SILTATION STUDIES OF RESERVOIRS

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I, **Shivam Sharma, Roll No. 2K17/HFE/14** student of M.Tech **(Hydraulics and Water Resources Engineering),** hereby declare that the dissertation titled "**Siltation studies of Reservoirs**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title of recognition.

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I hereby certify that the project dissertation titled "**SILTATION STUDIES OF RESERVOIR**" which is submitted by **SHIVAM SHARMA,** 2K17/HFE/14, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of **MASTER OF TECHNOLOGY IN HYDRAULICS AND WATER RESOURCES ENGINEERING**, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

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ABSTRACT

The most important practical and critical problem related to the performance of reservoirs is the estimation of storage capacity loss due to sedimentation process. The problem to be addressed is to estimate the rate of sediment deposition and the period of time at which the sediment would interfere with the useful functioning of a reservoir. Fairly a large number of methods and models are available for the estimation, analysis and prediction of reservoir sedimentation process. However, these methods and models differ greatly in terms of their complexity, inputs and computational requirements.

In the present study, trap efficiency is calculated for different reservoirs using different approaches like Brune's curve, Gill's method, Brown's method, etc. The trap efficiency of Bhadra reservoir(Karnataka) has been found out to be 96% according to brune's curve, 93.26% according to Heinemann's curve, 96.88% according to USDS-SCS equations, 96.063% according to Dendy's method, 99.51% according to brown's curve, 96.37% according to Gill's method, 97.93% according to Jothiprakash and Garg method. The trap efficiency of Upper Kolab reservoir(Odisha) has been found out to be 95.5% according to brune's curve, 92.985% according to Heinemann's curve, 96.749% according to USDS-SCS equations, 95.67% according to Dendy's method, 99.27% according to brown's curve, 96.14% according to Gill's method, 97.656% according to Jothiprakash and Garg method. The trap efficiency of Panchet reservoir(Jharkhand) has been found out to be 80% according to brune's curve, 76.166% according to Heinemann's curve, 80.7% according to USDS-SCS equations, 79.43% according to Dendy's method, 81% according to brown's curve, 82.078% according to Gill's method, 81.86% according to Jothiprakash and Garg method. The trap efficiency of Idamalayar reservoir(Kerala) has been found out to be 96.8% according to brune's curve, 93.67% according to Heinemann's curve, 96.987% according to USDS-SCS equations, 96.657% according to Dendy's method, 99.8% according to brown's curve, 96.71% according to Gill's method, 98.335% according to Jothiprakash and Garg method. The values of trap efficiency determined by Heinemann method and Brown method differ from the values

of trap efficiency obtained by other methods. The reason behind the variation in Heinemann's curve is because of the fact that it is developed using the data of small ponds while in our case the size of reservoirs is quite large. All the methods used above except Brown's method uses the relationship between capacity and inflow for the determination of trap efficiency. However Brown's method relates the trap efficiency with the ratio of capacity of reservoir and watershed area, therefore the variation in the results of Brown's method is attributed to this factor.

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LIST OF ABBREVIATIONS

Abbreviation	Expansion
A	Watershed Area
C	Capacity
C/A	Ratio of Capacity and Area
C/I	Capacity/ Inflow
CWC	Central Water Commission
FRL	Full Reservoir Level
Ha.m	hectare metre
I	Inflow
IS	Indian Standard
K	Constant
Km^2	Square Kilometer
M.Cu.m	Million Cubic Meters
NRSC	National Remote Sensing Centre
SCS	Soil Conservation Service
Sq.km	Square Kilometres
TE	Trap Efficiency
USDA	United States Department of Agriculture
WCD	World Commission on Dams
YR	year

CHAPTER – 1

INTRODUCTION

1.1 DAMS AND RESERVOIRS

Dams and Reservoirs are the most significant storage structures that have improved irrigation facilities in India. Improvement in the irrigation has lead to food security. In the last century there is noteworthy development in construction of reservoirs all across the world. There were 1,527 reservoirs operating in the world in 1970 out of which 152 were constructed in India (WCD, 2000). Now, India has about 4,300 reservoirs that irrigates 91.8 M ha and proves to be very useful to the society in many other ways (Sabeti, 2011).

Reservoirs are the storage structures that exists upstream of a dam constructed across a river with the intention to store water during period when river has excess water flowing through it and use it in the dry period or the time when river has less water. The construction of dam has many advantages like power generation, irrigation facilities through canal. Dams are also constructed with the purpose of flood control in flood prone areas. The construction of dam across a river alters the natural regime of the river by obstructing its flow. A reservoir holds a large amount of water in it and submerges large area of land. Construction of dam is a very big project economically, hence as a water resource development project all the benefit cost analysis are done prior. The number of river basins in India is 27. The numbers of river sub basins in India are 101. The number of watershed in India is 4566 (CWC and NRSC)

1.2 SEDIMENTATION

Rivers along with water takes with it large amount of sediments due to soil erosion from banks and beds. The construction of dam causes an obstruction to the flow of sediments through it and leads them to settle in its upstream side. Reservoir sedimentation causes a consequent loss of storage capacity of the reservoir. It also affects reservoir function, such as control of flood, supply of water, irrigation facilities, navigation facilities, electricity generation, etc. In dry regions, reservoir sedimentation become quite intense where the loss of active storage capacity is above 1 - 2 % per year and the lifetime of most reservoirs gets reduced by 20 to 30 years. The sedimentation of reservoirs reduces the useful life of the reservoirs, produces technical problems, water quality problems and also generates economical, social and environmental problems. The reservoir operation constraints sometimes make it compulsory to maintain certain minimum reservoir level and filling also happens at same level. After some period of time, large deposits of sediment built up in the reservoir. It develops a hump in the reservoir bed. This hump proves to be a natural barrier to the sediment flowing near to the dam. The harmful effect of this hump **is** the faster loss of live storage capacity. The sedimentation process in reservoirs increases the water turbidity in reservoirs that results to the environment problems for example it deteriorates the water quality and reduces the visibility for fish (IS 12182 - 1987).

The sedimentation of the reservoir over the years results in the accumulation of sediments, due to soil erosion, in the bottom layers which leads to the loss of storage of reservoir and thereby reduces the useful life of the reservoir.

1.3 THE EFFECTS OF SEDIMENTATION

The construction cost of dams and reservoirs is very huge and a large area is under submergence because of formation of reservoirs causing loss to flora and fauna of that area. The deposition of sediment in reservoirs sometimes affects the functioning of water intake structures and can create problems from the machinery point of view. The silt from the reservoir if not taken care of will flow into the canals and may deposit there thereby creating problems in the canal system causing over spilling conditions in the canals.

The large amount of water stored in the reservoirs is used for supply of water in dry seasons, electricity generation and irrigation purpose, navigation and recreational purpose.

The siltation in reservoir causes the storage capacity of reservoirs to reduce and therefore the reservoirs cannot deliver the benefits for the time it can have delivered without sedimentation. The top level of siltation affects the positioning of outlet structures of dam as otherwise it may cause problem in opening and closing of gate of these outlet structures. The efficiency of machinery working in the dam is affected by the process of sedimentation (Seethapathi et al 2008).

The location and height of outlet structures at the dam so that the water can go on the downstream side is affected by the process of sedimentation. The useful life of reservoirs or the economic life of the reservoir is affected by the sediment deposition.

The deposition of sediment exerts additional forces on the dam face in addition to the lateral forces for which the dam was designed for.

The sediments flowing in the river may affect the machinery for example turbine used in the power generation, outlets, sluice gates, etc may get affected due to sedimentation. Sedimentation reduces the efficiency of machinery and also increases the maintenance cost of these machinery.

The silt deposited in the reservoirs may sometimes go into the canal systems and get deposited there. This may increase the bed level of canal and can decrease the canal capacity. This may sometimes lead to flood in the areas through which the canal passes.

Sedimentation in the reservoir is caused due the deposition of sediments carried by the river with its flow. The river while flowing through its course erodes its banks and bed and carries the particles because of the velocity of flow. When the velocity of river becomes less the sediment carrying capacity of the river reduces and it leads to deposition of sediments. Due to soil erosion top fertile layer of soil is eroded and unfertile land is left behind.

The back water profile of the dam also changes because of the deposition of the sediments on the upstream side of the dam and therefore more area is submerged of the nearby land as compared with the area of submergence without sedimentation.

The sediment deposition at the entry of reservoir changes the regime of the river by forming delta and sometimes braided river patterns are formed. These structures further enhance the erosion and deposition process in the river thereby eroding the banks (Yu et al 2009).

The sedimentation process in reservoirs increases the water turbidity in reservoirs that results to the environment problems for example it deteriorates the water quality and reduces the visibility for fish.

1.4 TRAP EFFICIENCY

The trap efficiency of a reservoir is the ratio between the sediment deposited in the reservoir to the total amount of sediment inflow. It is the percentage of total inflowing sediment that is retained in the reservoir.

$$\text{TE} = \frac{sediment\ inflow - sediment\ outflow}{sediment\ inflow} \qquad (1.1)$$

Where, TE is the Trap efficiency of reservoir

The trap efficiency of reservoir depends on many factors such as hydraulic conditions in the reservoir, sediment characteristics, reservoir shape and age of reservoir, spillway location, reservoir operation conditions, outlet depth and outlet type and its location(Morris et. al.1998)(Garde et. al. 1985)(Espinosa et. al. 2009). Several approaches have been developed to calculate the trap efficiency of reservoirs because of the large number of factors that influence the trap efficiency and complex sedimentation process. It is very difficult and complex to develop a model by incorporating all the factors and then predict trap efficiency. It will be very time-consuming process also. Generally for the estimation of trap efficiency of reservoirs empirical data and formulas are used which are based on the survey data collected by various researchers from time to time. The various methods used in our present study has been discussed in chapter 4 under the heading methodology.

1.5 OBJECTIVES OF THE PRESENT STUDY

The objectives of the present study are

- To determine the trap efficiency of Bhadra Reservoir using different methods
- To determine the trap efficiency of Upper Kolab Reservoir using different methods
- To determine the trap efficiency of Panchet Reservoir using different methods
- To determine the trap efficiency of Idamalayar Reservoir using different methods
- To do a comparative study among different methods in assessing the trap efficiency of reservoirs.

