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Analysis of Sediment in Goronyo Dam, Sokoto, Nigeria

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ABSTRACT: Reservoir sedimentation has been a global bottle neck in maintaining the design storage capacity of reservoirs. Reservoir sedimentation leads to the reduction of the original capacity which affects irrigation, hydropower, flood control, drinking water supply and recreational activities. Introduction of mechanized farming without due regard to the nature of the environment is aggravating the erosion and sediment problem. This study has discussed and analyzed the most important parameters (bulk density, sediment volume, sediment mass, trap efficiency, sediment yield etc) for 31 years (1984 -2015) using Empirical Method and Goronyo Dam Stage Capacity Curve. The Mean bulk density (dBD) was gotten as 0.97gcm^3, Sediment Volume (SV) as 26,179,302m^3 , Sediment Mass (SM) as 25,393,922.94 tones, average annual sedimentation as 819,158.81ty^{-1}, Trap Efficiency (TE) as 90.2%, Sediment Yield (SY) as 908,158.00 ty^{-1}, Specific Sediment Yield (SSY) as $42.35tkm^{-2}y^{-1}$, The loss of storage (26,179,302m^3)

KEYWORDS: Stage Capacity Curve, Sediment Volume, Trap Efficiency, Sediment Mass, Sediment Yield.

INTRODUCTION

A reservoir is a body of water used for storage, regulation and control of water resources (Saenyi, 2002. Reservoir sedimentation leads to the reduction of the original capacity which affects irrigation, hydropower, flood control, drinking water supply and recreational activities. Sediment are fragments of rocks and minerals that are broken down by weathering and erosion, and are subsequently transported by water, wind or ice (Hoven, 2010).Sediments in reservoirs are heterogeneous mixture of soil particles and rock fragments, detached from the earth's crust, transported and deposited in the reservoir basin (De Villiers, 2006). Introduction of mechanized farming without due regard to the nature of the environment is aggravating the erosion and sediment problem. Due to lack of reservoir management practices such as periodical sediment flushing, reservoir sediment routing and catchment management to reduce the soil erosion, the sedimentation of reservoirs is inevitable and it has gradually becoming a greater threat for many countries around the world (Revel *et al*.,2013). Sediment pollution of water creates several problems: early silting up of reservoir, low water transparency in rivers and reservoirs, which adversely affects fish populations, and high water treatment costs, reduce navigability, increased flooding and blockage of irrigation canals (NESAT, 1991). The study of soil erosion helps in understanding of the interaction between sediment generation and sediment yield in a drainage basin (Msadala, 2009). There is need for an integrated approach in the determination of soil erosion, sediment yield, sediment transport and reservoir sedimentation in all catchments (Saenyi, 2002).Sediments that are transported and deposited in reservoirs are derived from catchment erosion (Hassanzadeh,1995). The aim of all good sediment management techniques is to reduce the accelerated erosion (Desta, 2005).Soil erosion by water is the most common and widespread form of erosion in the world (Shaozu *et al*., 2003). Reservoir trap efficiency is the ratio of the deposited sediment to the total sediment inflow (Rupasingha, 2002;Licher, 2003;Letsie, 2005; Ji,2006).It is simply the proportion of the total incoming sediment that is deposited or retained in the reservoir (Verstraeten and Poesen,2000; Letsie,2005;Kim,2006). Trap efficiency is often expressed in percentage (Campos, 2001). The aim of this study is to analyzed the most important parameters (bulk density, sediment volume, sediment mass, trap efficiency, sediment yield etc) for 31 years (1984 -2015) using Empirical Method and Goronyo Dam Stage Capacity.

