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Comparison of area reduction method and area increment method for reservoir sedimentation distribution - Case study Ujjani dam

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Abstract

The storage capacity of reservoirs is gradually depleted due to sediment accumulation that causes changes in the area-storage capacity curves (ASC). These curves are important for planners, designers and operators of dams. Many empirical and semi-empirical approaches have been suggested for establishing and predicting these curves. In this study two empirical methods were evaluated and used to determine the sedimentation volume for Ujjani reservoir, (also known as Yashwant sagar reservoir) on river Bhima in Solapur district, Taluka Madha of Maharashtra state of India. Ujjani reservoir started operating in 1980 with a storage capacity of 3320.008 MCM and a water spread area of 336.5 M sq. m.

In this research, sediment distribution concerning reservoir dam of Ujjani was estimated by area reduction and area-increment methods regarding primary area-volume-height information of dam. Finally, empirical method of area-reduction was chosen which estimates the sediment amount in this dam with lowest level of error. The experimental area reduction method is a technique for predicting sediment distribution in dam's reservoir and its parameters (C, m, n) have been obtained by Borland and Miller on the information from a limited number of dams in America.

Keywords: Sedimentation, Area Reduction, Area Increment, Ujjani reservoir dam

1. Introduction

Sediment particles in the river are in form of sand, silt, gravel and even larger boulders. Water flowing in the river, scours its bed and banks, detaching these sediment particles from the surface and carries them to the downstream. If a dam is constructed on this river, the velocity of the flowing water is reduced due to obstruction, thereby helping the sediment particles to settle down in the reservoir formed. This phenomenon is called "Reservoir Sedimentation". It results in loss of storage capacity of Reservoir. This problem can be addressed in planning stage itself by predicting the sedimentation in future. Also, proper management of dam operations can be planned for avoiding sedimentation. Reservoir sedimentation studies are essential for keeping a check on siltation over the years after closure of dam. Having known the quality of sediment distribution and prediction, we can choose the policies of exploiting the reservoir and decision making about the problems caused by sediments with higher confidence. Sediment settlement is not uniform. With the researches on 14 different reservoir dams done in India, the sediments often settle at the upper part of the reservoir where the water depth is 20 – 30 percent of the maximum reservoir depth (Houshmandzaeh *et al.* 2001) [5]. Because of the non-uniform and complex particles settlement, various methods have been developed for predicting sediment distribution in the different parts of the reservoir. These methods are based on presenting mathematical models, suggesting experimental and semi-experimental methods or they are based on making laboratory models, which are used only when there is a need for high accuracy since they are expensive and takes time to do it and are limited. Also, the presented mathematical models require several parameters most of which are hard to measure in most reservoirs or have not been measured accurately, but if they exist, they are highly accurate. Many experimental methods have been presented for calculating the feature of sediment distribution in dam reservoirs viz. Khosla's Procedure, Soil conservation Service procedure, Musgrave Method, CBIP Research Committee Method, Fournier Method, Douglas Method, Joglekar Method, Trigonometric Method, Volume-Reduction Method, Manual Design Curve Method, Van't Hul Method, Area-Increment Method, Area Reduction Method. However, area increment and area reduction methods are the most common (Amini *et al.* 2010) [1]. The base of both of which is the adjustment of the reservoir's primary due to the settlement of sediments. The cause of the advantages of these two methods over the others is that they need input data.

2. Methodology

The first empirical methods were developed by Borland and Miller (1958) referred to as "area increment method" and "area reduction method". The first one assumed that the reduction on water surface area at any depth above the new zero depth is constant, meaning that an equal amount of sediment will be deposited within the each depth increment of the reservoir (Borland, Miller, 1958; Strand, Pemberton, 1982) [2, 10]. The area reduction method is the most commonly used method for predicting the impact of sediment deposition in a reservoir or the change in the AEC curves with reservoir sedimentation. The method was proposed based on analysis of sedimentation data for 30 reservoirs in the USA and adopted by the U.S. Bureau of Reclamation (Morris, Fan, 1998) [3]. This technique is based on the adjustment of the water surface area above zero depth to a new area due to sedimentation that reflects the relationship between reduction in water surface area, sedimentation rate and reservoir characteristics. In this method the reservoirs are classified into four categories based on the shape factor of the reservoir "M" (table 1). The shape factor represents the reciprocal slope of the straight line for the relationship of reservoir depth at the dam site as the Y-axis against the storage capacity as the X-axis presented as a logarithmic scale plot (Borland, Miller, 1958; Mohammadzadeh-Habili, Heidarpour, 2010; Kaveh *et al.* 2013) [2, 8, 6]. The shape factor of a reservoir does not change linearly with time and depends on many factors including the characteristics, age and operation mode of the reservoir (Borland, Miller, 1958; Morris and Fan, 1998) [2, 3].

