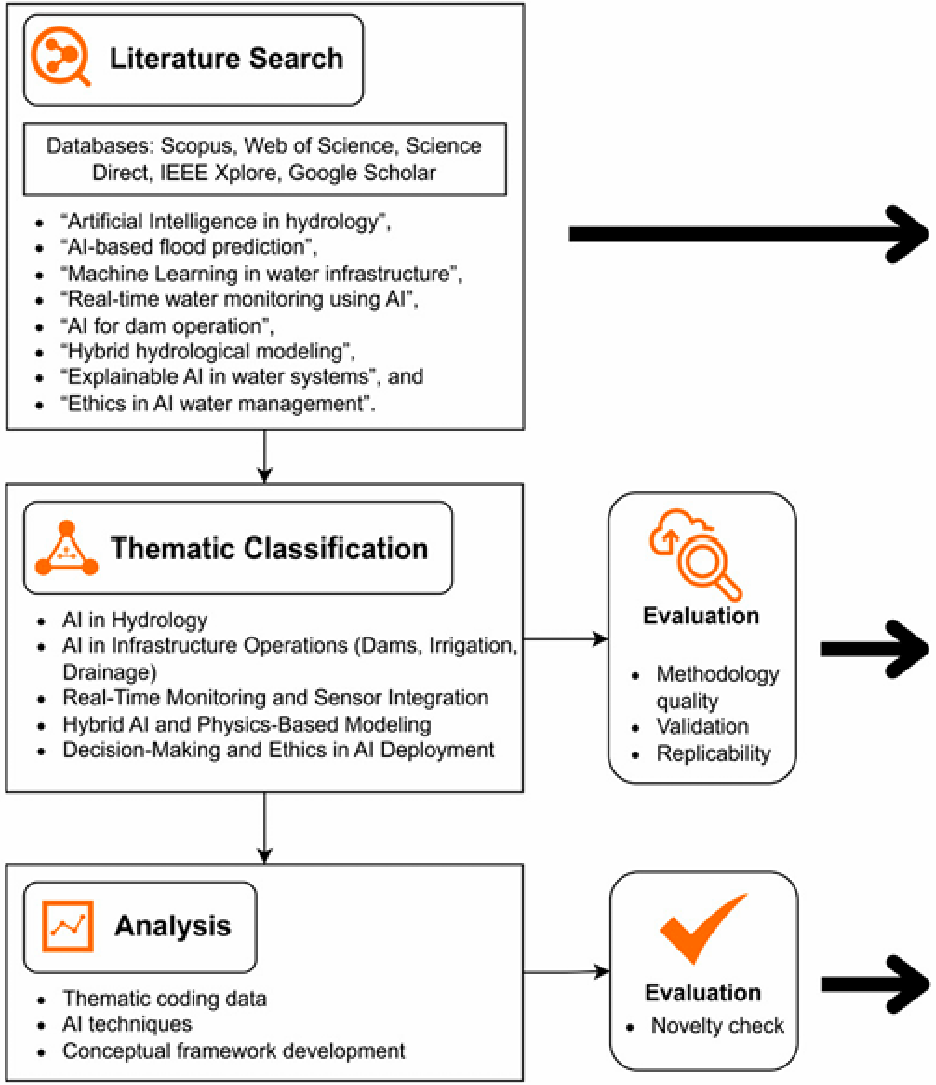
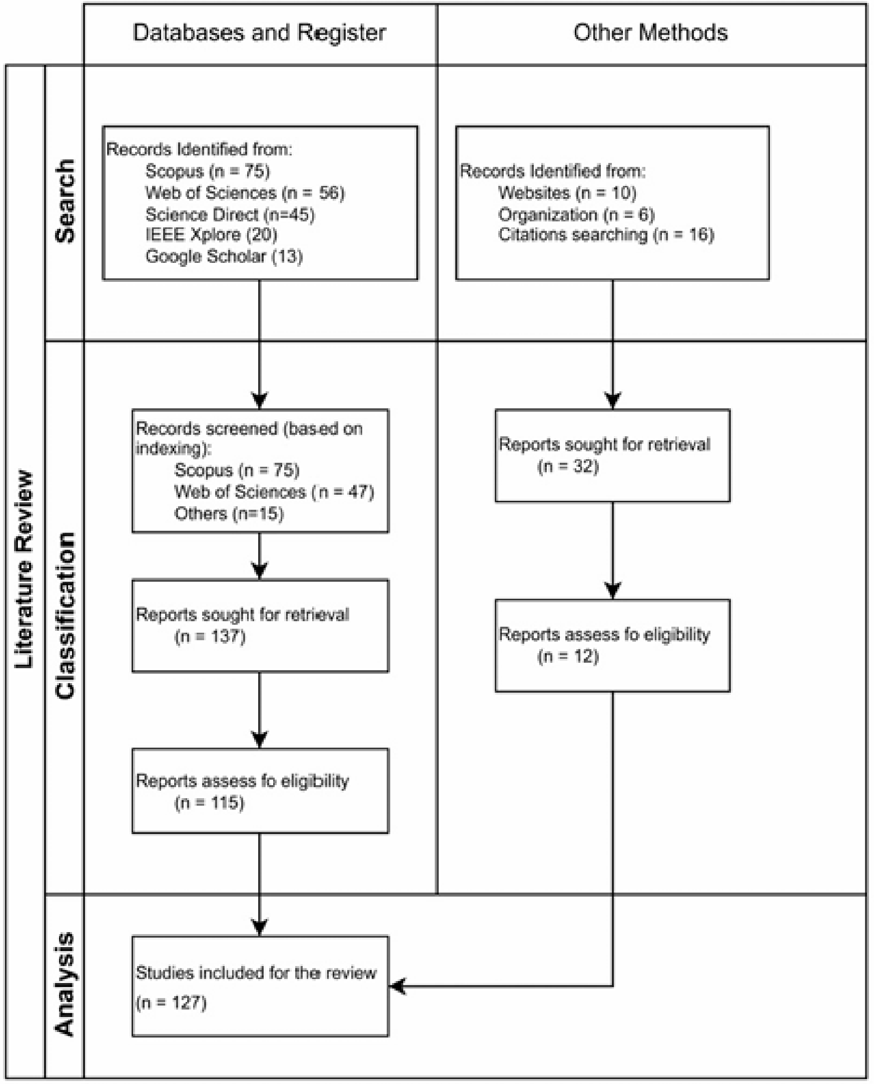
