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A BATHYMETRY-BASED RESERVOIR SEDIMENTATION EVALUATION

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Abstract: Reservoir sedimentation is a serious problem that normally reduces the capacity of a dam (reservoir) for water storage over a given period of time. This can lead to insufficient availability of water for domestic uses, irrigation and hydropower. This study was conducted to determine the rate of sedimentation, sediment yield and the capacity of the University of Ilorin dam (Ilorin, Nigeria) between June 2007 and June 2014. Geographic Information System (GIS), Global Positioning System (GPS), canoe and lead-line techniques were used for the measurement of depth of the reservoir of the dam. Soil and Water Assessment Tool (SWAT) model was used to simulate the sediment yield. The initial capacity of the dam after construction in 2007 was 1.800 x 10^6 m^3 but this capacity was reduced to 1.411 x 10^6 m^3 in 2014 due to sedimentation. The sediment was found to be clay soil which covered 389,170 m^3 of the reservoir and the mean bulk density of the clay soil sediment was 1139 kg/m^3. The mean values of clay, silt and sand contents of the sediment yield were 46.5, 35.6 and 17.9 %, respectively. The annual sediment yield was high in the reservoir due to farming activities at the upstream end of the dam, annual rate of sedimentation was 12.78 m^3/ha/yr and sediment yield was 14,557.14 kg/ha/yr. Farming activities should be prevented at the upstream of the dam and dredging should be done every 10 years when 30.87% of the storage capacity would be occupied by sediment.

Keywords: *Reservoir sedimentation, bathymetry, water conservation*

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1.0 Introduction

Dam is a hydraulic structure constructed across a river for the purpose of impounding and conserving water at the upstream side of the dam. Sedimentation of dam (reservoir) by soil particles normally reduces the capacity of dam for water storage. Globally, a dam usually losses 1 % of its storage capacity to sediment annually thereby causing problem of water conservation needed for domestic uses and irrigation, electricity supply and flood control (WCD, 2000). The change in transport capacity of dam has effect on rivers and water resources management such as eutrophication, reservoir storage capacity and channel incision (Kondolf and Swanson, 1993; Hamburg *et al*., 1997; Hay *et al*., 1997). Asseez ((1995) pointed out that the rate of decaying of submerged plant has an important effect on the settling rate of suspended sediments in tropical lakes. Trap efficiency (TE) is an important parameter that is used for quantifying reservoirs sedimentation as a ratio of amount of sediment deposit in the reservoir to the amount of sediment inflow to the reservoir (Revel *et al*., 2013). The TE of sediment by dam (reservoir) is used to determine the lifespan of a dam (Smith, 1990). Bathymetry is the study of beds or floors of water bodies like ocean, rivers, streams and lakes and it includes measurement of depths of ocean floors, rivers, streams and lakes. Bathymetry is synonymous to hypsometry which is the measurement of land elevation above sea level (Miller *et al*., 2010). The results of bathymetry can be used to describe the shape and volume of water reservoirs (Obregon *et al*., 2011). Bathymetry is obtained by recording water depths throughout the water body and connecting the recorded points of equal water depth. Bathymetric map is estimated from the water depth between two points of a known depth but several depths measurements give better accurate map of the depth (Obregon *et al*., 2011). Abdi *et al*. (2012) used the Soil and Water Assessment Tool (SWAT) model to simulate the sediment yield from the Fincha Watershed of 3,251 km^2, located in Western Oromiya Regional State, Ethiopia. The farming activities at the upstream of the dam (500 to 2000 m from the dam) that are very close to the university dam could create the problem of sedimentation and pollution of the dam. The objectives of this study were to determine the sedimentation rate and to determine the current capacity of the University of Ilorin dam (Ilorin, Nigeria).

2.0 Materials and Methods

2.1 Location of the Study Area

The dam is located at the University of Ilorin main campus, Ilorin, Kwara State, Nigeria. Ilorin is the capital of Kwara State, lies on the latitude 8°30′N and longitude 4°35′E at an elevation of about 340 m above mean sea level (Ejieji and Adeniran, 2009). Ilorin is in the Southern Guinea Savannah Ecological zone of Nigeria with annual rainfall of about 1300 mm. The wet season begins towards the end of March and ends in October while the dry season starts in November and ends in March (Ogunlela, 2001). University of Ilorin is 500 km from Abuja (Federal Capital Territory), 306 km from Lagos and 600 km from Kaduna. The maps of Kwara State and the University of Ilorin are shown in Figures 1 and 2, respectively.

