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Sediment Deposition in Nigeria Reservoirs: Impacts and Control Measures

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ABSTRACT
This work examines the issue of sediment deposition in reservoirs. As death is an inevitable end for humans, so is siltation an inevitable end for reservoirs. Sediment content of river inflows into reservoirs depletes the available storage capacity thereby reducing the benefits such as domestic and industrial water supplies, hydro power generation, irrigation, navigation, fish and wild life, sanitation and recreation, flood control, ground water recharge, etc. Sediment distribution pattern of the reservoir was examined. Factors affecting siltation in reservoirs were also captured. Impacts of reservoirs on the environment and our health were discussed. Different methods of controlling silting in reservoirs were examined. It was recommended that there should be periodic monitoring of sedimentation in our reservoirs to prolong the life of the reservoirs and sustain their benefits.
Keywords: sediment deposition, storage capacity, reservoir life.

1. INTRODUCTION

Dams are barriers to flow and water collects upstream forming a pool of water, called a reservoir. The water stored in a given reservoir during rainy season can be easily used almost throughout the year, till the time of arrival of the next rainy season, to refill the emptying reservoir again [1]. As death is an inevitable end for humans, so is siltation an inevitable end for reservoirs. Water is a critical natural resource. Without it, life could not exist and people could not survive. For more than 5000 years dams have provided people with reliable sources of water they need to live [2]. In Nigeria, there has been an upsurge in dam construction in the past three decades [3].

1.1 Statement of the problem

There are many existing dams in the country for different purposes such as hydropower (Kainji, Jebba, Shiroro, etc) and for water supply [Asejire in Ibadan, Ikpoba in Benin city, Challawa and Bagauda in Kano) and others for agricultural and irrigation purposes (e.g., Dams in Nasarawa, Gombe in Gombe state). Many dams exist in Nigeria. These dams impound water for various purposes. However, sedimentation in reservoirs of these dams has not been monitored over the years. In the near future, many other dams will be constructed and there will be need also to control the amount of sedimentation that will occur in them over time. Since sedimentation is the ultimate fate of all reservoirs, there is thus need to control siltation in some of the important dams in the country [4]. Fig 1 shows a cross section through Ikpoba dam, Benin City.

2. LITERATURE REVIEW

2.1 The Sedimentation Process

The material of the sediment load of the rivers originates basically from two sources. The first is the river bed material that is displaced b the stream shear stress and the second, the main source of sediments, is the material resulting-from the basin erosion. The eroded soils are brought to the rivers through the basin run-off. The knowledge of the process of sediment transport is fundamental for modeling reservoir sedimentation since transport equations are at the heart of sedimentation models. The mechanisms of transport will lead to the sediment transport governing equations of the phenomenon which are used in the model. As this model is for non-cohesive sediments, this subject will not be covered in this literature review. Despite this, in some reservoirs, the cohesive sediments can be predominant.

According to [5], Colby defined sediment as the material originated from decomposition of the rocks. They become fluvial sediments when they are transported by flowing water. The first sediments to be transported are those that compose the river bed. Despite this, the bed erosion generally is not a very important source compared with the basin erosion. Often, bed erosion in most rivers contributes less than 20% of the annual sediment discharge. As seen before, the other and main source of fluvial sediments is the river catchment erosion. It is in the catchment that the sediment transport process starts yielding sedimentary material to the streams.

The catchment sediments journey towards the rivers begins when the soil particles are detached from their places by any means. That is, something that provokes soil erosion which can be a natural or a human action. Depending on the presence of soil protection, such as vegetation canopy, the impact of the rain drops may cause high soil erosion. Many human activities, such as construction of roads or other earth works can also increase to a great extent the soil erosion. Once freed, the soil particles are transported to the rivers by the catchment run off. The runoff is originated mainly from rainfall or snow melting. It is able to displace soil particles still in their repose state and transport them. A part of the runoff, transported particles can be deposited in land depressions before reaching the streams. Figure 2 depicts the sedimentation process.