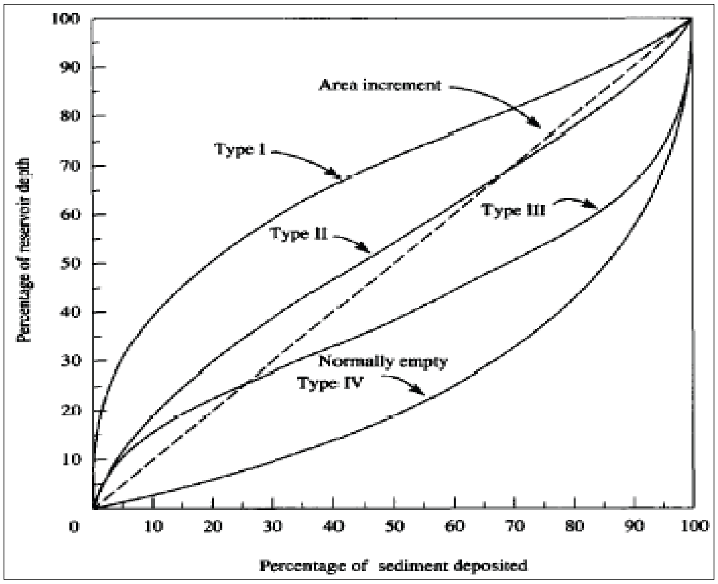


Fig 1: Type curves of reservoirs for area reduction method (modified Strand and Pemberton, 1987).

3. Study area Ujjani (Yashvant Sagar) reservoir

Ujjani reservoir (also called Yashavant Sagar reservoir) on river Bhima, in Solapur district of Maharashtra state of India. Ujjani Dam was built in 1980, mainly for the purpose of irrigation (1,12,940 ha of land), also caters to the drinking and industrial water supply requirements of Solapur city. It is the largest reservoir in Maharashtra in terms of storage capacity. Designed Sedimentation Rate assumed in design was 3.572 ha.m/100 km^2/year.

The water spread area at the time of impoundment at FRL 497.33 m was 349.304 Km^2 and corresponding capacity was 3491.21 Mm^3, and that at MDDL 491.03 m was 197.56 Km^2, and corresponding capacity was 1802.81 Mm^3. Two canals emerging from either banks cater water for irrigation to the command area from Solapur, Ahmednagar and Pune districts. Total catchment area of the project is 14856 Km. As informed by Irrigation Department that ever since the construction of the dam in the year 1977 the only capacity survey carried out was by MERI in 2001.

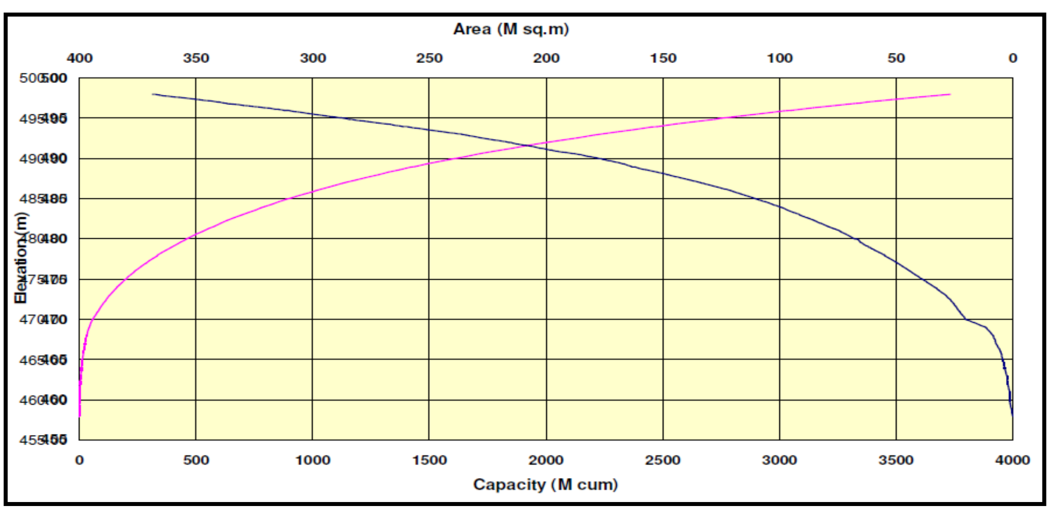


Fig. 2: Elevation-Area-Capacity Curve for Ujjani Reservoir for the Year 1977 (Original)

4. Data analysis for Ujjani reservoir

4.1 Area reduction method

One of the empirical methods in estimating sediments amount behind dams is area reduction method. This method was proposed by Borland and Miller in 1958 to field's reclamation committee of America and is obtained through studies of actual results of 30 great reservoirs in America. This method was modified by Lara in 1962. The results show that accumulation and distribution of sediments in different reservoir heights has a specific relation with reservoir shape and the reservoir shape is defined and categorized according to the relation between reservoir height and capacity.

Table 1. Different reservoirs gradation according to shape.

