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Assessment of Reservoir Storage Capacity and Silt Deposition Using Advanced Instruments: A Case Study

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Abstract

Reservoirs on the upstream side of sediment-laden river dams fill with sediment over time, lowering their storage capacity. This research focuses on advanced instrumentation techniques used to analyse storage capacity and estimate the quantity of sedimentation deposited in the reservoir at Kadana Dam, Kadana Village, Mahisagar District, Gujarat, India. During the research investigations, a multi-frequency acoustic system with frequencies of around 33 KHz and 210 KHz was employed to assess the reservoir bed level. In addition, Hypack was used to process the data. A Knudsen Chirp 3260 single-beam echo sounder with frequencies of about 3.5 KHz and 200 KHz was also employed to determine the reservoir's sub-bottom profile. MATLAB and Sonar Wiz Software were used to examine the sub-bottom survey data. During the results analysis, Surfer Software was used to generate 3D sections, contour maps, grid maps, isopach charts, and isoline maps. According to the findings, the current gross storage capacity at FRL 127.7 m is 1243.58 MCM, while the intended gross storage capacity is 1543 MCM. As a result, at an FRL of 127.7 m, there is a 19.40 percent loss in gross storage. The research also revealed that the annual rate of silt is 2.73 ham/100 sq. km/year.

Keywords: Echo Sounder; Sonar Wiz; MATLAB; Differential Global Positioning System (DGPS).

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INTRODUCTION

The Kadana reservoir project is located 3 kilometres upstream of Kadana village in the Mahisagar region of Gujarat, India, and is built over the Mahi river. The reservoir's initial gross storage capacity was 1,543 MCM for a surface area of 165.92 sq km and a depth of 127.71 m FRL. It serves 156 villages in the Mahisagar District's Santrampur and Kadana Talukas, as well as the Panchmahals District's Godhra Talukas. The building of the Kadana project began in 1968, and the majority of the work was finished in 1979. Stage I and Stage II were the two stages of construction. In stage II, the cost of the Kadana reservoir project was around 9,995 lacs INR.

Using hand-held GPS, the CWPRS Hydraulic Instrumentation Division team conducted a reconnaissance survey in November 2019. The survey area was examined, and bathy boundary bench mark points were recorded.

The survey was then conducted by the CWPRS team in February-March 2020. The work was interrupted due to unforeseen circumstances (i.e., COVID-19), and the final survey was continued from the last week of October 2020 to the first week of January 2021.

The sedimentation survey was carried out by the CWPRS Hydraulic Instrumentation Division to estimate reservoir storage capacity and other characteristics such as sedimentation, area elevation curve, and so on. Furthermore, a single-beam dual-frequency (210 KHz and 33 KHz) echo-sounder and a Differential Global Positioning System (DGPS) were used to conduct the hydrographic study.

The investigations were carried out with sophisticated instrumentation, *an Integrated Bathymetric Survey System (IBS)*, at a reservoir water level of EL 127.7 m and a grid spacing of 100 m, encompassing a 160 sq. km region.

The contours of the reservoir bed at 1.0 m intervals, the reservoir's living capacity, and the sediment volume of the reservoir were plotted for data analysis.

For the analysis, Navisoft, Hypack, QGIS, Surfer, Global Mapper, Google Earth, Auto-CAD, TCX convertor, and MATLAB were used in the analysis. Until FRL, the contour was created at 1 m intervals. The dam's current storage capacity is expected to be 1243.58 MCM at EL 127.7 m.

LITERATURE REVIEW

Reservoir Sedimentation Process

In a reservoir, sedimentation studies are essential for optimum reservoir operation based on a realistic evaluation of available storage [1–6]. A reduction in storage capacity beyond a certain point prevents the reservoir from serving numerous functions [7–10].

Figure 1 depicts the sedimentation process in a reservoir. Reservoir capacity surveys are conducted on a regular basis to determine the rate of sedimentation and storage capacity loss [11–17]. This facilitates the effective management of reservoirs as well as the decision-making process for the treatment of catchments if the rate of siltation is too high [18, 19].

