Estimation Of The Life Of Ikpoba River Reservoir

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ABSTRACT

Sediment accumulation in reservoirs depletes its water storage capacity. The sedimentation condition of Ikpoba reservoir was studied and the total volume of silt in the reservoir was obtained. Data obtained include the reservoir capacity, annual sediment inflow into the reservoir, trap efficiency of the reservoir, etc. The useful capacity of the reservoir lost every year by sediment deposition was estimated. The present volume of silt in the reservoir was found to be 347,378.41 m^3. The volume of the reservoir that silted up was obtained to be 23.16%, implying that the dead storage zone of the reservoir is filled up, suggesting urgent desilting to prevent silt from depositing in the life storage zone of the reservoir. This is to prolong the reservoir life and sustain the benefits (including hydro electric power generation, water supply, irrigation, navigation, flood control, recreation, sanitation, tourism and ground water recharge). It is recommended that there should be periodic monitoring of siltation in all reservoirs in our country to prevent silt from taking over the live storage zone. The life of the reservoir was obtained to be 171 years. Recommendations on how to prolong the reservoir life and sustain its benefits were outlined.

Keywords: life of reservoir, sediment, storage capacity

1. INTRODUCTION

1.1 The Project Site

The Ikpoba dam and reservoir site is located, spanning from Okhoro to Teboga, along the Ikpoba river running through Egor and Ikpoba in Okha local government area in Benin City, Edo state. It is found in the Benin-Owena River Basin in Nigeria. Its level of water is the same at all time during the year with just minor variation (Okeligho, 2011). The geological terrain is tertiary while the foundation is pile. The reservoir surface area is 1.07×10^6 m^2. The dam is 610m long and with a height, at crest level, of 35m above mean sea level (MSL). It has a spillway length (weir) of 60m and an emergency spillway length of 4m. The dam has a reservoir capacity of 1.5 x 10^6 m^3. The reservoir catchment area is 120 km^2 (www.wds.worldbank.org/external/defal.).

It is the main source of water supply for Benin City with water production per pump day of 34080m^3. The water supply design capacity is 90,000m^3/day serving an estimated population of 1.0 million people at design. The dam was impounded first in 1975 and commissioned October, 1987. At present, problems associated with the reservoir are over-silting and growth of weeds over the years (Edo State Urban Water Board, 2007).

1.2 Objective and Scope of Study

The objective of this study is to estimate the life of the reservoir. Also, the sediment yield of the reservoir will be estimated. The reservoir of study is the Ikpoba river reservoir, Benin City, Nigeria in the Benin-Owena River Basin of Nigeria.

2. METHODOLOGY

2.1 Theoretical Aspects

Hinemann (1981) considered the T_e to be the most informative descriptor for reservoir sedimentation estimation. T_e is the proportion of the incoming sediment that is deposited or trapped in a reservoir and is often expressed in percentage as given in equation 2.1.

$$T_e = \frac{V_1 - V_2}{V_1} x\,100\% \qquad 2.1$$

Where, V_1 is the inflowing sediment load and V_0 is the outflow sediment load. The T_e even though it is estimated from inflow and outflow of sediment, actually, T_e is dependent on several parameters, including sediment size, distribution, the time and rate of water inflow to the reservoir, the reservoir size, and shape, the location of the outlet structure and water discharge schedules (Verstraeten and Poesen, 2000; Campos, 2001; Yang, 2003).

2.1.1 Reservoir Useful Life Estimation

The period up to which the reservoir can serve the defined purpose is called usable life, the period after which the cost of operating the reservoir exceeds the additional benefits expected from its continuation is called economic life, design life is generally the useful life, full life period is that when no capacity is available in the reservoir for useful purpose (Murthy, 1980; Kulkarni et al., 1994). Useful life is the period during which the sediment collected does not affect the intended primary use of the reservoir (Arora and Goel, 1994; Kulkarni et al. 1994, Agrawal and Singh, 1994). In most of the developed countries, full life is said to have arrived, when half of the total capacity of reservoir is depleted. While in case of Trinity River basin reservoirs (Texas), it was considered as the period when the useful storage would be completely met (Arora and Goel, 1994). Useful life is an important design parameter of a reservoir which may affect the economic feasibility and sustainability of a water resources project (Gill, 1979).