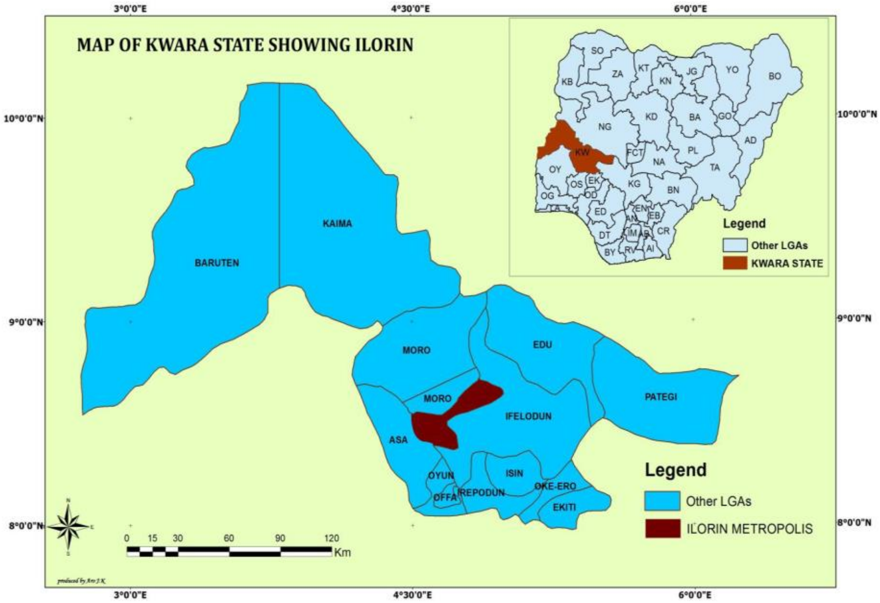

Figure 1: Map of Kwara State Showing Ilorin City and Map of Nigeria Showing Kwara State (insert) (Kwara State Ministry of Lands and Survey, 2014) ***Cannot be found in list of references***

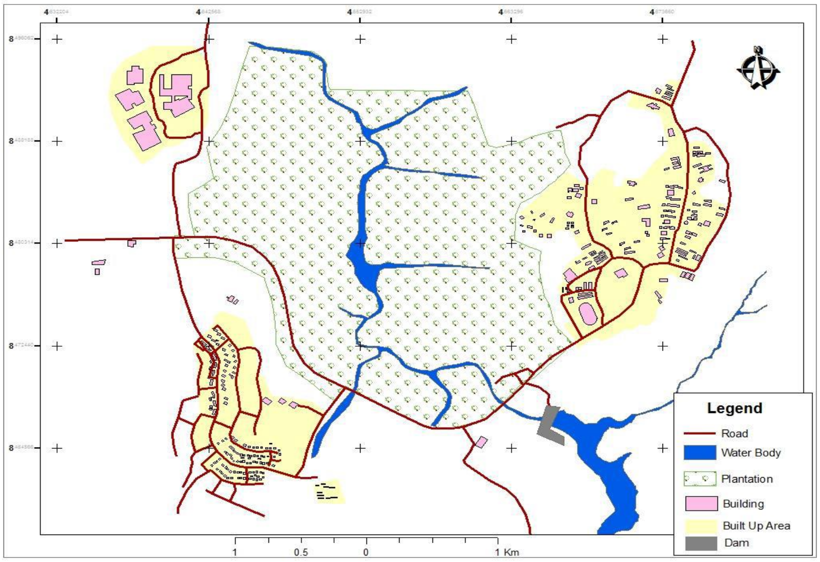

Figure 2: Map of University of Ilorin (Department of Geography and Environmental Sciences, 2014) ***Cannot be found in list of references***

2.2 Geomorphology and Local Geology of the Dam Area

The University of Ilorin dam site lies within the basement rocks in the Western part of Central Nigeria. The main river within the campus is river Oyun which flows from southeast to northwest direction. Ilorin Township is underlain by the Precambrian to Cambrian basement complex rocks basically by migmatite-gneisses, granitic gneisses and meta-sediments such as quartzites (Adekeye, 2001). The western part of the University is made up of gneiss rocks with strike foliation in NW-SE direction and dipping 10° - 45° westerly. The geological map of University of Ilorin and downstream end of the dam are shown Figures 3 and 4, respectively. The four sub-catchments (sub-basins) contributing water to the dam and the slopes in degree of the catchment are shown in Figures 5 and 6, respectively.