Classification number	Reservoir type	Parameter 'm'
1	Lake	>3.5
2	Flood plain, Foot hill region	2.5-3.5
3	Hilly region	1.5-2.5
4	Gorge	1.0-1.5

Following steps must be followed in the area-reduction method in order to define sediment distribution type

First step: Definition of reservoir type according to factor m. Factor m is reverse slope of best graphic representative line of reservoir height per reservoir capacity drawn on a full logarithm paper in which, vertical axis is the depth and horizontal axis is the volume.

Second step: Defining different values of comparative depth P. Comparative depth is calculated through dividing reservoir depth in definite level by reservoir depth in normal level.

Third step: Relative sediment area (a_p) is calculated through substituting different values of P relative depth in the equation relating reservoir type. Finally and by use of proportionality coefficient of K (according to the equation), sediment relevant area is converted to actual area and new zero will be defined.

In this relation, A_0 is the reservoir area in height h_0 (bed - building stage), a_0 is the relative area of sediment in new zero height. Relative area is calculated through following formula in which C, m, n are constant coefficients which are defined according to with regards to reservoir type. Of course, these are modified values of Borland and Miller method. It's favourable to optimize these values for each reservoir.

$A_p = Cp^m (1-p)^n$

Table 2. Reservoir type modified values of Borland and Miller method

Type	C	m	n	Sediment storage near
1	3.4170	1.5	0.2	Top
2	2.3240	0.5	0.4	Upper middle
3	15.882	1.1	2.3	Lower middle
4	4.2324	0.1	2.5	Bottom

Fourth step: Using depth-capacity curve of the reservoir, sediment volume below reservoir zero level is defined and then, sediment volume in different depths is estimated. It should be noticed that, this is a trial and error method and if calculated volume of sediments be greatly different from input sediments, proportionality coefficient should again be modified.

$K_2 = K_1 (S/S_1)$

The reservoir capacity between two elevations was then computed by prismoidal formula:

$V = h (A_1 + A_2 + \sqrt{A_1 * A_2}) / 3$

4.2 Area-increment method

Area-increment method was proposed by Christiphano in 1953. Principle of forecasting sediment deposit in reservoirs by this method is based upon calculation of areas-reduction in each height as a result of definite amount of sediment accumulation. It is supposed in this method that, sediment level all heights is constant and sediment volume is distributed evenly in height above zero. The mathematical relation is as follows:

$Vs = A_0 (H-h_0) + V_0$

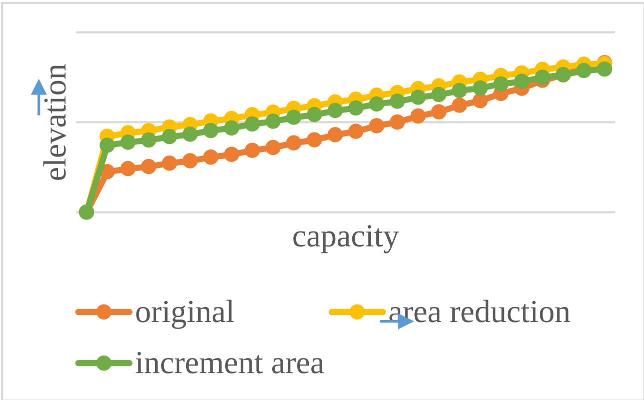
Where, Vs is total sediment volume per square meter, A_0 is area correction coefficient in meter square which equals to reservoir area in new zero digit, V_0 is sediment volume below new zero digit in cubic meters, H is reservoir height above stream bed to the maximum normal digit per meter, h_0 is the elevation of reservoir filled with sediment in new zero digit per meter.

In this method we should first guess a level concerning the new elevation and then, with regards to primary reservoir area-volume-height table of the reservoir, area and volume values of the reservoir are defined. Then, as for the area-increment relation, total volume is calculated and compared to predicted total volume at the time of design. In case these two values be the same, initial conjecture regarding new zero height is correct, otherwise, another new zero height will be guessed and the whole procedure is repeated until equality of two volumes is reached.

5. Results and Discussion

The difference between the cumulative capacities of original (1977), area reduction and increment area are compared. The comparative capacity-elevation curves are shown in figure.

Fig 3. Comparison of Capacity-Elevation Curve for Ujjani Reservoir



As it is seen in figure 3, the volume-height graph obtained through area reduction method shows better conformance to original values (hydrography).

The percentage error by area reduction method is 0.6 % and the percentage error by increment area method is 4.26%.

6. Conclusion

Results showed that:

1. Both method of area-reduction and area-increment can be used with a little difference, in estimating dam sediments.
2. Finally, area-reduction method shows closer results to dam hydrography values compared to area increment method.
3. The error rate in estimating Ujjani dam sediments by use of area-reduction method is 0.6 percent.
4. The error rate in estimating Ujjani dam sediments by use of area-increment method is 4.26 percent.

7. References

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