SILTATION IN RESERVOIRS

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Abstract

In most recent times, both nation with sound technological background and those without are beginning to show great concern on issues related to reservoir siltation, especially those nation with limited available water and those whose water sources are mainly from dams created reservoirs. This research work tries to highlight the implications of siltation on reservoir and consequently its effects on human resources. It is also intended to make known to the general public that though siltation cannot be totally eliminated, it can be controlled by employing some practices. This work goes further to make some recommendations towards minimization of reservoir siltation to a very manageable extent. Calls have been made to the government through various media to assist its populace in combating this nagging problem. It was concluded that sediment maximum accumulation is experienced in reservoir during the periods of maximum flow.

Keywords: reservoir model, siltation, sediment, catchment, sediment transport

1. Introduction

Sediment transport is the general term used for transport of materials like silt, sand, gravel, boulders, etc in rivers and streams. The transported material is called the *sediment load.* The total sediment is volume of sediment particles in motion per unit time. This includes the sediment transported by bed load motion and by suspensions as well as the *wash load.* Siltation is the accumulation of silt (fine particles of sand, mud, and other materials) in the reservoir. It is also known that any water containing silt is turbid in nature and hence require treatment before usage. This treatment will result in increasing the cost of water distribution and hence making it unaffordable. Bed load refers to grain rolling along the bed while suspended load refers to grain maintained in suspension by turbulence.

Water flowing in streams or rivers has the ability to scour channel bed, to carry particles and to deposit materials. This phenomenon of sediment transport can affect substantially the design of reservoirs. Many cases have been recorded where reservoir siltation rendered water storage structures useless in less than 25 years. Sedimentation problems were observed predominantly with small to medium size reservoirs (catchment area less than $100km^2$) [1]. Although each of the dams had advanced structural features, the hydrology of the catchments and sediment transport processes were not properly taken into account. This study highlights practical situations in which a reservoir must be analyzed as a complete system, taking into account structural features, hydraulics, hydrology, sediment transport, catchment erosion and catchment management.

Reservoirs created by dams on rivers, get silt through river water. A significant proportion of the sediments settles down in the reservoir, thus reducing the space available for water storage and also produces structural damages to the dam in question and causing appreciable damage to any power generating turbine located within the area. Studies reveal that silts get deposited in both the dead and live storage. Siltation reduces the benefits from dams constructed with a huge amount of money by any nation. This could also have a number of impacts, including increased evaporation losses and could damage the power turbines [1]. Several Australian dams failed slowly because of reservoir siltation, although the authorities do not acknowledge it [2].

The rate of sedimentation in 1,105 reservoirs with a capacity of less than 1.235 x 10^4m^3 was approximately 3.5 percent a year. In the case of medium-sized reservoirs, the annual storage loss was 2.7 percent per annum and the medium rate of sedimentation was 1.5 percent. For reservoirs with a storage capacity of more than 1.235 x 10^9 m^3, the rate of sedimentation was only 0.16 percent per annum, with the mean rate coming out at 0.11 percent a year [3].

In China, the Sanmenxia Reservoir, which was completed in 1960, had to be decommissioned in 1964 due to premature siltation. Worse still, the Laoying Reservoir actually silted up before its dam was completed [4].

In India, the expected siltation rate of the Nizamsagar dam in Andhra Pradesh was 654550 m^3 a year. The actual rate was closer to 1.07 x 107 m^3 a year. Indeed, the dams reservoir has already lost 60 percent of its storage capacity [5].

Studies carried out on 19 reservoirs in Central Europe with storage capacity ranging between 1.48 x 10^5 and 2.26 x 10^8 m^3; showed that they were depleted by sedimentation at an average rate of 0.51 percent per annum [6].

Several Australian reservoirs became fully silted because the designers did not take into account correctly the soil erosion and sediment transport processes, and no conservation practice was introduced. Fully silted reservoirs stand as a source of embarrassment for the scientist and the public. They are also potential hazards. During a large flood event probable maximum flood (PMF), the sediment weight adds to the wall compression stress and the safety factor (ratio of concrete strength to load) could become less than two! With concrete structures, the properties of the wall must be tested in-situ. Further a proper analysis of the reservoir catchment and dam wall should be conducted for each individual structure [1].

