VARIATION OF TRAP EFFICIENCY WITH AGE OF GANDHI SAGAR RESERVOIR-A CASE STUDY

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Abstract: Consistently the demand of water is increasing and available sources of potable water on earth are diminishing. Sustainable use of reservoir is ensured by monitoring sedimentation process of any reservoir and taking required measures timely to control the rate of sedimentation. Data is collected and analysis is carried out to know the rate of sedimentation and reduced capacity of the reservoir. Trap efficiency (TE), an important factor governs the sediment phenomenon in reservoir. As the age of reservoir increases, the TE decreases in most of reservoirs. This study is an attempt to predict TE of Gandhi Sagar Reservoir and to analyse the effect of age on TE. Results show that there is no significant reduction of TE in 55 years.

Index Terms: **Trap efficiency, Gandhi Sagar Reservoir, Age of the reservoir, Sedimentation.**

I. INTRODUCTION

Water is an essential element for all kinds of life on the earth but everywhere scarcity has emerged due to hydrological changes and increased use by human (Stewart, 2014). It is nexus of food security, energy production, nutrition security, economic growth, poverty reduction and human health. The water in the world is found in different forms and locations such as on the surface, in the air, in the oceans and under the ground. Only 2.5% of the water found on the earth is fresh water and remaining 97.5% water is useless for human or agriculture purposes. (Cullen, 2009; A Summary by Green Facts, 2016; WWDR, 2016). Only 0.3% of 2.5 % fresh water is in liquid form and remaining in the frozen state (Green facts, 2016). The availability of this fresh water varies from region to region in the world. Human activities and natural forces such as urbanization, climate change, deforestation, pollution, high living standard, ill management and wastage are reducing available water resource (Green facts, 2016). It has been found through gravitational data obtained from GRACE (Gravity Recovery and Climate Experiment) satellite system that more than 18 largest aquifers of earth are being depleted (Frankel, 2015).

It is expected that up to year 2050, the population of the world will rise to 9.5 billion from 7.0 billion in 2011 and this potential increment is about 33%. The urban population is also going to double in this period of 40 years. This population growth will cause increase in food demand by 60%. Water demand will definitely increase in all sectors such as agriculture, energy production, industrial and social development (UN WATER, 2016). Thus small amount of available fresh water is not sufficient to meet the future requirement. According to UN estimation, two third of the world's population will face the shortage of water by the year 2025 (Cullen, 2009).

The water is stored for sustainable management of water resources by constructing a dam across the river. This body of stored water is known as reservoir. Thus reservoirs are very important structures to store rain water directly as precipitation and run-off. These reservoirs help in the progress of society and meet the increasing demand of water (State of the Art Report, 2010). These reservoirs serve various purposes such as water supply, hydropower, irrigation, navigation, flood control and recreation (Gill, 1979; Morris and Fan, 1998).

1.1 Problem of Sedimentation in Reservoirs

All these reservoirs have lost their huge capacity because of sedimentation due to erosion of soil, which is continuously increasing and creating serious problems in all developed, developing and undeveloped nations on the earth (Vente et al., 2004).
The construction of dam and formation of reservoir provides valuable water storage on one hand but causes change in river flow regime on both upstream and downstream of reservoir on the other hand (Mathew et al., 2017). The flow velocity of river on upstream of reservoir reduces before it enters the reservoir due to large cross sectional area of reservoir (Carvalho et al., 2000). Thus the sediment transporting capacity of river is reduced and deposition of sediment takes place (Michalec, 2014). Coarse materials such gravel and coarse sand with small amount of fine particles start depositing first at the entry point of river into the reservoir and this deposition is known as delta or topset bed zone. Fine sediment particles travel ahead of coarse particles and enters into the reservoir and deposit near dam forming a bottomset bed zone (Fig.1). The zone of advancing part of delta between the topset bed and bottomset bed is recognized by steep slope known as foreset bed zone (Morris and Fan, 1998).

