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OPTIMIZING EMPIRICAL AREA REDUCTION PARAMETERS FOR SEDIMENT PROFILE IN A RESERVOIR

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ABSTRACT

The empirical area reduction method commonly used to determine sediment profile in a reservoir given by Borland and Miller, 1960 is based on three empirical parameters (C, m and n) determined from results of sedimentation studies of few reservoirs in U.S.A. In the present study, an attempt has been made to optimize the parameters of empirical area reduction method using Latin Hypercube, one parameter at a time (LH-OAT) technique for determination of sediment distribution in Ravishankar Sagar reservoir situated on river Mahanadi having gross storage of 909.54 Mm^3. The results obtained from optimized sediment distribution were compared with observed distribution through hydrographic survey (HS-2003) and further used to predict future sediment for future periods. The proposed optimization technique conferred root mean square error of 10.79 Mm^3 in comparison with conventional empirical area reduction method which provided the same as 11.85 Mm^3 when both were compared with results of hydrographic survey. The future sediment profiles for the year 2020, 2040 and 2060 using optimization through LH-OAT were made which may be helpful to water resource managers for revising reservoir operation plan and manage releases as per available storages in different zones.

Keywords: *Optimization, sediment distribution, hydrographic survey, reservoir operation.*

INTRODUCTION

The loss of capacity of reservoir due to accumulation of silt and sediment resulted less availability of water for irrigation, decreased ability to generate hydroelectricity, if not addressed properly led to make reservoir unusable (Morris & Fan 1998). Apart from loss of capacity sediment deposit in reservoir also lead to increase flood risks, interruption in hydropower generation, downstream river bed degradation, deterioration of water quality, increased complexity in reservoir operation, maintenance lead to increase in associated cost (Kothyari et al., 2002; Siyam et al., 2005, Smith & Pavelsky, 2009; Sreenivasulu & Udayabaskar, 2010). It is therefore necessary to monitor sediment deposit in different storage zones of reservoir which may be helpful to know the current status of availability of water, modification in reservoir operation plan, need for soil conservation measures in catchment areas, life of reservoir, environmental hazards etc. The sediment in reservoirs is computed by conventional techniques such as hydrographic surveys, inflow-outflow methods or recent technique of digital image classification of remote sensing data. If total sediment deposit is known, the sediment distribution in a reservoir can be computed with the help of empirical area-reduction method suggested by Borland & Miller, 1958 and 1960 which subsequently revised by Lara, 1962. In this method, the parameters *C*, *m* and *n* are computed with the help of original area-elevation-capacity curve of the reservoir.

Tebbi et al 2012 used an optimization technique for computation of cumulative trapped sediment curve in the absence of sediment trap curve for Foum El Kherza reservoir in Alzeria using eight bathometric surveys results in 44 year (1950-2007). Rahmanaian & Banihashemi, 2012 introduces a new shape function in the form of depth factor which is the ratio of volume of pyramid to the actual volume of water in the reservoir at that level based on the analysis of forty two dams in Iran. To determine sediment distribution two empirical functions called depth shape function (DSF) and relative depth shape function (RDSF) were introduced to determine sediment pattern in nine reservoirs. From the analysis of both conventional and new shape function based sediment pattern, it has been observed that the newly developed functions RDSF can be used predict relative sediment deposition and sediment deposition in reservoirs of different geometry and shape. Emadi & Kakouei (2014) used Shuffled Complex Evaluation (SCE) algorithm for determination of optimize parameters of empirical area reduction method and RMSE was used as objective function. They found that the objective function has reduced from 62% to 48% in calibration and verification periods respectively.

EMPIRICAL AREA-REDUCTION METHOD

The empirical are-reduction method is based on principle that the accumulation and distribution of sediment has specific relationship with the shape of reservoir. The main equation suggested in this method can be written as:

(1)

where, *S* is the total sediment distribution, *A* is the reservoir area at height *y*, *dy* is a small height increment, *a* is the approximate area of sediment, *H* is the total height of reservoir, y_o is the new zero elevation and *K* is a proportionality coefficient can be expressed by equation 2.