When the sediments arrive in a river, they are carried to a depositional site which can be the river bed, a reservoir, a lake or the sea. If the river has not sufficient capacity to transport totally a determined sediment load, part of it will settle immediately. Whilst a sediment particle is transported in water, it is basically under the influence of two forces. The first, is the particle submerged weight and the second is the uplifting force due to the flow turbulence. The balance between the vertical forces which act on the particles, i.e., the vertical component of the force due to turbulence and the particle submerged weight, makes possible their transport or deposition.). Sediment deposits in reservoirs may have significant effects on reservoir operation [6]. The life of a reservoir is increased by applying sediment deposition control measures aimed at reducing sedimentation in the reservoir.

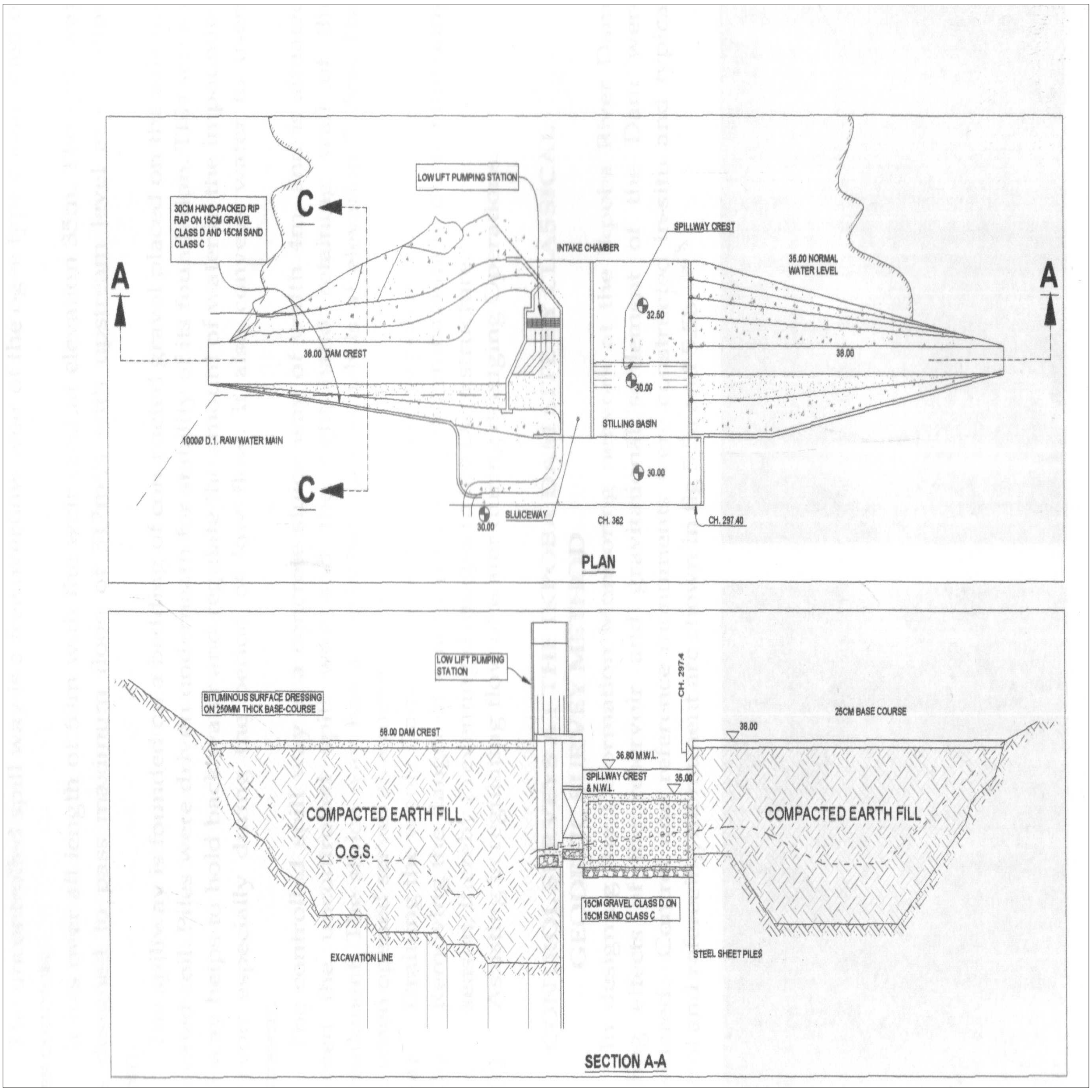

Fig. 1: Section through Ikpoba Dam, Benin City.