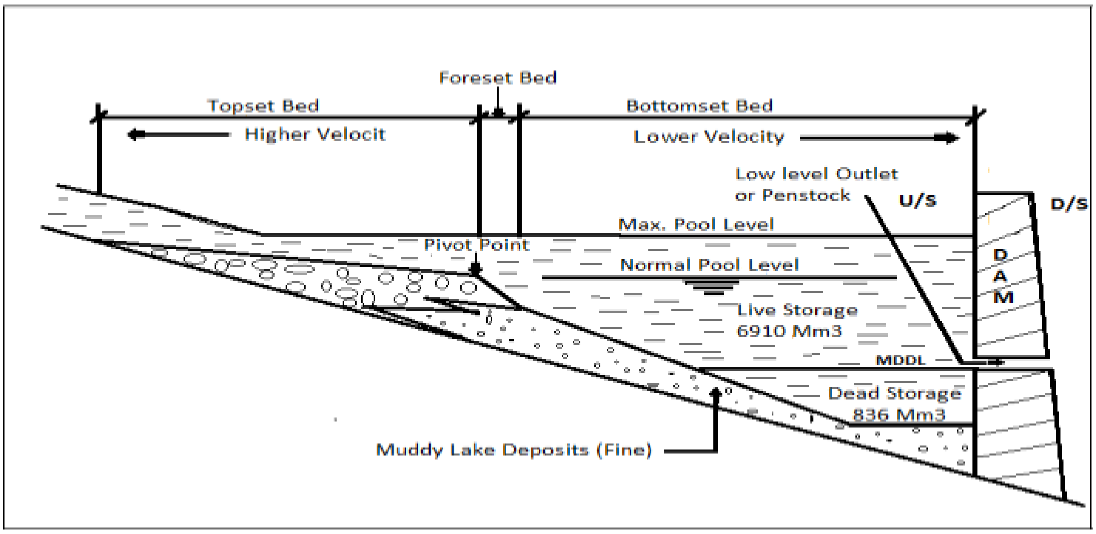

Figure 1: Sediment Deposit Zones in Reservoirs

This entrapped sediment in the reservoirs causes reduction in storage capacity and useful life of reservoirs and the whole world is concerned about this problem of sedimentation (White and Bettess, 1984). The deposition of sediment in the reservoirs not only reduces the storage capacity but affects the placement of sluices, design of dam walls and intake structures and flood lines on upstream of reservoirs and hence the desired purposes are not served by the reservoirs (Mulu and Dwarakish, 2015).

Reduction of storage capacity due to sediment deposition in the reservoir has been great concern of all engineers, planners and operators since formation of the reservoirs. The sedimentation causes total annual reduction in storage capacity of reservoirs in the world is approximately 1-2% of total capacity (Walling and Webb, 1996). According to the information of Central Water Commission (CWC), the department of Government of India under Ministry of Water Resources, 23 of 27 reservoirs surveyed by Remote Sensing Method have lost 214.2 Mm^3 of live storage capacity i.e. about 1% per year of their original live storage capacity (Thakkar and Bhattacharyya, 2017).

Thus all the reservoirs suffer with a perpetual problem of sediment deposition which is inevitable and irreversible (Rahmanian and Banihashemi, 2012). The rate of sedimentation in the reservoir depends upon varying capacity of reservoir, the nature and quantity of incoming sediment in the reservoir and the ability of reservoir to retain the sediment (Gottschalk, 1948). The water resources engineers are facing the biggest challenge of present to extend useful life of reservoirs and this challenge is going to be continued in future (Coker et al., 2009).

There are many reservoirs in the world which were silted at very high rate and did not perform up to their designed life. Hence designers, planners and operators always try to find the rate of sediment deposition, trap efficiency of reservoir, distribution pattern of sediment and usable life of the reservoir (Issa, 2015). The 20th century mainly focused on development of reservoirs but the 21st century will be focused on conservation and sustainability of existing reservoirs (Palmieri et al., 2003).