1.6 WORK PRESENTATION

This thesis work is presented in seven chapters.

Chapter 1 presents the induction and brief review of the process of sedimentation and trap efficiency and how it affects the reservoir useful life and its operations.

Chapter 2 presents the review of literature of the existing research in the area of sedimentation and trap efficiency calculation and also presents some comparative studies done by several researchers.

Chapter 3 describes the area of the present study along with the location. This chapter discusses the four reservoirs on which our study is based and describes the salient features of the respective projects.

Chapter 4 describes the methodology used in the calculation of trap efficiency. This chapter presents the methods used in this work for the calculation of trap efficiency of the four reservoirs.

Chapter 5 presents the results of the trap efficiency calculation of all the reservoirs along with graphs and tables and also has all the results in a tabular and graphical form in the end.

Chapter 6 presents the conclusions drawn from the results of the trap efficiency calculation of the reservoirs from all the methods.

The references are given at the end.

CHAPTER 2

REVIEW OF LITERATURE

2.1 STORAGE LOSS OF RESERVOIRS

The reservoir sedimentation causes a continuous decrease in the active storage capacity of the reservoirs this also reduces the useful life of the reservoir. Studies around the globe tell about the harm caused by the reservoir sedimentation.

The Indus River takes with about 74 billion cubic meters of water and the river also carries about 300 million tons of sediment annually into the Tarbela Reservoir. The Tarbela reservoir was opened in 1974, within six years of its construction it accumulated nearly 950 million cubic meters of sediment and gets deposited in the upper thirty kilometres of delta (Wu et al 1991).

Several reservoirs in India also lost their storage capacities due to the reservoir sedimentation. Shangle (1991) surveyed about forty three reservoirs of all sizes including major, medium and minor all across the country. The results of the sedimentation survey determined the sedimentation rates for all the sizes of the reservoirs separately.

The storage capacity of the Welbedacht Reservoir located in South Africa which was opened in 1973 lost about 66% of its capacity within the thirteen years of its construction. In 1973 the storage capacity of reservoir was 152.2 M.Cu.m (Rooseboom, 1992).

The monetary loss caused by sedimentation in reservoirs in the United States of America by reducing the storage capacity of reservoirs is about 100 million dollars annually (Julien 1995). From 1893 to 1897, the total storage volume of Austin Reservoir, Texas lost nearly 41.5%. In thirteen years, the capacity of the new Lake Austin, Texas lost about 95.6%. In twenty two years the capacity of Habra reservoir in Algeria lost about 58%. In thirty five years, the capacity of Wuchieh Reservoir in Taiwan lost about 98.7%.

According to Asthana (2007), the capacity of storage of 9 reservoirs in India is reducing having average annual loss ranging between 0.34% and 1.79%. Based on the studies of 23 reservoirs, it is determined that for 21 reservoirs the rate of storage loss was more than the designed rate and for only two reservoirs the rate of storage loss was less than the designed rate.

2.2 TRAP EFFICIENCY OF RESERVOIRS

The Trap Efficiency (TE) is the ratio of sediment trapped in the reservoir to the sediment inflow. It is very important aspect as per the design of reservoirs as it affects the useful life of reservoirs.

Rausch and Heinemann (1975) based on the study of reservoirs in the state of Missouri in USA found that the sediments characteristics also affect the trap efficiency of reservoirs. The particle size of sediment and the retention time of storm runoff have an effect on the trap efficiency of reservoirs. The rate of discharge of sediment laden outflow from the dam can also make a difference in the value of trap efficiency.

Verstraeten and Poesen (2001) developed a numerical model for a small pond with area < 1 ha to simulate deposition of sediments. The numerical model used by Verstraeten and Poesen proved to be very beneficial and accurate when it was used for ponds in Belgium it gave highly accurate results and an root mean square error of 4.7% only.

Tonioloa and Schultz (2005) performed an experimental study to determine the effects on a reservoir due to over spilling occurring in the downstream. According to the results the over spilling conditions downstream a reservoir causes minimum trap efficiency.

Jothiprakash and Garg (2008) estimated the rate of sedimentation of Gobindsagar Reservoir constructed across Satluj River in Himachal Pradesh and also calculated its useful life time using the trap efficiency approach. The brune’s method of determination of trap efficiency and the gill’s method of calculation of useful life of reservoir were modified to suit the condition of given reservoir. Bhakra Beas Management Board estimated the useful life of Govindsagar reservoir to be 142 years considering the size of sediments as medium. While in the present study the useful life of this reservoir has been determined using trap efficiency approach as three fourth of the period estimated by Bhakra Beas Manangement Board and the sediment size considered were coarse grained.

Jothiprakash and Garg (2008) determined trap efficiency of Pong Reservoir constructed across river Beas in Himachal Pradesh using Brune's and Brown's methods. The measured value of trap efficiency was matching Brune's medium curve. For calculating trap efficiency, they developed a new regression equation based on brune’s curve and age of reservoir. The constant used in Brown's curve was modified in this study so that the results come closer to the measured values. Despite the modifications the brown’s method and the Gill’s method gave relatively constant value of trap efficiency.

2.3 USEFUL LIFE OF RESERVOIR

The useful life span of a reservoir is the time period for which water storage gives beneficial outputs.

The sedimentation of reservoir and its useful life are also influenced by the pattern of inflow and the characteristics of catchment. The reservoir constructed across the River

Manso in Mato Grosso state, Brazil (Carvalho and Lou 1990) is expected to have a life span of 1000 years. If the catchment area is rocky in terrain and having thick vegetation then the soil erosion in the area reduces thereby the amount of sediment in the inflow reduces. Hence thick vegetation should be grown along the slopes in a catchment to reduce erosion of top layer of soil.

The reservoir life span can be indicated by the ratio of storage volume and the annual inflow (Richardson, 1996). If the ratio of storage volume and the annual inflow is less than 1 that means inflow will fill the reservoir completely and if this ratio comes out more than 1 that means reservoir is not filled to its capacity by that inflow.

Lawrence et al (2004) did a study of sedimentation in small dams in Zimbabwe and Tanzania and they describes development of a new method for predicting sediment yields and quantify them.

The useful life of a reservoir not only depends on sediment deposition in the reservoir but also on the inflow, characteristics of catchment and on the properties of reservoir (Asthana, 2007).

2.4 COMPARATIVE STUDIES OF DIFFERENT METHODS OF TRAP EFFICIENCY

Bube and Trimble (1986) revised the curves proposed by Churchill (1948) by using the Churchill (1948) data and the data added by Borland (1971). They further revised the curves by using an optimization technique in that they decreased local sediment yields variance that is given by these curves.

Trimble and Carey (1990) made a comparison between the Churchill (1948) method and the Brune (1953) method based on the data collected from 27 reservoirs in the Tennessee River Basin. The results shows that the values of trap efficiency calculated using Brune's method were equal to or more than the value of trap efficiency calculated by Churchill's method. The results concluded that the Churchill method gives more realistic results as compared to that of Brune's for sediments yields for a system of reservoirs.

Butcher et al. (1992) measured the sediment in inflow and outflow for two reservoirs in southern Pennines, UK. They performed a comparative analysis between the trap efficiency observed and the trap efficiency calculated using Brown's method, Churchill's method, Brune's curve and Heinemann's curve. The results of all the methods were quite reasonable and close to the observed trap efficiency. Brown's method was concluded to be the most accurate among all because the reservoirs in this study had the same hydrologic regime as the reservoirs used by brown in his study. The brown's curve uses two parameters capacity and catchment area, hence this method is simple to use.

According to Rowan et al. (1995) for Abbystead Reservoir, UK, the trap efficiency values determined from Heinemann (1981) method was 30% lower than that calculated by Brown (1944) method. The value of trap efficiency calculated from Brune (1953) method comes out in between the values obtained from other two methods.

Taher-Shamsi and Sabzivand (1999) did a comparative analysis of three different methods of calculation of trap efficiency. They used the data of various reservoirs in Iran. According to the results, the value of trap efficiency calculated from the brune's curve and brown's method were closer to the measured value in the field. However the Churchill's method overestimated the value of trap efficiency as compared with field data.

Rao (2018) made a study of Krishnagiri Reservoir, Tamil Nadu and according to his results the value of trap efficiency calculated using Gill's method is found to be closer to the measured value of trap efficiency. The dominant particle size of sediment in the reservoir was fine grained. The values of trap efficiency calculated for the reservoir ranges from 64.99% to 95.31%. The useful life of the Krishnagiri reservoir has been predicted to be 101 years.