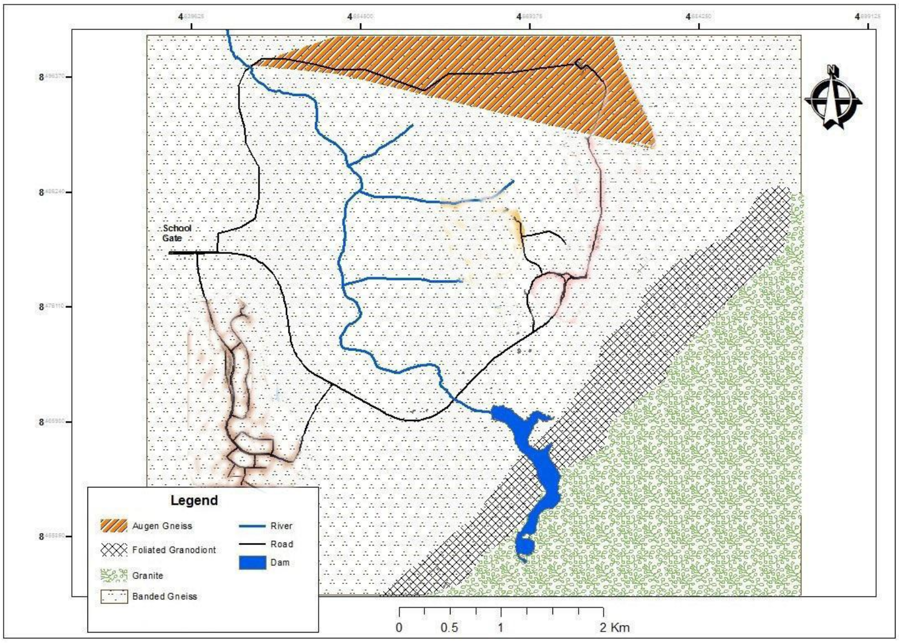

Figure 3: Geological Map of University of Ilorin (Geology and Mineral Sciences Department, 2011) ***Cannot be found in list of references***