Reservoir siltation affects the safety of old reservoir in several ways. The sediment in the reservoirs increases the load on the wall of the dam. The reduction in storage capacity reduces the attenuation of the flood and it may increase outflow, hence the head above the crest, for a given reservoir inflow. Often the original hydrological study of ancient reservoirs relied on a small sample of data, and the estimated inflow underestimate the *real* PMF of the catchment reservoir system. Altogether the sediment weight and larger head above crest creates pressure on the dam wall [1].

It is obvious from research materials that huge sum is required to construct a water retaining structure like dam and hence it is important to protect the reservoir and dam against this unusual situation. Siltation is the main threat of water harvesting schemes and hydroelectric power dams in Ethiopia and needs to be prevented rather than corrected [7].

Clearly the rate at which a reservoir *silts up* depends on the amount of silt carried by the river which feeds it and that, in turn, depends on the rate of soil erosion in the river's catchment area. Where that catchment is forested, the soil is not easily easily eroded due to the network of roots which underlies the forest floor, and is also protected from the effects of wind and rain erosion by the forest canopy above [8]. In those areas where forest cover has been depleted, however, the rate of soil erosion increases drastically; the organically poor soils of the tropics are particularly vulnerable to erosion and although the Monsoons only last for a short time, they can quickly wash away the soils from deforested slopes [8]. Given the present rate of deforestation in the tropics it is hardly surprising that rivers in the region carry enormous quantities of silt. Indeed, in many areas, the increased sediment load of rivers is clearly visible to the naked eye [8]. Reservoir siltation and sediment transport were measured and calculated directly by subtraction of measured surfaces of original and silted reservoir bottom [9, 10].

From the sieve analysis studies, coarse particles comprise the sand and gravel sizes ranging from 0.06mm to 2mm and greater. The fine particles range from less than 0.06 and comprise the silt (0.002mm to 0.06mm) and clay (less than 0.002mm) diameter sizes [11]. In practice it is possible to separate particles not finer than 0.06mm.

As a contribution towards reducing reservoir siltation, this paper uses a model reservoir to investigate the extent of reservoir siltation in a particular catchment area. With the results of the investigation, one would be able to employ adequate catchment measures to control and manage the inevitable menace.

Table 1: Dimensions and volume remaining in the reservoir model

Time (day)	**Length** (m)	**Width** (m)	**Height** (m)	**Volume** (m^3)
0	1.00	1.00	1.00	1.00
1	1.00	1.00	0.86	0.86
2	1.00	1.00	0.75	0.75
3	1.00	1.00	0.60	0.60
4	1.00	1.00	0.42	0.42
5	1.00	1.00	0.25	0.25
6	1.00	1.00	0.19	0.19
7	1.00	1.00	0.06	0.06

2. Experimental Procedure

At a natural drainage channel, which is fairly level and spanning 2.3m in width, a cubic volume of a reservoir model with dimensions 1mx1mx1m was dug. This was intended to aid in the measurement of rate of siltation or sedimentation in this particular area in Okpu-Orba, Enugu State. This was achieved by measuring the depth remaining or depth covered by sediments after each of seven days consecutive heavy rainfall. Also, 500g of deposited sediment (air dried) sample was collected for the sediment classification. The sizes of the soil particles were measured in terms of the diameter in millimeters.

3. Results and Discussion

From Table 4, some statistical tools like bar chart and pie chart can be used to analyze the rate at which the model reservoir is being covered with sediments. Using a bar chart to illustrate the extent of siltation after each heavy rainfall gives:

The pie chart of the silted volume in the various days is shown in figure 2 below.

It is obvious from the result obtained in various rainfalls that siltation or in other words

Table 3: Dimensions and volume silted up per individual rainfall in the reservoir model

Time (day)	**Length** (m)	**Width** (m)	**Height** (m)	**Volume** (m^3)	Angular equivalent of the silted volume per day (in degrees)
0	1.00	1.00	0.00	0.00	0°
1	1.00	1.00	0.14	0.14	53.7°
2	1.00	1.00	0.11	0.11	42.1°
3	1.00	1.00	0.15	0.15	57.4°
4	1.00	1.00	0.18	0.18	68.9°
5	1.00	1.00	0.17	0.17	65.1°
6	1.00	1.00	0.06	0.06	23.0°
7	1.00	1.00	0.13	0.13	49.8°

