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ICOLD'2024 : Release of Special Publications

During the opening session of the prestigious 92nd Annual Meeting and Symposium of ICOLD'2024 held at Bharat Mandapam, New Delhi, the following Special Publications were officially released by INCOLD. These books were launched during the event by Ms. Debashree Mukharjee, the Hon'ble Secretary, Ministry of Jal Shakti, Government of India.

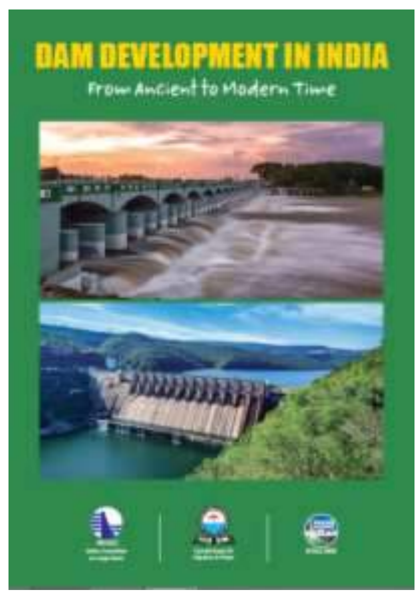
- ***A Pictorial Display of Dams in India***
- ***Dam Development in India - From Ancient to Modern Time***

Chief Editors:

Aditya K. Dinkar, Secretary General, INCOLD & Secretary, Central Board of Irrigation & Power
Kamlesh K. Singh, Treasurer, INCOLD & Director (Water Resources), Central Board of Irrigation & Power

A Pictorial Display of Dams in India**:** A Coffee table book that pictorially illustrates a panorama of dams built in India. The book showcases over hundred number of dams of various types, known for their merits based on great height, large reservoir capacity as well as for the design features and methodology of construction. Besides portraying state-of-the-art large multipurpose & hydropower dams and highlighting their technical features, the book also exhibits some of the old structures that rank among globally historic dams still in operation. ***[234 pages]***

Dam Development in India - From Ancient to Modern Time**:** This important publication documents the five thousand years of dam development history of India, to acquaint about the rich heritage of dam building of this nation. This book presents the chronology of dam development in India. It traces the evolution of dam building in this subcontinent, spanning across different eras - from Ancient to Modern time. It illustrates the knowledge of hydraulics that prevailed in the ancient time and portrays the engineering marvels built in this country through centuries. The activities during the different periods are elaborated that highlight the country as a leading dam building nation. ***[208 pages]***



The publications are ideal additions to the libraries of policy makers, engineers, and professionals in the water resources sector, contributing to research and development in dam infrastructure.

The cost of the publications (Hardbound):

- **Dam Development in India**: ₹ 3,000 per copy, excluding Postal charges [USD 50, inclusive of Postal charges]
- **Dams in India**: ₹ 3,000 per copy, excluding Postal charges [USD 50, inclusive of Postal charges]
- **Set of two publications**: ₹ 5000, excluding Postal charges [USD 100, inclusive of Postal charges]

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INCOLD Journal

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ABOUT JOURNAL

INCOLD Journal is a half yearly journal for fully-reviewed qualitative articles on aspects of the planning, design, construction and maintenance of reservoirs, dams and barrages, foundation and scientific aspects of the design, analysis and modelling of dams and associated structures.

In addition to the information on the research work on the relevant subjects, the journal shall provide information on the related technical events in India and abroad such as conferences/training programmes/exhibitions etc. Information related to ICOLD activities shall also be highlighted.

All communications to be addressed to :
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Editorial

Dear Readers,

Greetings from INCOLD, New Delhi!

Welcome you to the latest edition of the half-yearly journal of the Committee of the International Commission on Large Dams (INCOLD). In this edition, we bring you a compelling array of research papers that delve into critical issues facing the dam engineering and hydropower sectors today.

One of the papers explores the broader implications of hydropower as a sustainable energy source, highlighting both its positive contributions to energy security and its challenges, including the social and environmental impacts of large dams. It emphasizes the need for a holistic approach to hydropower, ensuring that these projects contribute meaningfully to sustainability while mitigating adverse effects.

Another paper focuses on the Bhopalpatnam Hydropower Project, a long-anticipated initiative in the Indrāvati sub-basin that promises to generate 1000 MW of electricity. Despite its potential, progress on the project has been stalled due to interstate coordination issues between Maharashtra and Chhattisgarh. This highlights the complexities of large-scale dam projects, where regional cooperation and governance play a pivotal role in moving forward.

The journal also covers the pressing issue of climate change and its disruptive effects on the water cycle, leading to extreme weather events such as floods and droughts. The Himalayan region, in particular, is facing significant challenges. These events underscore the urgent need for Early Warning Systems (EWS) to safeguard communities, reduce economic losses, and enhance disaster preparedness.

Lastly, the journal addresses the unique challenges of Himalayan hydropower dams. Recent disasters have highlighted gaps in current dam designs and spillway systems, which are often inadequate to handle extreme weather events like Glacial Lake Outburst Floods (GLOFs) and flash floods. In response, government initiatives such as India's Dam Safety Act and the World Bank's DRIP program are playing a crucial role in improving dam safety and ensuring the long-term viability of these critical structures.

We hope this edition provides you with valuable insights into the evolving landscape of dam engineering, hydropower sustainability, and climate resilience. These papers not only shed light on the current challenges but also encourage further research and discourse on how we can collectively improve dam safety, water resource management, and disaster resilience.

A.K. Dinkar
Secretary General
Indian National Committee on Large Dams

Sustainable Development through Dams and Hydropower

Dr. Bhagwan Sahay Meena & R.C. Senan

ABSTRACT

This paper highlighted the need of hydropower thinking from the perspective of sustainability. Hydropower is a true green and reliable source of energy but simultaneously it has significant impacts on the society and community economically, environmentally, and socially. Normal dam based hydro power generation mechanism is not only helps in producing of electricity but also helps in other ways to the society like irrigation, flood control and domestic water supply. Even large dam can also provide the facility of flood management and create an opportunity for water transportation as done in Three Gorges Project.

Generation of energy through hydroelectric power is one of the way of sustainability (in essence, sustainability means that what we are doing is not at the expense of the future generation) but also devoted to managing environmental, economic and social sustainable issues. Whereas run-of-river based projects only produce electricity which is one of the forms of sustainability.

INTRODUCTION

Electricity is essential for day-to-day activities of human beings. According to the International Energy Agency, the electricity demand will grow at an annual rate of 2.5% by 2030 and required corresponding investments for development. The fossil fuel has played an important role to generate electricity in the last century and still heavily dependent on it. However, the pollution associated with the coal-fired power plants is so serious that great efforts have been put forward to seek the alternative energy resources. Hydropower is a green energy source that contributes less Greenhouse Gas (GHG) emissions and produces less pollution. As compared to other green energy resources and traditional fossil fuel, there are several advantages associated with hydropower:

- The hydropower resources are widely available in India (2/3rd of identified sources is still untapped) and over the world as well.
- Very efficient energy conversion with the help of proven and advanced technology and experience collected in past century.
- Low operating cost and long-life span.
- The cost of fuel i.e. water is a free and its cost component not varying on market conditions.
- Helps in grid balancing due to flexibilization of electricity production mainly through renewable sources.
- Improves economic and social living conditions of surrounding areas.

However, the environmental and social costs of hydropower developments, e.g. resettlement requirements, potential restriction to navigation, modification to local land use patterns, impacts on terrestrial and aquatic habitats, and sediment composition are the very important part of ecosystem & biodiversity which must be considered.

Countries whose electricity generation dependent on hydro power witnesses the strong economic & sustainable growth even through encountering the global financial crisis. The rapid economic development in India creates a huge demand for energy and electricity.

India is a fast-growing nation and development required energy proportionately. As India is a power deficit country and to meet the growing requirement, dependency on fossil fuel based power generation exists. To match the growing demand of power either new large coal-based plants are being implemented or existing plants are being expended. Further, Solar based power plants are grooming in irrational/ haphazard manner which not fulfilling the gap between demand and supply but makes the entire electricity generation system unstable and fossil fuel-based power plants runs under stress and causing increase in emission and transmission losses.

In such circumstance the hydro power can play a vital role particularly dam-based project which are more energy sustained/ reliable as compared to the run-of-river projects. The reliability of run-of-river project affects with the weathers whereas, dam-based projects are more efficient and reliable.

HYDROPOWER AND SUSTAINABILITY

Sustainable development focuses more on the efficient measures of economic developmental activities that can be more in equitable manner and subsequently have limited impacts created to the environment.

Also, the dimensions of sustainability are well addressed in Sustainable Development Goals (SDGs) where the SDGs are measures devised to build the future that are sustainable, prosperous as well as equitable. The initiatives of SDGs are to provide a framework for addressing the needs of sustainable future through the initiatives and measures that works in broader aspects of activities that are planned for economic growth as well as living standards. This demand for strategic management which basically is 'understanding an organization's strategic position, making strategic decisions for the future, and managing strategy in action' that can address the three phases of development as reflected above.

UNDERSTANDING SUSTAINABLE DEVELOPMENT OF HYDROPOWER.

Hydropower must fit in the sustainability development models where it needs to take account of Economic, Social and Environment dimension starting from its planning phase and continue to operational phase. The dams are main components of hydropower where it need to be constructed in water abundant regions. On the other hand, due to climate change the risk of drought and serviceability of the dams in meeting the needful impacts are in rise.

Dams played a very important role in sustainability directly and indirectly. It has almost zero emission except minor formation of Methane. Other equal risk associated as a contribution of rising climate change are due to the floods that will be of risks to the dams associated with hydropower. Furthermore, there are series of risks as well uncertainty associated with hydropower project. Some pertaining includes Environmental, Social, Economic, Policies and Regulations, Technological Financial, Natural many more which needs to be managed else threatening the availability along sustainability hydropower. There is need understand environmental as well social effects of the hydropower these two factors are most significant indicators which highlighted in case sustainable hydropower.

ENVIRONMENT ASPECTS

The capacity addition for Renewable Energy (RE) mainly Solar & Wind (an uncontrolled and intermittent nature, hence termed VRE (Variable Renewable Energy) worldwide is in rapid phase without realising its side effects on the generation and distribution system. As per the new policy wherein preference being given to RE in the grid and to accommodate the RE during solar window when the requirement of power is at lowest level. In that situation the fossil fuel-based power plants are forced to run on minimum technical load (i.e. approximately 50-55%). The forced curtailment of generation mainly for thermal power plants, the major generating equipment experiences stress which causes to system instability. The entire generating system to work in variable/fluctuating with respect to the variable Renewable power. Particularly boilers where flame became unstable and to sustain the boiler sometimes oil support required which not only causing additional financial implication but also increases emission intensity.

Operating of thermal power plants at constant load produces less emission as compared to variable load and have impacts on environment which lacks unsustainability. Further, Consumption of basic natural resources used in power generation (coal and water) also increases with variable load compared to fixed load.

Soot blowing (is most commonly carried out using dry saturated or slightly superheated steam at boiler pressure) – is a regular feature in coal-based boilers to remove the fly ash contents deposited on water walls of boiler (normally done in each shift). Technically soot blowing is recommended while boilers are working on or above 75% PLF to avoid the flame instability. Since boilers are running on partial / minimum technical load in day times to till evening to accommodate variable renewable power (mainly solar) therefore, soot blowing during the time avoided to ensure flame stability. In such situation soot blowing is doing only after boiler attains the desired PLF which means before 6 AM and after 8 PM. It means during daytime the quantity of ash deposited on water wall became double (deposition of approximately 14 hours) and evening soot blowing generates much more fly ash quantity as compared to normal shift. The ESP is unable to cater the entire ash for that cyclic period. Therefore, the PM content in flue gases increases beyond the permissible limits that certainly affect the environment.

Economical Aspects - Grid unbalancing – Unlike conventional sources of energy, VRE cannot follow the grid power demand. The challenges for grid stability and operation becomes more demanding as the percentage of VRE increases in the total share of generation in the grid. It becomes more challenging when the bulk of

Conventional power generation comes from Coal power plants which has technical limitations for no of starts and stops as well as ramping up and down. There is urgent needs to be a balance in production and consumption within an electrical grid. For there to be stability, the energy generated must be equal to the energy consumed. So, "unreliable" energy sources don't fare well with conventional grids. Since Solar and wind power portfolio increased in grid the grid disturbance started. Initially in Indian grid perspective the disturbance was not much relevant as the but as the generation increased it started unbalancing the grid.

Auxiliary Power(AP) consumption – auxiliary power consumption is vary with the load variation and observed that AP is less while system running on constant load as compared to the variable load. New equipment are being designed to match the current variables, but older equipment faces the problems and due to variation in distribution system the AP consumption increases.

Social aspects – increase in Particulate Matter (PM) contents due to change is soot blowing cycle, directly affecting the social life of the people who resides in the vicinity of thermal power plants. The excess PM falls in field and affect the crop quality and yields. Due to use of oil required for flame supporting also adds the emission contents which affects the environment locally as well as globally.

All these factors cumulatively affecting the sustainability and anything which can neutralise the effects is the Dam / Reservoir based hydro power which can start-stop within a couple on minutes. The hydro power is clean and sustainable source of power and frequent start stop of hydro doesn't have any environmental impacts too. Hydropower's flexibility allows it to seamlessly integrate other energy sources and act as a force multiplier for other renewables and makes it an invaluable resource for powering the grid after an outage.

In addition to above hydro projects have various other advantages with respect to the Environment, Economic and Social, etc. are follow:

- Hydropower is a renewable source of energy. The energy generated through hydropower relies on the water cycle, which is driven by the sun, making it renewable. It is fuelled by water, making it a clean source of energy.
- Hydroelectric power is flexible. Some hydropower facilities can quickly go from zero power to maximum output. Because hydropower plants can generate power to the grid immediately, they provide essential backup power during major electricity outages or disruptions.
- Hydropower provides benefits beyond electricity generation by providing flood control, irrigation support, and clean drinking water.
- Hydropower complements other renewable energy sources. Technologies like pumped storage hydropower (PSH) store energy to use in tandem with renewables such as wind and solar power when demand is high.
- Hydropower creates jobs in rural locations and boosts local economies.
- Impoundment hydropower creates reservoirs that offer recreational opportunities such as fishing, swimming, and boating. Most hydropower installations are required to provide some public access to the reservoir to allow the public to take advantage of these opportunities.

Sustainability is not a term which can be defined in a statement, balancing between environment and development, but it is a sum of all good acts towards conservation of environment, fulfilment of commitments towards the society and improvement in the socio-economic aspects of the people who lives in the vicinity which large dam/ reservoir based hydro project does. The basics towards improvement in sustainability by hydro projects are as below:

- **Conservation of Environment** – Large dam based hydro project could serve the power whenever required within the shortest period in the desired quantum. They can provide the power throughout the year which can fill the gap created by the renewable power (solar and wind). By developing of dam based hydro power projects, a stress on thermal generation can be reduced by way of planning of operation schedule. Further, Hydro projects could frequent start-stop with variable load which helps in grid management. It helps greatly in reduction in emission, conservation of natural resources, reduction in auxiliary power consumption which finally helps in improvement in sustainability.
- **Economic aspects** – development of large dam / reservoir it creates huge direct or indirect employment and open many options for self-employment. Thousands of migratory labours work for years in the dam construction, and they spent for their livelihood which enhance the financial conditions of the locals. Development of basic / advance health centres and educational facilities also help in upliftment of the locals. It has a positive impact on stopping of migration of local in search of employment.
- **Social aspects** – Dams are being constructed from historical times to provide the needs of many civilisations and have the benefits of improved health and life from the provision of a clean water supply from reservoirs, protection from drowning

and damage from floods, the provision of power from hydro schemes, water for drinking and irrigation, pleasant recreational opportunities and environmental benefits.

Flood protection from river flooding- Dams provide the benefit of protection from flooding from rivers in two ways, either by direct protection or by routing the flood through a reservoir provided for other means thus reducing the peak flow in the river downstream of it. Flood defence reservoirs are often used as amenity areas or used for grazing or other agricultural purposes. Thus, dams provide the benefit of being able to carry out development without the risk of increased flooding downstream.

Further, large dam/reservoir holds the water throughout the year which keeps on recharging natural estuaries/ aquifers which maintains moisture in soil of mountains which helps in maintaining green covers even during dry seasons.

Climate Changes new Aspects - Renewable power like solar and wind creating grid imbalance due to intermittent nature. Till an economical battery storage system is developed, hydro (i.e. pumped a water battery) the answer for bridging gap. Climate change has disturbed rain patterns across globe heavy precipitation leading flood / flash flood, landslides, etc. A dam can mitigate damages downstream some extent. Advanced warning save lives plan better operating procedures. The future transportation likely be based on green hydrogen which requires large amount of water. As, already become scarce resource may required meet high demand hydrogen.

CONCLUSIONS

Hydropower is a green and clean power, still 80% of it is untapped which mean huge potential of hydropower worldwide exits. The hydropower development brings in several benefits such as GHG emission reduction, providing the flexibility of electricity production and supply, flood control, social and ecological development. However, the sustainability issues associated with hydropower developments should not be neglected. Reservoirs provide water quantity controls that are used for flood control and flexible electricity output while also providing security during drought for drinking water supply and irrigation. Hydropower ranks among the energy sources with the lowest levels of greenhouse gas emissions per unit of energy produced. Yes, there are very serious issues pertains to the dam safety, but it can be managed by way of installation of early flood warning mechanism within the catchment area which predicts the probable discharge dam can receive. Early flood warning system gives real time rain / snow data along with the flow rate which will help to understand how much time it will take to reach the dam boundaries. Accordingly, gate operation can be scheduled to avoid any damage to the structure and downstream as well. Considering the above fact, large dam / reservoir based hydro projects including pumped storage are the only mechanism to attain sustainability in totality.

Rivers, ponds, lakes and streams -
They all have different names, but they all contain water.
Just as religions do - They all contain truths.

Environmental and People Centric Development of Water Resources Projects in Indrāvati sub-basin of India for Sustainable Development : Review of proposed Bhopalpatnam Multipurpose Project

G. L. Dwivedi[1] and Rajesh Shrivastava[2]

ABSTRACT

The technological advancement in the field of remote sensing and contour mapping have immensely helped for water resources planning and evaluating the techno-economic feasibility of the multipurpose river valley projects. The Water Resources Engineers and Planners always intended to critically analyze the outcome of each area of development that may require the study for harnessing its optimum potential. In the instant case the study of the Bhopalpatnam hydropower project, which was planned about 43 years back, is primarily focused for development of the project as peaking power station to stabilize the grid by Madhya Pradesh Electricity Board (MPEB). As a matter of fact, the MPEB had identified all feasible sites in cascade manner across river Indrāvati in the erstwhile state of Madhya Pradesh (now in the state of Chhattisgarh) to harness its hydropower potential having total installed capacity of 2510 MW.