CHAPTER 3

STUDY AREA

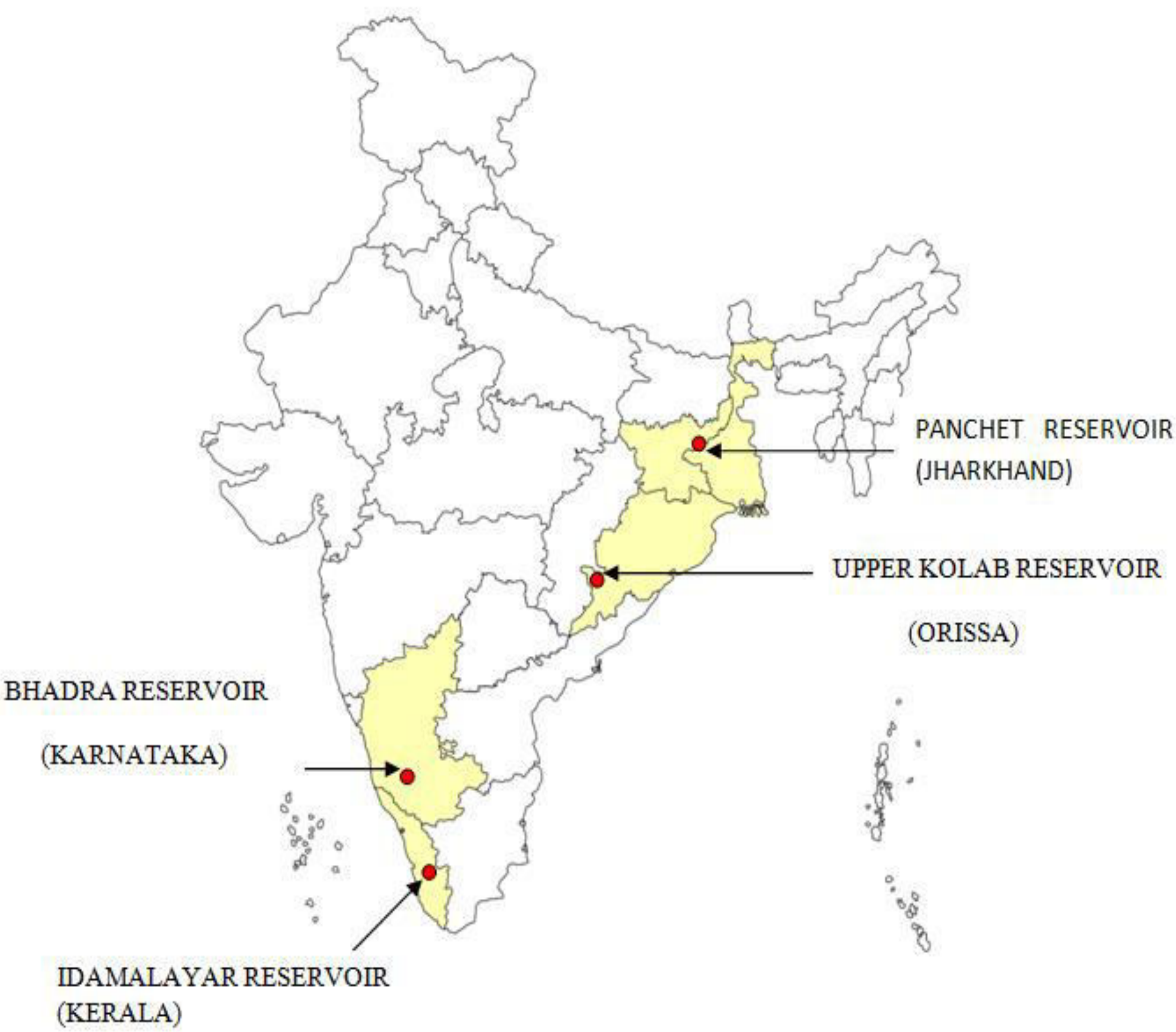


FIGURE 3.1 LOCATION OF RESERVOIRS IN INDIA

3.1 THE BHADRA DAM

The Bhadra dam constructed in 1964 is located at Tarikere tehsil of the Chikkamangalur district in the state of Karnataka. The dam was constructed to serve as a multipurpose project. The dam provides irrigation facilities through canals taking water from both right and left banks. In addition to the irrigation benefits provides by the Bhadra dam it generates electricity. The Bhadra dam is constructed across the river Bhadra thereby creating Bhadra reservoir on the upstream of it. The catchment area of the Bhadra dam is 1968.40 square kilometers. The average annual rainfall that occurs at Lakkavalli is 1168.4mm.

3.1.1 THE BHADRA RESERVOIR

The Bhadra reservoir formed by the Bhadra dam on the river Bhadra stores large amount of water which is used for multiple purposes like irrigation and electricity generation. The full reservoir level of the reservoir is 657.758m. The lowest bed level at the dam site is 601.065m. The water spread area at full reservoir level is 117.301 square km. The contribution of southwest monsoon is about 82% in the inflow of reservoir and northeast monsoon contribute about 18%.

3.1.2 BHADRA DAM AND ITS BENEFITS

The Bhadra Dam is a composite dam made of earth and masonry. The length of the Bhadra dam is 1708m. The top width of dam is 4.51m and the bottom width is 70.10m. The height of dam is 59.13m. The spillway type is ogee. The crest gates are four in numbers with sizes of 18.28 m x 7.62 m each.

The Gross Command Area of the Bhadra project is 162,818 Ha out of which the Cultivable Command Area is 121500 Ha and the annual irrigation done is 105,570 Ha. The Bhadra dam has installed capacity of power generation of 39.2MW. The total number of units installed is five. The power generated by the right bank powerhouse is 7.2MW and 6 MW. The power generated by the left bank powerhouse is 12 MW each by the two units. 2 MW of power is generated by the power house located on the left bank canal.

TABLE 3.1 SALIENT FEATURES OF BHADRA PROJECT

1	Type of Dam	Composite dam(masonry and earth)
2	Length of dam	1708m
3	Lowest bed level at Dam site	601.065m
4	Height of dam	59.13m
5	Average annual runoff	2832 M.Cu.m
6	Average annual rainfall at Lakkavalli	1168.4 mm
7	Catchment area	1968.40 sq.km
8	FRL	657.758m
9	Capacity at FRL (1964)	2025.87M.Cu.m
10	Capacity at FRL(2011)	1930.125M.Cu.m
11	Dead storage level	631.540m
12	Gross Storage capacity	2025.87 M.Cu.m
13	Dead storage capacity	240.72 M.Cu.m
14	Live storage capacity	1785.15 M.Cu.m

3.2 UPPER KOLAB DAM

The Upper Kolab Reservoir is created by the Upper Kolab Dam which is constructed across Upper Kolab River at village Keranga, Koraput. The Upper Kolab Reservoir has watershed area of 1630 square kilometers. The dam is located about 600 kilometers from Bhubaneswar in the state of Odisha.

3.2.1 UPPER KOLAB RESERVOIR

The upper kolab reservoir serves multiple purposes such as providing irrigation facilities, electricity generation and water supply in the area. The average annual rainfall in the watershed is 1415 mm. The average annual inflow into the reservoir is 1803M.Cu.m. The full reservoir level of the reservoir is 858.0m. The lowest bed level at dam site is 810.4m. The installed capacity of power generation is 240 MW. The number of units installed are three each having capacity of 80 MW. The type of intake of tunnel is open cut type with size of intake gate as 5.0m X 6.0m and the tunnel type is Horse shoe. The length of tunnel is 3924m and the diameter is 5.5m. The design discharge of tunnel is 120 cumecs. The tunnel is having a lining of concrete with an average thickness of 600mm.

3.2.2 UPPER KOLAB DAM AND ITS BENEFITS

The Upper Kolab Dam is a straight masonry gravity type dam. The elevation of top of the dam is 862.5m. The foundation level of dam is at 808.0m. The crest level of spillway is at an elevation of 845.80m. The length of non-overflow dam is 375 meters and the length of overflow portion of dam is 255.5m. The gate types are radial with size of 12.20m x 12.20m.

The upper kolab reservoir serves the purpose of irrigation also. The gross command area is 59644 Ha out of which the cultivable command area is 47715 Ha. The upper kolab reservoir also serves the purpose of supply of drinking water to the city of Jeypore.

TABLE 3.2 SALIENT FEATURES OF UPPER KOLAB PROJECT

1	Type of Dam	Straight masonry gravity type
2	Length of dam	630.5m
3	Lowest bed level at Dam site	810.4m
4	Height of dam	54.50m
5	Average annual runoff	1803 M.Cu.m
6	Average annual rainfall at Lakkavalli	1415 mm
7	Catchment area	1630 sq.km
8	FRL	858m
9	Capacity at FRL (1986)	1215M.Cu.m
10	Capacity at FRL(2011)	1073.95M.Cu.m
11	MDDL	844m
12	Gross Storage capacity	1215 M.Cu.m
13	Dead storage capacity	280 M.Cu.m
14	Live storage capacity	935 M.Cu.m

3.3 IDAMALAYAR DAM

The Idamalayar Dam is constructed across the Idamalayar River, Kerala. Idamalayar River is a tributary of the perennial River Periyar. Idamalayar River begins from the Anaimalai Hills from the height of 2520m. This perennial river drains a watershed area of 381 km^2. The topography of the catchment area has high relief. The annual rainfall that occurs in the watershed is 6000 millimeters. The catchment receives about 90% of its rainfall in the months of June to September which are the monsoon months.

3.3.1 IDAMALAYAR RESERVOIR

The Idamalayar dam was opened in 1985; it is situated in Ernakulum district in Kerala. It serves as a multipurpose project in Kerala. The Idamalayar dam is made of concrete and is a gravity dam. The length of dam is 373 meters. The reservoir created by the Idamalayar dam has water spread to the area of scenic hills located in the Western Ghats, the area is about 28.3 square kilometers.

The total width of river at dam site at the elevation of 8500m is 40m. The catchment area of the river is 481.79 square km at the dam site. The observed maximum flood is 4063.5m^3/sec at site of Idamalayar dam. The design flood considered was 3851m^3/sec. The average annual inflow into the reservoir is 1369.69M.Cu.m. The full reservoir level of the reservoir is 169m and the minimum drawdown level of the reservoir is 115m.

The reservoir created by the Idamalayar dam stores large amount of water which is used for electricity generation. The water is diverted using a long power tunnel of length 1700m. The power station generates 75 MW of power. The power intake has the diameter of 4.2m and is in circular shape. The center line of the power intake is at the elevation of 105.60m.

The maximum height of dam (non overflow) is 91.0 m. The height of the overflow dam is 88.0m. The volume of concrete used in the construction of concrete gravity dam is 8.80 Lakhs metric cube. The length of spillway section is 93.05m. The maximum height of the spillway section is 80m above bed level. There are four numbers of radial crest gates and the size of each crest gate is 11.5m X 9.7m. The area submerged by the reservoir consists of forest land mainly. The Idamalayar reservoir produces energy output of 380 GWH annually.

3.3.2 LOCATION OF THE PROJECT

Idamalayar dam is located at Ernakulum district in Kerala, India. We can reach to the place through road from Cochin harbor as well as for the Cochin airport through Kothamangalam. The distance between the two places is about 81 kilometers. It can also be approached for Alwaye through Kothamangalam by road and the distance between the two is about 63 kilometers. . The dam site can be approached for Trivandrum through Kothamangalam by road and the distance between the two is about 250 kilometers.

