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Bathymetric Survey and Volumetric Analysis for Sustainable Management
Case Study of Suleja Dam, Niger State, Nigeria

H. A. Samaila – Ija O. G. Ajayi* N. Zitta J. O. Odumosu A. A. Kuta
E. A. Adesina P. Ibrahim
Digital Hydro/Geo-Modelling Laboratory,Department of Surveying and Geoinformatics
Federal University of Technology, Minna, Nigeria
*Email: ogbajayi@gmail.com, gbenga.ajayi@futminna.edu.ng

Abstract
Ocean floor and the shape of the shoreline are major influencers of the changes in tidal propagation. Bathymetry; a survey operation aimed at determining the nature of the underwater level and topography of a water body's bed level plays a cogent role in the determination of both the shape of the shoreline and the ocean floor thereby aiding the monitoring and spatio-temporal modelling of the changes in tidal propagation as much as it ensures the availability of hydro-data which is the foundation of a Maritime Database Management System (MDBMS). This work presents the findings of the bathymetric survey and volumetric analysis of Suleja Dam located in the North central Region of Nigeria. The Differential Global Positioning System receiver (DGPS) (Promark 3), automatic level, echomap 50s in conjunction with the engine boat were used during this research. The data acquired was processed using the GNSS solutions software with the chart plotted in surfer 9 software environment. The surface area of the dam was discovered to be 24.64ha less than the designed area. Also the volume of water was found to be 3.6 x $10^6 m^3$ in contrast to the design volume of $34.7x10^6 m^3$. It was also observed that the lowest water depth was 0.56m and the highest water depth was 22.06m, therefore a difference of 5.94m was obtained as against the initial construction depth of 28.00m. The undulating nature of the reservoir bed and the difference in volume of water and surface area covered by the dam are pointers and clear indications of sedimentation and siltation process going on in the dam.
Keywords: Bathymetry, sounding, chart, reservoir, MDBMS

1.0 Introduction

The execution of a surveying operation, from its inception to the final submission of results, is a continuous process which must be meticulously carried out if maximum and accurate value is to be gained from it. The most accurate and carefully gathered data will be wasted if not processed carefully, collated and presented in a clear and understandable manner. All information must be gathered, validated, checked and rendered in a logical and uniform manner using clear unambiguous terms so that the data may be recovered and understood both immediately after the survey and in the future.

Hydrographic survey is the acquisition, analysis, visualization and management of spatial information concerning all marine features processes and properties in four dimensions (space and time). These include scientific study of lakes, dams, oceans and rivers etc. the above definition shows that hydrography literally covers almost all forms of operations involving measurement and analysis in the marine environment. (Ojinnaka, 2007)

Bathymetric survey is required whenever a detailed survey of the bed level is to be carried out, which is defined as the measurement of water Depth e.g. lakes, oceans, dams, and seas, rivers. (Encarta Dictionaries, 2009).

Bathymetry is also the measurement of the depths of water bodies from the water surface. It's the marine equivalent of topography. Bathymetric surveys are generally conducted with a transducer which both transmits a sound pulse from the water surface (usually attached to a boat) and records that same signal when it bounces from the bottom of the water body. An echo sounder attached to the transducer filters and records the travel time of the pulse. At the same time that the pulse occurs, a GPS unit can record the location of the reading.

Bathymetric survey is just like carrying out topographic survey on land. The chart produced from bathymetric survey of underwater depicts the nature of the underwater bed. In these circumstances the most recent details of the bottom shape are usually considered essential. A three Dimensional (picture) of the bottom would meet this requirement, and this is exactly what is meant by High Definition Gridded Bathymetric (HDGB). (Marc, 2012)

In recent times, more sophisticated attempts are gaining acceptance, or gradually been embraced in the field of hydrography e.g, the use of AUV (Autonomous Underwater Vehicle) named Blue fin-21AUV deployed in the search for the missing Malaysian airline MH370 by US Navy (Hydo international April 2014). (Raphael 2014 and Bruce 2013)