Location of Goronyo Dam on Rima River

The location of Goronyo Dam on Rima River is shown in Plate 1

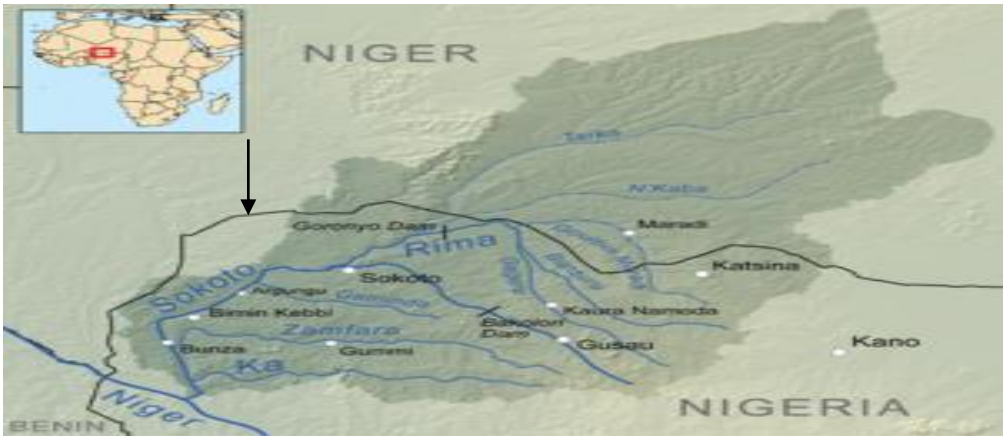

Plate1. Location of Goronyo Dam on Rima River

Source: SRRBRDA, 1991

Some Geographical Details of Goronyo Dam

Some of the Geographical details of Goronyo Dam are shown in Table 1

Table 1. Some Geographical Details of Goronyo Dam

Location		Sokoto State, Nigeria
Coordinates		
	Latitude	13°31'50"N
	Longitude	05°52'56"E
Opening date		1992
Dam and Spillways		
	Impounds	Rima River
	Height	21m
	Length	12.5km
Reservoir		
	Total capacity	976 million m^3

Source: SRRBRDA, 1991

Salient Features of Goronyo Dam

The salient features of the reservoir are as shown in Table 2 below.

Table 2. Features of the Reservoir

Parameter	Value
Maximum storage level	288 m
Minimum useful storage level	279.50m
Gross Storage capacity	942 x $10^6 m^3$
Dead storage	21.50 x 10^6 m^3
Lake area	200 km^2
Spillway capacity	1,540 m^3/s
Tributaries	River Gagare, River Bunsuru and Gada/Maradi River

Source: SRRBRDA, 1991

Analysis of Sediment in Goronyo Dam, Sokoto, Nigeria

Goronyo Dam

The Plate 2 below shows Goronyo dam

Plate 2 : Goronyo Dam

Source: SRRBRDA, 1991

MATERIALS AND METHODS

Empirical Method and Goronyo Reservoir Stage Capacity Curve were used in the study. Empirical Method was used for calculating the significant parameters while the Goronyo Reservoir Stage Capacity Curve was used for obtaining reservoir's readings of initial and current volume (m^3) at their respective elevations (m). The stage capacity curve is a graph of water level (Y-axis) plotted against reservoir volume (X-axis).It was designed by Impresit Bakolori Nigeria Limited (IBNL) in 1979 with storage capacity of 942,000,000m^3 at 288 m elevations. The designed stage-capacity curve of Goronyo Reservoir is shown in figure3.