2.2 Distribution of Sediment Deposits in Reservoirs

The planning and design of a reservoir requires an analysis to determine how sediment deposits will be distributed in the reservoir. This is a difficult aspect of reservoir sedimentation due to the complex interaction between the hydraulics of flow, reservoir operation policy, inflowing sediment load, and changes in the reservoir bed elevation. The traditional approach to analyzing the distribution of sediments has relied on empirical methods, all of which require a great deal of simplification from the actual physical problem.

(a) Main channel deposition: Conceptually, deposition starts in the main channel. As flow enters a reservoir, the main channel fills at the upstream and until the elevation is at or above the former overbank elevations on either side. Flow then shifts laterally to one side or the other, but present theory does not predict the exact location. During periods of high water elevation, deposition will move upstream. As the reservoir is drawn down, a channel is cut into the delta deposits and subsequent deposition moves material farther into the reservoir. The lateral location of the channel may shift from year to year, but the hydraulic characteristics will be similar to those of the natural channel existing prior to the impounding of the reservoir. Vegetation will cover the exposed delta deposits and thus attract additional deposition until the delta takes on characteristics of a flood plain.

(b) Sediment diameter: The diameter of sediment particles commonly transported by streams range over five log cycles. Generally, the coarse material will settle first in the outer reaches of the reservoir followed by progressively finer fractions farther down towards the reservoir dam.

Based on this depositional pattern, the reservoir is divided into three distinct regions: top-set, fore-set, and bottom-set beds. The top-set bed is located in the upper part of the reservoir and is largely composed of coarse material or bed load. While it may have a small effect on the reservoir storage capacity, it could increase upstream stages. The fore-set region represents the live storage capacity of the reservoir and comprises the wash load. The bottom-set region is located immediately upstream of the dam and is primarily composed of suspended sediments brought from upstream by density currents. The region is called the reservoir dead storage and generally does not affect the storage capacity. Some of the finest materials may not settle out and may pass through the dam. In order to calculate the volume of materials which will be deposited as a function of distance, grain size must be included as well as the magnitude of the water discharge and the operating policy of the reservoir.

(c)Reservoir Shape: Reservoir shape is an important factor in calculating the deposition profile. For example, flow entering a wide reservoir spreads out, thus reducing transport capacity, but the path of expanding flow does not necessarily follow the reservoir boundaries.

GPS is a U.S. space- based global navigation satellite system. It provides reliable positioning, navigation, and timing services to worldwide users on a continuous basis in all weather, day and night, anywhere on or near the Earth. GPS is made up of three parts: between 24 and 32 satellites orbiting the Earth, four control and monitoring stations on Earth, and the GPS receivers owned by users. GPS satellites broadcast signals from space that are used by GPS receivers to provide three dimensional location (latitude, longitude, and altitude) plus the time.