It was observed that since the dam was constructed, there has not been adequate information on the reservoir (Suleja dam). The fact remains, that sedimentation and siltation, is a gradual but continuous process which fills in ocean, lakes, rivers or dams if left unchecked. It thus becomes highly imperative to monitor the depth and storage capacity of such reservoirs through bathymetric survey, in order to maximize its usefulness for the intended construction purpose. Therefore the bathymetric survey and volumetric analysis of Suleja dam becomes necessary due to the natural and artificial activities going on within and around the dam.

Construction Data of Suleja Dam

The construction project of Suleja dam was initiated by the Niger State government in 1990, it was originally made to provide a reservoir with approximate capacity of 34.7 million meter cube (28, 000 AC/FF) to the people of Suleja and Abuja and its environs. The construction work of the dam started in 1992, and was completed in 1995. The catchment area of the dam spans to about $143KM^2$, while the reservoir itself has a crest length 870 meters and elevation of crest is 467.00 meters, the spill way is U – shape aqua crest with 105 meter long. The dam also has a dead storage capacity of $2.3x10^6m^3$ and a total storage capacity of $34.7x10^6m^3$. (Niger State water board management 2012)

2.0 The study area

2.1 Location of Suleja Dam

Situated South East of Niger State between latitude $09^0 14^1 37^{11}$.80E and $09^0 12^1 21^{11}$.13E and longitude 07^0 $17^1 15^{11}$.23N and $07^0 20^1 42^{11}$.17N, Suleja dam is located between Tafa local Government Area and Suleja local Government area of Niger State, Nigeria.

2.2 Climatic Condition around Suleja Dam

The maximum rainfall in the study area ranges from 3.66mm to 260mm between the months of May to September when peak rainfall is recorded with respect to temperature variations, November to February which is a little bit favorable with temperature ranging from 29^0c to 34^0c while March to April records high temperature in the range of 35^0c to 38^0c. The lowest temperature is recorded in the month of December with temperature value of 20^0c and within this month and February, the lowest relative humidity of 16% to 20% exists while July-August presents high humidity values 70% to 75%.

2.3 Relief and Drainage

In the Northern part of the dam is surrounded with hills, while the landscape of some sides is flat lying undulating surface. These rocks are predominantly igneous and sedimentary while some area metamorphic rocks, comprising of alluvium found along the entire project area.

2.4 Vegetation

Farming and grazing are the predominant activities around the Suleja Dam. Mostly involve are the Gbagyi people, Hausa’s and other tribes who are utilizing the rich soil of the area, a scene of tall trees and shrubs can also be sited within the dam premises too.

3.0 Materials/ Method

3.1 Equipment and Materials

The instrument used includes;

Equipment	Quantity
• EchoMap 50s / Accessories	1
• Automatic Level and accessories	1
• DGPS PROMARK 3 and accessories	1
• Garmin 76 Map GPS (Hand Held)	1
• 50m and 3m steel tape	1
• Cutlass	2
• Transducer	1
• Boat with 25hp engine	1
• Life Jackets	15
• Bi-pole	3

3.2. Test of instruments

The instruments used were tested to ascertain the manufacturers claim and to minimize instrumental errors in the acquired data. The instruments tested include: Echomap 50s, Automatic Level, DGPS (Promark3), Hand held

GPS, Boat and Boat Engine, etc.

3.2.1 Echomap 50s Test

The fish finder test was also carried out by comparing the depth obtained at a point with the physical reading gotten from a steel tape. A depth of 770mm was read from the fish finder and a corresponding value of 705mm was read from the steel tape. The difference between the two values was 65mm and is allowable in hydrographic work of this kind.

3.2.2 DGPS Promark3 Test

A node to node test of control coordinates was carried out with the ProMark3 DGPS. The result was within the allowable accuracy. This was further buttress by the specification given in the summary of accuracy parameter of the instrument in the user manual. Receiver and the Battery status were also checked.

