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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.

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Editorial

Dear Readers,

Greetings from INCOLD, New Delhi.

Welcome to the latest edition of the half-yearly journal of the Committee of International Commission on Large Dams (INCOLD). This edition brings forth a diverse array of research papers that delve deep into crucial aspects of dam management and hydraulic engineering, reflecting the cutting-edge developments and challenges faced by the global dam community.

This journal includes paper explores the intricate challenges associated with sediment management in large reservoirs, with a specific focus on the Bhakra Dam. As reservoirs age, sedimentation becomes a critical issue impacting reservoir capacity and operational efficiency. The case study from India provides valuable insights into spatial interpolation techniques for estimating sediment yield from siltation data. Such methodologies are pivotal for informed decision-making in reservoir sedimentation management strategies globally.

It also includes paper underscores the pressing need for dam rehabilitation, especially in the context of cascading impacts of floods. Dam safety and resilience against extreme hydrological events are paramount concerns in the wake of climate change and increasing frequency of severe weather patterns. This paper contributes to the discourse on enhancing dam infrastructure to mitigate flood risks and protect downstream communities and ecosystems.

The last paper introduces a novel approach to optimize hydraulic jump length in front of sluice gates, employing baffle blocks and sills as energy dissipators. Efficient energy dissipation is crucial for maintaining hydraulic stability and preventing erosion near dam structures. This research proposes practical equations that can be applied to enhance the performance and longevity of hydraulic structures worldwide.

Each of these papers represents a significant contribution to the field of dam engineering and management, addressing both current challenges and future directions. They embody the spirit of collaboration and innovation that defines the INCOLD community, fostering knowledge exchange and advancements in dam safety, sustainability, and resilience.

As we navigate the complexities of managing large dams in an era of climate uncertainty, these insights and findings will undoubtedly guide policymakers, engineers, and researchers towards more effective solutions and strategies. We encourage our readers to delve into these papers, engage with the research, and contribute to the ongoing dialogue shaping the future of dam engineering globally.

We extend our gratitude to the authors for their invaluable contributions and look forward to continued exploration and discovery in the field of large dam management.

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

Challenges For Management of Sediments in Large Reservoirs - A Case Study of Bhakra Dam

Manoj Tripathi[1] and CP Singh[2]

ABSTRACT

Large reservoirs play a crucial role in water resource management, providing various benefits such as flood control, hydropower generation, irrigation and water supply. However, the accumulation of sediments in these reservoirs poses significant challenges for their effective management. Sediment particles originating from erosion process in the catchments are propagated along the river flow. When river water is stored in a large reservoir, sediments settle down, thereby reducing the capacity the reservoir. Reduction in storage capacity of large reservoirs beyond a limit hampers the purpose for which these are designed. Assessment of sediments deposition, their removal/exclusion and management becomes crucial for smooth operation of large storage reservoirs.

This paper deals with the case study of sedimentation assessment and its management in a large storage reservoir i.e. Gobind Sagar Reservoir of Bhakra Dam, having gross storage capacity of 9867.84 MCM (million cubic meter) on river Sutlej located in the lower foothills of western Himalayas.

1. INTRODUCTION

Bhakra dam a 225.55m high, 518.16m long concrete gravity dam is located on the river Sutlej in the foot hills of western Himalayas/lower Shiwaliks in Himachal Pradesh, a northern state of India. The Gobind Sagar reservoir, created by construction of Bhakra Dam having gross storage capacity of 9867.84 MCM is one of the largest reservoirs in India. Since the sedimentation acts as a retrograde factor, its management, future exclusion from the reservoir and measurement of sediments deposited is an issue of regular monitoring.

2. GOBIND SAGAR RESERVOIR AND ITS CATCHMENT

The Gobind Sagar Reservoir, also known as Bhakra Reservoir, has a catchment area of 56880 sq km (21960 sq miles), rainfall of about 109 cm (43 inches) and mean annual run off of 17178.33 million cubic meter (13.93 million acre feet). The average gradient of the river is about 1.89 m/km (10 feet /mile) in the reservoir area. One of the oldest built dams in India, the Bhakra Dam is concrete gravity dam on the river Sutlej, was commissioned in the year 1963. In addition to controlling the severe and devastating floods successfully, this dam has not only provided Irrigation and Power benefits but also has brought prosperity in the Northern India. Having a gross storage capacity of 9867.84 MCM, the Bhakra Dam has a designed dead storage of 2431.81 MCM and live storage of 7436.03 MCM.

Water-spread area of Bhakra reservoir extends over 168.35 sq.km at full reservoir level (El.515.11m) and it touches the tail race of Dehar Power Plant (990MW).

Precipitation in catchment area of the reservoir is in the form of rain as well as snowfall. Snow-melt contribution into Bhakra reservoir is about 59%. A study of precipitation distribution shows that maximum contribution to annual rainfall (42 to 60%) is received during the monsoon season (June to August), whereas a nominal 5-10 % is received in the post-monsoon season. Consequently, the reservoir attains its maximum water level either during the monsoons or just after. The water level of the reservoir gradually reduces due to water use and reaches lower levels in the months of March/April.

River Sutlej transports a heavy amount of sediment, which is detrimental to life of the reservoir. The sediment contribution is mainly due to the dry desert portion of the catchment in Tibet area and Spiti area in Himachal Pradesh. Deforestation, over-grazing in the pasture lands, construction activities, farming at elevated terraces, cloud bursts etc. are other causes of concern. Landslides/ slips in the higher reaches of the catchment, steep topographic gradient, poor structural characteristics of soil, disintegrated rock mass with clay in Spiti Valley and minning of limestone deposits in the catchment area at other locations add to the sediment intake in the reservoir.

The catchment of river Sutlej at Bhakra Dam is about 56880 sq km (21960 sq miles), out of which 37050 sq km (14305 sq miles) lies in Tibet and only 19830 sq km (7655

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sq miles) lies in India. For the purpose of silt studies, the catchment area falling in India has been sub divided in to 57 sub-catchments. Topographically and climatically these catchments have been divided into five zones for monitoring purpose.

2.1 Capacity Surveys

After arrival of sediment-laden water flow into a reservoir, the coarser particles settle first in the upper reach of the reservoir due to sudden decrease in the flow velocity and widening of the cross section area. Subsequently, the finer sediment material deposits further along the reservoir bed. Sediment deposition into reservoir reduces its storage capacity, damage to hydro-equipment and upstream aggradation. Assessment of reservoir sedimentation is part of the basic information needed for operation of any reservoir. A regular monitoring of the sedimentation process helps in ensuring suitable management measures that are taken well in advance so that reservoir operation schedules can be planned for optimum utilization. Two most common conventional techniques for quantifying sedimentation in a reservoir are - direct measurement of sediment deposition by hydro-graphic surveys and indirect measurement using the Inflow-Outflow sediment records of a reservoir.

To study and compare actual silt deposits vis-à-vis the project assumptions, capacity surveys of Bhakra Dam reservoir have been carried out annually from 1963 to1977 and thereafter biannually. The latest survey completed in 2022. The survey consists of sounding along pre-determined cross sections approximately 610m (2000 ft) apart. Executed with an echo-sounder, the results are superimposed on the previous observations for working out the quantity of silt deposited at each cross-section of the reservoir during that period. For the purpose of observation, the reservoir has been sub-divided into 273 cross-sections. In order to facilitate the survey operations in a systematic manner, each x-section has permanent survey-posts of suitable heights on both the sides of the reservoir.

2.2 Suspended Sediment Measurements

Whereas capacity surveys reveal the live and dead storage capacity lost in the reservoir, it does not indicate the area wise silt contribution from the catchment to pin point the areas, which contribute to the maximum sediment load. Consequently, measurement of suspended sediment load at various sites along the river and main tributaries is being carried out to know the sediment contribution from the catchment area between any two-observation sites. This helps in carrying out priority wise soil conservation measures in the sub-catchments. It involves the measurement of suspended sediment load in the main river including its major tributaries along with suspended sediment load being discharged downstream of the dam. By deducting the total suspended sediment flowing out of the reservoir from the total sediment brought in, the sediment retained in the reservoir is also being worked out. Bed load carried by the river and its tributaries has not been measured and has been taken as 15% of the total suspended sediment load. The suspended sediment load in known volume of water is observed and from this, the total sediment load in the total inflow is derived.

The above measurements are being carried out at four sites on the main river and also on five tributaries in the case of Bhakra Dam. The suspended silt observations are being carried out throughout the year on the main river and during the flood season (June to Sept.) on its major tributaries.

2.3 Sediment Load, Rate of Sedimentation and Sediment Yield

Approximately 43% of the total sediment contribution is from Spiti and Sutlej catchments above Khab (Namgia), located downstream of the place where the river Sutlej enters India. It has further been observed that the average sediment load from the suspended sediment load measurements varies by about 7.05% when compared with the echo-sounding results.

Heavy erosion has been experienced in the higher reaches from Rampur to Kasol warranting soil conservation measures in the affected areas. The average annual rate of sedimentation has been worked out as 38.19 MCM (31775 acre feet) for the year from 1965 to 2022 against a designed figure of 33.61 MCM (27250 acre feet).

The rate of sedimentation has shown a higher trend after the year 1990. Rate of sedimentation has increased noticeably after 2005, probably due to increased construction activities in the catchment area among other influencing factors. The average sediment yield per annum per thousand hectares of catchment area works out to be 6891.17 cubic meter (1.45 acre feet per sq mile of catchment area) for the period from 1959 to 2022.

2.4 Trap Efficiency and Delta/Hump Formation

A delta/ hump of sediments, positioned as per the reservoir bed profile, is still far away from the dam axis and this deposited sediment is not yet finding its way through the dam outlets. Sediment observation taken on downstream of the dam shows that only negligible percentage of silt is flowing out. The average trap efficiency so far is 99.4% against designed value of 85%. Due to high trap efficiency, sediments have deposited over the years in the reservoir and are not discharging downstream of the dam.

Length of reservoir is 96.56 km (60 miles) and area of reservoir is 168.35 sq km (65 sq miles). Satluj river from Kasol to Bilaspur i.e. from RD (reduced distance) 273 to 159 follows a narrow and circuitous course. It fans out near Bilaspur to a width of about 914m (3000 feet).

It again narrows down from RD-141 to 83 after which it opens into a wide expanse leading to a width of 6.44 km (4 miles) at full reservoir level just upstream of the dam. River reaches, where the width of the reservoir increases, act as sediment trap. With the decrease in velocity, heavy sediment settles down in these reaches. Due to heavy inflows of water, this settled sediment in the upper reaches again gets eroded from the upper reaches and settles further at the still pond conditions in the reservoir, thus forming a delta at that point.

This manner of silt deposition in the reservoir over the years, has created a delta/hump from RD 39,000 ft to 91,000 ft, upstream of dam axis as shown in Fig. 1. The movement of crest of the hump towards the dam, though very slow, has taken place from RD 59,000 ft to 51,000 ft during 1998-2000. This was mainly due to low level operation of the reservoir in this period. The movement from RD 49,000 ft to 47,000 ft, as observed during 2002-05, is also attributable to a similar low level operation. It further moved from RD 47000 ft to 41000 ft in last a few years due to low level operation of reservoir and presently moved to RD 39000 ft. Thus movement of sediments from live storage to dead storage available towards dam. A discrete balance between the desirable movement of the hump and the higher utilization of water in low level operations has been maintained during the reservoir regulation.

2.5 Loss of Storage Capacity

The percentage loss of live and dead storage capacity in 61 years (from 1961 to upto the end of the year 2022) has been worked out as 18.47% and 46.66% respectively. Against gross storage capacity of 9867.84 MCM (8000000 acre feet) of the reservoir, total sediments deposited up to the year 2022 are 2508.43 MCM (2033623 acre feet). Thus, overall loss of gross storage capacity is 25.42%.

2.6 Management of Sediments from Bhakra Reservoir

Removal or management of the sediments from the reservoir area will help restoration of live storage capacity of the reservoir which will ensure taking of floods in an organised way, Irrigation and drinking water problems of the stakeholders can be addressed if more capacity is available in these reservoirs. Following initiatives are being taken for removal of sediments from Bhakra reservoir:

- The joint inspection has been conducted by BBMB with Himachal Pradesh (HP Directorate of Energy and Geological wing of HP Industry Department) as per Mineral Policy of Himachal Pradesh for desilting of Bhakra Dam Reservoir.
- Lifting of sediments from the reservoir by mechanical means through tender for desilting from upstream reaches of reservoir near Bilaspur as pilot project where the ground levels available every year for six to eight months for lifting of sediments. The tendering for the same is under process.
- In large storage reservoir like Gobind Sagar, trap efficiency (99.4%) has been found more than the designed value (85%) thereby reducing its useful life. Movement of sediments in Gobind Sagar Reservoir can be carried out through low-level operations of the reservoir upto/near MDDL. It is likely that as the hump moves nearer to the dam, some sediment will

Distance in 1000 feet from the Dam Axis

Fig.1 : L-Section of Bhakra Reservoir Along River Sutlej

pass downstream with the density currents, through the low-level openings of the dam, thus, increasing life of the reservoir. The partner states may be convinced for frequent low-level operations of Bhakra Reservoir so that the silt may move from live storage to dead storage and its probable consequences on water availability.

- A study on delineation of soil erosion hotspots and assessment of sediment transfer through magnitude-frequency-analysis in catchment of Bhakra dam has been conducted from IIT Ropar.
- For management of erosion from catchment remote sensing study of the Bhakra catchment area has carried out for finding changes in land use and land cover over the years and identifying sediment generating hot spots for taking specific treatment measures.
- Based on above study, the desilting measures like construction of check dams, gabion structures, silt retaining structures and gully plugging in critically eroding areas etc are proposed to be undertaken in upcoming DRIP Phase III, based on the recommendations of Detailed Project Report(DPR) of Bhakra catchment. To accomplish this task, preparation of DPR for management of sedimentation by formulating sediment control strategies, treatment of hot spots and landslides in vulnerable reaches around Bhakra reservoir and restoration of live storage capacity of Gobind Sagar Reservoir of Bhakra Dam is being undertaken in DRIP Phase II.
- The consistent efforts are being made for increased vegetation cover by taking afforestation measures in the catchment areas downstream of Kol Dam as well as in the fringe areas of the reservoir by plantation work. BBMB has planted more than three lakhs plants in catchment area between 2019 to 2023.
- Awareness campaigns among the local population for adopting soil conservation measures and afforestation in the fringe area of the Bhakra reservoir by distributing brochures & displaying posters and hoardings.
- A study on productive use of sediments in Bhakra reservoir has been conducted from IIT Roorkee.
- The analysis of samples collected from upper reaches of reservoir indicates that the samples contain predominantly clay with some fine sand having fineness modulus varying from 1.4 to 1.65. Such grading of sand can be beneficially used for building construction such as plaster work for internal & external walls as well as on ceilings. Clay in upper layer can be used for making bricks and clay pottery works.

3.0 CONCLUSION

Effective reservoir sediment management requires a combination of proactive measures, adaptive strategies, and innovative techniques. In large storage reservoir, trap efficiency has been found more than the designed value thereby reducing its useful life. Flushing of sediments in large storage reservoirs is extremely difficult. The movement of sediment hump/delta is experienced during the low level operations of the reservoir. It is likely that as the hump moves towards the dam, the sediments move from live/useful storage to dead storage and some sediments may pass downstream with the density currents through the low level openings of the dam thus increasing life of the reservoir. Operation of reservoir at lower levels and extraction of sediments by mechanical means found useful in large storage reservoirs.

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Spatial Interpolation of Sediment Yield Estimated from Reservoir Siltation Data of India

Y.C. Jabbar[1] and S.M. Yadav[1]

ABSTRACT

Estimation of design sediment yield (SY) on a long-term basis is necessary to allocate adequate reservoir dead storage space. Incompetence of the distributed SY models with the input data (of spatial and temporal scale) leads to an error in model results. Therefore, prudent management of the calibration and validation process of SY predicting model is essential. The absence of the observed SY data brings indeterminacy in the validation process. However, a reference value for validation can be determined with spatial interpolation of the observed regional SY. In the present study, 161 spatially distributed Indian reservoirs were analyzed. Considering SY computed from these reservoirs as sampling values, inverse distance weighting and various Kriging interpolation methods were used to generate 25 interpolated datasets. Optimization of interpolation parameters is carried out by an exhaustive cross-validation process, and the best-interpolated surface is identified. Comparing the observed and predicted SY, the coefficient of determination is found to be 0.78, with the index of agreement being 0.88. This obtained surface model was utilized to generate a sediment yield contour map for India.

***Keywords** : Inverse distance weighting · Variogram · Kriging · Reservoir sedimentation · Sediment yield*

1. INTRODUCTION

Sediment yield (SY) of a catchment can be defined as the delivery of sediment load from a delineated catchment area to a particular location within a definite period of time. Prediction of design SY is critical to the useful life of the reservoir. Fixing the level at which the spillway gates and flushing gates are to be installed depends on the SY rate. Direct measurement (stream measurement) and quantification of reservoir trap sediments will provide information about the sediment produced and delivered by a catchment (Bussi et al. 2013; Jabbar and Yadav 2019a, b; Van Rompaey et al. 2003; Verstraeten and Poesen 2002). However, both the observation techniques (i.e., stream gauging and quantification of reservoir trap sediments) have their drawbacks and benefits.

In stream gauging, the bed load is not observed as there are practical limitations for measuring bed load. A high temporal resolution of suspended sediment data is required for a fair SY assessment (Walling 1977). The need for high temporal resolution data can be sufficed by linking sediment rating curve (SRC) to the flow duration curve (Crawford 1991; Jabbar and Yadav 2019a, b; Thomas 1985). Atieh et al. (2015), Jain (2008) and Tfwala and Wang (2016) have attempted to predict the transport of sediment load using soft computing techniques. Multiple input parameters such as precipitation, antecedent sediment load and discharge improve the efficiency of these models derived from soft computing techniques.