Indrāvati sub basin is part of larger Godavari basin, which is the second largest basin in India after Ganga basin. It offers excellent natural suitable sites for creation of storage dams at 6 locations situated in the state of Chhattisgarh of India. The proposed Bhopalpatnam HEP is an inter-state project of Maharashtra and Chhattisgarh (a joint venture of erstwhile state of MP and Maharashtra) having power sharing of its 1000 MW installed capacity in the ratio 45% and 55% respectively. The total project cost shall be borne each beneficiary state in the same proportion. (Ref. DPR 1983).

The award passed by Godavari Water Dispute Tribunal (GWDTA) in the Year 1980 in respect of allocation of utilization water of Godavari basin paved the way for identification, planning and development of multipurpose water resources projects in Indrāvati sub basin by the erstwhile state of Madhya Pradesh in order to primarily harnessing the abundant hydropower potential available in this basin. However, the development of these power projects comprising major part of the Indrāvati valley have been stalled since last 43 years due to lack of coordinated approach involving various interstate issues.

1. INTRODUCTION

The Bhopalpatnam project is located across river Indrāvati bordering with Maharashtra state such that entire reservoir submergence area is in the state of Chhattisgarh. The identified major Bhopalpatnam hydropower project site now need to be reviewed considering the change in demography, inflows and environmental aspects etc. for people centric and sustainable development.

In the present technical paper, the authors have reviewed the inter-state Bhopalpatnam hydroelectric power project for construction of storage dam planned by MPEB about 43 Years back. The project was conceived by MPEB as peak load hydropower project. In the present scenario efforts have been made to evaluate and plan the scheme by way of inclusion of sustainability features like making provision of peaking power requirement, pumped storage provision, gravity flow irrigation canal and utilization of water head by making provision of canal powerhouse at off take point.

1.1 Indrāvati sub basin

This sub basin includes all the areas drained by the Indrāvati from its source to its confluence with the Godavari river. Indrāvati River is one of the major tributary of the Godavari River which contributes significant inflows during monsoon to the Godavari river. It originates from the Eastern Ghat of Dandakaranya range of Odisha and flows across Chhattisgarh state and meets Godavari near Somnoor Sangam at an elevation of 82.3 m in Maharashtra, where it forms the tri-junction boundary with the state of Chhattisgarh, Maharashtra and Telangana.

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2. Senior Consultant (Water Resources & Structures)

The Indrāvati sub basin lies between latitude 18°27'00" N to 20°27'00" N and longitudes 80°05'00" E to 83°07'00" E and drains a total area of 41665 Sq. Km. The Indrāvati rivers flows for a total length of 536 Km from its origin to confluence with Godavari. The Indrāvati sub basin (G-11) * is part of the larger Godavari Basin. The Indrāvati river during its course flows from the rich forest areas with good rain fall compared to other parts of the Godavari Basin which ensures availability of water almost round the year in this river.

1.2 Hydropower potential of Indrāvati river in the state of Chhattisgarh (India)

There are 7 hydroelectric power project sites are identified in cascade across Indrāvati river and one across Kotri-Nibra river within the state of Chhattisgarh. The total installed capacities of these 8 hydropower sites is 2510 MW as shown in Figure 1.

1.3 Proposed Bhopalpatanam hydroelectric pumped storage scheme*

Bhopalpatnam is the largest proposed hydro power project having installed capacity of 900 MW across river Indrāvati. It has live storage capacity of 4377.64 Million Cum. at FRL 200.00 m. It is an interstate joint venture project to be constructed by Chhattisgarh and Maharashtra state. Contributions of regulated releases from all upstream hydropower storage projects will further benefit all downstream projects in general due to non-consumptive use of water in particular to Bhopalpatanam Project. These benefits shall also include flood and sedimentation control, water availability during non-monsoon period for power generation, irrigation, domestic and industrial use.

An attempt has been made to develop Bhopalpatnam hydroelectric project as pumped storage scheme by proposing a dam / barrage about 2000 m downstream of main dam which is named as Bhopalpatnam-II. The Bhopalpatnam pumped storage scheme shall have higher installed capacity of 1000 MW in place of 900 MW proposed in initial planning. The revised plan shall also include 3X10 MW (one standby / intermittent operation) Canal outlet power house on left flank. A 50 Km long gravity canal for onward irrigation, drinking water and industrial use plan has been prepared to irrigate allocated water of the order of 963 M Cum in Vidharva area of Maharashtra state.

1.4 Upstream and downstream reservoir planning for pumped storage scheme

It is proposed to construct a main concrete dam across river Indrāvati having its location at latitude 19°3'45" N and longitude 80°19'05" E based on DPR named as Bhopalpatnam-I and the location of Bhopalpatnam–II gravity dam which is about 2000 m in having its location as Latitude 19° 03'9.72"(N) and Longitude 80°18'6.01" (E).

The reservoir areas, capacities and contours have been developed using remote sensing and GIS techniques to determine the submergence area at FRL 200 m (msl*) for upstream dam and FRL 175 m for downstream dam at 10 m contour intervals. The submergence area map for Bhopalpatnam-I and Bhopalpatnam- II have also been generated to develop area -capacity table for entire Bhopalpatnam pumped storage scheme. The reservoir area and capacity are presented in the Table 1 and Table 2.

The reservoir submergence area and the contours plotted at the 10 m intervals have been prepared for Bhopalpatnam –I upstream and Bhopalpatnam –II downstream reservoirs are appended as Annexure-I and Annexure-II respectively.

2. WATER AVAILABILITY STUDIES

The water availability studies for Bhopalpatanam Project incorporating Rainfall and Runoff and Gauge and Discharge Data from the year 1943 to 1983 for the intervening catchment between Bodhghat 500 MW hydropower project located in the upstream of Bhopalpatnam dam site have been carried out. The water availability studies were undertaken for the 4 months of rainy season (June to October) only to arrive at reasonable and conservative water availability for Bhopalpatnam Project. The releases from Bodhghat and intermediate projects proposed in the cascade across river Indrāvati in the downstream of Bodhghat project have not been considered in the studies.

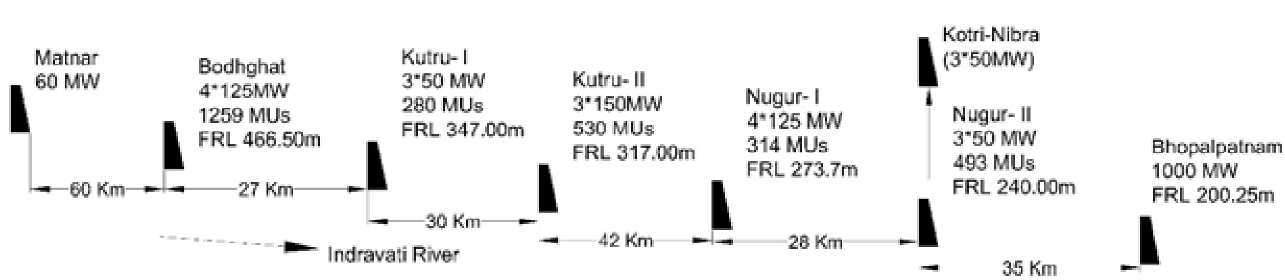

Fig. 1 : Proposed hydropower project sites in Indrāvati sub-basin in the state of Chhattisgarh

Table 1 : Reservoir area and capacity of Bhopalpatnam-I upstream reservoir

	Gross storage area - volume (Cum)				Lives storage area- volume (Cum)	
S.N.	Elevation (m)	Area (m)	Avg. area	Volume (Cum)	Avg. Area	Volume (Cum)
1	128	0		0		0
2	130	112218.033	56109.0165	112218.033		0
3	140	763763.544	437990.7884	4379907.884		0
4	150	2930120.37	1846941.957	18469419.57	1846941.96	0
5	160	7120520.37	5025320.37	50253203.7	5025320.37	50253203.7
6	170	19016970	13068745.17	130687451.7	13068745.2	130687451.7
7	180	49074863.3	34045916.65	340459166.5	34045916.6	340459166.5
8	190	156642000	102858431.5	1028584315	102858432	1028584315
9	200	404297570	280469785	2804697850	280469785	2804697850
	Total Volume (Cum)			4,377,643,532		4,354,681,987
	Total Volume (M Cum)			4,377.64		4,377.53

(*) msl = Mean sea level

Table 2 : Reservoir area and capacity of Bhopalpatnam-II downstream reservoir

		Gross storage area - volume (Cum)			Lives storage area- volume (Cum)	
S.N.	Elevation (m)	Area	Avg. area	Volume	Avg. Area	Volume
1	120	241,253				
2	130	616,761	429,007	4,290,070		
	135	697,280	657,020	3,285,102		
3	140	777,799	697,280	3,486,400	737539.454	3687697.27
4	150	942,824	860,312	8,603,117	860311.731	8603117.308
5	160	1,091,641	1,017,233	10,172,328	1017232.78	10172327.81
6	170	1,267,989	1,179,815	11,798,151	1179815.11	11798151.07
7	175	1,432,458	1,350,223	6,751,117	1350223.39	6751116.941
	Total Volume (Cum)			48,386,285		41,012,410
	Total Volume (M Cum)			48.39		41.01

The computations of 50%, 75% and 90% dependable annual yields have been carried out by the authors on the basis of the CWC data for the Bodhghat project. The MPEB had computed dependable annual yields in the DPR for intervening catchment area between proposed upstream Bodhghat project and Bhopalpatnam which is tabulated in table 3.

Table 3 : Dependable annual yields for Bhopalpatnam project

Dependability (%)	Dependable yield for Bodhghat* (June- Oct)	Dependable yield for Bhopalpatnam** (June - Oct)	Total annual yield for Bhopalpatnam project
50%	4939.29 M Cum	14296.055 M Cum	19235.345 M Cum
75%	3812.01 M Cum	12581.51 M Cum	15993.52 M Cum
90%	3141.73 M Cum	10081.247 M Cum	13222.977 M Cum

(M Cum = Million cubic meter)

(*) DPR Bodhghat Project Vol. -I Table-V, Reservoir Operation Studies.

(**) Salient features of Bhopalpatnam hydroelectric project (a joint venture of MP and Maharashtra) MPEB DPR 1983)

Note: After construction of Bodhghat Project, the releases after power generation from Bodhghat shall contribute significantly to Bhopalpatnam project.

3. PLANNING AND OPTIMIZATION OF WATER RESOURCES POTENTIAL OF BHOPALPATNAM MULTIPURPOSE PROJECT

On the basis of water availability studies it is found that the abundant water resources potential may be utilized to optimize people centric development by application of recent technological developments made in the field of surveying, remote-sensing and GIS applications. The allocation of overall water resources potential has been utilized in the following areas:

1. Development of hydropower pumped storage scheme (underground intake and powerhouse in right flank of Bhopalpatnam –I and planning for construction of downstream dam (Bhopalpatnam –II)
2. Utilization of allocated water for irrigation, drinking and industrial use for Vidharva region of Maharashtra state through gravity flow canal up to Pranitha river and thereafter by lift scheme.
3. Utilization of available head at the canal out-let to generate hydropower at the downstream of Bhopalpatnam –I dam. (underground intake, power house and canal out-let on left flank).

   On the basis of site specific data and water availabilities studies, the desk studies have been carried out by the authors to optimize the allocation of available water during the water year as per GWDT Award for Maharashtra state from Indrāvati river from Bhopalpatnam interstate project.

3.1 Development of hydropower pumped storage scheme

The basic salient features of the proposed reservoirs and installed pumped storage capacity of Bhopalpatnam pumped storage scheme are shown in table 4.

3.2 Development of scheme for utilization of water for irrigation, domestic and industrial use

The allocation of 34 Thousand Million Cubic feet (963 M Cum) of water has been made by the Godavari Water Dispute Tribunal (GWDT)* from Indrāvati river in the upstream of Bhopalpatnam dam (Clause-D page 45). The state of Maharashtra can use additional quantum of 7 TMC* (198 M Cum) water from the downstream of Bhopalpatnam hydropower project (Clause-E page 45) for its existing / proposed projects / schemes each not more than 1.5 TMC (42.5 M Cum). Thus state of Maharashtra can use its right to drawl of total 1161 M Cum of water from Indrāvati river from Bhopalpatnam reservoir.

Table 4 : Salient features of Bhopalpatnam pumped storage scheme

Descriptions	Bhopalpatnam-I		Bhopalpatnam-II	
Latitude	19^{o} 03’ 45” N		19^{o} 03’9.72” N	
Longitude	80^{o} 18’ 05” E		80^{o} 18’ 6.01” E	
Length of dam at top	445 m	At top	470 m.	At top
Top of dam (elevation)	202.25 m	With free bd.	176.50 m	
FRL	200.00 m	Revised FRL	175.0 m.	Adopted FRL
MWL	201.16 m.		175.0 m	
River Bed Level	128.50 m.		130 m	
MDDL *	142.0 m		135 m	
Gross Head	71.75 m	60 m Pumped	45 m	
Gross Storage at FRL	4377.64 M Cum	At FRL 200 m	48.39 M Cum	At FRL 175 m
Design Head	65 m	w.r.t. D/s MDDL	NA	MDDL135 m
Peaking Time Operation	6 Hours		6 Hrs.	
Live storage Capacity	4,377.53		41.01 M Cum	At EL 135 m
Installed Capacity	4X 250 MW**	Pumped Storage	NA	
Discharge after power generation	460 Cum / sec per unit	Total 1840 Cum per sec		

(*) MDDL Maximum draw down level
(**) Selection of lower capacity turbine of 150 MW each with 8 units having discharge 275 Cum / sec per unit may also be considered.

In order to utilize the head available at canal off take point it is proposed to harness hydropower energy from Bhopalpatnam-I reservoir:

3.2 Canal bed power house for utilization of available head at take-off point

It is proposed to construct a lined canal from left flank of Bhopalpatnam dam by constructing an underground intake and power house. The take off point of canal is located in the downstream of Bhopalpatnam-I reservoir at left flank. The gravity flow canal having discharging capacity of about 30 Cum per second and it is 50 Km long planned to be constructed up to Pranitha river in the state of Maharashtra. The canal shall pass over river Pranitha through an aqueduct having its bed level 130 m at the location of 19^o 17’ 23” N and longitude 79^o 56’ 59” E. The authors have developed the gravity flow canal alignment for 50 Km length as per scope of the technical paper, with the intention that the detailed planning shall be carried out by the concerned state government to utilize the allocated water by introducing lift irrigation scheme for higher elevations, allocation of industrial and domestic water to water starved region of Maharashtra. The contour plan showing the gravity flow canal alignment for 50 Km length from origin to aqueduct over river Pranitha is appended as Annexure-III. The salient features of canal outlet intake and power house are as shown in table 5.

Table 5 : Salient features of canal outlet intake power house

Description	Values
MDDL	160.0 m
Gross Head	40.00 m
Canal bed level at off take point	160 m
Gross Storage at FRL (200 m)	4,377.64 M Cum
Design Head	40 m
Installed Capacity	20 MW (3X10 MW one unit standby)
Canal designed discharge	31 Cum per sec per unit.
Normal and peaking operation	24 hours during monsoon and canal operation
Irrigation requirement during nonmonsoon season for 6 months	963 M Cum (34 TMC*)
Total Discharge after power generation	62 Cum / sec for 2 units. 50 % through diversion arrangement to canal and balance to downstream of Bhopalpatnam - I dam

(*) TMC- Thousand million cubic feet

4. CONCLUSION

The most commonly adopted storage technology is hydropower pumped storage scheme which nearly 90.3% accounts far to absorb variable renewal energy demand either locally or at the grid level. In order to harness the water resources potential of river valley projects, a holistic and people centric development approach shall be adopted to maximize the scares renewal water resource. The technological advancements made in the field of remote sensing and GIS areas which may be used to approximately estimate the overall potential that may be harnessed from the suitable site such as Bhopalpatnam. The authors have not only made attempts to study and present the harnessing the available water resources potential of Bhopalpatnam pumped storage scheme but also included the irrigation, domestic and industrial water requirements for the water starved region of Maharashtra state of India.