TABLE 3.3 SALIENT FEATURES OF IDAMALAYAR PROJECT

1	Type of Dam	concrete gravity dam
2	Length of dam	373.0m
3	Lowest bed level at Dam site	81m
4	Height of dam	91m
5	Average annual runoff	1369.69 M.Cu.m
6	Average annual rainfall at Idamalayar	4750 mm
7	Catchment area	481.79 sq.km
8	FRL	169m
9	Capacity at FRL (1986)	1208.23M.Cu.m
10	Capacity at FRL(2011)	1176.187M.Cu.m
11	MDDL	115m
12	Gross Storage at MWL	1153 M.Cu.m
13	Dead storage below MDDL	72M.Cu.m
14	Live storage up to MWL	1081 M.Cu.m

3.4 PANCHET DAM

Panchet Dam was opened in 1959, it is constructed across the river Damodar in Dhanbad district at Panchet in the state of Jharkhand. Panchet dam was the last among the four dams constructed according to the Voorduins plan in the Damodar valley for the purpose of water resources development.

W.L. Voorduins made the plan of water resources development in the Damodar valley. The Damodar flood enquiry committee was appointed by the Bengal Governor after the flood of 1943 for suggestion of the remedial steps. It was suggested by the committee that an authority should be formed same as the Tennessee Valley Authority in the USA. Voorduin, engineer in Tennesee Valley Authority made a report that suggested a plan to have flood control, irrigation facilities, generation of electricity and navigation facilities. Although initially it was suggested to have construction of 8 dams and a barrage but later only four dams were constructed. The four dams are located at Konar, Tilaiya, Maithon, Panchet and Barrage at Durgapur.

3.4.1 THE DAMODAR RIVER

The Damodar River makes the border of Dhanbad district (Jharkhand) and Purulia district (West Bengal). After that it meets the Barakar (Dishergarh) and flows through the state of West Bengal. The Panchet Dam has been constructed slightly above its mergence with the Barakar River. The Dhanbad district (Jharkhand) is on the northern side of Panchet reservoir and the Purulia district (West Bengal) is on the southern bank.

3.4.2 DAM FEATURES

The Panchet Dam is a composite dam i.e, earthen dam with concrete spillway. The catchment area of reservoir is 10966 km^2 including the area covered by Tenughat and Konar Reservoir. The average annual basin rainfall is 1140 mm and the average annual inflow is 4539.23 M.cu.m. The maximum observed flood was 12432m^3/s at the dam site. The spillway design flood considered for this project was 17,840m^3/s.

3.4.3 FLOOD CONTROL

The Damodar river was once considered to be a flood-prone river. The Maithon and Panchet dams, opened in 1957 and 1959 respectively, have appreciably reduced the amount of discharge flowing daily and annually. These reservoirs to a larger extent removed the flow extremes occurring in the reservoir. The deposition of sediment in the reservoirs and due to lack of proper maintenance of reservoirs i.e., not performing operations like flushing, dredging happening due to reduced flow extremes have made the lower Damodar basin to get transformed into an area that is certainly ecologically imbalanced.

3.4.4 LOCATION OF THE PROJECT

The nearest railway station to the Panchet is kumardhubi railway station, chirkunda, Jharkhand. The distance between them is about 10 kilometres. Panchet Dam is 9 kilometres away from the city of Chirkunda on GT road and about 54km from the ditrict of Dhanbad.

TABLE 3.4 SALIENT FEATURES OF PANCHET PROJECT

1	Type of Dam	Composite (earth and concrete)
2	Top of dam(elevation of road)	139.3m
3	Lowest bed level at Dam site	97.54m
4	Type of spillway	ogee
5	Average annual runoff	4539.23 M.Cu.m
6	Average annual rainfall	114.17 mm
7	Catchment area	8852 sq.km
8	FRL	124.97m
9	Capacity at MWL (1964)	1580.94M.Cu.m
10	Capacity at MWL(2011)	1193.46M.Cu.m
11	MDDL	119.48m
12	Conservation storage	1837.5 M.Cu.m
13	Dead storage	1191.4 M.Cu.m
14	Flood management storage	6363 M.Cu.m

SECTION – 4

METHODOLOGY

4.1 BRUNE'S CURVE

The brune's method (1953) is the most widely used method of determining the trap efficiency for estimating the reservoir sedimentation. Brune (1953) developed a curve between trap efficiency and the capacity- inflow ratio by taking the data from 44 normally ponded reservoirs in USA. It gives reasonable values of trap efficiency and also simple to use, only uses capacity and average annual inflow hence making it the most commonly used method for the calculation of trap efficiency. Brune developed three curve's one as the median curve and two envelope curves. The standard curve developed by the brune gives the trap efficiency in percentage directly using the capacity and inflow ratio.

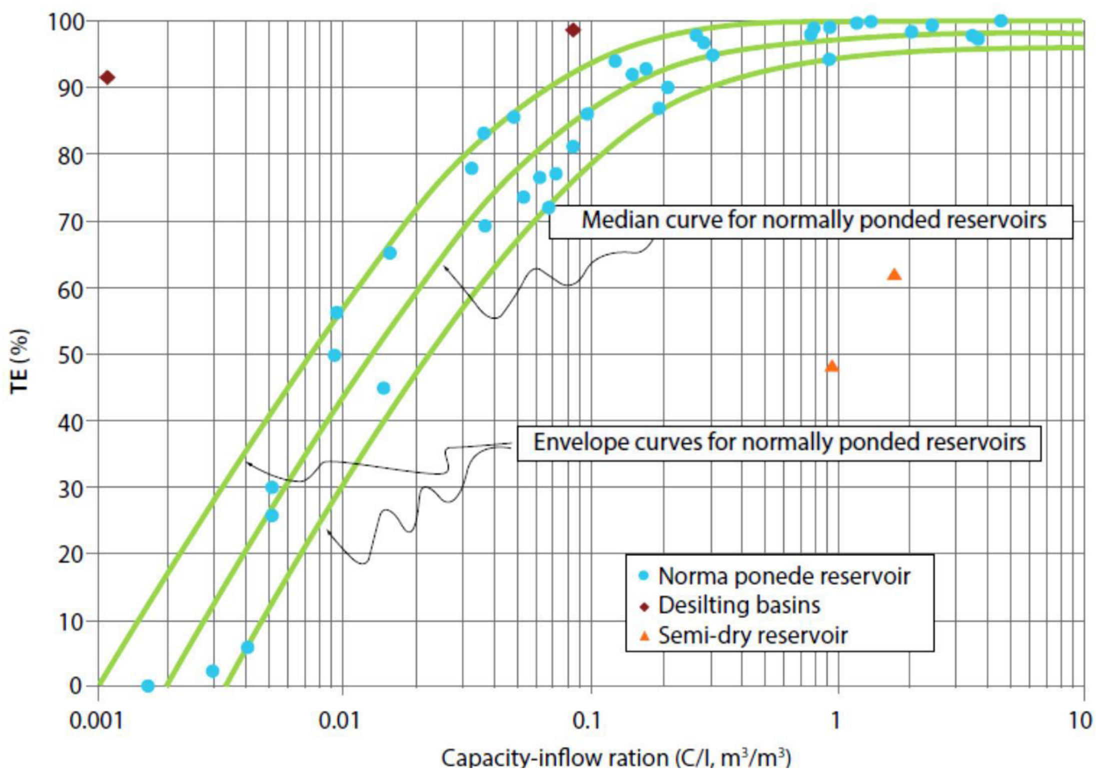


FIGURE 4.1 the graph between trap efficiency and the ratio of capacity and inflow of reservoir (Brune, 1953)

The Brune's curve should be used for the reservoirs that are normally ponded. Normally ponded reservoirs are the reservoirs which are completely filled with water and they have their outlet at the top of the embankment. In the case of flood water-retarding structures and the semi-dry reservoirs the brune's curve may lead to error.

4.2 Trap Efficiency Prediction Equations Used by the USDA-SCS(1983)

The two envelope curves and one median curve given by the brune's method have been transformed by the USDA-SCS based on the sediment texture and using the C/I ratio into one curve for medium size sediments and upper curve for primarily coarse grained sediments and lower curve for fine sediments. The Summit County Soil and Water Conservation District transformed the curves into equations as follows:

TABLE 4.1 Equations used by USDA-SCS

	C/I > 1	1 > C/I > 0.02	C/I < 0.02
Upper curve (coarse grained sediments)	100	$100 - (0.485\|\ln(C/I)\|^{2.99})$	$124 - (6.59\|\ln(C/I)\|^{1.52})$
Median curve (medium sediments)	97	$97 - (1.275\|\ln(C/I)\|^{2.47})$	$128 - (11.51\|\ln(C/I)\|^{1.304})$
Lower curve (fine sediments)	94	$94 - (3.38\|\ln(C/I)\|^{1.92})$	$94 - (3.38\|\ln(C/I)\|^{1.92})$

4.3 GILL'S METHOD

Gill in 1979 developed empirical equations for all the three curves of brune's method as a better fit. The three equations derived by the gill are as follows:

Primarily for upper curve i.e. coarse grained sediments:

$$TE = \frac{\left(\frac{C}{I}\right)^2}{0.3 \text{ X } 10^{-5} + 0.006297\left(\frac{C}{I}\right) + 0.994701\left(\frac{C}{I}\right)^2} \qquad (4.1)$$

For Median curve i.e. for medium sediments Morris and Wiggert (1972):

$$TE = \frac{\frac{C}{I}}{0.012 + 1.02\left(\frac{C}{I}\right)} \qquad (4.2)$$

For fine-grained sediments:

$$TE = \frac{\left(\frac{C}{I}\right)^3}{0.1 \text{ X } 10^{-5} - 0.133 \text{ X } 10^{3}\left(\frac{C}{I}\right) + 0.02621\left(\frac{C}{I}\right)^2 + 1.02655\left(\frac{C}{I}\right)^3} \qquad (4.3)$$

4.4 BROWN METHOD

Brown in 1944 developed the first method for calculating the trap efficiency of reservoirs by developing a curve having relationship between trap efficiency and the ratio of capacity of reservoir and the watershed area upstream of dam. The method is expressed by the general Equation as:

$$TE = 100\left(1 - \frac{1}{\frac{K \text{ X } C}{A}}\right) \qquad (4.4)$$

Here C is in acre-feet; A is in square miles and *K* is a factor that depends on retention time and size of sediment. The value of K is taken as 0.046 for fine sediments, 0.1 for medium sediments and 1 for coarse sediments. This method is used if watershed area has one dam. Brown's method uses only two parameters i.e., catchment area and the reservoir capacity hence relatively simpler to use.