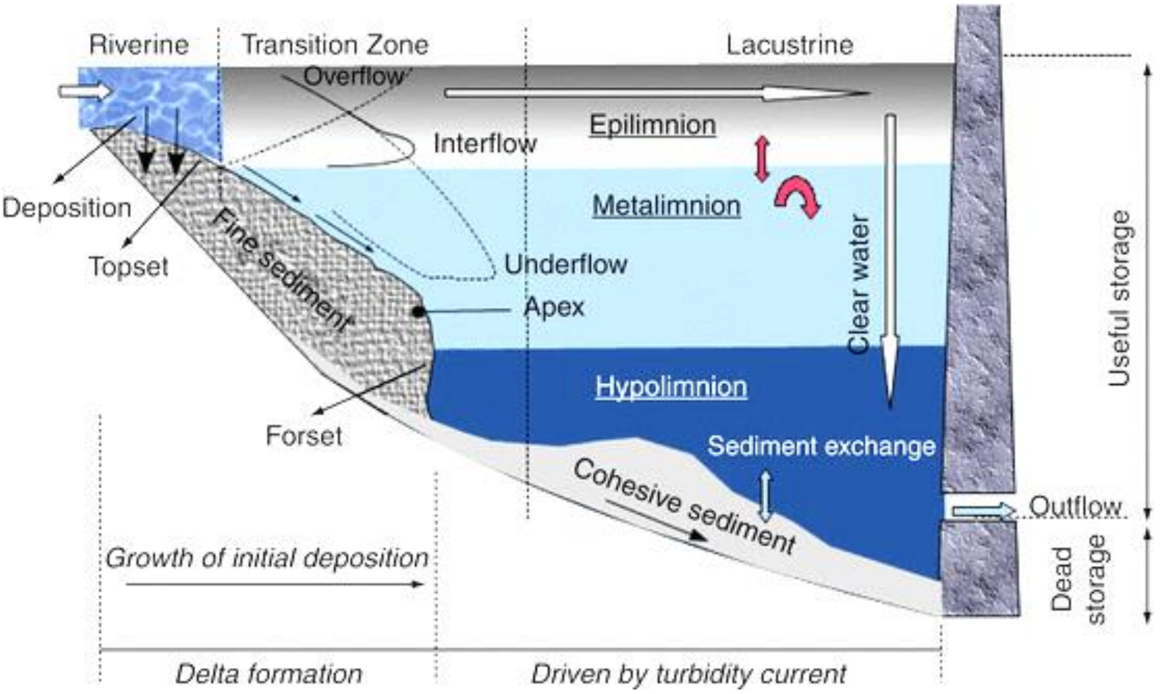

Figure 1. Process of Sedimentation in a Reservoir [20].

An Integrated Bathymetry Survey System (IBS) with DGPS mounted on a boat is an advanced technique that generates precise information among the many bathymetric survey methods [21–24]. The data for this study was collected using the Integrated Bathymetry Survey System (IBS), which was then analysed and the results were obtained. For a submergence area of around 116 km^2, the reservoir was built with a gross storage capacity of about 1,543 MCM at a FRL of about 127.5 m.

FIELD INVESTIGATIONS

The Kadana dam project is providing irrigation water for 2,69,150 hectares of land across a weir crossing the Mahi River. It also generates water for about 300 MW of hydropower through reversible turbines. At Latitude 23° 18' 30" North and Longitude 73° 49' 45" East, it is a composite dam.

Figure 2 shows an aerial view of the Kadana dam reservoir on Google Earth [25].

Figure 2. Kadana dam reservoir on Google Earth.

Instruments Incorporated During the Studies

In order to conduct the studies, the Integrated Bathymetric Survey System (IBS) was employed, which is composed of highly advanced electronic equipment such as a DGPS, Echo Sounder, Discus Antenna, Sensor, and a Fixture to hold the sensor.

An echo-sounder made by Knudsen with dual frequencies (210 KHz and 33 KHz) and Trimble's DGPS were used in the survey. Hypack was used for data collection, processing, and calculations. Results were more accurate due to the advanced Integrated Bathymetry Survey System. At a FRL of 127.7 m, the survey was carried out.

