ADDRESSING SEDIMENT-INDUCED PROBLEMS UNDER THE DAM REHABILITATION AND IMPROVEMENT PROJECT IN INDIA

S. GIRI
Deltares, Delft, The Netherlands

D. C. FROEHLICH
Individual Specialist, North Carolina, USA

P. NARAYAN AND B. PATRA
Central Water Commission, New Delhi, India

ABSTRACT

The water stress situation in several states of India can be attributed to improper management of available water resources, a large part of which is associated with suboptimal operation and poor management of infrastructures like dams and canals. Construction of new dams in India has become more difficult due to increasing social, environmental, resettlement and rehabilitation constraints and compliances. Consequently, dam rehabilitation and improvement efforts have become indispensable in the country. This paper sheds some light on existing sediment-induced problems in some dams and reservoirs in India including some first efforts that have been undertaken within a scope of the ongoing Dam Improvement and Rehabilitation Project (DRIP). The activities include detection, quantification, rapid assessment and possible measures for sediment-induced problems in some selected pilot reservoirs, namely in Uttarakhand and Tamil Nadu. The study shows how distinctive and com-plex the sediment induced problems are in various regions of India in terms of magnitude, type as well as source of the problems. The sediment-induced problems are associated with storage loss on the one hand, while abrasion, clogging and malfunctioning of civil structures on the other. Additionally, a comprehensive handbook on assessing and managing sediment-induced problems has been prepared within the scope of DRIP. The handbook can subsequently be used for preparation of the tailor-made guideline for each dam and reservoir.

1. BACKGROUND

Dams and reservoirs are important asset, particularly for countries such as India with strong seasonal variations in flow pattern as well as ever-growing water and energy demand due to rapid growth of economy and population. It is obvious that any intervention in a natural system induces adverse im-pacts as well. Nevertheless, the negative impacts of dams and reservoirs can also be attributed to poor planning, mismanagement, inefficient operation and improper consideration (or negligence) of impact mitigation options and conditions. The importance of dams and reservoirs, their positive and negative impacts shall objectively be weighed vis-a-vis multi-sectorial benefits and any nation's specific priorities and demands.

India has 5262 completed large dams, among which 2329 commissioned before 1980, and 437 dams under construction. Consequently, loss of storage capacity in these reservoirs has become one of the major concerns for water security and structural safety. For the sake of comparison, it is to be noted that the reservoir sedimentation studies of only 243 dams in India1 have revealed that about 26 billion m^3 of gross storage volume has already been lost, which is more than the total storage capacity (about 23 billion m^3) of all (2730) large dams in Japan. The aging of the existing dams (most of the structures are over 30 years old and an important percentage of them have been operated for more than 50 years) and deteriorating exponentially due to lack of proper operation and maintenance. How-ever, reservoir sedimentation depends upon several factors like its geographic location, pattern of sedimentation management etc. and not directly linked to the age of the dam. This means more the age of the dam doesn't necessarily means more storage loss, contrary it's the location of the dam, type and amount of sediment carried by the river, sediment management practices etc. Figure 1 shows the gross storage losses state-wise in India. To review the actual sedimentation in some important reservoirs of India, a plan scheme has been initiated by ministry of water resources, river development and Ganga rejuvenation to conduct the hydrographic surveys on a regular basis.