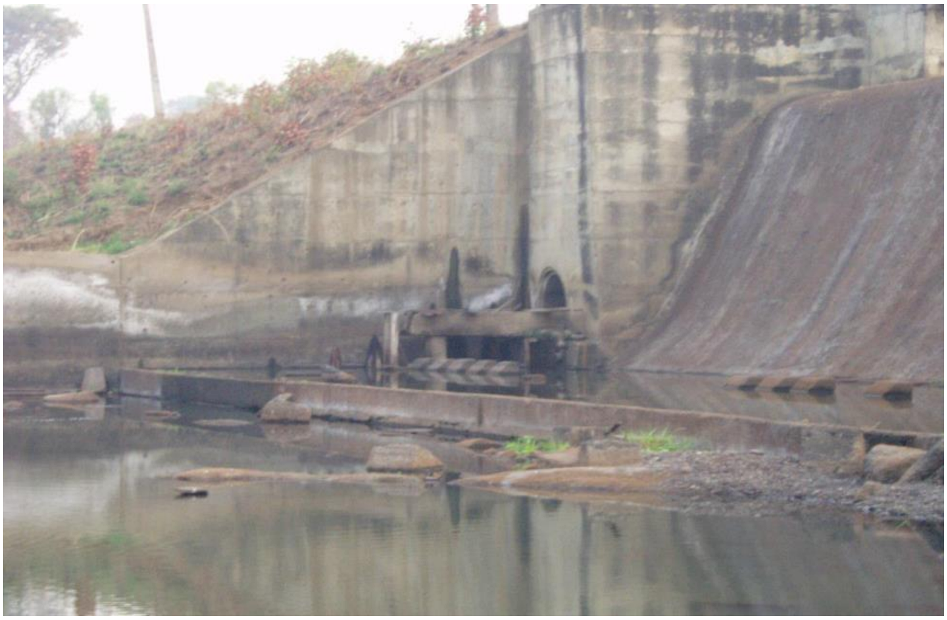

Figure 4: Downstream Section of the University of Ilorin Dam

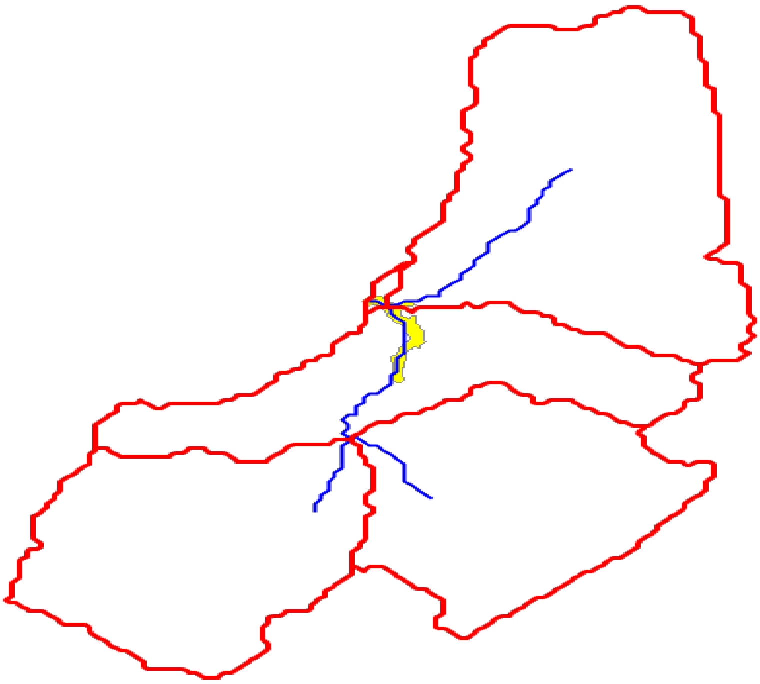

Figure 5: The four sub-basins contributing water to the study area

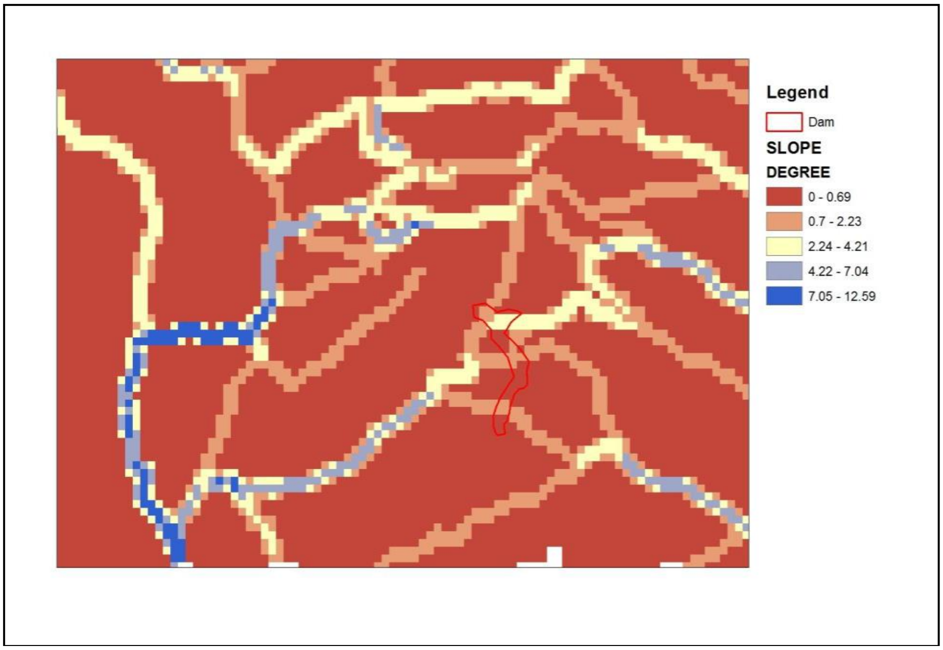

Figure 6: Slopes of the Catchment

2.3 Determination of Depth of the Reservoir

The hydrographic survey was carried out using GPS Model: GPS map 76CS GARMIN with +5.0 horizontal accuracy and lead-line was used technology for sounding and depths measurements of the reservoir. The GPS was calibrated for the location of the grid points before sounding. The lead-line technology consists of a graduated steel tape having a sinker weight at the end and was used for depth measurement with help of canoe as shown Figure 7. The sinker weight consists of a cylindrical can having 10 cm diameter and 14.5 cm high filled with concrete. A hook was provided at the centre of the can for the attachment to the steel tape. The grid point coordinates and elevations obtained by the hand-held GPS were exported into the Geographic Information System environment (ArcGIS 10^{+}) for spatial interpolation. The delineation of the reservoir area was produced using arcGIS software. The database which includes location of the study area, depth and underwater topography were populated in arcGIS software and exported to exel.cso format. The excel data were then inputted into Surfer™ and Mapsource™ Software which was used to generate map of the surface elevation of the reservoir, depths of water in the reservoir, map of underwater topography of the reservoir and the present capacity (volume) of the reservoir in 2014 (seven years after the construction of the dam) and the average annual rate of sedimentation was determine using Equation (4) by Onwuegbunan *et al*. (2010).

Figure 7: Depth measurement at the dam using lead-line

2.4 Determination of Impounded Sediment, Sediment Yield and Present Capacity of the Dam