A direct method for the useful life estimation of a reservoir was proposed by Gill (1979) which correlates the reservoir capacity with age in years algebraically. With the relationship between sedimentation rates, T_e, specific weight of sediment deposited, the storage available after sedimentation for a given period t was estimated using the following equation:

$$C_0 - C = \frac{G \; x \; T_e \; x \; \Delta_t}{y} \qquad 2.2$$

where, C_o is the initial capacity of reservoir, C. is reduced capacity of reservoir at any time t, G, is characteristic weight of annual sediment inflow; Δt is a short interval of time in years in which capacity is reduced from C_0 to C; and y is specific weight of sediment deposited.

Assuming a period in which the initial reservoir capacity will reduce to half (means C= C_o/2) as useful life of a reservoir ,Gill (1979) derived equations for estimating the useful life of a reservoir and are reported here in as Equation 2.3 to 2.5.

Primarily for Highly Flocculated and coarse Grained sediments:

$$T_L = \left[y \frac{1}{G} \right] \left[0.49735 \frac{C_0}{I} + 0.3x10^{-5} x \frac{I}{C_0} + 0.00436 \right] \quad 2.3$$

Median Curve (for Medium Sediments):

$$T_L = \left[y \frac{I}{G} \right] \left[0.008 - 0.51 \frac{C_0}{I} \right] \quad 2.4$$

Primarily colloidal and Dispersed Fine-grained sediments:

$$T_L = \left[y \frac{I}{G} \right] \left[0.51328 \frac{C_0}{I} - 0.133x10^{-3} x \frac{I}{C_0} + 0.513x10^{-5} x \left[\frac{I}{C_0} \right] + 0.018167 \right] \quad 2.5$$

where T_L is useful life of reservoir in years, e.g., time in which the initial reservoir capacity C_0 will reduce to half.

2.1.2 Life of a Reservoir

Every reservoir is expected ultimately to silt up. Since silting is expected, a certain percentage of the total storage is left unutilized and is called the dead storage, but with the passage of time, more and more silting takes place gradually, beyond the dead storage, reducing the live storage. Figure 2.1 shows the storage zones of a reservoir. They are the dead storage, live storage and flood storage zones.