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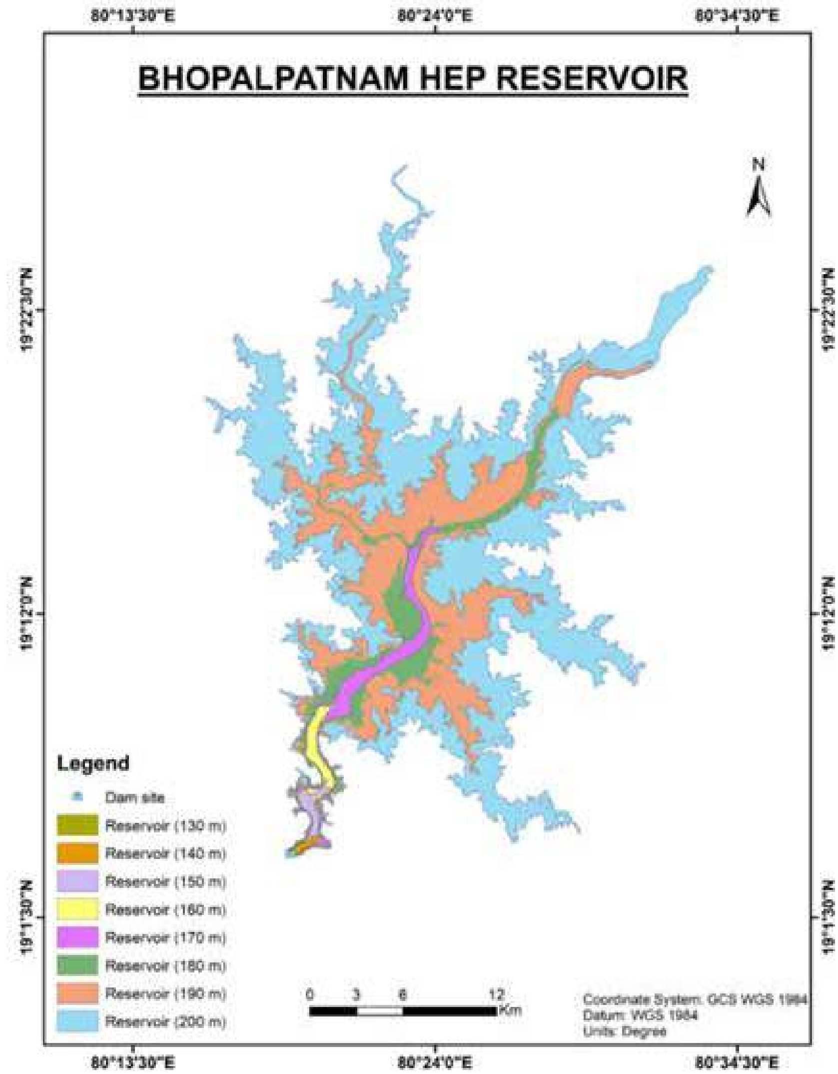
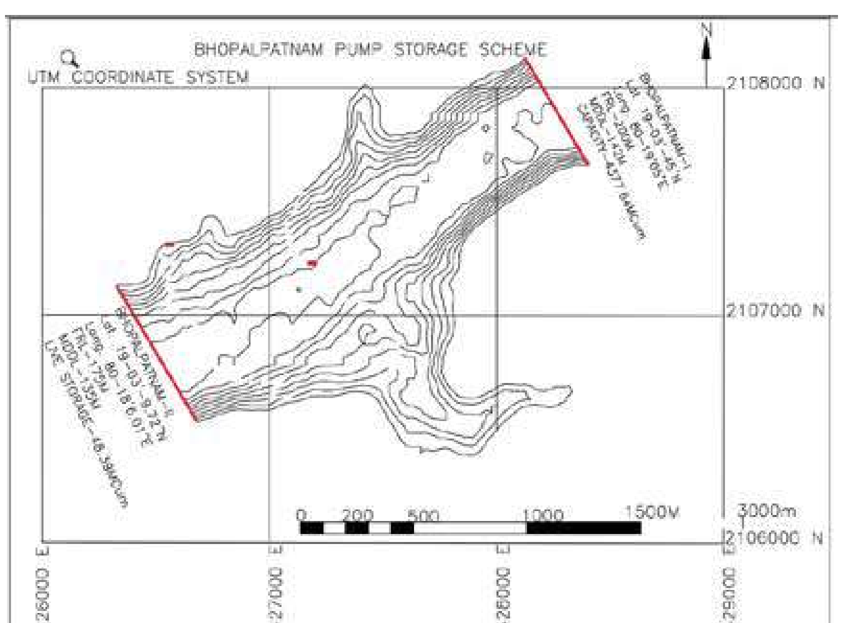
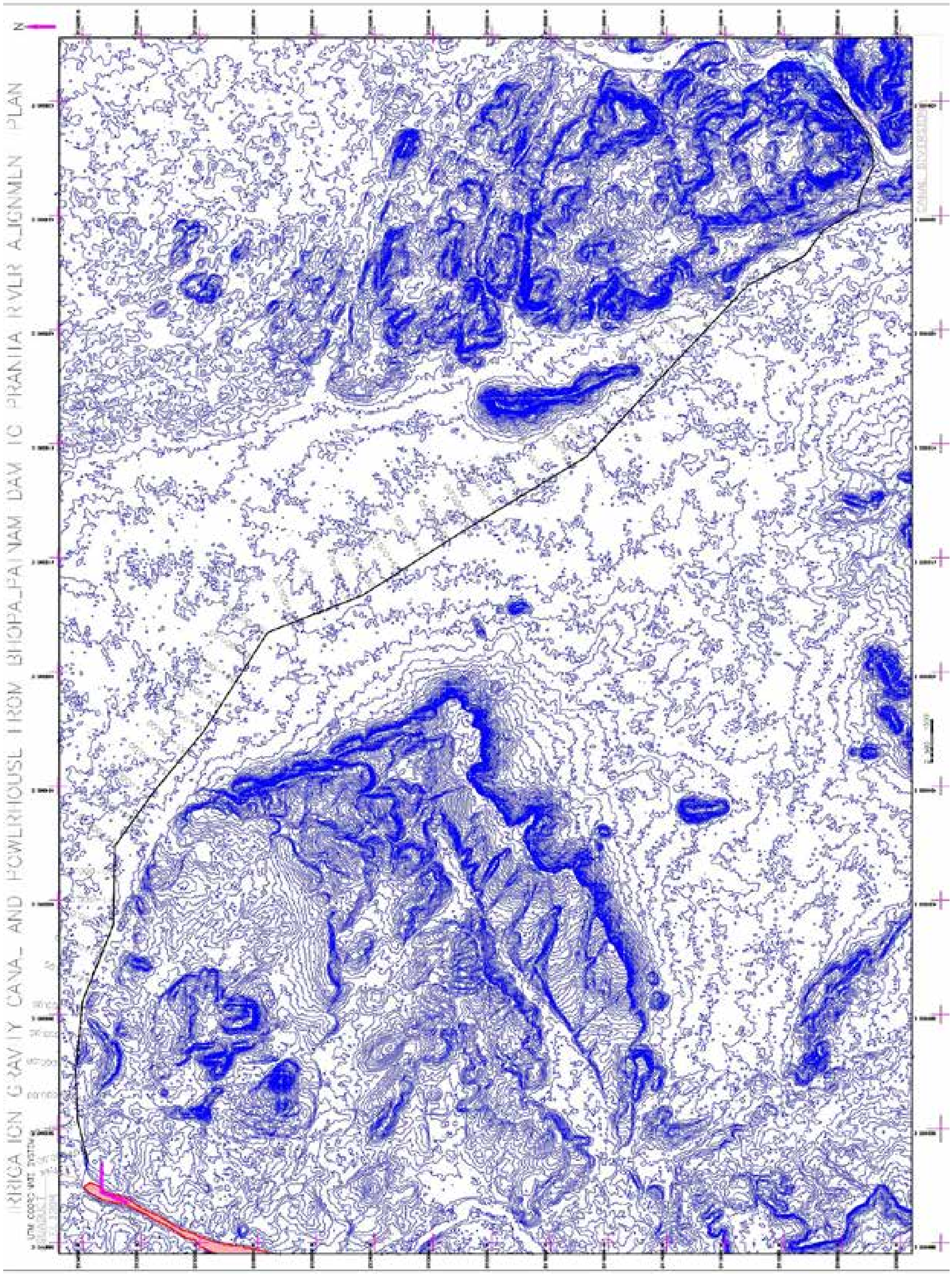
Annexure- I



Annexure- II



Annexure- III



Protection of Communities from Flooding by Way of Effective Early Warning Systems: Mitigating Costs and Enhancing Resilience in Hydroelectric Projects

V. K. Saini[1], M. Mishra[1] and K. Kumar[1]

ABSTRACT

Climate change is impacting the water cycle by influencing when, where, and how much precipitation falls which thereby causing severe droughts and floods. In recent years, Himalayan Region has witnessed multiple disasters such as Uttarakhand Disaster of 2013, Chamoli District disaster in Feb'2021 and Glacial Lake Outburst Flood (GLOF) event in Teesta Basin in Oct' 2023 which resulted in flash floods in downstream areas claiming numerous lives, damaging Hydroelectric projects and other infrastructure. Developing an Early Warning System (EWS) especially in the hilly regions is essential to mitigate the impact on lives, property damage, displacement, environmental degradation, and health risks.

Flooding is one of the most common and devastating natural disasters that affect millions of people around the world every year. Therefore, protecting communities from flooding is the need of the hour. There are various measures that can be taken to prevent or reduce the impact of flooding, such as improving drainage systems, building flood barriers, restoring natural habitats, implementing early warning systems, and raising awareness among the public.

Effective Early Warning Systems (EWS) plays a crucial role in mitigating the economic loss due to various hazards, ranging from natural disasters to health emergencies. This paper delves into the significance of EWS in terms of reducing economic losses, enhancing preparedness, and fostering long-term resilience of Hydroelectric Projects and Power Stations. By examining case studies and available economic data, the paper underscores the tangible benefits of investing in robust EWS to protect economies and livelihoods.

1. INTRODUCTION

Hydropower Projects located at Himalayan regions of India are most vulnerable for multiple kind of disasters such as Widespread rainfall, Landslides, Cloudburst, Flash floods, Earthquakes, Avalanches, Glacial Lake Outburst Flood (GLOF), and Landslide Lake Outburst Flood (LLOF) etc. Rock mass/Glacier fall sometimes blocks the flow of water in the stream which leads to the creation of artificial lake. This artificial dam breaches suddenly and thereby creating flash floods.

The Early Warning System (EWS) is a need of the hour to reduce the risk to the life and property due to such disasters. An early detection of incoming flood and warning system in place can provide sufficient time to protect life and property. One cannot stop natural disasters but can arm ourselves with knowledge to minimize the damages. Early Warning Systems (EWS) are integral components of disaster risk reduction strategies, providing timely information to decision-makers, communities, and businesses to make informed choices and undertake proactive measures. This paper focuses on the economic aspects of EWS, demonstrating how their effectiveness can lead to significant cost savings and bolstering overall resilience as per experience gained by NHPC.

2. ECONOMIC IMPACTS OF HAZARD EVENTS

Hazards, whether natural or human-induced, can cause substantial economic losses. The direct costs include infrastructure damage, property loss, and medical expenses, while indirect costs encompass casualties (human/ livestock's), business interruption, decreased productivity, and long-term economic setbacks.

EWS offer several economic benefits:

2.1 Timely Response and Preparation:

EWS provide advance notice, enabling authorities to activate emergency response plans and implement preventive measures. This timely response reduces the extent of damage and accelerates recovery, resulting in lower economic losses.

2.2 Business Continuity:

For businesses, EWS facilitate informed decision-making and contingency planning. They allow companies to adapt their operations such as flushing, protect assets by passage of flood safely to the downstream, and ensure the safety of employees, minimizing disruptions and financial losses.

1. NHPC Limited, Faridabad, India

2.3 Reduced Reconstruction Costs:

By minimizing the impact of disasters, EWS significantly decrease the need for extensive postdisaster reconstruction efforts. This translates to substantial cost savings for governments, communities, and businesses.

2.4 Preservation of Critical Infrastructure:

When disasters strike, infrastructure damage can disrupt services for extended periods, affecting economies and people's lives. EWS help safeguard these vital systems by providing advance notice, allowing operators to take preventive measures. By minimizing damage to infrastructure, EWS prevent prolonged service outages and mitigate the associated economic toll.

2.5 Insurance:

Effective EWS reduces insurance claims and thereby lowers premiums. Insurers recognize projects/power station with robust risk management practices.

2.6 Community Impact:

Hydropower projects often serve local communities. EWS protects lives, livelihoods, and property, fostering goodwill and social stability.

3. EARLY WARNING SYSTEM IN DAM SAFETY ACT, 2021

Dam Safety Act 2021, Chapter VIII, clause 35 of Gazette Notification states:

(1) Every owner of a specified dam in respect of each specified dam , shall

(a) Establish well designed hydro-meteorological network and an inflow forecasting system

(b) Establish an emergency flood warning system for the probable flood affected areas downstream of dam.

(c) Test or cause to be tested periodically the functioning of systems referred to in clauses (a) and (b)

(d) Install such scientific and technical instruments which are invented or adopted from time to time for the purpose of ensuring the dam safety and the life and property of people downstream

(e) Make available the information related to maximum anticipated inflows and outflows including flood warning and an adverse impact of the same, if any, on persons and property towards the upstream or downstream of dam, to the concerned district authorities and also make available the information related to the operation of reservoirs.

The inclusion of Early Warning System (EWS) in Dam Safety Act, 2021 by law makers, shows its importance and emphasis given for proper and timely implementation.

4. EARLY WARNING SYSTEM IN NHPC PROJECTS/ POWER STATIONS

NHPC Limited, a Govt. of India Enterprise, incorporated in the year 1975 with an objective to plan, promote and organise an integrated and efficient development of hydroelectric power is the leading organisation and largest hydropower producer of the country in Central Sector. NHPC's total installed capacity as on 29 February,2024 is 7097.20 MW including 1546 MW in Joint Venture, comprising 6971.20 MW from 22 Hydro Power Stations, 76 MW from two Solar Power Project and 50 MW from a Wind Power Project. NHPC's hydro share of 6971.20 MW comes to about 14.88% of the country's total installed Hydro capacity of 46850.18 MW.

Most of the NHPC's power stations/projects are located in disaster prone Himalayas. NHPC has been working religiously to implement EWS in its and its subsidiaries projects and power stations. NHPC has established a Master Control Room at Corporate office, Faridabad, Haryana, India with 24X7 real time monitoring and alert generation mechanism. A software named "eAABHAS" for this purpose has been developed.

4.1 Structure of an Early Warning System adopted in NHPC Projects:

- Establishment of Gauge and Discharge (G&D) Site at upstream location of dam with Automatic Water Level Recorder (AWLR) and Telemetric communication (through application programming interface) or coordination with already existing upstream power station/ project with at least 1-2 hour lead time.
- Continuous monitoring of real time data at Dam control room and Master Control Room.
- Dissemination of information/warnings to all the stake holders / downstream populations and persons working at project site through hooters and sirens, SMS, Whatsapp etc.
- Identification of vulnerable areas and evacuation of the affected people to safe places if required.

Fig. 1 : Master Control Room in NHPC with Video Wall

5. CASE STUDIES: SEVERAL EXAMPLES HIGHLIGHT THE ECONOMIC BENEFIT OF EFFECTIVE EWS:

5.1 Construction Projects

5.1.1 *Rangit IV Project (120 MW), Sikkim, India:*

NHPC's under construction project Rangit –IV HEP lies approximately 10 km d/s of dam of already commissioned Rangit-III Power Station.

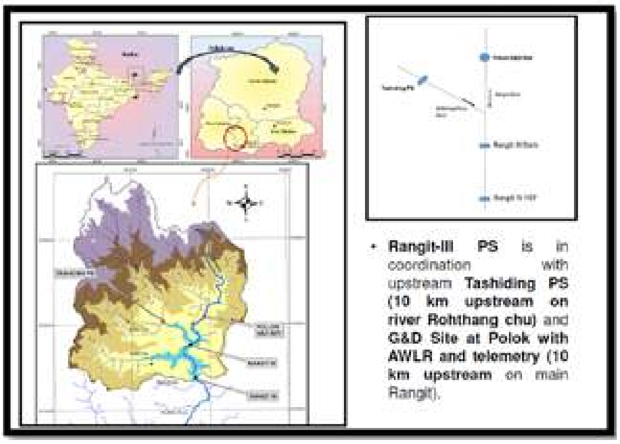


Fig. 2 : EWS Plan for Rangit-III and Rangit IV HEP

With the help of well-developed EWS, Project managed to pass the floods above its diversion capacity of 300 cumec on 07th June 2023 and 15th June 2023, after timely evacuating workers and machineries. Thereby saving lives of men (around 200 each time) and construction equipment worth crores of rupees.

Fig. 3 : Before and After Flood Scene at Rangit-IV

5.1.2 *Subansiri Lower H.E. Project (2000 MW),Assam, India:*

Automatic water level Recorders (AWLR) with auto transmission facility/telemetry (GSM based) has been installed at two upstream location with lead time of about 6 hours. On various occasions i.e. 16th June 2022, 3rd Sept 2022, 25th -26th Sept 2022 and 26th Oct 2022 during the active construction of the project, floods of magnitude in the range of 5800-7000 cumec were successfully passed due to advance warning from above two stations along with warning from Centre Water Commission's (CWC) and Indian Meteorological Department's (IMD) long range forecasts.. Timely evacuation of workers and machineries, resulted in saving of crore of rupees worth of construction equipment's and invaluable lives (around 5000 in each event).

Fig. 4 : EWS Plan for Subansiri Lower HEP (As visible in eAbhaas Portal)

Fig. 5 : Before and After Flood Scene at SLP

5.1.3 *Kiru Hydroelectric Project (624 MW), UT of Jammu and Kashmir:*

Kiru HEP's well developed EWS has demonstrated its economic value through issuing timely alerts on 18th of June 2023 at 10 PM. This has led to complete evacuation of construction site, lives of around hundreds of men were saved and construction equipment worth crore of rupee were saved.

Fig. 6 : EWS Plan for Kiru HEP

5.2 Power stations:

5.2.1 *During floods, with the help of early warning system (EWS), Sediment Flushings are planned*

and conducted after closing intake gates which helped in rejuvenating the reservoir capacity against sediment deposition in following Power Stations and in turn will enhance generation from these Power Stations during lean season:

In Ravi Basin-Chamera II, Chamera III and Bairasiul

In Chenab Basin-Salal and Dulhast

In Teesta Basin - Rangit III. Teesta V. TLDP III and TLDP IV

In Sharda Basin - Dhauliganga PS

5.2.2 *During the unprecedented floods in Himachal Pradesh in July 2023, the early warning system*

played a crucial role in safely navigating the floods, ensuring the safety of dams situated in the state.

6. COST-BENEFIT ANALYSIS OF EARLY WARNING SYSTEMS:

Evaluating the economic impact of Early Warning Systems (EWS) necessitates a comprehensive cost-benefit analysis. This analysis must account for the initial and ongoing costs associated with the implementation and maintenance of the EWS. Concurrently, it should consider the potential financial savings derived from mitigating losses and reducing the expenses associated with recovery efforts.

Furthermore, EWS plays a pivotal role in safeguarding critical infrastructure, including turbines and transmission lines, from damage caused by floods or landslides. By pre-empting such damages, project operators can avoid hefty repair costs, thereby accruing significant savings. Additionally, operational efficiency is enhanced through the timely issuance of warnings, which enables operators to cease turbine operations and evacuate personnel promptly. This proactive approach minimizes operational downtime and averts expensive equipment failures.

Investing a modest sum in the realm of lakhs of rupees on an EWS can fortify the resilience of the system. It yields both tangible and intangible benefits for all stakeholders involved. While the tangible benefits are readily quantifiable, the intangible advantages, though challenging to measure, are substantial. EWS proves particularly advantageous for communities situated downstream of dams, as it aids in minimizing property damage and preventing loss of life. It also bolsters the capacity of dam owners to effectively manage flood situations and execute sediment flushing operations when necessary.

8. INVESTMENT AND SUSTAINABILITY

While implementing and maintaining robust EWS incurs costs, these investments are often outweighed as experienced by NHPC by the long-term economic benefits they bring. Governments, businesses, and communities now started to recognize the value of EWS and started allocating resources for it.

7. CHALLENGES AND FUTURE DIRECTIONS:

Despite its benefits, challenges such as data accuracy, lack of reliable network in disaster simulation, communication, and public awareness remain as hindrance for its success. Ensuring sustained funding, technological advancement, and collaboration among stakeholders are crucial for enhancing the economic effectiveness of EWS.

8. CONCLUSION

Effective Early Warning Systems demonstrate their economic value by significantly reducing losses, preserving critical infrastructure, and promoting swift recovery as experienced by NHPC in its journey of implementing Early Warning System. As societies face an increasing array of hazards, investments in robust EWS not only protect lives and property but also contribute to overall economic resilience. Recognizing the pivotal role of EWS and addressing challenges through ongoing innovation and collaboration will lead to a safer and more economically secure future.