The estimation of Trap Efficiency (TE) is considered very important in study of capacity reduction due to sedimentation of reservoirs (Garg and Jhothiprakash, 2010). TE is defined as the percentage of the ratio of sediment retained in the reservoir to the total incoming sediment. Factors such as ratio of reservoir capacity to inflow, shape of the reservoir, types of the outlets and reservoir operation affect the TE. Characteristics of the sediment such as shape and size of the particles also affect the TE. TE generally decreases with passes of time due to increasing sediment deposition (**Minear and Kondolf, 2009**) but some large reservoirs maintain high TE for long life. Volume of sediment can be easily estimated through TE.

A research on prediction and mitigation of sedimentation in Roseires and Aswan High Dam reservoirs of Nile Basin, it was found that the Aswan High Dam constructed across the Nile River in Aswan, Egypt, suffering with very high rate of 100% TE. On the other hand it is found in the case of Roseires Reservoir that the TE falling at exceptionally high rate. TE was decreasing linearly with the square root of time and after 100 years it will remain only 14% (**Kamaleldin et al., 2010**).

The Gandhi Sagar Reservoir is the biggest and most important structure constructed under joint venture for power and irrigation project of Madhya Pradesh and Rajasthan in 1959 on the Chambal River in Madhya Pradesh. The catchment area of about 23025 Km^2 is intercepted by this reservoir. This Reservoir provides water for power generation in Gandhi Sagar, Rana Pratap Sagar and Jawahar Sagar dams and for irrigation through canals taking off from Kota Barrage.

1.2 Location

Gandhi Sagar Reservoir is the biggest and oldest reservoir of Madhya Pradesh in India. This reservoir was created by constructing a dam across the Chambal River, a major tributary of Yamuna River flowing in Mandsaur District of Madhya Pradesh and in Rajasthan. This was completed at the end of first five year plan in 1960. The dam is 8 km away from Bhanpura tehsil in Mandsaur district of Madhya Pradesh in North-East direction. The Location and satellite image of Gandhi Sagar Reservoir are shown in Fig. 2 and Fig. 3 respectively. Gandhi Sagar Dam is 64.63 m high straight gravity rubble stone masonry dam, 514 m long, 53.4 m wide at the base with 182.93 m central spillway and five power blocks on its right flank along with non-overflow blocks at both flanks. This reservoir was first impounded in 1961 with total storage capacity of 7746 Mm^3 which includes 836 Mm^3 as dead storage capacity and 6910 Mm^3 as live storage. The total catchment area of reservoir is 23025 km^2. The capacity to inflow (C/I) ratio of Gandhi Sagar Reservoir is more than 50% hence it is classified as hydrologically large reservoir (Morris & Fan, 1998).

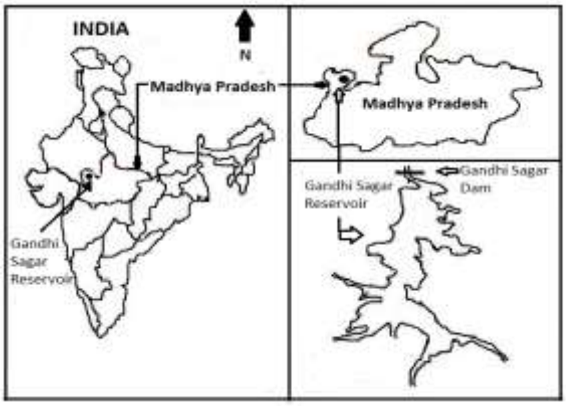

Figure 2: Location of Gandhi Sagar Reservoir

Figure 3: Satellite Image of Gandhi Sagar Rservoir

II. METHODOLOGY

The available data of annual Inflow, incoming and outgoing sediment from 1962 to 1989 and predicted data from 1990 to 2016 based on available data have been used in this study to estimate TE.