Differential Global Positioning System (DGPS)

To derive the position through satellites, the positioning system used during the studies uses a transponder or DGPS unit. This device is highly accurate, reliable, and state-of-the-art [26–29]. Additionally, the GPS receiver is able to track over 12 satellites in order to obtain maximum positional accuracy. A satellite-based position determination system also integrates information from the reference station with satellite signals for a more accurate calculation of the position [30–33].

The DGPS display interface unit from Trimble, which also includes an antenna during the study, is shown in Figure 3.

Figure 3. DGPS with antenna.

The mobile antenna was used to record the GPS satellite location data from available satellites and correct satellite introduced errors with the help of beacon correction and sub-meter accuracy.

As part of the studies, an integrated bathymetric survey system was adopted, which was compact and could be carried in a smaller boat. Figure 4 shows an integrated bathymetric survey system (IBS) that consists of an echo-sounder, a laptop, and a DGPS interface that is mounted on the boat during the study.

Figure 4. Survey Boat with Equipment.

Laptop Runnning Navisoft

As shown in Figure 5, the real-time position and depth data were captured by the laptop using Hypack Navisoft.

Dual Frequency Echo-Sounder

Figure 6 illustrates a single beam dual frequency echo sounder which was used during the research studies for depth measurement using an echo-sounder with a range of -0.2 m to 200 m and an accuracy of 0.01 m +/- 0.1% at 210 kHz and 0.10 m +/- 0.1% at 33 kHz. During the studies, a dual-frequency echo-sounder was used to distinguish between the top depths and the consolidated bottoms of the reservoir.

Under favourable conditions, the low-frequency signal (of about 33 KHz) penetrated the bottom and showed information about the bottom profile. The high-frequency signal (210 KHz) detected the top layer of sediment, and the low-frequency signal (of about 33 KHz) penetrated the bottom layer. Furthermore, the echo-sounder system has the capability of setting the energy levels of the beams being transmitted underwater. Based on sound velocity calibrator readings, the velocity of the echo-sounder was set at 1500 metres per second. This velocity was verified against the echo track sensor.

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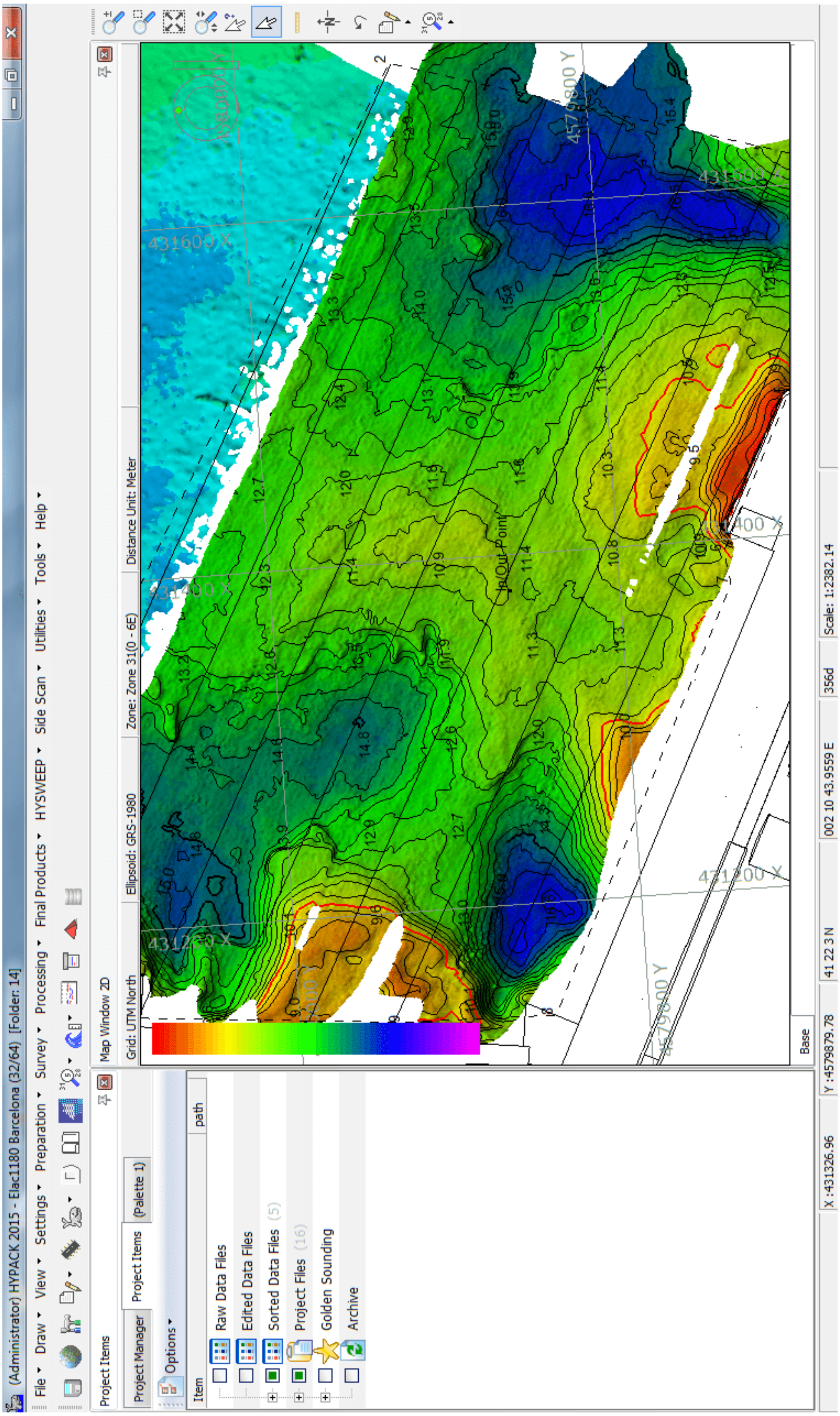

