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Prediction of siltation in Kaptai reservoir

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Abstract

Kaptai Lake at Rangamati is the only reservoir in Bangladesh. Its catchment area of 11003 km^2 and capacity is 6170 Mm^3. One of the most important problems in the development and maintenance of the reservoir is the loss of storage capacity due to siltation. Decrease of storage capacity prevents the reservoir from supplying the services for which it was designed, thus disturbing the economic life of the reservoir. Actually it is extremely difficult to make a good estimate of sedimentation in a peculiar shaped vast pool of water but it is very important to know as far as possible the extent and the rate of sedimentation which might affect the storage capacity of the reservoir. In order to carry out the study on the last 12 years annual inflow data with other necessary information and field survey data for the last 18 years were also collected. The Prediction model developed by Swamee has been used to predict the future trend of sediment deposition and annual sedimentation rate for the reservoir. The rates obtained by field measurements and Prediction model are 3.33 and 4.09 ha-m/100 sq.km/year respectively. In the light of comparison made the sedimentation rates obtained by both the methods, it is appeared that the Prediction model can be applicable for the reservoir with reasonable accuracy. Empirical equations have also been used to compare the results with obtained the Prediction model and field measurements. Therefore Prediction model can suitably be used with reasonable accuracy than any other empirical equations. Expected life of the reservoir was also estimated by the method provided by Hachiro Kira approach, Garde and Swamee's equatioin and Step method which is related to the Brune's trap efficiency curves.

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1. Introduction

The deposition of sediment in reservoir will autonomically reduce its water storing capacity. If this process of deposition continues longer a stage is likely to reach when the

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reservoir may get seriously silted up and become useless. Hitou River in Northern China lost 54% of the initial storage capacity of 4.23 Mm^3 in a period of 7 years (Bruk, 1985). World wide reservoir storage is being depleted due to sedimentation at an estimated rate of one percent per year (Mahmood, 1987). Reservoir sedimentation is a problem that plagues all reservoirs (Fan, Jiahua 1992). So, sedimentation studies have led to a better understanding of the various aspects of reservoir sedimentation and their effect on the life of reservoirs. In order to combat this problem of silting and extent the useful life of the reservoirs various measures have to be adopted. Bed load is difficult to measure and data is also scarce. When the observed data on suspended sediment is not available, empirical equations can be used to estimate the quantity of sediment likely to deposit in the reservoir.

Kaptai Lake is the only reservoir in Bangladesh. This is the only hydropower generation unit of the country and has contributed significantly to countries power grid. No mentionable works have been carried out to find out the volume of sediment deposition and sedimentation rate for the Kaptai reservoir. Therefore, the siltation study was directed towards the prediction of sedimentation in the reservoir by applying a prediction model. This model has been compared with other empirical equations and observed data of the reservoir. In addition, expected life of the reservoir was also estimated by various available methods.

2. Data collection

The annual inflow data for the year 1989 to 2000 and other required data were collected from Karnafuli Hydropower Station (KHS). Field survey data for the year of 1983 and 2000 at 67 cross-sections along the Kaptai reservoir was collected from the Surface Water Hydrology Division, Bangladesh Water Development Board (BWDB), Comilla. The following methods were also used to predict the sediment deposition and annual sedimentation rate and expected life of the reservoir. The values of the different parameters of the methods are reproduced in Table 1.

Table 1
Hydrologic and Hydraulic data

Average annual inflow (Mm^3)	Average rainfall (cm)	Full water level (m)	Average width at full water level (m)	Average initial bed slope
14521.31	248.92	33.22	664.13	0.00028

3. Prediction model

The cumulative water inflow can be obtained by sequential data generation. The following equation was used for generating data:

$$Q_{i+1} = Q_i + (1-r)\overline{Q} + s\,(1-r^2)\,\eta^+ \quad (1)$$

Where Q_i is the mean annual flow in the ith year (Mm^3); Q_{i+1} is mean annual water flow in the ith year; s is standard deviation of the given data; η^+ is the random normal deviate having zero mean and unit standard deviation; r is first serial correlation coefficient of observed annual inflow data and $\overline{Q}$ is the mean annual flow (Mm^3).