The sediment yield between May 2007 and June 2014 was determined using Soil and Water Assessment Tool (SWAT) model. The SWAT model inputs were digital elevation model (DEM), land use map and weather data. The SWAT model was used to discretize the catchment and extract the SWAT model inputs data. The DEM was used to delineate and generate topographic parameters such as over land slope and slope length for each sub-basin (sub-catchment). The daily weather data between 2007 and 2014 were collected from Department of Geography and Environmental Science, University of Ilorin, Ilorin, Nigeria. The weather data precipitation, relative humidity, solar radiation, wind speed and temperature were imported into the SWAT model. The impounded volume of sediment yield, annual volume of sediment yield, annual weight of sediment yield and present capacity of the dam were determined using Equations (1), (2), (3) and (4) given by Onwueghunan *et al*. (2010).

$$V_{sed} = \frac{S_y \times A_c}{\rho_b} \tag{1}$$

$$VS_a = \frac{V_{sed}}{N \times A_c} \tag{2}$$

$$SW_a = \frac{S_y}{N} \tag{3}$$

$$C_c = V_i - V_{sed} \qquad (4)$$

where V_{sed} is the impounded volume of the sediment yield in the reservoir (m^3), S_y is the sediment yield at the upstream of the dam (kg/ha), A_c is the area of the catchment (ha), ρ_b is the bulk density of the soil particle of the sediment (kg/m^3), VS_a is the annual volume of sediment yield (m^3/yr), N is the age of the dam (yr), SW_a is the annual weight of sediment yield (kg/ha/yr), C_c is current capacity of the dam (m^3) and V_i is the initial capacity of the dam (m^3). When S_y was 101.9 x 10^3 kg/m^3, A_c was 4350 ha and ρ_b was 1,139 kg/m^3, the impounded volume of the sediment yield (V_{sed}) was calculated to 389,170 m^3 using Equation (4). Annual volume of sediment yield (VS_a) was determined to be 12.78 m^3/ha/yr when N was 7 years and V_{sed} was 389,170 m^3 using Equation (5). The annual weight of sediment yield (SW_a) was calculated to be 14,557.14 kg/ha/yr when S_y was 101.9 x 10^3 kg/ha and N was 7 yr using Equation (6). The current capacity of the dam as at June 2014 was determined to be 1,410,830 m^3 from Equation (7) when the initial capacity of the dam (V_i) in June 2007 was 1.8 x 10^6 m^3 and impounded volume of the sediment yield (V_{sed}) was 389,170 m^3.