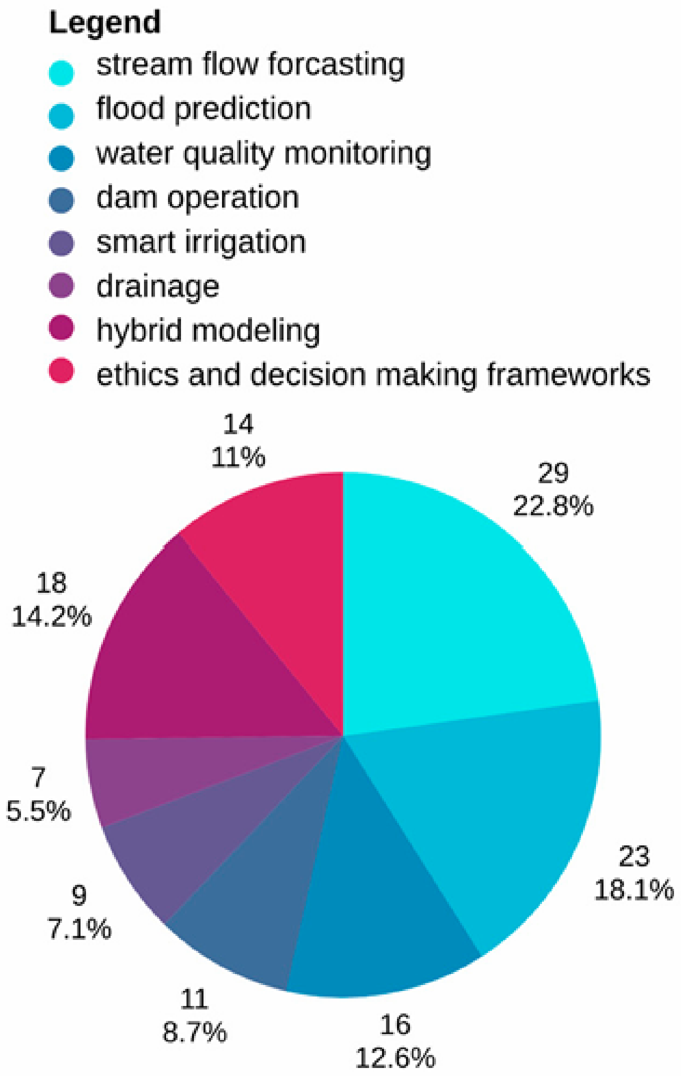
Key Research Areas in AI in Dam Safety



