

Bathymetric components towards ensuring navigable channel along a section of lower river Niger, lokoja, kogi state, Nigeria

Abstract

Navigation in Lower River Niger is seasonal because of insufficient water depth during the dry season. This is a limitation to economic benefits derivable compared to when the river is navigable throughout the year. Government and stakeholders alike have exerted efforts in the past years to create an unimpeded navigable channel without much success. The need to ensure all-year-round navigation in the Lower River Niger for industrial and commercial purposes necessitated this research work. The main thrust of this work is to determine bathymetric components parameters of the river necessary for the design of an appropriate river training structure to divert river flow from the secondary channel to the main channel. The specific objective hereto is to assess the extent and geometry of the river banks, the configuration of the river bed, the river flow velocity and discharge. The approach deployed in this work is the classical method of acoustic principle premised on Remote Sensing techniques. The shape of the river was obtained through waypoint survey using Garmin eTrex 10 handheld GPS, while the riverbed configuration was determined through bathymetric survey using Odom Echotrack MK III single beam Echo Sounder and the flow velocity data was acquired using Valeport 106 Current Meter.

Data processing and analysis were achieved using Garmin Basecamp 4.7.3, Wintopo V7.03, Valeport Datalog X2 and Surfer 13 software. The length of the study area measured along the main channel was obtained as 5.94km while that of secondary channel gave 4.30km. Area occupied by the main channel was found to be 2,636,331.3m² and 1,759,045.4m² for the secondary channel. Average depth on the main channel was 0.21m while on the secondary channel was -0.89m, depth figures referred to Lokoja local datum. The average flow velocity was obtained to be 0.449m/s and the cross-sectional area of the river as 1568.75m², which gave a value of 704.2m³/s for the river discharge. The research produced the digital terrain model (DTM) and bathymetric charts of the study area. The parameters obtained in this study is a useful tool in defining an appropriate embankment dam suitable to divert the flow from the secondary channel to the main channel to enhance depth towards all-season navigation in Lower River Niger.

Keywords: bathymetric, river bed, echo sounder, local datum, GPS

Introduction

Inland Water Transportation System (IWTS) offers an alternative economic and eco-friendly mode of transport. Within the last few centuries, river navigation has significantly augmented the ability of industry to transport goods to and from inland ports which in many cases has provided an economical method of transporting large quantities of goods (Admiraal, Garcia and Rodriguez, 2000). Earliest recorded navigation along the Nigerian inland waterways is traced back to 1832, when the steam vessel Alburkah, sailed up the River Niger to Lokoja which lies 500 km inland, from the Atlantic Ocean.¹ Since then, River Niger and many other rivers in Nigeria have been traversed apparently only when the nature permits, usually at rainy seasons when water levels were sufficient. Over the years, this seasonal usage on River Niger has declined almost to a halt as a result of post-independence increase in the construction of roads, rails and infrastructure. Passengers began to opt for faster commute by roads as compared to long boat journeys and the trucks and rails took over the bulk cargoes that hitherto passed through the waterways.²

Over time, as usage on the road heightens and rail system slackens for lack of maintenance which culminated in the road network

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reaching its economic and ecological limits, the agitation came once again for a shift to water transportation mode. The government came up with a revival plan for the Inland Water Transportation System under which was the execution of the dredging of the lower River Niger which came up between 2009 and 2013.³ After the project was adjudged completed, many people believed it was another hoax as no visible improvement was observed in the utilization of the river. Due to the high rate of sediment moving through the river, dredged sections are quickly filled up thus rendering the efforts put in through dredging or other means to improve navigation on the river a wasteful exercise.

This research looks at creating an enduring navigable channel along the Lower River Niger. It focuses attention on alternative, and more scientific approach. The study looks into the use of dam to regulate water flow into secondary branch of the river by diverting the flow to the main channel, thus increasing the volume of water on the main channel and enhancing navigability. River Niger is a braided river with many secondary branches along its flow. The dam is to block partially the secondary branch of the river to guide the water towards the main branch to enhance its depth through increased volume and velocity of the water. It is a part of structural measures

taken to improve the functionality of a river and its banks, generally referred to as River Training.⁴ It is important that the hydraulic structure must have the capacity to withstand the pressure and the stress of the aquatic environment, therefore this research investigates into different bathymetric components to provide useful guides in the design and installation of a diversion dam.