3.2.3 Automatic level instrument test

The popular two peg test method was used in testing the Automatic level instrument. **(**Bannister and Raymond 1981). The instrument was set up properly and well leveled with the spirit bubbles centralized at the mid- way i.e. between the established ground control at the dam side and the water surface, so as to obtain the water level at the time of sounding. The test was to verify and ascertain that the instrument is in a good working condition. To achieve this, two pegs were set apart at distance of 50m on an approximately level ground (field) and designated as P and Q. The instrument was set at midpoint of the line PQ. All the necessary temporary adjustment was carried out at the instrument station. Staff's reading at P and Q was taken. The height difference was deduced between P and Q (i.e. P - Q = -1.800m).

The Automatic level was moved 20m behind the staff at P and staff readings were taken to staff at station P and Q respectively. The height difference between the two stations was deduced and found to be -1.805m.

The difference between the two set of reading was **-** 0.005m.

This difference was within permissible limit for the third order spirit levelling operation which should be 20mm √K where K, is the total distance covered. **(**Agor 1993)

3.3 Methods of Data Collection

The collection of data for this research cuts across various methods of surveying. In line with the aim and objectives of the research, the following methods were employed to acquire all the necessary data needed.

a) Sounding
b) Perimeter surveying using DGPS (Promark3).
c) Water level observation using automatic leveling instrument.

3.3.1 Sounding Operation

Before the commencement of the sounding operation, the control station whose coordinates are known was transferred to the Dam site via static mode. About 15 to 20 minutes occupation time was used for tracking the satellites covering about 15 km. This is done in order to obtain the Height (**BM)** at which the sounding will be reduced.

The next step is to setup the leveling instrument. The BS and FS readings were obtained 0.631m and 2.436m i.e. on the control and at water surface (level) respectively. **BM + BS – FS = RL OR BM + HI =RL,** where the transducer depth is added to the observed depths.

Once the echomap was switched on, data capture commenced as the boat was navigated along the planned sounding lines. The instrument automatically stores the XYZ values of every point.

3.3.2 Perimeter Surveying (Static versus Stop and Go)

This was done using Promark3DGPS. The rover was used to survey the entire perimeter of the dam via Stop and Go mode, the time was set at interval of 15 seconds which also serves as the occupation time spent on each point to be observed.

3.3.3 Computation and reduction of sounding data

The reduction of soundings means the calculation of reduced levels of sub-marine surface in terms of the adopted datum Victor et al, (2010). The depth of transducer (0.070) in water is measured and reduces from the depths acquired for each point. A correction equal to the difference of actual water level (read by gauges) and the datum level was applied to the observed soundings. This factor was added to the depths acquired to get the actual depths of water from the surface.

3.4 Charting

The bathymetric data was examined and reduced using Excel software. The graphics display has advanced interactive plotting and editing functions specifically tailored to meet the needs of offshore survey charting. Track plots were compiled by importing the processed datum track lines into the processed charts. Bathymetry charts were compiled by importing the processed sounding data into the charts. The Charts are based on UTM Projection.

3.5.0 Data processing and computation

3.5.1 Bathymetry data processing

Acquired data was processed off-line using a combination of Microsoft Excel, Surfer9, and SurvCorrect software environment.

3.5.2 GPS raw data processing

GNSS Solutions Software was used in the post processing of the raw data from the storage device (SD). The performance, processing speed, compactness and flexibility of the software is commendable. The raw data collected by Promark-3 DGPS receivers (master and rover) were processed to determine the differential relationship between the points occupied during data collection. The result of the processed GPS raw data is a vector defining this relationship. Computation of these vectors is the role of the data processing module within GNSS Solutions. The data processing module automatically analyzes the quality of the raw data files and adjusts processing parameters to produce the best vector possible, transferring most of the processing effort from the user to the processing software. However, the GNSS Software was pre-configured to process based on Clark 1880 spheroid so that the processed heights will be at the reduced height.

