

The Effect of Sedimentation on the Useful Life of the Unilorin Dam

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Abstract

The presence of sediments in a reservoir reduces full utilization of reservoir for its intended purposes. This is because sediments pollute the water, reduces the holding capacity of the reservoir and ultimately reduces the amount of water available for use from such reservoir. This study determines the effect of sedimentation rate of the Oyun River on the life span of the University of Ilorin dam. Both practical and theoretical approaches were used. Solids values of water samples obtained from the mouth of the reservoir was obtained and used to compute the total volume of sediment coming into the reservoir. The obtained values was compared with values obtained by using existing equations and curves from literature. The water demand for the university community was also computed and compared with the rate of sedimentation of the dam to also estimate its useful life. The practical and theoretical approach yielded 149.08 and 86.2 years respectively as the useful life of the dam. This exceeds the usual recommended design years for Dams. The sedimentation of the reservoir is also relatively low because the catchment area enjoys a substantial vegetative growth for long periods of the year which reduces erosion of loose soils. However, considering the primary use of the dam to supplying water to the campus, and assuming all other factors remain the same, the service life is about 40 years.

Keywords

Bed load, sedimentation, reservoir, dam, community.

1. Introduction

Water is vital for life and is one of the basic resources for the existence and development of the human society. Water is undoubtedly the most precious

natural resource that exists on our planet comprising of about 70% of the earth (Du Plessis, 2017). It is required for a variety of human uses including domestic consumption (drinking, washing, cooking), primary industry (consumption by animals, irrigation, mineral exploration), secondary industry (industrial processes, cooling) and in tertiary industry (tourist industry). Water supply development is concerned with both the quantity and quality of water required to meet the needs of man in an efficient and economic manner. Water is stored in reservoirs for various beneficial purposes such as irrigation, water supply, hydro-electric power generation and navigation.

The movement of sediment which rolls and creeps along the bed of a river is known as bed load. Accumulation of sediments in a reservoir reduces its holding capacity and therefore reduces the water available for these beneficial purposes (Rahmani et al, 2018). Estimation of the rate of sedimentation of a reservoir helps in calculating the expected life of a dam. Therefore, the aim of this study is thus to determine the effect of sedimentation on the useful life of the University of Ilorin (Unilorin) Dam. If the rate of sedimentation of the dam is known, the amount of sediments entrenched in the dam can be estimated and proper management can be done to increase the life span of the dam.

The suspended load is that part of the sediment load which is held in suspension against gravity by the vertical component of the eddies of the turbulent flow (Al-Ansari & Knutsson, 2012; Joshi & Xu, 2017). The suspended load usually consists of fine materials dispersed throughout the river cross-section. Bed load is that part of the sediment load which remains in contact with the bed when moving with water. There is many methods for the estimation of sediment transport in rivers but each is an approximation to the truth over a limited range of hydraulic and sediment characteristics and none has been universally accepted (Habibi & Sivakumar, 1992). It is important that the Engineer be able to estimate as fairly as possible sediments in a river. Although sediment is a natural component of streams and rivers, it can be damaging when it is present in excess. There is the tendency for infilling of natural riverine pools, altered instream vegetation and flow dynamic, reduced photosynthesis, altered macroinvertebrate communities, influence on fish distribution and food availability and disruption of the food web (Till & Trayler, 2000).

2. Study Area

The University of Ilorin is located in the ancient city of Ilorin about 500 kilometers from Abuja, the Federal Capital of Nigeria and about 15 kilometers from the city Centre. The University has a land area of about 15 000 hectares with about 95% yet to be occupied and largely used by Communities around for farming activities (Oloyede et al, 2009).

The University of Ilorin Dam, commissioned in 2007 primarily for water supply, is located on the Oyun River which flows through the University. The Dam is a zoned earthfill embankment with an ogee-shaped concrete spillway. The Dam parameters are shown in Table 1.

3. Material and Methods

Stream-flow data of Oyun River at the entrance to the reservoir of the University of Ilorin dam and other dam parameters such as reservoir volume, dam height etc. were obtained from the design report by messers CIWAT Engineering Consultants Limited. The flow is intermittent. Before embarking on the collection of samples from the Upstream of the University of Ilorin Dam, a detailed reconnaissance survey was undertaken and some features of the reservoir such as reservoir catchment, vegetal cover and predominant sediments were noted. The reservoir has no significant floating debris. There are farming activities going on in the catchment area and thus loose soil is a possible source of sedimentation.