A diversion dam is a barrier constructed wholly or partially across the width of a river or stream to divert all or a portion of the flow of the river from its natural course. Diversion dams do not generally impound water in a reservoir; instead, the water is diverted into a different river or canal for purpose of navigation, irrigation or made to run through hydroelectric plants for power generation. The impacts of a proposed diversion dam are to be evaluated to ensure that water quality, fish and wildlife, aesthetics, and other environmental concerns are considered in the design and layout of the structure(s). The practice is also carefully evaluated to ensure compliance with

state and local laws concerning natural watercourses.⁵ The aim of the research is to determine Bathymetric Component Parameters of a section of the Lower River Niger. The specific objectives of this study are thus, to determine accurate positional information of the river course within the study area, to obtain the configuration of the bottom of the river within the entire study area, to determine the flow velocity, the discharge of the water body and to compute the elements of the diversion dam as a river training structure.

Study area

The study area is a section of the lower River Niger located in Lokoja, Kogi local government area of Kogi state. The area is defined by the following coordinates: Latitude 08° 03' 50"N, Longitude 006° 44' 47"E; Latitude 08° 03' 50"N, Longitude 006° 48' 19"E; Latitude 07° 59' 30"N, Longitude 006° 48' 19"E and Latitude 07° 59' 30"N, Longitude 006° 44' 47"E. The extent along the river measures 5.94km from upstream to downstream. The study area is illustrated in Plate 1.

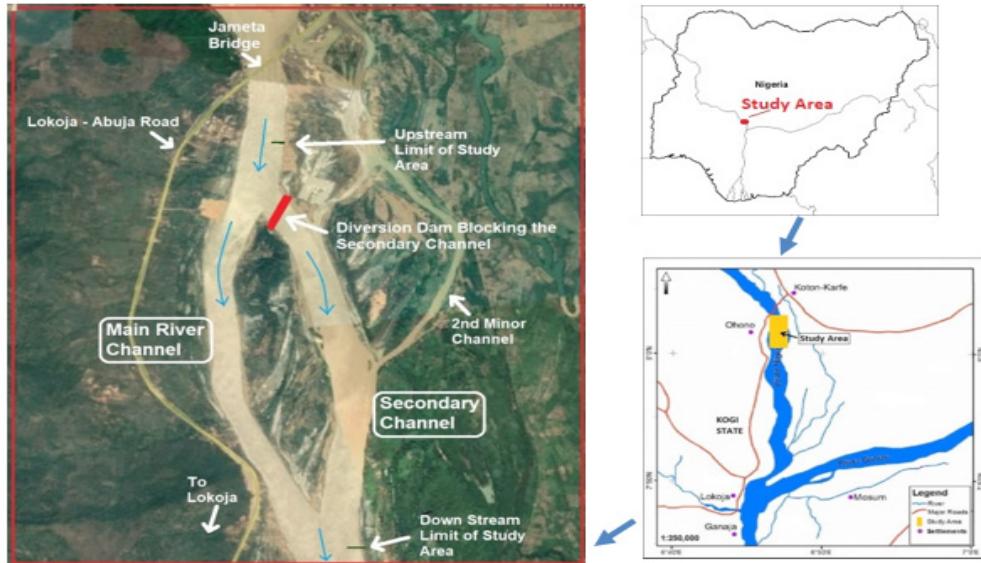


Plate 1 Image of the Study Area (source: Google Earth, 2020).

Materials and methodology

The research entailed GPS survey to detail the riverbank; bathymetric survey to obtain the configuration of the river bed and current measurement to obtain the flow velocity along the river.

Riverbank survey

Riverbank survey was carried out to obtain an accurate positional information of the riverbanks. The bank survey was carried out using Garmin eTrex 10 handheld Global Positioning System (GPS) receiver which uses the concept of Global Navigation Satellite System (GNSS) based on the principle of radio wave propagation. The GPS receiver takes the information from the satellites and mathematically determines its position by using the calculated pseudo-ranges and the satellite position information that has been supplied by the satellites. The receiver uses four satellites in view to determine its position by solving the four equations (the GPS equation) for the x, y, z coordinates of the receiver and a value 'd' which is the difference in time between the receiver's clock and the satellite's clocks called the clock offset. Equation 1 is the set of GPS equations (Blewitt, 1997) to obtain the receiver's position.

$$\begin{aligned}
 P2 &= (x - A2)^2 + (y - B2)^2 + (z - C2)^2 + (c(t2 - d))^2 \\
 P2 &= (x - A2)^2 + (y - B2)^2 + (z - C2)^2 + (c(t2 - d))^2 \quad \text{Eq.1} \\
 P3 &= (x - A3)^2 + (y - B3)^2 + (z - C3)^2 + (c(t3 - d))^2 \\
 P4 &= (x - A4)^2 + (y - B4)^2 + (z - C4)^2 + (c(t4 - d))^2
 \end{aligned}$$

where P is the pseudo-range to the satellite, x, y, and z are the coordinates of the receiver, A, B, and C are the coordinates of the satellites, d is the clock offset, t is the signal's travel time from the satellite to the receiver and c is the speed of light in a vacuum. To carry out the riverbank survey, the GPS receiver was calibrated, and using the waypoint approach, points along the river bank were measured at an average interval of 50m. Both sides of the river on both the main and secondary channels were measured. Measured data were retrieved from the handheld GPS in XYZ coordinates and saved in the computer using the Garmin Basecamp software.