The value of K used above increases for regions of smaller retention time and having varied retention time, it also increases as the mean sediment grain size increases, also it gets increased if release of sediment is prevented for some reservoir operations. If the catchment area and capacity of reservoir are the only parameters known than brown's method is very useful.

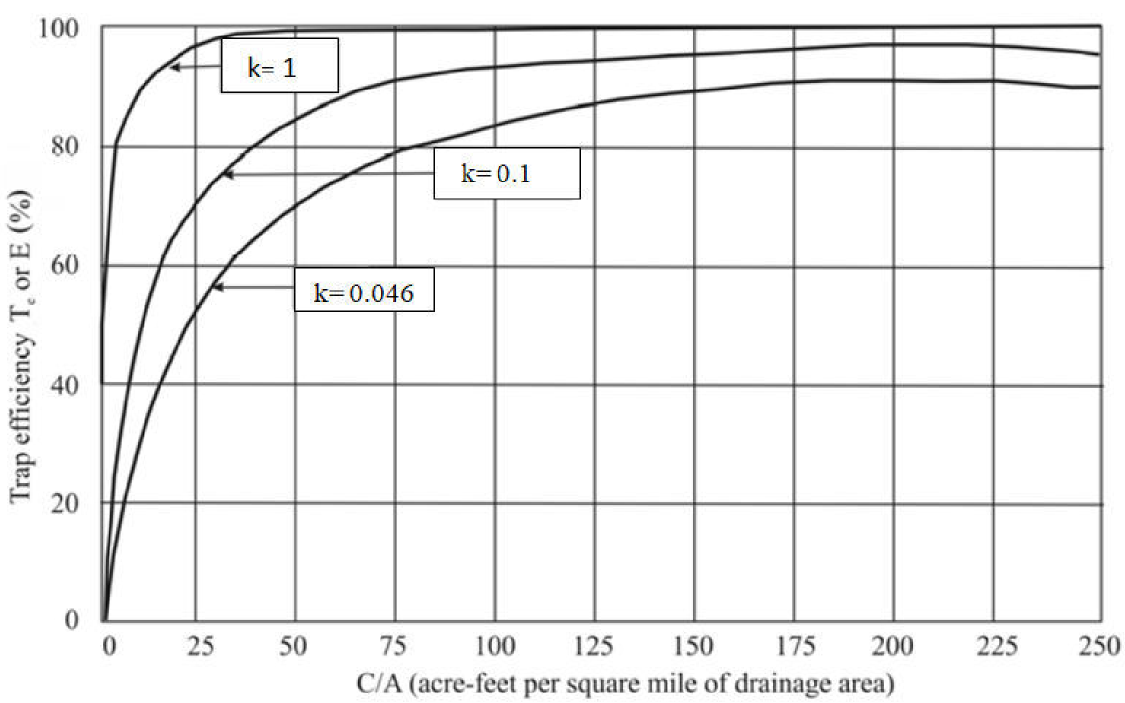


FIGURE 4.2 The graph relates the trap efficiency of reservoir with the ratio of capacity and watershed area (Brown, 1944)

4.5 HEINEMANN METHOD

Heinemann (1981) developed a new method for the calculation of trap efficiency with little variation from Brune's curve taking data of 20 agriculturally ponded reservoirs in the USA. The sizes of the reservoirs from where the data have been taken were having the size range as 0.8 to 36.3 Km^2. According to Heinemann (1981) the value of trap efficiency predicted using his method comes out lesser than that of brune's curve. The Heinemann method has restrictions to its use since it was developed taking data from small size reservoirs. The Heinemann curve can be expressed as following equation:

$$\text{TE (in \%)} = -22 + \frac{119.6C/I}{.012+1.02\,C/I} \qquad (4.5)$$

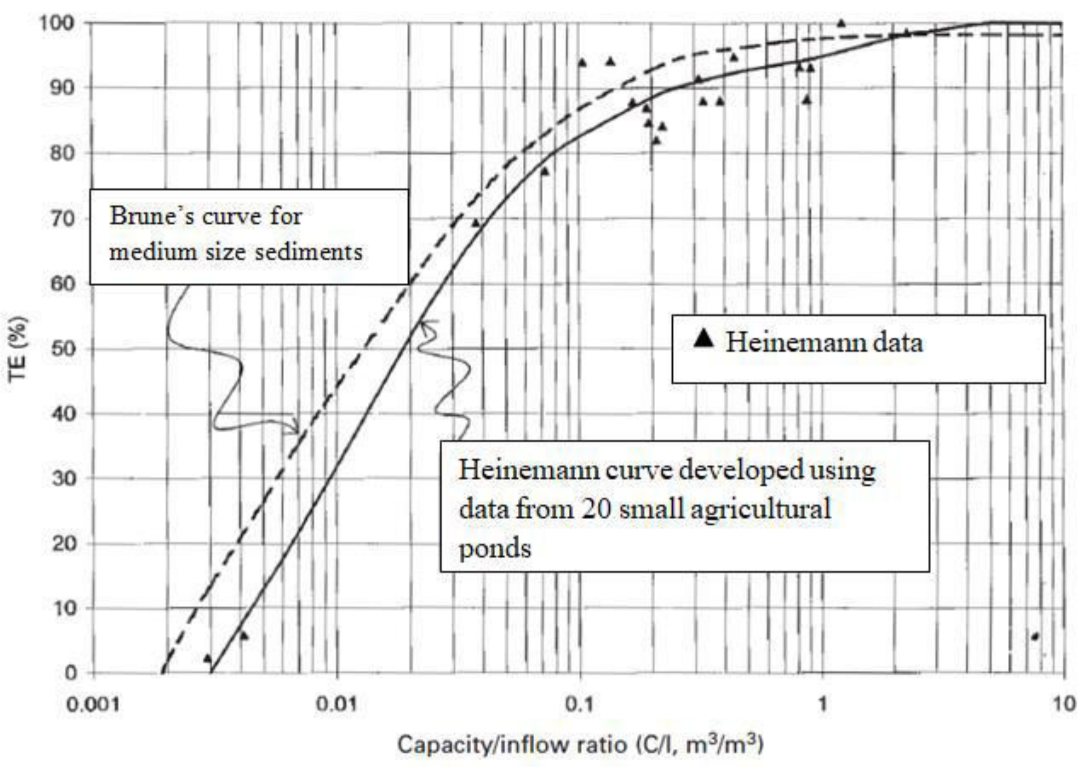


FIGURE 4.3 the graph relates the trap efficiency of reservoir with the ratio of capacity and inflow (Heinemann, 1981)

4.6 DENDY'S EQUATION

Before Brune's curve was developed, capacity-watershed area ratio was used for calculation of trap efficiency instead of capacity-inflow ratio. After the development of Brune's curve, capacity-inflow ratio is used. Dendy suggested another equation by taking data of 17 more small size reservoirs ($A \leq 60$ km2) to Brune's curve. Likewise Heinemann method this method also offers restrictions because of the small size of reservoirs taken for study. The equation derived by dendy is for median curve of brune's method.

$$TE = 100 \text{ X} \left[0.97^{0.19^{\text{Log}(C/I)}} \right] \qquad (4.6)$$

4.7 JOTHIPRAKASH AND GARG METHOD

Vinayakam Jothiprakash and Vaibhav Garg (2008) developed equations for the estimation of trap efficiency using brune's curve (1953) for predominantly coarse grained sediment and medium grained sediment sizes. They determined the trap efficiency of Govindsagar reservoir, Himachal Pradesh, India using the brune's and brown's method and compared them with new set of equations developed after the regression analysis performed for the brune's method and compared it with the brown's method. According to the results, the new set of equations gives the results better than the other equations reported in the literature. The equations developed by them are as follows:

Equation for coarse grained sediments

$$TE = \frac{8000 - 36 \text{ X} \left(\frac{C}{I}\right)^{-0.78}}{78.85 + \left(\frac{C}{I}\right)^{-0.78}} \qquad (4.7)$$

Median curve (for medium sediments)

$$TE = \frac{\frac{C}{I}}{0.00013 + 0.01 \text{ X } \frac{C}{I} + 0.0000166 \text{ X} \sqrt{(\frac{C}{I})}} \qquad (4.8)$$

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 TRAP EFFICIENCY

The trap efficiency of different reservoirs is determined through various methods available such as brune's method, gill's method, Brown's method, etc. Sediment type to be adopted (coarse, medium and fine) depends on the dominant size of particles in the inflowing water determined through soil analysis. The trap efficiency calculated in our project is single event trap efficiency. The capacity of different reservoirs and the mean annual inflow has been taken from the capacity survey reports provided by the central water commission. The capacity- inflow ratio is used for the calculation of trap efficiency in all the methods except brown method which uses the capacity- watershed area ratio for determination of trap efficiency.

5.2 BHADRA RESERVOIR

Catchment area = 1968.40 km2

Mean annual inflow = 2832 M.Cu.m

FRL = 657.758m

Storage capacity corresponding to FRL = 1930.125M.Cu.m

Adopted size is for medium sediments.