The volume of sediment trapped in the reservoir can be determined by the sediment delivery of the catchment. Bussi et al. (2013) proposed an approach for validation/calibration of SY models by means of check dam sedimentation data. Foster and Walling (1994) analyzed the grain size distribution of the sediment deposited in the check dams in order to obtain information on SY. Estimation of trap efficiency (TE) is necessary for the quantification of trap sediments and for the determination of the SY. The SY would be underestimated if the TE adjustment is not implemented (Verstraeten and Poesen 2002). Accuracy in the computation of SY relies on the TE of the reservoir. However, Verstraeten and Poesen (2002) suggested that reservoir siltation records could be an acceptable alternative to stream gauging, as the errors produced by incorrect trap efficiency assumptions correspond to those produced by low-frequency stream gauging.

In the absence of stream gage data, SY prediction is performed by indirect means. Precise hydrodynamic and morphodynamic modeling on the catchment scale is used to predict design SY for a specific catchment (Batista et al. 2017; Lazzari et al. 2015; White 2005). The predicted SY from the empirically or theoretically distributed models is very sensitive to the spatial lumpness and temporal resolution of the input data. If compatibility of the model to the scale of input explanatory variables is not set, then wrong prediction is bound to occur. In the absence of the

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SY observations, the calibration/validation of the model is not possible. In this case, an SY based on regionalization approach is considered to be the first estimate. Hydrologically and meteorologically similar catchment located nearby is identified, and the model validation is done from the identified catchment's data statistics. The spatial proximity of the catchment area under study and the catchment area identified is considered to be important in such regionalization approaches. Babu et al. (1978), Garde and Kothyari (1987), Kothyari et al. (1994) and Narayana and Babu (1983) have found the variation of SY influencing parameters with the geographical location of the catchment. They worked on developing relationships to estimate SY from different physical factors that influence it with respect to their geographical identity. Garde and Kothyari (1987) have produced an iso-erosion map of India. The map showed the national perspective for erosion and its variation in different parts of the country. Iso-erosive curve stands as the foremost approximation for the prediction of long-term SY in ungauged catchments or catchments with lack of data. It is assumed that the sediment erosion is a continuous (geographical) phenomenon that can be measured as SY. In other words, the SY value measured across India is assumed to be continuous surface data. The aim of the present research is to identify the competence of deterministic and geostatistical interpolation algorithms for the prediction of SY. The influence of the IDW and Kriging parameters to interpolate SY is studied. An exhaustive cross-validation process is used to train the parameters by optimization. The best-interpolated surface is used to produce an SY contour map of India. The generated SY contours may act as a reference for ungauged catchment SY predictions. The results of the study will show the situation of the reservoir sedimentation of the country and will identify the regions where reservoir sedimentation rate is high, so that appropriate catchment or basin management can be given.

The research intends to use the valuable dataset generated from hydrographic surveys carried out in reservoirs across India to show the long-term spatial distribution of sediment yield, which is why the paper structure addresses the process as follows in different sections. The introduction section is followed by the section which describes the computation of sediment yield from the reservoir capacity loss observed from consecutive bathymetry surveys, area of the catchment and reservoir trapping efficiency. The section after it gives information on interpolation method and its parameters which is followed by the explanation on how the spatially scattered data of SY will be converted into gridded surface models using different interpolation methods. The results and analysis of the work carried out will then be discussed, leading to specific conclusions.

2. COMPUTATION OF SEDIMENT YIELD

In accordance with the national register of larger dams, India has about 4877 larger dams and 313 are under construction (CWC-NRLD 2015); 88% of the larger dams in India were constructed between 1951 and 2001. Watershed and Reservoir Sedimentation (WS&RS) Directorate published a compendium in 2015 (CWC 2015) which assembled bathymetric survey results in terms of volumetric capacity loss for 243 important reservoirs of India. The value of SY is computed utilizing the volumetric loss of the reservoir capacity which is obtained from bathymetric survey reports. Average sediment yield is determined by Eq. 1 from the available record of loss of reservoir capacity. Hereafter, the SY will be referred to in terms of 1000 $m^3/km^2/y$:

$$SY = \frac{V_{loss}}{T * A * E} \tag{1}$$

where SY = average sediment yield (1000 $m^3/km^2/y$), Vloss = capacity loss of the reservoir in thousand cubic meter, and T = time period in year (y) from the construction of a reservoir to that of the last bathymetric survey from which Vloss is computed. A = catchment area (km^2) delineated upstream of the reservoir from which sediment is contributed to the reservoir. E = trap efficiency of the reservoir.

For precise analysis, the SY computed from the loss of reservoir storage capacity due to siltation of the reservoir needs to be adjusted by trap efficiency. In general, the trap efficiency of bed load remains close to unity, but the trap efficiency of suspended sediment load may vary significantly.

In the absence of upstream and/or downstream sediment measurement data for the determination of actual TE for different reservoirs, an estimate of TEs was made. Estimation of TE using empirical equations and curves (Brown 1943; Brune 1953; Garg and Jothiprakash 2008) may induce uncertainty in the computation of sediment yield understanding it as a limitation of the study; trapping efficiency of the selected reservoir is obtained as per Brown (1943). Universal transverse mercator (UTM) coordinates on the World Geodetic System of 1984 (WGS84) datum are identified for 161 dams. Figure 1 shows the discrete spatial spread and the reservoir storage capacity of the selected dams. For the study, 72 reservoirs between the latitude 8° 26′ 3.27″ and 17° 39′ 19.4″, 78 reservoirs between latitude 17° 39′ 19.4″ and 24° 55′ 3.11″ and 11 reservoirs between latitude 24° 55′ 3.11″ and 32° 35′ 48.97″ are selected. Longitudinally, almost all of India is covered between 68° 39′ 28.05″ and 91° 54′ 0.84″. The available data show that the reservoirs are more evenly distributed longitudinally than latitudinally. The state-wise distribution of the reservoir is shown in Fig. 2. The statistical summary of the parameters used in Eq. 1 for the selected reservoirs is shown in Table 1. The size of

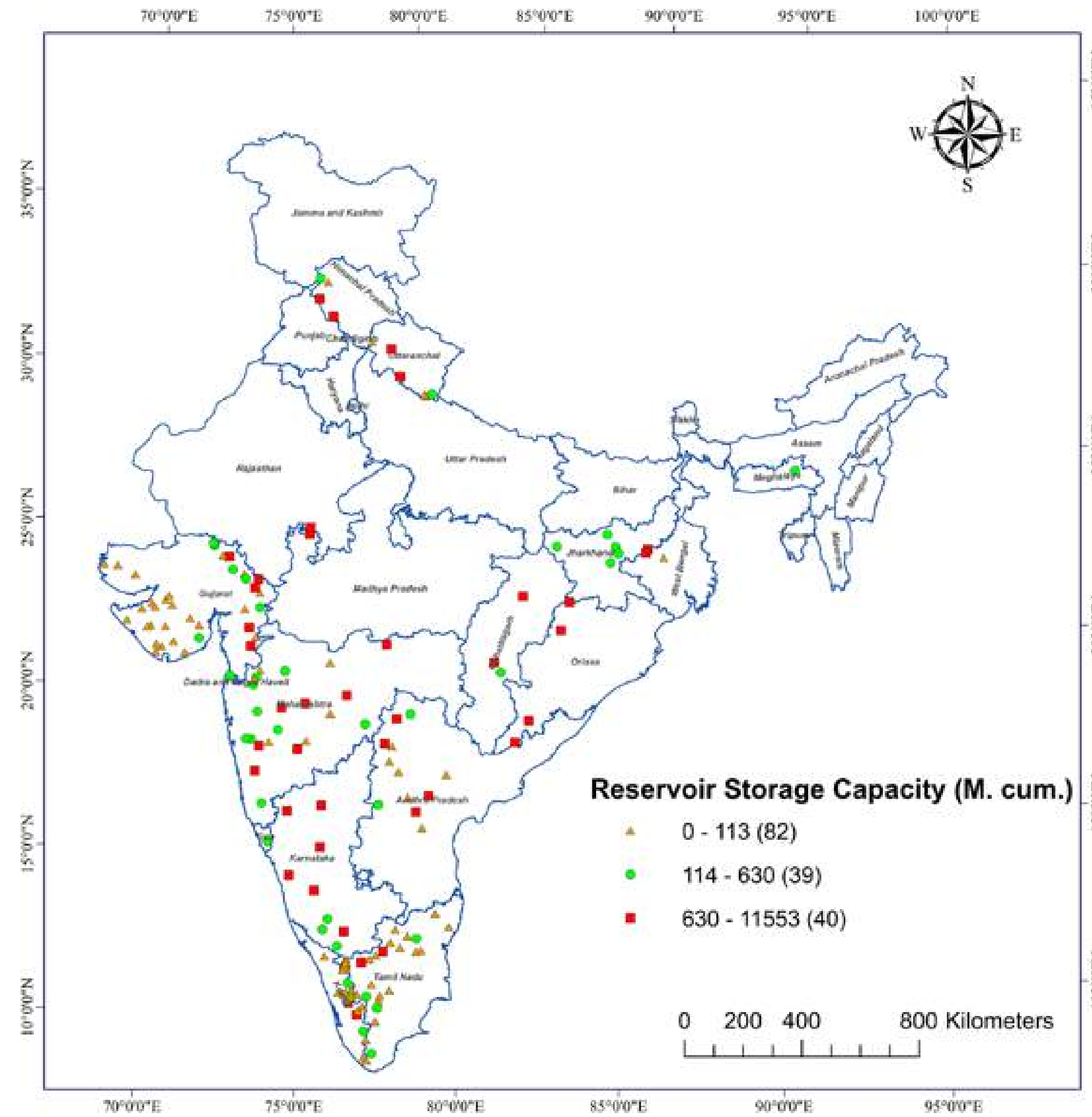

Fig. 1 : Location of 161 reservoirs distributed spatially

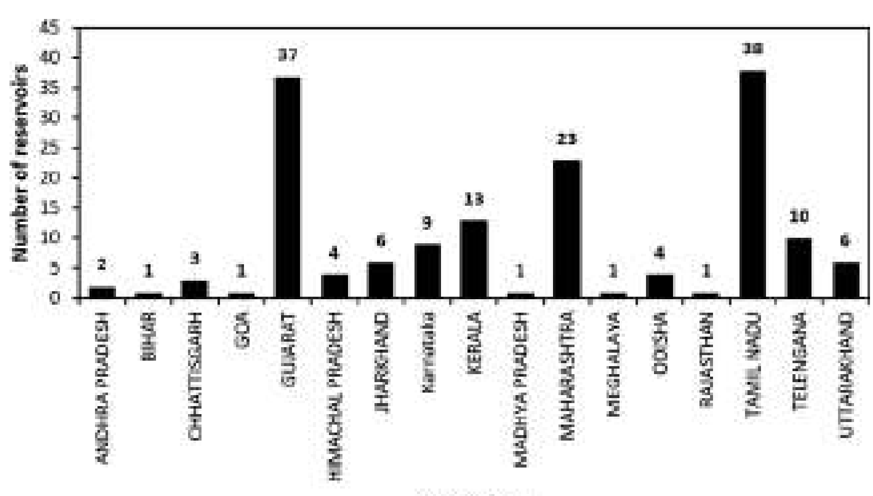

Fig. 2 : State-wise distribution of reservoirs which are studied

the catchments varies from 2.59 to 215,185 sq. km. Such an assortment of catchment sizes may generate a biased dataset. Terrain, land use and soil cover within a basin, along with the type of stream network, will produce distinct sediment dynamics with respect to the size of catchment and individual hydrological events (Ongley 1973; Walling 1983). However, the reservoir siltation dataset under study does not pertain to any specific event since the median of the observed sedimentation for 161 reservoirs is 50 years (median of the year of the first impoundment is 1967, Table 1). Larger time span absorbs fluctuations in hydrological and morphodynamic processes caused by individual events (Trimble 1981; Walling 1983).

3. DETERMINISTIC AND GEOSTATISTICAL INTERPOLATION

A number of algorithms have evolved to process spatially scattered or disoriented data into a gridded or oriented surface model (Lam 1983). Selection of a proper interpolation method and its parameters hold prime importance in obtaining a surface model which actually represents the spatial pattern of SY rate. The choice of interpolation algorithm is based on the physical phenomena which determine the value of SY. It varies largely from soil type, land cover, wind speed, temperature, rainfall duration, rainfall intensity, stream network type, catchment characteristics and type of hydraulic structures in the streams (Baker and Miller 2013; Elçi et al. 2007; Fornis et al. 2005; Haan et al. 1994; Nyssen et al. 2005; Verma and Jha 2015; Wainwright et al. 2015; Yang and Lim 2003). The most widely used interpolation algorithms work with an assumption that the distance between sampling point (SY observation point) and target point (node on the grid) is a major physical parameter for the interpolation (Achilleos 2011; Lam 1983). Determining the best spatial data interpolation algorithm for SY values in association with the physical parameters influencing it is necessary. Assuming that SY is spatially reliant, it is probable that the nearer values are more alike than the distant values. Inverse distance weighting (IDW) and Kriging are utilized to interpolate SY.

Impact of parameters of IDW and Kriging is questioned, as the datasets of observed SY are not evenly spaced and can generate a spatial bias. The cluster points may have artificially larger weights if inappropriate parameters are selected for interpolation. Spatially interpolated SY estimates are the weighted average of the sampled data. The interpolated values at the target location points of a grid are estimated by the generic mathematical form as presented in Eq. 2 (Abedini et al. 2008; Li and Heap 2008):

$$\mathrm{SY}(S_0) = \sum_{i=1}^{n} W_i \mathrm{SY}(S_i) \tag{2}$$

where $\mathrm{SY}(S_0)$ = interpolated sediment yield value at target location point x_0, y_o, n = number of sampling point considered for interpolation, W_i = weight function assigned to each sample point, SYSi = observed sediment yield at the sampling point x_i, y_i, and IDW is a deterministic interpolation method. Weight function assigned for IDW is dependent on the distance between the target and sampling point. The weight function is as per Eq. 3:

$$W_i = \frac{1/d_i^p}{\sum_{k=1}^{n} 1/d_k^p} \tag{3}$$

where Wi = weight function assigned to each sample point, d_i = distance between ith sampling point and target point, d_k = distance between kth sampling point and target point, p = weighting exponent that is taken as a positive number.

The higher the weighting exponent, the more influential the nearer points will be. The value of the weighing function increases with distance when the exponent value is lower (less than 1). With a higher exponent, the nearby observations have a more localized effect in the resulting grid point, while the grid points have smoother interpolated values for the lower exponent. The continuous stochastic

Table 1 : Statistical summary

Statistical parameter	Catchment area in sq. km.	Storage capacity in M. m³	Year of the first impoundment	Percentage loss of capacity up to the last survey	Percentage annual loss of capacity
1	**2**	**3**	**4**	**5**	**6**
Mean	7767.00	916.63	1953	16.80	0.58
Median	512.00 112.75	1967	12.69	0.38	
SD	26,423.14	2003.08	–	12.70	0.61
Kurtosis	43.30	11.18	–	1.03	8.22
Skewness	6.17	3.27	–	1.13	2.67
Minimum	2.59	0.74	1891	0.57	0.03
Maximum	215,185.00	11,553.00	2005	63.07	3.38

spatial variation of the SY can be well modeled by Kriging as it is a geostatistical interpolation method. The main benefit with the geostatistical interpolation method is that the estimate of SY is done using the statistical properties of the sample points, and this delivers a measure of the uncertainty for the estimated SY (Abedini et al. 2012; Adhikary and Dash 2017). The basic mathematical form of Kriging is altered from Eq. 2 to Eq. 4 (Li and Heap 2008):

$$\mathrm{SY}(S_0) - \mu(S_0) = \sum_{i=1}^{n} \lambda_i(S_0)\left[\mathrm{SY}(S_i) - \mu(S_0)\right] \quad (4)$$

where $\mathrm{SY}(S_0)$ = interpolated sediment yield value at target location point x_0, y_o, n = number of sampling points considered for interpolation, $\lambda(S_0)$ = Kriging weight function within the search window, $\mu(S_0)$ = mean of the sample within the search window, and $\mathrm{SY}(S_i)$ = observed sediment yield at the sampling point x_i, y_i.

The number of sampling points (n) is dependent on the search window, and it affects the results of interpolation (Abedini et al. 2008; Obroślak and Dorozhynskyy 2017). Weights in the Kriging are determined by the distance between the sample and the target points along with the consideration of the complete spatial arrangement of the sample.

3.1 Variogram Modeling

Variogram characterizes the spatial variability of a dataset and can be mathematically defined as Eq. (5). It shows the difference squared between the values of the paired locations:

$$\gamma(h_j) = \frac{1}{2N_{h_j}} \sum_{i=1}^{N_{h_j}} \left[\mathrm{SY}(S_i) - \mathrm{SY}(S_i + h_j)\right]^2 \quad (5)$$

where $\gamma(h_j)$ is the semi-variance, i.e., half of the average squared difference between two points (at spatial location S_i and $S_i + h_j$) separated by distance h_j. N_{hj} is the number of data pairs separated by distance hj (called lag). After repeating different lags (say j is varied from 1 to 10), the semivariance can be plotted as a function of distance. In practice, the dataset is not evenly distributed and data pairs may not have unique distances. Hence, the data pairs are grouped into lag bins (lags bounded by a range) to plot the semi-variogram. The empirical semi-variogram is a graph of hj on the ordinate and the distance, h_j (lag) on the abscissa. This graph presents descriptive information about the spatial structure of the dataset. For Kriging interpolation, a positive definite model of spatial variability is required; hence, a theoretical variogram model is fitted to the empirical semivariogram (Fig. 3) (Ly et al. 2011). Kriging weights depend on a theoretically fitted model to the measured points, the distance to the prediction location and the spatial relationships among the measured values around the prediction location. A number of theoretical variogram

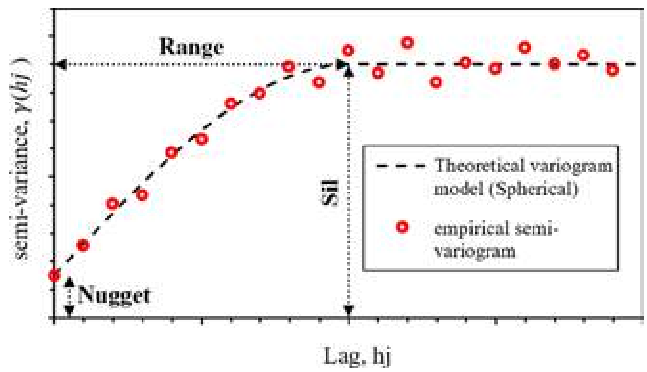

Fig. 3 : Schematic diagram of variogram model and its parameters

models are there to choose from, such as circular, exponential, Gaussian, rational quadratic, hole effect, K-Bessel, J-Bessel and stable. In-depth discussion of the interpolation methods and variogram models has been found in the literature (Abedini et al. 2012; Azpurua and Dos2010; Henley 1981; Li and Heap 2008; Mair and Fares 2011; Montero et al. 2012; Oliver and Webster 2015; Otieno et al. 2014; Webster and Oliver 2008).