2.1 Trap Efficiency of Reservoir

There are various empirical relationships given by various researchers such as Brown (1944), Churchill (1948), Brune (1953), Borland (1971), Dandy (1974), Gill (1979), Heinemann (1981) and many others available for estimation of TE of reservoirs. These empirical relationships are widely used for estimating TE of reservoirs but they suffer with the limitations that the characteristics are entirely different which were used to develop these relationships. Hence results do not match with the results of bathymetric surveys conducted for the same reservoir. Thus modification of these empirical relationships is required to suit for a particular reservoir.

Further these empirical methods have been modified by many researchers to minimize the errors in estimation of TE and sediment and to make more suitable and easy in implementation.. There are three methods namely Brune (1953), Ward (1980) and Heinemann (1981) have been modified in this study particularly for Gandhi Sagar Reservoir. The original and modified models of these studies are presented in Table 1 below.

Table 1: Original and Modified Empirical Models

Method	Original Model	Modified Model
Brune (1953)	$\mathrm{TE_{Brune}} = 100\left[1 - \frac{1}{1 + 50\left(\frac{C}{I}\right)}\right]$	$\mathrm{TE_{Brune}} = 100\left[1 - \frac{1}{40 + 750\left(\frac{C}{I}\right)}\right]$
Ward (1980)	$\mathrm{TE_{Ward}} = 100\left[1 - \left(\frac{0.05}{\sqrt{\Delta\tau}}\right)\right]$	$\mathrm{TE_{Ward}} = 100\left[1 - \left(\frac{0.001}{\sqrt{\Delta\tau}}\right)\right]$
Heinemann (1981)	$\mathrm{TE_{Heinemann=}}\left[-22 + \frac{119.6\left(\frac{C}{I}\right)}{0.012 + 1.02\left(\frac{C}{I}\right)}\right]$	$\mathrm{TE_{Heinemann}} = \left[-20 + \frac{120\left(\frac{C}{I}\right)}{0.001 + \left(\frac{C}{I}\right)}\right]$

III. ANALYSIS

Here the effect of reservoir age at one year and five year interval on variation of TE has been investigated.

3.1 Effect of Reservoir Age at One Year Interval

The TE has been estimated considering C/I ratio changed due to sedimentation at the age of reservoir at one year interval. The results of three modified empirical methods namely Brune (1953), Ward (1980) and Heinemann (1981) were examined for variation in TE. The TE estimated by these approaches is presented in Table 2 below.

Table 2: Variation of TE at the Interval of One Year of Reservoir Age

Age of Reservoir	TE by Inflow-Outflow Sediment Approach %	TE by Brune Approach %	TE by Ward Approach %	TE by Heinemann Approach %
1	100	99.917	99.919	99.922
2	100	99.907	99.915	99.913
3	100	99.922	99.922	99.928
4	100	99.935	99.929	99.940
5	100	99.942	99.933	99.946
6	100	99.944	99.934	99.949
7	100	99.941	99.932	99.945
8	100	99.929	99.926	99.934
9	100	99.927	99.924	99.932
10	100	99.925	99.924	99.931
11	100	99.927	99.925	99.933
12	100	99.906	99.914	99.912
13	100	99.904	99.913	99.910
14	100	99.903	99.913	99.909
15	100	99.897	99.910	99.904
16	100	99.896	99.910	99.903
17	100	99.896	99.909	99.902
18	100	99.899	99.911	99.905
19	100	99.900	99.912	99.907
20	100	99.902	99.912	99.908
21	100	99.904	99.913	99.910
22	100	99.906	99.914	99.912
23	100	99.905	99.913	99.911
24	100	99.906	99.914	99.912
25	100	99.903	99.913	99.909
26	100	99.905	99.913	99.911
27	100	99.905	99.914	99.911
28	100	99.907	99.915	99.913
29	100	99.906	99.914	99.912
30	100	99.906	99.914	99.912
31	100	99.908	99.915	99.914
32	100	99.909	99.915	99.915
33	100	99.907	99.915	99.913
34	100	99.906	99.914	99.913
35	100	99.904	99.913	99.911
36	100	99.904	99.913	99.911
37	100	99.905	99.914	99.911
38	100	99.906	99.914	99.912
39	100	99.908	99.915	99.914
40	100	99.909	99.916	99.915
41	100	99.911	99.917	99.917
42	100	99.912	99.917	99.918
43	100	99.912	99.917	99.918
44	100	99.913	99.918	99.919
45	100	99.910	99.916	99.916
46	100	99.910	99.916	99.916
47	100	99.912	99.917	99.918
48	100	99.913	99.917	99.919
49	100	99.914	99.918	99.920
50	100	99.914	99.918	99.920
51	100	99.914	99.918	99.920
52	100	99.913	99.917	99.919
53	100	99.914	99.918	99.920