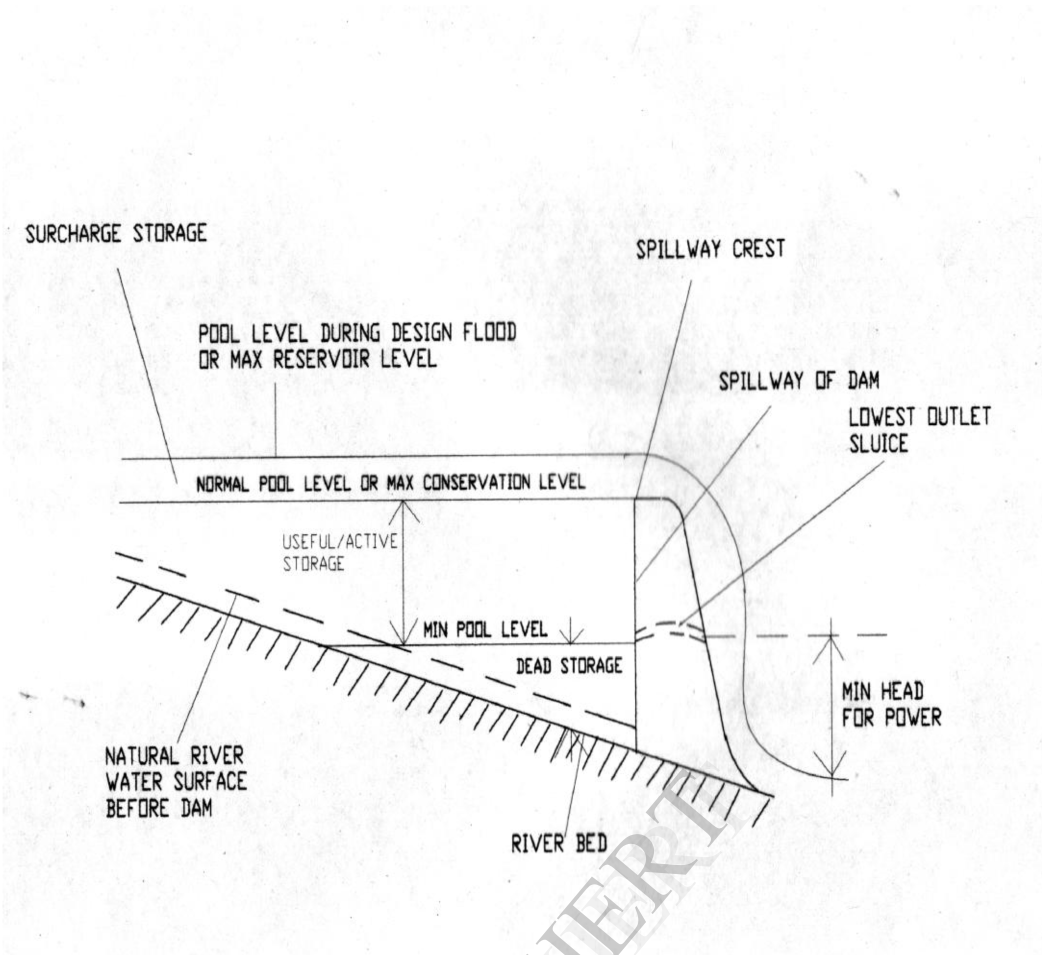

Fig. 2.1: Storage zones of a reservoir

The rate at which the capacity of a reservoir is reduced by the deposition of sediment depends upon:-

(i) Sediment load, i.e., the rate of sediment inflow.

(ii) Trap efficiency of the reservoir

(iii) The density of the deposited sediment.

The above factors are taken into consideration before the probable life of a reservoir can be predicted. The useful life of a reservoir lost every year by sediment deposition is

$$V_s = Q_s \eta \qquad 2.6$$

where V_s= volume of useful capacity of a reservoir lost each year, Q_s = sediment load of the reservoir, η = trap efficiency of the reservoir.

Accumulating sediment deposit causes the reservoir bottom to be raised, diminishing the reservoir usable area, causing negative changes of water quality and spoiling the aesthetic values of the reservoir and the adjoining areas (Tolouie, et al., 1993). Sediment deposits in reservoirs may have significant effects on reservoir operation (Sloff, 1991). The life of a reservoir is increased by applying sediment deposition control measures aimed at reducing sedimentation in the reservoir. Sedimentation processes in reservoirs and lakes have been reported by many authors, e.g., Mahmood (1987), Fan and Morris (1992), Hotchkiss and Parker (1991), Sloff (1997) and many others. In recent years, experimental and numerical research on these topics has been actively pursued at Saint Anthony Falls Laboratory (SAFL), (2003b), University of Minnesota. For instance, a moving boundary model of deltaic sedimentation in lakes and reservoirs that captures the co-evolution of the river-delta morphology and the associated deposit was developed.

Reservoir water storage capacity starts depleting with the inflow of water and sediment into the reservoir as the reservoir usage is commenced.

Generally, a reservoir life of one hundred years is mostly used. It is required that silt storage space be provided in the dead storage equal to the estimated total volume of silt deposition during its entire life. This will make the silt not to encroach on the live storage zone of the reservoir.

2.1.3 Factors Effecting Silting of Reservoirs

Rate of silting in reservoirs is controlled by the following principal factors:-

(i) The quantity, quality and concentration of the sediment brought down by the river.

(ii) The percentage of the silt intercepted by an upper reservoir or all the silt from the river that reaches the reservoir.

(iii) The percentage of the silt reaching the reservoir trapped or what proportion passes through, which in turn depends upon methods of reservoir operation and nature of spillway and other discharging facility in operation.