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DMR Safety Protocol for Enhancing Climate Resilience of Himalayan Hydropower Dams

S.C. Mittal[1], Shankracharya[1], Vishal K. Gupta[1] and Anoop Mathur[1]

ABSTRACT

Vast hydropower energy in Himalayas has been tapped and is being tapped to meet the expanding needs of the society for renewable and carbon free electric power and electric energy. Himalayan Hydropower dams are an integral component of hydroelectric projects constructed and planned across Himalayan states in India, Nepal and Bhutan. These Himalayan hydropower dams, being located in Steep topography, narrow valleys with fragile geology are considered to possess unique characteristics which are different from other dams planned on broad and flat river valleys in other parts of India. Planning and design of these hydropower dams has been influenced in the past by the geomorphological, geological and topographical characteristics of Dam Sites where these dams have been built.

Climate change in 21st century is a reality. Recent incidents in India and elsewhere indicate that current design, construction and operation practices of Himalayan hydropower dams are not sufficient to account for climate change. In climate related Incidents (GLOF/cloud burst/landslides), it has been observed that crest type gated spillways as well as low level gated spillways were inadequate to handle sudden flashfloods coupled with movement of Boulders, debris and tree logs. With spillways non-functional, both concrete dams and earthen dams have been found to be overtopped.

Current technical literature and standards on dams do not fully address the climate change induced scenarios. Therefore, a new protocol for enhancing climate resilience of existing and new Himalayan hydropower dams has been proposed. This new protocol is suggested to supplement/alter the current practices to ensure safer and dependable dams for their entire lifecycle.

Several other initiatives on enhancing dam safety have also been taken up by governments such as enactment of dam safety act in India, World Bank funded DRIP Phase-I and Phase-II program for up gradation and rehabilitation of select existing dams in India and other initiatives in Nepal and Bhutan.

We believe, our suggested new protocol together with initiatives of dam owners and regulatory Authorities will result in safer dams which will continue to serve the society for years to come.

1. INTRODUCTION

Hydropower energy derived from harnessing the potential energy of rivers and river systems is today recognized as green, renewable energy essential for the power grid. It provides much needed peaking power in grid for grid stability as well as base power in grid for certain months in the year.

Himalayas are the mountain system, encompassing the northern states of India (J&K, Himachal, Uttarakhand, Sikkim and Arunachal Pradesh) and nations of Nepal and Bhutan, besides certain parts of Pakistan and China. Several large Himalayan rivers have their origin from lakes in Tibet and several others originate from the himalayan glaciers at altitude of 4500 m and above.

Indus system (comprising Indus, Jhelum, Chenab, Ravi, Beas, Sutlej and others) with drainage area of 11,65,500 sq km flow westwards and merge in Arabian sea. Ganges system comprising (Ganga, Yamuna, Ramganga, Ghagra, Gandak, Burhi Gandak, Kosi, Mahananda and others) flows into Bay of Bengal with drainage area of 10,86,000 sq km. Brahmaputra River system (comprising Subansiri, Siang, Dibang, Lohit, Manas, Sankosh, Kameng, Teesta and others) also flows into Bay of Bengal with drainage area of 5,80,000 sq km. However, only a part of drainage areas of these river systems comprises of Himalayas.

The Himalayas (Fig. 1) are considered as the world's youngest, tallest and most populated mountain systems. The Himalayas are bounded by the Tibetan Plateau in the north, Hindu Kush and Karakoram Mountain ranges in the North West and vast Indo-Gangetic plains in the south. Himalayan mountain ranges cover an area of 5,95,000 sq km and its maximum width varies from 150 to 350 kms.

Several hydropower dams have been built and are being built on the tributaries and sub-tributaries of Himalayan Rivers with catchment areas at Dam sites ranging from below 1000 sq km to above 10,000 sq km.

1. DMR Hydroengineering and Infrastructures Ltd, Faridabad, India

Fig. 1 : Map of Himalayas

Dams are important components of hydropower projects as these structures are built to store water, raise head and divert water to water conductor system to produce power. Height of Dams vary from below 30 m to above 200 m. The volume of water stored in the reservoir can vary from below 2 million m^3 to above 5000 million m^3. Thus, there are wide range of hydropower dams and associated reservoirs constructed/under construction/under design/ under investigation on the tributaries and sub-tributaries of Himalayan rivers.

2. ABOUT DAM SAFETY WORLDWIDE

Dams have been built across rivers since several centuries. The pace of dam construction, however accelerated from beginning of 20th century and continues till date. Dams and reservoirs of varying sizes and various types have been built to fulfill the requirements of water storage for irrigation, flood control, hydropower and several other purposes such as drinking water, pumped storage etc. United States, Europe, China and India have built most dams. Total number of large dams at global scale is estimated to be 60000 while total number of dams exceed 800000. (CWC, 2019)

Dam safety worldwide has gained attention as stock of dams constructed has increased and available resources per dam, post construction have decreased. Dams continue to exist for 100 years and beyond. Financial institutions such as World Bank have focused on the safety of dams and downstream communities in the context of ageing infrastructure, population growth and changing environmental conditions. Various international and national agencies such as ICOLD, US Federal Emergency Management Agency (FEMA), USBR, Canadian Dam Association, Dam Safety NSW, Australia are some of the pioneer organizations who have prepared extensive guidelines and literature on dam safety.

Several countries including India have passed dam safety legislation for enhancing the safety management of dams.

Dr. Martin Wieland, a globally recognized International Dam Expert in paper titled "Safety Aspects of Sustainable Storage Dams and Earthquake Safety of Existing Dams", 2016 has emphasized an integral Dam Safety Concept. (Wieland, 2016)

According to Dr. Wieland, an Integral Dam Safety Concept includes the following key elements:

- Structural safety (main elements: geologic, hydraulic, and seismic design)
- Dam safety monitoring (main elements: dam instrumentation, periodic safety assessments by dam experts, etc.);
- Operational safety (main elements: reliable rule curves for reservoir operation under normal and extraordinary hydrological conditions, training of personnel, dam maintenance, sediment flushing, and engineering back-up; the most important element for a long service life is the maintenance of all structures and components);
- Emergency planning (main elements: emergency action plans, inundation maps, water alarm systems, evacuation plans, etc.).

Therefore, as long as the proper implementation of these safety issues can be guaranteed according to this integral safety concept, a dam can be considered to be safe. Periodic safety assessments are indispensable because they will show what measures have to be taken to maintain or improve safety and thus to even extend the life span. Deficiencies observed after commissioning must be rectified as early as possible. If a dam does not comply with current dam safety standards or shows unusual behaviour, the most effective means of reducing the risk is lowering the reservoir level. It must be pointed out that both new and existing large dams must satisfy today's safety criteria, which are the same for new and existing dams. There shall be no difference in the safety of the people living downstream of a new or an old dam.

3. DAM SAFETY IN INDIA

There are about 6000 large dams in India as per National Register of Dams, Central Water Commission, Govt. of India (CWC, 2019). Prior to enactment of dam safety act, 2021, the Central Water Commission (CWC), Govt. of India issued dam safety guidelines in 1987 which were to be followed by the dam owners comprising of state government water resources departments, state power companies, central power companies and private dam owners. Based upon these guidelines, pre-monsoon and post-monsoon inspections of dams as part of dam safety monitoring was institutionalized.

Under financial assistance from World Bank, Dam Rehabilitation and Improvement Project (DRIP) Phase – I was launched in 2012 with an objective to improve the safety and operational performance of selected existing dams along with dam safety institutional strengthening with system wide management approach. In the process, Central Dam Safety Organization (CDSO) under CWC has published 10 no. Guidelines documents, 5 no. Manuals and 1 no. Technical Specification document for dam safety in India (Table 1).

At present DRIP Phase – II & Phase – III, funded by World Bank, is under implementation. Under this program, 736 No. of dams are proposed for physical rehabilitation during the period of 10 years (2021-2031).

Dam Safety 2021, together with DRIP – I and DRIP – II has reinvigorated the implementation of Dam Safety processes which shall gain further momentum in times to come.

4. CLIMATE CHANGE

Climate change refers to long term shifts in temperatures and precipitation patterns both in terms of time and space. The consequences of climate change now include among others, intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms and declining biodiversity. In 21st Century, climate change is a reality that is being experienced on daily basis across the globe. (Sanmartín, García, Torres, & Bueno, 2018)

The effects of climate change are expected on a variety of factors affecting the dams, from the incoming floods to the definition of downstream consequences. Thus, in order to analyze the impacts of climate change on the global safety of a dam, it is necessary to decompose them into the different aspects that integrate the dam risk. Floods, reservoir water levels, gate performance and flood routing are some of the potential dam safety factors impacted by climate change. This will result in impact on potential dam failure modes, which will need serious examination. (Sanmartín, García, Torres, & Bueno, 2018)

5. CHARACTERISTICS OF HIMALAYAN HYDROPOWER DAMS

Based upon the broad examination, of constructed and under-planning Himalayan dams, following broad characteristics of Himalayan dams can be listed:

Table 1 : Guidelines, Manuals and Technical Specifications, CWC-CDSO

A. Guidelines	
Doc. No. CDSO_GUD_DS_01_v2.0	Guidelines for Developing Emergency Action Plans for Dams – Feb 2016
Doc. No. CDSO_GUD_DS_02_v1.0	Guidelines for Instrumentation of Large Dams –- Jan 2018
Doc. No. CDSO_GUD_DS_03_v1.0	Guidelines for Preparing Operation and Maintenance Manual for Dams - Jan 2018
Doc. No. CDSO_GUD_DS_04_v1.0	Handbook for Assessing and Managing Reservoir Sedimentation -– Feb 2019
Doc. No. CDSO_GUD_DS_05_v1.0	Guidelines for Mapping Flood Risks Associated with Dams - Jan 2018
Doc. No. CDSO_GUD_DS_06_v1.0	Guidelines for Selecting and Accommodating the Inflow Design Floods for Dams – June 2021
Doc. No. CDSO_GUD_DS_07_v1.0	Guidelines for Safety Inspection of Dams – Jan 2018
Doc. No. CDSO_GUD_DS_08_v1.0	Operational Procedures for Assessing and Managing Environmental Impacts in Existing Dam Projects – Nov 2020
Doc. No. CDSO_GUD_DS_09_v1.0	Guidelines for Classifying the Hazard Potential of Dams – Nov 2020
Doc. No. CDSO_GUD_DS_10_v1.0	Guidelines for Assessing and Managing Risks Associated with Dams - Feb 2019
B. Manuals	
Doc. No. CDSO_MAN_DS_01 _v1.0	Inspection Manual for Dam Field Engineers After Seismic Events, Ichari Dam, Uttarakhand - Jan, 2018
Doc. No. CDSO_MAN_DS_02_v1.0	Manual for Rehabilitation of Large Dams – Jan 2018
Doc. No. CDSO_MAN_DS_03	Manual for Assessing Structural Safety of Existing Dams – Nov 2020
Doc. No. CDSO_MAN_DS_04_v1.0	Manual for Assessing Hydraulic Safety of Existing Dams - Vol. I – Jun 2021 Manual for Assessing Hydraulic Safety of Existing Dams - Vol. II – Jun 2021
Doc. No. CDSO_MAN_DS_05_v1.0	Inspection Manual for Dam Field Engineers after Seismic Events, Maithon Dam, Damodar Valley Corporation, Jharkhand - Feb 2019
C. Technical Specifications	
Doc. No. CDSO_TS_DS_01_v1.0	Technical Specifications of Hydro-meteorological, Geodetic, Geotechnical and Seismic Instruments - Jan 2018

(a) The Himalayan rivers are mostly glacier fed. The dams are located on perennial rivers with large variation of flows during monsoon season and lean season.

(b) The dams are typically of 30m to 100 m height, (200 m height in some cases), the height measured from the average river bed level.

(c) The dams are invariably located in steep gorge. While the, top of the dam shall be located 50 m to 100 m above river bed, the mountain topography on both banks may extend to 200m to 400 m. The length of the dam at the top spanning across the two banks of the river, may be the order of 250m for a typical 100 m high dam, indicating steep abutments and mountain slopes.

(d) All Himalayan dams are located in the region of high to very high seismicity.

(e) Dam and reservoir sites are having fragile geology with potential for land slide in the reservoir area and upstream.

(f) The dam sites are remotely located involving several kilometers of access roads constructed in steep and unstable topography, frequented by cross streams.

(g) The river sections, where dams are located, often have steep longitudinal gradient in the range of 1:100 to 1:30.

(h) The Himalayan rivers carry heavy sediment load. Since the reservoir capacities are small, in the order of 5 to 100 million m3, the heavy sediment load impacts the capacity of the reservoir, unless measures are taken to flush them regularly.

(i) Spillways are designed to pass the design flood equal to probable maximum flood (PMF) and also to pass the sediment load due to small sediment holding capacity of the reservoir. In view of this requirement, spillway openings are provided close to the river bed 40-50 m from the dam top with very high discharge intensity (more than 200 m^3/s per m).

(j) Concrete dams with central spillways, are the first preference of the design. In cases, where the competent rock foundation in the river bed is too deep (more than 50 m), alternative dam type such as rock-fill dams with side spillway are considered.

Because of these unique characteristics, Himalayan dams are quite susceptible to climate change events. The climate change events could include Glacier Lake Outburst Floods (GLOF), heavy precipitation in local areas (Cloud burst phenomena), land slide in the upper reaches forming temporary unstable dams and temporary reservoirs.

The climate change events could impact the Himalayan dams in number of ways. Some of the ways are listed below:

(a) Hindrance to access to dam site due to land slide from heavy rains/cloud burst

(b) Unusually high sediment transport with boulder movement into the reservoir, blocking the spillway openings

(c) Raining of boulders/pebbles on the dam top, from above the mountain on either bank

(d) Land slide in the reservoir area resulting in creation of large waves with potential for overtopping

6. RECENT INCIDENTS

Climate change in 21st Century is a reality. Recent Incidents listed below, indicate that current design, construction and operation practices of Dams are not sufficient to account for climate change.

- 2013, Kedarnath - Chorabari lake Burst, severely impacted the functioning of Phata Byung Dam in Mandakini Valley. High Intensity rains and cloud burst overwhelmed Vishnuprayag Barrage in Alakhnanda Valley
- 2021, (Flashflood in Rishi and Dhauli ganga rivers – severely affected Rishiganga Hydroelectric project and Tapovan Vishnugad Hydroelectric Project Barrage and its appurtenant structures in Uttarakhand
- Aug, 2023, several Hydropower projects in Kullu and Mandi Districts of Himachal Pradesh were overwhelmed raising concerns
- Oct 2023, incident of Glacier Lake Outburst in upper reaches of Teesta Valley resulted in severely affecting the functioning of Teesta III and Teesta V Dams, which also resulted in washing out of several permanent bridges across Teesta River and heavy loss to life and property

Gated spillways in dams are planned to successfully handle and mitigate the high floods, say, 1000 years or more return period flood. An innovation in gated spillways in the form of low-level gated spillways as an alternative to crest type gated spillways, was introduced in late 1990s for Himalayan hydropower dams in India to provide for passing of sediment laden flows and high floods to preserve the live capacity/pondage required for peaking operation. Both crest type gated spillways as well as low level gated spillways have been found inadequate to handle sudden flashfloods coupled with movement of boulders, debris and tree logs.

With spillways nonfunctional, both concrete dams and earthen dams have been found to be overtopped, though, concrete dams have withstood overtopping with limited damage. Earthen dams, earth and rockfill dams, rockfill dams, CFRDs and other embankment dams are presently not designed for overtopping as it is assumed that under the severe most condition, the available freeboard will ensure its safety. This assumption is found to be vitiated with non-functioning/non-operation of gated spillways in critical hours and technical personnel at dam site are unable to control the situation.

7. NEED FOR CORRECTIVE MEASURES

Provision of dependable overtopping protection for all existing earthen embankment dams including rockfill dams and CFRD dams in Himalayas hydropower projects is considered as the first critical intervention requiring immediate implementation to ensure their capacity to handle future glacier lake bursts and non-functional/ non-operative gated spillways scenarios. The provision of ungated spillways to supplement the gated spillways in all concrete and rockfill dams are considered to be next requirement to face climate change induced floods.

Current technical literature and standards on dams do not address the climate change induced scenarios, therefore, there is an urgent need to upgrade the knowledge of engineers, managers and planners regarding coping the future situations in existing dams. Dam safety protocols for existing and new dams should be based upon, climate change reality of 21st century.

8. SUGGESTED PROTOCOL

We have drafted a ten-point protocol which could act as checklist for ensuring safety of Himalayan dams to cope with climate change induced scenarios. The protocol is listed in table 2 below:

Table 2 : Ten-point dam safety protocol for Himalayan dams proposed by DMR

Protocol No.	Protocol Description
1	Liberal additional free board (over and above the requirement of present codes)
2	Mandatory provision of ungated auxiliary spillway of 25% of PMF/design flood placed above FRL/ MWL
3	At least 50% capacity of spillway as crest spillway which could be kept open during monsoon season
4	50% capacity as low-level gates spillways for sediment flushing
5	All gates should be designed for impact load equal to 100% of hydrostatic pressure
6	Gates armac system should be ensured to be operational 100% with sufficient long-term O & M contracts
7	All embankment dams should have mandatory dependable overtopping protection
8	Compulsory on site disaster management training to the operation staff each year
9	Provision for early warning system
10	Real-time coordination and cooperation of all dam owners and operators in the valley

Adherence to above mentioned protocol for Himalayan dams, could help the dam operators to cope climate induced operational challenges and resulting hazards in a significant way.

9. RETROFITTING OF EXISTING DAMS IN HIMALYAS

In view of above protocol, several Himalayan existing dams, will require retrofitting. Each dam should be re-analyzed for potential failure mode (PFM) and retrofitting requirements of each dam should be worked out by experienced dam design and dam safety engineers. Implementation of the retrofitting design should be completed in a time bound manner. The operations guidelines for the retrofitted dams should be reworked.

10. CARE IN DESIGN FOR NEW DAMS UNDER DESIGN AND CONSTRUCTION

All new dams under design and construction should be reexamined from the climate induced safety scenarios which include landslide, mud flow, glacier outburst flood and more frequent intense rainfalls in the catchment. The dam safety of a lower dam is also compromised if, an upper dam fails due to any reason. Rigorous potential failure mode analysis, which could include both gate jam condition as well as gate collapse condition should be examined and safety protocol should be worked out, which takes into account the potential failures.