Table 2: Dimensions and volume silted up in the reservoir model

Time (day)	**Length** (m)	**Width** (m)	**Height** (m)	**Volume** (m^3)
0	1.00	1.00	0.00	0.00
1	1.00	1.00	0.14	0.14
2	1.00	1.00	0.25	0.25
3	1.00	1.00	0.40	0.40
4	1.00	1.00	0.58	0.58
5	1.00	1.00	0.75	0.75
6	1.00	1.00	0.81	0.81
7	1.00	1.00	0.94	0.94

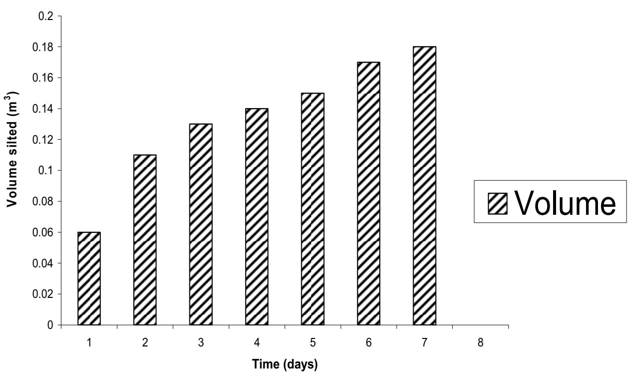

Figure 1: Extent of siltation after heavy downpour.

Table 4: Sieve analysis result of the sample obtained from the deposited material in the reservoir model

Sieve No.	**Sieve size** (mm)	**Weight retained** (g)	**% retained** (%)	**% cumulative passing** (%)
8.00	2.00	13.00	2.60	97.40
10.00	1.670	3.00	0.60	96.80
12.00	1.140	3.00	0.60	96.20
16.00	1.00	38.00	7.60	88.60
22.00	0.699	91.00	18.20	70.40
30.00	0.50	121.00	24.20	46.20
44.00	0.35	114.00	22.80	23.40
60.00	0.250	61.00	12.20	11.20
85.00	0.175	38.00	7.60	3.60
120.00	0.124	9.00	1.80	1.80
150.00	0.104	2.00	0.40	1.40
170.00	0.089	3.00	0.60	0.80
240.00	0.084	3.00	0.60	0.20
300.00	0.053	1.00	0.20	0
Tray		0.00	0.00	0

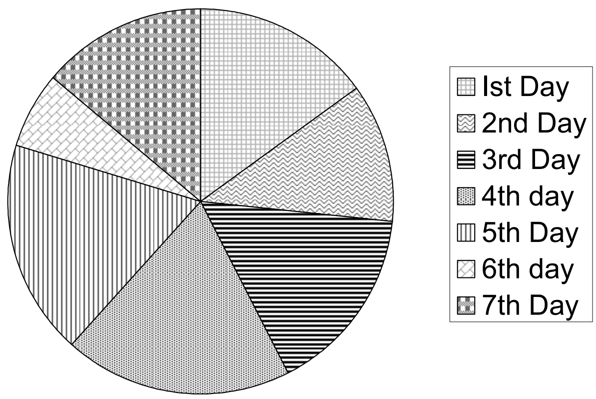

Figure 2: Silted volume on various days.

sedimentation is totally dependent on rainfall intensity, duration, ground moisture content and the soil type.

From the result it can be generalized that the fourth day rainfall has the greatest intensity and lasted virtually for the whole day. This was followed by the fifth day rainfall. From the plotted bar and pie charts the trend of the variation of the intensity and duration can be deduced.

The amount of silt present in any reservoir is attributed to the geological nature of the area surrounding the reservoir. If the area is rich in silt, definitely any reservoir located within the area will have a greater proportion of silt in any sediment transported to the reservoir. From the result it can be generalized that the area where the experiment took place was rich in sand (ranging from 0.06mm – 2mm) [11]. Hence the reservoir model was rich in sand and poor in silt content.

4. Conclusion

The sediment maximum accumulation is experienced in reservoir during the periods of maximum flow. Several documented materials illustrate that reservoir failures are caused by siltation and catchment erosion.

5. Recommendations

Since erosion sedimentation has a serious problem in different parts of the world today resulting in several reservoirs becoming fully silted, designers should aim at the following soil erosion and sediment transport processes measures:

- Prevention of further land degradation in any catchment to reduce siltation.
- Prevention of soil erosion from catchment to reduce siltation of reservoir.
- Ensuring adequate irrigation water to the demand area.
- Improving land capability moisture regime in the watershed.
- Improving land use to match capability.
- Maintaining ecological balance in a catchment area.
- Educating people in the management of catchment.

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