— (2)

where, A_o is the original area and A_p is the relative area at new zero elevation y_o. The methodology of empirical area reduction method consists of determination of reservoir's shape. The shape of reservoir is determined by plotting gross capacities on X-axis and respective reservoir depths on Y-axis in a log-log plot. The reciprocal of slope (*m*) is used to determine type of reservoir as given in Table 1 or Fig 1.

The constants *C*, *m* and *n* of empirical area reduction method may be determined using Table 2.

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Table 1: Classification of reservoir (Borland and Miller, 1960)

Reciprocal of slope (*m*)	Reservoir type	Standard Classification
1.0 to 1.5	Gorge	IV
1.5 to 2.5	Hill	III
2.5 to 3.5	Flood Plain	II
3.5 to 4.5	Lake	I

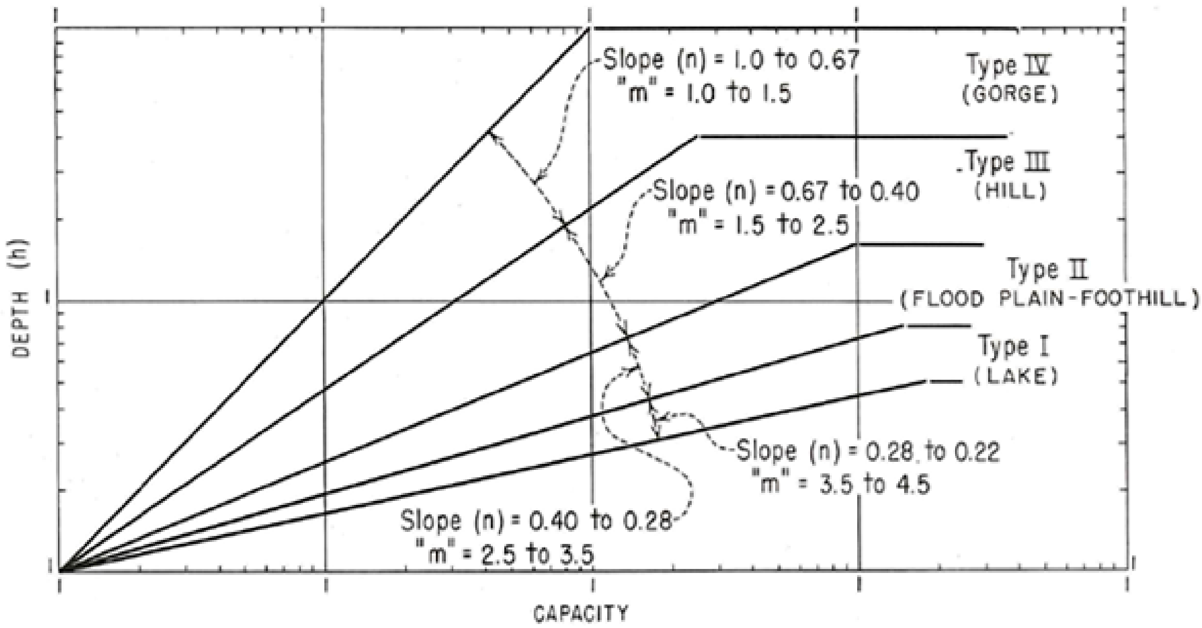

Fig. 1: Determination of type of reservoir (reproduced from Borland & Miller 1960)

Table 2: Constant *C*, *m* and *n* for empirical area-reduction method

Type	*C*	*M*	*m*
I	3.1470	1.5	0.2
II	2.3240	0.5	0.4
III	15.882	1.1	2.3
IV	4.2324	0.1	2.5

After determination of constants, a new zero elevation is assumed for a given sediment deposit and relative depths (p) for different elevations can be computed as the ratio of depth to total depth of reservoir. The relative areas (A_p) at different elevations are computed using following equation or Fig 2.

(3)

Now, constant K is computed using equation 2. By multiplying K and A_p at different depths, the sediment areas can be determined which subsequently used to compute sediment volume between the levels using trapezoidal formula. The total sediment volume at HFL is then computed by adding subsequent sediment volumes between the elevations and compared with total desired sediment deposit. If computed volume is not near to the total sediment need to be deposited, the next new zero elevation is assumed and whole process is repeated again till difference between computed and needed sediment deposit come within the limit (Generally 10% or as decided). In the present study, an attempt has been made to optimize the parameters C, m and n for a reservoir in India using Latin Hypercube one parameter at a time (LH-OAT), an optimization technique.