11. CONCLUSION

It is to conclude, that, climate risks to the Himalayan dams are quite visible as has been witnessed in several recent incidents. Therefore, a new protocol, suggested by us, has become necessary for all existing Himalayan dams and future dams, which are presently under construction and planning. Retrofitting of several of the dams will be required. Retrofitted design should be robust and climate change resilient. This will go a long way for enhancing the safety and reliability of the dams and enhance confidence of downstream populations in the neighborhood dams.

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Trends and Variability of Future PMP and PMF considering Climate Change: A Study on Dams of Godavari River Basin

Dinesh Roulo[1] and Subbarao Pichuka[2]

ABSTRACT

The future variation of design flood inputs, i.e., Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) for fifteen dams located in the Godavari River Basin (GRB) are assessed by considering the effect of climate change. The raw GCM data outputs from the CNRM-CM6-1-HR model from Coupled Model Intercomparison Project phase 6 (CMIP6) over historical rainfall (1971-2014) and future rainfall data (2021-2100) is considered for the analysis. Also, the monthly rainfall data at 0.25° × 0.25° grid size are obtained from the India Meteorological Department (IMD), Pune. The Quantile Mapping (QM) bias correction method is applied to improve the raw GCM data and the bias corrected outputs are used for the analysis. Firstly, the association between the bias corrected raw GCM data versus observed data is checked during the historical period. Upon obtaining the satisfactory performance, the bias corrected GCM data is used for the future analysis. Next, the PMP values at each dam location are computed using the Hershfield approach for historical period. Further, the Gumbel Extreme Value (GEV) method is employed to assess the rainfall extreme value (EV) over different return periods (50, 100, and 1000 years), and its magnitude is compared with the PMP value. It is clearly evident that the PMP values at most of the dam locations are falling below 100-year return period. Further, the PMF is estimated using the Soil Conservation Service Curve Number (SCSCN) method. The future variation of PMP and, subsequently, PMF are projected for the future period (2021-2100) considering Shared Socioeconomic Pathway (SSP) scenarios, viz. SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. The results revealed that the increasing trend in PMP and PMF is noticed for SSP5-8.5 in the future period. The Bhupathipalem dam, which is designed for a spillway capacity of 2314 m^3/sec, shows projected PMF values of 3024 m^3/sec for epoch-1 (2021-2050), and 3340 m^3/sec for epoch-2 (2051-2080) under the SSP5-8.5 scenario. This indicates that the PMF is expected to increase by 31% during epoch-1, and 45% during epoch-2. Therefore, the findings of the study indicate an alarming for significant concern regarding dam safety. From this analysis, crucial insights about the variation in PMP and PMF values can be drawn for the selected dam sites. It is worth noting that this study also offers a valuable information for stakeholders regarding the occurrence of critical situations in the near future. However, the GCM data sets are associated with several uncertainties and have limitations to adopt for regional scale studies. Hence, we recommend to downscale the GCM outputs and use it for local scale impact assessments.

Keywords *: Dam Safety, PMP, PMF, Climate Change, Godavari River Basin.*

1. INTRODUCTION

The increasing frequency and intensity of extreme weather events due to Climate Change (CC) emphasize the urgent need for adaptive strategies in the design and management of dams, which are crucial for supporting people, water resources, the environment, and development. Most importantly, many dams are aging and may not be equipped to handle new climatic challenges, potentially compromising their structural integrity. Therefore, the comprehensive management practices are essential for dams situated in between the upstream and downstream hydrology in order to mitigate the risk of overtopping during uncontrolled flood events. This study aims to address these issues by assessing the future variations in design flood inputs, specifically Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF), for fifteen dams located in the Godavari River Basin (GRB), considering the effects of CC. By doing so, it seeks to enhance the resilience and safety of these critical infrastructures in the face of evolving climatic conditions.

According to the World Meteorological Organization (WMO), the definition of PMP is the greatest depth of precipitation calculated for a given duration meteorologically possible for a design watershed or a given storm area at a particular location (WMO, 2009). The objective of estimating PMP is to determine the magnitude of PMF for a particular project in a given

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watershed. This PMF estimation assists in designing the size of project components, including dam height, reservoir storage capacity, and spillway. The report presented several methods for calculating PMP, among which the Hershfield method is the quickest but requires long-term precipitation data.

Many scientific studies have been conducted globally to estimate PMP for various projects in different watersheds. For instance, Panday et al. (2023) performed a PMP analysis using the Hershfield method and Gumbel's Extreme Value distribution to estimate rainfall extremes for high rainfall regions in India, including Uttarakhand, Maharashtra, Assam, and Meghalaya and found that PMP values were higher than those recorded during La Nina years. Fattahi and Habibi (2022) found that the Hershfield method provided reliable PMP (1-day) estimates over Iran compared to the Hershfield-Desa method. Desa et al. (2001) estimated PMP values over Southeast Asian monsoon regions (Selangor and Malaysia) using the Hershfield method by considering long-term precipitation data. Daba et al. (2022) used daily maximum rainfall data from 1986 to 2019 to determine PMP for the Dedessa sub-basin in Ethiopia and created a PMP isohyetal map using Hershfield's statistical method. Tajbakhsh and Al-Ansari (2019) compared the multi-station method and Hershfield's approach for PMP determination in Northeast Iran and reported the variations in the ratio between PMP (1-day) and observed maximum rainfall. On the other hand, IPCC reports stated that to provide a comprehensive assessment of CC, its causes, impacts, and potential solutions, emphasizing the urgent need for global mitigation and adaptation efforts to address the escalating climate crisis.

Considering the impact of CC in the field of dam engineering, several research studies have been carried out in order to see the variations in rainfall patterns which are crucial for the design and safety of dams. For example, Visser et al. (2022) conducted a PMP analysis under non-stationary climate conditions using Shared Socioeconomic Pathways (SSPs) and predicted that PMP estimates across Australia would increase by an average of 13% by 2100 for SSP1-2.6 and 33% for SSP5-8.5. Herbozo et al. (2022) adopted a four-stage methodology (data gathering, hydro-climatic, hydrological, and hydraulic analyses) along with the PMP analysis to assess the impact of future precipitation under RCPs in the spillway design of a Reservoir (Sube y Baja Dam) in Ecuador and concluded that 25% increase in the spillway maximum flow upon 20% increase in PMP under RCP 8.5. Also, a recent study conducted by Pichuka and Roulo (2024) in the Godavari River Basin (GRB), India, found that future rainfall patterns are changing under different RCPs for fifteen dam locations (dam locations considered in this study). Building on these findings, the current work attempts to analyze trends and variability in rainfall patterns under various SSPs using Coupled Model Intercomparison Project Phase 6 (CMIP6) data and utilizes statistical approaches like the Hershfield method for PMP estimation and the Soil Conservation Service Curve Number (SCSCN) method for PMF estimation for the fifteen dam locations in the GRB.

2. STUDY AREA AND DATA

The selected fifteen dam locations in the GRB are considered areas of interest in this current study, and their geographical locations are represented in Figure 1. The report of Godavari Basin published in March 2014 provides a comprehensive overview of the basin's water resources assets, topographic features, climatic variability, Land Use Land Cover (LULC) patterns, and associated natural resources, along with socio-economic information (Godavari Basin, 2014). The summary of this report declares that the Godavari and its tributaries are an interstate river system, flowing through the states of Maharashtra, Andhra Pradesh, Chhattisgarh, Odisha, Madhya Pradesh, Karnataka, and Puducherry. The core components of the water network include the river Godavari and its principal tributaries (Purna, Penganga, Wardha, Wainganga, Pranhita, Indravati, Sabari, Kolab, Pravara, Manjra) finally draining into the Bay of Bengal. As per the hydrology of the GRB, it consists total 8 sub-basins (clustered into 466 small watersheds), 968 structures (Dams and Barrage/Weir/Anicuts are constructed for providing irrigation, diversion, storage purpose, and other facilities), 18 flood forecasting systems (4 are flood inflow stations at reservoirs and 14 are flood level stations at the river), and 88 hydrological observation stations. Also, it has 226 India Meteorological Department (IMD) stations, 69 Central Water Commission (CWC) observation stations, and 86 Indian Space Research Organization (ISRO) AWS stations for recording meteorological parameters. Further, the salient features of each dam have been taken from the National Register of Large Dams report (NRLD, 2023) and are presented in Table 1.

2.1 data description

In the proposed study, all the data are sourced from freely available resources. The gridded rainfall data at 0.25° × 0.25° spatial resolution are obtained from the IMD, Pune for the historical period (1971–2014). The General Circulation Model (GCM) data (precipitation) is taken from the Earth System Grid Federation (ESGF) portal https://esgf-data.dkrz.de/search/cmip6-dkrz/ for the CNRM-CM6-1-HR model from CMIP6 during historical (1971-2014) and future periods (2015-2100). All Shared Socioeconomic Pathways (SSPs) scenarios are considered in this study. The GCM data is taken at a 50 km resolution, with monthly frequency, using the variant label 'r1i1p1f2'. Next, LULC map is prepared in

Quantum Geographic Information System (QGIS) with the help of 10 m resolution data from Environmental Systems Research Institute, Inc. (ESRI) using the ESA Sentinel-2 satellite we created precise and detailed LULC map (https://livingatlas.arcgis.com/landcover/) which is shown in Figure 2. Similarly, detailed soil map (refer Figure 1) is also prepared for the GRB using QGIS, where the soil data was sourced from the Food and Agriculture Organization (FAO) (https://www.fao.org/). Furthermore, the study collected data related to each dam from the NRLD, published in September 2023.

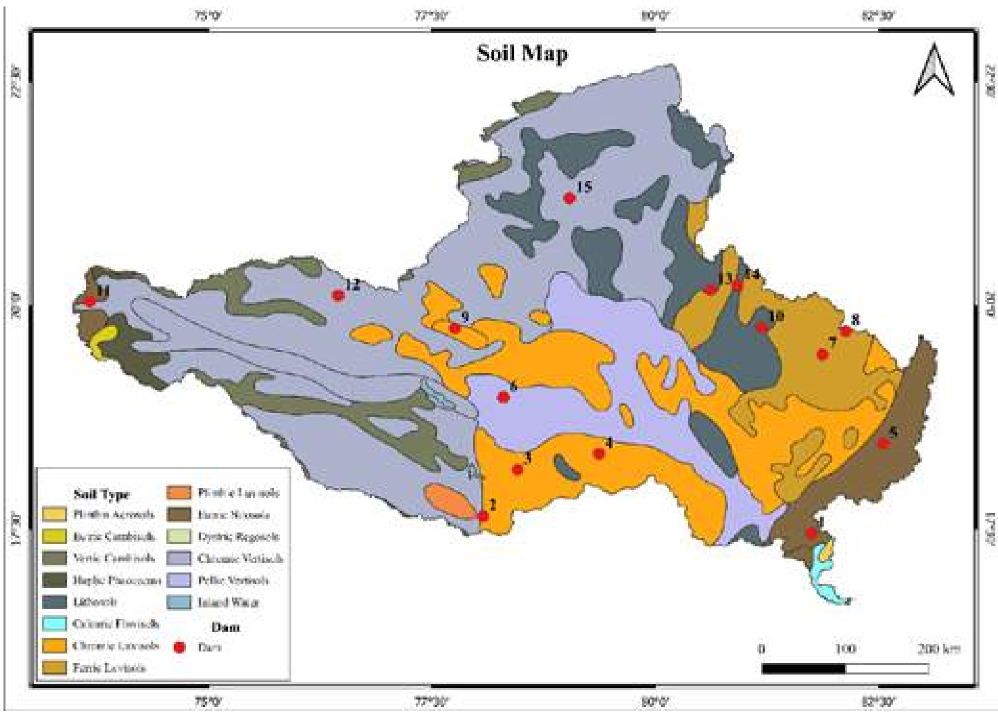

Figure 1 : Soil classification within the GRB, with study locations marked by red circles

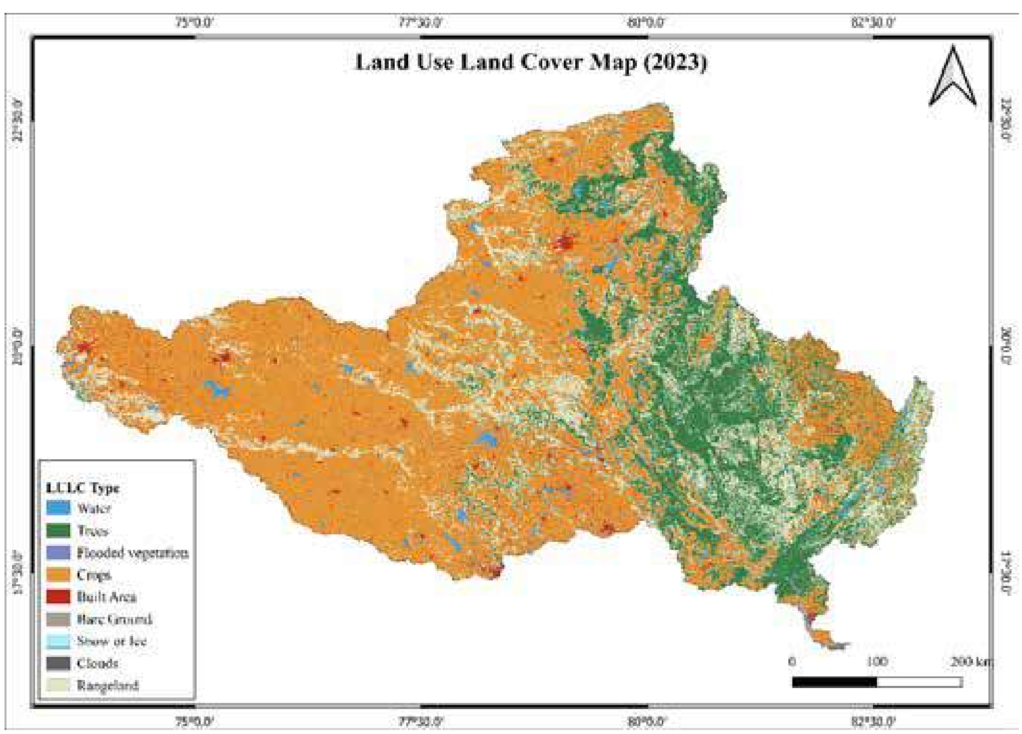

Fig. 2 : LULC classification within the GRB for the year 2023

Table 1. Salient features of fifteen dam locations considered in the GRB (NRLD, 2023)

Loc. No.	Dam Name	River	Year of built	Type	Latitude (N)	Longitude (E)	Purpose	Height (m)	Length (m)	Gross storage capacity (10^3 m^3)	Reservoir Area (10^3 m^2)	Designed spillway capacity (m^3/s)
1	Bhupathi Palam	Sethupalli Vagu	2011	ED	17.45	81.75	IR	34.50	748.00	18.27	3588.00	2314.00
2	Manzira	Manzira	1965	GM	17.64	78.07	IR	38.40	502.60	42475	10000	13763
3	Peddamalareddy	Godavari	1892	ED	18.16	78.46	IR	15.50	NA	NA	NA	NA
4	Sripada Sagar	Godavari	NA	GM	18.34	79.37	IR	26.30	1180.70	NA	NA	55900
5	Jalaput	Sileru	1957	GM	18.45	82.55	HE	60.65	1425.00	70610.00	97120.00	5664
6	Sri Ram Sagar	Godavari	1977	ED/GM	18.97	78.30	WS	43.00	15600.00	3172000	450820.00	45300
7	Kosarteda	Kosarteda	2013	ED	19.45	81.87	IR	25.60	1305.00	7276.00	15870.00	1100
8	Bhaskel	Bhaskelnalla	1966	ED	19.71	82.13	IR	26.86	1672.80	29820.00	6422.00	566.00
9	Mudana	Local Nalla	1979	ED	19.74	77.76	IR	11.47	637	1050.00	500.00	100.8
10	Binjali	Local Nalla	1988	ED	19.75	81.19	IR	13.30	2130.00	4360.00	15783.00	77
11	Gangapur	Godavari	1965	ED	20.04	73.67	IR	36.59	3902.00	215880.00	22310.00	2294
12	Kalapvihir	Local Nalla	1983	ED	20.11	76.45	IR	14.04	810	1580.00	61.55	245
13	Paralkot	Kotri	1973	ED	20.17	80.62	IR	25.21	1231.00	66300.00	11370.00	974
14	Palachur	Local Nalla	NA	ED	20.22	80.92	IR	14.63	933.00	2160.00	498.00	38
15	Gorewada	Local Nalla	1911	ED	21.20	79.04	IR	17.37	710	8840.00	1920	NA

Note: ED – Earthen Dam; GM – Gravity/Masonry Dam; IR – Irrigation; WS – Water Supply; HE – Hydroelectric; NA – Not Available

3. METHODOLOGY

The detailed methodology of this study is presented in Figure 3. This study involves six key steps to assess the design inputs of PMP and PMF at considered dam locations in the GRB, considering the effects of climate change. The first step is the selection of dam locations within the study area and collecting all necessary data sets from various agencies in order to achieve the study's objective. In the second step, Quantile Mapping (QM) is employed to apply bias corrections to the raw GCM data. This technique is used to adjust the outputs of GCM to better match observed climate data. This method involves mapping the quantiles of the modeled data distribution to the quantiles of the observed data distribution, ensuring that the statistical properties of the modeled data align more closely with those of the observed data. To carry out this technique, the historical period (1971-2014) is divided into a calibration period (1971-2000) and a validation period (2001-2010). In the third step, the future rainfall over epoch-1 (2021-2050) and epoch-2 (2051-2080) is projected across all SSPs using the same bias corrections, i.e., QM. The fourth step involves conducting PMP analysis using the Hershfield method (Hershfield, 1965; Hershfieldl, 1961) based on a general frequency equation (Equation-1) developed by Chow (1951). The details of this method are as follows –

$$PMP = K \times S_N + \overline{P}_N \qquad ...(1)$$

where PMP is the estimated 1-day PMP for a particular period at the selected dam location,

$\overline{P}_N$ is the mean of the Annual maximum monthly Precipitation (AMMP) time series for the same period at that location,

S_N is the standard deviation of the AMMP time series for the same period at that location,

K is the frequency factor, which can be calculated using Equation-2.

$$K = \frac{P_{max} - \overline{P}_{N-1}}{S_{N-1}} \qquad ...(2)$$

where P_{max} is the maximum rainfall in the AMMP time series for the selected dam location

$\overline{P}_{N-1}$ and S_{N-1} are the mean and standard deviation of the AMMP time series at the selected dam location, respectively, for (N-1) years after removing the year with the maximum rainfall value.