3.5.3 Back computation

Back computation was carried out to calculate bearings and distances between each traverse leg. These bearings and distances are determined from final corrected coordinates.

$$distance = \sqrt{(\Delta N^2} + \Delta E^2)$$

$$Bearing = \ tan^{-1}(\Delta E/\Delta N)$$

3.5.4 Area and Volume Computation

Area of the dam covered by traverse was computed by Cross coordinate method and checked by the Double Latitude method. The Formula used for the cross coordinate computation was.

$$Area(m^3) = (\sum N_1(N_1 \times E_2 + 1) - \sum E_1(E_1 \times N_2 + 1))/2$$

Where $\sum$ = Sum

N_1 & E_1 = The Northing and Easting coordinates points.

+1 = Repetition of the 1st Northing and Easting coordinates.

AUTOCAD map 2004 software was also used to double check the manually computed area.

4.0 Result and Analysis

Presented herein (Figure 1.0) is the sounding chart of the Suleja Dam which was generated from the sounding data. This shows the water level/depth at various points within the dam area. A contour map was subsequently overlaid on the bathymetry chart and the result of this overlay is depicted by Figure 2.0. Figure 3.0 shows the wire frame Digital Terrain Model generated from the sounding data while Figure 4.0 shows the overlay of contour map on Digital Terrain Model wire Frame thus showing the nature of the terrain. Figure 5.0 is the Surface Digital Terrain Model and colored Elevation range in meters. From the DTM it can be seen that the bed of the reservoir has varying levels of depth ranging from shallow spots to deep spots scattered across the reservoir.

Figure 6.0 is a Pie chat depicting the storage capacity at different levels (dead storage, designed storage, active storage capacity) respectively while another chat showing the volume of the dam at various stages was presented in Figure 7.0 This was generated from the result of the column computation presented in Table 1.0.

Also, the following observations and computational results were noted:

- RL_{BM} = Reduce Level of Bench Mark = 462.676
- RL_1 =Reduced Level of day one = 460.849
- RL_2 =Reduced level of day two = 460.974
- RL_3 =Reduced level of day three = 460.893
- $RL_{AV} = (RL_1 + RL_2 + RL_3)/3$ = 460.905
- RL_M = Reduce Level of mean depth = 438.579

- Lowest depth of water Level Observed = 0.56m
- Highest depth of water Level Observed = 22.06m
- Depth Range = highest – lowest = 22.06m – 0.56m = 21.50m
- Construction depth of dam = 28.00m
- Change in water depth = 28.00m – 22.06m = 5.94m
- Area of the lake (reservoir) covered: Surface Area covered by sounding survey and computed from ArcGIS = 5433550.55m^2 = 543.36Ha
- Design Surface Area of the Lake (reservoir) = 565.00Ha
- Difference between designed surface area and surface area covered by sounding operation is = 565.00 – 543.36 = 21.64Ha
- Volume of the reservoir computed from Surfer9 Grid Volume with Z value (460.849m) = 31084711.336292m^3 = 31.1 x 10^6m^3
- Design Volume of the dam reservoir at maximum storage capacity = 34.7x10^6m^3
- Difference between designed volume and computed volume covered by sounding operation is = 3.6 x 10^6m^3

4.1 Analysis of results

The reduced level of the Bench Mark established at the bank of the dam is 462.676meters, and at the water surfaces at the time of sounding for the three days are 460.849m, 460.974m and 460.893m respectively. The average of the reduced water level for the three days was 460.905m and the reduced minimum level given as 438.579meters. The highest depth observed during this research was 22.06 meters and a corresponding lowest depth of 0.56meters, giving a depth range of 21.5meters. The construction depth was 28meters, the change in depth from when constructed and the observed was 5.94meters. The design area of the dam when constructed was 565Ha; the area of the dam computed from surfer9 software was 503.16Ha.