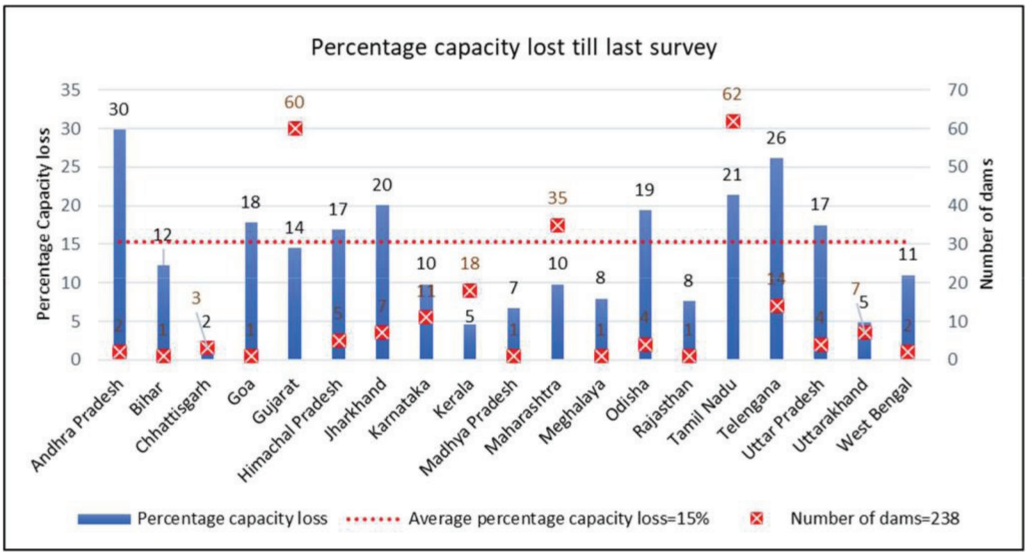

Figure 1 : Observed capacity loss in some selected reservoirs, grouped state-wise, based on data by CWC (2015)

2. SEDIMENTATION STUDIES UNDER DRIP

2.1 Problem identification

Based on requests from the state dam authorities, five reservoirs were have been selected for rapid assessment of sediment-induced problems at the first phase, namely Kundah Palam, Pillur and Papanasam reservoirs in Tamil Nadu State (in sedimentation zone of south part of India, characterized by Deccan Plateau1), ManeriBhali Stage I and Dakpathar barrage in Uttarakhand State (in sedimentation zone of north part of India, characterized by Himalayan Region and Indo Gangetic Plains1). It is to mention that silting of these Southern reservoirs are not due to high silt erosion in upper catch-ments but are due to non-professional operation of these dams even spite of having full provision of addressing these problems due to being power generating entities as well as located in water scarce areas, hence a balance trade-off is essential to address the issue holistically.

Variability in type, magnitude and source of the sediment-induced problems reveals their complex-ity and distinctiveness, indicating the need for a tailor-made approach to each individual dam to ad-dress the problems of each individual reservoir. Another important aspect to mention is that almost no recent data and information are available for most of these reservoirs. Therefore, rapid assessment and analyses were made based on field reconnaissance, some old data and information that were readily available and some measurements, such as for a pilot study of Dakpathar barrage, for which sediment and bathymetry measurements have been carried out within the scope of Dutch Partners for Water program (Giri et al., 2019a). The concerns are obvious in most cases. Table 1 provides an impression about distinctiveness of the problems in some of these reservoirs. Figure 2-3 provide pictorial impression about the problems in said dams and reservoirs.

Table 1 : Problem identification in selected DRIP dams/reservoirs.

Dam	Type (gross storage)	Sedimentation Zone	Purpose	Problems
Kundah Palam	Forebay (1.76 million m^3)	Deccan Plateau	Hydro-power	• Storage loss (≈60%) • Partially clogged scour vent andtrash rack at tunnel intake leading to risk of failures and disruption in power generation
Pillur	Storage (34.97 million m^3)	Deccan Plateau	Hydro-power Water supply	• Storage loss (≈42%; about 20 million m^3 deposited materials) • Increasing sedimentation near water supply intake • Clogged under sluices • Large deposition layer and consolidation (apparently up to about 40 m thick deposited layer)

Manei Bhali Stage I	ROR (0.6 million m^3)	Himalayan Region	Hydro-power	• Abrasion and damages of spillway, gates, stilling basin, guide banks/walls • Large deposition (up to spillway crest) • Migrating sediment delta
Dakpathar	Barrage Forebay (0.71 million m^3)	Indo Gangetic Plain	Hydro-power Irrigation Recreation	• Storage loss • Unfavorable sediment concentrations in power intake area, erosion and sedimentation

Figure 2 : Deposition in the Kunda Palam (left) and Pillur (right) reservoirs during depletion in 2015 and 1992 respectively

Figure 3 : Abrasion of spillway due to sediment in Maneri Bhali-I (left) and side slopes at the landslide areas near the reservoir, showing the outcrop of alluvial deposits

2.2 Rapid assessment and management

For rapid assessment of impacts associated with sediment management options and alternatives within a scope of the DRIP (and also in cooperation with the PfW program), several methods, meas-urement and tools have been used, such as (i) professional knowledge and local experience, (ii) hy-draulic and morphological modelling with Delft3D, (iii) sediment and bathymetry measurement (for Dakpathar pilot case), (iv) smart dredging plan to be executed using environmental friendly equipment, (v) application of novel techniques for dewatering, treatment and reuse of dredged mate-rials among others.

