Assessment of Sediment Generation from Tagwai Drainage Basin

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Abstract

Systematic plans and policies are needed to reduce adverse impacts of sedimentation and prolong the useful life of reservoirs. The ability to estimate the rate of drainage basin surface erosion, deposition, and distribution in a reservoir is essential to the development of sound sediment management plans and policies. An attempt is made to study sediment generation rates in Tagwai drainage basin, Niger state, Nigeria. Periodic mapping of reservoirs to determine the depth to water surface with respect to a known reference level (spillway) provides insight to the changes in topography of the reservoir. The method used classifies Sediment generation as a function of nine drainage basin characteristics. The Estimated numerical ratings for Tagwai reservoir drainage basin is 0.0245 – 0.049mm / year and its drainage basin sediment yield classification is class 3. A 100 years sediment generation estimate for Tagwai reservoir drainage basin at 0.0245 mm and 0.049 mm is 269.5 m^3 and 539 m^3respectively.

Introduction

Soil movement is of considerable interest to Water managers. Vegetation loss is often accompanied by erosion and transport of eroded sediments. As a result of runoff, soil particles on the surface of a Drainage basin can be eroded and transported through the processes of erosion. Once eroded, sediment particles are transported through a river system and are eventually deposited in a reservoir or at sea, and sediment deposition can reduce reservoir storage capacity. Soil loss and movement in Drainage basins are difficult to measure, and may go unnoticed until it is a severe problem. Deposition is often easier to identify and measure. Water supply reservoirs collect sediment as well as runoff water, and can be monitored to assess sediment generation.

The objective of this paper is to briefly describe sediment measurement methods and to present a summary of sediment generation from Tagwai Drainage basin.

Study Area

The study area is a drainage basin of Tagwayi River upstream of the Tagwai Reservoir embankment. It lies in the southeastern part of Minna, Niger State Capital (Figure 1). It lies within latitudes 9^o 33’ 0” to 9^o 41’ 0” and longitudes 6^o 31’ 30” to 6^o 50’ 0”. The dam is built across river Tagwayi which is a tributary of river Chanchaga in Niger State (NSWB, 1982). The dam is an earth filled dam, initiated by the Niger State Government in 1976 and completed in 1978 to augment the source of raw water supply for the Chanchaga treatment plant (Minna Water Supply Scheme, 1992). The dam was commissioned on 1st November 1978 with project data in Table 1. The dam is classified as a large dam (Nigeria Register of Dams, 1995).

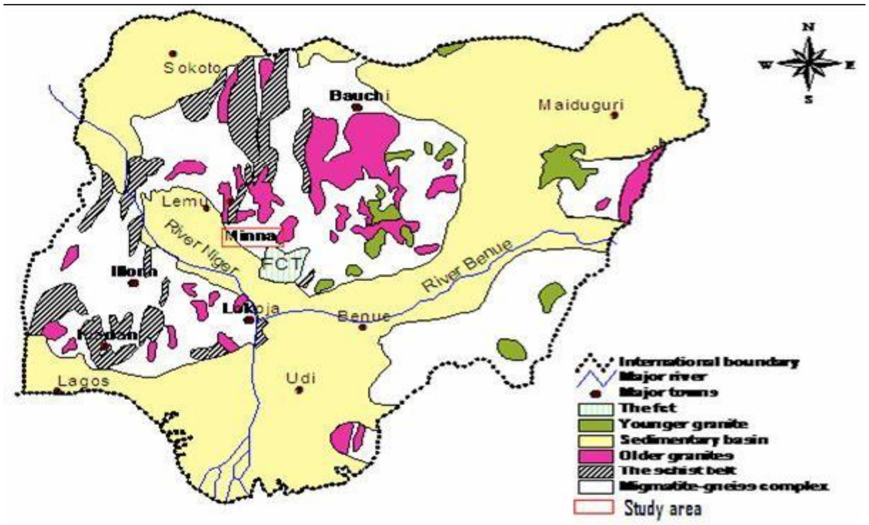

Figure 1: Geological Map of Nigeria Showing Study area (Ajibade, 1980)

Table 1. Tagwai Dam Project Data. (NSWB, 1982)

1.	Average annual precipitation	1270 mm
2.	Catchment area	110 km^2
3.	Average annual run off	25 x 10^6 m^3
4.	Type of Dam	Zone earth fill
5.	Crest length	1770 m
6.	Crest level	259 m O.D
7.	Free Board	3 m
8.	Maximum flood level	257.5 m O.D
9.	Full supply level	256 m O.D
10.	Crest width	10 m
11.	Maximum structural height	25 m O.G.L
12.	Hydraulic height	21 m
13.	Maximum width of base	150 m
14.	Total storage capacity	28.3 x 10^6 m^3
15.	Active storage capacity	26.5 x 10^6 m^3
16.	Dead storage capacity	1.8 x 10^6 m^3
17.	Dead storage level	245.5 m
18.	Surface area of lake	5.50 x 10^6 m^2
19.	Total volume of Earthwork	870,000 m^3
20.	Service spillway	110 m long with crest elevation 258.3 m
21.	Emergency spillway	170 m long with crest elevation 258.3 m
22.	Intake tower	2 (24'') diameter steel pipe penstocks with guan and control valve.
23.	Date of commencement	20th September, 1977
24.	Date of completion	1st November, 1978
25.	Cost	₦ 6,960,000