Swamy related the sediment deposited in a reservoir to cumulative volume of water inflow per unit width of the reservoir at the full reservoir level and the average initial bed slope (Mutreza, 1995). The best fit equation is

$$V_s/B = 1.16\ (V_w)^{0.94}\ S_0^{0.84} \tag{2}$$

where V_s is the volume of sediment deposited in the reservoir (Mm^3); B is the average width of reservoir at the full water level (m); V_w is cumulative volume of water inflow per unit width of the reservoir at full water level (m^3/m) and S_0 is the average initial bed slope.

4. Standard deviation

The standard deviation is defined as:

$$s = \left(\frac{N}{N-1}\right)\sqrt{\left(\frac{\sum x_i^2}{N} - \overline{Q}\right)} \tag{3}$$

where N is the total number of observations (Years) and Σx_i is the cumulative water inflow in the ith year (Mm^3).

5. Serial correlation coefficient calculation

The serial correlation coefficients are defined as:

$$r = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1} x_i . x_{i=1} - \frac{1}{(N-1)^2}(\sum_{i=1}^{N-1} x_i)(\sum_{i=1}^{N-1} x_{i+1})}{\left[\frac{1}{N-1}\sum_{i=1}^{N-1} x_i{}^2 - \frac{1}{(N-1)^2}(\sum_{i=1}^{N-1} x_i)^2\right]^{\frac{1}{2}}\left[\frac{1}{N-1}\sum x_{i+1}^2 - \frac{1}{(N-1)^2}(\sum_{i=1}^{N-1} x_{i+1})^2\right]^{\frac{1}{2}}} \tag{4}$$

6. Sediment deposition rate

The sedimentation rate per 100 sq.km/year was calculated by the following equation:

$$R = \frac{Vs}{A * y} * 100 * C_f \tag{5}$$

where, R is the sedimentation rate per 100 sq.km/year (Mm^3); V_s is the volume of sediment deposited in the reservoir (Mm^3); A is the catchment area of the reservoir (Km^2); y is the number of years and C_f is the consolidation factor in percent is ranged between 0.30 and 0.60 for the reservoir.

7. Empirical equations

7.1 Joglekar's equation

Based on observed data Joglekar suggested:

$$Q_s = \frac{0.597}{A^{0.24}} \qquad (6)$$

Where Q_s is the annual silting rate from 100 sq.km of watershed area ($Mm^3/100$).

7.2 Khosla's method

Khosla analysed the data from various reservoirs and observed data that the annual sediment deposited against the catchment area and suggested the following relationship:

$$Q_s = \frac{0.323}{A^{0.28}} \qquad (7)$$

7.3 Garde and Swamee's equation

An approximate empirical method for estimating the total volume of sediment in a reservoir is given by Swamee and Garde (Garde and Rangu Raju, 1985) as follows:

$$\frac{V_S}{V_r} = \frac{\left(\frac{T}{T*}\right)^m}{\left[1+\left(\frac{T}{T*}\right)^{\frac{m}{n}}\right]^n} \qquad (8)$$

Here, V_r is the original reservoir volume in Mm^3; T* is the number of years in which the reservoir would be completely filled up and may be calculated by

$$T* = 2.21*10^{-8} * \frac{A^{0.38}\,\overline{P^{4.11}}}{V_r^{0.019}} \qquad (9)$$

where $\overline{P}$ is the average annual rainfall in cm; m is ranged between 0.47 and 1.0 and n is ranged between 0.15 and 0.36 for the observed reservoir. The life of the reservoir is also obtained by the equation (9).

7.4 Deposition rate from field data

The entire Kaptai reservoir consists of 67 cross-sections. The total area of the reservoir was calculated by Simpson rule. Siltation and erosion volume has been computed for all sections by multiplying the area calculated with length between the individual cross-section. The sedimentation rate per 100 sq.km/year from field measurements was calculated by the equation (5).

8. Life of the reservoir

8.1 Step method

Estimation of the life of reservoir has been studied by Murthy (Mutreza, 1995). He related the capacity inflow-ratio with the sediment trapped in percent. Initially, the computations were made for 10, 20 and 30 year intervals. It was found that the trap efficiency changes with time because of a reduction in the reservoir capacity due to silt deposition. If trap efficiencies change more rapidly, as in the case at the end of the period, the reservoir approaches to the point of being filled with sediment. Sediment deposited in the reservoir during the periods are equal to the product of annual sedimentation rate, number of years, and trap efficiency during the period. Results obtained by this method have been given in Table 2.