LH-OAT OPTIMIZATION TECHNIQUE

The Latin Hypercube Sampling was first presented and explained by McKay et al in 1979 (McKey et al 1979) and used for solving the problem of uncertainty for a particular class of problems (Wyss and Jorgensen, 1998) and generating a reasonable sample from a collection of distributed multidimensional field. McKay et al (2000) has compared random, stratified and Latin Hypercube sampling random variables in Monto Carlo studies. Zhang and Pinder (2003) applied Lattice sampling which is a special case of Latin Hypercube sampling (LHS) for groundwater flow and transport and found that LHS realization is not affected by seed and reduces the computational effort. Flores et al (2010) compared Latin Hypercube and random sampling techniques

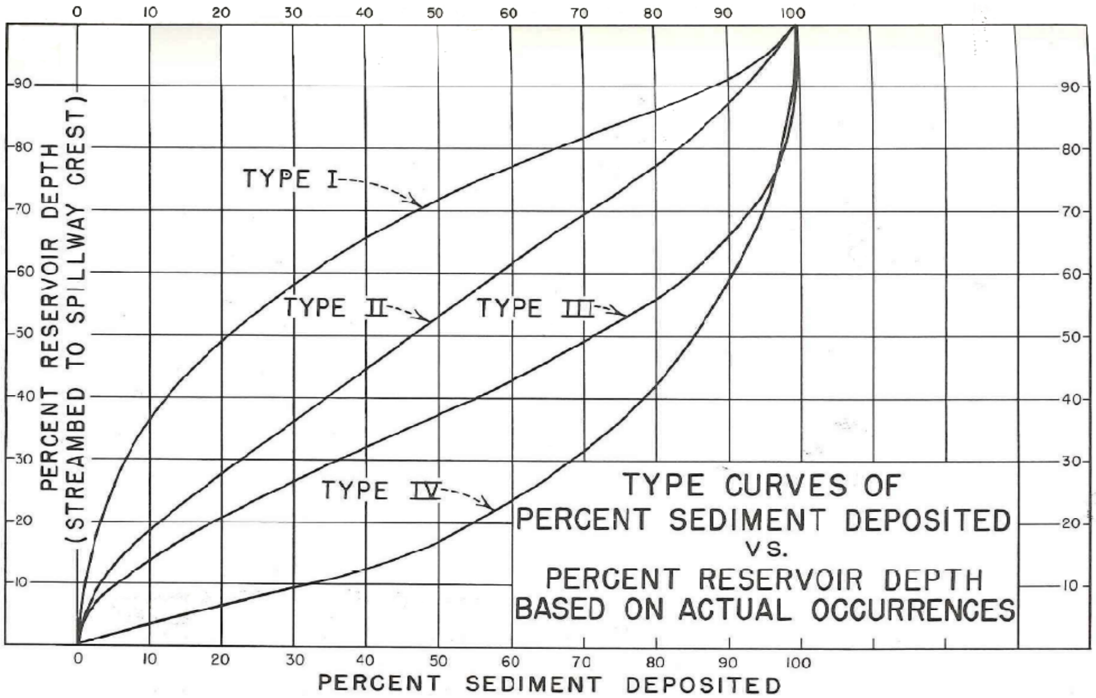

Fig. 2: Sediment distribution in different types of reservoirs (reproduced from Borland & Miller 1960)

to sample soil hydraulic and thermal properties and concluded that LH based approach yielded less variance in the estimate of ensemble moments of all sizes. In the LH sampling, whole space or probability distribution was split into *x* numbers of intervals or probabilities in such a way so that exactly one observation laid in each interval (Hung 2013). The one at a time method has been used in optimization where the value of one parameter is changed as per LH keeping other parameters constant to examine all combinations that may prevail in the system.