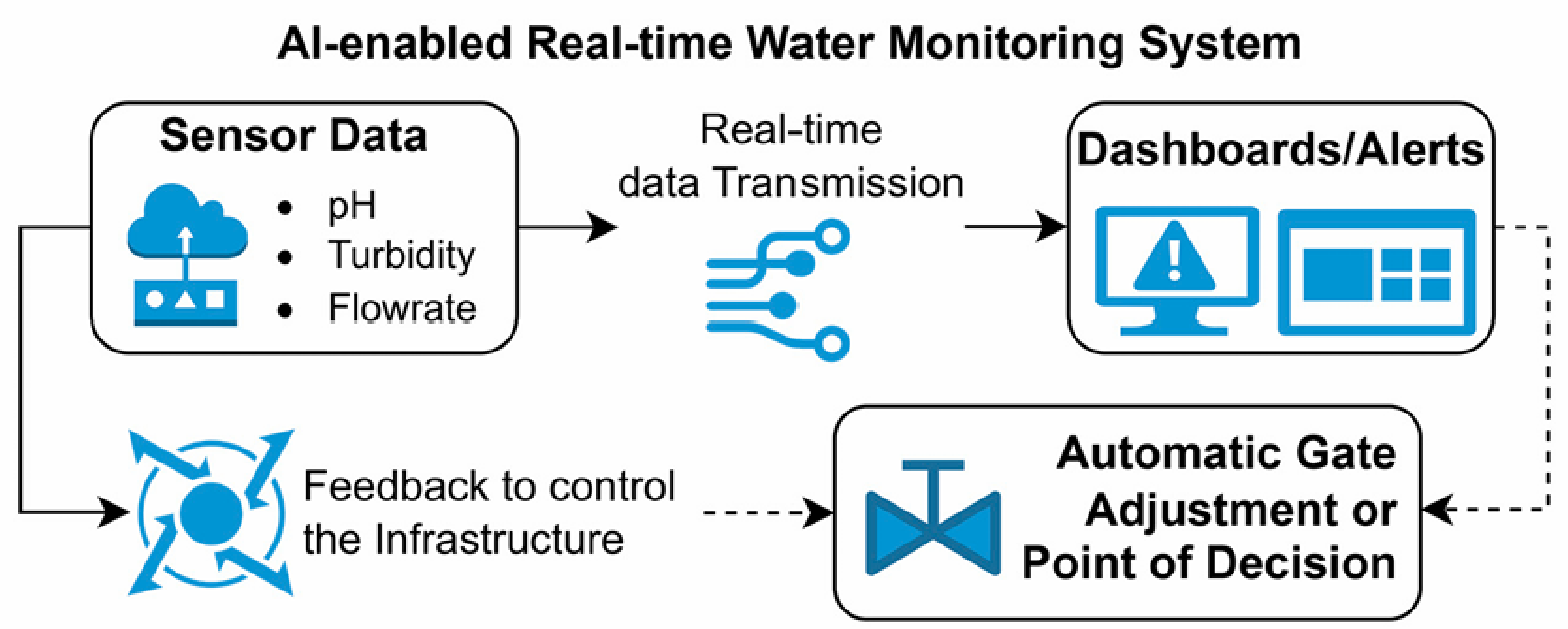




Key differences conventional and AI-driven approaches

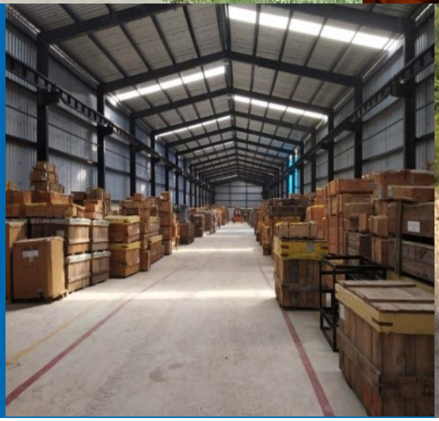
Traditional Approach	AI Approach
Manual data acquisition and data analysis	Real-time data acquisition (IoT) and efficient data analysis
May lack inclusive decision-making	Intelligent decision-making
Rely on historical data for hydrological modeling	Combines historical data, AI, remote sensing, and cloud computing for flood modeling
Involves laborious, expensive, and time-consuming laboratory methods	Can handle massive amounts of data and uses remote sensing and the IoT for quality monitoring
Lack of comprehensive data monitoring	Heavily depends on data and needs expertise

AI-driven real-time water monitoring framework






Key Implementation Domains



Key Applications of AI in Dam Safety

- **Structural Health Monitoring and Prediction**
- **Seepage and Pore Pressure Prediction**
- **Slope Stability Analysis**
- **Predictive maintenance**
- **Automated Dam Operation**
- **Hazard Detection**
- **Early warning systems**
- **Risk assessment and decision-making**

Use of AI in Dam Safety : Power of Technology

- Reliability based predictive maintenance and replacement of equipment/instrument and spares
- Optimized Dam operations based on water inflow, release rate, reservoir level, weather pattern & energy demand for higher generations and maximizing revenue
- Automated alarm system from Dam instrumentation data
- Analysis of Dam instrumentation data and reporting abnormality from previous pattern

AI in Dam Safety: Remote Inspections

Remote and autonomous inspection

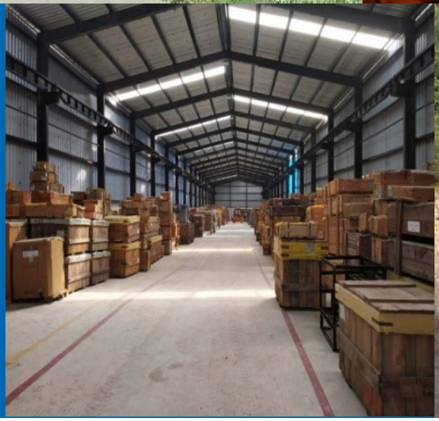
- **Geospatial AI:** AI and geospatial data, including satellite imagery: to track ground movement, vegetation changes, and moisture levels
- **AI-powered drones:** Drones equipped with AI for autonomous or guided inspection are being used to efficiently survey dams for cracks and other structural issues
- **Inspections of Penstocks/Turbines:** AI powered ROV with camera/instruments can be used for inspection of hazardous locations like penstocks and turbines.

AI in Dam Safety: Other Domains

- **Flood simulation and risk assessment:** The Centre for Development of Advanced Computing (C-DAC), in partnership with the National Dam Safety Authority (NDSA), is developing a nationwide dam-break flood simulation system.
- **Cost-effective monitoring:** AI provides cost-effective and scalable monitoring solutions compared to manual and traditional methods
- **Digital twins:** Researchers are developing digital twin platforms - virtual replicas of real dams - that enable real-time monitoring and simulation. By simulating various scenarios, these platforms help optimize operational efficiency and inform timely decisions during critical events.