Following studies have been carried out: (i) division of reservoir reach based on analysis of mor-phological features and quantification of dry areas for different reservoir level for phase-wise sedi-ment removal planning in Kundah Palam and Papanasam, (ii) impact of sediment release from Kunda Palam, (iii) social and environmental impacts of transport of dredged materials, (iv) safety of transport and dumping area, (v) dewatering of dumping area, (vi) feasibility and safety of slurry transport, (vii) impact of sediment replenishment at Pillur reservoir on downstream river and barrage (Bhavani), (viii) effect of dredging on flow-field and sediment transport, not only to gain the storage but also to minimize spillway damages in Maneri Bhali, (viii) effect of sediment trap in Maneri Bhali, (ix) effect of gate operations in Maneri Bhali and Dakpathar, (x) effect of dredging and reservoir improvement (using geotubes) in Dakpathar, (xi) concept and options of sediment reuse for Dakpathar pilot case.

2.2.1 *Sediment management plan for Kundah Palam*

Based on quick assessment of technical, economic and environmental feasibility and impacts, approaches for sediment handling has been selected for further consideration. One of the examples is the sediment management plan in Kundah Palam reservoir. Some key points can be outlines as fol-lows:

- The three-phase sediment removal plan has been envisaged over three (3) working seasons covering three characteristic reaches of the reservoir. However, the proposed approach herein shall not be considered as a firm rule in terms of area and period, since desilting operation could be carried out concurrently in shallow and deeper parts of all the reaches depending upon the situa-tion at the site and technological possibilities.
- Based on dry and wet areas while maintaining a minimum reservoir level so as not to interrupt the power generation as well as weather condition at the site, the sediment removal operation can be carried out throughout the year except for the monsoon period with high floods, when it is not safe to carry out the work.
- In case of acquiring more precise data, measurement and analysis of the reservoir bathymetry, providing more precise representation of the deposition pattern in the reservoir, it shall be analysed rigorously, and thereby an improved sediment removal plan can be proposed, which shall improve the efficiency of the work to be carried out. This shall be included in the technical proposal. Although it is expected that the basic approach would remain the same.
- Similarly, it would be possible to improve the sediment removal plan after bathymetry survey, which is supposed to be carried out after the award of the contract given that it will provide more precise representation of the deposition pattern in the reservoir.
- The reservoir area near the dam (i.e. Reach III as described in next section and shown in Figure 3) is the most important area, where desiltation operation shall be carried out with special care and attention.
- There is flexibility to define the reservoir reaches for different phases based on the actual situation. For example, during the first phase, desilting operation can be carried out not only within the Reach I and Reach II, but also in the dry areas with deposits in Reach III. Similarly, the desilting operation can be carried out concurrently in all three phases during most of the period and reaches in any combination thereon.
- Since the reservoir bed level varies in these three reaches (e.g. deeper near the dam in Reach III and shallower along the upstream tributaries in Reaches I and II), the silt layer to be removed shall be varying within the reservoir. Consequently, the desilting operation shall be planned in such a way that the abrupt changes in the slope of the reservoir bed can be avoided.
- The total volume of the material to be removed has been determined to be equal to 750000 m^3 based on the measurement of 2009. Out of this volume, the 50 000 m3 shall be allowed to be discharged downstream of the river. This volume of downstream discharge can be increased only if it is allowed by the Employer after the first experience and assessment of the down-stream effects.
- Sediment reuse options: (i) Land improvement by filing a valley-like area, owned by dam authority, and develop it as a playground or recreational park, (ii) top soil enhancement for agricultural land, (iii) sediment trap upstream (by simply keeping intact a part of consolidated deposition in form of a spur)
- Downstream morphological and ecological enhancement by controlled release of deposited material