4. GENERATION OF SEDIMENT YIELD CONTOUR MAP

Geographical SY variations are signified on a two-dimensional map by contour lines. Contours are drawn only if the data are available for a continuous surface. The uneven spatial distribution of SY computed from reservoir sedimentation data does not allow direct contouring; hence, it will not produce sound results. Observed SY magnitude across different spatial locations is deterministically and geostatistically processed to form a continuous surface dataset. IDW and various Kriging models are tested with the spatial SY dataset. Parameters of the interpolation models are optimized for generating the surface. An exhaustive leave-oneout cross-validation method is used to optimize the interpolation parameters and to validate the interpolated surface. For a SY dataset with N samples, N surfaces are generated. Each surface is generated using N-1 sampled data for training, and the remaining one sample is used for testing.

Plotting the sediment yield data as a histogram revealed that the frequency distribution of the data is not bell-shaped. The mean and median are 1.4947 and 0.73572, respectively. The skewness value is 3.1621. Thus, a transformation of the log is applied to perform Kriging interpolation. The transformed values of mean, median and skewness are − 0.35118, − 0.30785 and − 0.41653, respectively. Using the transformation, the variance is made more constant throughout the SY observations. The number of points surrounding each station sampling point search radius (search window) is kept variable, and the number of sampling points (n) is specified for target point interpolation. Neighboring sampling points are searched until it reaches the specified number. Thus, the distances from the target points differ. As a result, for some target points, distance from sample points is very small, while for some, the distance is high. Specific value of n considered in the study after analyzing the spatial SY data by variogram models is 20. Anisotropy of SY data is dependent on the catchment and climatic properties which is not considered in the study. Thus, higher autocorrelation in a single direction is not deliberated and the shape of the search neighborhood is selected as circular. As the data are very much distributed in space, clustering is not applied.

For IDW, the exponent was varied and optimized, while for Kriging nugget, sill, range and lag size are optimized by cross-validation. Simple, ordinary and universal Kriging types are tested subject to the circular, exponential, Gaussian, rational quadratic, hole effect, K-Bessel, J-Bessel, and stable variogram models. Three Kriging types subjected to eight variogram models which produced 24 Kriging-based gridded datasets. Thus, IDW and various Kriging interpolations are used to obtain 25 sets of interpolated grids. These grids are converted into raster surface models (RSMs) in ArcGIS release 10.5. The best-obtained raster surface is converted into contours, in order to obtain information from the surface model.

5. RESULTS AND DISCUSSION

The RSMs developed are labeled as RSM1 to RSM25 (Table 2). The exponent parameter of IDW (RSM1) is optimized to 1.215 (Fig. 4). The optimized parameters for Kriging models are presented in Table 3. Figure 5, 6 and 7 show the ordinary, simple and universal Kriging surfaces, respectively, produced using the optimized parameters. Figures 4, 5, 6 and 7 contain legends that represent the classification of SY, and therefore, its unit is the same as that of SY (i.e., 1000 $m^3/km^2/y$). By leaving-one-out crossvalidation process, the mean error, root mean square error, mean standardized error, root mean square standardized error and average standard error statistics are computed for the optimized parameter values. For the best fit, mean of the error is expected close to zero, while root mean square is expected to be minimum. Standardizing mean and root mean square removes the effect of the scale on the readings. Root mean square standardized error is expected to be close to one. Between the eight variogram models used, the rational quadratic model was the best fitted model, as it gave the least mean standardized error (Table 4). Ordinary Kriging-based RSM5 is further tested for complete dataset. Extraction of the SY from the RSM at the sampling point location is done. The extracted SYs (model predicted SYs) are compared with the observed SYs. The SY surface model for India (RSM5) will have the least deviation from observed SY present at sampling points. The observed SY and predicted SY at 161 points are presented as a scattered plot in Fig. 8. Statistical error functions, i.e., Nash–Sutcliffe model efficiency (NSME), mean absolute percentage error (MAPE), discrepancy ratio (DR) and index of agreement (d), are computed. Correlation between observed and predicted SY is found using the coefficient of determination (r^2). Table 5 shows the predictive capability of the RSM5 with respect to observed SY. The SY contour is thus drawn using RSM5 (Fig. 9).

Table 2 : Raster surface models

Raster surface model	Interpolator	Theoretical variogram models
RSM1	IDW	–
RSM2	Kriging—ordinary	Circular
RSM3	Kriging—ordinary	Exponential
RSM4	Kriging—ordinary	Gaussian
RSM5	Kriging—ordinary	Rational quadratic
RSM6	Kriging—ordinary	Hole effect
RSM7	Kriging—ordinary	K-Bessel
RSM8	Kriging—ordinary	J-Bessel
RSM9	Kriging—ordinary	Stable
RSM10	Kriging—simple	Circular
RSM11	Kriging—simple	Exponential
RSM12	Kriging—simple	Gaussian
RSM13	Kriging—simple	Rational quadratic
RSM14	Kriging—simple	Hole effect
RSM15	Kriging—simple	K-Bessel
RSM16	Kriging—simple	J-Bessel
RSM17	Kriging—simple	Stable
RSM18	Kriging—universal	Circular
RSM19	Kriging—universal	Exponential
RSM20	Kriging—universal	Gaussian
RSM21	Kriging—universal	Rational quadratic
RSM22	Kriging—universal	Hole effect
RSM23	Kriging—universal	K-Bessel
RSM24	Kriging—universal	J-Bessel
RSM25	Kriging—universal	Stable

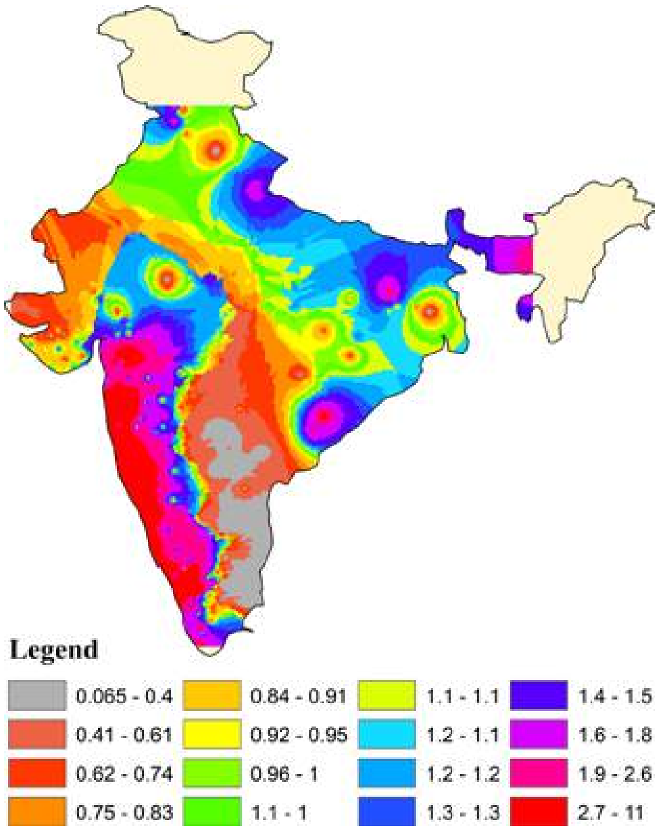

Fig. 4 : RSM produced using optimized IDW

Contour map produced on RSM5 gives a holistic view of the production of sediment, trapping efficiency and sediment delivery ratio. If RSM5 is taken as a benchmark to validate catchment erosion rate, the average long-term SY will be lower than the surface predicted. Sediment erosion in the catchment and the sediments delivered to the reservoir differ. So the sediment delivery ratio averaged over a longer period may remain well below unity. Therefore, it is obvious to understand that SY predicted from the siltation rate of the reservoir without considering the delivery ratio will be an under-prediction, which makes the RSM5 contour as the lowest physical bound.

6. CONCLUSIONS

Prediction of sediment yield (SY) from different modeling approaches and model setup datasets will not produce a single SY value. Confidence intervals are required to be assigned to quote the uncertainty of the estimates. In such a case, it is challenging to validate the model result and to select the design SY value in the ungauged catchment area. In the present study, IDW and various Kriging interpolation methods are tested for their competency to produce a SY contour map. The parameters of the interpolation methods are optimized. To optimize and validate the parameters, an exhaustive cross-validation (leave-one-out) approach is used.

Table 3 : Optimized parameters of the raster surface models

Raster surface model name—figure reference	Optimized parameter			
	Nugget	Partial sill	Range Lag	size
RSM2—Fig. 5a	2.75	4.33	1.50	0.19
RSM3—Fig. 5b	2.01	5.08	1.25	0.16
RSM4—Fig. 5c	3.15	2.61	0.65	0.08
RSM5—Fig. 5d	3.3734	3.0458	2.3460	0.2932
RSM6—Fig. 5e	1.9329	2.1224	0.2283	0.0285
RSM7—Fig. 5f	3.4357	3.0113	2.4627	0.3078
RSM8—Fig. 5g	1.7187	1.3644	0.3334	0.0417
RSM9—Fig. 5h	1.7504	4.7608	2.5851	0.3231
RSM10—Fig. 6a	0.4330	0.6641	1.0482	0.1310
RSM11—Fig. 6b	0.2141	0.8473	0.9889	0.1236
RSM12—Fig. 6c	0.1334	0.6132	0.2196	0.0275
RSM13—Fig. 6d	0.0817	0.8013	0.5160	0.0645
RSM14—Fig. 6e	0.1512	0.5136	0.3367	0.0421
RSM15—Fig. 6f	0.2527	0.9634	1.9320	0.2415
RSM16—Fig. 6g	0.1658	0.5954	0.3857	0.0482
RSM17—Fig. 6h	0.0231	1.1445	2.4627	0.3078
RSM18—Fig. 7a	3.1923	0.1254	0.1549	0.0194
RSM19—Fig. 7b	2.0065	0.0000	0.4964	0.0620
RSM20—Fig. 7c	2.0065	0.0000	0.4964	0.0620
RSM21—Fig. 7d	2.0065	0.0000	0.4964	0.0620
RSM22—Fig. 7e	1.1528	2.1510	0.1579	0.0197
RSM23—Fig. 7f	2.0065	0.0000	0.4964	0.0620
RSM24—Fig. 7g	1.5213	0.6676	0.3302	0.0413
RSM25—Fig. 7h	2.0065	0.0000	0.4964	0.0620

The unit of nugget and partial sill is square of the SY (i.e., $m^3/km^2/y)^2$, while the unit of range and lag size is 10^5 m

Ordinary Kriging with the rational quadratic variogram model was found to be the best. The SY contours are generated from the raster surface model (RSM), which was produced using ordinary Kriging and rational quadratic variogram. The coefficient of determination computed between the observed and the predicted SY is 0.78, the Nash–Sutcliffe model efficiency is 0.7084 and the average of discrepancy ratio is 1.59.

The proposed SY contour map depicts the historic longterm SY record and can be helpful in obtaining knowledge of SY variation in India. The value obtained from the curve can become a reference value for validation of the SY models. The results of the predicted and observed SY are between the appreciable ranges. Yet, it can be improved further by detrending the SY dataset by understanding the hydrological and fluvial processes. It is identified from the study that the

