MATHEMATICAL ANALYSIS FOR THE LOSS OF FUTURE STORAGE CAPACITY AT MAITHON RESERVOIR, INDIA

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ABSTRACT

Reservoir siltation is inevitable because of continuous deposition of silts, pollutants etc due to soil erosion from upstream part of river and domestic / industrial waste intrusion in the river. The pace of siltation process can only be retarded which would indirectly aid to life of the reservoir. This paper presents a study on the future storage capability along with reliability in the serviceability of the Maithon reservoir, India. The surveyed capacity elevation data for the year 1956, 1965, 1971, 1979, 1987, 1994, 2002 and 2010 were considered for the analysis. A graphical relation for storage loss at different stages such as dead storage, live storage, flood storage level and overall capacity loss are presented. Mathematically linear trend equations of the above relations are developed with vide validation with the original surveyed data. From the above equations the loss of storage capacity in the future years are also found out at the various stages of the reservoir storage.

Keywords: maithon reservoir dead storage, flood storage, live storage, overall gross capacity, siltation.

INTRODUCTION

All the reservoirs in the world receiving water from natural rivers are bound to be silted up by these rivers. Efforts can only retard the process and allows a reservoir more time effective and economical functioning in respect of its assigned specified tasks. It sounds ominous for future generations who would one day find themselves without sites of reservoirs for water storing though there would be greater and acute. Flushing can bring about the necessary useful volume for regulation of daily discharge in the Dez River and Sezar River of Iran [1].

In India, in the early stages practically no data on silt load was available. Depending on the scanty data available, assumptions based on thumb rules were made for the design purposes. In many cases, these assumptions have proved partially accurate while in some reservoirs siltation rates were observed high (or even low). Life of Govind Sagar reservoir was found by using the capacity inflow ratio, trap efficiency, sediment density and different sediment characteristics [2]. The detailed methodology for calculating the reservoir life period was well explained by [3]. In India, Himalayan Rivers carrying large amount of silts would need to be sampled at many points and the ratio of number of sediment sampling station to discharge station of these rivers must be 1:5 and 1:10 for the rivers of South India [4].

The Maithon Reservoir, main focus of this study was first ponded in 1955 just after impounding the Tilaiya Reservoir in 1953. There has been substantial progress in Maithon reservoir; yet, the severe floods that occurred during September 1999 in West Bengal indicate there are limits to which the Damodar Valley Corporation (DVC) can meet all the expectations conceived in 1948 [5].

Barakar is the main tributary of the Damodar River, in which two multipurpose reservoirs at Tilaiya and at Maithon have been built up in series as shown in Figure-1. Several reservoir capacity surveys were carried out at Maithon in 1956, 1965, 1971, 1979, 1987, 1994, 2002 and 2010 prior to the said study. After about 56 years of successful reservoir operations, it was felt that the time has come to study the serviceability of the reservoir and to discuss the need for adopting precautionary measures in time to make future plans successful. By empirical-area reduction method depicts that the dead storage capacity of the Maithon reservoir would be silted up by the year 2039 [6]. In that study it was also seen that the trap efficiency of the reservoir may decrease rapidly during years 2110 and 2140, reducing the rate of sediment deposition to 5.3 and 2.8 Mm^3/ year respectively. According to Murthy's recommendation the designed siltation rate of the reservoir was 4.79 Mm^3/ year [7] and the actual rate of deposition of silt from catchment area of 5300 km^2 was found to be 6.32 Mm^3/ year.

In this study past survey data of the storage capacity of Maithon reservoir are considered and loss percentage in storage capacity of main three levels i.e., dead storage, live storage and flood storage level are calculated for each surveyed year with respect to initial ponded year i.e., 1955. An effort is made to find out a mathematical relation from the above calculation so that future year's loss of storage in the above main three levels along with the average overall capacity could be estimated.

STUDY AREA DESCRIPTION

The prime motivating concepts for development of the Maithon Reservoir led to addressing needs for flood control, hydropower generation, irrigation, navigation, municipal water supply, malaria control, reforestation, and soil conservation. This project was undertaken in a valley comprising two distinct landforms, in accordance with the variations in topography, climate, and soil characteristics. The upper valley has abundant mineral resources (it is, for instance, a major coal mining area for India) and extensive forests. It has a drier climate and more steeply sloping

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land. The dam was subsequently built had relatively larger watersheds having a catchment area of about 5300 km^2.