Applicability Domains



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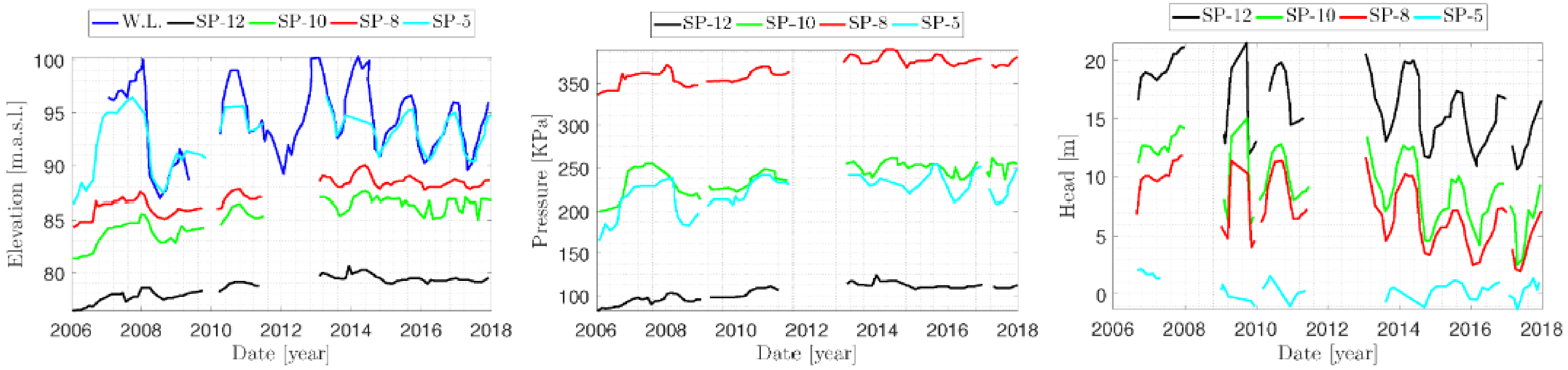
Surveillance and Security

Surveillance: Some dams, like the Almatti Dam in Karnataka, are using AI-based CCTV cameras to monitor visitor activity for enhanced security. The system uses facial recognition and visitor counting, with plans for future upgrades.

AI-based surveillance enables to incorporate vehicle number plate identification systems and advanced ticket counters.

Analysis of complex instrumentation data

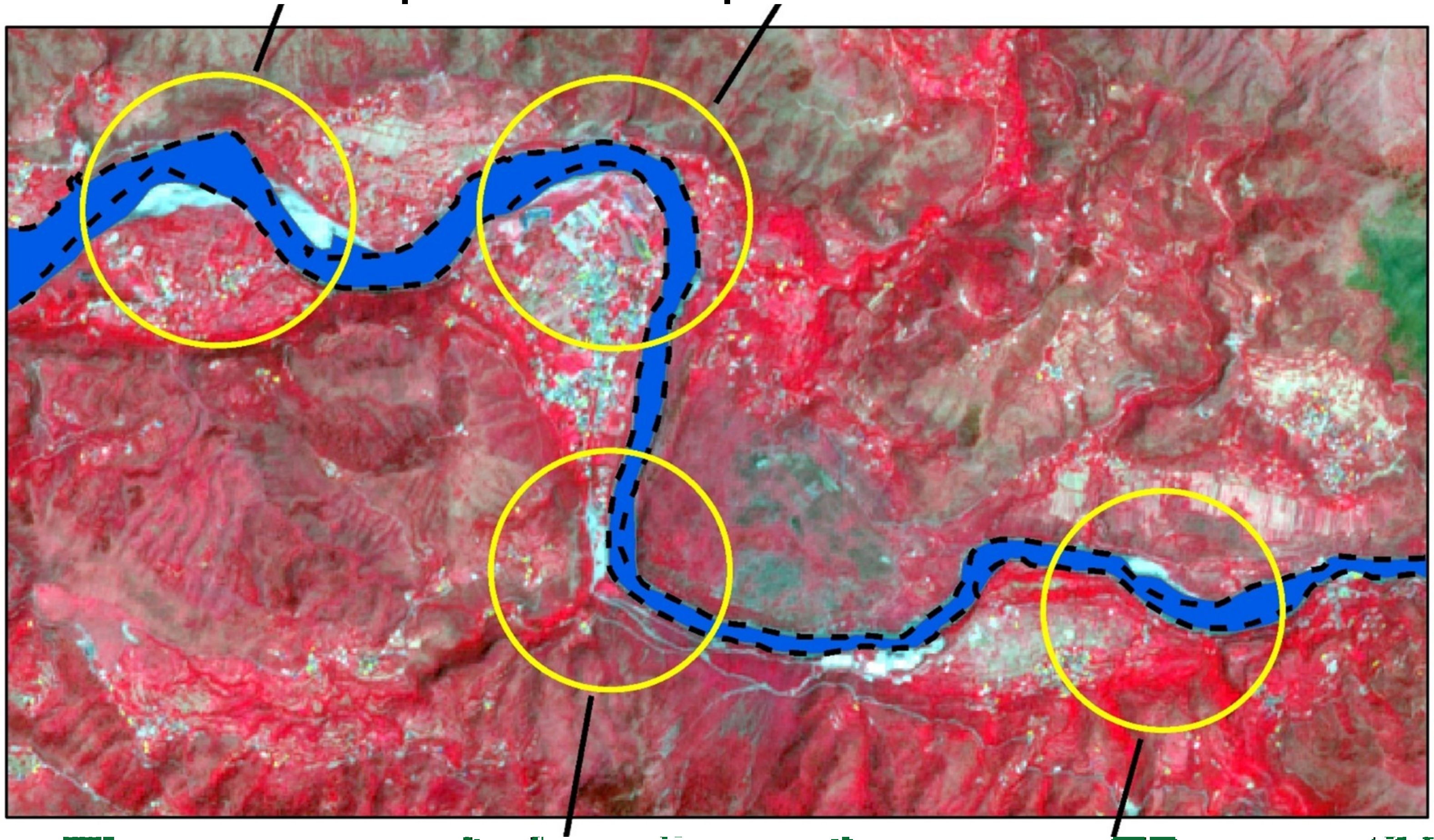
AI can analysis the huge instrumentation data with historical references and can generate alarms for any abnormal variations and suggest corrective measures a