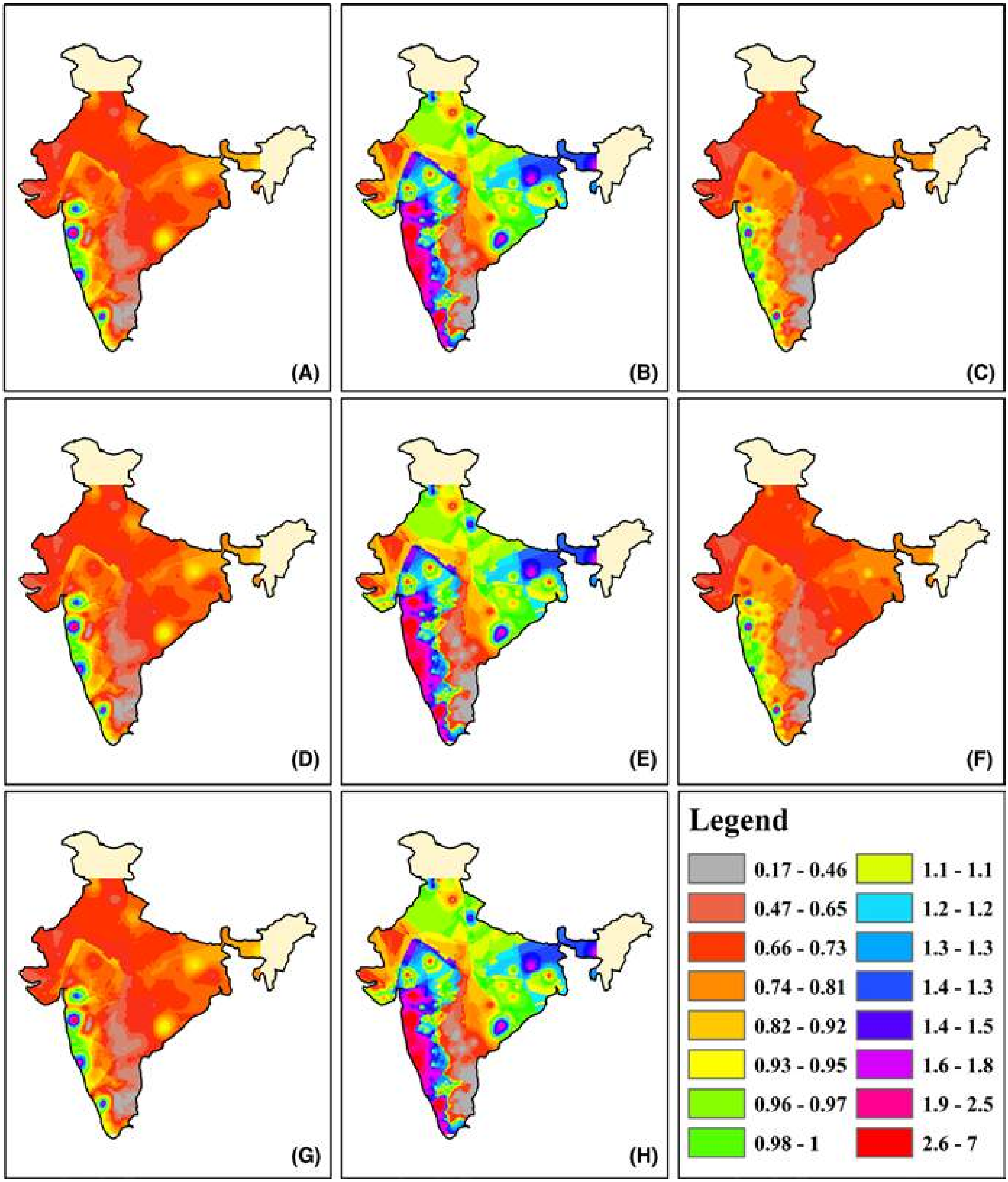

Fig. 5 : RSM produced using optimized ordinary Kriging

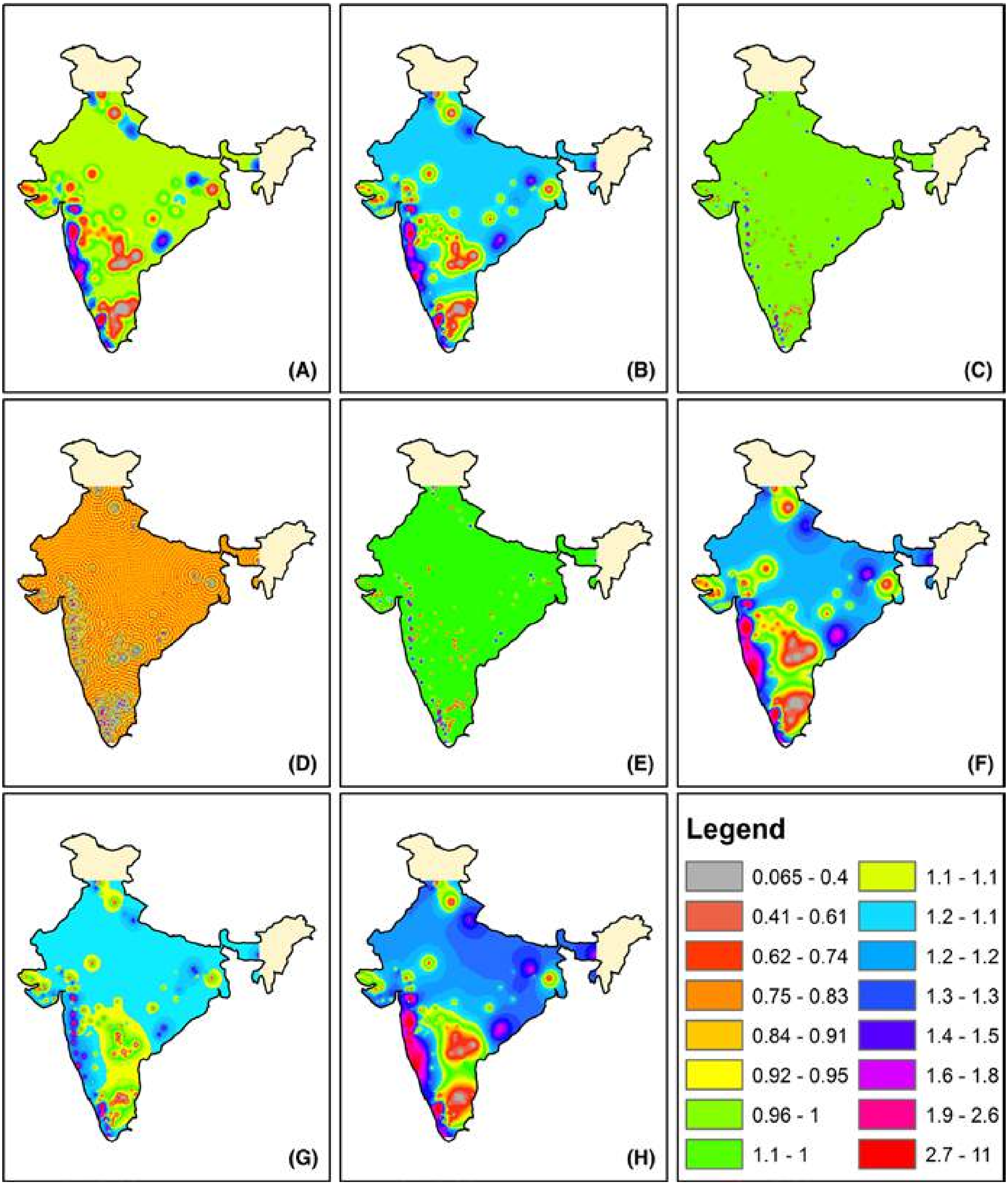

Fig. 6 : RSM produced using optimized simple Kriging

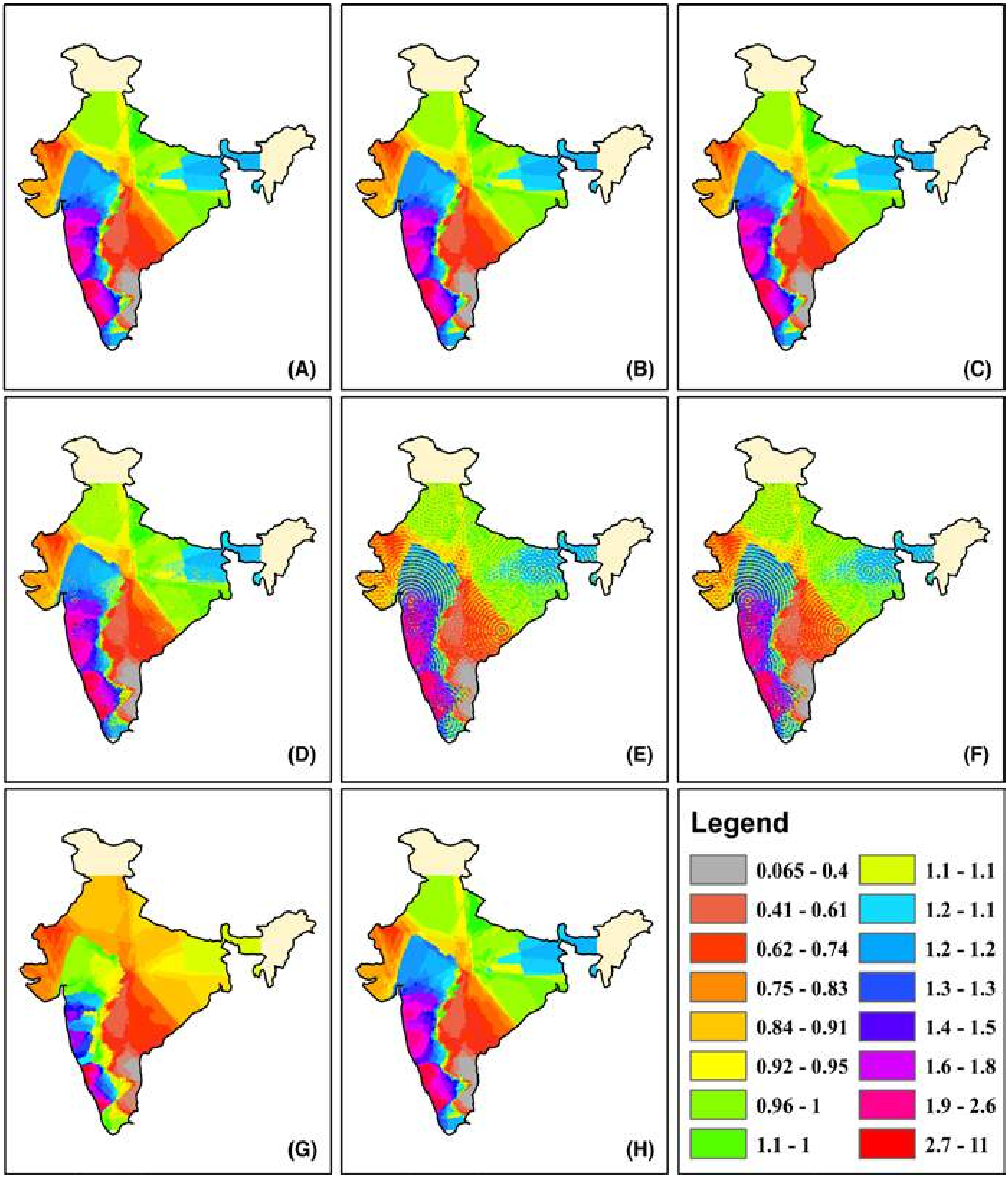

Fig. 7 : RSM produced using optimized universal Kriging

Table 4 : Predictive capability of raster surface models obtained from cross-validation

Raster surface mode	Mean error	Root mean square error	Mean standardized error	Root mean standardized error	Average standard error
RSM1	0.103	1.920	–	–	–
RSM2	0.001	1.944	− 0.002	0.862	2.313
RSM3	0.013	1.899	0.001	0.792	2.455
RSM4	0.017	1.914	0.003	0.832	2.332
RSM5	0.006	1.932	0.000	0.843	2.326
RSM6	0.049	1.957	0.021	0.963	2.048
RSM7	0.005	1.921	0.000	0.811	2.394
RSM8	0.038	1.852	0.020	1.072	1.739
RSM9	0.011	1.887	0.002	0.804	2.382
RSM10	0.096	1.923	0.060	0.881	2.089
RSM11	0.106	1.899	0.058	0.903	2.067
RSM12	− 0.099	1.935	− 0.060	1.248	1.612
RSM13	0.017	1.896	0.017	1.042	1.833
RSM14	− 0.193	1.973	− 0.145	1.456	1.428
RSM15	0.154	1.891	0.086	0.823	2.197
RSM16	− 0.088	1.936	− 0.054	1.227	1.642
RSM17	0.126	1.873	0.089	0.807	2.174
RSM18	0.047	2.087	0.025	1.119	1.866
RSM19	0.048	2.110	0.033	1.454	1.451
RSM20	0.048	2.110	0.033	1.454	1.451
RSM21	0.047	2.094	0.025	1.123	1.865
RSM22	0.056	2.031	0.027	1.105	1.851
RSM23	0.048	2.110	0.033	1.454	1.451
RSM24	0.038	1.902	0.024	1.282	1.490
RSM25	0.048	2.110	0.033	1.454	1.451

Table 5 : Statistical assessment of the deviation of the surface from the observed values

Model	NSME	MAPE (%)	DR	d	r^2
RSM5	0.7084	59.8010	1.5980	0.8832	0.7821

Western Ghats region of India requires intensive basin management practices, as the reservoir sedimentation rate in the region is found to be the highest and discrepancy of the design and observed sedimentation rate is more.

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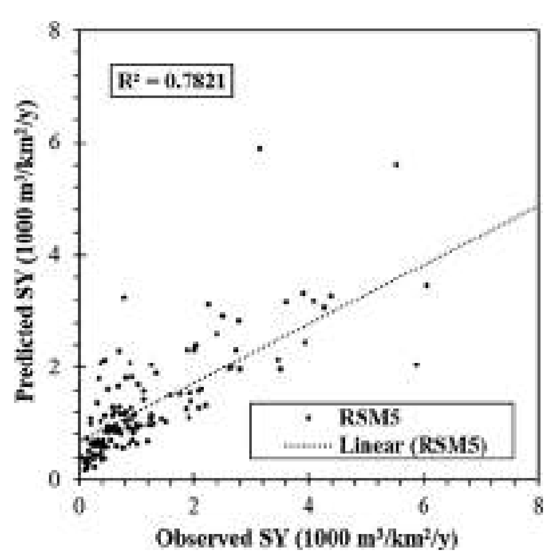

Fig. 8 : Comparison of observed and predicted values

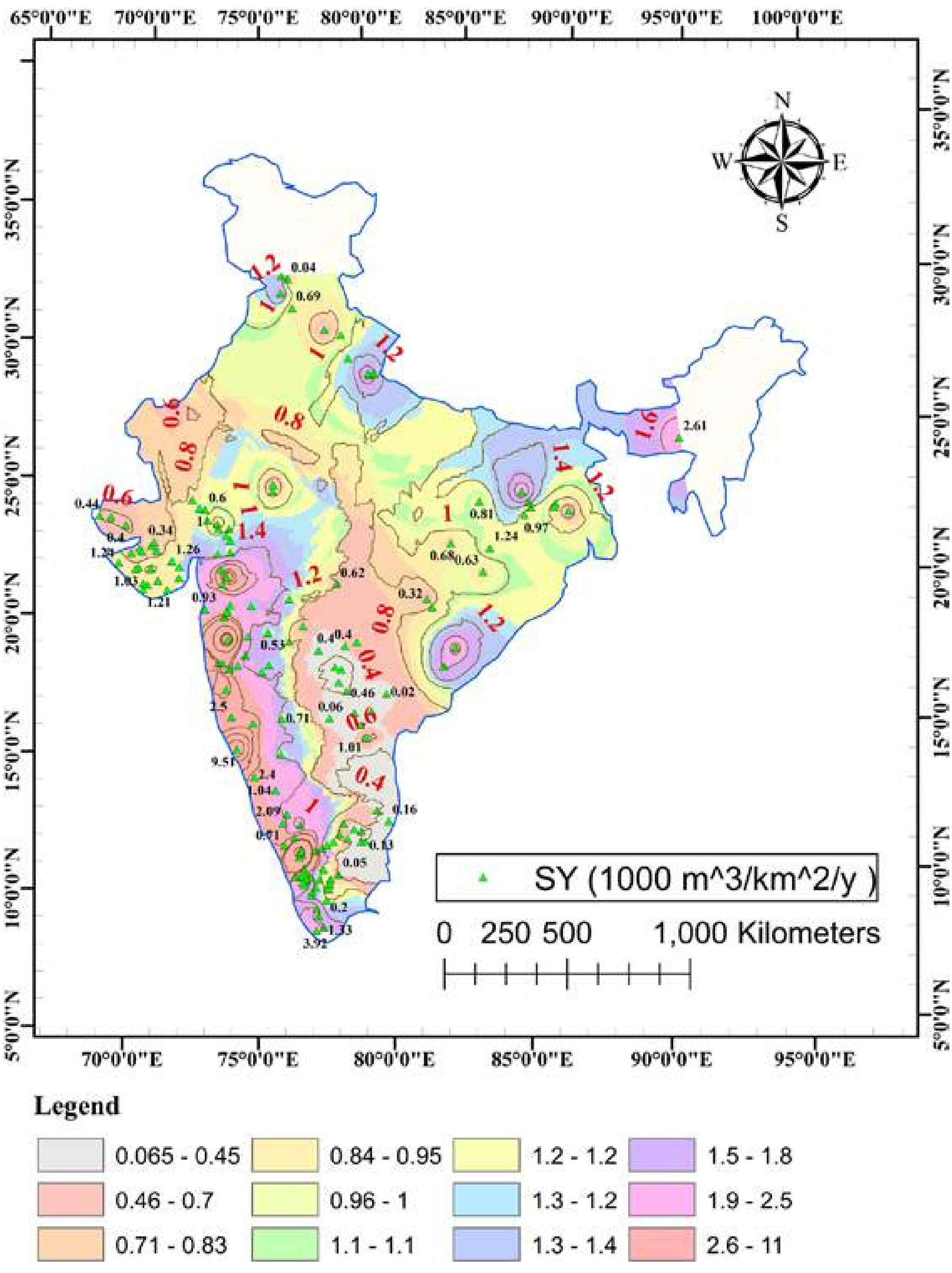

Fig. 9 : Contours generated on RSM5

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Need for Rehabilitation of Dam Considering the Cascading Impact of Flood

Suresh Maurya[1] and Karthikeyan M[2]

ABSTRACT

Risk from cascading reservoir is enormous as compared with single reservoir. To ensure the safety of river basin, risk assessment from cascading impact of flood is of utmost importance. Rehabilitation of a dam in today's climate change is not only the act of restoring the distressed dam to its original state but also to meet added requirements caused by changes in the safety criteria and risk assessment from time to time. Climate change can lead to increase in the frequency and severity of hazards like glacial lake outburst floods (GLOFs), torrential floods, debris flows, landslides, glacier movement, snow melt and extreme precipitation. The cascading impact of flood can pose danger to series of dams in River and downstream residents in terms of hydraulic discharge, debris flow etc. Most dams in existence today were built during the 1970s. The risks from aging dams are of particular concern in the face of climate change. Dams at the time of construction are designed to withstand worst case conditions. However, extreme weather events have begun occurring with increasing regularity, putting dams at great risk of either failure or a significant weakening of their integrity.

The recent collapse of series of dams in Libya was due to sudden accumulation of water beyond dam capacity. The dam could not hold 30 MCM of accumulated water due to rainstorm and failed. The recent incident of a Glacial Lake Outburst Flood in North Sikkim has raised alarm about the safety of hydropower potential in Himalayas. The tragic dam failure due to cascading impact of flood in Libya and Sikkim is a warning signal from the dangers of climate change and also old infrastructure. This paper presents the case studies on failure of dams from cascading impact of flood and suggests need for comprehensive rehabilitation considering the impact of series of dams in a River. It emphasis on the need to have integrated early warning system that can alert the people towards the impending disaster.

***Keywords** : Cascading, Flood, Dam, Risk Assessment, Rehabilitation*

1. INTRODUCTION

Hydropower construction has slowly moved towards the cascade reservoir construction. Regardless of generating extensive benefits, dams may breach and cause unwanted floods menacing downstream settlements and economy. Breach of single cascade dam can easily lead to successive dam's failure in the downstream. At the time of independence India had nearly 1200 dams and with 6138 large dams currently in place in the last 76 years. These dams are vital for ensuring the water security of the Country to meet demand. About 80 % of these dams in our country are more than 25 years of age and 227 dams have exceeded 100 years of age. The World Bank estimates that 19,000 large dams in the world are over 50 years old and most of them are reaching the end of their life span. In the year 2000, World Commission on Dams (WCD) published its report in which, world's large dams were, on average, 35 years old [1]. Like any infrastructure, dams require maintenance and if they are not maintained adequately, there is increased risk to downstream populations from dam failure. The risks from aging dams are of particular concern in the face of climate change and because of this rehabilitating dam become a challenging task. Most of these dams were built with the available technology and material of that corresponding period.

Events of dam failures from cascading impact of flood due to extreme climate are increasing and few of them are listed below:

(i) Territorial storm name Daniel completely damaged Derna Dam and Abu Mansour Dam in the Wadi Derna River, Libya on September 11, 2023 during wee hours.

(ii) Glacial Lake Outburst Flood (GLOF) breached the Teesta-III Dam and damaged Teesta V dam on Teesta River, India on October 4, 2023.

(iii) Chamoli disaster from Avalanche Rockslide of Himalayan Mountain. It triggered flash flood and damaged four different H.E Project in downstream on February 7, 2021.

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(iv) Torrential rain breached Chorabari glacial Lake and flooded Mandakini River, covering pilgrimage Kedarnath city and severely damaged two Hydro Power Projects downstream from 14-17th June 2013.

In the aftermath of recent disaster events, the role of infrastructure, especially hydropower and its interplay with natural hazards has emerged as a topic of strong debate. The melting of glaciers due to global warming contributes to the formation of more glacial lakes. As these lakes increase, the risk of GLOFs also increases putting downstream infrastructure at risk. With the need to increase the green energy sector and the challenges with solar and wind energy, hydropower seemed to be a viable option. However, hydropower development faces multiple challenges in the Himalayas. Figure 1 presents the evolution of the dam across the country and their failure over several decades [2-3]. As per Central Water Commission (CWC) website data, out of 36 numbers of dams failed, 30 are earth type dams, 03 are composite type dams and 03 are masonry dams. The most common cause of dam failures in India has been due to dam breaching (44% cases) followed by overtopping (25% cases).