Figure 5. Data logging through Hypack Navisoft.

Figure 6. Dual frequency echo sounder.

Sub Bottom Profiler System

A sub-bottom profiler was used to assess the bottom profile of the reservoir and the sediment deposition type and classification, viz., sand, silt, and clay, with further sub-classifications of coarse, medium, and fine. A sub-bottom profiler, a Knudsen Chirp 3260 single-beam echo sounder, was used. A low frequency was used to penetrate the seabed, and a high frequency was used to track the level of the bed.

Data from the sub-bottom profiler survey was processed using MATLAB and Sonar Wiz. In the MATLAB-based analysis, depth contours were displayed on the sub bottom profile and a 3D image was generated from the depth contours. Similarly, bed level and the bottom of the silty/sandy clay layer are digitized in Sonar Wiz, along with an overall thickness measurement. ISOPACH maps are

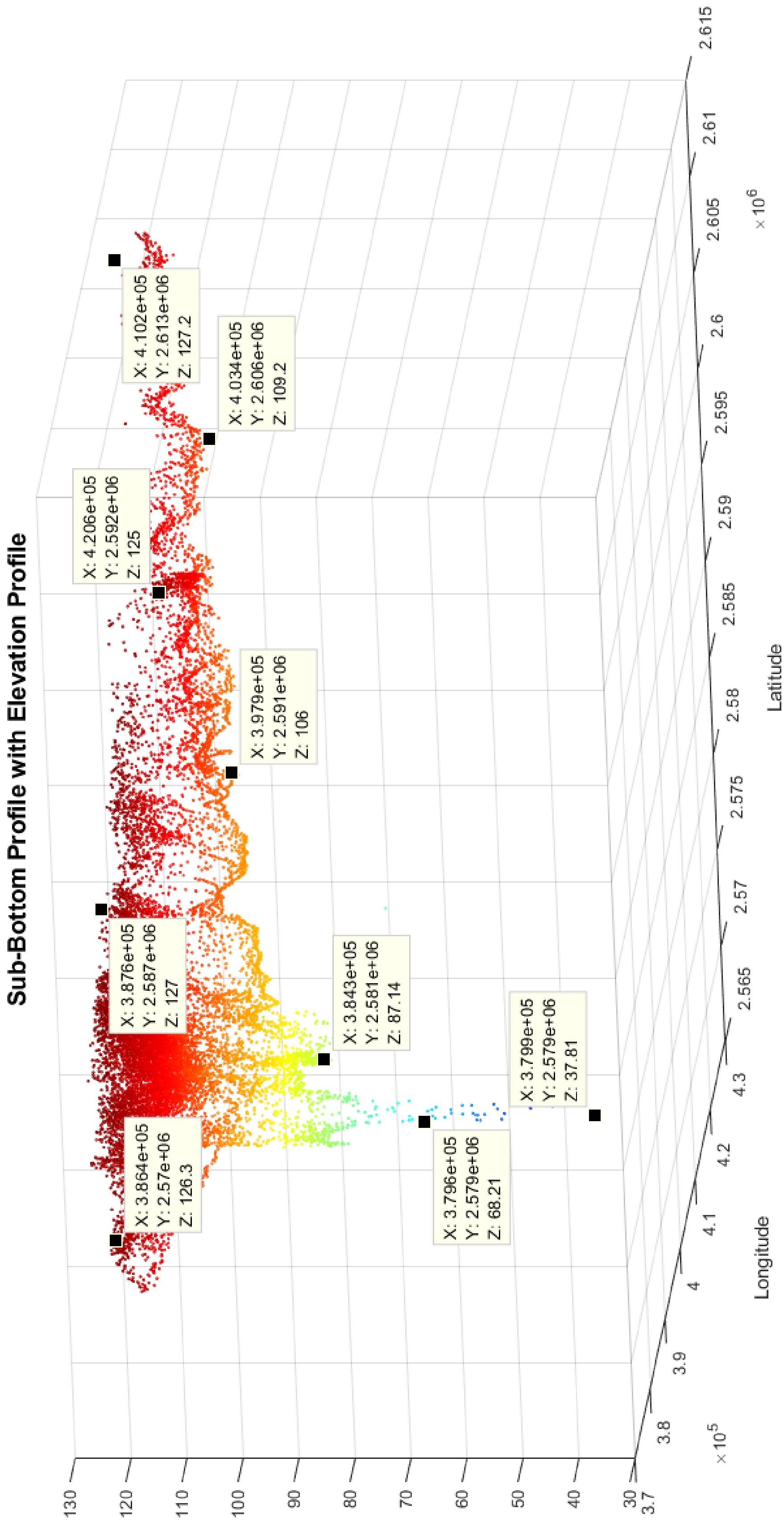

Figure 7. Sub-Bottom Profile with data values.

RESULTS AND DISCUSSION

At CWPRS, the data collected at the dam site was analysed using Hypack, Surfer, Autocad, and MATLAB. By applying krigging to the uneven data, the noisy spikes have been eliminated, and the useful data samples have been obtained (depth values). To remove the spikes in bathymetric data, special filters were applied. In general, noises result from boat motion, underwater vegetation, engine noise, and wave disturbance from the waves on the surface. Initially, the depth data was processed for preparing grid files, and then the processed data was used for further analysis in Surfer. Moreover, the grid files were used to prepare contour plots and surface plots as well as estimations of surface area and volume based on standard formulae, including the Trapezoidal Rule, 1/3 Simpson's Rule, and Simpson's 3/8 Rule. Results were obtained by interpolating depth data acquired by an echo sounder in dual frequency mode. Interpolation is performed using the krigging method for the zone that lies between two survey lines. This process generates the grid data set that is used for the analysis. A bathymetric survey at FRL 127.7 m with echo sounder channel 1 frequency (210 KHz) found the volume to be 1243.58 MCM and the corresponding area to be 141.17 square kilometres.

As shown in Figure 8, the Area-Capacity Curve for Kadana Reservoir compares with the original design, the 2000 Survey Results, and the 2020–21 CWPRS Survey Results.