STUDY AREA & DATA USED

The Ravishankar Sagar dam is constructed on river Mahanadi in Dhamtari district of Chhattisgarh state. The Ravishankar Sagar dam is one of the major dams of Multipurpose Mahanadi project consists of Pairi, Ravishankar Sagar, Moorumsilli, Dudhawa, Sondur and Sikasar reservoir. The gross storage capacity of reservoir is 909.54 Mm^3 at HFL. The base map of the study area has been presented in Fig 3**.** The Ravishankar Sagar Reservoir project was designed with the following objectives:

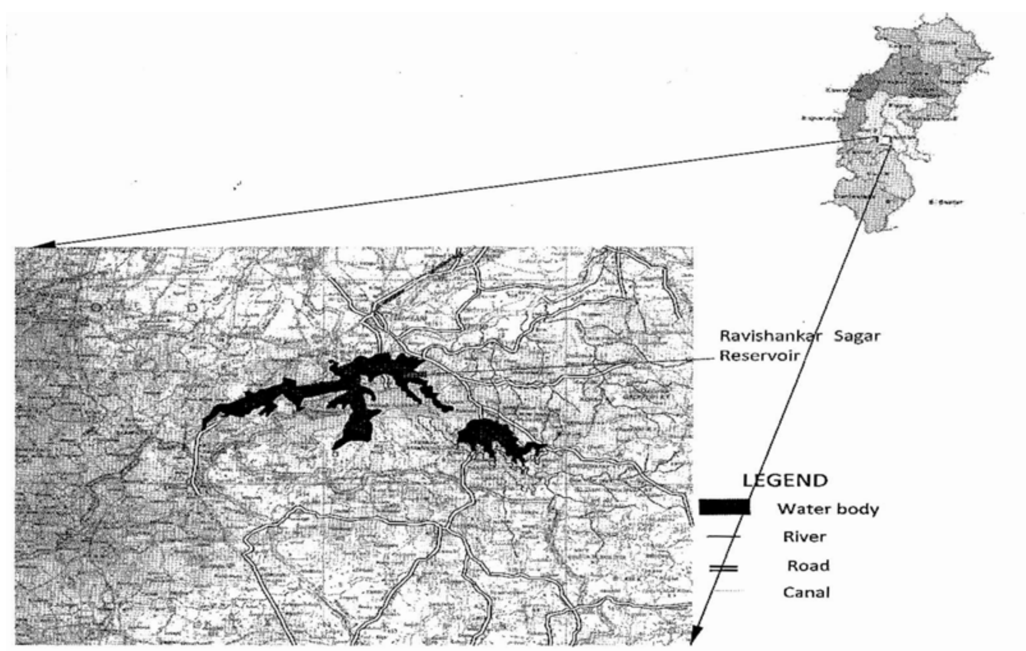

Fig. 3: Location map of Ravishankar Sagar reservoir in Chhattisgarh

- Supplying annually 61 Mm^3 water to municipal requirements of Dhamtari town and Raipur City.
- Converting existing 'Protective' Irrigation of Kharif paddy in about 1,82,500 hectare (1,47,500 hectare in Mahanadi old command and 35,000 hectare New area) to 'Productive' irrigation by providing timely, reliable and equitable supply of water of the land to boost present per hectare yield of about 1.4 to 3 tonnes.
- Expanding irrigation in new area of 1, 56, 500 hectare.
- Increasing irrigation intensity in the CCA for present 72% to 100% in Kharif and 1% to 35% in Rabi season.
- Generating farm and non-farm employment to about 1, 80,000 persons.

The original area-elevation-capacity table and revised area-elevation-capacity table obtained from hydrographic survey in the year 2003 (CWC 2015) were used to compute optimized parameters of empirical area reduction method.

METHODOLOGY

The LH-OAT method has been used in the present study to optimize the parameters *C*, *m* and *n* of empirical area reduction method. Firstly, the original elevation and capacities were plotted on log-log paper to determine the type of reservoir and parameters *C*, *m* and *n* for Ravishankar Sagar reservoir. The profile of revised bed was then determined using conventional methodology proposed in this method. Now, considering the normal distribution of parameters, the LH-OAT method has been applied in which one parameter was considered for optimization keeping other constants and revised profile of sediments was obtained. A computer program was developed in FORTRAN, where, the parameters *C*, *m*, *n* were changed one-by one and revised profile were determined considering appropriate new zero elevation using trial and error method. For doing this, each time for value of *C*, *m* and *n*, a revised bed level was assumed and taking these, revised sediment volume at highest flood level was computed and compared with actual sediment volume obtained from hydrographic/remote sensing survey. If the difference between actual sediment volume and computed sediment volume was within limit (0.5 Mm^3 in this case), the sediment profile was computed else next revised level was considered. If the computed revised sediment did not converge with actual sediment, then next combination of *C*, *m* and *n* were using LH-OAT sampling and best selection which gave the minimum difference between observed and computed total computed sediment has been selected for that reservoir.