RATE OF SILTATION

Capacity Corresponding to FRL as per pre-impoundment survey 1964	= 2025.87M.Cu.m
Capacity corresponding to FRL as per 2011 survey	= 1930.125M.Cu.m
Silting in 47 years	= 95.745M.Cu.m
Annual siltation	= 2.037M.Cu.m/YR
Rate of siltation	=10.35 ha.m/100sq.km/year

5.2.1 BRUNE'S CURVE

C/I = 1930.125/2832 = 0.6815

TE = 96%

5.2.2 TE PREDICTION EQUATIONS USED BY THE USDA-SCS

$$= 97 - (1.275 \left| \ln C/I \right|^{2.47}) \qquad (5.1)$$

= 96.88%

5.2.3 HEINEMANN CURVE

$$TE = -22 + \frac{119.6C/I}{.012+1.02\,C/I}$$ [applying equation (4.5)]

= 93.26 %

5.2.4 DENDY'S EQUATION

$$TE = 100 \text{ X} \left[0.97^{0.19^{\text{Log (C/I)}}} \right]$$ [applying equation (4.6)]

= 96.063%

5.2.5 BROWN'S CURVE

$$TE = 100 \left(1 - \frac{1}{\frac{\text{K X C}}{\text{A}}}\right)$$ [applying equation (4.4)]

C = Reservoir capacity in Acre-Feet

A= area in square mile

k= 0.1

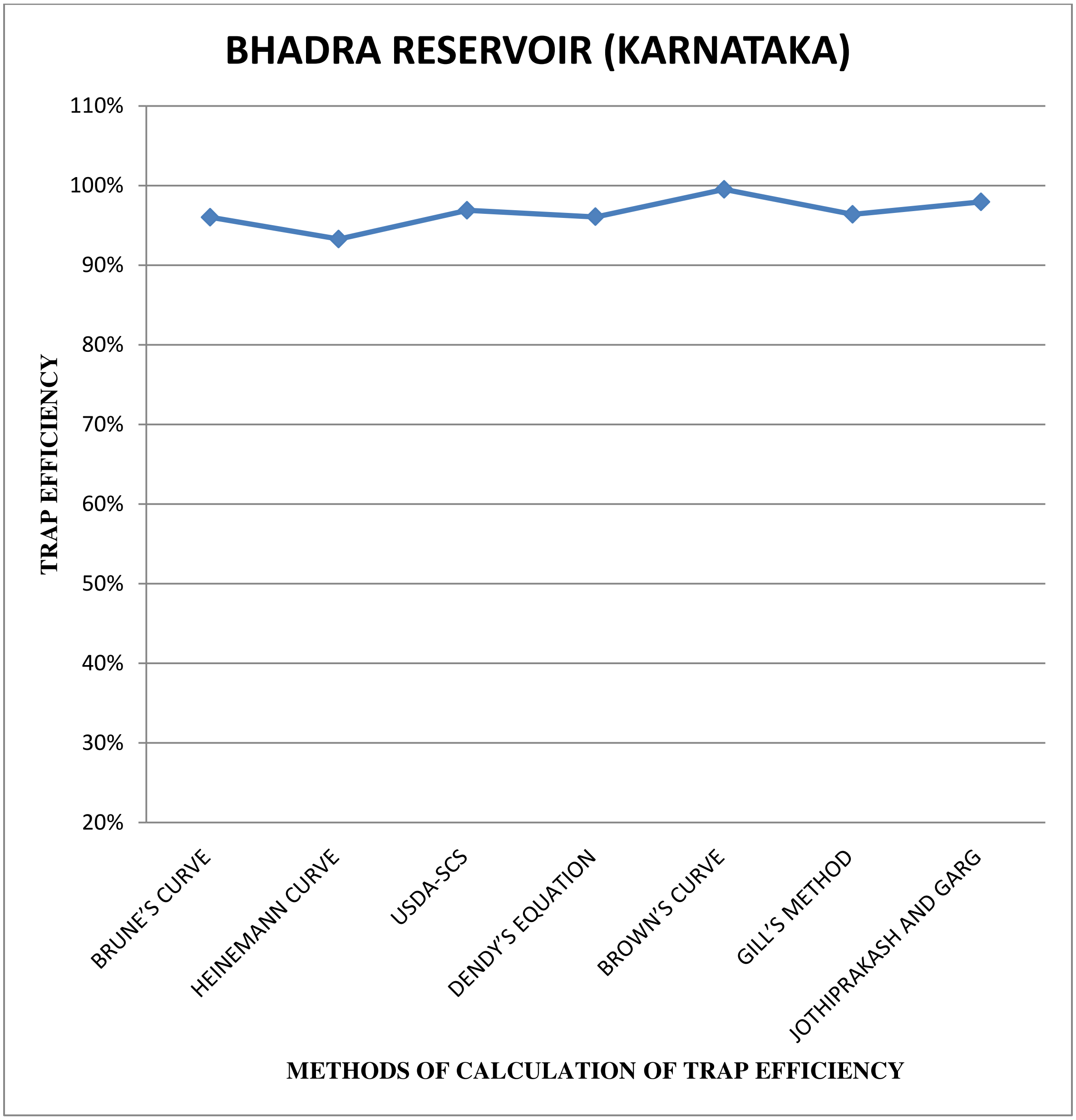
TE= 99.51%

5.2.6 GILL'S METHOD

Applying equation (4.2), TE = 96.37%

5.2.7 JOTHIPRAKASH AND GARG

Applying equation (4.8), TE = 97.93%



GRAPH 5.1 The graph shows the values of trap efficiency (in %) calculated using different methods for Bhadra reservoir.

5.3 UPPER KOLAB RESERVOIR

Catchment area = 1630 km2

Mean annual inflow = 1803 M.Cu.m

FRL = 858m

Storage capacity corresponding to FRL = 1073.95M.Cu.m

Adopted size is for medium sediments.

RATE OF SILTATION

Capacity Corresponding to FRL as per pre-impoundment survey 1986	=1215.00 M.Cu.m
Capacity corresponding to FRL as per 2011 survey	=1073.95 M.Cu.m
Silting in 25 years	=141.05M.Cu.m
Annual siltation	= 5.642M.Cu.m/YR
Rate of siltation	= 34.61 ha.m/100sq.km/year

5.3.1 BRUNE'S CURVE

C/I = 1073.95/1803 = 0.596

TE = 95.5%

5.3.2 TE PREDICTION EQUATIONS USED BY THE USDA-SCS

$= 97-(1.275\,|\ln C/I|^{2.47})$ [applying equation (5.1)]

= 96.749%

5.3.3 HEINEMANN CURVE

$$TE = -22 + \frac{119.6C/I}{.012+1.02\,C/I}$$ [applying equation (4.5)]

= 92.985 %

5.3.4 DENDY'S EQUATION

TE = 100 X $\left[0.97^{0.19^{\text{Log}\,(C/I)}} \right]$ [applying equation (4.6)]

= 95.67%

5.3.5 BROWN'S CURVE

TE = 100 $\left(1 - \frac{1}{\frac{K \, X \, C}{A}}\right)$ [applying equation (4.4)]

C = Reservoir capacity in Acre-Feet

A= area in square mile

k= 0.1

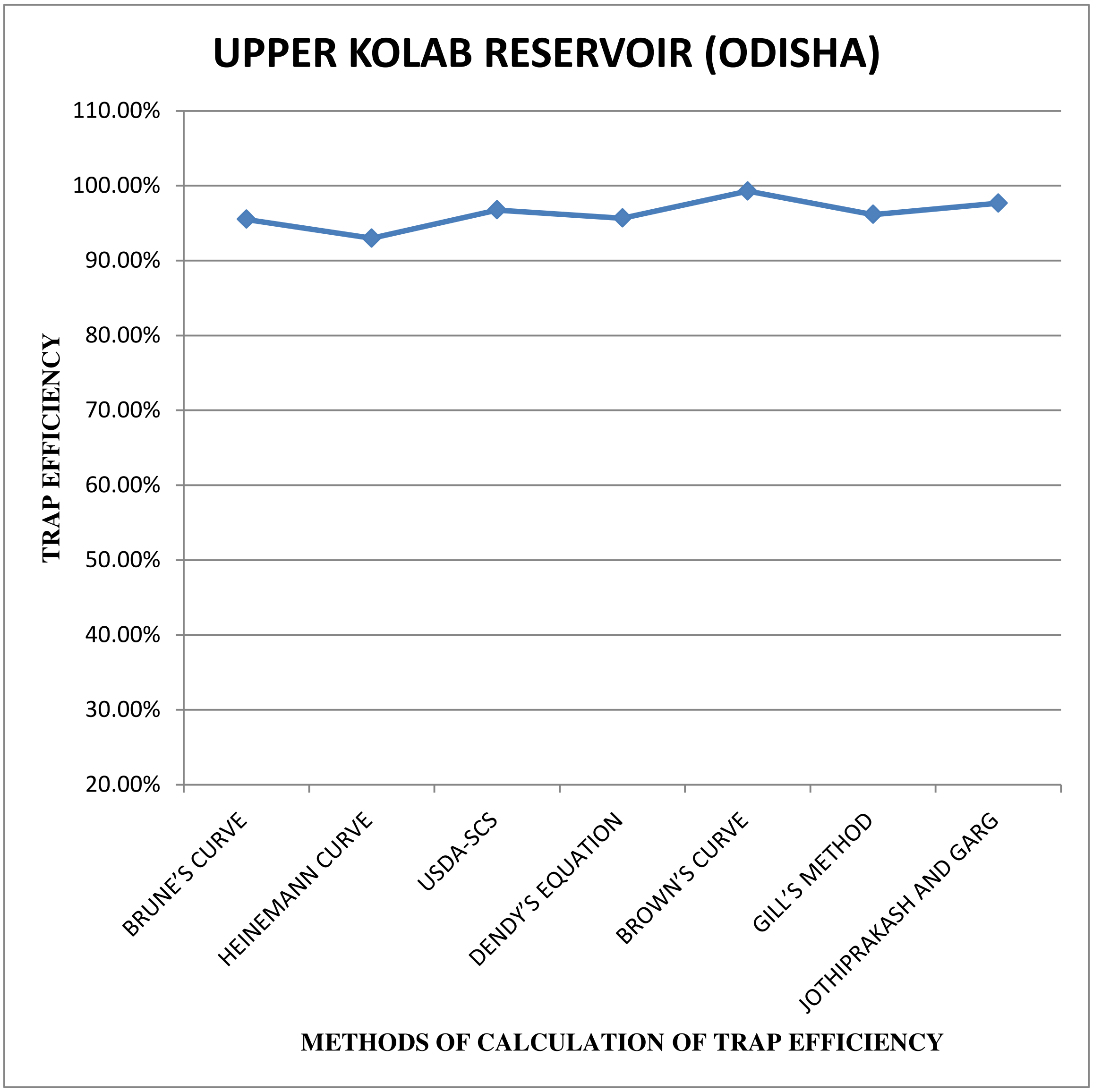
TE= 99.27

5.3.6 GILL'S METHOD

Applying equation (4.2), TE= 96.14%

5.3.7 JOTHIPRAKASH AND GARG

Applying equation (4.8), TE = 97.656%



GRAPH 5.2 The graph shows the values of trap efficiency (in %) calculated using different methods for Upper Kolab reservoir.