(a) Piezometric level variations (b) Pore pressure variations (c) Hydraulic loss variations

Analysis of Siltation Pattern in Reservoir

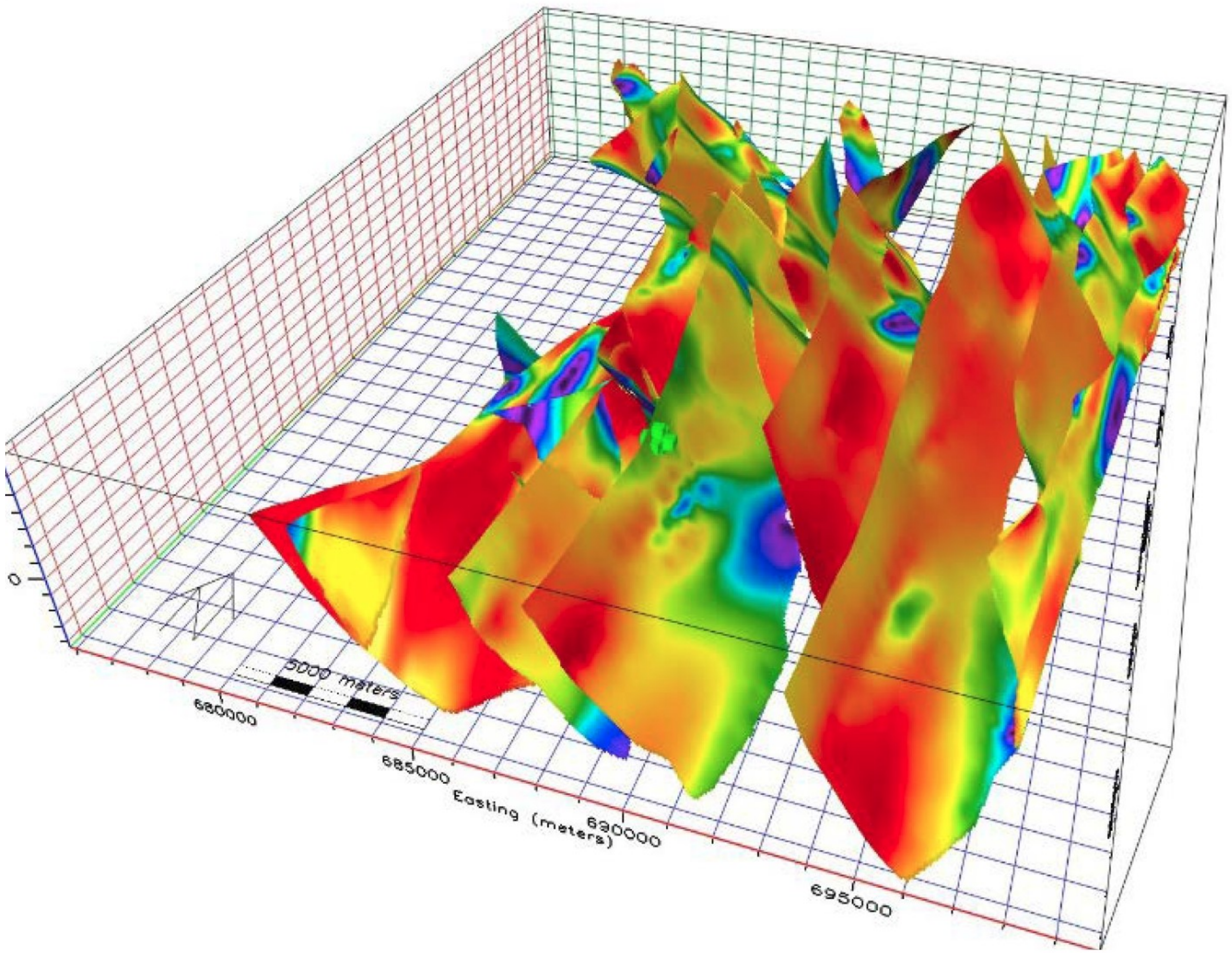
AI integrated with Satellite imagery can analysis and predict siltation along reservoirs rims and variation in river flow width can be calculated along with the submergence zones: Temporal and Spatial Variation



Prediction of Land slides/ slope failure

Analysis of Geophysical investigation data

AI can analysie the Geophysical & other investigation results and can identify the weak zones with w.r.t. seepage/stability