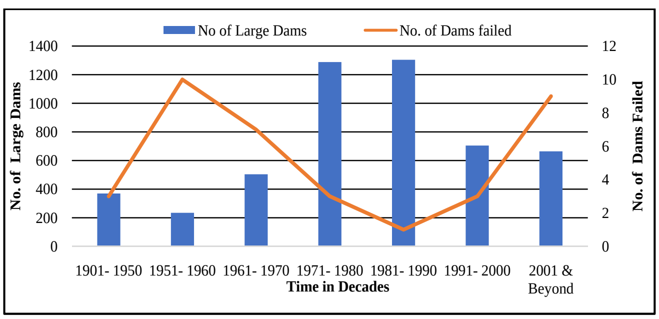

Fig. 1 : History of constructed and failed dam decade wise

1.1 Global Climate Change and Glacial lakes in Indian Himalayan Region

Increased concentration of greenhouse gases in the atmosphere is the most significant factor which affects global climate change. Glacial retreating and melting are the true indicators of climate change. Glacial meltwater induced flood, Glacial lake outburst floods, glacial related debris flow, ice avalanches, Ice mass loss, paraglacial destabilization, and glacial surge are the risk associated due to glacial change [4]. Glacier recession associated with climate change has led to the formation of new glacial lakes and the expansion of existing ones across the Himalayas [5]. Table 1 presents the status of glacial lakes in Indian Himalayan Region. With the continuous process of glacial retreating the number and size of glacial lakes are increasing and it will lead the increased situations of GLOFs. These GLOF situations adversely affect the property and life of the people of the mountainous regions. Climate change, glacier retreat and glacial lake outburst floods (GLOF) are intertwined [6]. Atmospheric warming has accelerated glacier mass loss in mountain regions worldwide resulting in formation of glacier lake and it traps glacier melt water thus increasing their numbers about 50% along with their area since 1990s [7]. Glacial lakes are generally of two types i.e., bedrock dammed and moraine dammed. Bedrock dammed lake do not generally pose an outburst danger. However, Moraine dammed glacial lakes are dammed by material accumulated from a glacier and has the potential for bursting.

Table 1 : Status of Glacier lakes in Indian Himalayan Region (IHR)

State	No. of Glacial Lakes	Moraine Dammed	Bedrock Dammed
Jammu and Kashmir	2292	25% lake	57-84 % lakes
Arunachal Pradesh	1451	-	
Sikkim	352	41% lake	
Uttarakhand	135	76-80% lake	-
Himachal Pradesh	188		-
Total lakes in IHR	4418		

The hydropower potential in Himalayas is tremendous and play a crucial role in meetings India's energy demands and at the same time it is densely populated with communities residing downstream of hydropower projects. An infrastructure failure can have negative consequences on human lives and property impacting delicate ecosystem. The river basin has multiple dams along its course, so a cumulative assessment of upstream and downstream dam needs to be in place to ensure dam safety and risk management. The purpose of this paper is to share our understanding of the cause and downstream propagation of the flood. The case studies presented below touches upon the cascading nature of floods, the challenges to infrastructure development and the need to consider environmental sustainability while planning infrastructure development.

2. CASE HISTORIES OF DAMS FAILED FROM CASCADING IMPACT OF FLOOD

Due to climate change cloud burst, rainstorm and GLOF is increasing and happening all over the world. In this section, series of dams failed from cascading impact of flood due to extreme climate events are presented.

2.1 Libya Dam Failure from Torrential Rain (2023)

Recently due to Daniel storm from Mediterranean Sea in the Derna coast of Libya there was a catastrophic event causing failure of two clay filled dam in series (i.e., Derna Dam (height 75 m) and Abu Mansour Dam (height 45 m)) on 10-11th September, 2023 resulting in around 11,300 causalities, ten thousands of people missing and 34000 people displaced. The upstream Derna Dam had a water storage capacity of 22.5 MCM and downstream Mansour dam has a water storage capacity of 1.5 MCM. The dam collapses released an estimated 30 MCM of water causing flood downstream as the Derna Dam overflowed its bank in the upstream. Torrential rain dumped so much water that, it was larger than water holding capacity of existing dams built for the purpose. The Derna Dam located at the convergence of two valleys, collapsed initially. The released water rushed 12 km towards the sea and overwhelmed the Mansur Dam, which was already under stress from rising water levels in its reservoir. Figure 2 shows the location of Dams in Wadi Derna River and cascading impact of flood [8]. The dams constructed in the late seventies to control flood failed due to extreme rainfall (due to storm Daniel) and poor maintenance resulting in a vast devastation. The flood partially affected the city Derna in Libya.

Fig. 2 : Location of dams failed and cascading impact of flood

2.2 TEESTA-III Dam Failure from GLOF (2023)

The GLOF from South Lhonak Lake in North Sikkim has breached and damaged 60 m high concrete faced rockfill dam of 1,200 MW Teesta III H.E. Project (also called Chungthang dam of Sikkim) on River Teesta, resulting 40 lives lost in downstream, 76 missing along with extensive damage to infrastructure on October 4, 2023. Heavy damage has also been suffered at Teesta-V (510 MW) 37 km downstream at Dikchu. The devastation has refreshed worries over development of hydropower projects in fragile Himalayan Mountain. Figure 3 shows the location and failure of Teesta III H. E. Dam caused due to GLOF [9].

Fig. 3 : Failure of Teesta III H.E. Dam caused by GLOF

2.3 Chamoli Flood Disaster from Rock Avalanche (2021)

Recently, massive rockslide (mixed with ice and snow) situation happened in the Garhwal Himalayan region of Uttarakhand and suddenly increased the volume and velocity of water in the downstream. This incident occurred about 60 km northeast from Uttarakhand flash flood which occurred in 2013. On 7th February 2021, massive rockslide pushed the water trapped behind the Tapovan Project, in Chamoli District northern state of Uttarakhand at a speed of 300km/hr. River along with loose debris, dust and rock moved toward dam. 120 m length of tunnel was filled with sludge and debris. It destroyed under construction Tapovan Vishnugad Hydropower Project (520 MW), Rishi Ganga Hydroelectric Power Project (13.2 MW) and caused extensive damage to Vishnuprayag H E Project and Vishnugad H E Project. [10] The result of this disaster was worst because hundreds of people died and Hydro Power Projects (HPPs) worth 1500 crores were also destroyed [4]. Approximately 2,500 people in 13 villages were affected by the flood. Figure 4 shows washed away Tapovan hydropower project due to flash flood [11].

Fig. 4 : Washed away Tapovan Hydropower Project due to flash flood

2.4 Uttarakhand Flash Flood Disaster from Heavy Rain and Glacier Outburst (2013)

In June 2013, Uttarakhand area received heavy rainfall, which was about 375 % more than the benchmark during normal monsoon. This caused melting of chorabari glacier and outburst at height of 3800 m and eruption of Mandakani River which lead to heavy floods near Gobind Ghat. The flood carried huge amount of silt and rock and destroyed that came its way. The dam gates breached and 4,00,000 cubic metres of water rushed into the already flooded Mandakini river, covering the pilgrimage city of Kedarnath and severely damaging at least two HPPs downstream. Approximately 5,000 people lost their life including residents and tourist [12]. Figure 5 shows the affected Kedarnath city and Vishnuprayag H.E. Project due to flash flood [13].

2.5 Panshet-Khadakwasla Dam Failure from Cloud Burst (1961)

The catastrophic event occurred in Pune on July 12, 1961, due to heavy rain. The newly constructed Panshet Dam of 10.69 TMC located on the Ambi River (a tributary of Mutha) failed due to cloud burst in the upstream. The entire flood is discharged into Mutha River and it reached the Khadakwasla Dam of 2.5 TMC capacity. This Khadakwasla masonry dam initially started impoundment in 1879 with meagre capacity was successful up to 1960. The Khadakwasla Dam could not sustain the heavy flood coming from Panshet Dam and failed in 1961. Failure of Khadakwasla Dam due to cascading impact of flood is shown in Figure 6 [14]. At present, Temghar Dam (3.15 TMC), Panshet Dam (10.69 TMC) and Varasgaon Dam (10 TMC) drain water into the Khadakwasla Dam, which can hold a maximum of 5 TMC water only.

The case studies covered above consists of cascading impact of flood with multiple hazards interconnected with a primary hazard trigger and a chain of secondary-tertiary hazards. Human settlement in the mountain environment is increasing in size and land use patterns are changing. Infrastructure such as roads and hydropower projects are rapidly penetrating mountain landscapes. The flood now also carries huge chunks of broken concrete, smashing into next dam in downstream. The interplay between natural hazards with human settlements and infrastructure

Fig. 5 : Affected Kedarnath city and Vishnuprayag H.E Project due to flash flood

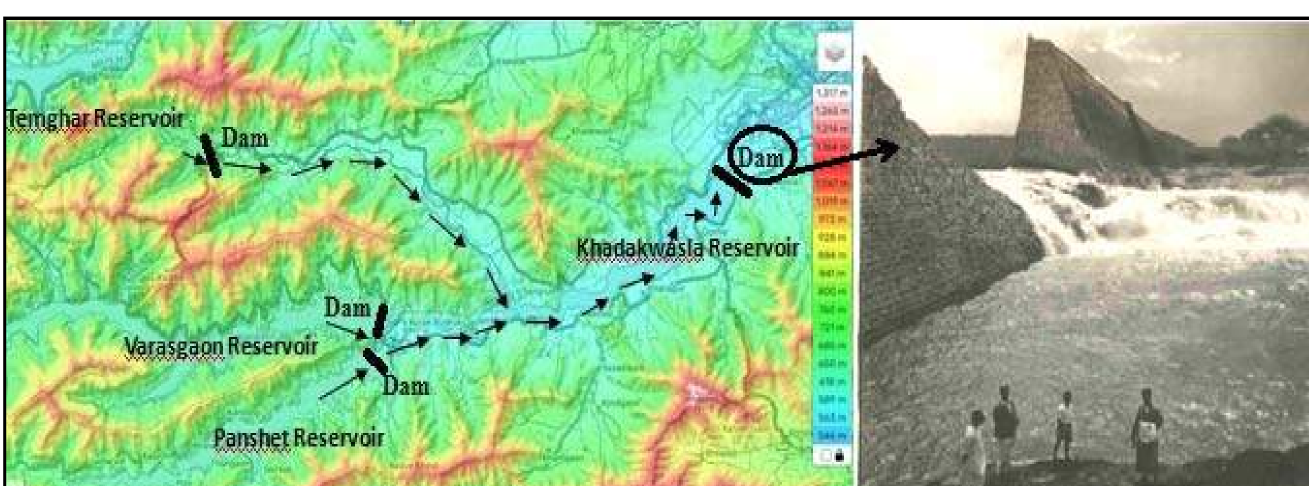

Fig. 6 : Failure of Khadakwasla Dam due to cascading impact of flood

is an important aspect, which can significantly escalate the impacts of event like that happened in Chamoli and Uttarakand flash flood. The reason behind the flash floods, call for an integrated early warning system.

Nour Chahrour et al., 2023 [15] studied cascading impact through physics based model to examine the deterioration of dams. The result obtained reveals that stability of downstream dam decreases the deterioration rate of upstream dams. With series of dams constructed in River, dam located in the downstream should perform the function of both storage as well as flood control reservoir. Te Wang et al., 2022 [16] studied five cascade reservoirs as an example and risk consequences of each cascade dam breach were evaluated to quantify the risk transmission. Compared with a single reservoir, the risk in cascade reservoirs has the transmission and superposition effect, which increases the risk loss. Therefore, dam safety management needs to incorporate a risk assessment approach for cascading impact of flood.

3. NEED FOR REHABILITATION OF DAM CONSIDERING THE CASCADING IMPACT OF FLOOD

From the case studies, it is seen that, the upstream dam failed due to huge volume of water accumulating from flash flood, also leading to successive dam breach in the downstream. Here, successive breach in the downstream was uncertain until actual damage happened. Therefore, reasonable measurement of risk assessment considering cascading impact of flood is very much important to ensure the safety of the structure and people residing. Figure 7 shows upstream dam and successive dams having reasonable risk assessment (i.e., Actual Risk and Uncertain Risk). Actual risk in the figure refers to breach possibility of Dam under its own risk loss. Uncertain risk refers to additional risk loss due to passing of flood from upstream dam. If the Dam B retains the flood without overtopping, the cause will be certain inundation loss within this region. If the Dam B fails to withstand the flood, the actual risk will expand and uncertainty of risk will shift beyond this to successive dam in the downstream.

As reported in International Centre for Integrated Mountain Development (ICIMOD) [10], Chamoli cascading flood caused damage to series of hydropower projects at different reach from source are presented in Table 2.

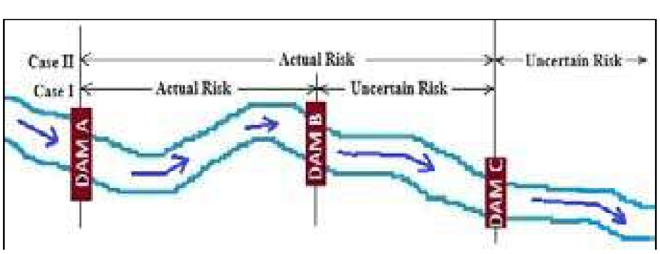

Fig. 7 : Actual and Uncertain Risk due to Cascading Impact

Table 2 : Chamoli cascading flood caused damage to series of hydropower projects

Sr. No	Name of Hydro Power Projects (HPP)	Capacity	Distance from Rockslide
1	Rishi Ganga HPP	13.2 MW (Operational)	14 km
2	Tapovan Vishnugad HPP	520 MW (under construction)	22 km
3	Vishnuprayag HPP	400 MW (Operational)	35 km
4	Vishnugad Pipalkoti HPP	444 MW (Under Construction	55 km

Dam Safety management is mostly aimed to improve safety aspects of the dams through structural and non-structural intervention. However risk assessment is in the transitional phase and focuses on mainly risk possibility and dam failure consequences. Therefore, it is important to consider cascading Impact of Flood in Planning, Development and Rehabilitation of Dams.

The ability of water bodies to be impounded has expanded along with their numbers with improvements in experience, understanding, and technology accessibility. India is able to meet its needs for irrigation, water supply, industrial processing, hydropower generation, flood control and the development of riverfront areas. Recent steps taken by Indian Government are presented in following section.

4. STEPS TAKEN BY INDIAN GOVERNMENT

India is ranked third in the world in terms of building large dams. As per the National Register of Large Dams, 2023, India has 6138 numbers of operational large dams and 143 are under construction [3]. About 1,100 large dams have already reached 50 years of age and some are older than 120 years. The number of such dams will increase to 4,400 by 2050. Dams were built according to the rainfall pattern of the past decades. With dams age, sediment replaces the water in the reservoirs which decreases its storage capacity, leading to less crop yield, frequent flood and natural hazard risks due to climate change in recent years has left them vulnerable. To safeguards people lives, water crises, energy requirement and Investments, various initiatives have been taken by Government of India.

(i) **Dam Rehabilitation and Improvement Project (DRIP)**: Government of India with World Bank Support initiated DRIP scheme in April 2012 with an objective to improve the safety and operational performance of selected existing dams, coupled with institutional strengthening through system wide management approach. The scheme addressed overarching pillars of dam safety like structural integrity, surveillance and maintenance, instrumentation and monitoring, design intrinsic risks, natural hazard risks, emergency and operational planning with adequate provision of capacity building including physical rehabilitation. In DRIP-I (2012-2021), 223 dams located in seven states were rehabilitated at cost of Rs 2567 Cr. With the success of DRIP I scheme, DRIP-II and III (2021-2031) is targeted to rehabilitate 736 more dams located in 19 states of the country at a cost of Rs 10,211 Cr. To ensure strengthening of technical regulation in dam safety and standardise its practice across the country, 13 guidelines/manuals have been published under the scheme. Steps taken by Indian Government has generated opportunities for various African and South Asian Countries in the area of dam safety [17].

(ii) **The Dam Safety Act, 2021**: The Dam Safety Act was introduced in response to dam failures caused by deficient surveillance, inspection, operation and maintenance. It regulate a unified dam safety procedures to prevent dam failure related disasters and lay emphasis on creating multi-tier institutional mechanism and capacity building for comprehensive dam safety management in the country. It also establishes key responsibilities and formation of national and state-level bodies for its implementation [18].

(iii) **Prioritizing solar and wind Projects**: At the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow in November 2021, India announced its intention to achieve 500 GW of its installed power generation capacity through non-fossil fuels (solar, wind, hydro, biomass and nuclear) and 50 % of its energy requirement from renewable energy by 2030.) The government has recently revamped the process for concurrence of Detailed Project Report (DPR) for speeding up of Pumped Storage Projects [19] at suitable locations without impacting the existing natural water systems. Wind-Solar-Pump Storage Hybrid Projects present a viable solution to the problem at hand and also for future to meet energy demand.

5. CONCLUSIONS

Many of the dams constructed in 1970s are reaching close to their shelf life. Government is enabling the dams with information intelligence systems like rainfall alerts, flood alerts and preparing emergency action plan, however the storage capacity cannot be claimed to be the same as it was in the late fifties. Sedimentation over a long period is an undisputed cause of frequent flood. Dams constructed on Himalayan belt has fragile environment. Hydropower projects have gradually moved from downstream part to upstream area where cascading effects can create compounding impacts on the system. Dam failures discussed in the case studies have been caused by sudden accumulation of high volume of water which was beyond dam capacity in the reservoirs that were overwhelmed by an extreme event. Early detection and wide publicity could have reduced the loss of life and property. Cascading impact of flood becomes pronounced when it carries huge debris of upstream dam along with it. Recent failure of series of dams one after another in Libya, Sikkim and Uttarakhand is a wake-up call to the dangers of climate change and also for old infrastructures. And they won't be the last big dams to collapse unless we remove and repair some of the aging and obsolete structures that are long past their shelf life. Glaciers melting rapidly as a result of warming are now a major safety hazard to dams and communities living downstream.

In the aftermath of recent disasters, the role of infrastructure and its interplay with natural hazards have raised the question. While some aging dams still supply drinking water, help farmers in irrigation and generate electricity, the default approach is to go for timely repair and upgradation of aging dams, continuous and close monitoring of reservoir levels, anticipation of rainfall with increased flow from upstream. When number of dams are build in same river, the necessary rehabilitation of dam may extend to river basin considering cascading impact of flood. Instrumentation of dams may be strengthened to establish integrated early warning systems that can detect landslides, GLOFs and other potential hazards to improve preparedness that can save life and minimize damage.

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Disclaimer

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the department/ organisation.