(iv) The degree of consolidation, i.e., weight of silt per unit volume

(v) The length of reservoir.

(vi) The runoff volume and peak discharge from catchment and sub-catchment.

(vii) The ratio of reservoir capacity to annual runoff, i.e., capacity inflow ratio. This is a function of trap efficiency.

(viii) The exposure of deposited material.

(ix) The size and shape of reservoir. Increased reservoir area leads to reduced silt yield.

(x) The depth and age of sediment deposited.

(xi) The steepness of thawleg. Steep slopes give rise to higher velocities and hence higher silt-charge.

(xii) The growth of vegetation at the head of reservoir: Adequate vegetation cover in the catchment area reduces erosion of soil, hence reducing silt deposition.

(xiii) The nature of soil in the catchment area: Clayey and coarse grained sandy soils are less erodible than silty soil. Soils are more erodible when dry than when moist.

(xiv) Type of rainfall and snow fall in the catchment area: High intensity rainfall of short duration yields higher runoff and more silt charge.

(xv) Effective annual rainfall

(xvi) The mean monthly and annual temperature in the watershed area.

(xvii) Earthquakes generate additional amount of silt:

During earthquakes, huge amount of debris are displaced and carried by the rivers which are ultimately deposited in the reservoir.

There is a reduction of silting rate as the reservoir ages due to consolidation and shrinkage as a result of the superimposed load and periodical exposure of deposit to weather, fall in trap efficiency and mainly due to the progressive formation of deltas at the mouth of the main river and as well as in the tributaries where most of the silt is trapped above reservoir level. As a consequence, a smaller amount of sediment is received into the reservoir basins. A provision of sedimentation at the rate of 0.1 to 1.2 ha m/year/sq .km of drainage area is made for the entire economic life of the reservoir. Reservoirs are losing a capacity of ½ -1% annually. There are many dam and reservoir facilities in Nigeria. Some of the important ones are as in Table 2.1

showing location, surface area and primary usage. Most dam and reservoir facilities are located in the Northern part of the country since rainfall is low in the area. Some of the major dams in Northern Nigeria are shown in Figure 2.2.