5.4 PANCHET RESERVOIR

Catchment area = 8852 km2

Mean annual inflow = 4539.23 M.Cu.m

FRL = 124.97m

Storage capacity corresponding to FRL= 274.8075M.Cu.m

Adopted size is for medium sediments.

RATE OF SILTATION

Capacity Corresponding to MWL as per pre-impoundment survey 1956	=1580.94 M.Cu.m
Capacity corresponding to MWL as per 2011 survey	=1193.46 M.Cu.m
Silting in 55 years	= 387.48M.Cu.m
Annual siltation	=7.05M.Cu.m/YR
Rate of siltation	=8.00 ha.m/100sq.km/year

5.4.1 BRUNE'S CURVE

C/I = 274.8075/4539.23 = 0.06054

TE = 80%

5.4.2 TE PREDICTION EQUATIONS USED BY THE USDA-SCS

$= 97-(1.275\,|\ln C/I|^{2.47})$ [applying equation (5.1)]

= 80.7%

5.4.3 HEINEMANN CURVE

$TE = -22 + \frac{119.6C/I}{.012+1.02\,C/I}$ [applying equation (4.5)]

= 76.166 %

5.4.4 DENDY'S EQUATION

$TE = 100 \text{ X} \left[0.97^{0.19^{\text{Log (C/I)}}} \right]$ [applying equation (4.6)]

= 79.43%

5.4.5 BROWN'S CURVE

$TE = 100 \left(1 - \frac{1}{\frac{K \text{ X } C}{A}}\right)$ [applying equation (4.4)]

C = Reservoir capacity in Acre-Feet

A= area in square mile

k= 0.1

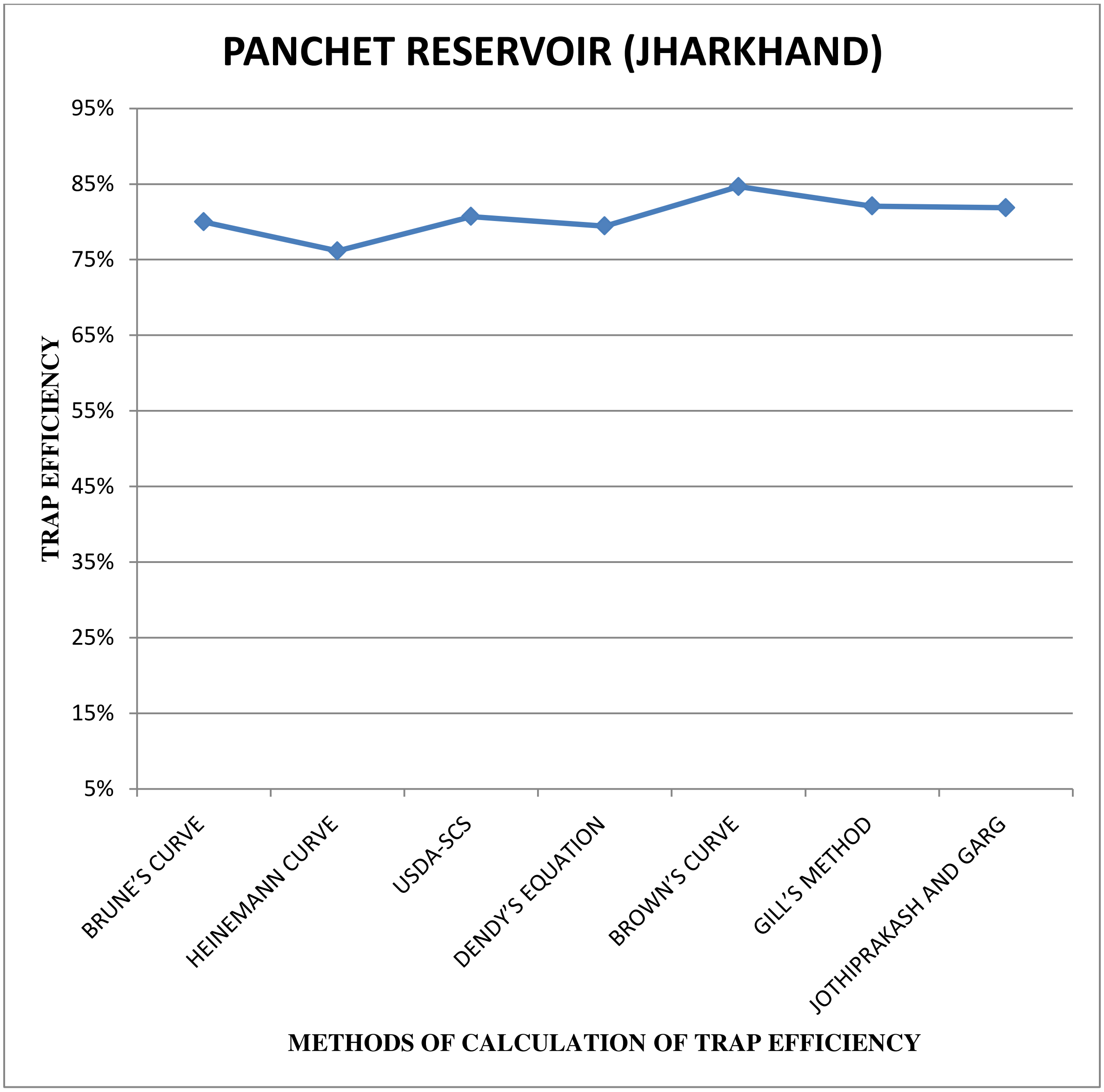
TE= 84.65%

5.4.6 GILL'S METHOD

Applying equation (4.2), TE = 82.078%

5.4.7 JOTHIPRAKASH AND GARG

Applying equation (4.8), TE = 81.86%



GRAPH 5.3 The graph shows the values of trap efficiency (in %) calculated using different methods for Panchet reservoir.

5.5 IDAMALAYAR RESERVOIR

Catchment area = 481.79 km2

Mean annual inflow = 1369.69 M.Cu.m

FRL = 169m

Storage capacity corresponding to FRL = 1176.19M.Cu.m

Adopted size is for medium sediments.

RATE OF SILTATION

Capacity Corresponding to FRL as per pre-impoundment survey 1986	=1208.23 M.Cu.m
Capacity corresponding to FRL as per 2011 survey	=1176.187 M.Cu.m
Silting in 25 years	=32.043M.Cu.m
Annual siltation	=1.282M.Cu.m/YR
Rate of siltation	=26.60 ha.m/100sq.km/year

5.5.1 BRUNE'S CURVE

C/I = 1176.19/1369.69 = 0.8587

TE = 96.80%

5.5.2 TE PREDICTION EQUATIONS USED BY THE USDA-SCS

$= 97-(1.275\,|\ln C/I|^{2.47})$ [applying equation (5.1)]

= 96.987%

5.5.3 HEINEMANN CURVE

$$TE = -22 + \frac{119.6C/I}{.012+1.02\,C/I}$$ [applying equation (4.5)]

= 93.67 %

5.5.4 DENDY'S EQUATION

TE = 100 X $\left[0.97^{0.19^{\mathrm{Log}\,(C/I)}} \right]$ [applying equation (4.6)]

= 96.657%

5.5.5 BROWN'S CURVE

TE = 100 $\left(1 - \frac{1}{\frac{K\,X\,C}{A}}\right)$ [applying equation (4.4)]