Table 2
Life of the reservoir (Brune's trap efficiency relationship)

Time (year)	Capacity (ha-m)	Capacity inflow ratio (capacity/inflow)	Trap efficiency in percent	Sediment deposited (ha-m)	Cumulative sediment deposited (ha-m)
0	617000.00	0.42489	95	-	-
10	610864.14	0.42067	95	6135.860	6135.8600
20	604728.28	0.41644	95	6135.860	12271.720
50	586320.70	0.40377	95	17407.58	30679.300
100	555641.40	0.38264	95	30679.30	61358.600
200	494282.80	0.34038	94	61358.60	122717.20
300	433570.08	0.29857	94	60712.72	183429.92
400	372857.36	0.25677	93	60712.72	244142.64
500	312790.52	0.21540	92	60066.84	304209.48
600	253369.56	0.17448	91	59420.96	363630.44
700	194594.48	0.13401	88	58775.08	422405.52
800	137757.04	0.09487	85	56837.44	479242.96
900	82857.24	0.05706	79	54899.80	534142.76
1000	31832.72	0.02192	63	51024.52	585167.28
1030	19625.59	0.01352	54	12207.13	597374.41
1050	12650.09	0.00871	43	6975.500	604349.91
1070	7095.52	0.00489	27	5554.570	609904.48
1080	5351.64	0.00369	25	1743.880	611648.36
1090	3736.94	0.00257	11	1614.700	613263.06
1100	3026.47	0.00208	5	710.4700	613973.53
1110	2703.53	0.00186	0	322.9400	614296.47

8.2 Hachiro Kira approach

In 1995 Hachiro Kira has analysed observed sedimentation data of a number of reservoirs collected from Japan, U.S.A and Taiwan and found out the number of years when the reservoir will be fully silted up. The following relationship obtained

$$Y_s = 467(c/i)^{0.473} \tag{11}$$

where Y_s is the average number of years during which the silt will filled up in the reservoir; c is the original storage capacity of the reservoir in m^3 and i is the annual mean flow into the reservoir in m^3.

9. Results and discussions

Volume of sediment deposition for the year 2001 to 2015 in the Kaptai reservoir has been predicted by the Prediction model. It is found that the sediment deposition is linearly increasing in every year. A critical examination reveals that the Prediction model has a significant role to predict sediments linearly in the reservoir which is clearly discernible from the Figure 1.

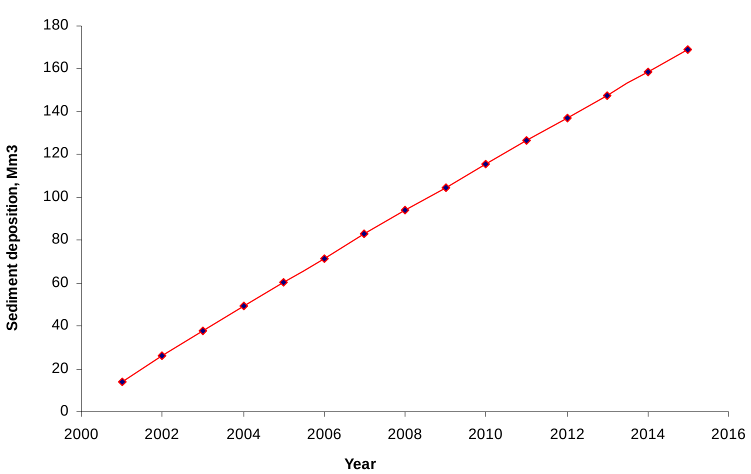

Figure 1: Predicted yearly sediment deposition in Kaptai Reservoir

Sediment deposition and erosion volume of the reservoir from the field measurements has been measured. It is observed that most of the sections of the reservoir produced siltation and few of them produced erosion. It is appeared from the Figure 2 that maximum amount of sedimentation has been occurred at the section 16 due to landslide in the adjoining hills and maximum amount of erosion has been occurred at the section 43 due to erosion from reservoir banks by wave action and current flow.