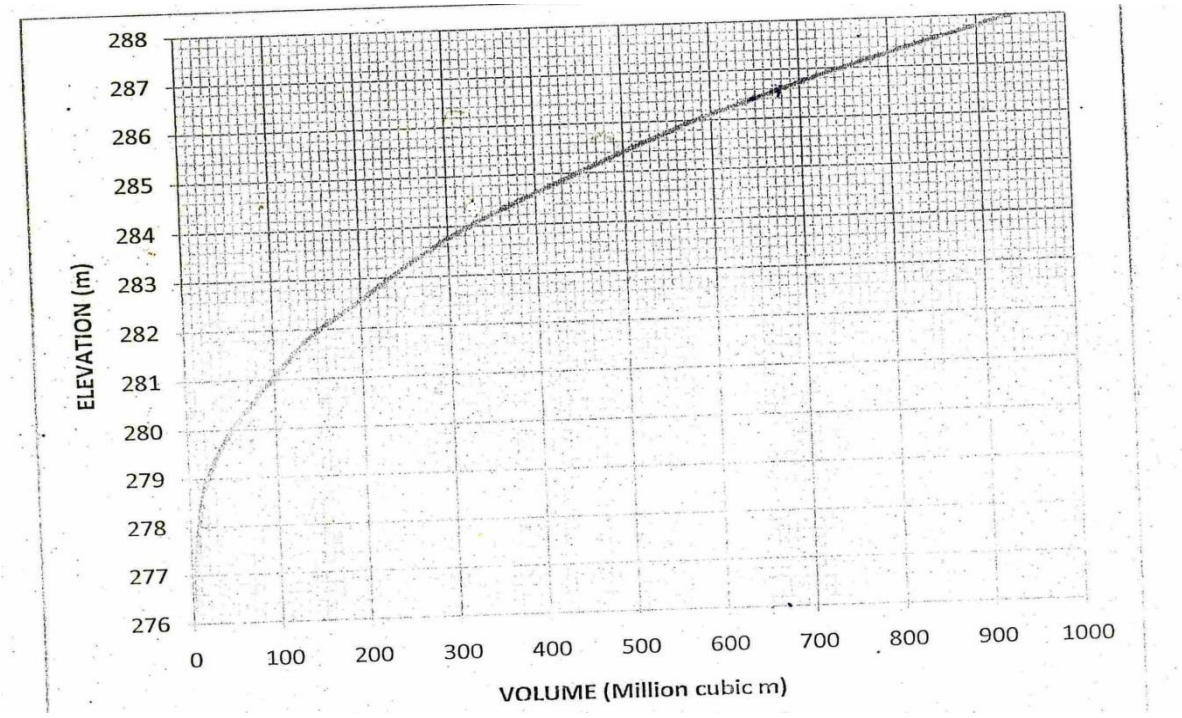

Figure 1: Goronyo Reservoir Pre-impoundment Capacity

SOURCE: SOURCE: IBNL, 1979

RESULTS AND DISCUSSIONS

Goronyo Dam Sedimentation

Goronyo Reservoir Sediment Volume

The sediment volume of the reservoir was calculated as the difference between the original and current capacity of the reservoir. The data was given as follows:

At 286.4m, initial reservoir storage capacity = 650, 000,000m^3

At 286.6m, current reservoir storage capacity = 623,820,698m^3

Therefore, Reservoir Sediment Volume (SV) can be determine using equation (1) and the relation is as follows:

SV =Initial reservoir storage capacity– current total water volume in the reservoir (1)

SV =650,000,000m^3– 623,820,698m^3 = 26,179,302m^3

In comparison, Mohammed (2014) calculated the sediment volume of Goronyo Reservoir from 1984 to 2013 (29 years) as 24,490,315m^3.

Sediment Mass and Average Sedimentation Rate

The sediment mass of Goronyo Reservoir is computed using equation (2) as follows:

$$SM = SV \times dBD \quad (2)$$

Where SM Sediment mass

SV Sediment volume

dBD Mean bulk density

The parameters used to calculate the average annual sedimentation rate of the Reservoir are:

Sediment volume (SV) = 26,179,302m^3

Mean bulk density (dBD) = 0.97gcm^3

Reservoir age (y) = 31 years

Substituting the values into equation(2) gives:

$$SM = 26{,}179{,}302m^3 \times 0.97gcm^3 = 25{,}393{,}922.94\ tones$$

Therefore, the total quantity of sediment deposited in the Reservoir from 1984 to 2015 is 25,393,922.94 tones. In comparison, Haregeweyn *et al* (2008) calculated the mean sediment mass of 42,000 tones for 11 reservoirs in Tigray, Northern Ethiopia.

The average annual sediment rate of Goronyo Reservoir was calculated by dividing the sediment mass by the age (years) of the reservoir.

Therefore, the average annual sedimentation rate of the reservoir (RS) is the relation of equation (3) as follows:

$$RS = \frac{SV \times dBD}{y} \quad (3)$$

Where RS Average annual sedimentation rate

SV Sediment volume

dBD Mean bulk density

y Reservoir age (years)

Substituting the values into equation (3) gives:

$$RS = \frac{26{,}179{,}302 \times 0.97}{31\ years} = 819{,}158.81 ty^{-1}$$

Therefore, the average annual sedimentation of Goronyo Reservoir is 819,158.81ty^{-1}. In comparison with that of Opa Reservoir was calculated as 38,830.26ty^{-1} (Adediji, 2005). It can also be compared with the mean annual sedimentation rate of 6,625ty^{-1} as computed for some reservoirs of Tigray, Northern Ethiopia (Haregeweyn *et al*., 2006). The average annual sedimentation rate shows the amount of sediment in unit mass that enter into the reservoir per year.