3.0 Results and Discussion

The bathymetric survey of the reservoir (dam) seven years after construction of the dam revealed that the original capacity of the dam which was 1.800 x10^6 m^3 in May 2007 was reduced to 1,410,830 m^3 (1.411 x 10^6 m^3) in June 2014 due to sedimentation. The maximum depth of the reservoir was 7.6 m while the minimum depth was 2.2 m. At the centre of the reservoir, the depths varied from 3.4 to 6.0 m while the depths at the upstream of the dam varied from 3.4 to 5.8 m. This means that more sediment was deposited or trapped by the wall of the dam thereby reducing the depth of the reservoir. The characteristics of University of Ilorin earth-dam is shown in Table 1.

The depths profile of the reservoir is shown in Figure 8. The elevation of the sounding points across the cross section of the reservoir varied from 278 to 314 m above the sea level and the map of underwater topography of the reservoir is shown in Figure 9. The volume of impounded sediment seven years after construction of the dam was 389,710 m^3 and the annual sediment yield was 12.78 m^3/ha/yr. The annual weight of sediment yield was 14,557.14 kg/ha/yr and sediment yield was predominantly clay soil with percentage mean contents of clay, silt and sand were 46.5%, 35.6 % and 17.9 %, respectively and mean bulk density of the sediment was 1139 kg/m^3 as shown in Table 2. The annual sediment yield was high in the reservoir due to farming activities at the upstream end of the dam and high rainfall intensity that could cause erosion. The farming activities accelerated rate of erosion and runoff containing soil particles and organic matter after soil tillage. The sediment yield (14,557.14 kg/ha/yr = 14.55714 tons/ha/yr) obtained in this study was less than the sediment yield (255.8 tons/ha/yr) obtained by Adeogun *et al*. (2015) for a watershed (12,992 km^2) at the upstream of

Jebba lake in Nigeria using SWAT model embedded in Geographical Information Systems (GIS). The annual impounded volume of sediment in the reservoir was 12.78 m^3/ha/yr (= 55,595.7 m^3/yr) was high due to farming activities at the upstream of the reservoir (dam) and this high sediment yield was similar to the value of obtained by Alkali *et al*. (2015) at Gubi dam reservoir (Bauchi State, Nigeria) with sediment rate of 41,000 m^3/yr.

Table 1: Characteristics of University of Ilorin dam

Parameter	*Value*
Name of the river	River Oyun
Crest length (m)	191
Crest Elevation above sea level (m)	296.5
Maximum storage height above sea level (m)	294
Maximum flood level above sea level (m)	293.5
Minimum flood level above sea level (m)	289.5
Height of the dam (m)	8.2
Spillway type	Gated Ogee
Length of spillway (m)	50
Spill crest elevation above sea level (m)	293

Source: Works Department, University of Ilorin, Ilorin

Table 2: Initial and current capacity of the reservoir, annual sediment yield and the bulk density

Parameter	*Value*
Longitude of the study reservoir (°)	4.675
Latitude of the study reservoir (°)	8.486
Initial capacity of the reservoir in 2007 (m^3)	1.800×10^6
Current capacity of the reservoir in 2014 (m^3)	1.411×10^6
Maximum depth of the reservoir (m)	7.6
Minimum depth of the reservoir (m)	2.2
Maximum elevation of underwater topography above sea level (m)	314
Minimum elevation of underwater topography above sea level (m)	278
Predominant soil of the sediment	Clay soil
Clay content (%)	46.5
Silt (%)	35.6
Sand (%)	17.9
Mean bulk density of the sediment (kg/m^3)	1139
Sediment yield between May 2007 and June 2014 (kg/ha)	101.9×10^3
Catchment (ha)	4350
Volume of impounded sediment between May 2007 and June 2014 (m^3)	389,710
Average annual sediment yield (m^3/ha/yr)	12.78
Annual weight of sediment yield (kg/ha/yr)	14,557.14