Sedimentation rate between the Prediction model and measured values are 4.09 ha-m/100sq.km/year and 3.33 ha-m/year respectively. The rates obtained by three empirical equations are 6.40, 2.39 and 2.25 ha-m/100sq.km/year respectively. It is observed in

Figure 3 that the variation between measured and predicted sedimentation rate by using prediction model is smaller than any other empirical equations. Therefore prediction model can be applied with reasonable accuracy compared to other empirical equations.

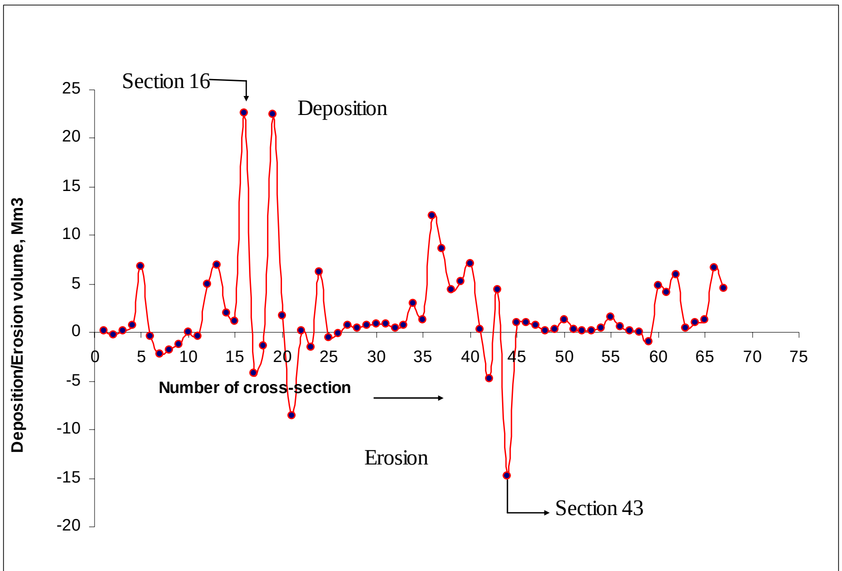

Figure 2: Measured amount of sediment and erosion volume

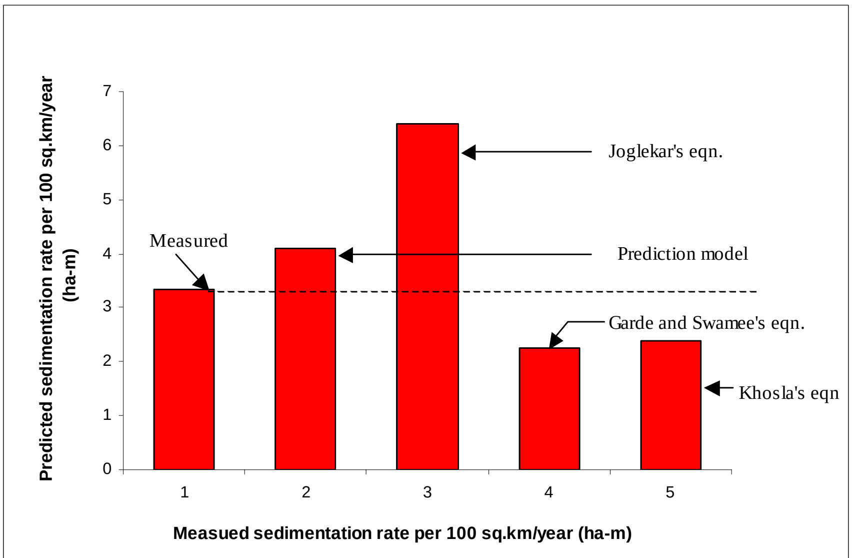

Figure 3: Comparison of sedimentation rate among Prediction model, Empirical equations and Observed values

The life of the reservoir has been estimated using the Hachiro Kira approach, Step method and Swamee and Garde method and obtained as 312 years, 1110 years and 4527 years respectively. The life of the reservoir obtained by Step method is shown in Figure 4 and Figure 5.