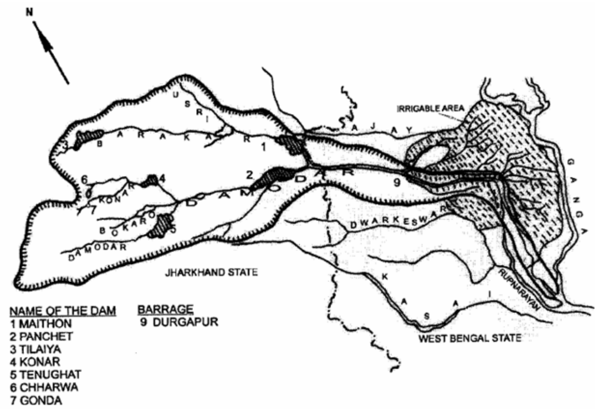

Figure-1. Map of Damodar River basin

The lower valley impinges into the lower deltaic region of West Bengal and is largely agricultural, especially in the vicinity of the Durgapur Barrage. The deposition of pollutants and silts due to soil erosion from the upstream of the rivers such as Usri and Barakar as till date Balpahari Reservoir could not have been implemented. The river erosion mechanism and enhancement of sediment removal technique were well enlightened by [8, 9, 10]. Barakar River has Tilaiya Dam to control much of silts but due to high river slope geographically between Tilaiya and Maithon suggest a clear chance of high soil erosion in between Tilaiya and Maithon and result in high siltation at Maithon reservoir. Moreover Usri River doesn't have any dams or barrages to control the flow of water along with silts. Several reservoir capacity surveys were conducted at Maithon in 1956, 1965, 1971, 1979, 1987, 1994, 2002 and 2010 prior to the said study and analysis are done according to the received data of capacity survey from DVC, Maithon.

METHODOLOGY

a) In order to suggest the future trend of the loss of the storage capacity at various reservoir levels the storage elevation and area elevation curves from past surveyed years was collected.
b) From the initial ponded year the losses of storage capacity for the later surveyed years were found out in terms of percentage. This is the difference between the storage capacity of initial ponded year and the later surveyed years.
c) A graphical relation between losses of storage capacity and surveyed years apart from the initial ponded year is to be drawn.
d) An equation of the trendline from the above graphical relation is useful to calculate the exact year when the storage capacity of the reservoir at three main levels would lose their capacity.
e) Loss of gross overall storage capacity can also be found out along with a trendline equation which would suggest the threat of reservoir to lose its life unless precautionary steps are taken to retard this severe siltation process.
f) Trendline equations are validated using the relations of three main storage levels i.e., dead storage, live storage and flood storage with the surveyed original values

RESULTS AND DISCUSSIONS

By using the surveyed capacity data four graphical relations for storage loss at different stages such as dead storage, live storage, flood storage level and overall gross capacity loss are developed. The trendline equation gives the future remarks in view of the exact loss of storage capacity of the reservoir at different stages.

Outcome of loss of storage capacity of dead storage level (upto 132.588 m elevation of the reservoir):

Figure-2 illustrates the year wise loss of storage capacity at the dead storage level of the reservoir and it is observed that the percentage of storage loss of that level increases linearly with correlation coefficient (*r*) of 0.978.

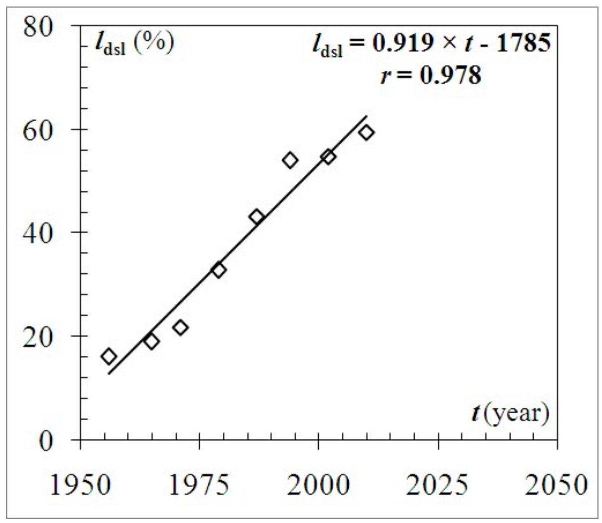

Figure-2. Year wise loss of percentage of storage capacity at dead storage level (l_{dsl}).