The bathymetry chart plotted from the sounding data is shown in Figure 1. The chart which was in Clark 1880 coordinates system with semi major axis 6378247.145m, flattening 1/293.455 and projected in Universal Transverse Mercator (UTM). The chart was plotted in a scale of 1 in 50000 and is composed of transect lines and sounding depths, the surface area covered by the sounding survey, the perimeter transverse and grid lines.

The change in volume was discovered to be 3.6 X 10^6m^3. This was obtained by computing the difference between the grid volume of the dam with Z value of 460.849m (31.1 X 10^6m^3) and the designed volume of the dam (34.7 X 10^6m^3), This major discrepancy as observed could be as a result of the various activities surrounding the dam chief among which includes farming and erosion. Other contributing factors include sedimentation and siltation of the dam leading to the reduction in water volume. The total area covered from traverse computation was 519Ha covering a total distance of about 29.05km.

5.0 Conclusion

Bathymetric survey of Suleja is not only important but timely as few discoveries that needs urgent attention and consideration has been made. Some of these observations are:

- The dam is not functioning at the optimum construction and design specification e.g: The dam was designed to accommodate a hydro-volume of 34.7 X 10^6m^3 while the estimated current volume of the dam is 31.1 X 10^6m^3 implying that the dam is functioning below expected capacity by 3.6 X 10^6m^3. It could be inferred from this that various activities as earlier highlighted in section 4.1 are fast preventing the dam from functioning optimally to the design specification hence, urgent research should investigate the likely cause(s) of this menace and the possible means of mitigating it.
- The dam's highest depth of observed water level is 22.06m as against the designed construction depth of 28.00m. This implies that an approximate depth of 5.94m has been lost to siltation/sedimentation between when the dam was construction and the period of this research. This is a serious concern that should be looked into by the Government in charge of the dam's management.
- Finally, the dam's designed surface area is 565.00Ha while the computed surface area of the dam is 543.56Ha implying that an approximate area of 21.64Ha has been taken over by sand or other non-hydro substances between the construction period and the period of this research. This is also a subject of grave concern.

Recommendation for Further Research

The Authors wish to recommend that a system for the Spatio-temporal monitoring of the dam be put in place so as to be able to model the rate and pace of sedimentation and siltation. This can help in forecasting what the state of the dam will be in the next couple of years.

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Table 1.0 Volume Computed at Different Level

Points	R/L	Mean depth	Area(Ha)	Volume	Remark
RL_{BM}	462.676	6.03	503.16		**Ija02**
RL_1	460.849	6.03	503.16	31.1×10^6	**Day One**
RL_2	460.974	6.03	503.16	31.7×10^6	**Day Two**
RL_3	460.893	6.03	503.16	31.3×10^6	**Day Three**
RL_M	438.579	6.03	503.16		**Mean RL**
RL_{AV}	460.905	6.03	503.16		**Average Rl**

Source: Researcher's Field Work.

This table contains the summary of the Reduced levels, Mean depths, Area and Volume of the dam over 3 days of observation.