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Save water today, secure your tomorrow

Equation of Hydraulic Jump Length in Front of Sluice Gate using Baffle Block and Sill as Energy Reducer

Sunik Sunik[1]

ABSTRACT

While the sluice gate is operated, a hydraulic jump always occurs in front of the gate. The formula for the length of the hydraulic jump in front of the sluice gate has not yet been determined exactly. The length of a hydraulic jump in a rectangular channel can be estimated using the following empirical equation. This research is development from previous researchers (Sunik, 2019). Running model test was carried out 270 times with detail as 71 times for cubic baffle block (K1, K2, K3) and 199 times for trapezoidal (T1, T2, T3, T4, T4A, T4B, T4C, T4D). The aim of this research is to determine the length of a hydraulic jump that occurs in a model test channel using sluice gate while additional structures as baffle blocks and sill installed at a certain distance from the sluice gate. The research result show that equation model for hydraulic jump length based on the best regression curve (close to 1) obtain $Lj = y_1(30.166x^2 + 10.854x + 7.0963)$ (trapezoidal baffle block (T4C)); as function $Lj = y_1 (30.166 (f (h,w))^2 + 10.854 (f (h,w))+ 7.0963)$, $R^2 = 0,9887$ x represent the Froude number which is the beginning of a hydraulic jump.

***Keyword** : sluice gate, hydraulic jump, Froude number, length jump*

1. INTRODUCTION

A hydraulic jump in front of a sluice gate occurs when there is a rapid change from supercritical flow to subcritical flow downstream of the gate. This phenomenon is a result of the sudden energy dissipation caused by the obstruction created by the sluice gate. The length and characteristics of the hydraulic jump depend on various factors, including the flow rate, sluice gate opening, channel geometry, and roughness. Hydraulic jump had various of length (Lj) and height of water level. The length of the hydraulic jump (Lj) is defined as the distance from the initial vortex formed at the downstream in front of the gate to the final vortex in the transition flow condition (supercritical to subcritical). Although the length of the hydraulic jump is difficult to determine, the better approximate values are around $5y_2$ (for Fr value = 2.5 – 5) and $6y_2$ (for Fr value > 5). Previous researchers had examined the length of the hydraulic jump and analyzed it based on the y_2-y_1 value (peak water level – initial water level of jump) is (Woycicki, 1935); (Elevatorski, 1959), based on the value of the Froude number (Fr_1), initial water level (y_1) and peak water level (y_2) is (Chow, 1959); (Rajaratnam, 1978), based on the value of the velocity (v_1 dan v_2) and Froude number (Fr_1), initial water level (y_1) and peak water level (y_2) (Bushra & Afzal, 2006) research base on initial water level (y_1) and peak water level (y_2). Other researchers that analyzed about hydraulic jump length is (Bélanger, 1828); (Belanger, 1841); (Belanger, 1849); (Bhowmik, 1971); (Bradley & Peterka, 1958); (Chanson & Montes, 1995); (Chanson & Brattberg, 2000); (De Padova & Mossa, 2021); (Ead & Rajaratnam, 2002); (Gualtieri & Chanson, 2007); (Gupta et al., 2019); (Gupta & Dwivedi, 2023); (Hayawi & Mohammed, 2011); (Kim et al., 2015); (Mammadov, 2017); (Satoh et al., 2022); (Schulz et al., 2015); (Sulistiono, 2017); (Sunik et al., 2019); (Sunik Sunik, 2020); (S. Sunik et al., 2020); (Sunik, 2024); (Urbański et al., 2018); (Yousefi et al., 2019); (Wüthrich et al., 2022).

Until now, it is still not possible to definitively determine the length of the hydraulic jump, especially for hydraulic jumps with additional structures using baffle blocks and sills at a certain distance from the sluice gate. This research is a development from previous research (Sunik, 2019) which will examine the modelling of the hydraulic jump length equation through a sluice gate using additional structures (baffle block and sill) that installed at a certain distance from the sluice gate base on the blockage safety requirement from USBR (50%). The classification and type of hydraulic jump are shown in the Figures 1 and 2.

Figure 3 shown the length of hydraulic jump phenomena and Figure 4 shown relation Froude number and L/y1.

Novelty of this research is obtaining the equation of hydraulic jump length through a sluice gate with addition of baffle block and sills as energy reducer which provides optimization using blockage ratio and ratio dimension between the blocks.

2. EXPERIMENTAL WORK

The prototype model as horizontal channel made from fiberglass (dimension as width (B) = 50 cm, length (L) = 9 m). Sluice gate placed on it using dimension: width

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Upstream Fr_1	Depth Ratio y_2/y_1	Fraction of Energy Dissipation	Description	Surface Profile
<1	1	0	*Impossible jump*. Would violate the second law of thermodynamics.	
1–1.7	1–2	<5%	*Undular jump* (or *standing wave*). Small rise in surface level. Low energy dissipation. Surface rollers develop near Fr = 1.7.	
1.7–2.5	2–3.1	5–15%	*Weak jump*. Surface rising smoothly, with small rollers. Low energy dissipation.	
2.5–4.5	3.1–5.9	15–45%	*Oscillating jump*. Pulsations caused by jets entering at the bottom generate large waves that can travel for miles and damage earth banks. Should be avoided in the design of stilling basins.	
4.5–9	5.9–12	45–70%	*Steady jump*. Stable, well-balanced, and insensitive to downstream conditions. Intense eddy motion and high level of energy dissipation within the jump. Recommended range for design.	
>9	>12	70–85%	*Strong jump*. Rough and intermittent. Very effective energy dissipation, but may be uneconomical compared to other designs because of the larger water heights involved.	

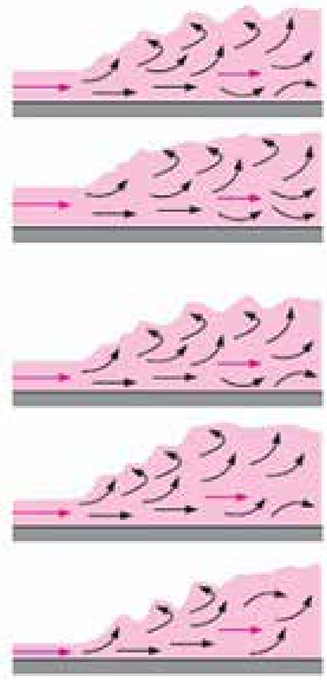

Fig. 1 : The classification of hydraulic jump *(Source: Subramanya, 1982)*

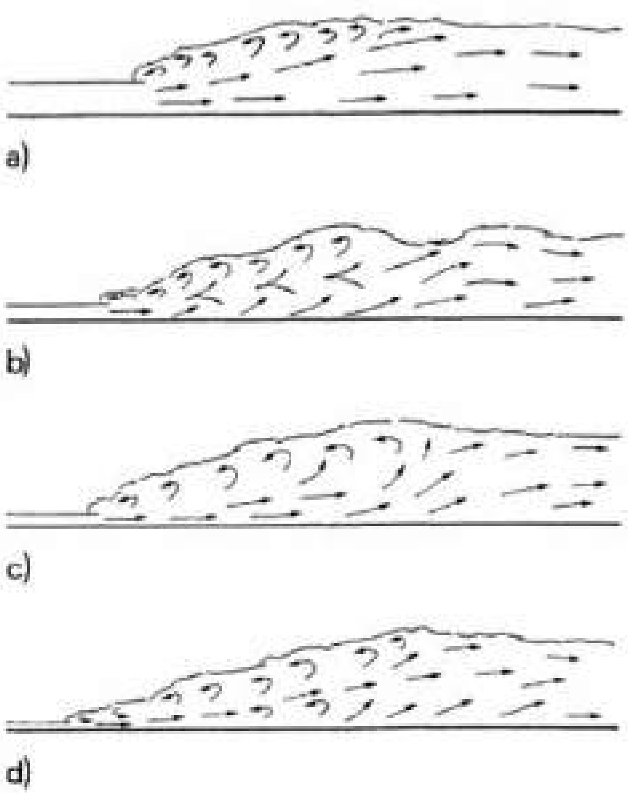

Fig. 2 : Type of classical jump (4 type), (a) pre jump, (b) transition jump, (c) stabilised jump, (d) choppy jump (Bradley and Peterka, 1957a) *(Source: Hager,1992:13)*

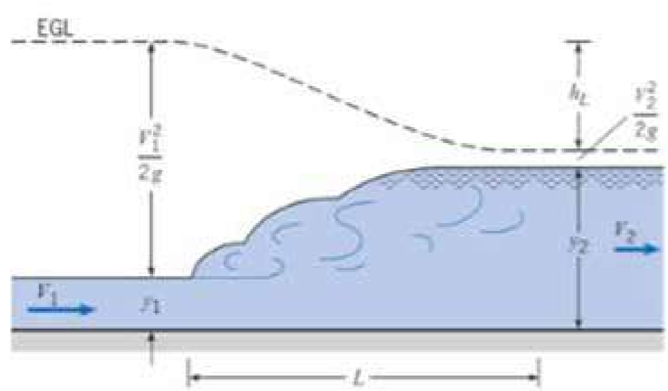

Fig. 3 : The length of hydraulic jump *(Source: Elevatorski, 1959)*

(b) = 50 cm, thick (t) = 1 cm, height (h) = 80 cm and added square baffle block as energy dissipator and the end of the channel added the sill. Simulation of flow for each run was trial until configuration of hydraulic jump was performed in stabilized to the desire location of 25 cm downstream from the sluice gate

The channel separated into 12 sections (before and in front of the sluice gate). Measurement for each section consist point of left, middle and right part that each part measure in above, middle and bottom of the height flow (one section consists of nine measured, so for 12 sections, it needs 108 measurement). The water depth

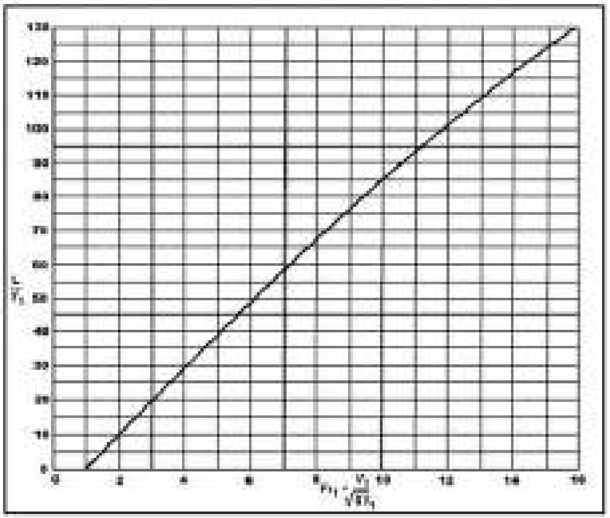

Fig. 4 : Relation between Froude number and the length of hydraulic jump for square channel *(Source: Elevatorski, 1959)*

Fig. 5 : Hydraulic jump and length of jump in front of the sluice gate *(Source: Sunik, 2019)*

and velocity (v) for 12 section was measured in the same procedure. It used 10 baffle blocks (square and trapezium) with code as K1, K2, K3 (square) and T1, T2, T3, T4A, T4B, T4C, T4D (trapezium). Figure 5 shown hydraulic jump phenomena base on model test in laboratory.

Configuration dimension of square and trapezium baffle block type 1 as width (b_{b1}) = 7 mm, length (l_{b1}) = 7 mm, height (h_{b1}) = 15 mm; type 2 as width (b_{b2}) = 14 mm, length (l_{b2}) = 14 mm, height (h_{b2}) = 35 mm; type 3 as, width (b_{b1}) = 21 mm, length (l_{b1}) = 21 mm, height (h_{b1}) = 7 mm, type 4 as, width (b_{b1}) = 28 mm, length (l_{b1}) = 28 mm, height (h_{b1}) = 8.5 mm. Sill placed in downstream channel with dimension width (b_{s1}) = 50 cm, thick (t_s)= 1 cm, height (h_{s1}, h_{s2}, h_{s3}, h_{s4}, h_{s5} = no sill, 1.5 cm, 2.0 cm, 2.7 cm, 3.6 cm). Some results of running flow cannot be measured because the flow sinks, small and thin of hydraulic jumps, overflow through the sluice gate, flow is unstable. To create a hydraulic jump phenomenon, back water flow conditions are created during running using sills placed downstream of the channel, the distance between sill placement varies (initial running is in the form of free flow and simulation trial error until hydraulic jump occurs). Table 1, Table 2, Table 3 and Table 4 shown the length of jump base on the model test measurement.

The distance between the sill and sluice gate (Ls) is Ls_1 = 1 m, Ls_2 = 2 m, Ls_3 = 3.75 m. Optimization the use of the selected baffle block and sills based on analysis comparing the ratio of the hydraulic jump length (L/y_1) to the Froude number value which provides the best regression value ($R^2 < 1$) from 270 running data.

3. RESULTS AND DISCUSSION

3.1 Ratio of Hydraulic Jump Length (Lj/y1) to Froude Number (K1, K2, K3)

The ratio value of the hydraulic jump length (Lj/y1) against to Froude number (Fr) for three types of square baffle block (K1, K2, K3) is shown in Figure 6 with the equation in the form of 2nd order polynomial to provide the best approach. For baffle block type K1, K2, K3 the value obtained of R2 = 0.9665, R2 = 0.99, R2 = 0.9658. Baffle block K2 represent the good R2 value which has dimension of 14 mm, compared to K1 with dimensions of 7 mm and K3 with dimension of 21 mm, even though the three of baffle blocks are treated with the same sill placement for 2 cm and 2.7 cm. This can be interpreted that the use of the K2 type baffle block can provide a better ideal of hydraulic jump length ratio compared to K1 and K3 (K1 dimension are too small, K3 dimension are too large).

3.2 Ratio of Hydraulic Jump Length (Lj/y1) to Froude Number (T1, T2, T3, 4A, T4B, T4C, T4D)

The ratio value of the hydraulic jump length (Lj/y_1) against to Froude number (Fr) for seven types of trapezoidal baffle block (T1, T2, T3, T4A, T4B, T4C, T4D) is shown

Table 1 : Discharge, water level, length of jump (K1) - filter

No	Run	Type	hrech	Qrech	Elv	a	h_{sill}	h_A	Lj
			cm	l/det	cm	cm	cm	cm	(cm)
1	1	K1	5.00	7.51	79.80	1	2.7	0.80	5.5
2	6	K1	6.70	11.56	79.80	2	2.7	2.00	6.0
3	7	K1	7.50	13.57	79.80	3	2.7	3.00	9.0
4	22	K1	4.50	6.44	77.20	1	2	0.70	3.6
5	18	K1	6.50	11.01	77.20	2	2	1.50	5.1
6	20	K1	6.15	10.15	78.40	2	2	1.60	5.0
7	17	K1	7.90	14.65	77.20	3	2	3.00	9.1
8	25	K1	3.20	3.94	78.25	1	-	1.35	4.2
9	27	K1	4.65	6.76	78.25	2	-	1.20	3.6
10	29	K1	5.95	9.67	78.25	3	-	1.77	5.5
11	31	K1	7.25	12.92	78.25	4	-	2.65	8.0
12	48	K1	5.15	7.84	78.50	1	-	1.00	3.0
13	49	K1	3.60	4.66	78.50	1	-	1.80	5.0
14	50	K1	7.00	12.27	78.50	2	-	2.00	6.0
15	51	K1	5.00	7.51	78.50	2	-	1.70	5.0
16	52	K1	8.50	16.31	78.50	3	-	3.00	11.0
17	53	K1	6.50	11.01	78.50	3	-	3.00	10.0
18	54	K1	10.00	20.71	78.50	4	-	3.10	9.0
19	55	K1	7.80	14.38	78.50	4	-	3.20	10.0

Source: Sunik, 2019

Table 2 : Discharge, water level, length of jump (K2) - filter

No	Run	Tipe	hrech	Qrech	Elv	a	h_{sill}	h_A	Lj
			cm	l/det	cm	cm	cm	cm	(cm)
1	56	K2	3.60	4.66	77.25	1	2	0.80	8.5
2	57	K2	4.70	6.86	77.25	1	2	0.90	10.0
3	58	K2	5.00	7.51	77.25	2	2	1.90	12.5
4	59	K2	6.55	11.13	77.25	2	2	1.80	11.0
5	60	K2	6.55	11.13	77.25	3	2	2.70	15.0
6	61	K2	8.20	15.47	77.25	3	2	1.95	14.0
7	62	K2	8.20	15.47	77.25	4	2	3.80	22.0
8	63	K2	9.60	19.51	77.25	4	2	2.35	22.0
9	64	K2	4.70	6.86	77.25	1	2.7	0.90	12.0
10	65	K2	5.50	8.63	77.25	1	2.7	0.80	30.0
11	66	K2	6.55	11.13	74.90	2	2.7	3.00	25.5
12	67	K2	7.30	13.05	74.90	2	2.7	1.90	27.0
13	68	K2	7.80	14.38	74.90	3	2.7	4.00	25.0
14	69	K2	8.85	17.31	74.90	3	2.7	2.90	30.0
15	70	K2	9.60	19.51	74.90	4	2.7	4.00	24.0
16	71	K2	10.20	21.33	74.90	4	2.7	2.55	20.0

Source: Sunik, 2019

Table 3 : Discharge, water level, length of jump (K3) - filter

No	Run	Tipe	hrech	Qrech	Elv	a	h_{sill}	h_A	Lj
			cm	l/det	cm	cm	cm	cm	(cm)
1	109	K3	10.40	21.95	77.60	4	2.7	2.60	26
2	111	K3	9.00	17.74	77.60	3	2.7	1.85	20
3	114	K3	7.30	13.05	77.58	2	2.7	1.38	16
4	116	K3	5.75	9.20	77.58	1	2.7	0.80	19
5	117	K3	5.00	7.51	76.90	1	2	0.90	13
6	122	K3	6.70	11.51	76.90	2	2	1.40	15
7	123	K3	8.00	14.92	76.90	3	2	1.90	20
8	124	K3	9.20	18.32	76.90	4	2	2.50	25