A linear equation is thus found out between the percentage of loss of storage capacity and the affected years where this loss is incurred.

Outcome of loss of storage capacity of live storage level (from 132.588 m upto 146.304 m elevation of the reservoir)

In Figure-3 it is observed that year wise linear increment of percentage in loss of storage capacity (l_{lsl}) is less prominent than that shown in Figure-2 having a correlation coefficient of 0.938. A linear trendline equation of the above relation is found in order to depict about the future reliability of the reservoir in providing water for irrigation, drinking and industry.

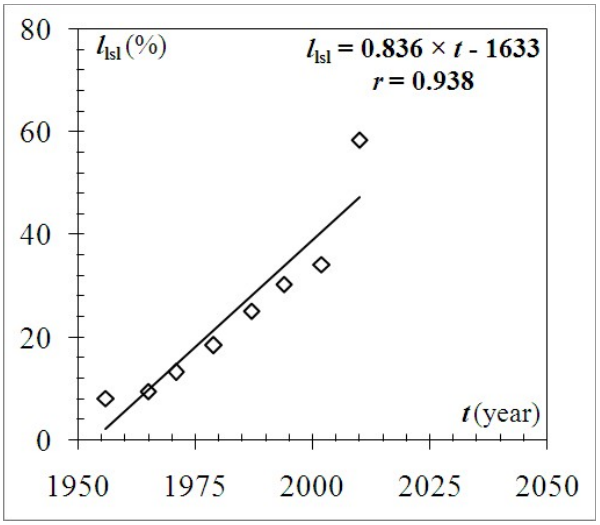

Figure-3. Year wise loss of percentage of storage capacity at live storage level (l_{lsl}).

Outcome of loss of storage capacity of flood storage level (from 146.304 m upto 150.876 m elevation of the reservoir)

Figure-4 illustrates about the future reliability of the reservoir against flood. From Figure-4 it is observed that the year wise increment of the percentage loss of storage capacity (l_{fsl}) is in a most prominent linear fashion with a correlation coefficient of 0.987 accordingly a linear

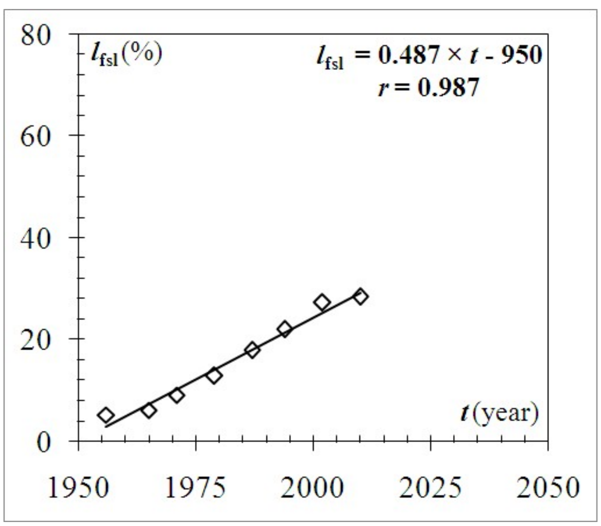

Figure-4. Year wise loss of percentage of storage capacity at flood storage level (l_{fsl}) equation is also found out to mark about the future reliance towards flood.

Outcome of loss of storage capacity of overall reservoir storage capacity

The life of the reservoir mainly depends on its reliability to store water in overall main three levels such as dead storage, live storage and flood storage until the overall percentage loss of storage capacity increases above a specified limit practiced in India. Year wise loss of percentage of storage capacity of overall reservoir (l_{osl}) is found in Figure-5 and linear trend is observed having a correlation coefficient 0.987. The linear equation, found from the relation as shown in Figure-5, may depict about the probable life of the reservoir if it runs in same fashion without undertaking any siltation controlling steps.

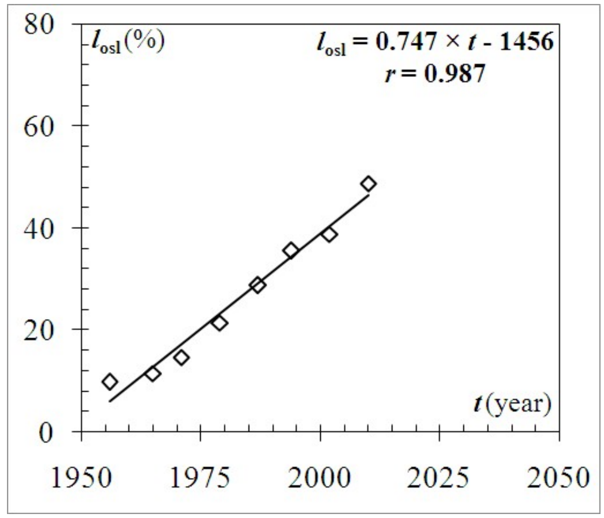

Figure-5. Year wise loss of percentage of storage capacity of overall reservoir (l_{osl}).