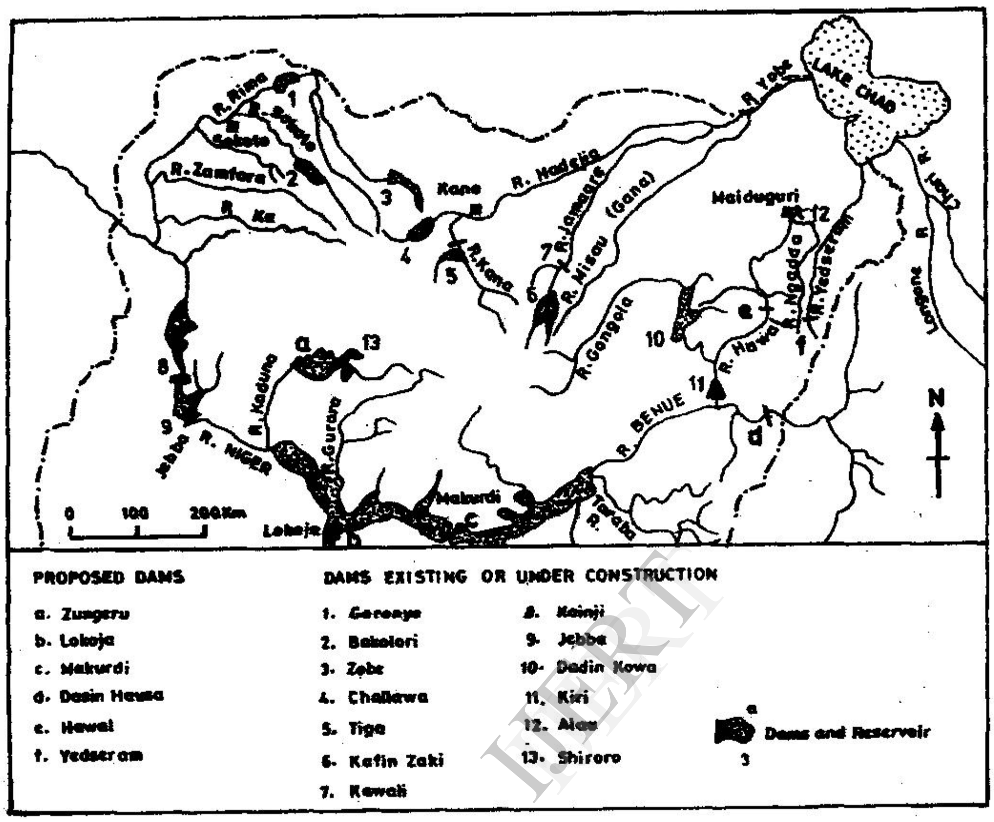

Fig. 2.2: Major dams and reservoirs in Northern Nigeria

Source: Oyebande(1995)

Table 2.1: List of Dams and Reservoirs in Nigeria

State	Dams	Capacity (Millions of m^3)	Surface area (Hectares)	Primary usage
Oyo State	Asejiere Reservoir		2369	Water supply
Sokoto State	Bakolori Dam	450	8,000	Irrigation
Kano State	Challawa			

	Gorge Dam	930	10,117	Water supply
Gombe State	Dadin Kowa Dam	2,800	29,000	Water supply
Sokoto State	Goronyo Dam	942	20,000	Irrigation
Oyo State	Ikere Gorge Dam	690	4,700	Hydro-electric, Water supply
Niger State	Jebba Dam	3,600	35,000	Hydro-electric power
Katsina State	Jibiya Dam	142	4,000	Water Supply, Irrigation
Bauchi State	Kafin Zaki Dam	2,700	22,000	Planned-irrigation
Niger State	Kainji Dam	15,000	130,000	Hydro-electric
Adamawa State	Kiri Dam	615	11,500	Irrigation, plans for hydro-electric
Ogun State	Oyan River Dam	270	4,000	Water supply, irrigation
Niger State	Shiroro Dam		31,200	Hydro-electric power
Kano State	Tiga Dam	1,874	17,800	Irrigation, water supply
Kebbi State	Zauro polder project			Irrigation
Katsina State	Zobe Dam	177	5,000	Water supply

Source: Wikipedia, the free encyclopedia.

Nigeria experiences varying rainfall in different parts of the country with the least rainfall in the Northern part of the country. Annual rainfall and hydroecological zones of Nigeria are shown in Figure 2.2.