ANALYSIS OF RESULTS

Conventional Method

The results of hydrographic survey in the year 2003 confirmed that 28.20 Mm^3 of volume has been lost at H.F.L. and to determine revised bed or sediment profile using conventional method, the slope of elevation and capacity were determined to assess the shape of valley. For Ravishankar Sagar reservoir, the slope of best-fit line of heights and original capacities values on log-log scale was computed and found as 0.04 which indicate it is a gorge shape valley (Type IV). For gorge shape valley, the value of *C*, *m* and *n* were taken as 1.486, 0.10 and 2.50 respectively. The distribution of this volume was computed using conventional values of *C*, *m* and *n* that led to new zero elevation (revised bed level) as 331.50 m and revised capacity of reservoir at HFL may be 882.09 Mm^3.

LH-OAT Optimization Method

In the study, LH-OAT technique has been applied for optimization of parameters *C*, *m* and *n* of empirical area reduction method and new zero elevation for given sediment deposit (28.02 mm^3) was found as 2.1, 2.4 and 1.8 respectively. The revised river bed and capacity at HFL using these values have been computed as 327.50 m and 881.59 Mm^3 respectively. The original capacity, revised capacity curve from hydrographic survey (HS-2003), conventional and optimized methods has been presented in Fig 4. The root mean square error have been computed to compare the results

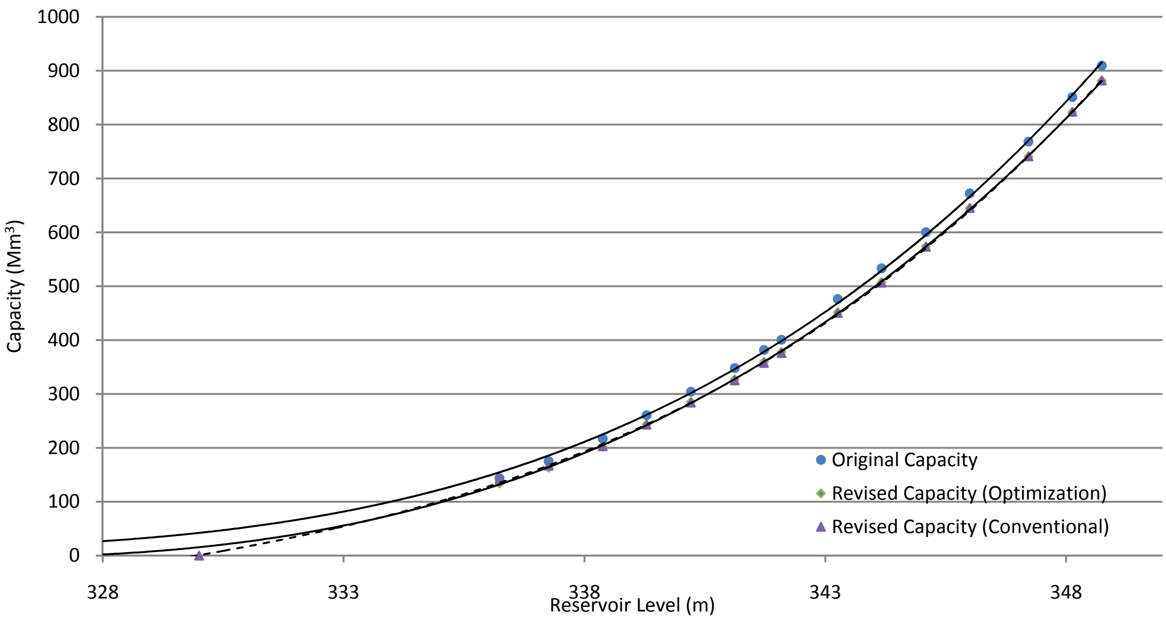

Fig. 4: Original and revised gross capacity from hydrographic survey, conventional and optimization technique