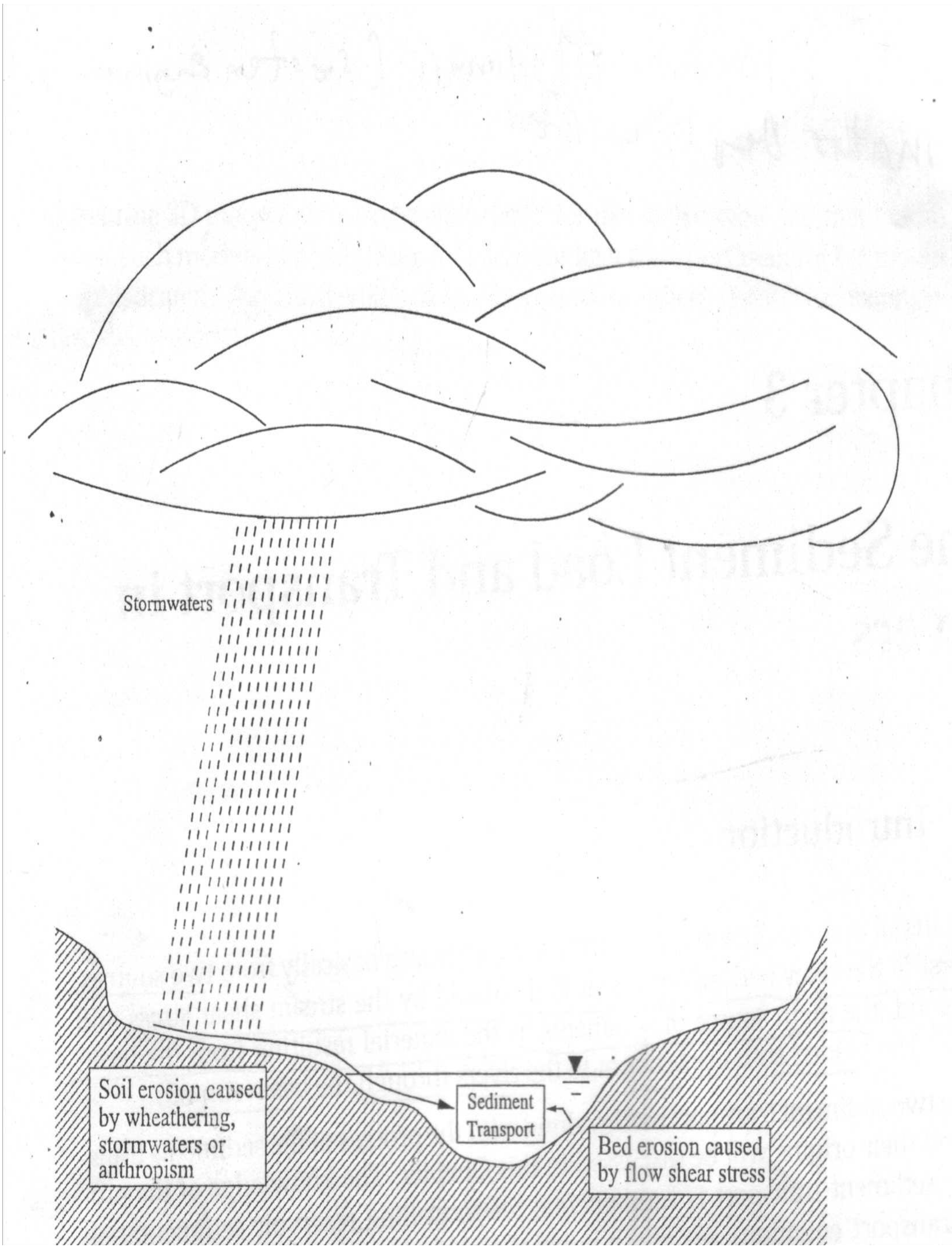

Fig. 2: The Sedimentation Process

2.3 Reservoir Sedimentation Surveys Using Global Positioning System (GPS)

2.3.1 Sedimentation Studies in Ikpoba River Reservoir

Study Area

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[7].

Table 1 depicts sedimentation data from Ikpoba river reservoir, Benin, Nigeria.