In the fifth step, maximum rainfall values for return periods of 50, 100, and 1000 years are determined using Gumbel's Extreme Value (GEV) distribution to annual maximum rainfall data series based on the following equations developed by Gumbel (1941) –

$$Y_t = -\ln[\ \ln\{\frac{T}{T-1}\}] \qquad ...(3)$$

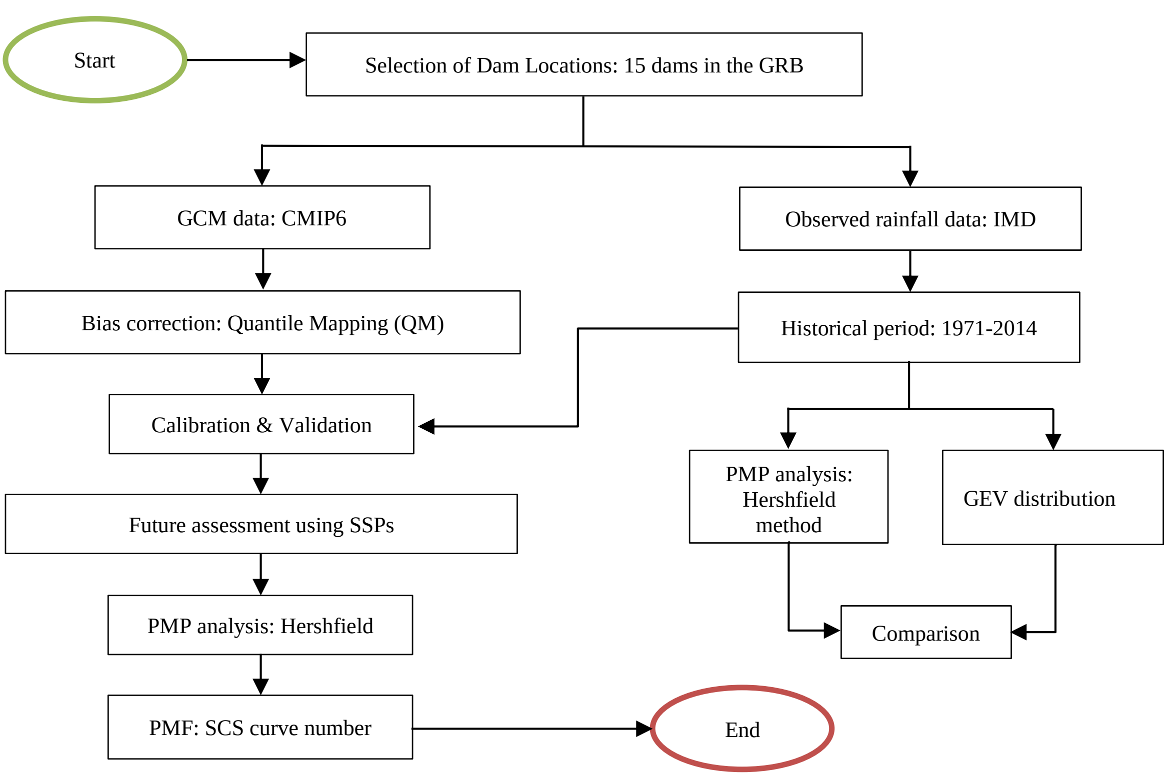

Fig. 3 : A detailed methodological Flowchart

Y_t is the reduced variate

T is the Return Period

$$K = \frac{Y_t - \bar{Y}_N}{S_N} \quad ...(4)$$

K is the Frequency factor

$\bar{Y}_N$ is the reduced mean

S_n is the reduced standard deviation

$$X_T = \bar{X} + (K \times \sigma_{n-1}) \quad ...(5)$$

X_T is the Random variate for the Tth return period.

$\bar{X}$ is the Mean of the variate

σ_{n-1} is the standard deviation for n-1 degrees of freedom

$$\sigma_{n-1} = \sqrt{\frac{\sum(X-\bar{X})^2}{N-1}} \quad ...(6)$$

N is the sample size

Finally, the PMF is estimated using the SCSCN method. The weighted Curve Number (C_N) for the study area is calculated based on soil and LULC data using QGIS software (Victor Ponce & Hawkins, 1996). Subsequently, determine the potential maximum soil retention (S) and initial abstraction (Ia) from the weighted C_N. Using PMP data, calculate the runoff depth by accounting for the abstraction and retention values. Then, the Kirpich method is employed to determine time of concentration (T_c), utilizing the length of the longest flow path and the basin slope. Finally, applied unit hydrograph method to translate the runoff depth into peak discharge. The utilized equations in the estimation of PMF are presented as follows –

$$S = \frac{1000}{\text{Weighted } C_N} - 10 \quad ...(7)$$

$$I_a = 0.2 \times S \quad ...(8)$$

$$Q = \frac{(P-Ia)^2}{(P-Ia)+S} \quad ...(9)$$

$$Q_p = \frac{Q \times A}{T_c} \quad ...(10)$$

$$TC = 0.0078 \times L^{0.77} \times S^{-0.385} \quad ...(11)$$

where, S is the potential maximum soil retention in inches

I_a is the initial abstraction in inches

P is the PMP in inches

Tc is the time of concentration in hours

A is the area of the catchment in m^2

4. RESULTS AND DISCUSSIONS

The association between observed rainfall data and raw GCM data for the historical period (1971-2014) are obtained through various statistical performance measures such as correlation coefficient (r), root mean square error (RMSE), unbiased root mean square error (URMSE), Nash-Sutcliffe Efficiency (NSE), and Degree of Agreement (Dr) are calculated at all the study locations (Refer Figure 1). The poor performance is observed and therefore, the raw GCM data outputs are bias corrected using the Quantile Mapping (QM) technique. The bias corrected GCM data is shown satisfactory performance (results shown in Table 2) when compared with the observed data during the historical period. In this study, the historical period is divided into a calibration period (1971-2000) and a validation period (2001-2014). It is worth noting that the validation is done for checking the effectiveness of QM technique. The confidence is gained from this analysis and the same bias correction factors are used to correct the future GCM rainfall data for different SSP scenarios. Overall, the performance is satisfactory for the basin scale analysis. However, if we look for a location-specific study, the results can be further improved by adopting the suitable downscaling techniques (This study not presented any downscaled analysis). The downscaling part is kept as future research scope in this direction.

This study considered various SSP scenarios, namely SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, for projecting future rainfall. The future period is divided into two epochs: epoch-1 (2021-2050) and epoch-2 (2051-2080), each spanning 30 years. The calibrated QM bias corrections are applied to the raw future GCM data corresponding to all SSPs across both epochs. The future variation in rainfall patterns and variability with respect to baseline (BL) (1981–2010) data at the selected dam locations are investigated in terms of change in the mean, standard deviation, and extreme rainfall events (90th and 95th percentiles). The results of BL and epoch-wise analysis are presented in Table 3.

Additionally, the analysis of PMP (using the Hershfield method) and the estimation of extreme rainfall values (using GEV distribution for various return periods 50, 100, and 1000 years) at each dam location is carried out over the historical period. The obtained results are presented in Table 4. Comparing the both results, it is observed that the PMP values fall between the 100 and 1000-year return period values at six dam locations (Loc. No 1, 5, 6, 7, 10, and 11). Next, Loc. No 2 and 15 lies between the 50 and 100-year return periods, while the remaining locations are close to the 50-year return period. It is clearly evident that the PMP values are falling below 100 years return period at most of the dam locations. Further, the Hershfield method of PMP analysis is applied over each epoch to examine variations in future PMP magnitudes relative to the BL period and resulted PMP values are presented for Loc. No 2, 3, 5, 8, and 15 in Table 5. The similar PMP analysis could be done for other dam locations.

Furthermore, the PMF is estimated using the SCSCN method (refer Equations 7 to 11), followed by the unit

Table 2 : Performance statists during calibration (1971-2000) and validation period (2001-2014)

Loc. No	Calibration					Validation				
	r	RMSE	URMSE	NSE	Dr	r	RMSE	URMSE	NSE	Dr
1	0.58	124.52	124.38	0.10	0.60	0.56	152.07	147.70	0.07	0.50
2	0.55	115.93	115.69	0.10	0.61	0.54	119.06	115.74	0.10	0.50
3	0.64	79.83	79.57	0.17	0.63	0.58	91.91	89.38	0.20	0.52
4	0.63	110.26	109.47	0.30	0.67	0.68	101.74	101.64	0.35	0.68
5	0.65	107.59	107.41	0.15	0.63	0.67	133.17	133.11	0.39	0.68
6	0.59	108.25	107.52	0.22	0.65	0.59	108.65	108.52	0.02	0.63
7	0.70	117.20	116.64	0.36	0.70	0.71	134.85	134.54	0.41	0.72
8	0.68	112.69	112.65	0.30	0.70	0.78	107.66	107.61	0.49	0.75
9	0.54	100.82	97.14	0.18	0.67	0.43	114.72	111.78	0.06	0.65
10	0.71	109.88	105.80	0.45	0.73	0.79	100.42	97.87	0.57	0.76
11	0.44	200.41	183.84	0.03	0.67	0.47	308.27	277.60	0.01	0.66
12	0.45	100.95	97.71	0.04	0.65	0.50	97.83	94.43	0.15	0.67
13	0.66	148.65	142.00	0.38	0.73	0.67	154.00	151.42	0.40	0.73
14	0.64	148.14	144.08	0.35	0.72	0.67	154.31	153.82	0.29	0.73
15	0.69	94.45	92.40	0.42	0.70	0.63	111.82	111.54	0.30	0.69

Table 3 : Future (2021–2100) variation of rainfall parameters (mean, standard deviation, 90th and 95th percentiles) with respect to the baseline (1981–2010) data considering the SSP5-8.5 scenario: carried out using the monthly time-series data

Loc. No	Mean (mm)			Standard Deviation (mm)			90th Percentile (mm)			95th Percentile (mm)		
	BL	Future		BL	Future		BL	Future		BL	Future	
		Epoch-1	Epoch-2		Epoch-1	Epoch-2		Epoch-1	Epoch-2		Epoch-1	Epoch-2
1	120.27	51.65	64.00	152.91	102.18	110.68	336.29	189.78	234.84	413.00	270.59	324.90
2	91.15	37.06	49.61	130.63	59.83	84.73	291.70	131.01	185.77	380.22	168.67	243.40
3	73.81	56.74	71.68	99.07	93.88	120.23	225.57	188.67	252.70	288.37	266.24	335.24
4	78.53	30.50	40.84	121.34	61.61	79.81	257.14	108.86	129.21	338.71	157.49	205.88
5	117.70	101.12	114.09	144.24	184.89	189.22	344.50	374.20	454.17	423.02	518.19	564.62
6	72.50	37.63	46.03	111.35	65.11	78.67	261.34	125.89	151.54	313.45	156.49	201.48
7	109.37	58.57	65.26	161.32	109.48	110.70	383.32	219.18	247.80	464.27	316.51	309.43
8	101.04	65.37	70.33	155.38	118.92	116.23	367.42	247.19	262.31	444.92	339.93	334.63
9	46.63	13.98	17.76	81.58	29.84	35.65	176.73	39.84	52.54	233.50	70.62	86.35
10	82.36	39.64	47.54	133.47	72.94	82.95	279.67	160.43	178.66	361.33	207.01	226.63
11	42.47	16.40	23.38	98.91	23.96	35.89	135.02	46.10	66.80	226.26	61.80	106.48
12	39.55	16.66	21.36	71.38	29.93	36.44	134.96	47.01	63.81	202.63	71.53	110.63
13	83.76	35.37	43.91	144.73	63.67	76.61	285.41	120.16	155.00	389.43	187.85	219.65
14	89.01	42.67	53.97	162.78	77.09	92.14	312.58	155.92	203.40	431.06	225.16	260.52
15	75.95	42.25	47.91	113.23	76.10	86.64	247.67	146.50	158.35	310.79	218.34	216.20

hydrograph method to convert runoff depth to peak flow. For brevity, the results for Loc. No 1 i.e., Bhupathipalem dam is presented using SSP5-8.5 over epoch-1 (2021-2050), epoch-2 (2051-2080). The dam, which is designed for a spillway capacity of 2314 m^3/sec, shows projected PMF values of 3024 m^3/sec for epoch-1, and 3340 m^3/sec for epoch-2. This indicates that the PMF is expected to increase by 31% during epoch-1, and 45% during epoch-2 under the SSP5-8.5 scenario.

Table 4 : Resulted PMP values over historical period and GEV corresponding to return period

Loc. No	PMP (mm)	GEV (mm)		
		50 years	100 years	1000 years
1	1036.37	817.70	909.79	1214.10
2	649.07	621.36	687.13	904.46
3	473.59	474.17	521.89	679.58
4	746.55	783.46	867.21	1143.96
5	970.12	801.14	890.27	1184.78
6	825.10	673.68	742.08	968.11
7	1132.97	839.41	918.96	1181.82
8	587.95	698.18	759.47	961.98
9	557.07	657.08	726.73	956.85
10	888.55	741.07	804.38	1013.55
11	1696.73	1520.69	1694.39	2268.33
12	563.86	586.99	647.59	847.83
13	992.52	1006.14	1099.88	1409.64
14	967.50	1004.50	1102.28	1425.38
15	654.41	653.02	712.18	907.69

Table 5 : Future variation of PMP values under all SSPs across each epoch with respect to the BL period

Loc. No	BL (mm)	SSP1-2.6 (mm)		SSP2-4.5 (mm)		SSP3-7.0 (mm)		SSP5-8.5 (mm)	
		Epoch-1	Epoch-2	Epoch-1	Epoch-2	Epoch-1	Epoch-2	Epoch-1	Epoch-2
2	585.27	341.27	327.43	439.51	435.16	746.38	415.43	289.35	608.02
3	485.18	474.72	514.23	543.13	566.89	841.58	502.67	638.66	707.65
5	974.15	939.18	1007.94	834.78	1062.34	869.55	950.38	1303.82	793.57
8	590.79	548.65	567.06	608.80	658.00	640.25	934.10	547.43	588.49
15	667.27	661.94	499.64	414.16	520.25	532.77	755.36	731.72	538.51

5. CONCLUSIONS AND FUTURE SCOPE

An analysis of rainfall pattern variations from 1971 to 2014 at fifteen dam locations in the GRB was conducted using Quantile Mapping (QM) bias correction. The performance statistics indicated satisfactory results during calibration and validation period. Subsequently, the study extended to future period at these fifteen dam locations under all SSPs (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5), demonstrating good correlation statistics (mean, standard deviation, and the 90th and 95th percentiles) with respect to the baseline. Additionally, the PMP values and extreme rainfall values are determined at each dam location using the Hershfield method and Gumbel's Extreme Value distribution, respectively. It is found that the PMP values are falling below 100 years return period at most of the dam locations. Further, the PMP analysis over future period (epoch-1: 2021-2050, epoch-2: 2051-2080) was conducted using the Hershfield method across all SSPs. These PMP values are then used to project PMF values for the same epochs by considering all SSPs. For brevity, the study presented PMF projection for one location i.e. Loc. No 1 (Bhupathipalem dam) under the SSP5-8.5 scenario for epoch-1 and epoch-2. The result revealed that the PMF is expected to increase by 31% over epoch-1, and 45% during epoch-2 under the SSP5-8.5 scenario.

In this study, the performance statistics yield satisfactory for analyzing GCM data. However, from the dam safety perspective, the outputs should be improved by bringing them into finer resolution using the downscaling techniques. This enhancement is earmarked for future research.

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Save water today, secure your tomorrow

Grouting Issues for Rehabilitation of Ukai Spillway Block under DRIP

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ABSTRACT

Seepage is a complex problem in dams. Seepage results not just in loss of water, it increases pore pressure in the body of the dam. The loss of cementitious material from the masonry over the years results in reduced integrity of the dam structure and can become a dam safety problem. A systematic and scientific approach is needed to address the issue of seepage in masonry dams. Grouting is the universally accepted method of addressing the problem which not only helps in reducing the quantum of seepage but also impregnates the masonry with cementitious material making up for its loss over the years. However, proper investigations using the state-of-the-art methods is a pre-requisite in drawing an efficient grouting plan. Grouting methodology, drilling pattern, grouting equipment, grout material, admixtures to be used, grout pressure to be applied, tests to be conducted for the drill holes before and after actual grouting are matters of careful design and execution.

This paper deals with a case study of Ukai dam in Gujarat state of India wherein grouting an overflow block successfully addressed its seepage problem. It describes the systematic approach adopted before actual grouting in terms of investigations carried out to assess the need for grouting, exploration of various grout materials, suitability of grout equipment, methodology of actual grouting, pre and post grout tests carried out and the efficacy of the grouting achieved.

Ukai is a Multipurpose project on the second largest westward draining interstate river Tapi in Gujarat which is considered to be the lifeline of south Gujarat. The dam is more than 50 years old and consists of 868 m long uncoursed rubble stone masonry gravity dam and 4058 m long earthen dam of zoned filled embankment. The Masonry dam has a maximum height of 80.7 m above its deepest foundation in the NOF. The spillway block 9 showed excessive seepage of about 400 LPM measured at the foundation/drainage gallery. Therefore, it was decided to tackle this block first. There were 5 continuous leakage/seepage spouts which were found to be interconnected in the dye tests conducted. The reservoir could not be depleted for operational reasons and treatment had to be given at a high reservoir level. The core recovery from the drilled holes was very low. In the dye test the dye traveled within 8-11 minutes from the Bore holes 1 to 7, into nearby Vertical Porous Drain (VPD-23) at stage 15-18 m. At stage 18-21 m the dye test indicated connectivity of the grout holes with the downstream ogee surface. The high discharge through the bore holes was possibly due to the passage of reservoir water with suction points on the upstream face. Use of thick colgrout mix also did not work. Polyurethane (PU) grout with quick setting admixture followed by cementitious grout ultimately reduced the discharge in the VPD from 400 LPM to 120 LPM. With this the grouting could continue in the planned manner which is now being extended to other blocks of the spillway to render desired safety to Ukai dam.