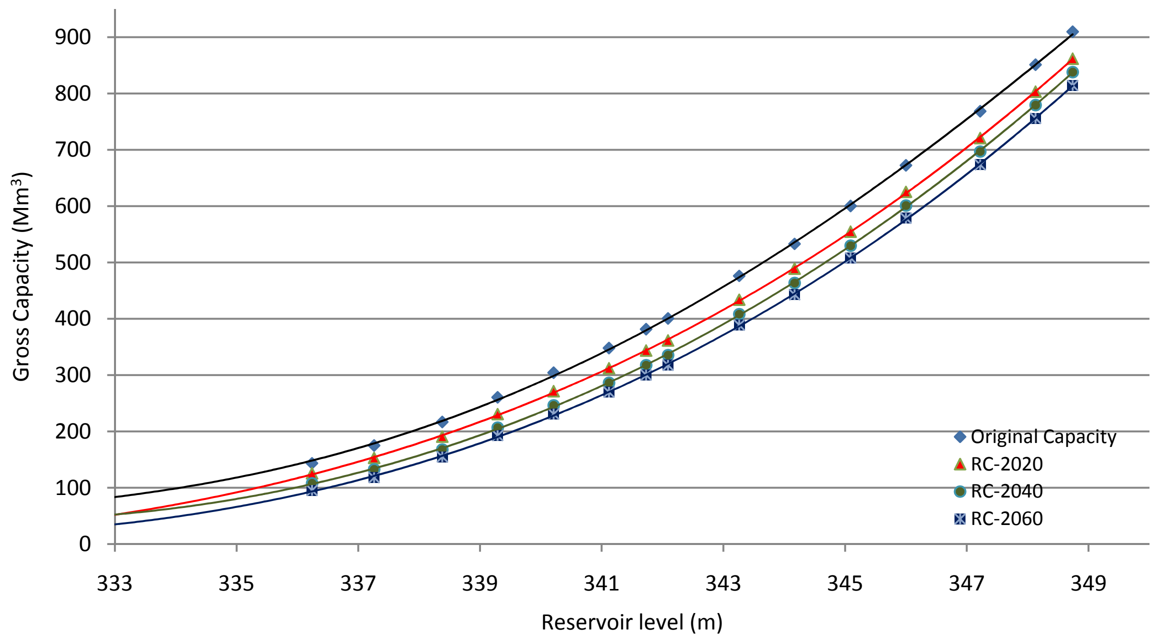

Fig. 5: Original and revised capacity curves for different periods (LH-OAT optimization technique)

of conventional and proposed optimization method and found their values as 11.85 and 10.79 Mm^3 respectively that confirmed the suitability of optimization technique.

Prediction of Sediment Profile for Future Period

Considering the present trend of reservoir sediment inflows based on hydrographic survey (1.18 Mm^3/year), the total sediment deposit for the year 2020 (RC-2020), 2040 (RC-2040) and 2060 (RC-2060) have been computed as 48.18, 71.68 and 95.19 Mm^3 respectively. The LH-OAT optimization technique has been used to determine sediment profile for these future periods and presented in Fig. 5. The predicted sediment profiles during different periods can be used to optimize releases from reservoir and selection of appropriate soil conservation measures.

CONCLUSION

Assessment of reservoir sediment and its profile is important for water resources managers to operate reservoir efficiently and modification of releases as per available capacities. In the present study an attempt has been made to optimized parameters *C*, *m* and *n* of empirical area reduction method using LH-OAT in which all parameters were considered as normally distributed and one-by-one considered for optimization. The analysis has been carried out for Ravishankar Sagar reservoir situated on river Mahanadi in Chhattisgrah state having gross storage of 909.54 Mm^3. The results of hydrographic survey conducted in the year 2003 have been used as input in a program developed in FORTRAN where sediment profile were determined using conventional and proposed optimization method for empirical are reduction method. It may be concluded that the revised elevation-capacity curve obtained from optimization technique have close resemblance with observed hydrographic survey with lesser root mean square error than conventional technique. Using optimization technique, predictions of sediment profile for 2020, 2040 and 2060 were made which can be useful to water resource managers for reservoir release and modification in reservoir operation plan.