Table: 1 Sedimentation Data from Ikpoba River Reservoir

Data Set	Chainage (m)	Cross Sectional area (m^2)	Sediment Load/Vol. (m^3)	Specific Weight (tons)	Velocity (M/s)	Flow rate ($M^3/_5$)	Sedimentation Rate (tons/km^3/yr)	Trap eff. (%)
1	0+000	387.00	17250.00	17472.35	0.60	232.20	4.04	87.00
2	0+050	522.00	24062.50	24373.67	13.84	7224.48	5.64	90.20
3	0+100	412.50	22287.50	22574.79	17.86	7367.25	5.23	89.50
4	0+150	502.50	24212.50	24524.60	10.14	5095.35	5.68	90.00
5	0+200	483.00	24043.75	24353.67	10.44	4042.52	5.64	90.20
6	0+250	450.75	22518.75	22809.02	16.03	7225.52	5.28	89.60
7	0+300	416.25	21687.50	21969.08	10.83	4507.99	5.09	89.30
8	0+350	486.75	22687.50	22979.94	13.24	6444.57	5.32	89.70
9	0+400	359.25	20481.25	20745.25	8.61	3093.14	4.80	88.70
10	0+450	534.00	24750.00	25069.03	12.90	6888.60	5.80	90.50
11	0+500	474.75	23743.75	24049.81	14.20	6741.45	5.57	90.10
12	0+550	416.25	21275.00	21549.23	10.50	4370.63	4.99	89.10
13	0+600	413.25	21350.00	21625.20	12.73	5260.67	5.01	89.10
14	0+650	492.75	23541.67	23845.12	8.56	4217.94	5.52	90.02
15	0+700	440.75	22507.33	22797.45	9.43	4156.27	5.28	89.61
16	0+750	445.13	22180.00	22465.90	7.46	3320.67	5.20	89.48
17	0+800	440.33	23609.58	23913.91	10.70	4711.53	5.54	90.05
18	0+850	626.70	28516.92	28884.50	14.00	8773.80	6.69	91.62
19	0+900	474.90	25116.25	25440.00	13.68	6496.63	5.89	90.59
20	0+950	487.65	24561.83	24878.43	12.75	6217.54	5.76	90.40
21	1+000	521.92	21461.08	21737.71	10.97	5725.46	5.03	89.16
22	1+050	531.10	21854.42	22136.12	12.60	6691.86	5.12	89.30
23	1+100	498.13	25136.42	25460.43	10.91	5434.60	5.89	90.60
24	1+150	492.75	24766.92	25086.17	10.52	5183.73	5.81	90.47
25	1+200	502.90	24878.75	25199.44	12.10	6085.09	5.83	90.51
26	1+250	481.10	24327.50	24641.08	10.10	4859.11	5.70	90.32
27	1+300	492.00	24544.58	24860.96	12.30	6051.60	5.75	90.31
28	1+350	496.25	24964.58	25286.37	11.97	5940.11	5.85	90.54
29	1+400	518.75	25789.58	26122.01	10.80	5602.50	6.05	90.81
30	1+450	523.50	25923.75	26257.91	13.10	6857.85	6.08	90.86
31	1+500	498.10	25122.08	25445.90	12.13	6036.97	5.89	90.59
32	1+550	498.75	25957.17	26293.78	12.97	6468.79	6.09	90.87
33	1+600	502.00	25183.33	25507.94	12.20	6124.40	5.90	90.61
34	1+650	515.25	25593.75	25923.65	10.10	5204.03	6.00	90.75
35	1+700	508.25	25391.67	25718.97	10.25	5209.56	5.95	90.68
36	1+750	498.75	24902.92	25223.92	10.15	5062.31	5.84	90.52
37	1+800	485.10	24428.33	24743.21	11.23	5447.67	5.73	90.35
38	1+850	492.25	24827.92	25147.95	10.20	5020.95	5.82	90.49
39	1+900	525.25	25949.58	6284.07	12.65	6644.41	6.08	90.87
40	1+950	520.70	25874.58	26208.10	10.82	5633.97	6.07	90.84
41	2+000	496.90	25002.5	25324.78	9.62	4780.18	5.86	90.55
42	2+050	492.00	24858.75	25179.15	10.18	5008.56	5.83	90.50
43	2+100	518.15	25380.00	25707.15	11.61	6015.72	5.95	90.68
44	2+150	481.00	24478.25	24793.77	12.1	5820.10	5.74	90.37
45	2+200	495.24	24893.42	25214.30	11.2	5546.69	5.84	90.51
46	2+250	525.25	25952.28	26286.80	10.68	5609.67	6.08	90.87
47	2+300	518.10	25981.67	26316.57	12.1	6269.01	6.09	90.88
~~48~~	~~2+350~~	~~520.15~~	~~26031.75~~	~~26367.30~~	~~12.3~~	~~6397.85~~	~~6.10~~	~~90.89~~
49	2+400	525.11	26220.75	26558.74	11.98	6290.82	6.15	90.95
50	2+450	525.90	26288.83	26627.69	10.9	5732.31	6.16	90.97
51	2+500	525.95	21914.17	22196.64	10.55	5548.77	5.14	89.36