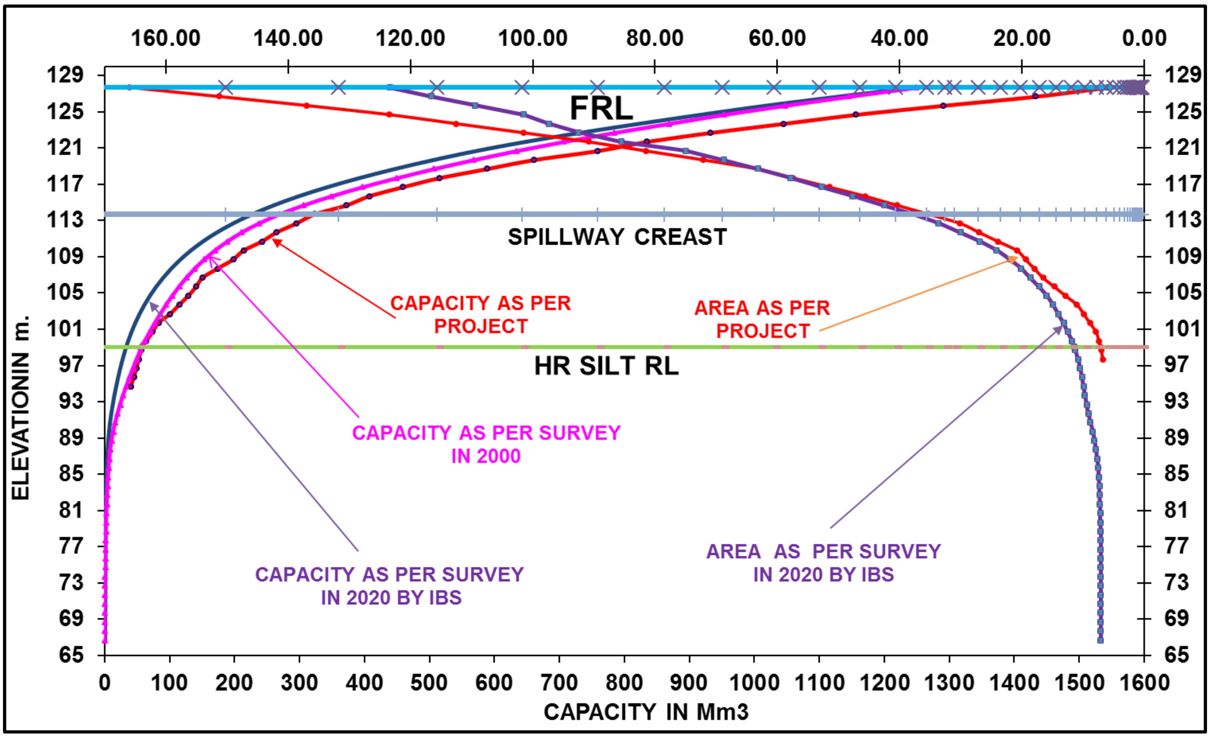

Figure 8. Area-Capacity Curve of Kadana Reservoir.

CONCLUSIONS

An assessment of the sedimentation capacity of a reservoir and what amount of silt is deposited in a reservoir are crucial components of sedimentation survey. For the investigation of reservoir storage capacity and silt deposition, it is critical to have strong knowledge of the latest instrumentation, sub bottom profile, and software expertise. It is generally recommended to conduct sediment-related surveys every three (03) to five (05) years. These surveys are necessary because the ramifications are quite significant, such as an increase in dead storage because storage capacity is diminished. In order to maximize storage capacity, regular sedimentation surveys and an automated process are essential.

As a result of computing the results, it was observed that present storage capacity of the reservoir had decreased by *299.42 MCM, or 19.40%*, as measured at *FRL 127.70 metres.*

Deviations in the reservoir capacity are within the specified limits of ISO 6421:2012(en), “Hydrometry—Methods for assessment of reservoir sedimentation”, ISO 4366:2007(en), “Hydrometry—Echo sounders for water depth measurements”, ISO 19115 and IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44) [37–40].