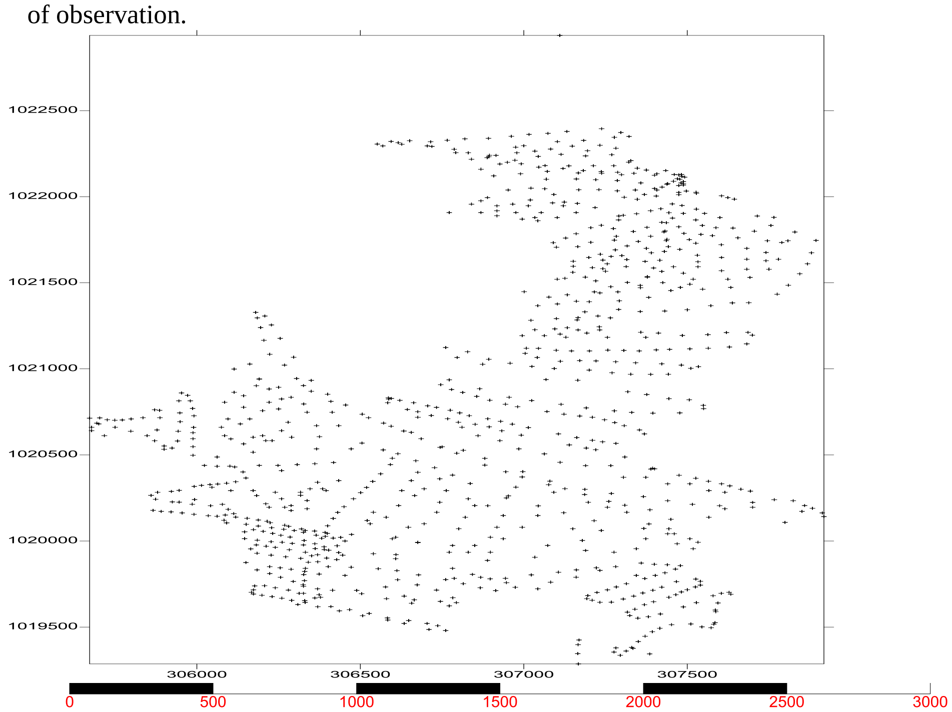

Fig. 1: Bathymetric chart of Suleija Dam reservoir.

This Figure shows the Bathymetric chart of the dam after the acquired sounding data has been processed.

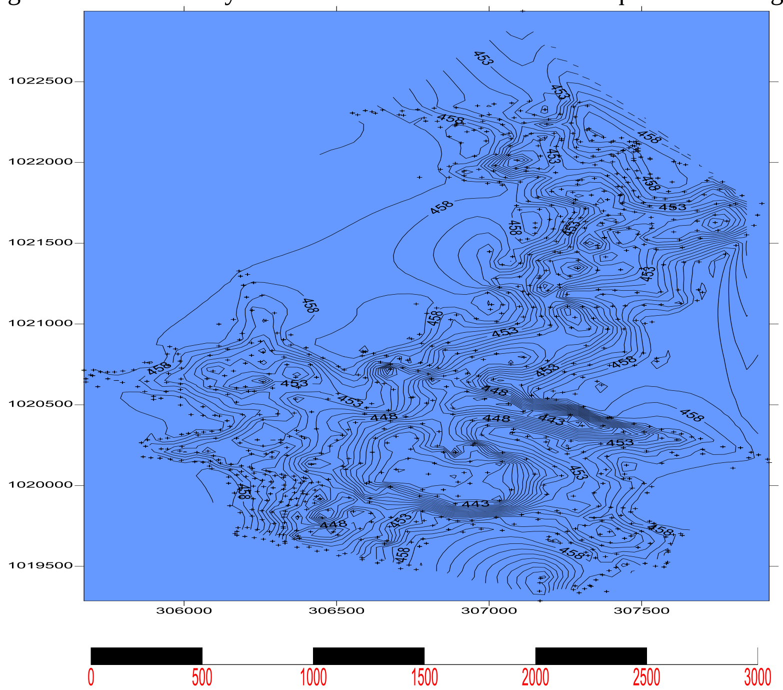

Fig. 2.0: Overlay of Contour on Bathymetry Chart.

Figure 2.0 presents the result of overlaying the contour map over the bathymetric chart.