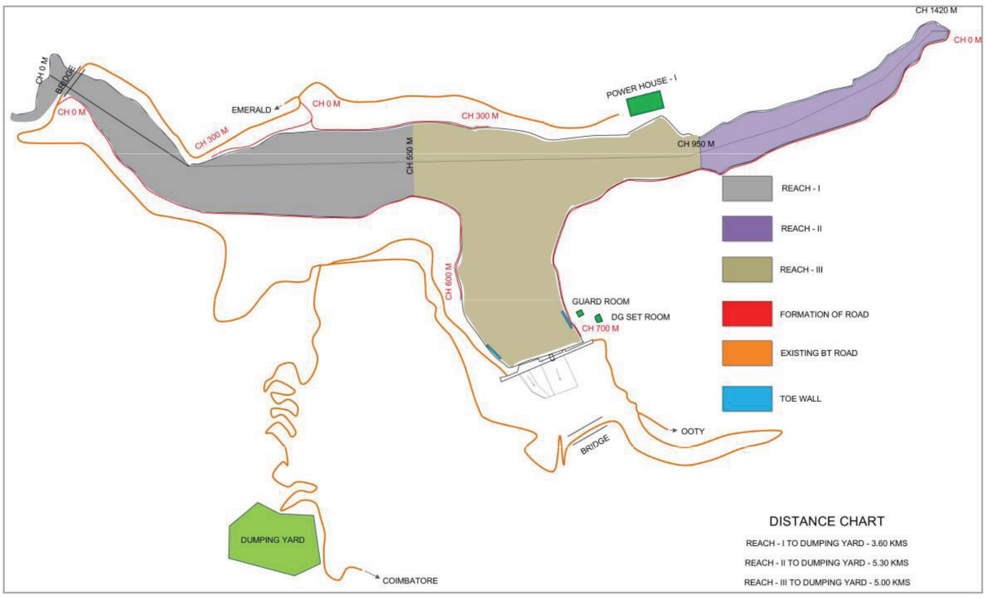

Figure 3 : Sediment management plan for the Kundah reservoir including transportation route to the dumping yard and location of protection wall (sketch courtesy: DRIP)

2.2.2 *Sediment management plan for Pillur*

Sedimentation problem in Pillur reservoir is rather large comparing to Kundah Palam, and dredging is not feasible technically as well as economically. Besides, a sediment disaster occurred during flush-ing in 1991. An attempt was made to flush the reservoir by depleting it (drawdown flushing). Apparently, the flushing operation was carried out first time after commissioning in 1967. The deposited amount of sediment was huge for uncontrolled flushing through the scour vent. The slurry during flushing appeared to be hyper-concentrated fluidized sediment mass that did not seem to behave like normal sediment-water mixture, bursting towards the powerhouse (located downstream at the left side of the dam body), resulted in a severe sediment disaster. The powerhouse was covered with large amount of sediments, and thus the generation had to be stopped for few months before all the sedi-ments were removed. Since then the under-sluices have never been used for sluicing or flushing, and apparently, they have been clogged again. Following sediment management option has been pro-posed:

- Regular maintenance using hydraulic dredging (syphoning or pumping)
- Downstream release and replenishment
- Regular sediment removal (recurrent measure) from key locations such as near water supply in-take, hydropower intake, under-sluices
- Proper study and measurement to avoid downstream impacts
- Investigate the options for sediment bypass system
- Sediment measurement and monitoring (Reservoir Morphology Information System)
- Regular sluicing/venting during monsoon
- Sediment reuse options: (i) Land improvement and agricultural enhancement, (ii) construction material, (iii) enhancement of downstream river environment

2.2.3 *Sediment management plan for Maneri-Bhali*

Following is an outline of sediment handling proposal for Maneri Bhali-I:

- Sediment removal by dry dredging and trucking (removing sediment in front of the spillway provides favorable condition to minimize damages of spillway and gates due to the trapping of gravels and boulders4)
- Regular maintenance using hydraulic dredging (pumping or syphoning)
- Soft and temporary sediment trap upstream of the reservoir (also to assess the transport)
- Improved gate operation during high flows and sluicing4
- Monitoring and forecasting systems
- Sediment reuse options: (i) Construction materials for river and other infrastructure, (ii) soft structural and recurrent measures (geotubes, gabions) to trap sediment

2.2.4 *Sediment management plan for Dakpathar*

There is already an ongoing sediment management pilot study with the sediment reuse. More details about this can be found in our other publications (Giri et al., 2019a, Omer et al., 2020)

- Intelligent dredging (pumping) and dumping within reservoir considering morphological features, location of power channel intake and gates
- Regular maintenance using hydraulic dredging (pumping or syphoning)
- Regular and intelligent sluicing
- Improved gate operation
- Monitoring and forecasting systems
- Sediment reuse options
  - o Filling geotubes to be used as baffle and traps for improving morphological condition in the reservoir
  - o Construction materials for using within and outside the reservoir, for example protection along the erodible bank using geotubes (Fig. 4)
  - o Improving environmental conditions for migrating birds and habitats

There are several publications and reports, made under the DRIP, which provide more detailed information about afore-mentioned sedimentation studies (Giri & Narayan, 2018; Giri et al., 2017; Giri et al., 2016a, Giri et al., 2016b).