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REFERENCES

1. L. Dong, W. Shu, D. Sun, X. Li, L. Zhang, “Pre-alarm system based on real-time monitoring and numerical simulation using internet of things and cloud computing for tailings dam in mines,” IEEE Access. September 2017; 5: 21080–21089.
2. S.N. Ciolofan, G. Militaru, A. Draghia, R. Drobot, M. Drăgoicea, “Optimization of water reservoir operation to minimize the economic losses caused by pollution,” IEEE Access. 2018; 6: 67562–67580.
3. A.J. Schleiss, M.J. Franca, C. Juez, G. De Cesare, “Reservoir sedimentation,” Journal of Hydraulic Research. 2016; 54 (6): 595–614.
4. G. Petkovsek, M. Roca, “Impact of reservoir operation on sediment deposition”. Water Management. November 2014; 167 (10): 577–584.
5. R.K. Jaiswal, T. Thomas, R.V. Galkate, S. Singh, “Revised Capacities and Sediment Pattern Assessment in Rajaval and Kharo Reservoirs of Gujarat (India).” IUP Journal of Soil and Water Science. 2010; 3 (4): 7–19.
6. S.K. Jain, A. Chaudhary, “CS (AR)-1/2007-08: Assessment of sedimentation rate of reservoirs using remote sensing techniques (summary of studies completed during 2002-2007)” Sediment Problems and Sediment Management in Asian River Basins; September 2009; Hyderabad, India. IAHS Publisher; 2011; 163–170 p.
7. S. Ahmad, S.P. Simonovic, “System dynamics modeling of reservoir operations for flood management,” Journal of Computing in Civil Engineering. 2000; 14 (3): 190–198.
8. L.-C. Chang, F.-J. Chang. “Intelligent control for modelling of real-time reservoir operation,” Hydrological Processes. vol. 15, no. 9, pp. 1621–1634, 2001.
9. G. M. Kondolf et al., “Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents,” Earths Future, vol. 2, no. 5, pp. 256–280, 2014.
10. B. D. Richter and G. A. Thomas, “Restoring environmental flows by modifying dam operations,” Ecol. Soc., vol. 12, no. 1, 2007.
11. S. Dutta and D. Sen, “Sediment distribution and its impacts on Hirakud Reservoir (India) storage capacity,” Lakes Reserv. Res. Manag., vol. 21, no. 3, pp. 245–263, 2016.
12. M.K. Goel, S.K. Jain, and P.K. Agarwal, “Assessment of sediment deposition rate in Bargi Reservoir using digital image processing,” Hydrol. Sci. J., vol. 47, no. S1, pp. S81–S92, 2002.
13. S.K. Jain, P. Singh, and S. M. Seth, “Assessment of sedimentation in Bhakra Reservoir in the western Himalayan region using remotely sensed data,” Hydrol. Sci. J., vol. 47, no. 2, pp. 203–212, 2002.
14. V. Jothiprakash and V. Garg, “Reservoir sedimentation estimation using artificial neural network,” J. Hydrol. Eng., vol. 14, no. 9, pp. 1035–1040, 2009.
15. K. Narasayya, “Assessment of reservoir sedimentation using remote sensing satellite imageries,” Asian J. Geoinformatics, vol. 12, no. 4, 2013.