Three Grab samples were taken in 10 litre size containers at intervals of 20m along the river channels at the mouth of the reservoir. The samples were collected when there is substantial streamflow. The samples were taken to the laboratory for analysis. Solids were analysed as specified by Standards Methods (AWWA, 1995).

Measurement of Sediment Load: The average annual sediment transported by the river is obtained by multiplying the mass of the sediment per unit volume by the average annual inflow volume (Arora, 2004).

$$\text{Annual sediment} = MS \times VA \dots \quad (1)$$

Where MS = sediment per unit volume of water (mg/l) and VA = Annual volume of water (l)

$$T.R \text{ (mg/l)} = \frac{(A-B) \times 1000}{V} \dots \quad (2)$$

Where: T.R=Total Residue (Solid) (mg /l), A= weight of sample + dish (mg), B= weigh of dish (mg), V= Volume of sample (ml).

The total residue obtained from Equation (2) is the weight of sediment (mg) in 0.001m^3 of water. Practically, the weight of sediment deposited in the reservoir yearly is obtained by multiplying the weight of sediment in 1m^3 of water by the reservoir average annual sediment yield (m^3).

$$W_s = \frac{T.R(\text{mg/l}) \times \text{average annual yield (m}^3\text{)}}{1000} \quad (3)$$

Where W_s = Total weight (kg) of sediment deposited in the reservoir per year
The volume (V_s) in m^3 occupied by W_s is obtained from

$$V_s = W_s / \rho \quad (4)$$

Where ρ is the mass density of the sediment in kg/m^3 . The useful life of the reservoir is obtained by dividing the reservoir volume by volume occupied by annual sediment depositions.

$$\text{Useful life of reservoir} = \text{Reservoir volume} / V_s \quad (5)$$

An empirical method, described in detail by Arora (2004), was also used to estimate the useful life of the reservoir.

4. Result and Discussion

The average total residue solids obtained was 306.67 mg/l. Total weight of sediment deposited in the reservoir per year W_s is estimated as $15.5 \times 10^6 \text{kg}$, Average annual yield (m^3) = 50.53×10^6 (from Table 1)
Taking density of consolidated sediment (ρ) as 1500kg/m^3 (Armanini, 2018)
The volume (V_s) occupied by W_s is $10.33 \times 10^3 \text{m}^3$.

Live storage of the reservoir = $1.54 \times 10^6 \text{m}^3$ (from Table 1). Based on Equation (5), the useful life of reservoir is 149.08 years.

For empirical computations, Total Residue is taken as 1000mg/l (Gill, 1979). Annual inflow of water (average annual yield) (I) = $50.53 \times 10^6 \text{m}^3$ (from Table 1). The initial capacity of reservoir (live storage + dead storage) = $1.8 \times 10^6 \text{m}^3$ (from Table 1)

Table 1: Relevant details of the Unilorin dam

S/No	Item	Details
A	Reservoir	
1	Catchment area	573km ²
2	Average Annual Yield (Catchment Runoff)	$50.53 \times 10^6 \text{m}^3$
3	Live storage	$1.54 \times 10^6 \text{m}^3$
4	Dead storage	$0.26 \times 10^6 \text{m}^3$
5	Surface area @ elevation 294 m ams	$0.696 \times 10^6 \text{m}^3$
6	Reservoir capacity @ elevation 294 m amsl	$1.80 \times 10^6 \text{m}^3$
7	Length of the river (Source to Dam)	48.30km
8	Maximum Fetch	6.10km
B	Dam Embankment	
1	Type	Zoned Earthfill embankment
2	Crest Elevation	EL 296.50 masl
3	Crest length	178m
4	Top width	5m
5	Maximum height of embankment	10.30m
6	Maximum height of earth core	8.90m
7	Maximum width of base	31.40m
8	Base of the earth core	21.40m
9	Upstream slope	1:3
10	Downstream slope	1:2
11	Upstream and Downstream slope of earth core	1:1
C	Spillway	
1	Type	Ogee-shaped concrete spillway
2	Crest length	50m
3	Crest elevation	EL294
4	Maximum height	7.7m
5	Maximum flood discharge	$434.81 \text{m}^3/\text{s}$
6	Free board height	2.50m

Source: Technical Report on Unilorin dam by CIWAT Engineering Consultants

The useful life is computed at an average of 10% loss of the storage as described by Arora (2004) is shown in Table 2 and useful life of reservoir is 86.2 years.

By considering only the sediments collected from the Oyun River, the useful life of the Unilorin reservoir was obtained to be 149.08 years. The empirical method yielded 86.2 years. The Brune's curve (Lewis et al, 2013) used for the empirical method at low values of C-I (Capacity – Inflow) ratio give an approximately straight line graph which becomes curved as the C-I ratio increases.