2.3.2 Sedimentation Studies in Samaru and Goruba Rivers

Study Area

The Kubanni Watershed has an area of 57.6 km^2 and drains two rivers – Samaru River and Goruba River – into the Kubanni River downstream of Kubanni Reservoir (that is Ahmadu Bello University Reservoir. It was reported that Samaru River carries higher higher sediment concentrations than Goruba River from the Kubanni watershed as shown in Table 2[8].

Based on measurement technique, the US Army Corps of Engineers (1985) categorized total sediment loads into and unmeasured loads. The measured load is mainly the suspended sediments that can be sampled with depth integrated hand held samplers while the unmeasured load include some of the unaccounted suspended load, within the 0.15m depth of a sampled water column and the entire bed load[8][9][10]. Since the bed materials wholly represent the unmeasured loads, it is pertinent that the bed materials be separated into its components.

Table 2: Seasonal sediment load (in kg/annum) transport in Kubanni Watershed.

Month	Samaru River		Goruba River		Total($x10^3$) (kg/annum)
	Measured sed. Load$x10^3$ (kg/month)	Unmeasured sed. Load$x10^3$ (kg/month)	Measured sed. Load$x10^3$ (kg/month)	Unmeasured sed. Load$x10^3$ (kg/month)	
June	44	10	8	2	64
July	929	97	210	22	1258
August	3137	243	816	101	4297
September	5339	349	1346	152	7186
October	4369	307	1183	134	5993
November	1062	107	285	41	1495
December	62	12	15	3	94
Total	14944	1125	3863	455	20387

Source: Otun and Adeogun (2010).

4 Factors Affecting 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.

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

(iii) The length of reservoir.

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

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

(vi) The exposure of deposited material.

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

(viii) The depth and age of sediment deposited.

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

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

(xi) 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.

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

(xiii) Effective annual rainfall

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

(xv) Earthquakes generate additional amount of silt: During earthquakes, huge amount of debris are displaced and carried by the river which are ultimately deposited in the reservoir.

2.5 Impacts of Silting In Reservoirs

Sedimentation in reservoirs has serious impacts on the reservoir capacity since it depletes the available water storage capacity. This leads to reduction in the reservoir life and benefits in the area of power generation, irrigation, water supply, flood control, navigation, wild life development, recreation and sanitation, ground water recharge, etc.

2.51 Positive Impacts

At upstream of dam (reservoir area):

- Influx of rich and dense vegetation characterized by rain forest species.
- Increase in the ground water table associated with the new lake.
- The forest species established would form a sanctuary for wild life and serve as wind breakers as well as firewood for human use.
- Increase in the population of aquatic fauna especially fish species.

At downstream of dam:

- Flood control: Most of the flooded lands will be recovered due to contraction of the main stream.
- Most arable land would be made available downstream due to channel contraction of the main stream. Such lands if undisturbed would regenerate true guinea savanna vegetation.
- It is expected that there will be an increase in the population of terrestrial wildlife with increase in vegetation growth downstream of dam.