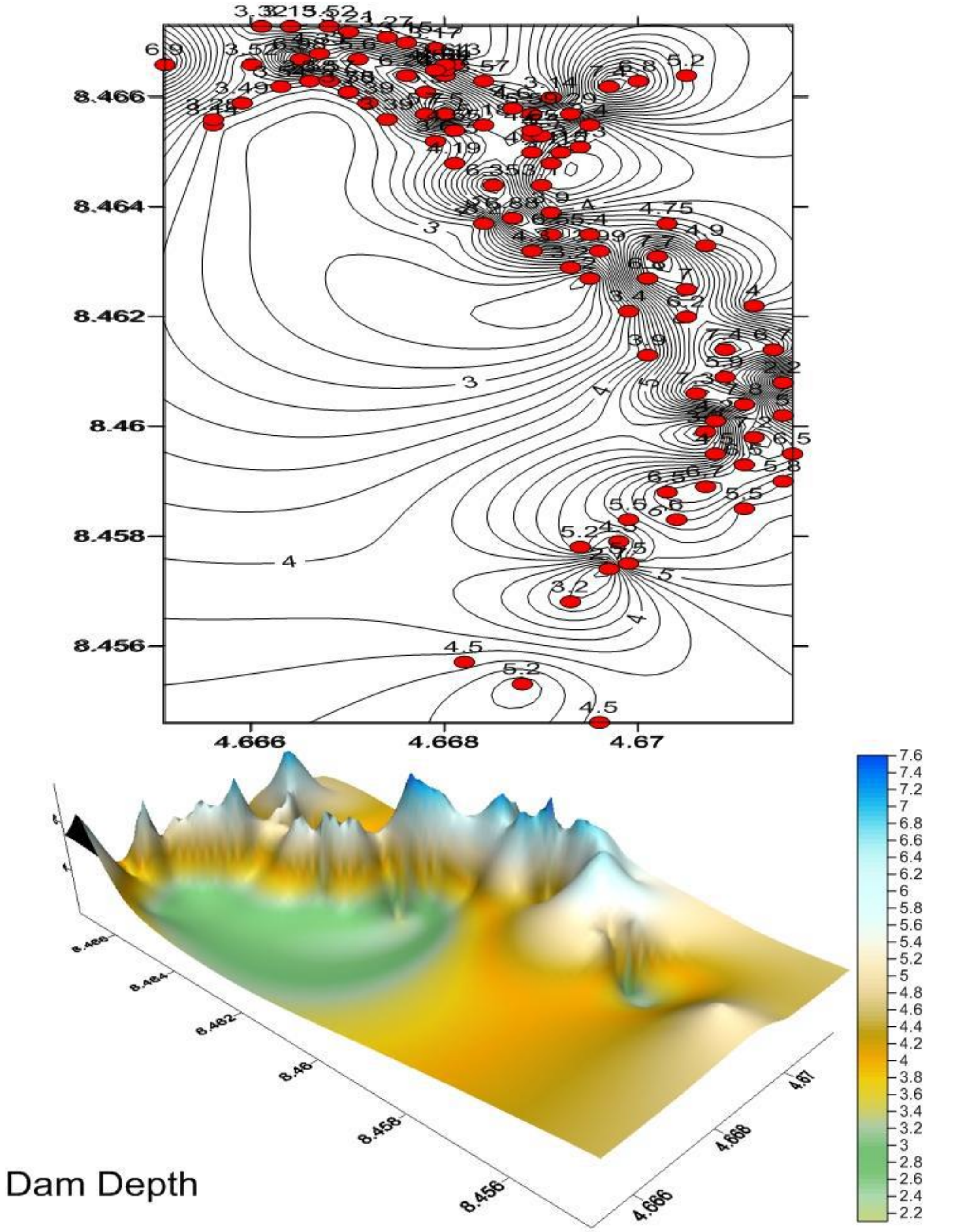

Figure 8: Depth profile of the reservoir dam (values in metre)