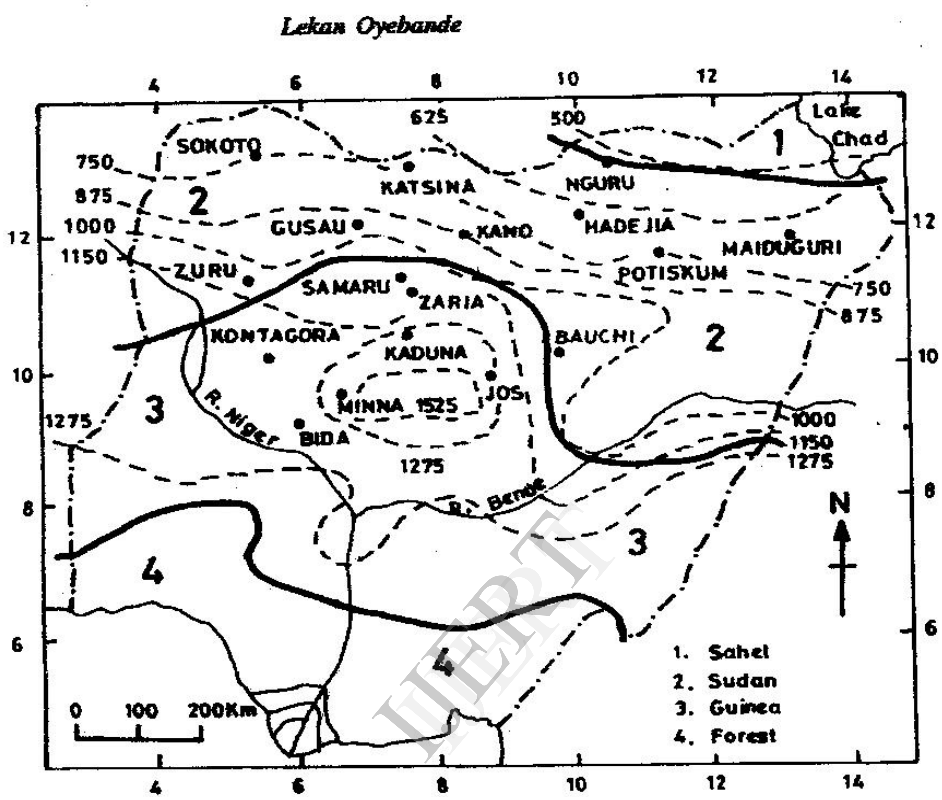

Fig. 2.3: Annual rainfall and hydroecological zones of Nigeria (isohyets in mm)

Source: Oyebande (1995)

2.2 Data Acquisition

Data for this work was collected and the procedure for the study and analysis of results were as follows:

i. Literature Review on reservoir sedimentation and distribution. This involved extracting useful information on this work from a literature review of the subject matter carried out using journals, textbooks, articles, etc by different authors.

ii. Field Data Collection/ Presentation and Analysis: This involved data collection on the sediment distribution pattern both longitudinally and latitudinally. A boat will be used to collect data using GPS equipment. The GPS is a survey equipment that records silt charge of the reservoir longitudinally, latitudinally and at the bottom vertically, all at a point. This information obtained from the GPS equipment enabled calculation of the volume of sediment deposited in the reservoir.

The volume of sediment accumulated in the reservoir was measured by measuring the height of sediment at the head of the reservoir, i.e., the delta area and the height of silt at the tail of the reservoir which is the zone of the main sediment deposition.

Then, Total volume of sediment deposition = Area of sediment deposition multiplied by the thickness of the sediment.

Moreover, data was collected on the reservoir dimensions (length, surface area, height of water level, etc).

2.3 Analysis and Results

2.3.1 Total Volume of Sediment in the Reservoir

The total volume of silt (sediment) is calculated using Simpson's Rule for volume calculation (Primordial Rule).

$$V = \frac{d}{3}\left\{A_1 + A_n + 4\left(oddoffsets\right) + 2\left(evenoffsets\right)\right\} \qquad 2.7$$

Where d=50m, i.e. distance between successive chainages.

$$V = \frac{50}{3}\left[\begin{array}{l} 387.00 + 521.925 + 4\left(\begin{array}{l} 412.50 + 483.00 + 416.25 + 359.25 + 474.75 \\ +413.25 + 440.55 + 440.33 + 474.90 \end{array}\right) \\ +2\left(\begin{array}{l} 522.00 + 502.50 + 450.75 + 486.75 \\ +534.00 + 416.25 + 492.75 + 445.13 + 626.70 + 487.65 \end{array}\right) \end{array}\right]$$

$$= 347,378.41 m^3$$

2.3.2 Weight of Silt in the Reservoir

The weight of the deposit in the reservoir depends on the specific weight of the silt. However, it has been established that the specific weight of sediments varies with the type and age of sediment. According to Lane and Koelzer (1953), specific weight, W_t at time t can be defined by

$$W_t = W_i + k \log t$$

Where $W_i =$ average initial specific weight of a mixture of sand, silt and clay

$$= 1{,}002 kg / m^2 s^2 \left(N / m^3\right)$$

$K =$ consolidation coefficient average value of 7.0

Therefore, the specific weight of deposited silt after 36 years

$$W_{36} = 1{,}002 + 7 \log 36$$
$$= 1{,}012.89 kg / m^2 s^2 \left(N / m^3\right)$$