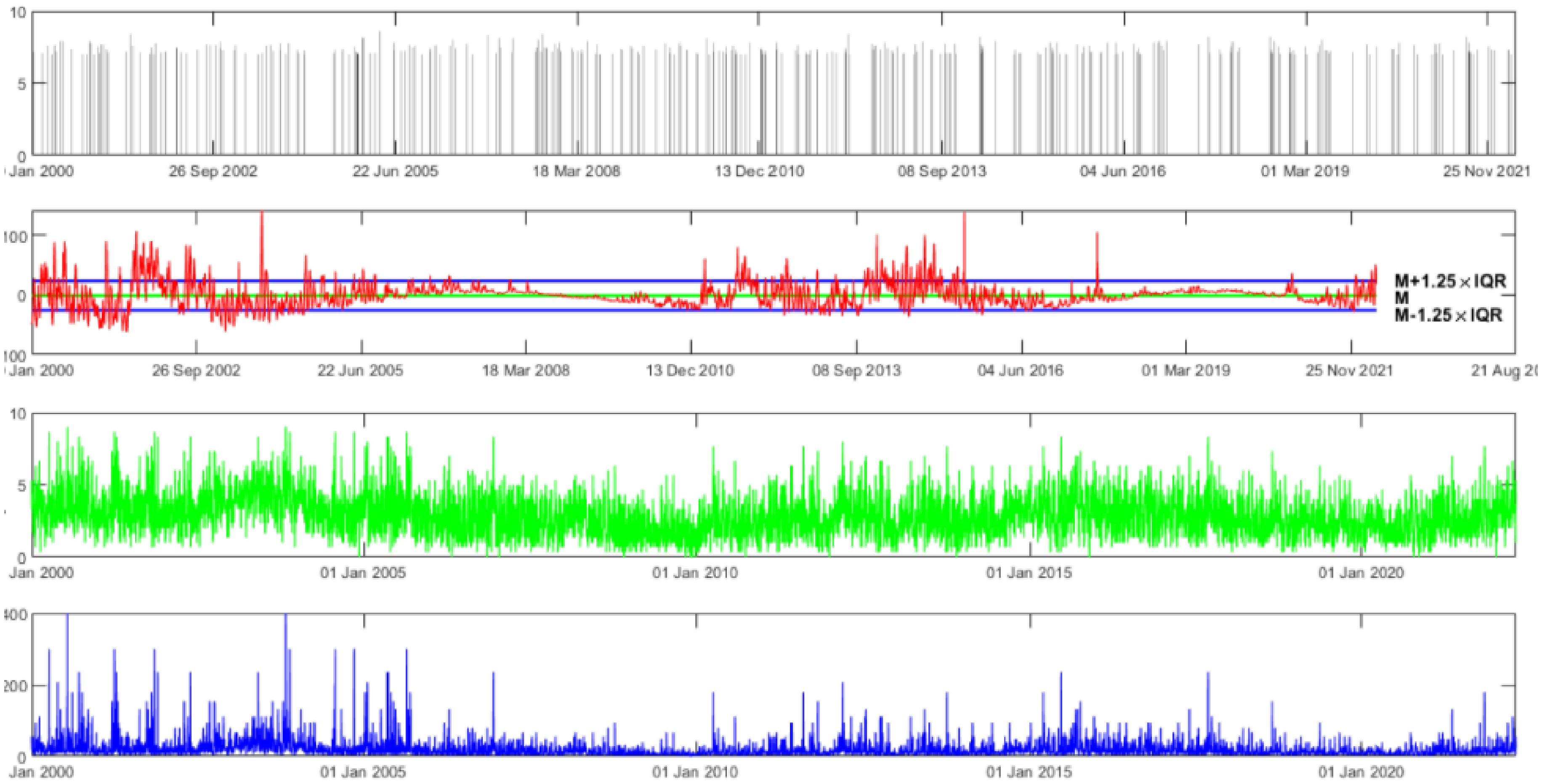
Study of Vortex like Complex Problems

Vortex generation at power intakes can be analyzed/predicted and any damage to hydraulic structures and turbine can be protected with the help of AI