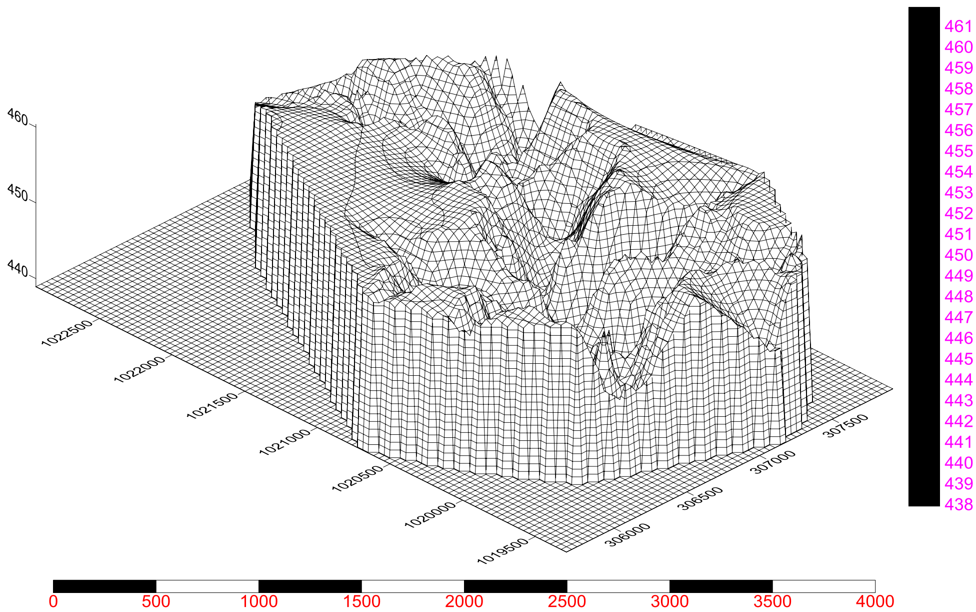

Fig. 3.0: 3D Wireframe Digital Terrain Model Showing X,Y,Z Zones.

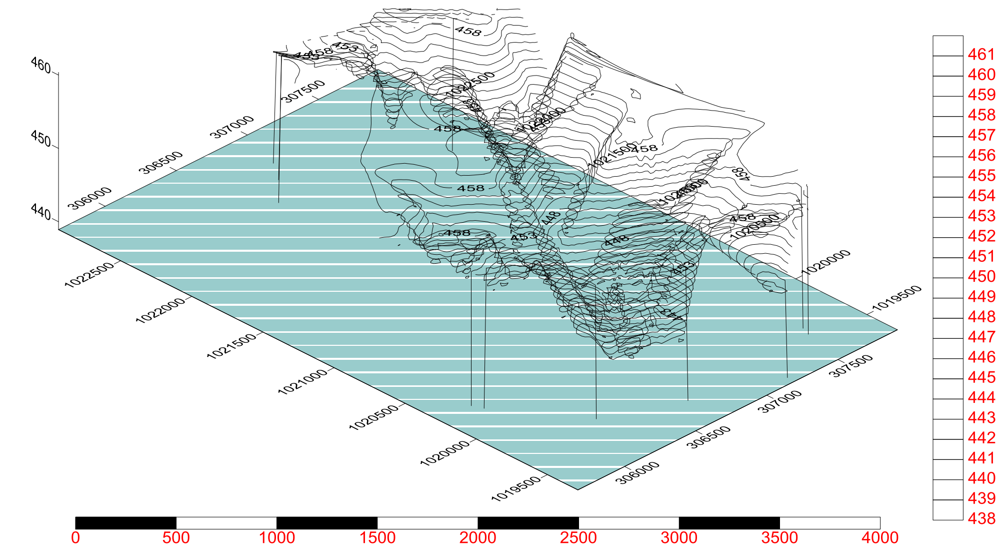

Fig. 4: Overlay of Contour Map on Digital Terrain Model Wireframe.

Figure 4.0 Presents the output of overlaying the Contour Map on the Digital Terrain Model (DTM) WireFrame so has to pictorially show the nature of the terrain configuration or surface configuration of the dam's depth. This is also better represented in Figure 5.0.