This explains why the number of years for filling successive 10% of the reservoir capacity with consolidated sediment increases from 6.4 years for the first reduction to 14.1 years for the 10th reduction (Table 2).

The practical method applied here however assumed a constant rate of reduction in reservoir capacity. Dams are usually designed to have a useful life of 50 years (Arora, 2004) and both values obtained shows a satisfactory useful life for the .Unilorin dam. The rate of sedimentation of the dam is relatively low because of the compact soil surrounding the reservoir and the vegetation which reduces washing away of soil resulting from erosion.

It is also to be noted that samples were obtained at the bank of the River. This does not give a representative value of the total. A different result might have been obtained if samples were obtained at the bank and middle of the reservoir and at some depth

The water use requirement of the university community is based on the standard recommended by World Health Organization of 120 liters (0.12m³) per capita per day. Table 3 shows the water demand computation.

Table 2: Computation of Useful Life of the Unilorin Reservoir

Capacity $\times 10^6 \text{m}^3$	C/I ratio	Trap Efficiency for C/I ratio (%) η	Average Trap Efficiency η_{average}	Annual tapped sediment		Loss of reservoir capacity ΔC (m^3)	Number of years for capacity loss $\Delta C/V$	Cumulative number of years for capacity loss
				Mass (kg)	Volume (m^3)			
				$\times 10^6$	$\times 10^3$			
				M $=W_s \times \eta$	$V=M/\rho$			
1.800	0.036	72.0	-	-	-	-	-	-
1.646	0.033	70.0	71.0	35.9	23.9	1.54×10^5	6.4	6.4
1.492	0.030	68.0	69.0	34.9	23.3	1.54×10^5	6.6	13
1.338	0.026	65.5	66.8	33.7	22.5	1.54×10^5	6.8	19.8
1.184	0.023	62.5	64.0	32.3	21.5	1.54×10^5	7.2	27
1.030	0.020	60.0	61.2	30.9	20.6	1.54×10^5	7.5	34.5
0.876	0.017	53.0	56.5	28.5	19.0	1.54×10^5	8.1	42.6
0.722	0.014	51.0	52.0	26.3	17.5	1.54×10^5	8.8	51.4
0.568	0.011	44.8	47.9	24.2	16.1	1.54×10^5	9.6	61
0.414	0.008	38.0	41.4	20.9	13.9	1.54×10^5	11.1	72.1
0.260	0.005	27.0	32.5	16.4	10.9	1.54×10^5	14.1	86.2

Storage capacity at the end of useful life (dead storage) = $0.26 \times 10^6 \text{m}^3$ (from Table 1)

Table 3: Estimated water demand for the University community.

Estimated Population of official residents (2018)	6000
Population of un-official residents(assume ½ of official residents)	$\frac{1}{2} \times 6000 = 3000$
Number of staff quarters	141
Staff dependent rate.(assume 5 per house)	$5 \times 141 = 705$
Total resident population	$6000 + 3000 + 141 + 705 = 9846$
Current resident population	Assume 10,000
Adopting the W.H.O standard, total volume of water demand per day	$10,000 \times 0.12 = 1200 \text{ m}^3/\text{day}$ $= 1200 \times 365 = 0.44 \times 10^6 \text{ m}^3/\text{year}$

Source: Academic and Planning Unit, University of Ilorin.

From Table 3 the current resident population of the university community is about 10,000. Adopting W.H.O standard, total water demand is $0.44 \times 10^6 \text{ m}^3/\text{year}$. Assuming the population of the university community increases by 2.8% every year, (based on the Nigerian Population Commission (NPC) rate for population increase in Nigeria), the Dam will serve for 35 to 40 years before the storage becomes inadequate due to silting, for the projected population of the University. The Dam became operational in the year 2007. If all other factors (structural, hydrological, land use, environmental) remain the same, the Dam reservoir can serve the university up to the year 2045.

5. Conclusion

A practical method for estimating rate of sedimentation was used which gave a service life of 149.08 for the Dam. The empirical approach using Brune's curve shows a useful life of 86.2 years.

When the estimated water demand for the University community was computed, it was deduced that the Unilorin dam will meet the water demand of the university community for almost 40 years.

In all cases, it was obtained that the Unilorin dam has a useful life greater than 50 years for which dams are usually designed.

It can therefore be concluded that the Unilorin dam has an appropriate design life. Farming activities which may lead to soil stripping and dislodgement of soil material will increase sediment transport in the catchment and measures to reduce this should be undertaken. Regular dredging will also increase the lifespan of the reservoir.

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