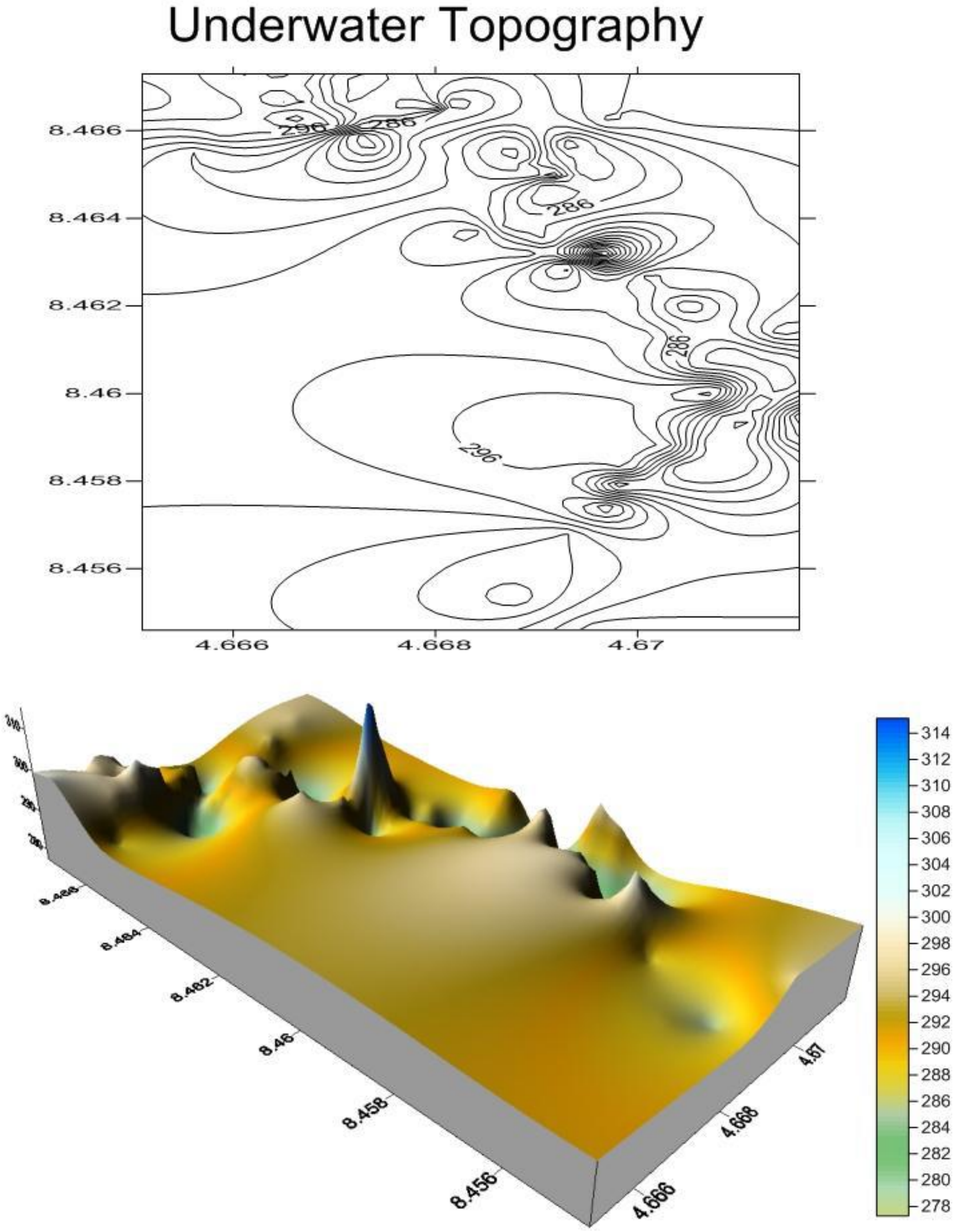

Figure 9: Map of the underwater topography of the dam (values in metre)

4.0 Conclusions

Bathymetric survey of the reservoir (dam) seven years after construction revealed that the initial capacity of the dam, 1.800 x10^6 m^3 in May 2007 was reduced to 1.411 x 10^6 m^3 in June 2014 due to sedimentation. This indicates 21.6% reduction in the capacity of the reservoir. The sediment was predominantly clay soil with mean bulk density of 1139 kg/m^3 and the volume of impounded sediment seven years after construction of the dam was 389,710 m^3 while the annual sediment yield was 12.78 m^3/ha/yr. The annual sediment yield was high in the reservoir due to farming activities at the upstream end of the dam. Tillage operations pulverize the soil thus accelerating the rate of erosion and sedimentation. It is recommended that farming at the upstream end of the dam (reservoir) should not be allowed to reduce sedimentation rate of the reservoir and dredging of the reservoir should be carried out at ten years interval.

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