REFERENCES

1. *Borland, W. M. and Miller, C. R., 1958. "Distribution of Sediment in Large Reservoirs", Journal of Hydraulic Engineering Division-ASCE 84, 1-18*
2. *Borland, W.M. and Miller, C.R., 1960. "Distribution of Sediment in Large Reservoirs", Trans. ASCE, 125 (I), 166-180*
3. *Central Water Commission. 2015. "Compendium of Silting of Reservoirs in India", New Delhi, 23-24*
4. *Emadi, A.R. and Kakouei, S., 2014. "Determination of Optimal Parameters of Empirical Area Reduction Method in Karaj Reservoir Dam using SCE", Journal of Water & Soil Conservation, Winter 21(4), 179-195*
5. *Flores, A.N, Entekhabi, D. and Bras, R.L., 2010. "Reproducibility of Soil Moisture Ensembles when Representing Soil Parameter Uncertainty using a Latin Hypercube-Based Approach with Correlation Control" Water Resources Research 46, W04506, doi:10.1029/2009WR008155*
6. *Hung, Y., 2013. "Optimal Experiment Design, Latin Hypercube", Encyclopedia of System Biology, Eds: Dubitzk W, Wolkenhauer O, Cho KH, Yokota H, Springer New York, 1583-1585*
7. *Kothiyari, U.C, Jain, M.K. and Ranga Raju, K.G., 2002. "Estimation of Temporal Variation of Sediment Yield using GIS", Hydrological Sciences Journal, 47(5), 693-706*

8. *Lara, J. M., 1962. "Revision of the Procedure to Compute Sediment Distribution in Large Reservoirs", US Bureau of Reclamation, Denver, Colorado.*
9. *McKay, M.D., Beckman, R.J. and Conover, W.J., 1979. "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code", Technometrics (JSTOR ABSTRACT) (American Statistical Association) 21 (2), 239–245*
10. *McKay, M.D., Beckma, R.J. and Conove, W.J., 2000. "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code", American Statistical Association and American Society for Quality 42(1), 55-61.*
11. *Morris, G.L. and Fan, J., 1998. "Reservoir Sedimentation Handbook", McGraw-Hill Book Co., New York*
12. *Rahamanian, M.R. and Banihashemi, M.A., 2012. "Introduction of a New Empirical Reservoir Shape Function to Define Distribution Pattern in Dam Reservoirs", Iranian Journal of Science & Technology, Trans Civil Engineering 36(C1), 79-92*
13. *Siyam, A. M., Mirghani, M., Elzein, S. , Golla, S. , and El-sayed, S. M., 2005. " Assessment of the Current State of the Nile Basin Reservoir Sedimentation Problems Group-I Repot", Nile Basin Capacity Building Network for River Engineering (NBCBN-RE), River Morphology, Research Cluster, Sudan*
14. *Smith, L. C., and Pavelsky, T. M., 2009. "Remote sensing of Volumetric Storage Change in Lakes", Earth Surface Processes & Landforms 34(10), 1353 – 1358, doi:10.1002/esp.1822*
15. *Sreenivasulu, V. and Udayabhaskar, P., 2010. "An Integrated Approach for Prioritization of Reservoir Catchment using Remote Sensing and Geographic Information System Techniques", Geocarto International 25(2), 149-168*
16. *Tebi F.Z., Dridi, H. and Morris, G.L., 2012. "Optimization of Cumulative Trapped Sediment Curve for an Arid Zone Reservoir: Foum El Kherza (Biskra, Algeria)", Hydrological Sciences Journal 57(7), 1368-1377, DOI: 10.1080/02626667.2012. 712740*
17. *World Commission on Dams, 2000. "Dams and Development- a New Framework for Decision-Making", Earthscan publications Ltd., London, 356 pp*
18. *Wyss, G.D. and Jorgensen, K.H. 1998. "A User's Guide to LHS: Sandia's Latin Hypercube Sampling Software", Sandia National Laboratories Albuquerque NM 87185–0747*
19. *Zhang, Y. and Pinder, G. 2003. "Latin Hypercube Lattice Sample Selection Strategy for Correlated Random Hydraulic Conductivity Fields", Water Resources Research 39(8) doi:10.1029/2002 WR001822*