1. INTRODUCTION

Dam construction using stone masonry is no longer in vogue. However, there are a very large number of dams constructed with stone masonry which are now aging. Seepage is the major problem faced by these old dams. Seepage not only increases pore pressure within the dam body, but it also results in the loss of cementitious material holding the masonry together apart from creating ugly scenes. Continued seepage and loss of binding material for a long period puts the structural integrity of the dam in jeopardy. These dams require rehabilitation measures to bring them back to their normal functioning. At present, grouting technology is still the main technical means of anti-seepage treatment (Huikin Y. et al. 2021). Grouting is the process of injecting liquids, mixed suspensions, or semi-solid mixtures under pressure to achieve one or more desirable end results in terms of improving

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engineering properties. (USACE, EM 1110-2-3506). The practice of grouting masonry dams with cementitious materials, incorporating non-expanding admixtures to mitigate the expansion of cement particles and utilizing other cost-effective admixtures, addresses several critical challenges in dam maintenance and repair. The process of grouting is aimed at filling gaps, cracks, and voids between stones, which are often exacerbated by aging, cyclic water loading due to reservoir filling and emptying, seepage, and the potential failure of internal drainage systems. Over time, these issues can lead to the leaching of mortar, creating voids and weakening the structural elements of the dam. The non-core drilling and grouting method is a widely adopted solution for these problems, as it allows for the direct injection of grout into voids and gaps, effectively sealing off seepage paths and also restoring strength to the dam structure. This method, while seemingly straightforward, can pose significant challenges that require careful planning and meticulous execution for achieving a sustainable solution in terms of dam safety.

2. SITE INFORMATION

The Ukai multipurpose project, constructed on the second largest west draining Tapi River in Gujarat, India was commissioned in 1972 and has been providing continuous benefits for over five decades. Ukai is the largest and the terminal reservoir on the interstate Tapi river having a catchment area of 62,225 square kilometers. The gross storage capacity of Ukai reservoir is 7414 million cubic meters. This project utilizes over two-thirds of the Tapi River's waters for irrigation, covering nearly 400,000 hectares in south Gujarat. It also generates hydroelectric power at the dam foot power house to the tune of 300 MW. It supports fisheries in addition to offering flood and water security to the inhabitants along the river course. Many heavy industries along the banks are served by river Tapi, especially in the city of Surat about 90 km downstream of the dam, which is known as Diamond city and Textile hub of India. The Ukai Dam, an earth-cum-masonry structure, has a length of 4926.79 m in which the length of the masonry portion of the dam is 868.82 m including 425.195 m spillway. The maximum height of the dam in the earth dam portion is 68.5 m and that in the masonry portion from the deepest foundation to the top is 80.772 m. Its masonry consists of random rubble with a mortar mix of cement, surkhi, and sand in a ratio of 0.8:0.2:5 by weight. The upstream face and the high-stress zone near the dam's toe are constructed with a richer cement-sand mortar mix of 0.8:0.2:3 by weight.

2.1 Spillway Section of Ukai Dam

The spillway portion of the Ukai Dam is 425.19 m. long and comprises 22 blocks. The downstream slope at the straight portion of glacis is 0.75:1. There are 22 numbers of radial gates measuring 15.545 m × 14.78 m capable of discharging 37,859 cumecs when fully open and at FRL, which corresponds to the standard project flood inflow of 49,470 cumecs. Emergency stoplogs are provided for the radial gates and can be lowered into stoplog grooves as needed. With approximately 75% of the live storage above the crest level of the spillway, very little time would be available for carrying out any over water treatment on the upstream of spillway.

2.2 Need for seepage control measures

The aging Ukai dam is showing signs of distress in the form of increased seepage and some deterioration of masonry blocks. Downstream Ogee surface of Spillway Block no. 9 shows continuous and major leakage/seepage at five spots, The steel reinforcement is exposed at one location due to spalling of concrete. There are a few surface cracks with water jetting from them. Figure1 shows gushing water with dye from the vertical porous drain (VPD) in the gallery at chainage 2136.6 m in block 9. Dye was introduced to see whether the connection of the seepage/leakage path is continuous and leading to the reservoir, which was confirmed. The discharge was of the order of 400 liters per minute (LPM). Figures 2, 3 and 4 show the cracks and the deterioration of the ogee surface. The other two VPDs in block 9 were dysfunctional probably due to leaching. Increased seepage can result in an increased rate of deterioration of concrete and mortar, leaching of concrete, loss of mortar and reduced structural

Fig. 1 : VPD at chainage 2136.6 m. in block number 9 showing flushing of water with dye

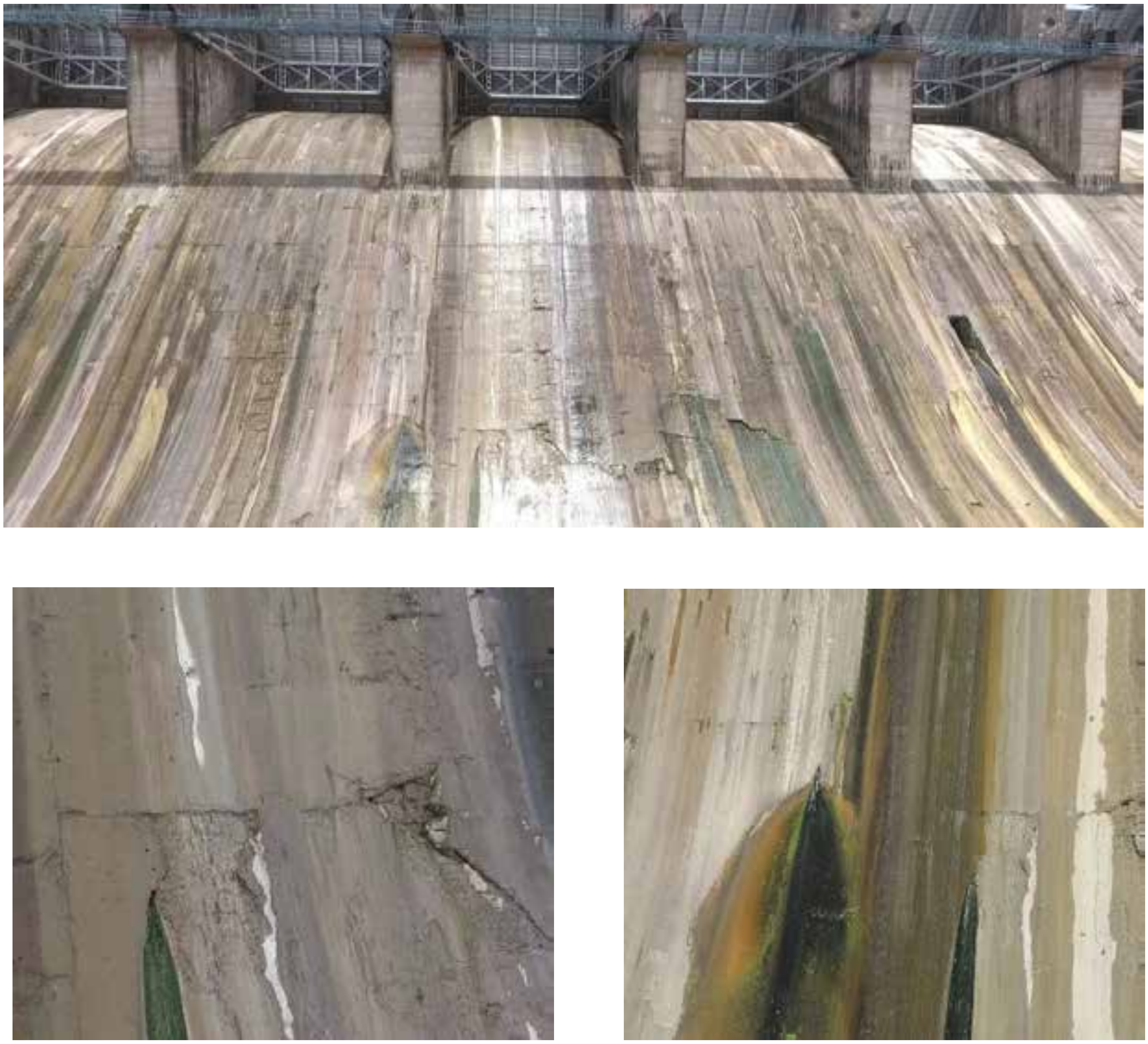

Fig. 2, 3 and 4 : Surface deficiencies on the downstream ogee of block 9.

strength (CWC, 2018). Therefore, there was a dire need to repair the masonry portion of Ukai dam and it was decided to start the repair work with the most severely affected Block no. 9, having dimensions of 43.89 m in height up to the crest level and 54.89 m in width. Depending upon the experience gained and the success of the procedure adopted, it was decided to carry out treatment to the other blocks of Ukai dam.

2.3 Planning

Grouting operation involves a lot of planning. Not just the procurement of materials, their storage, transport to the site, handling during use, also need to be planned meticulously. The layout of the plant and machinery on site need a careful consideration. The actual grouting scheme involved scanning the spillway crest for the location of reinforcement bars using Ground Penetration Radar (GPR) to avoid damage during drilling, vertical drilling of seven boreholes at a center-to-center distance of 2 m with small adjustment to avoid the reinforcement. The drilling and grouting work, covering a total depth of approximately 48 m for each borehole was to begin in the reinforced concrete portion on the spillway crest, proceed through the masonry, and finish in the foundation rock. The borehole diameter was set at 76 mm (Nx Size), and the grout mix was planned with a ratio of 80:18:2 in terms of Cement, Ultrafine processed fly ash and micro-silica. In addition, 225 gm of a non-expanding admixture per 50 kg bag of cement was also planned to be used. The construction procedure was planned to be in accordance with the principle of first thin and then dense grouting, as per the predetermined sequence of grouting holes (Huikin Y. et al. 2021).

Therefore, the water-cement ratio was to be kept at 5 initially and adjusted later as needed on-site, with fine sand mixed to fill larger gaps. Due to anticipated low core recovery rates, downward grouting at a 3 m interval was planned. The properties of materials planned to be used are given in the following paragraphs.

2.4 Materials

2.4.1 *Cement*

Normal and fine grade cement grouts have been used with success (Schrader, 1980; Gouvenot, 1991; Brighton and Lampa, 1991; Diaz, 1994; ICOLD, 2000; Noret and Laliche, 2017). In this case, Ordinary Portland Cement (53 Grade), as per IS 12269: 1987, known for its high specific surface area, superior strength, and durability, was procured which was supplied in 50 kg bags, facilitating ease of handling and usage on site.

2.4.2 *Water*

Water to be used for grouting operations should be as outlined in IS 456-1978. It should be devoid of saltiness or brackishness, maintaining cleanliness and clarity while being free from objectionable quantities of silt, oil traces, harmful alkalis, salts, organic substances, and any other materials detrimental to the mortar or concrete's integrity or that could precipitate efflorescence or corrode the steel reinforcement within reinforced concrete structures.

In the present case water from Ukai Reservoir, subjected to necessary quality assessments in a laboratory to ensure compliance with specified standards has been used. It was conveyed via supply lines situated in proximity to the upstream surface of the right-side dam. Storage tanks were used to facilitate settlement of any suspended fine particles and maintain a cool temperature ideal for grout mix preparation. It is imperative that the water does not contain particles larger than those of cement.

2.4.3 *Ultrafine Processed Fly-ash*

This material is a highly efficient pozzolanic substance designed for utilization as a component of cement alongside Portland clinker. It serves as a partial substitute for Portland cement, aimed at producing high-performance grout mix. The characteristics and specifications of the material are presented in Table 1.

Table 1 : Properties of Ultrafine Processed Fly-ash

Property	Value
Color	Greyish white
Bulk weight	0.65 tonne/m3
Density	2.30 tonne/m3
Loss on ignition	less than 2.5%
Particle size	Zero retention on 45-micron sieve and less than 0.25% retained on 25-micron sieve.
Particle shape	Spherical

2.4.4 *Micro-silica*

The material, primarily comprising silicon dioxide (SiO2) derived from silicon metal and ferrosilicon, is formulated to engage in a chemical reaction with Calcium Hydroxide present in cement. This reaction results in the formation of additional Calcium Silicate Hydrate, thereby enhancing the strength and durability of the concrete or grout mix. Furthermore, the material conforms to the standards set by IS 9103: 1999, ensuring its quality and efficacy. The properties and specifications of the material are given in Table 2.

Table 2 : Properties of Micro-silica

Property	Value
SiO2	92%
Available alkalis	0.5 – 1.5%
Loss on ignition	2.0 – 4.0 %
Moisture content	0.1 – 0.35 %
Particle size	0.03 – 0.1 micron
Retained on 325 (45 micron)	0.4 – 2.5%
Particle shape	Spherical
Dry bulk Density	0.5 – 0.7 tonne/m^3

2.4.5 *Plasticized expanding grout admixture.*

This admixture is specifically designed for cementitious grouts and concrete formulations where a reduced water-to-cement ratio and controlled expansion are essential. The specifications of this admixture are outlined in BS-8110, (Part 1): 1997.

Grouting procedures will utilize a cement-based mixture, enhanced with a plasticizing, expanding powder admixture. This admixture, devoid of iron and chloride, should be used at a rate of 225 grams per 50 kilograms of cement. It is designed to induce up to 4% expansion in the unset grout through a gaseous expansion mechanism.

With high compressive strength, unaltered setting time, with expansion rate up to 4% occurring within 15 -120 minutes as per the requirement and countering the plastic settlement as per ASTM C827, the admixture is compatible with all types of Portland cements.

3. EXECUTION OF THE WORK

The execution commenced with the mobilization of two drilling rigs on to the crest of ogee portion of the dam in a tightly confined space between the radial gate and the four tiers of stoplog gates. GPR surveys were carried out and locations of the reinforcement bars were marked on the concrete ogee surface to avoid their rupture during the drilling. The initial phase of drilling and grouting was performed in the reinforced concrete portion, adopting a downward grouting method at 3 m stages. The diameter of the grout holes is commonly between 38 and 75 mm (Corns et al., 1988; ICOLD, 1997; Woodson, 2009; Panasyuk et al., 2014). In this case 75.44 mm diameter (Nx Size) drill holes were adopted, to get desirable surface for grout penetration and to enable the inspection of the drilled holes by videography for assessing the general condition of the masonry before grouting.

3.1 Core recovery in Reinforced Concrete

Core recovery, in general, is a measure of the quality of masonry/concrete. Higher core recovery indicates less voids in the masonry/concrete. In the present case, the core recovery in the concrete portion was not satisfactory ranging between 24.89 – 64.78% in all the seven boreholes. The core recovery for all the seven boreholes in concrete portion is presented in Table 3. Also, on close observation of the later extracted cores it could be inferred that there was interconnectivity between the voids in the concrete. This was evident from the presence of the fresh grout from earlier boreholes in the cores of subsequently driven boreholes. Figures 5 and 6 show the fresh grout present in the core of bore hole No 2 from the grout of earlier grouted borehole Nos 5, 6 and 7.

Table 3 : Core recovery in concrete portion.

Sl. No.	Bore Hole identification	Core recovery in %
1	BH-01	56.45
2	BH-02	64.78
3	BH-03	64.33
4	BH-04	40.78
5	BH-05	27.33
6	BH-06	24.89
7	BH-07	34.45
Average core recovery		44.72

Fig 5 & 6 : Traces of new grout material in concrete cores extracted

3.2 Difficulties faced while drilling and grouting in Masonry portion

The drilling and stage grouting in the masonry portion of spillway posed more complex problems. Not only the core recovery was poorer, the average being 36%, but also the grout material traveled to larger distance and started to come out of the VPDs and the drilled adjacent bore holes. The reservoir was connected to bore holes due to which water under hydraulic head was posing resistance to the grout. Even the thicker cementitious grout mix, with addition of sand and lower water-cement ratio was also not sustainable in any of the boreholes. The grout material was either flushing down the VPD at Ch 2136.6 m or throwing back upon removal of packer assembly in the borehole. This resulted in difficulties in deciding the stop criteria and the grouting pressure (Zhang S., et al. 2022). Ideally, an empty reservoir offers the best situation for grouting. However, this ideal situation may not always be available in a functioning dam. In such situations, the unemptied reservoir might be the only repair solution (Javanmardi and Léger, 2005; ICOLD, 1997). The same was adopted in the present case with site specific modifications and measures as needed.

The borehole-wise tracer tests were carried out to understand the exact situation. The observations from tracer tests are presented in Table 4. To assess the deficiencies of masonry, the borehole videography was carried out for six holes, which showed high turbulence of water inside the borehole, and aslo confirmed direct connection between the reservoir, boreholes and VPD at Ch. 2136.6 m. The videography of BH-7 was not possible due to upward trust of reservoir water.

Table 4 : Observations of tracer tests on bore holes in masonry portion.

Sl. No.	Bore Hole	Stage (m)	Observation
1	BH-01	12-18	Tracer travel time upto VPD at Ch 2136.6 m was 5 minutes Tracer also came out from downstream face.
2	BH-02	12-18	Tracer travel time upto VPD at Ch 2136.6 m was 3 minutes 3 BH-03 12-18 Tracer travel time upto VPD at Ch 2136.6 m was 2 minutes
4	BH-04	12-18	Tracer travel time upto VPD at Ch 2136.6 m was 2 minutes
5	BH-05	9-12	Grout came out from BH-02 and BH-03
		12-18	Tracer travel time upto VPD at Ch 2136.6 m was 3 minutes
		9-12	Bore hole was connected to reservoir.
6	BH-06	12-18	Tracer travel time upto VPD at Ch 2136.6 m was 7 minutes Tracer came out from VPD at Ch 2130.8 m in Block No.9.
7	BH-07	12-18	Bore hole was connected to reservoir

4. PU GROUTING WITH ACCELERATOR TO OVERCOME THE PROBLEM

The team of experts from DRIP-DSRP visited the site and suggested some remedial measures to deal with the difficulties faced in drilling and grouting for masonry. It was suggested to first identify the upstream suction points using thin ribbons and videography and to plug the same by underwater treatment and then use some quick setting system such as PU grout to seal the path initially before the cementitious grout is injected.

Accordingly, the upstream surface of spillway Block no. 9 and adjacent Block no. 8 were divided into eight vertical segments each of 2 m width. Divers were sent to find out the suction points in the masonry using thin ribbons, videograph the locations and mark the same with underwater markers.

4.1 Quick setting poly-urethane (PU) resin

Polyurethane grouts have controllable set times that can be varied from seconds to minutes (Weaver and Bruce, 2007). They are also expansive when unconfined, with some reports noting expansion of 30 times the injected volume (Warner, 2004). The abilities to expand and rapidly set are greatly beneficial (USACE, EM 1110-2-3506) under most high-flow, high-head circumstances. The advantageous properties of single component PU resin are (i) single shot application (ii) formation of impermeable membrane (iii) no leaching and (iv) non-diluting.

The single-component polyurethane (PU) resin used in the present treatment included an accelerator as well. The function of the accelerator was to regulate the reaction time that initiates the foaming process when the resin comes in contact with water. This ensures that the foaming occurs in a timely manner, allowing for effective sealing of the entire leakage path. Figure 7 shows the foaming of the PU resin.