C = Reservoir capacity in Acre-Feet

A= area in square mile

k= 0.1

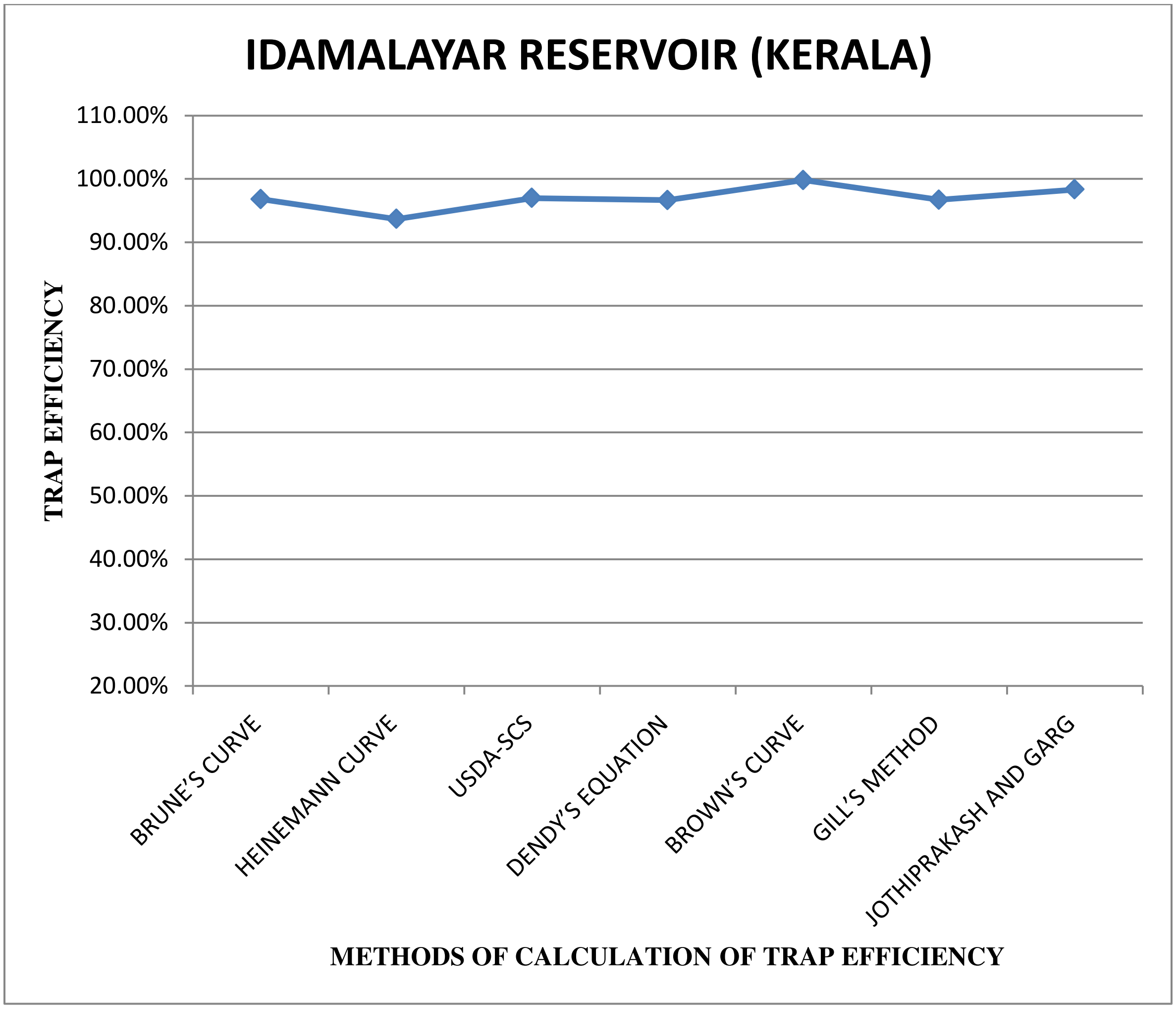
TE= 99.8%

5.5.6 GILL'S METHOD

Applying equation (4.2), TE = 96.71%

5.5.7 JOTHIPRAKASH AND GARG

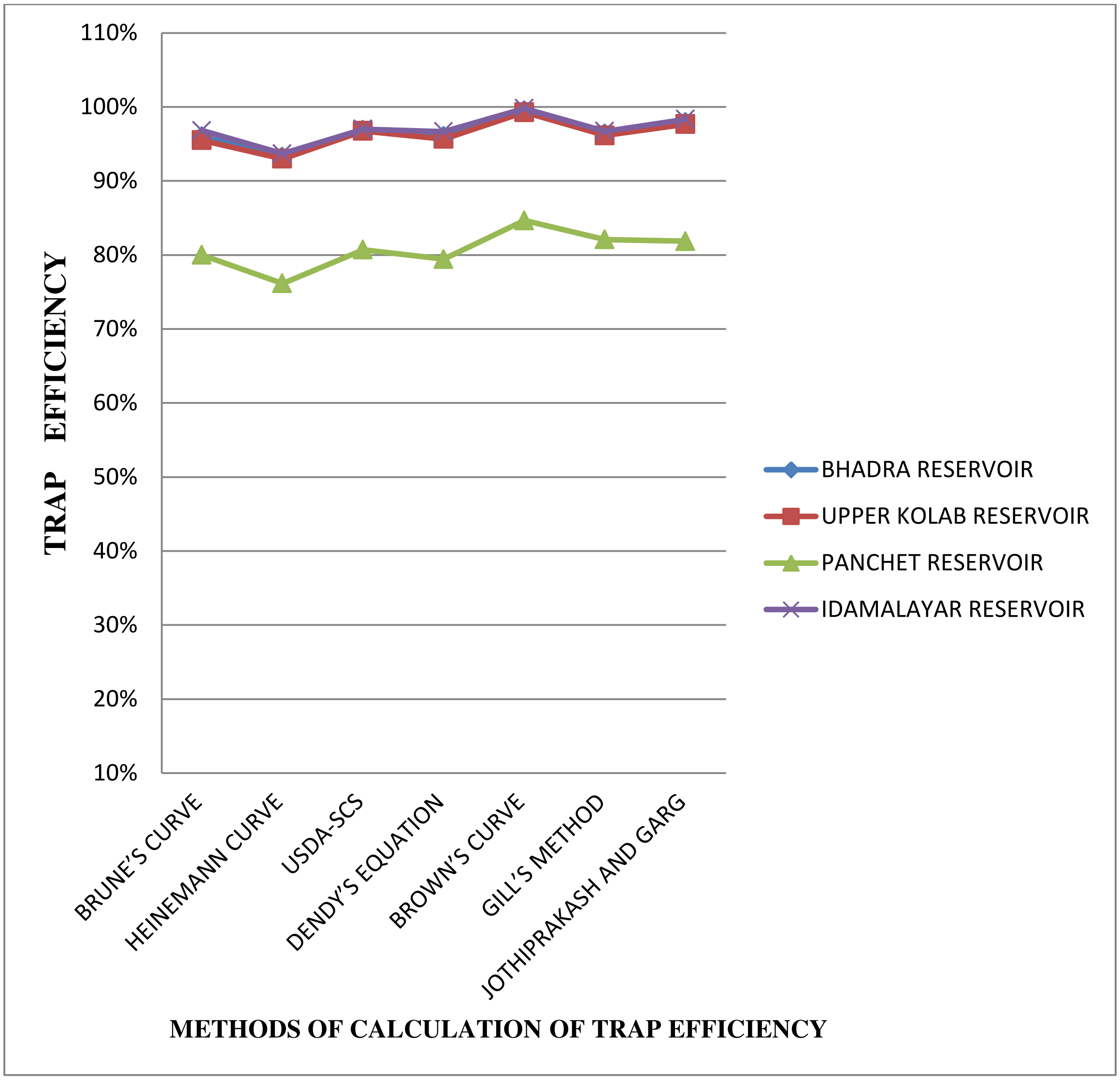
Applying equation (4.8), TE = 98.335%



GRAPH 5.4 The graph shows the values of trap efficiency (in %) calculated using different methods for Idamalayar reservoir.

TABLE 5.1 The Values Of Trap Efficiency Calculated Using Different Methods Summarize into Tabular Form.

METHODS / RESERVOIRS	BRUNE'S CURVE	HEINEMANN CURVE	USDA-SCS	DENDY'S EQUATION	BROWN'S CURVE	GILL'S METHOD	JOTHIPRAKASH AND GARG
BHADRA RESERVOIR (KARNATAKA)	96%	93.26	96.88%	96.06%	99.51%	96.37 %	97.93%
UPPER KOLAB RESERVOIR (ODISHA)	95.5%	93%	96.75%	95.67%	99.27%	96.14 %	97.656%
PANCHET RESERVOIR (JHARKHAND)	80%	76.157 %	80.7%	79.43%	84.65%	82.078 %	81.86%
IDAMALAYAR DAM (KERALA)	96.8%	93.67%	96.987 %	96.657 %	100%	96.71 %	98.335%



GRAPH 5.5 The graph shows the values of trap efficiency (in %) for all the reservoirs calculated using different methods.

The trap efficiency of Bhadra reservoir(Karnataka) has been found out to be 96% according to brune's curve, 93.26% according to Heinemann's curve, 96.88% according to USDA-SCS equations, 96.063% according to Dendy's method, 99.51% according to brown’s curve, 96.37% according to Gill’s method, 97.93% according to Jothiprakash and Garg method. The trap efficiency of Upper Kolab reservoir(Odisha) has been found out to be 95.5% according to brune’s curve, 92.985% according to Heinemann’s curve, 96.749% according to USDA-SCS equations, 95.67% according to Dendy’s method, 99.27% according to brown’s curve, 96.14% according to Gill’s method, 97.656% according to Jothiprakash and Garg method. The trap efficiency of Panchet reservoir(Jharkhand) has been found out to be 80% according to brune’s curve, 76.166% according to Heinemann’s curve, 80.7% according to USDA-SCS equations, 79.43% according to Dendy’s method, 84.65% according to brown’s curve, 82.078% according to Gill’s method, 81.86% according to Jothiprakash and Garg method. The trap efficiency of Idamalayar reservoir(Kerala) has been found out to be 96.8% according to brune’s curve, 93.67% according to Heinemann’s curve, 96.987% according to USDA-SCS equations, 96.657% according to Dendy’s method, 99.8% according to brown’s curve, 96.71% according to Gill’s method, 98.335% according to Jothiprakash and Garg method. The above table shows that the trap efficiency values calculated using Heinemann’s curve and Brown’s curve differ from the values calculated from the other methods.

CHAPTER 6

CONCLUSIONS

The trap efficiency of four reservoirs namely Bhadra reservoir, Upper kolab reservoir, Panchet reservoir and Idamalayar reservoir has been determined in this thesis using different methods. The different methods used for the determination of trap efficiency of above reservoirs are Brune's curve, USDA-SCS equations, Dendy's method, Brown's curve, Gill's method and Jothiprakash and Garg method.

The trap efficiency of Bhadra reservoir(Karnataka) having rate of siltation 10.35 ha.m/100sq.km/year has been found out to be 96% according to brune's curve, 93.26% according to Heinemann's curve, 96.88% according to USDA-SCS equations, 96.063% according to Dendy's method, 99.51% according to brown's curve, 96.37% according to Gill's method, 97.93% according to Jothiprakash and Garg method.

The trap efficiency of Upper Kolab reservoir(Odisha) having rate of siltation 34.61 ha.m/100sq.km/year has been found out to be 95.5% according to brune's curve, 92.985% according to Heinemann's curve, 96.749% according to USDA-SCS equations, 95.67% according to Dendy's method, 99.27% according to brown's curve, 96.14% according to Gill's method, 97.656% according to Jothiprakash and Garg method.

The trap efficiency of Panchet reservoir(Jharkhand) having rate of siltation 8.00 ha.m/100sq.km/year has been found out to be 80% according to brune's curve, 76.166% according to Heinemann's curve, 80.7% according to USDA-SCS equations, 79.43% according to Dendy's method, 84.65% according to brown's curve, 82.078% according to Gill's method, 81.86% according to Jothiprakash and Garg method.

The trap efficiency of Idamalayar reservoir(Kerala) having rate of siltation 26.60 ha.m/100sq.km/year has been found out to be 96.8% according to brune's curve, 93.67% according to Heinemann's curve, 96.987% according to USDA-SCS equations, 96.657%

according to Dendy's method, 99.8% according to brown's curve, 96.71% according to Gill's method, 98.335% according to Jothiprakash and Garg method.

As it can be seen from the results that the trap efficiency values calculated using Heinemann's curve and Brown's curve differ from the values calculated from the other methods. The reason behind the variation in Heinemann's curve is because of the fact that it is developed using the data of small ponds while in our case the size of reservoirs is quite large. All the methods used above except Brown's method uses the relationship between capacity and inflow for the determination of trap efficiency. However Brown's method relates the trap efficiency with the ratio of capacity of reservoir and watershed area, therefore the variation in the results of Brown's method is attributed to this factor.

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