VALIDATION

Figures-6-9 represent a comparison of original loss of storage capacity from the surveyed data and loss calculated from the trendline equation in all the four storage conditions mentioned above.

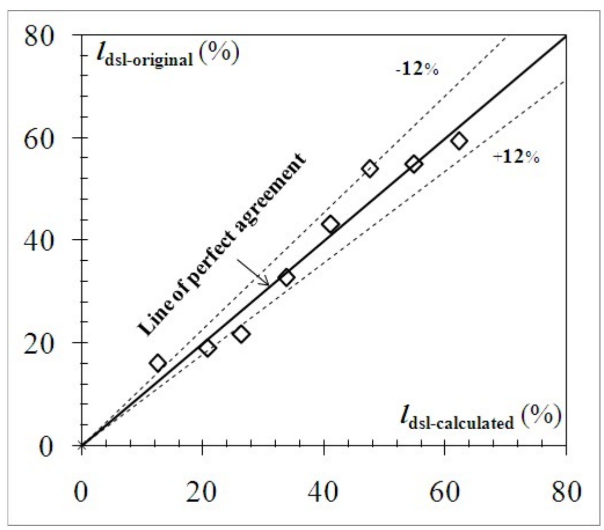

Figure-6. Comparison of original loss from the surveyed data and loss calculated from the trendline equation for dead storage level.

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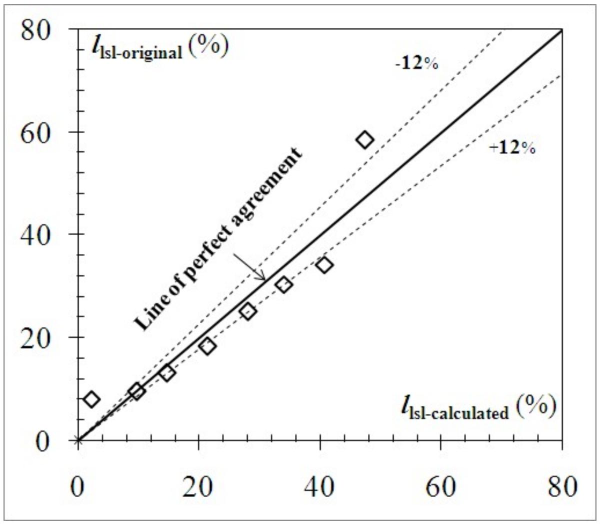

Figure-7. Comparison of original loss from the surveyed data and loss calculated from the trendline equation for live storage capacity.

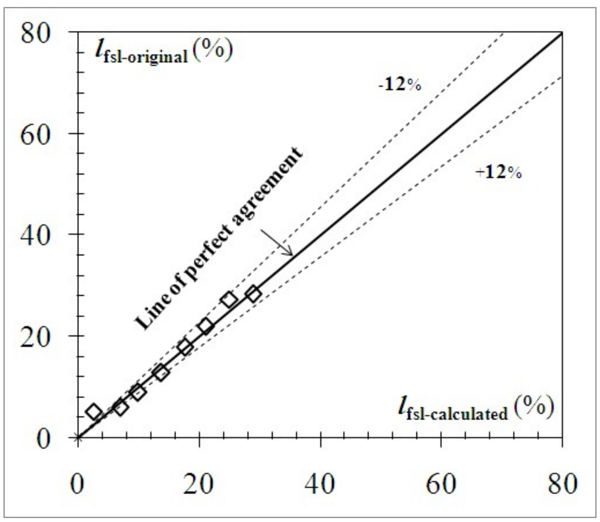

Figure-8. Comparison of original loss from the surveyed data and loss calculated from the trendline equation for flood storage level.