Fig. 7 : Foaming of PU Resin after exposure to water

Extensive preliminary trials were conducted to determine the optimal percentage of accelerator necessary to achieve the desired foaming time. These trials helped establish a precise correlation between the accelerator concentration and the foaming kinetics. Further refinement of the accelerator dosage was guided by data obtained from tracer tests. This data was instrumental in fine-tuning the amount of accelerator used, optimizing it to minimize waste and effectively seal the leakage path from the discharge point up to the borehole intake.

4.2 The effectiveness of PU treatment

The leakage paths extending from various boreholes (BH-1 to BH-6) to VPD at Ch. 2136.6 m were effectively sealed which is evidenced by the successful intake of cementitious grout following the polyurethane (PU) resin grouting. Subsequently, the drilling and cementitious grouting operations were completed without any complications in Block No. 9 of the spillway. The leakage path from BH-7 to the reservoir appeared to be effectively sealed, as indicated by the stable uplift water pressure and the successful completion of further cementitious grouting work. The discharge rate from the VPD at Ch. 2136.6 m, has been significantly reduced from 400 liters per minute to 120 liters per minute. However, there remains the possibility of additional leakage paths from the adjoining blocks into this VPD. Similar treatment to the adjoining blocks, which is planned based on the experience of Block No 9 would further reduce the present discharge of 120 liters per minute.

5. CONCLUSION

Drilling and grouting operations in large masonry dams pose numerous challenges. Poor quality of masonry, presence of water with pore pressure, established continuous seepage paths, connectivity with reservoir, connectivity to VPDs, connectivity to downstream dam surface and collapsing of drilled boreholes are particularly significant problems faced. Flushing of grout material without pressure being developed or rejection of grout due to clogging of bore hole is the result of all these problems. Despite these issues, grouting is the single most effective treatment for dams with high-head and high-flow seepage problems. The major task is to plug the seepage path and facilitate the grout intake into the dam body and develop some pressure for the grout to travel to the smaller crevices. Polyurethane (PU) resin as a quick setting system can come handy as a practical and specialized solution that can effectively address these issues. However, successful application of PU resin grout requires expert knowledge and precise execution.

In dams similar to Ukai dam, where water levels do not significantly decrease even at the end of the season and emptying the reservoir is not feasible due to its critical role in supporting large populations, PU resin grout becomes especially valuable. This technique can be employed for strengthening the dam structure by sealing water leakage paths with PU resin grout in conjunction with cementitious grout applications. It is essential that the entire operation is meticulously planned and executed to enhance the structural integrity and safety of the dam infrastructure.

Acknowledgement

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Workshop on
Sedimentation Management in Reservoirs for Sustainable Development

2nd – 3rd May, 2024, Chandigarh

View of the dais during inaugural session (L-R) Shri K.K. Singh, Director (WR), CBIP; Shri C.P. Singh, Chief Engineer, BBMB; Shri A.K. Dinkar, Secretary General, INCOLD and Secretary CBIP; Shri Manoj Tripathi, Chairman BBMB and Shri Ashok Kumar Singh, Principal Secretary, WRD Kerala

Brief Report

Indian National Committee on Large Dams (INCOLD), Central Board of Irrigation and Power (CBIP), in collaboration with Bhakra Beas Management Board (BBMB) organised a National level workshop at Chandigarh on 2nd – 3rd May 2024 which includes A technical visit to Bhakra Nangal Dam which was arranged on 3rd May 2024 i.e. 2nd day of the workshop.

The workshop on "Sedimentation Management in Reservoirs for Sustainable Development" held on 2nd May 2024 at the Institution of Engineers (India), Chandigarh, provided a platform for experts, researchers, and practitioners to discuss and exchange insights on the challenges and solutions related to sedimentation management in reservoirs. The event was jointly organized by INCOLD and CBIP in collaboration with BBMB, aiming to address the critical issue of sedimentation in reservoirs and its implications on sustainable water resource management.

Lighting the lamp by Shri Manoj Tripathi, Chairman, BBMB

HIGHLIGHTS OF THE WORKSHOP:

1. **Inaugural Session**: The workshop commenced with an inaugural session by welcome address

by Shri A.K. Dinkar, Secretary General, INCOLD and Secretary CBIP The Guest of honor Shri Manoj Tripathi, Chairman BBMB, Shri Ashok Kumar Singh, Principal Secretary, WRD Kerala and Shri C.P. Singh, Chief Engineer, BBMB addressed the participants and emphasized the significance of sedimentation management in ensuring the long-term sustainability of reservoirs. At the end of inaugural session Shri K.K. Singh, Director – Water Resources, CBIP proposed vote of thanks.

2. **Technical Sessions**: The workshop comprised multiple technical sessions covering various aspects of sedimentation management, including sediment monitoring techniques, sediment flushing methods, and environmental impacts assessment. Eminent experts and researchers presented their studies, case studies, and best practices, offering valuable insights into effective sediment management strategies.

Technical Session - I

- Presentation 1 – Challenges for Management of Sediments In Large Reservoirs - A Case Study of Bhakra Dam - *Sh. C.P. Singh, Chief Engineer, BBMB.*
- Presentation 2 – Reservoir Sedimentation using Remote Sensing and GIS.- *Prof. Sanjay Kumar Jain- National Institute of Hydrology, Roorkee*
- Presentation 3 - Sediment Management in Hydro Power project - *Dr A.K. Singh, GM, NTPC.*

Technical Session - II

- Presentation 4 – Diagnosis of effect of October-2023 flood at hydropower projects in Teesta basin and formulation of sediment management strategy – *Ms. Manjusha Mishra – GM, NHPC*
- Presentation 5 – Spatial Interpolation of Sediment Yield Estimated from Reservoir Siltation Data of India – *Dr. Yazad Jabbar, Asstt. Professor, SNPIT*
- Presentation 6 – Exploring the efficacy of Magnitude Frequency Analysis in managing reservoir sedimentation - *Dr. Sagar Rohidas Chavan - IIT Ropar*

Technical Session – III

- Presentation 7 – Dealing with Sediments-Case Studies - *Sh. M.K. Verma, Scientist-D, CWPRS*
- Presentation 8 – Solutions for Siltation and Erosion utilizing Tech Revetment Mattress - *Mr. Tanmay Dutta Gupta, TERRE ARMEE*
- Presentation 9 - Brief introduction about Bhakra Dam, BBMB - *Sh. C.P. Singh, Chief Engineer, BBMB*

Shri A.K. Dinkar, Secretary General, INCOLD and Secretary CBIP, delivering the welcome Address

Shri Manoj Tripathi, Chairman BBMB, addressing the participants during inaugural session

Shri Ashok Kumar Singh, Principal Secretary, WRD Kerala, addressing the participants during inaugural session

Technical Session - IV

- Presentation 10 – Technical Visit to Bhakra Dam - Interactive Session, BBMB.

The workshop facilitated knowledge sharing and networking opportunities among participants, fostering collaborations and partnerships for addressing sedimentation challenges collectively. Participants had the chance to interact with industry experts, academia, and policymakers, gaining valuable perspectives and forging professional connections.

Technical Tour : Following the workshop, a technical tour was organized on 3rd May 2024 to Bhakra Nangal Dam, one of India's iconic multipurpose dams managed by BBMB. The technical tour provided participants with first-hand experience of sedimentation management practices implemented at the dam site. Participants were guided through the dam infrastructure, sedimentation control structures, and sediment flushing operations, gaining insights into the practical aspects of reservoir management.

Shri C.P. Singh, Chief Engineer, BBMB, addressing the participants during inaugural session

Mr. K.K. Singh, Director (WR), CBIP, proposing vote of thanks

The workshop on "Sedimentation Management in Reservoirs for Sustainable Development" served as a significant platform for knowledge exchange, capacity building, and collaborative efforts towards addressing the challenges of sedimentation in reservoirs. The event underscored the importance of adopting holistic approaches, leveraging technological innovations, and fostering stakeholder engagement for sustainable sediment management practices. The technical tour to Bhakra Nangal Dam offered participants a deeper understanding of sedimentation management techniques and reinforced the importance of proactive measures in preserving reservoir functionality and ecosystem integrity.

Overall, the workshop and technical tour were instrumental in advancing the discourse on sedimentation management and fostering a shared commitment to sustainable water resource management practices.

Group Photograph

Conference on
Pumped Hydro Power Storage: The Need to Support High Penetration of Renewable Energy

25th – 26th July 2024, New Delhi

View of the dais during inaugural session (L-R) Shri K. K. Singh, Director (WR), CBIP; Shri P. Ravikumar, Chairman KERC, Shri Ghanshyam Prasad, Chairperson CEA & President CBIP; Shri Anuj Kanwal, Commissioner, Jal Shakti Mantralaya and Shri A. K. Dinkar, Secretary, CBIP

Brief Report

The conference on "Pumped Hydro Power Storage: The Need to Support High Penetration of Renewable Energy" was held over two days 25th – 26th July 2024 at the Pradhan Mantri Sanghralaya, New Delhi. The event, hosted by the Central Board of Irrigation and Power (CBIP) and the Indian National Committee on Large Dams (INCOLD), in association with the Central Electricity Authority (CEA), aimed to address the critical role of pumped hydro storage in integrating renewable energy sources into the power grid.

The Chief Guest Shri Ghanshyam Prasad, Chairperson CEA & President CBIP along with Guest of honor Shri P. Ravikumar, Chairman KERC, Shri Anuj Kanwal, Commissioner Jal Shakti Mantralaya, Shri A. K. Dinkar, Secretary, CBIP and Shri K. K. Singh, Director (WR), CBIP inaugurated the conference.

Lighting the Lamp during inaugural session

The conference was attended by about 170 delegates from 67 different organisations. The primary objective of the conference was to explore, pumped hydro storage (PHS) can be leveraged to support the increased deployment of renewable energy sources like solar and wind. Discussions focused on technological advancements, project implementation strategies, policy frameworks, and case studies relevant to India's energy landscape.

The following technical session were held during the conference.

Day 1 : 25/07/2024 (Thursday)

Technical Session 1

Fundamental, Policy and Regulatory Frameworks; Preparation of Detailed Project Reports (DPRs); Economic and Financial Analysis:

- Fundamental, Policy and Regulatory Frameworks by *Shri Shravan Kumar, CE, CEA*
- Preparation of Detailed Project Reports (DPRs) by *Shri Amit Singhal, CEA*
- Economic and Financial Analysis by *Shri Praveen, CEA*
- Fundamental of pump storage technology and preparation of DPR by *Shri Kalachand Mahalik-Torrent Power*
- Integration of Pump Storage with Renewable Energy: Synergies between pump storage and variable renewable sources by *Shri Abhishek Ranjan-E&Y*
- The Insurance Backbone: Supporting the Growth of Pumped Hydro Power and Renewables by *Dr Anoop Harjani, Epoch Insurance Group*

Technical Session 2

Future Perspectives and Research Directions; Environmental Impact Assessment and Mitigation:

- Growth trends and opportunities in pump storage by *Shri. S. N. Tripathi-NTPC*

Shri A.K. Dinkar, Secretary, CBIP, delivering Welcome Address

Shri Ghanshyam Prasad, Chairperson CEA & President CBIP, delivering the inaugural address

Group Photograph

Shri P. Ravikumar, Chairman KERC, addressing the participants during inaugural session

Shri Anuj Kanwal, Commissioner, Jal Shakti Mantralaya, addressing the participants during inaugural session

- Pumped Hydro Power Storage -Future Development Perspectives by Shri Sankarnarayan – *EX ED SJVN*
- Integrating Smart Sensing Technology (SST) for Comprehensive Health Monitoring with Early Detection Techniques in Pumped Hydro Power Projects for Analyzing Structural Heath Integrity & Effective Decision Support System – *Shri Ramji Singh, Panel Member, Dam Safety Review Panel (DSRP), Govt. of Gujarat*
- Environmental aspects in the development of Pumped storage hydro projects in Western Ghat, Maharashtra by *Shri Nilesh - WRD Maharashtra*
- Ultrasonic Flow Measurement With Intelligent Applications (Sediment Monitoring, Turbine Efficiency Measurement And Penstock Leak Detection System) And Level Measurement With Dam Safety by *Shri Prem Shankar - Rittmeyer.*

Day 2 : 26/07/2024 (Friday)

Technical Session 3

Design and Engineering Considerations & Construction and Project Management:

- Geological/geotechnical inputs for ensuring safe and sustainable DPRs of Pumped Storage Projects by *Ms. Neetu Chauhan-GSI*
- Presentation by *Shri Hari Dev- CSMRS*
- Design Aspect of EM system of Pumped Storage Projects by *Shri J. C. Kakoti- NTPC*
- Presentation by GREENKO - *Shri P M Nanda- Vice President, Greenko*

Technical Session 4

Design and Engineering Considerations & Construction and Project Management; Case Studies and Project Showcases:

Technical Session 1

Technical Session 2

Technical Session 3

Technical Session 4

- Application of New Age Geophysical Technology for Faster and Smooth Execution of Pump Storage Projects by *Shri S L Kapil- Ex-ED NHPC*
- Innovative Geophysical Methods for Pumped Storage Projects: Speeding Up Investigations and Mitigating Geological Uncertainties by *Shri Sanjay Rana – Parsan Group*
- Optimizing Grid Resilience: Renewables and Energy Storage Technologies by *Ms. Shivani Sharma- Hitachi*
- Hybrid wind energy Generation and Pumped Storage Plat (PSP): case study by *Shri Karan Saren-CEA*

Visit to Pradhanmantri Sangrahalaya

The attendees visited the iconic Pradhanmantri Sangrahalaya, This visit provided delegates with an opportunity to explore the museum's exhibits that chronicle India's political history and development. The tour was not only a cultural enrichment but also a moment of reflection on India's journey towards energy sustainability and progress. The historical significance of the venue added a unique dimension to the conference, underscoring the connection between India's past achievements and its future energy aspirations.

Networking Session

Attendees had the opportunity to network with experts and peers, fostering collaborations and discussing potential aspects in the domain of Hydro Power Projects.

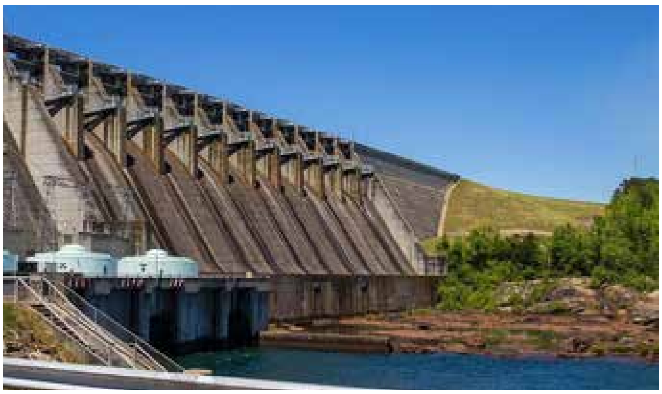
Conclusion

The conference successfully highlighted the critical role of pumped hydro storage in supporting the high penetration of renewable energy sources. It provided valuable insights into the technology, shared best practices from successful projects, and identified strategies to overcome existing challenges. The discussions underscored the need for integrated approaches combining technological innovation, supportive policies, and collaborative efforts to achieve a sustainable and resilient energy future.

Visit to Pradhanmantri Sangrahalaya

INCOLD News

GOVERNMENT UNDERTAKES COMPREHENSIVE SAFETY REVIEWS OF AGING DAMS ACROSS INDIA



In a recent announcement, the Government of India has disclosed significant efforts to ensure the safety and integrity of aging dams across the nation. According to the data compiled by the National Dam Safety Authority, there are 234 large dams in India that are more than a century old, raising concerns about their structural soundness and safety standards. Responsibility for the safety, operation, and maintenance of these dams primarily lies with the respective dam owners, predominantly state governments and Central/State Public Sector Units. As part of routine procedures, dam owners conduct periodic pre-monsoon and post-monsoon inspections. Moreover, many states have established Dam Safety Review Panels to conduct comprehensive audits of these critical infrastructure assets.

During the fiscal year 2023-24, dam-owning agencies reported conducting pre-monsoon and post-monsoon inspections for approximately 6414 and 4150 dams, respectively, in compliance with the Dam Safety Act 2021.

To address concerns and ensure the longevity of these aging structures, the Government of India has been implementing the Dam Rehabilitation and Improvement Project (DRIP), aimed at enhancing safety and operational performance. The Phase-I of DRIP, completed in March 2021, involved the review and rehabilitation of 198 dam projects across seven states. Following the success of Phase-I, the government has initiated Phase-II & III of DRIP, which involves the comprehensive auditing and rehabilitation of about 736 dams with financial support from international bodies like the World Bank and the Asian Infrastructure and Investment Bank. Under this scheme, the Dam Safety Review Panels have already completed inspections and reviews for approximately 408 dams.

The enactment of the Dam Safety Act 2021, effective from December 30, 2021, provides a comprehensive framework for the surveillance, inspection, operation, and maintenance of all large dams in the country, aimed at preventing dam failure-related disasters. Section 38 of the Act mandates a thorough dam safety evaluation for each specified dam.

It's important to note that while aging dams pose concerns, proper maintenance and timely repairs can ensure their continued safe operation. The Minister of State for Jal Shakti, Shri Bishweswar Tudu, emphasized this point in a written reply in the Rajya Sabha today.

INDIA'S STRATEGIC HYDROPOWER PROJECT ON THE SIANG RIVER

To counter China's construction of a massive dam on the Yarlung Tsangpo River in Tibet, India is advancing plans for its largest hydropower project on the Siang River in Arunachal Pradesh. The proposed ₹1.5 lakh crore dam aims to bolster India's energy security and address concerns over downstream water flow. However, local communities have raised concerns about potential displacement and impacts on livelihoods, particularly in orange farming. YouTube+11Latest news & breaking headlines+11Financial Times+11India TodayThe Economic Times

CONCERNS OVER CHINA'S MEGA-DAM PROJECT ON THE BRAHMAPUTRA RIVER

China's approval of the world's largest hydropower dam on the Yarlung Tsangpo River in Tibet has raised significant concerns in India and Bangladesh. The project could disrupt the natural flow of the river, impacting agriculture and drinking water supplies downstream. Both countries are closely monitoring developments and assessing potential ecological and geopolitical implications. Al Jazeera+7Financial Times+7Renewable Energy World+7

SEISMIC RISKS HIGHLIGHTED BY RECENT EARTHQUAKE IN TIBET

A recent earthquake in Tibet, which resulted in significant casualties and damage to reservoirs, has underscored the seismic risks associated with dam construction in the Himalayan region. Both India and China are developing numerous hydroelectric projects in this seismically active zone, raising concerns about the sustainability and safety of such infrastructure. Reuters

These developments highlight the dynamic and complex landscape of dam-related projects and policies in India, reflecting both advancements and ongoing challenges in the sector.

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