Trap Efficiency

The Parameters used for calculating the sediment trap efficiency of Goronyo Reservoir is presented below:

Table 3. Parameters used to calculate the trap efficiency of Goronyo Reservoir

SN	Parameter	Value
1	D	0.1
2	C	942,000,000 m^3
3	A	21,445 km^2

Source: IBNL, 1979; Adwubi *et al*, 2009.

The trap efficiency of Goronyo Reservoir is the relation of equation (4) as follows:

$$TE = 100\left(1 - \frac{1}{1+0.0021D\frac{C}{A}}\right) \quad (4)$$

Where TE Trap efficiency
D Coefficient
C Total Reservoir storage capacity
A Catchment area of the Reservoir

Substituting the values into equation (4) gives:

$$TE = 100\left(1 - \frac{1}{1+0.0021 \times 0.1 \times \frac{942,000,000}{21,445}}\right) = 100\left(1 - \frac{1}{1+\frac{197,820}{21,445}}\right) = 100(1 - 0.098) = 90.2\%$$

The trap efficiency of Goronyo Reservoir is 90.2 percent. This shows that Goronyo Reservoir has high trap efficiency. For comparison, (Adediji, 2005) calculated the trap efficiency of Opa Reservoir as 79.6 percent. Also (Haregeweyn *et al.,* 2012) calculated the mean trap efficiency of some reservoir in Ethiopia as 97 percent.

Sediment Yield

The sediment yield of Goronyo Reservoir is calculated using parameters as shown in Table 4.

Table 4. Parameters used to Calculate the Sediment Yield of Goronyo Reservoir

SN	Parameter	Value
1	Sediment Volume (SV)	26,179302.24m^3
2	Mean Bulk Density (dBD)	0.97 gcm^3
3	Trap Efficiency (TE)	90.2%
4	Age of Reservoir (Y)	31 yr

The sediment yield of the Reservoir is the relation of equation (5) as follows:

$$SY = 100\frac{S.V \times dBD}{TE \times Y} \quad (5)$$

Where SY Sediment yield
SV Sediment volume
dBD mean bulk density
TE Trap efficiency
Y Age of the Reservoir in year

Substituting the values into equation (5) gives:

$$SY = \frac{26,179,302\text{m}^3 \times 0.97\text{cm}^3}{90.2\% \times 31\ years} = 100 \text{ X} \frac{25393922.94}{2,796.2} = 100 \text{ X} 9,081.58 = 908,158.00 \text{ ty}^{-1}$$

Therefore, the sediment yield of Goronyo is 908,158 .00 ty^{-1}

Specific Sediment Yield of Goronyo

The area Specific Sediment yield of Goronyo Reservoir is calculated using equation (6) as follows:

$$SSY = \frac{SY}{A} \quad (6)$$

Where SSY Area Specific Sediment Yield
SY Sediment Yield
A Catchment area of the reservoir

Substituting the values into equation (6) gives:

$$SSY = \frac{908158.00\text{ty}^{-1}}{21445km^2} = 42.35\ tkm^{-2}y^{-1}$$

CONCLUSION

The sediment volume of Goronyo Reservoir was gotten as 26,179,302m^3 for 31 years (1984 -2015).The reservoir dead storage = 21,500,000m^3,the loss of storage (26,179,302m^3) is above the dead storage This means that Goronyo Reservoir has lost storage capacity at about its dead storage. The loss of storage when compared with the design storage capacity (942,000,000m^3) of the dam shows that the reservoir is high and adequate to satisfy its design mandates (irrigation, water supply, hydropower etc). The reservoir laboratory analysis of sediment collected from the reservoir provides relevant information on bulk density and particle size distribution of the sediments. The average annual sedimentation of the reservoir represents average sediment export from the catchment area for 31yrs of operation. The reservoir's sediment yield is a pointer to soil erosion processes and sediment transport in the catchment area. The result of the study will serve as a tool for planning and management of the reservoir. Despite the fact that, sediments are inevitable in the reservoirs, it can be curtailed upstream by aforestation, minimized mechanized

farming, minimized digging of holes for hunting underground animals (rats, giant rats, hedgehogs etc), planting of carpet grasses and sediment flushing.

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