Age of Reservoir	TE by Inflow-Outflow Sediment Approach %	TE by Brune Approach %	TE by Ward Approach %	TE by Heinemann Approach %
54	100	99.913	99.917	99.919
55	100	99.913	99.917	99.918
Average	**100**	**99.911**	**99.917**	**99.917**

The results of variation shown in Fig. 4 indicate that a very insignificant reduction in TE occurred in age of reservoir 10 to 20 years and then with negligible increment it became almost constant up to present age. Hence no significant variation of even 0.2% is observed. In 55 years, TE varied from 99.89% to 99.94%.

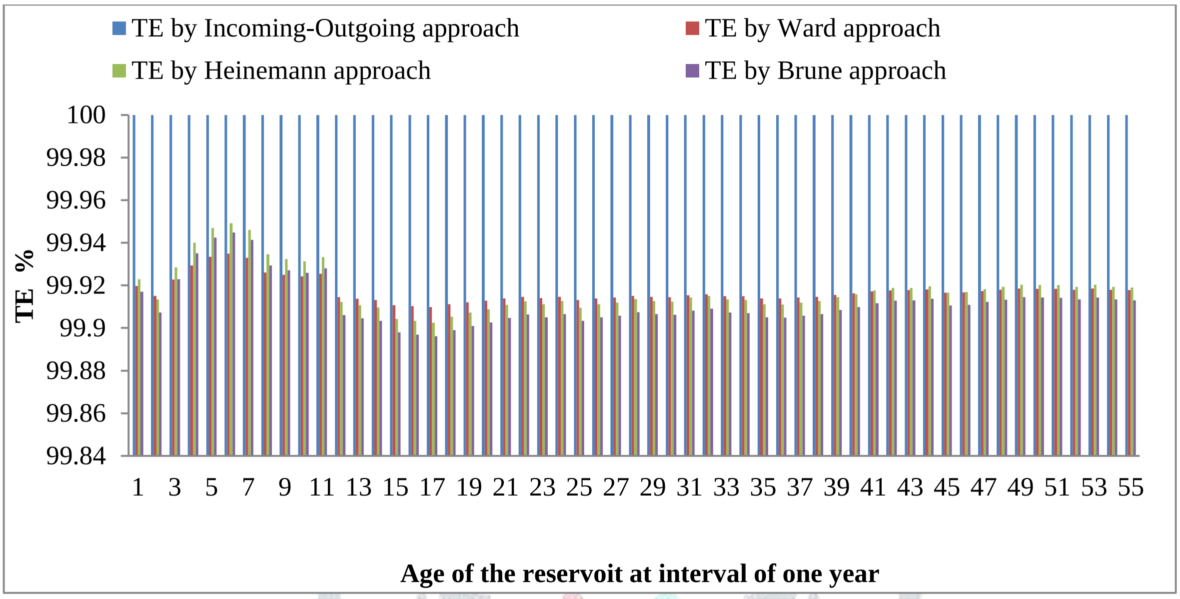

Figure 4: Variation of TE at Age of the Reservoir at Interval of One Year

3.2 Effect of Reservoir Age at 5 Year Interval

The variation of TE has been observed considering the reservoir age at five years interval. Modified Brune (1953), Ward (1980) and Heinemann (1981) empirical methods were used to estimate TE considering C/I ratio at five years interval. The results are presented and shown in Table 3 and Fig. 5 respectively. Results show that TE reduces very insignificantly in the beginning and the remains constant up to present year.