Tonnage of silt in the reservoir

Weight at time (t) x Volume of silt

1000

$$\frac{1{,}012.89 \times 347{,}378.41}{1000} = 351{,}857.55\, tons$$

2.3.3 Percentage of Reservoir Silted up

Present volume of silt in the reservoir (2011) = 347,378.41 m^3

Capacity of the reservoir = 1.5 x 10^6 m^3

Present Capacity of Reservoir Silted up

$$= \frac{\text{Present Total Volume of Silt}}{\text{Reservoir Capacity}}$$

$$= \frac{347,378.41}{1.5x10^6} x100\% = 23.16\%$$

2.3.4 Life of the Reservoir

The useful capacity of the reservoir lost every year by sediment deposition is

$$V_s = Q_S \, \eta_{trap} \qquad 2.8$$

Where V_S = volume of useful capacity of reservoir lost each year

Q_s = annual sediment inflow into the reservoir

η_{trap} = trap efficiency of the reservoir

$$\text{The Reservoir Life} = \frac{Capacity\ of\ reservoir\left(m^3\right)}{V_S\left(m^3/yr\right)} \qquad 2.9$$

$$Q_s = \frac{347{,}378.41\,m^3}{36\,yrs} = 9{,}649.40\,m^3/year$$

Adopting $\eta_{trap} = 91\%$ (Average value from field data)

$$V_s = 9649.40 \times 0.91 = 8780.95\,m^3 / year$$

Therefore, Life of Reservoir $= \dfrac{C}{V_s} = \dfrac{1.5 \times 10^6\, m^3}{8780.95\,m^3 / year}$

$$= 171\,years$$

3. DISCUSSION OF RESULTS

It was found that large quantity of silt has accumulated inside the reservoir over the years since it was constructed. The accumulated silt depletes the reservoir storage capacity which will lead to reduced life of reservoir and benefits. The life of the reservoir obtained to be 171 years shows that the Ikpoba reservoir has long life when compared to other reservoirs in the world. For most reservoirs a reservoir life of 100 years is normally used. The reservoir should be desilted to ensure long reservoir life and sustained benefits.

4. CONCLUSION

Sediment trapping in our reservoirs is a serious issue that threatens its functionality and benefits. In view of tremendous amount of money spent on putting up a dam and reservoir facility, there is urgent need to protect this to prolong its life and benefits.

There is a lack of adequate data on sedimentation in most reservoirs in Nigeria. The rate of sedimentation in these reservoirs is not monitored. This may lead to the reservoirs being filled up with sediments before the estimated reservoir life is reached leading to sudden end of the benefits.

A total of 347,378.41 m^3 of sediments has been trapped and deposited into the reservoir bed since it was built in year 1975. 23.16% of total storage has been depleted. The study has found that the deposited sediments are progressively moving towards the dam.

5. RECOMMENDATIONS

It is recommended that studies should be carried out on different reservoirs in our country periodically (say every ten years) to monitor their sedimentation rates.

Measures to control reservoir sedimentation like putting up vegetation at reservoir area, construction of check dams, provision of multiple sluiceways at the foot of the dam, etc should be applied to prolong the life of the reservoir and its benefits.

It is also recommended that the usage of dead storage zone should be abolished in reservoir design in Nigeria. Multiple sluice gates should be provided at the dead storage region to ensure that most sediments entering the reservoir are flushed out as they approach the dam.

There is urgent need to commence sedimentation and general reservoir management studies in all reservoirs in our country to save them from rapid siltation and loss of benefits.

The Ikpoba water supply reservoir should be optimized by making it a multi-purpose facility by using it to provide potable water, hydroelectric power and irrigated agriculture to Benin City and environs to improve standard of life of people in the area.

Sedimentation data should be obtained for different reservoirs in the country and empirical model developed and applied for periodic sedimentation studies.

Due to lack of periodic sedimentation studies in Ikpoba river reservoir, 23.16% of the total capacity has silted-up. This implies that the 20% of the total capacity allotted for the dead storage zone has been utilized before the supposed life of the reservoir is reached. There is urgent need to commence desilting of the reservoir to save it from total reservoir siltation and loss of benefits. The Edo State government should embark on this immediately in view of the tremendous cost to save the dam-reservoir facility.

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