16. S. Wagh and V. Manekar, "Assessment of reservoir sedimentation using satellite remote sensing technique (SRS)," J. Inst. Eng. India Ser. A, vol. 102, no. 3, pp. 851–860, 2021.
17. L. Khaba and J. A. Griffiths, "Calculation of reservoir capacity loss due to sediment deposition in theMuela reservoir, Northern Lesotho," Int. Soil Water Conserv. Res., vol. 5, no. 2, pp. 130–140, 2017.
18. N. Haregeweyn et al., "Reservoirs in Tigray (Northern Ethiopia): characteristics and sediment deposition problems," Land Degrad. Dev., vol. 17, no. 2, pp. 211–230, 2006.
19. C.N. Luwesi and E. Bader, "Essentials of Implementation of Improved Green Water Management In Muooni Catchment, Machakos District of Kenya," J. Agri-Food Appl. Sci., vol. 1, no. 2, pp. 63–70, 2013.
20. B. Dargahi, "Reservoir Sedimentation," in Encyclopedia of Lakes and Reservoirs, L. Bengtsson, R. W. Herschy, and R. W. Fairbridge, Eds. Dordrecht: Springer Netherlands, 2012, pp. 628–649. doi: 10.1007/978-1-4020-4410-6_215.
21. T. Giachetti, R. Paris, K. Kelfoun, and B. Ontowirjo, "Tsunami hazard related to a flank collapse of Anak Krakatau Volcano, Sunda Strait, Indonesia," Geol. Soc. Lond. Spec. Publ., vol. 361, no. 1, pp. 79–90, 2012.
22. R.A. Patil and R.V. Shetkar, "Sediment deposition in Koyna reservoir by integrated bathymetric survey," Int J Res Eng Technol, vol. 4, no. 11, pp. 114–118, 2015.
23. M.M. Rashid, R. Roy, M.M. Ahsan, and Z. Siddique, "Design and Development of an Autonomous Surface Vehicle for Water Quality Monitoring," ArXiv Prepr. ArXiv220110685, 2022.
24. M. Séranne, "The Gulf of Lion continental margin (NW Mediterranean) revisited by IBS: an overview," Geol. Soc. Lond. Spec. Publ., vol. 156, no. 1, pp. 15–36, 1999.
25. "Google Earth." https://earth.google.com/web/search/Kadana+Dam,+Gujarat/@23.3057915,73.8255487,79.02726171a,960.8436932d,35y,0h,0t,0r/data=CigiJgokCTVlQDCA3DRAETRlQDCA3DTAGY5HGpTD3z1AIVJSswrVM1LA (accessed Feb. 09, 2022).
26. G. Gartner, A.U. Frank, and G. Retscher, Pedestrian navigation system in mixed indoor/outdoor environment-the navio project. Citeseer, 2004.
27. K.P. Germann, Flight test evaluation of a differential global positioning system sensor in runway performance testing. Mississippi State University, 1997.
28. A. LaMarca and E. De Lara, "Location systems: An introduction to the technology behind location awareness," Synth. Lect. Mob. Pervasive Comput., vol. 3, no. 1, pp. 1–122, 2008.
29. R. Sabatini and G. Palmerini, Differential global positioning system (DGPS) for flight testing. RMIT University, 2008.
30. J.C. del Rey, J.A. Vega, M. Pérez-Ruiz, and L. Emmi, "Comparison of Positional Accuracy between RTK and RTX GNSS Based on the Autonomous Agricultural Vehicles under Field Conditions," Appl. Eng. Agric., vol. 30, no. 3, pp. 361–366, 2014.
31. P.K. Enge, "The global positioning system: Signals, measurements, and performance," Int. J. Wirel. Inf. Netw., vol. 1, no. 2, pp. 83–105, 1994.
32. H. Kaartinen et al., "Accuracy of kinematic positioning using global satellite navigation systems under forest canopies," Forests, vol. 6, no. 9, pp. 3218–3236, 2015.
33. J. Wang, T. Tsujii, C. Rizos, L. Dai, and M. Moore, "Integrating GPS and pseudolite signals for position and attitude determination: Theoretical analysis and experiment results," in Proceedings of the 13th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS 2000), 2000, pp. 2252–2262.
34. K. J. Bird, "Structure-contour and isopach maps of the National Petroleum Reserve in Alaska," U. S. Geol. Surv. Prof. Pap., 1989.
35. K. J. Bird, "16. Structure-Contour and ISOPACH Maps of the National Petroleum Reserve in Alaska," US Geol. Surv. Prof. Pap., vol. 1399, p. 355, 1984.
36. C.-L. Shaw, "Stratigraphic correlation and isopach maps of the western Taiwan Basin," Terr. Atmospheric Ocean. Sci., vol. 7, no. 3, pp. 333–360, 1996.
37. "ISO 6421:2012(en), Hydrometry — Methods for assessment of reservoir sedimentation."

https://indocal.isolutions.iso.org/obp/ui#iso:std:iso:6421:ed-1:v1:en (accessed Feb. 09, 2022).
38. 14:00-17:00, "ISO 4366:2007," ISO. https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/03/70/37097.html (accessed Feb. 09, 2022).
39. 14:00-17:00, "ISO 19115-1:2014," ISO. https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/05/37/53798.html (accessed Feb. 09, 2022).
40. "International Hydrographic Organization Standards for Hydrographic Surveys S-44 Edition 6.0.0 International Hydrographic Organiz." https://webcache.googleusercontent.com/search?q=cache:nbUrgWoKwCoJ:https://iho.int/uploads/user/pubs/Drafts/S-44_Edition_6.0.0-Final.pdf+&cd=1&hl=en&ct=clnk&gl=in (accessed Feb. 09, 2022).