AI can analysie difficult flow equations easily

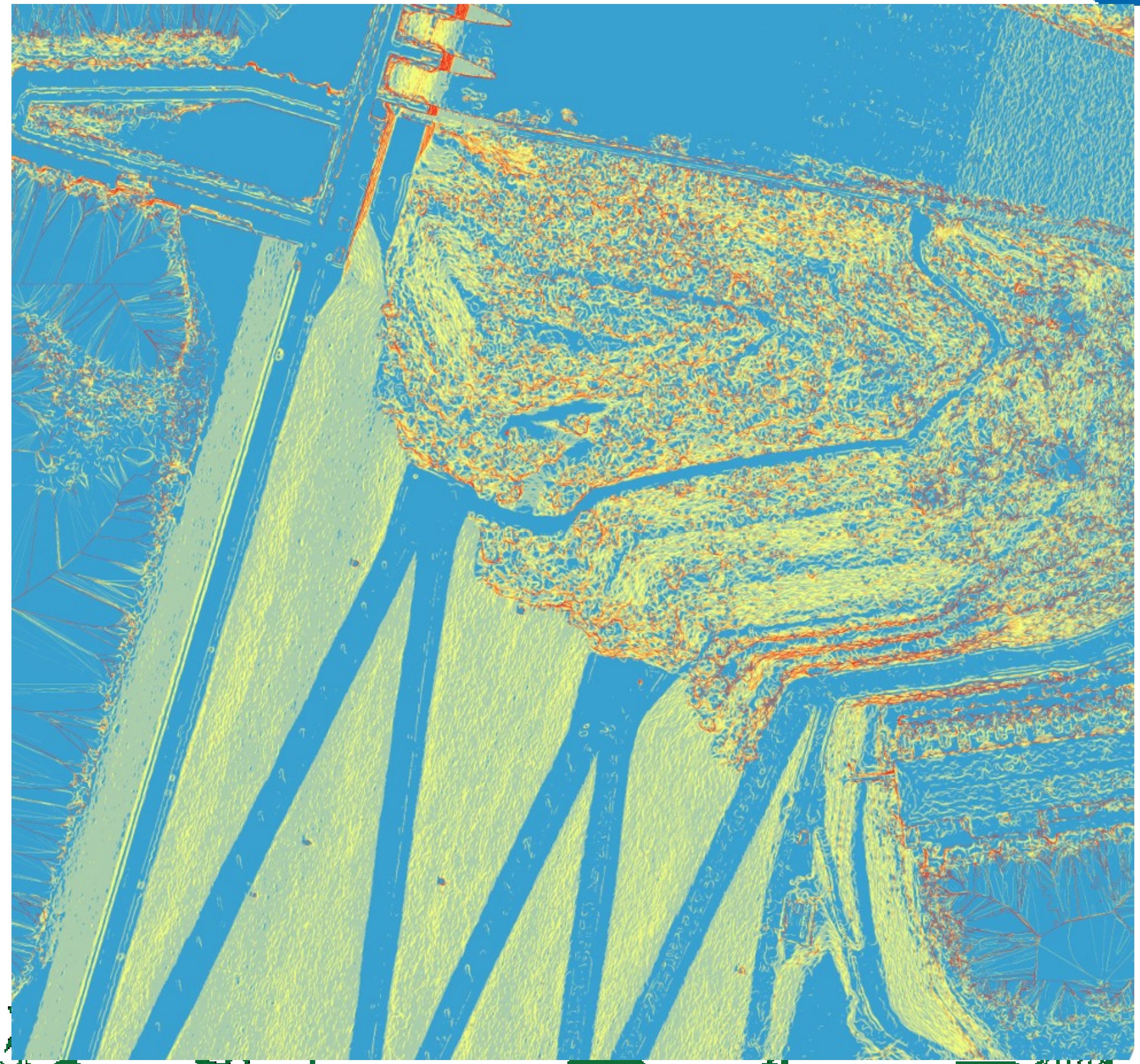
Analysis of Earthquake data of SMA

AI can analysis the huge earthquake data of SMA networks and can generate alarms for any abnormal / beyond limit variations



Displacement monitoring of Dam/Spillway/Slopes

- AI integrated with TLS or survey grade drone can identify any displacement of dam/spillway etc.
- can generate alarms for any abnormal / beyond limit displacements
- DEM can be generated
- Weekly, monthly, yearly Reports can be generated and compared automatically



Analysis of Bathymetry study

Bathymetry data can be effectivity processed by AI tools to analysis the siltation zones in the reservoir and its temporal/ spatial variation

Elevation (m)	Area of year 2025 (Ha)	Volume of year 2025 (Ha. m)	p	Ap	K	Sediment Area (Ha)	Sediment Volume (Ha. m)	Accumulated Sediment Volume (Ha. m)	Revised Area (Ha)	Revised Volume (Ha. m)
500.00	0.00	0.00	0.00	0.00	98.45	0.00	0.00	0.00	0.00	0.00
505.00	0.00	0.00	0.04	0.39	98.45	38.40	95.99	95.99	-38.40	-95.99
510.00	0.00	0.00	0.07	0.53	98.45	52.38	220.50	316.49	-52.38	-316.49
515.00	0.00	0.00	0.11	0.66	98.45	64.98	293.37	609.86	-64.98	-609.86
520.00	0.00	0.00	0.14	0.76	98.45	75.31	350.74	960.60	-75.31	-960.60
525.00	1.00	1.00	0.18	0.85	98.45	84.08	398.44	1359.04	-83.08	-1358.04
530.00	4.00	13.00	0.21	0.93	98.45	91.56	438.93	1797.97	-87.56	-1784.97
535.00	11.00	40.00	0.25	1.00	98.45	98.15	474.38	2272.35	-87.15	-2232.35