Figure 4 : Bank protection using geotubes downstream of Dakpatthar barrage: an example of reuse of dredged sediment from the reservoir (Omer et al., 2020)

2.3 Handbook on assessment and management of sediment-induced problems

Within the scope of DRIP project, a handbook has been prepared synthesizing past and on-going experiences, technologies, researches, case studies and practices related to a broad spectrum of sedi-ment-induced problems in reservoirs and their handling. The handbook also guides through relevant processes on how to assess and manage sediment-induced problems in dams and reservoirs. Figure 5 provides an impression about the content of the handbook (Giri et al., 2019b).

2.4 Constraint and challenges

Complexities and constraints, associated with reservoir sediment management in India, are related not only to techno-economic feasibility, but also to social, environmental and legal aspects depending on the region and the States. Major constraints are social and environmental impacts of sediment removal, transport and disposal options, presence of preserved areas and sanctuaries in the vicinity of reservoirs, consolidation and contamination of the deposited materials due to lack of regular sediment management practices and also due to the impact of uncontrolled industrial effluents. There are several legal and institutional constraints such as ambiguous regulations for sediment removal and disposal from reservoirs, inefficient rules and decision-making processes for operation of hydropower and multipurpose reservoirs as well as disputes on operation and management of reservoirs that are located across the inter-state transboundary rivers.

Regarding the activities within the scope of DRIP, also lack of relevant data and information (hy-drological, hydraulic, sediment characteristics, bathymetric) has made it more difficult to undertake sediment management endeavours within a limited period of the project. As the project is under im-plementation, the feasibility report for desilting of reservoirs need to be discussed with all stakehold-ers along with publication of EMPs in advance with prior consultations with all statutory bodies. As some of these reservoirs are located in reserved forest areas which are governed by different rules and regulations, and ultimately such activities lead to unwarranted long delays which impact adversely on over all implementation of such projects. For such reservoirs located within the forest areas, new set of rules and guidelines need to be activated to have a balance between overall interest of societal needs as well as environment and forests.

3. CONCLUDING REMARK

Keeping in view ever-growing demand for water resources in India, it is utmost essential to restore the lost capacity of reservoirs due to siltation given large number of issues in construction of new dams. Monitoring programs and measurements are integral part of the water and sediment assessment and management in reservoirs. A few innovative methods, technologies and equipment are available globally. Besides, there is rapid growth in available knowledge and tools on post-processing and analyses of real-time measurement and monitoring data, remote sensing techniques and freely avail-able satellite data and images. The major challenge is a proper processing, application, analyses and interpretation of these data and information, which requires human resources with sound technical background on the issues and relevant disciplines.

Another important aspect for sustainable management is that the sediment management activities shall be taken as a resource availability, not as a waste. Some of the state dam authorities within DRIP are already looking for taking up sediment management activities as a regular endeavour with the use of state-of-the-art technologies and good practices available globally. The guidelines and procedures are being framed under the ongoing DRIP to assist the various dam owners to address this challenge systematically and holistically.

4. REFERENCES

Central Water Commissions 2015. Compendium on Silting of Reservoirs in India. Watershed & Reservoir Sed-imentation Directorate. Central Water Commission

Giri, S., Narayan, P., Kumar, M. & Sharan, S. 2019b. Handbook for Assessing and Managing Reservoir Sedi-mentation. Doc. No. CDSO_GUD_DS_04_v1.0. Prepared for Central Water Commissions.