Source: Sunik, 2019

Table 4 : Discharge, water level, length of jump (T1) - filter

No	Run	Tipe	hrech	Qrech	Elv	a	h_{sill}	h_A	Lj
			cm	l/det	cm	cm	cm	cm	(cm)
1	39	T1	3.24	4.01	80.30	1	-	3.00	11.5
2	37	T1	4.70	6.86	86.85	2	-	2.50	9.0
3	34	T1	7.70	14.11	80.40	3	-	4.20	22.0
4	35	T1	6.05	9.91	86.85	3	-	5.00	19.0
5	32	T1	7.40	13.31	86.85	4	-	3.00	12.0
6	40	T1	9.10	18.03	80.40	4	-	3.25	14.0
7	42	T1	5.15	7.84	80.40	1	2.7	3.50	30.5
8	43	T1	6.70	11.51	80.40	2	2.7	4.40	23.0
9	44	T1	7.00	12.27	80.40	2	2.7	3.50	25.5
10	45	T1	8.50	16.31	75.80	3	2.7	9.00	33.3
11	46	T1	9.10	18.03	75.80	4	2.7	3.20	21.8
12	47	T1	10.00	20.71	75.80	4	2.7	6.30	31.5

Source: Sunik, 2019

Table 5 : Discharge, water level, length of jump (T2) - filter

No	Run	Tipe	hrech	Qrech	Elv	a	h_{sill}	h_A	Lj
			cm	l/det	cm	cm	cm	cm	(cm)
1	72	T2	3.60	4.66	82.12	1	-	2.45	22
2	73	T2	3.65	4.76	82.12	1	-	2.30	20
3	79	T2	7.20	12.79	82.12	4	-	1.90	17
4	80	T2	7.85	14.51	82.25	4	-	6.20	54
5	91	T2	5.10	23.50	77.98	1	2	2.00	22
6	88	T2	7.00	12.26	77.98	2	2	2.50	25
7	86	T2	8.40	16.03	77.98	3	2	2.80	26
8	87	T2	8.20	15.42	77.98	3	2	2.50	23
9	85	T2	8.20	15.47	82.25	4	2	3.20	30
10	92	T2	5.60	8.85	78.00	1	2.7	2.20	25
11	93	T2	7.50	13.57	78.00	2	2.7	2.50	26
12	94	T2	9.05	17.88	78.00	2	2.7	3.00	29

Source: Sunik, 2019

Table 6 : Discharge, water level, length of jump (T3, T4) - filter

No	Run	Tipe	hrech	Qrech	Elv	a	h_{sill}	h_A	Lj
			cm	l/det	cm	cm	cm	cm	(cm)
1	102	T3	4.90	7.29	78.60	1	2	1.20	15
2	101	T3	6.85	11.89	78.60	2	2	1.90	21
3	98	T3	8.25	15.61	75.90	3	2	2.70	28
4	100	T3	9.40	18.91	75.90	4	2	3.00	30
5	103	T3	5.40	8.40	78.60	1	2.7	2.30	24
6	104	T3	7.40	13.31	78.60	2	2.7	2.85	39
7	105	T3	8.90	17.45	78.60	3	2.7	3.00	33
8	97	T3	10.30	21.64	75.90	4	2.7	2.80	29
9	161	T4	7.90	14.65	81.85	3	1.5	2.20	24
10	167	T4	10.80	23.20	75.25	3	1.5	1.85	27
11	156	T4	7.90	14.65	80.50	3	1.5	2.15	25
12	169	T4	7.90	14.65	75.30	3	1.5	2.50	27
13	140	T4	10.80	23.20	78.85	4	1.5	2.70	32
14	142	T4	9.20	18.32	78.83	4	1.5	2.50	27

Source: Sunik, 2019

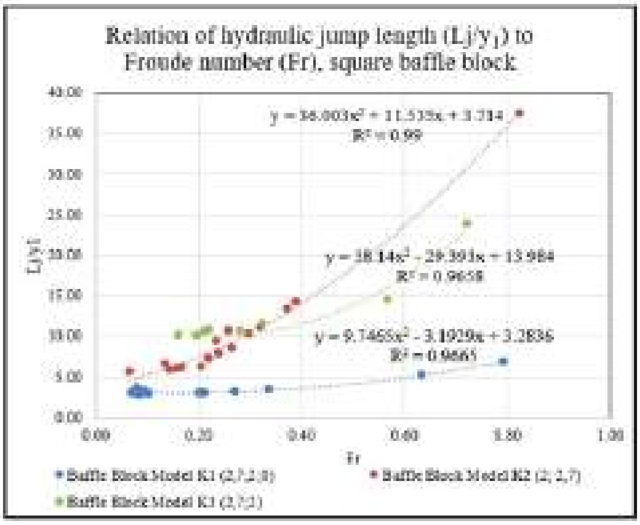

Fig. 6 : Relation between the ratio of the hydraulic jump length (Lj/y_1) to Froude number (Fr) for baffle block of K1, K2, K3

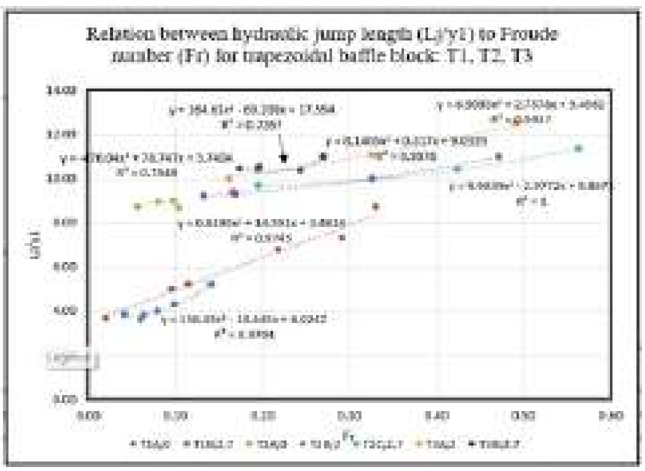

Fig. 7 : Relation between the ratio of the hydraulic jump length (Lj/y1) to Froude number (Fr) for baffle block of T1A, T1B, T2A, T2B, T2C, T3A, T3B

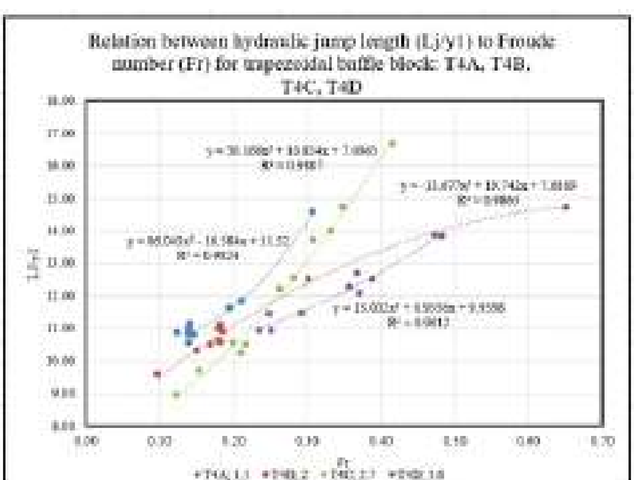

Fig. 8 : Relation between the ratio of the hydraulic jump length (Lj/y1) to Froude number (Fr) for baffle block of T4A, T4B, T4C, T4D

in Figures 7 and 8 with the equation in the form of 2nd order polynomial.

Baffle block type T1A(0;6), T1B(2.7;6), T2A(0;4), T2B(2;5), T2C(2.7;3), T3A(2;4), T3B(2.7;4), the value obtained of R^2 = 0.9704, R^2 = 0.9745, R^2 = 0.7548, R^2 = 0.9976, R^2 = 1, R^2 = 0.9937, R2 = 0.7267. Other type of T4A(1.5;10), T4B(2;10), T4C(2.7;11), T4D(3.6;10) the value obtained of R^2 = 0.9824; R^2 = 0.9863; R2 = 0.9887; R^2 = 0.9612.

4. CONCLUSION

Trapezoidal baffle block model T4C represent the good R2 value which has dimension of 28 mm and the sill placement for 2.7 cm with equation:

Lj = y1 ($30.166x^2 + 10.854x + 7.0963$), with x represent Fr value.

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Workshop on
Seismic Response Analysis of Dam - Numerical Analysis

24th - 25th August, 2023, IIT Roorkee

View of the dais during inaugural session (L-R) Mr. A.K. Dinkar, Secretary, CBIP; Shri Manish Shrikhande (Prof.), IIT Roorkee; Shri Bhupender Gupta, Director (Technical), THDC India Ltd.; Shri Vivek Kapadia, Secretary to Govt. of Gujarat & Director, SSNL and Mr. K.K. Singh, Director-WR, CBIP

BRIEF REPORT

The Workshop on the Seismic Response Analysis of Dam- Numerical Analysis was organized by International Commission On Large Dams, India (INCOLD) in association with Central Board of Irrigation and Power (CBIP) & Indian Society of Earthquake Technology (ISET) on 24th - 25th August, 2023 at Conference Hall, Department of Earthquake Engineering, IIT Roorkee to provide participants a comprehensive understanding of the role of seismic & numerical analysis in the construction, operation, and maintenance of dams. The event aimed to disseminate knowledge and best practices related to Seismicity, foster collaboration among professionals, and promote the efficient and sustainable use of seismicity response and its analysis in dam projects.

The workshop attracted a diverse group of professionals from different disciplines, including dam engineers, geotechnical engineers, civil engineers, researchers, academicians, and industry experts. The participants represented a wide range of organizations, including engineering firms, government agencies, academic institutions, and consulting companies.

The workshop started on the 24th August 2023, with the inaugural session.

Mr. A.K. Dinkar, Secretary, CBIP, delivering the welcome Address

Guests present on & off the dais:

Guest on the Dias

Shri Sandeep Singhal, MD, UJVNL - on line

Shri Vivek Kapadia, Secretary to Govt. of Gujarat & Director, SSNL,

Shri Bhupender Gupta, Director (Technical), THDC India Ltd.,

Shri Manish Shrikhande (Prof.), IIT Roorkee

Shri A. K. Dinkar, Secretary, CBIP

Shri K.K. Singh, Director (WR), CBIP

Guest off the dais

Dr. Mahendra Singh, President, ISRM (India) & Professor, IIT Roorkee

Shri Atul Jain (Executive Director-Technical), THDC India Limited

Shri M. L. Sharma (Prof.), IIT Roorkee

Shri N. K. Goel (Prof.), University of Roorkee

Shri B.K. Maheshwari (Prof.), IIT Roorkee

Shri Pankaj Agarwal (Prof.), IIT Roorkee

Shri Ravi Sankar Jakka (Prof.), IIT Roorkee

Shri Ritesh Kumar (Assistant Prof.), IIT Roorkee

About 62 participants from 23 organizations participated in the workshop.

Shri A.K. Dinkar delivered the welcome Address. He welcomed the dignitaries and the experts present on and off the dais and briefed the gathering about the workshop and various activities of the CBIP. Shri Sandeep Singhal, MD UJVNL, also welcomed all the participants and graced the workshop as the chief guest of the event. Shri Bhupender Gupta, Director (Technical), THDC, also welcomed all the participants. Shri Vivek Kapadia, Secretary to Govt. of Gujarat & Director, SSNL also addressed the gathering during inaugural session.

Prof. Shrikhande, IIT Roorkee also addressed participants on the subject of the workshop.

Prof. Mahendra Singh, President of Indian National group of International Society for Rock Mechanics and Rock Engineering and Professor, IIT Roorkee, had also graced our gathering with his profound wisdom and invaluable insights. In his address to the participants, he shed light on the significance of the subject matter, enriching our understanding of it.

Mr. Manish Shrikhande (Prof.), IIT Roorkee

Mr. Vivek Kapadia, Director, SSNL

Mr. Bhupender Gupta, Director (Technical), THDC India Ltd.,

Dr. Martin Weiland, Chairman of the Committee on Seismic Aspects of Dam Design of the International Commission on Large Dams (ICOLD), had also addressed the participants and shared his enrich experience through the presentation on “Methods of Seismic Analysis of Large Concrete and Embankment Dams.”

The inaugural session concluded with a Vote of thanks, proposed by Shri K.K. Singh, Director, CBIP. He expressed sincere gratitude to all the dignitaries on and off the dais for gracing the inaugural session. He conveyed special thanks to Shri Manish Shrikhande (Prof.), Head of Department of Earthquake Engineering and his team for extending all out support for the success of this workshop.

Shri K.K. Singh also conveyed his thanks to all the speakers, invitees and participants for joining this workshop.

Expert Speakers and Facilitators: The workshop featured following renowned experts and experienced professionals in the field of seismicity in dam engineering and its application. They shared their knowledge, experiences, and insights through engaging presentations and interactive sessions, ensuring a valuable learning experience for the participants:-

1. Shri Vivek Kapadia, Secretary to Govt. of Gujarat & Director, SSNL
2. Prof. M.L. Sharma, IIT, Roorkee
3. Prof. B.K. Maheshwari, IIT Roorkee
4. Prof. R.S. Jakka, IIT, Roorkee
5. Prof. Manish Shrikhande, HOD, Earthquake Engg. Deptt., IIT, Roorkee
6. Shri Ankur Vishwakarma, NHPC
7. Prof. Pankaj Agarwal, IIT, Roorkee
8. Prof. Ritesh Kumar, IIT, Roorkee
9. Dr. Martin Weiland (Switzerland), Chairman, INCOLD committee on Seismic aspect of Dam design
10. Shri S.L. Kapil, Ex ED, NHPC

Dr. Mahendra Singh, President, ISRM (India) & Professor, IIT Roorkee

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

The workshop featured a series of presentations, discussions, case studies, and hands-on activities. The following presentations were made during the workshop:

1. Preparing Dam Foundation in Seismically Active Zone: Case Study of Sardar Sarovar Dam
2. Presentation of case study of THDC
3. Seismic Design of Dams including Embankments

View of the participnats

4. Seismic Response and Stability Analysis of Embankment Dams: A case study of Shatoot Dam
5. Seismic Design Criteria of Large Dams and Selection of Ground Motion parameters
6. Presentation of a case study of Subansiri Dam
7. Finite Element Modeling and Stress Analysis of Concrete Gravity Dams.
8. Quantification of seismic wave scattering considering site-specific SPT borehole data-based non-uniformity and seismic absorbing boundary conditions.
9. Methods of Seismic Analysis of Large Concrete and Embankment Dams.
10. Seismic Safety Aspects of Existing Dams.

The workshop provided ample opportunities for networking and collaboration among the participants. Breakout sessions, group discussions, and interactive exercises encouraged knowledge exchange, the sharing of challenges and solutions, and the formation of professional connections. Participants also had the chance to interact with the speakers and industry experts during Q&A sessions and networking breaks.

The Department of Earthquake Engineering graciously granted access to its state-of-the-art testing laboratory, facilitating a seamless connection between workshop knowledge and real-world field experiences. This invaluable opportunity empowered participants to gain a comprehensive understanding of seismicity, bridging the gap between theory and practical application.

The workshop on the seismic response analysis of dam-numerical analysis in dam engineering proved to be a significant event for professionals in the field. It enhanced participants' understanding of the role and benefits of analysis of seismicity and its numerical modelling, exposed them to best practices and case studies, and facilitated networking and collaboration. The workshop contributed to promoting the effective and sustainable use of seismic response analysis of dam and numerical modelling in dam projects, ultimately leading to improved construction practices and increased dam safety.

Prof. M.L. Sharma, IIT Roorkee

Shri Vishan Dutt, GM, CBIP, proposing vote of thanks

INCOLD would like to express the gratitude to Chief Guest, Guests of Honours, Department of Earthquake Engineering, IIT Roorkee for providing venue and other organizational support for the workshop.

Group Photograph

Workshop on
Tailings Dam Safety

12-13 October 2023, New Delhi

View of the dais during inaugural session (L-R) Mr. A.K. Mishra, Former MD, MHPA; Mr. A.K. Dinkar, Secretary, CBIP and Mr. K.K. Singh, Director-WR, CBIP

BRIEF REPORT

The Tailings Dam Safety Workshop, held on 12-13 Oct 2023 at CBIP Conference Hall, New Delhi was a gathering of experts and stakeholders in the mining industry to discuss and address the pressing issues related to the safety and management of tailings dams. This report provides an overview of the workshop's objectives, participants, key discussions, and recommendations.

The main objectives of the Tailings Dam Safety Workshop is to act as a curtain raiser for ICOLD 2024 event which is going to be held next year in Oct 2024, New Delhi. To facilitate the sharing of knowledge and best practices in tailings dam safety, to provide insights into the regulatory framework, compliance requirements, to Explore and showcase emerging technologies and innovations to enhance the safety and monitoring to Highlight the environmental and social considerations associated with tailings dam management in the mining sector, ash disposal in thermal power generation and to develop a set of actionable recommendations to improve the safety and sustainability of tailings dams.

Guest on Dias was Shri A.K. Dinkar, Secretary, Central Board of Irrigation and Power, Shri A.K. Mishra, Former MD, Mangdechhu Hydroelectric Project Authority and Shri K.K. Singh, Director Central Board of Irrigation and Power.

Mr. A.K. Dinkar, Secretary, CBIP, delivering the welcome Address

The workshop was attended by approximately 50 participants engaged in different disciplines, including mining engineers, geotechnical engineers, civil engineers, researchers, academicians, and industry experts. The participants represented a wide range of organizations, including engineering firms, government agencies, academic institutions, and consulting companies.

The workshop was a two days event with a structured agenda. Participants represented a diverse cross-section of the industry, including mining professionals, geotechnical engineers, environmental experts, regulators, and mining industry representatives. The event commenced with keynote addresses by experts in the field, setting the stage for the day's discussions.