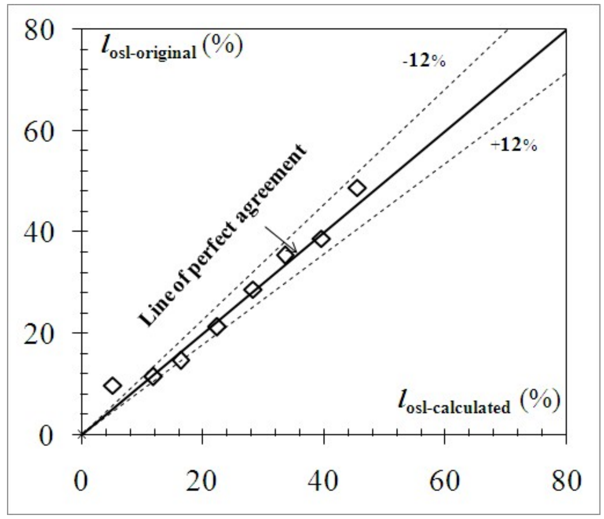

Figure-9. Comparison of original loss from the surveyed data and loss calculated from the trendline equation for overall storage level.

The ±12% deviation intervals are added as dashed lines. It is observed from Figures 6-9 that the deviation between the original loss of storage capacity from the surveyed data and loss calculated from the trendline equation are mostly in a range of -12% to 12% i.e., the trendline equation outcomes match well with the original surveyed data. For the year 1956 a minor variation is observed between than actual and estimated values of the percentage of losses for dead storage level, overall storage capacity, flood storage level and live storage level.

Only the ± 12% variation is given because the original storage capacity depends on the siltation rate which is due to deposition of pollutants and silts in the river at various times in a year.

From the trendline equations shown in Figures-2-4 the future trends about the storage loss depicted are shown in Table-1.

Table-1. Future year results for percentage of loss of storage capacity at various storage levels

Storage condition	Future year for percentage loss of storage capacity				
	60%	70%	80%	90%	100%
Dead storage level	2008	2019	2029	2040	2051
Live storage level	2025	2037	2049	2061	2073
Flood storage level	2073	2094	2114	2135	2156
Overall storage level	2029	2043	2056	2069	2083

CONCLUSIONS

The linear trendline equation is found out in Figures-2-4. The future conditions of the serviceability of the Maithon reservoir would depend as mathematically the correlation coefficient found out from the above said Figures ranges 0.938 to 0.987. This correlation coefficient which is near to value one justifies the year wise loss of percentage of storage capacity at various reservoir level

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increases in prominent linear fashion. Geographically it is seen that the Maithon reservoir gets contribution from two rivers i.e., Barakar and Usri. Barakar River has Tilaiya Dam to control much of silts. But due to high river slope terrain between Tilaiya and Maithon suggests a clear chance of high soil erosion in between Tilaiya and Maithon and results in high siltation at Maithon reservoir. Moreover Usri River doesn't have any dams or barrages to control the flow of water along with silts. Table-1 which is a tabulated version of the relations found in Figures-2-4 suggest that the siltation at the upstream of the reservoir can cause a serious threat to loss of reservoir storing capacity around the year 2043 if the positive approach for controlling the siltation process is delayed. The serviceability of the reservoir depends mainly on the live storage which is also matter of concern around year 2037 due to loss of storage. The increase in the stream bed level due to the siltation is bound to result in decrease in the storage capacity at the upstream of the reservoir. Time has come to think about constructing small dam at the conjunction point of two rivers so that it can trap the silt to a handful amount. To cope up with the water demand due to migration of people to urban areas the authorities are concerned about the enhancement of the capacity of the water distribution in an urban area. [11]. In this regard few study were done on concepts of pumps and pipeline selection which may help to conserve the water use to some extent. [12]. For a global scenario this types of conservation may not be enough. So, by seeing the national interest the time has come to carry out a research study and also to find out more controlling techniques of reducing the huge amount of sediment flow to the Maithon Reservoir so that the life and reliability of the old DVC reservoir which was once made for the national interest of the two states Bihar (now Jharkhand) and West Bengal can be enhanced.

List of symbols

The following symbols are used in this study:

l Percentage of loss of storage capacity [-]
r Correlation coefficient [−]
t Time in terms of year [T]
l_{dsl} Percentage of loss of storage capacity at dead storage level [-]
l_{lsl} Percentage of loss of storage capacity at live storage level [-]
l_{fsl} Percentage of loss of storage capacity at flood storage level [-]
l_{osl} Percentage of loss of storage capacity of overall storage level [-]

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