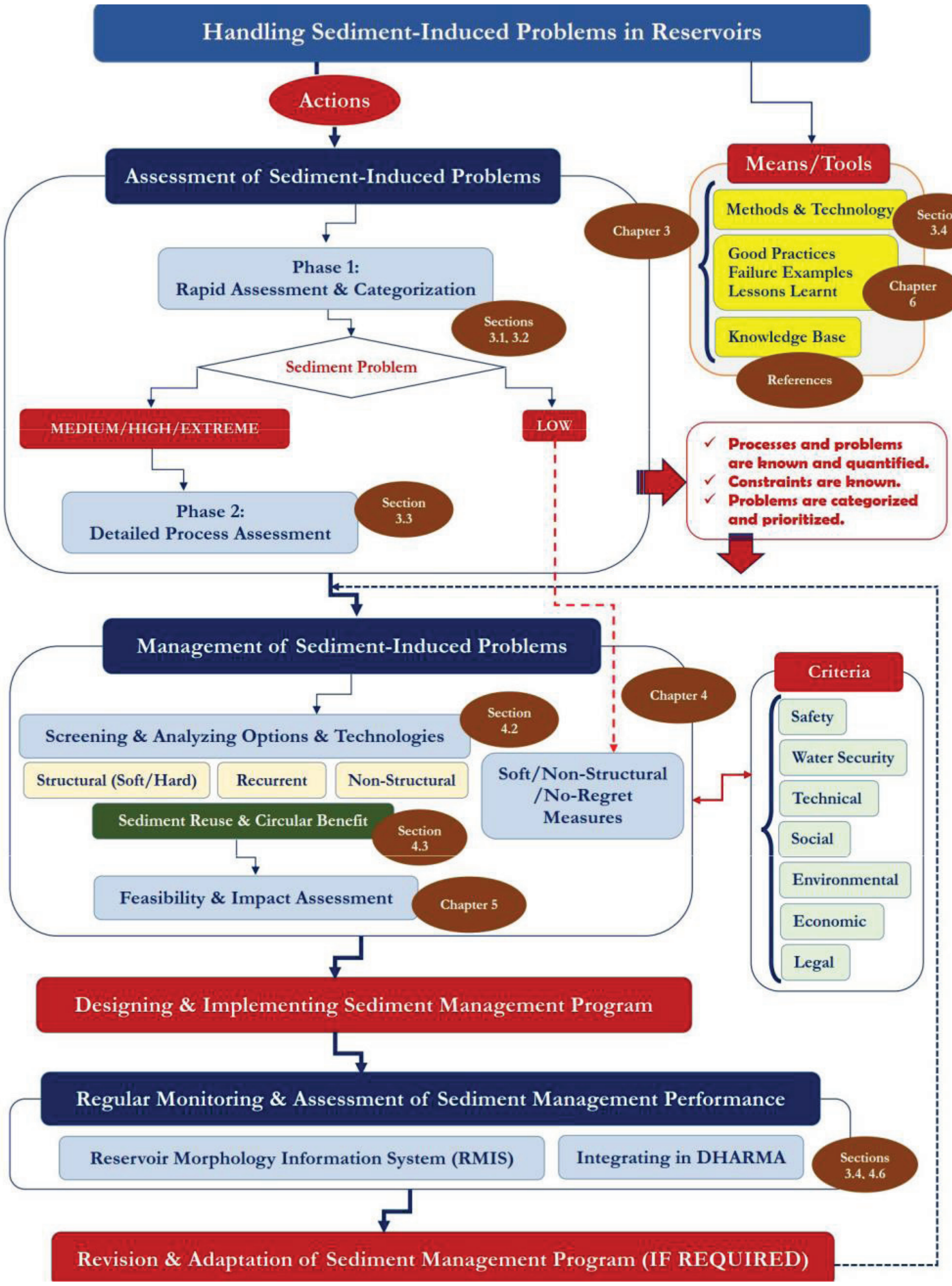

Figure 5 : Content of the handbook prepared under the DRIP on assessment and management of sediment-in-duced problems in dams and reservoirs.

Giri, S. & Narayan, P. 2018. On Sediment-Induced Problems under the Dam Rehabilitation and Improvement Project in India. Hydrolink, IAHR publication, Issue 3: 83-86.

Giri, S., Omer, A.& Dahal, S. 2019a. Sediment Removal and Beneficial Use (Part-2): Morphological Modelling of Dakpathar Barrage. International Dam Safety Conference 2019, India.

Giri, S., Nabi, M., Cleyet-Merle, P., & Pillai, B.R.K. 2017. Reservoir sedimentation issues in India as a part of Dam Rehabilitation and Improvement Project (DRIP): Field reconnaissance and modelling, River Sedimen-tation – Wieprecht et al. (Eds), Taylor & Francis Group, London, ISBN 978-1-138-02945-3.

Giri, S., Raman, S., & Chetan, M. 2016a. Reservoir Desiltation: Case Studies of Kundah Palam and Pillur Dams in Nilgiris Basin, Compendium of Second National Dam Safety Conference, Bengaluru, India.

Giri, S., Yossef, M., Raman, S., Cleyet-Merle, P., & Pillai, B.R.K. 2016b. Reservoir sedimentation issue in Pillur reservoir in Nilgiris basin (India): Field reconnaissance and numerical modelling using Delft3D, River Flow 2016 - Constantinescu, Garcia & Hanes (Eds), Taylor & Francis Group, London, ISBN 978-1-138-02913-2.

Omer, A., Giri, S., Kamphuis, J., Meerse, K., Wijnands J., Ekkelenkamp, H. & Besseling, E. 2020. An inte-grated approach for circular sediment management (CSM) in reservoirs. Submitted to ICOLD-2020, New Delhi, India.