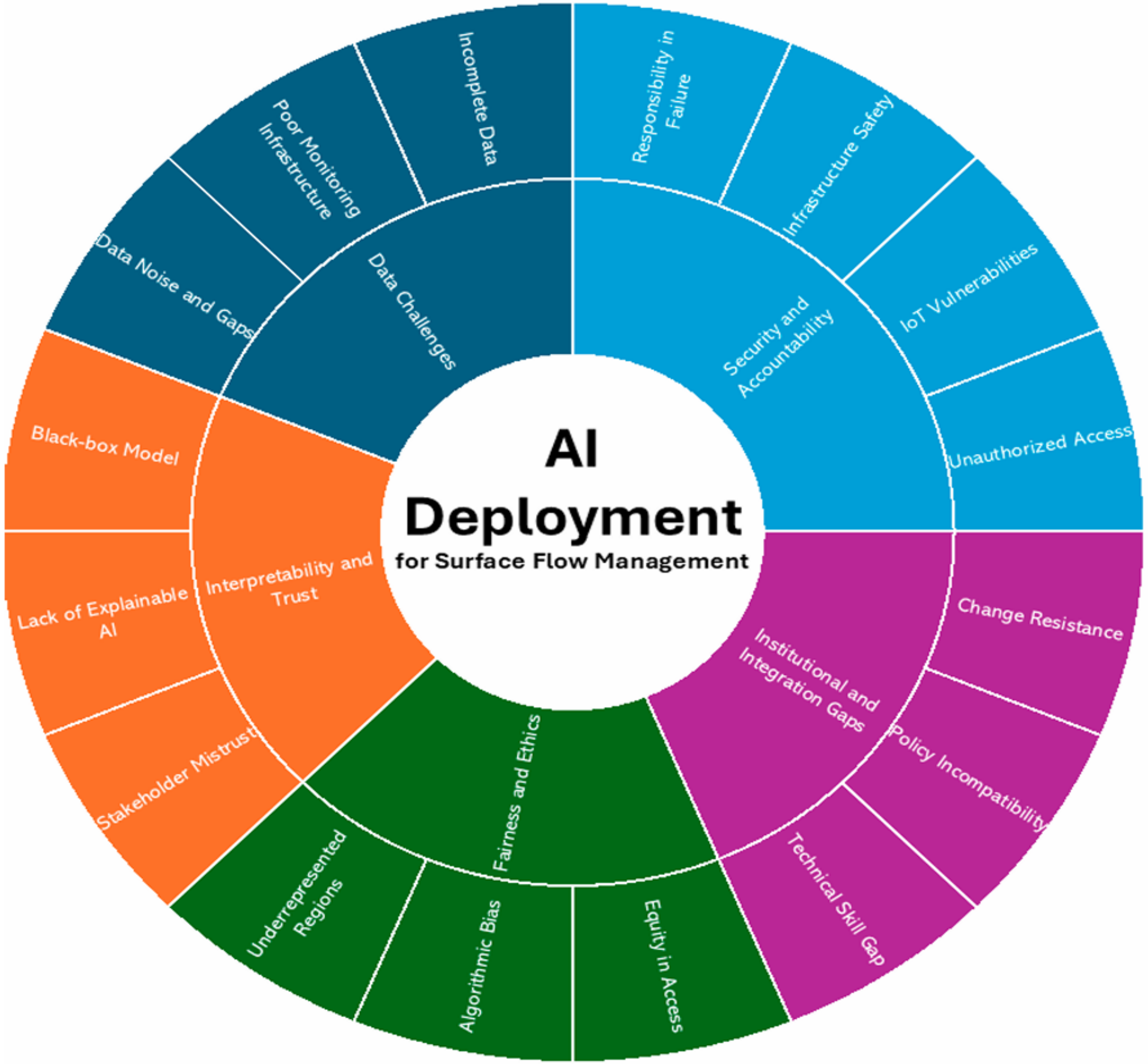
Conservation of Bio-diversity

Improvement in bio-diversity before/after construction of a dam can be examined with help of AI synchronizing with remote sensing data/ AI drones

Government initiatives and key projects

- **Dam Rehabilitation and Improvement Project (DRIP):** Launched in 2012 with World Bank assistance, DRIP aims to improve dam safety and operational performance in participating Indian states. As part of this initiative, the web-based **Dam Health and Rehabilitation Monitoring Application (DHARMA)** was developed as a step toward using AI to manage existing water assets.
- **India AI Mission:** Launched in 2024, this government-led initiative aims to bolster India's global leadership in AI, with benefits expected to apply across sectors, including dam safety.
- **Dam Safety Act, 2021**: This legislation strengthens the institutional and regulatory framework for dam safety in India, creating a pathway for integrating innovative technologies like AI.
- **NHPC** is setting up National level **Master Control Room (MCR)** to analyze the data of all hydro project for timely alarms in case of any abnormal patterns/emergency

Core challenges of deploying AI



- **Data quality and availability**
- **Algorithm interpretability**
- **Human supervision**
- **Ethical considerations**
- **Adaptability to changing conditions**
- **Investment and resources**
- **Policy compatibility**
- **Technical skills**

Implementation methodology: From Part to Whole

- Tailormade training program on AI in dam safety
- Mock drills for EAP/DMP procedures with d/s population, NDMA, SDMA and local administration for awareness about various alarms/sirens, do's/don'ts
- Instrumentation Data Recording and Analysis by Expert Agency along with AI
- Information sharing with villagers and other stakeholders by news papers, display boards, pamphlets, radio messages, physical visits and meetings, Nukkad Natak in local language, videos and animations, Competitions in schools
- Plan to communicate to all nearby travellers through automatic SMS
- Integrate AI in instrumentation data analysis and revival of instruments
- Integration of Dam Safety with Disaster management for higher utility

Miles to Go: Way Forward

1. Various Studies Related to Dam Safety/ AI in Dam Safety
2. Automatic data recording and transfer from remote locations: e.g. Discharge, Temperature, pore pressure etc. from Galleries, dam core
3. Remote Operation of Spillway gates in case of non-accessibility of spillway control room: through AI: to avoid gate failures
4. Knowledge sharing with Nearby projects/Govt Bodies in same basin
5. More technical conferences on dam safety/ AI in Dam Safety
6. Dam Health assessment via Geophysical investigations and integration with AI
7. Inputs of Siltation study/ Bathymetry data to be merged with AI
8. Better Hydrometeorological and SMA networks in Basin for reliable data

Conclusions

- Statistical Analysis of dam failures data is summarized
- Koldam is safe as per all case of dam failures statistics
- AI and ML can be used in dam safety domains
- Lot of improvement at the machine level and human level
- Serious need of knowledge sharing and training, Govt support for implementing AI in Dam Safety
- AI can be used in many areas in thermal also: Ash dyke stability, instrumentation data, Chimney & Cooling Tower Stability, alarm systems, flow patterns etc.

References

- Dam Safety Act 2021
- ICOLD/INCOLD/CBIP Literature
- ASDSO Literature
- News Clippings
- Research Papers on Dam Safety/AI
- FEMA/USBR Presentation on Dam Safety

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Thank You

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