The area is accessible through Federal Government College, Minna road. The vegetation is mainly guinea savannah which is characterized by grasses, shrubs and trees. The study area lies within the Middle-Belt of Nigeria which is a transitional zone between the rainforest of Southern Nigeria and the Guinea Savannah of the Northern Nigeria.

The annual rainfall distribution pattern shows a maximum of 1300 and minimum of 1000 mm rainfall (Minna Airport, 2002). This corresponds with datum read from Map of mean annual depth of rainfall in Nigeria (Schoeneich, 2003) as 1250 mm/a.

The study area is generally gently undulating. It slopes gently southwards from the hills in the northern part of the area. The drainage pattern is dendritic and drained by River Tagwayi and its tributaries. The wet season starts, on long term average, on 9th April and ends on 25th October, lasting 200 days. The dry season starts on 26th October and ends on 8th April, lasting 165 days. The study area has mean annual Stevenson Screen temperature of 27.2 ^{o}C (Schoeneich and Garba, 2010). The study area is located within the Crystalline Hydrogeological Province of Nigeria (Ajibade, 1980; Offodile, 2002 andMohammed *et al.*, 2008).

General Geology of the Area

The study area is part of the North-central part of the Nigerian Basement Complex which is composed of two lithological units: schist belts and the granite (Truswell and Cope, 1963; Ajibade, 1980; Ajibade and Wright, 1988). Geological mapping revealed that the study area is underlain by granite and schist with granite occupying greater portion of the area (Figure 3). The fieldwork shows that the granite did not digest completely the schist which it intruded.

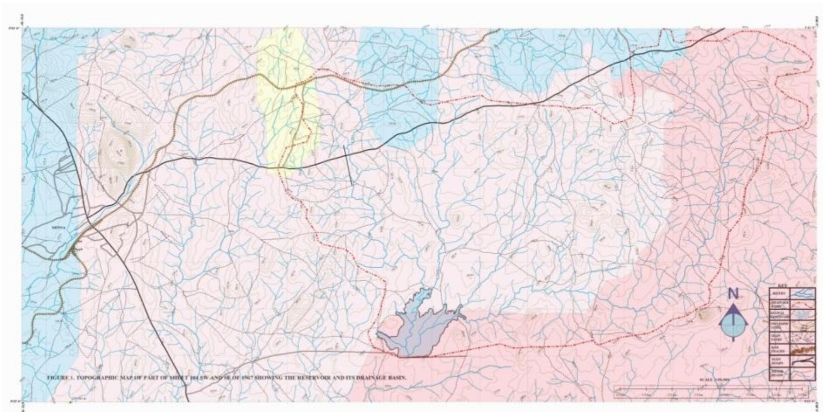

Figure 3: Geological Map of Part of sheet 164 SW & SE of 1967 showing the Reservoir and its Drainage Basin

Sediment generation in Tagwai Dam Drainage Basin

A brief description of methods used for the estimation of the rate of surface erosion or the rate of sediment generation from a drainage basin. Various methods can be used to estimate the rate of surface erosion or the rate of sediment generation from a drainage area:

- **Universal soil loss equation:** The empirical Universal Soil Loss Equation is

A = RKLSCP (Wischmeier and Smith, 1962),

Where:A = computed soil loss in tons acre^{-1} year^{-1},

R = rainfall factor,
K = soil-erodibility factor,
L = slope-length factor,
S = slope-steepness factor,
C = cropping-management factor,
P = erosion-control practice factor.

The equation was based on statistical analyses of data from 47 locations in 24 states in the central and eastern United States. Because all the parameters in the equation were based on agriculture practices, its application is limited.

- **Sediment yield as a function of drainage area:** Empirical sediment yield equations can be developed strictly as a function of drainage area based on reservoir sediment survey data. For example, Strand (1975) developed the following empirical equation for Arizona, New Mexico, and California:

$Q_S = 2.4A_d^{-0.229}$ (Strand, 1975)
$Q_S = 1.84A_d^{-0.24}$ (Strand and Pemberton, 1982)

Where: Qs = sediment yield in acre-feet per square mile per year
A_d= drainage area in square miles.

- **Sediment yield as a function of nine drainage basin characteristics.**

This method classifies sediment yield as a function of nine individual drainage basin characteristics (Table 2). These nine drainage basin characteristics are surface geology, soil, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion.