Table 3: Variation of TE with Age of Reservoir at 5 Year Interval

Age of Reservoir	TE by Inflow-Outflow Sediment Approach	TE by Brune Approach	TE by Ward Approach	TE by Heinemann Approach
5	100	99.942	99.933	99.946
10	100	99.925	99.924	99.931
15	100	99.897	99.910	99.904
20	100	99.902	99.912	99.908
25	100	99.903	99.913	99.909
30	100	99.906	99.914	99.912
35	100	99.904	99.91	99.911
40	100	99.909	99.916	99.915
45	100	99.910	99.916	99.916
50	100	99.914	99.918	99.920
55	100	99.913	99.917	99.918
Average	**100**	**99.911**	**99.917**	**99.917**

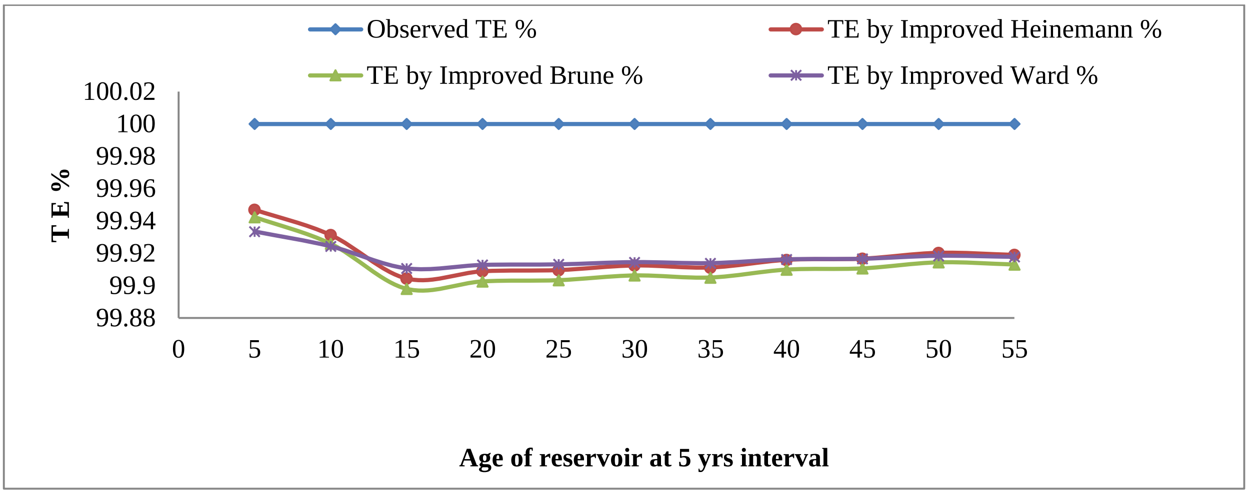

Figure 5: Variation of TE at Age of the Reservoir at Interval of Five Year

III. RESULTS AND DISCUSSION

Average TE estimated by all three methods is 99.91% in 55 years. Generally TE reduces as the age of reservoirs increases but in the case of Gandhi Sagar Reservoir, TE has not reduced and is constant at about 100%. It shows that all the sediments are being trapped in the reservoir except for few days during floods in year 1963, 1969, 1971, 1973, 1974, 1976, 1996, 2006, 2013 and 2015.

Here the effect of age of reservoir at one year and five year interval on variation of TE has been investigated.

The results indicate that very insignificant reduction in TE occurred in age of reservoir 10 to 20 years and then with negligible increment it became almost constant up to present age. Hence no significant variation of even 0.2% is observed. In 55 years, TE varied from 99.89% to 99.94%.

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IV. CONCLUSIONS

The effect of reservoir age on trap efficiency has been found quite insignificant i.e. it is almost constant. The reason seems to be non-overflowing of Gandhi Sagar Reservoir, which is also indicated by observed negligible amount of outflow sediment.

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