2.52 Negative Impacts

At upstream of dam (reservoir area):

- Most able bodied wildlife would migrate out of the lake position, while the old, weak and young ones would be drawned.
- Drowning of vegetation by impounding water.
- Reduction in water pH because of increased decomposition of organic matter.
- The area occupied by the reservoir will be a loss of habitats to wildlife due to a change in landuse.
- The newly created lake would act as a barrier to the migratory pathway of some terrestrial wildlife species.
- Terrestrial wildlife would be drastically reduced.
- Disease vectors like mosquitoes, snails, black flies, etc would invade the periphery of the lake. These vectors would transmit malaria, flariasis, etc.
- The emission of greenhouse gases (GHG) from reservoirs due to rotting vegetation and carbon inflow from the catchments is a recently identified ecosystem impact of storage reservoirs.

At downstream of dam:

- Wildlife would lose breeding sites and sanctuary. Natural habitats would be destroyed thereby exposing wildlife to more dangers to hunters.

2.6 Silting Control Measures In Reservoirs

Measures discussed here under are employed to control the deposition of sediments so as to increase the life of the reservoir and its benefits.

(1) Pre-construction measures

(2) Post-construction measures

2.6.1 Pre-construction measures:

These are adopted before and during the execution of the dam construction project.

(i) **Dam site selection: -** Silting increases with increase in erosion in the catchment. Less erodible soil results in less silt. Hence, the silting can be reduced by choosing the reservoir site in such a way as to exclude the runoff from the easily erodible catchment.

(ii) **Construction of Check-Dams: -** Check-Dams could be built to control sediment inflow across the river streams contributing major sediment load.

(iii) **Construction of the Dam in stages:-**During the first stage of the dam construction, due to the low level of the dam and with low storage capacity, a large proportion of the sediment is thrown out over the dam to the downstream.

Hence, when the storage capacity is much less than the average annual runoff entering the reservoir, a large amount of water will get out of the reservoir, thereby reducing the silting rate compared to what it could have been if the entire water would have been stored. Therefore, the life of the reservoir can be prolonged by constructing the dam in stages. In this way, the dam is firstly built lower, and raised subsequently when some of its capacity gets silted-up.

(iv) Vegetative Screens:-Vegetative screens trap large amount of sediments. Therefore, the vegetation growth is promoted at the entrance of the reservoir as well as in the catchment to reduce the quantity of sediment that enters the reservoir. Vegetative screens are vegetative covers through which flood waters have to pass before entering the reservoir. They trap large amounts of sediments.

(v) Construction of under-sluice in the Dams: - The dam is provided with openings in its base, so as to remove the more silted water to the down- stream side.

Sediment concentration differs from one level of dam to the other. Therefore, there is need to locate sluices at the levels of higher sediment concentration. This method has short-comings since the water digs out a channel behind the sluice for movement and leaves most of the sediment undisturbed. Therefore, this is simultaneously supplemented with mechanical loosening and scouring of the neighboring sediment in order to increase its effectiveness. The use of this method is limited due to the fact that providing large sluices near the bottom of the dam again creates a structural problem.

2.6.2 Post Construction Measures:- These are measures used during the operation of the project. They are used as under:-

(i) Removal of Post flood water:-

Flood waters carry large amounts of silt in them. The sediment content increases just after the floods. It is required that flood water be not collected. Hence, efforts should be made to remove the water entering the reservoir immediately after floods by constructing a canal to divert the water to another area for irrigation or any other purpose.

(ii) **Erosion control and soil conservation:**

This implies applying all those methods to reduce erosion of soil and to make it more and more stable. This is the most effective method for controlling siltation, since when the soil erosion is reduced; the sedimentation problem is reduced automatically.

(iii) **Mechanical stirring of the sediment:**

The deposited sediment is scoured and distributed by mechanical means so as to keep it in a moving state, and thus, help in pushing the sediment towards the sluices.

3. RESULTS AND DISCUSSION

Large quantities of sediments have been found trapped behind Nigerian dams over years. There is urgent need to desilt our reservoirs to prolong their usefulness.

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 sustain its benefits.

4. CONCLUSION

There is 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.

5. RECOMMENDATIONS

- 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 sediment 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.

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