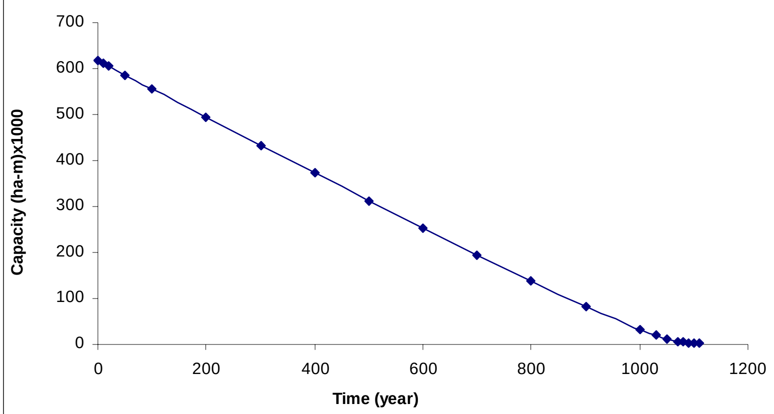

Figure 4: Estimated life of the reservior

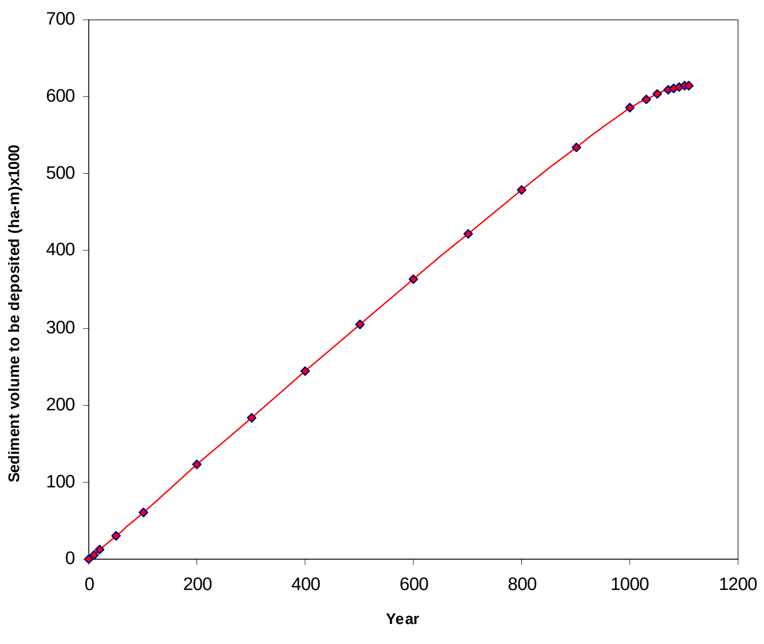

Figure 5: Estimated life of the reservoir

10. Conclusions

The Swamee's prediction model used in this study is quite reasonable to assess the prediction of siltation in Kaptai reservoir. Since the siltation in Kaptai Reservoir is difficult, it is worth to use the prediction model to assess the sediment loads. Result obtained from the prediction model has been compared with measured data and found good agreement. Percentage of discrepancy ratio of sedimentation rate obtained between the model and field measurement is found to be 22.82. Therefore Prediction model can suitably be used with reasonable accuracy to predict the volume of sediment deposition and sedimentation rate for the reservoir than any other empirical equations. Finally life of the reservoir has been calculated using various available methods. Hachiro Kira approach is found to be suitable for estimating the life of the Kaptai reservoir.

References

Bruk (1985). Methods for computing sedimentation in lakes and reservoir, UNESCO, Paris

Brune, G.M (1953). “Trap efficiency of reservoir”; American Geophysical Union, 34 (3), USA

Fan and Jiahua (1992). “Reservoir sedimentation”; Journal of Hydraulic Engineering, ASCE 118 (3):pp 354 -369

Mahmood K. (1987). “Reservoir sedimentation”; Impact, extent and mitigation, World Bank Technical Paper No.71, Washington, D.C, 1987, USA.

Mutreja K.N (1986). “Applied Hydrology”; Fourth Reprint 1995, Published by Tata McGraw-Hill Publishing Company Limited, New Delhi, India

Shahidullah M. (2002). “Prediction of Sedimentation in Kaptai Reservoir”; M.Engg Thesis, Dept. of Water Resources Engineering, BUET, Dhaka.