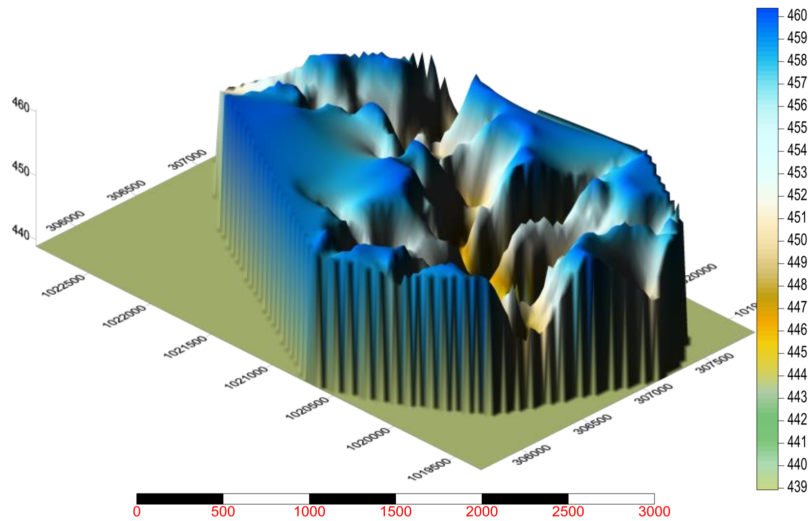

Fig. 5.0: 3D Surface Digital Terrain Model of the Dam

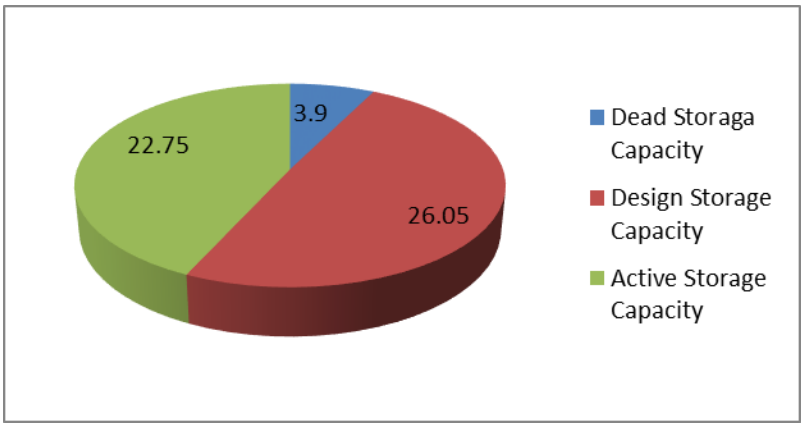

Fig 6.0: Relationship between the design capacity and the active capacity of the dam.

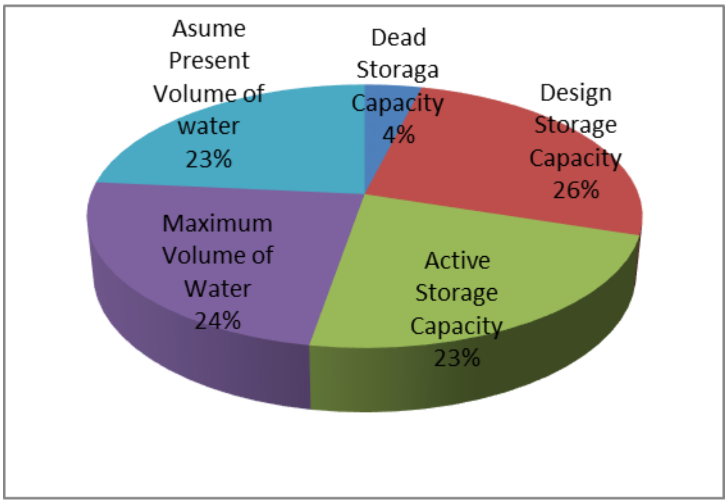

Fig. 7.0: Pie Chart Showing Volumes at Different Stage in the Reservoir.