The following presentations were delivered during the workshop by the experts:

Presentation - Application of Geophysical Methods in a Tailing Dam Project - *Dr. Sanjay Rana, Managing Director- PARSAN Overseas Pvt. Limited.*

Presentation – Enhancing Safety and Reliability in Tailing Dam : Observation based Risk Mitigation Strategies - *Mr. Subrata Das, Consultant- Project Management & Design Consultancy Service*

Presentation -Physics-based seismic vulnerability assessment of tailing dams using smooth particle hydrodynamics - *Shri Ritesh Kumar, Assistant Professor- IIT Roorkee.*

Presentation - Considerations for Effective Tailings Dam Breach Analysis Study for Risk Assessment - *Shri. Ram Manohar Bishwal, Assistant Professor (Mining) - NIT Rourkela.*

Presentation – Rehabilitation Measures With Several Construction Methods at Tailing Dams - *Michael Baltruschat-Bauer Engineering India Pvt Ltd*

Mr. A.K. Mishra, Former MD, Mangdechhu Hydroelectric Project Authority

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

Technical Discussion and Tailings Activities in ICOLD 2024- *Mr. Ram Manohar Bishwal, Assistant Professor (Mining) - NIT Rourkela).*

Presentation – Geotechnical Considerations for the Design of Filtered Tailings Facilities - *Mr. Bryan Murich- Bryan Ulrich LLC- Tailings Solutions Denver, Colorado, USA*

Presentation –The Use of Geosynthetic Products in Tailing Dams- *Shabana Khan, AVP – Technical - M/s Strata Geosystem Pvt. Ltd.*

Presentation – *Ms. Dola Roy Chowdhury- Geosynthetic Industry Professional, Principal Consultant & Founder Director at GCUBE Consulting Engineers llp*

Presentation - An overview of Tailing Ponds and It's Management Practices at OMQ division- *Saroj Kumar Banerjee, Chief, Safety RM & Mr. Santosh Kumar Singh, Head of Civil Projects, Raw material Division -Tata Steel*

Presentation – Maccaferri Introduction & Solutions for Tailing Deposits in Mines- *Manthan Chauhan - Assistant General Manager (AGM)-Maccaferri Environmental Solutions Pvt. Ltd.*

Presentation - Dynasoure Concrete – *Rohit Shinge, Assistant Manager,* Dynasoure Concrete

Presentation - Sustainable systems of Coal-ash Disposal in Ash Pond, Ash Mound, & Abandoned Mine Voids Case Studies- *Vinod Kumar Mauriya, Dy. General Manager (PE-Civil)- NTPC-CC EOC, Hyderabad.*

Dr. Sanjay Rana, Managing Director-PARSAN Overseas Pvt. Limited

Shri Subrata Das, Consultant, Project Management & Design Construction Services Land & Building

Shri Ritesh Kumar, Assistant Professor- IIT Roorkee

Shri Ram Manohar Bishwal, Assistant Professor (Mining) - NIT Rourkela

Ms. Shabana Khan, AVP-Technical - Strata Geosystem Pvt. Ltd.

Ms. Dola Roy Chowdhury- Principal Consultant & Founder Director at GCUBE Consulting Engineers llp

Mr. Saroj Kumar Banerjee, Chief-Safety RM, Tata Steel

Mr. Santosh Kumar Singh, Head of Civil Projects, Raw material Division -Tata Steel

Mr. Manthan Chauhan - Assistant General Manager (AGM)- Maccaferri Environmental Solutions Pvt. Ltd

Mr. Vinod Kumar Mauriya, Dy. General Manager (PE-Civil)- NTPC-CC EOC, Hyderabad

Mr. Rohit Shinge, Assistant Manager, Dynasoure Concrete

Mr. Bryan Murich- Bryan Ulrich LLC- Tailings Solutions Denver, Colorado, USA - virtual presentation

Main highlights were:

1. Understanding Tailings Dams:
   - An in-depth look at the nature of tailings dams, including different types, challenges, and inherent risks.
2. Regulatory Framework and Compliance:
   - Exploration of international and national regulations governing tailings dams.
   - Case studies illustrating compliance and non-compliance scenarios.
3. Best Practices in Design and Construction:
   - Presentation of design principles and construction techniques for safe tailings dams.
   - Geotechnical considerations for long-term stability.
4. Operation and Maintenance:
   - Safety protocols for operational tailings dams.
   - Inspection and monitoring procedures.
   - Emergency response planning.
5. Emerging Technologies and Innovations:
   - Showcasing advanced technologies, including remote sensing and monitoring, innovative materials, and predictive modelling for early warning systems.
6. Environmental and Social Considerations:
   - Discussion on the environmental impacts of tailings dams on ecosystems.
   - Strategies for responsible mining and community engagement.

The workshop resulted in several key takeaways, including:

- Acknowledgment of the complex challenges and potential risks associated with tailings dams.
- Emphasis on the importance of robust regulatory oversight and compliance.
- The significance of a holistic approach to tailings dam safety, covering design, construction, operation, and monitoring.
- Recognition of the role of emerging technologies in preventive maintenance and monitoring.
- Stress on the need for environmental and social responsibility in the mining industry.

The Tailings Dam Safety Workshop was a resounding success, fostering collaboration and knowledge sharing among stakeholders in the mining and environmental sectors. The recommendations and action plans developed during the breakout sessions will serve as valuable guides for enhancing tailings dam safety in the future.

Group Photograph

National Workshop on
Risk-Informed Dam Safety

21 - 22 December 2023, THDC Takshshila, Rishikesh

View of the dais during inaugural session (L-R) Shri Bhupendra Gupta, Director (Tech.), THDC Shri J. Behra, Director (Finance) THDC, Shri A.K. Dinkar, Secretary CBIP and Shri Veer Singh, CGM (HR)

REPORT

The National Workshop on "Risk-Informed Dam Safety" was organized from 21st 22nd Dec 2023 at THDC Takshshila Rishikesh, which was a curtain raiser to the upcoming international event i.e. ICOLD 2024. The purpose of workshop was to enhance understanding and implementation of risk-informed approaches in the management of dam safety. Moreover, the workshop aimed to bring together dam safety professionals, engineers, regulators, and stakeholders to share knowledge, experiences, and best practices.

The guest on Dias was, Sh. J. Behra, Director (Finance) THDC, Sh. Bhupendra Gupta, Director (Tech.), Sh. Veer Singh, CGM (HR) and Sh. A.K. Dinkar, Secretary CBIP

Several presentation were delivered in Technical Sessions:

TECHNICAL SESSION - I

- Presentation - Dam Health Monitoring, Data Acquisition and Processing with case studies - Paper-Beyond Visual Inspections: Employing Geophysical Methods in Dam Health Monitoring - *Dr. Sanjay Rana, Managing Director-PARSAN Overseas Pvt. Ltd.*
- Presentation -Under the Theme - Dam Health Monitoring Dam Health Monitoring by Analysis & Interpretation of Dam Instrumentation Data - *Shri M.S. Hanumanthappa, Scientist D, CWPRS.*
- Presentation -Under the Theme Major Rehabilitations Cementitious grouting of Masonry dams- CWPRS Experiences - *Shri S.J. Pillai, Scientist C, CWPRS.*

Mr. A.K. Dinkar, Secretary, CBIP, delivering the welcome Address

- Presentation -'Dam Safety and Protocol for Enhancing Climate Resilience of Existing and New Dams – *Shri S.C. Mittal, DMR Engineering.*

TECHNICAL SESSION - II

- Presentation -'Overview of Latest Advancements in Dam Health Monitoring' – *Shri P.C. Sharma & Ms. Subhra Shah, NHPC Ltd.*
- Presentation -Structural Health Monitoring Dams & Water Retaining Bodies under DRIP Project - *Ramji Singh, Member, Dam Safety Review Panel (DSRP) & National Level Expert & Technical Advisor, NWRWS&K Dept. Govt. Gujarat..*

TECHNICAL SESSION - III

- Presentation -Reservoir Management Strategies for Optimal Power Generation during Monsoon Season – *Sh. Sandeep Batra,Group General Manager, NHPC.*

Technical Session - III

- Presentation- Emerging Challenges and Best Practices in Dam Safety Management at Tehri Dam - *Sh. A. K. Singh, Additional General Manager, THDC.*
- Presentation -Seismic Hazard Assessment of VPHEP, Pipalkoti in Chamoli district of Uttarakhand (India) - *Shri Subhash Patel, Deputy Manager, THDC*

  Presentation - Integrated Flood Management System for Tehri Dam and Its Downstream Area- *Bhanu Sharma, Hydrologist, THDC*

TECHNICAL SESSION - IV

- Presentation - Snow/glacier change and impact on runoff in Himalayan basin - *Shri Sanjay Kumar Jain.*
- Presentation - Dam failure mechanism and associated uncertainties - *Dipankar Chaudhuri, DVC*
- Presentation - Development of Emergency Action Plan (EAP) for Tilaiya Dam - A Case Study - *Aloke Banerjee, Deputy Manager (Civil), DVC.*

TECHNICAL SESSION - V

- Presentation - Integrating technology in /dam Emergency Management - *Shri Subrata Das.*
- Presentation - An Overview on the fragility analysis of Concrete Gravity Dams - *Dr. Arnab Banerjee, Dept. Civil Engineering, IIT Delhi*
- Presentation - Best Practices Of Dam Safety Management In BBMB - *Shri C.P. Singh, Chief Engineer, Bhakra Beas Management Board (BBMB), Chandigarh (India)*

Shri J. Behra, Director (Finance) THDC, addressing the participants during inaugural session

Shri Bhupendra Gupta, Director (Tech.), THDC, addressing the participants during inaugural session

Shri Veer Singh, CGM (HR), THDC, addressing the participants during inaugural session

- Prsentation- Trend Analysis In Return Period of Rainfall Values Over Shani Devgaon High Level Barrage at Upper Godavari River Catchment- *Sh S. K. Manik, Scientist D , Indian Metrological Department.*
- Presentation - An Innovative Waterproofing Solution for all types of Ageing Dams to Enhance the Service Life.- *Sumit Singh, CARPI*

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

The workshop was attended by approx. 90 participants from different engineering organisations, the workshop commenced with an overview of the importance of risk-informed dam safety practices. Emphasis was placed on the evolving nature of dam safety management, necessitating a shift from traditional deterministic methods to risk-informed approaches for effective decision-making.

A series of presentations were delivered by industry experts, covering various aspects of risk-informed dam safety. In addition to this, participants shared case studies from different regions, illustrating the successful implementation of risk-informed dam safety practices. These case studies highlighted challenges faced, lessons learned, and the positive impact on overall dam safety.

Workshop participants engaged in interactive sessions, including group discussions and hands-on exercises. These sessions facilitated knowledge exchange, networking, and the development of practical skills in risk-informed decision-making.

The workshop successfully promoted a deeper understanding of risk-informed dam safety practices. Participants left with valuable insights, new connections, and a shared commitment to advancing the field. Continued efforts in implementing risk-informed approaches will contribute to the resilience and safety of dam infrastructure worldwide.

Group Photograph

INCOLD News

DELHI WATER CRISIS: A DAM TO QUENCH DELHI'S THIRST, BUT LIKELY TO BE READY ONLY BY 2030

Delhi has been battling with Haryana and Himachal Pradesh for water in the Supreme Court. The arguments from both the parties mentioned numbers like 137 cusecs, 150 cusecs. A cusec is 28.3 litres of water per second. A simple math would suggest that the national capital requires around 33.5 crore to 36.7 crore litres a day.

It's a lot of water, but not as much as what Delhi could have got every summer without having to fight and plead in the Supreme Court, if a long-promised dam was built on a small river 250 km away.

A river called Giri

Giri is a small, perennial river that originates from the springs of Kharapathar in Shimla district's apple belt. In its 150 km course, the river gathers volume, skirts the famous Renuka Lake in Sirmaur, and joins the Yamuna.

A look at it in summer or winter would not give an idea that the river could quench Delhi's thirst. But it swells up in the monsoon, and during last year's flood it was pushing 32 lakh litres of water every secon, not even close to its record. In September 1978, it went on the rampage with a discharge of 85 lakh litres per second.

Source : ET Online, Jun 17, 2024

WATER LEVELS DANGEROUSLY LOW IN MAJOR DAMS IN SOUTH INDIA: DATA

With most major dams in the State filled to close to 50% of their capacity, Kerala is the only exception.

Most of the major reservoirs in the southern States of Karnataka, Tamil Nadu, Andhra Pradesh, and Telangana are filled to only 25% of their capacity or less. This is worrying as peak summer is round the corner. Some large dams such as the Tungabhadra in Karnataka and the Nagarjuna Sagar on the Andhra Pradesh-Telangana border are filled to 5% or less of their full capacity. Other large dams such as Mettur in Tamil Nadu and Srisailam on the Andhra Pradesh-Telangana border are also filled to less than 30% of their capacity. The water crisis in Bengaluru may soon hit other urban centres and rural areas if this situation continues in the following days.

Across India, the current water level in 150 primary reservoirs put together as a share of their total capacity stood at 38%, according to the latest weekly bulletin by the Central Water Commission.

All the reservoirs put together are filled to only 23% of their capacity in this region, which is about 17% points lower than the levels recorded last year and 9 points lower than the 10-year average. No other region — central, west, east, or north — shows such a drastic difference in levels compared to last year as well as the 10-year average. For instance, in the northern and central regions, the reservoirs are filled to 33% and 46% of their capacities, respectively, similar to the 10-year average levels recorded in those regions. In the western region, the reservoirs are filled to 45% of their capacity, slightly higher than their 10-year average, while the 49% recorded in the eastern region was only marginally lower than the 10-year average.

Among the southern States, a comparison of the capacities of individual reservoirs with their current storage shows that water levels in many are dangerously low. Andhra Pradesh-Telangana, Karnataka and Tamil Nadu.

The Linganamakki reservoir in Karnataka's Shivamogga district, with a total capacity of 4.3 lakh crore litres of water, is currently filled to just 22%. The Supa reservoir in Karnataka's Uttara Kannada district, with a total capacity of 4.1 lakh crore litres, is filled to only 36%. The Tungabhadra dam in Vijayanagara district of Karnataka, with a total capacity of 3.2 lakh crore litres, is filled to only 5%.

The Srisailam reservoir on the Andhra Pradesh-Telangana border, with a capacity of 6 lakh crore litres, is filled to only 15%, whereas the Nagarjuna Sagar dam on the same border, with a capacity of 5.1 lakh crore litres, is filled to a mere 4%.

The Mettur dam in Salem district of Tamil Nadu, with a full capacity of 2.65 lakh crore litres, is filled to 28%.

Kerala is the only exception among the southern States, with most of its major dams filled to at least 50% of their capacities. The Idukki reservoir is filled to 47%, the Idamalayar dam to 48%, and the Kallada and Kakki reservoirs to 50%.

Source : Central Water Commission

Aims & Scope

INCOLD Journal is a half yearly journal of Indian Committee on Large Dams (INCOLD) which is involved in dissemination of the latest technological development taking place in the field of dam engineering and its related activities all over the world to the Indian dam/hydropower professionals.

The aim of the journal is to encourage exchange of ideas and latest technological developments in the field among the dam engineering Professionals. The journal is for fully-reviewed qualitative articles on planning, design, construction and maintenance of reservoirs, dams and barrages and their foundations. The articles cover scientific aspects of the design, analysis and modelling of dams and associated structures including foundations and also provides information relating to latest know how in the field of construction technology for the related works. In addition to the information on the research work on the relevant subjects, the journal provides information on the related technical events in India and abroad such as conferences/ training programmes/ exhibitions etc. Information related to ICOLD (International Commission on Large Dams) activities such as ICOLD Congresses, its technical symposia, workshops, technical lectures, technical bulletins are also highlighted for the benefit of INCOLD members.

The original unpublished manuscripts that enhance the level of expertise and research in the various disciplines covered in the Journal are encouraged. The articles/technical papers are peer reviewed by editorial Board consisting of renowned experts before publication. The Journal has both print and online versions. There are no publication charges on the author.

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

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Bulletin 151 - Tropical residual soils as dam foundation and fill material
Bulletin 152 - Cost savings in specific dams
Bulletin 153 - Sustainable design and post-closure performance of tailings dams
Bulletin 154 - Dam safety management: Operational phase of the dam life cycle
Bulletin 155 - Guidelines for use of numerical models in dam engineering
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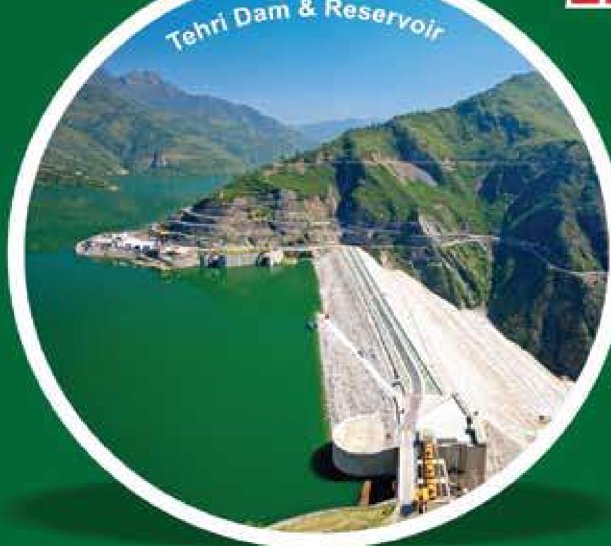

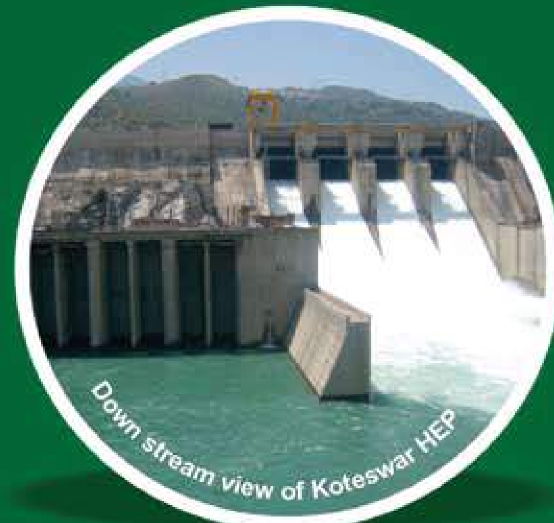

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