Table 2: Drainage Basin Characteristics and Possible Range of Numerical Ratings (Modified from Pacific Southwest Inter-Agency Committee, Water Management Subcommittee, 1968)

Drainage basin Characteristic	Sediment yield levels: High rating	Moderate rating	Low rating
Surface geology	10: marine shales and related mudstones and siltstones	5: rocks of medium hardness moderately weathered and fractured	0: massive hard formations
Soils	10: fine textured and easily dispersed or single grain silts and fine sands	5: medium textured, occasional rock fragments, or caliche crusted layers	0: frequent rock fragments, aggregated clays, or high organic content
Climate	10: frequent intense convective storms	5: infrequent convective storms, moderate intensity	0: humid climate low intensity rain, arid climate with low intensity rainfall, or rare convective rain
Runoff	10: high flows or volume per unit area	5: moderate flows or run off volume per unit area	0: low flows or volume per unit area or rare runoff events
Topography	20: steep slopes (in excess of 30%), high relief, little or no flood plain development	10: moderate slopes (about 20%), moderate flood plain development	0:gentle slopes (< 5%), extensive flood plain development
Ground cover	10: ground cover less than 20%, no rock or organic litter in surface soil	0: ground cover < 40%, noticeable organic litter in surface soil	-10: area completely covered by vegetation, rock fragments, organic litter with little opportunity for rainfall to erode soil
Land use	10: more than 50% cultivated, sparse vegetation, and no rock in surface soil	0:< 25% cultivated, < 50% recently logged, < 50% intensively grazed	-10: no cultivation, no recent logging, and only low intensity grazing, if any
Upland erosion	25: rill, gully, or landslide erosion over more than 50% of the area	10: rill, gully, or landslide erosion over about 25% of area	0: no apparent signs or erosion
Channel erosion	25: continuous or frequent bank erosion, or active headcuts and degradation in tributary channels	10: occasional channel erosion of bed or banks	0: wide shallow channels mild slopes, channels in massive rock, large boulders, or dense vegetation or artificially protected channels

This is a subjective procedure for estimating an annual basin erosion rate. It can be used as a reference for assigning drainage basin sediment yield classes (Table 3).

Table 3: Drainage Basin Sediment Yield Classification (Modified After Randle, 1996)

Drainage basin classification number	Total rating	Annual sediment yield(mm)
1	>100	>0.147
2	75 to 100	0.049 – 0.147
3	50 to 75	0.0245 – 0.049
4	25 to 50	0.0098 – 0.0245
5	0 to 25	<0.0098

Based on information in Tables 2 and 3, the estimated sediment yield rating and the 100 year sediment yields for the Tagwai Reservoir are shown in Tables 4 and 5, respectively.

Table 4: Estimated Numerical Ratings for Tagwai Reservoir Drainage Basin

Drainage basin characteristics	possible ratings	Estimated sediment yield rating	Estimated description
Surface geology	0 – 10	5 Moderate	varies from crystalline rocks to unconsolidated alluvium and colluvium
Soil	0 – 10	5 Moderate	surface material is ferruginous soil, rock fragment and bedrock outcrops
Climate	0 – 10	5 Moderate	distinct dry and wet season, moderate intensity rains
Runoff	0 – 10	10 High	high volume / unit area, high runoff
Topography	0 – 20	5 Low	gentle slopes, flood plain development
Grand cover	-10 – 10	0 Moderate	area moderately covered by vegetation, noticeable organic litter in surface soil
Land use	-10 – 10	0 Moderate	active cultivation and grazing Upland
erosion	0 – 25	10 Moderate	low apparent signs of erosion, upland compose of older more consolidated rocks, rill erosion noticeable
Channel erosion	0 – 25	10 Moderate	occasional erosion of beds and Banks, wide channels
Total rating	–	50 Class 3	0.0245 – 0.049 mm

Table 5: 100 Years Sediment Yield Estimate for Tagwai Reservoir Drainage Basin

Reservoir	Drainage name	Area (km^2)	100 year sediment yield (m^3): at 0.0245(mm)	at 0.049 (mm)
Tagwai dam	Tagwayi (Tagwai)	110	269.5	539

Conclusion

Sediment generation from Tagwai drainage basin is based on nine drainage basin characteristics and possible range of numerical ratings, and on drainage basin sediment yield classification.Tagwai drainage basin is in class 3 of the drainage basin sediment yield classification which has an estimated sediment yield rating of 50 – 75 with annual sediment yield of between 0.0245 mm – 0.049 mm respectively. A 100 year sediment yield at 0.0245 mm and 0.049 mm is 269.5 m^{3}and 539 m^{3}respectively. It is highlyvariable because precipitation and runoff are highlyvariable. The variability suggeststhat average annual sediment generation rates may notprovide sufficient information to interpret causes andeffects of upland land management.Continued monitoring of sediment generation is necessaryto obtain long-term records sufficient to incorporatevariability when assessing trends.

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