Bathymetric survey

Bathymetric survey was carried out on both the main and secondary channels of the study area using a single beam echo sounder Odom Echotrac MK III interfaced with a Septentrio AsteRx2e C-NAV GPS setup. The survey was controlled in the computer using the Qinsy Console Software. Running the sounding lines witnessed a longitudinal section and cross sections run at 50m intervals. Water level information (referred to Lokoja local datum - LLD) was taken before and after the survey for depth referencing. Data processing was done using WinTopo and Total Commander Applications. Data in XYZ was retrieved into the WinTopo program where the data is processed and imported into CAD environment for plan making.

River flow measurement

One simple method for estimating the velocity of flow in a river is to measure the time taken for a floating object to travel from one point to another downstream with known distance from the first. The velocity can then be obtained as 'distance divided by the time taken'. The velocity is not the same at all places in a river or stream. It is determined by many factors, including the shape of its channel, the gradient of the slope of flow on the riverbed, the volume of water

that the river carries and the amount of friction caused by rough edges within the riverbed. Around the perimeter of the river, friction is created as water flows against the edges resulting to lower flow velocity as compared to water flowing through a wide, deep river channel where resistance against flow is less. Hence the center of the river experiences the greatest velocity (Ames, 2018). Determining the flow velocity with more reliable measurement, this study used the battery operated Valeport CM 106 Current Meter.

As shown in Plate 2, the Valeport CM 106 is factory calibrated propeller Current Meter. Taking measurement, the current meter was installed in the water at half the depth of the river so as to get average readings. It was set on self-recording mode, so it logged data in its internal memory which was latter extracted and processed in the computer. For reliable measurement, the inner part of the impeller was filled with water, and the meter balanced on a horizontal position before being launched into the water. Sampling interval was 10secs on an average recording interval of 15mins, the study logged with the velocity meter for one week between 28/02/2020 and 05/03/2020. Three sets of measurement at three different known locations across the river were made. The same program 'Datalog X2' used in data logging on the field was also used for data processing after the operation.

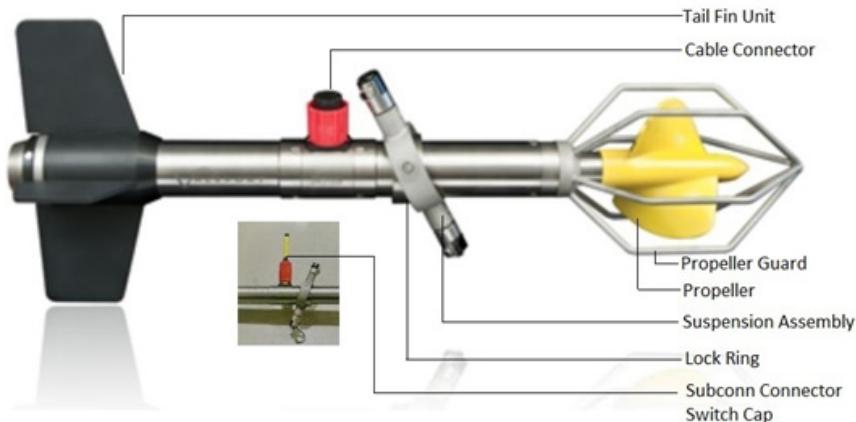


Plate 2 Valeport Model 106 Current Meter (Valeport Limited, UK).

Results and discussion

Determining the accurate positional information of the river course

With the GPS survey of the river banks acquired, the boundary limits of the river course were prepared into drawing using AutoCAD software. The following results were also obtained:

Main Channel Area	=	2,636,331.3m ² .
Main Channel Length	=	5.94km (measured along the river centerline)
Secondary Channel Area	=	1,759,045.4m ² .
Secondary Channel Length	=	4.30km (measured along the river centerline)

Obtaining the configuration of the bottom of the river

Positional data in XYZ of the riverbed were generated from the survey, and through which the bathymetric drawing of the area was

produced using AutoCAD software. The result gave this study the following information Figure 1:

$$\begin{array}{lll} \text{Average Depth of the Main Channel} & = & 0.21\text{m} \\ \text{Average Depth of the Secondary Channel} & = & -0.89\text{m} \\ \text{Average Depth for Both Channels} & = & -0.34\text{m} \end{array}$$

With the data generated from the GPS and the bathymetric surveys, the 3D digital terrain model (DTM) of the study area was prepared as shown in Figure 2.

Flow velocity and discharge results

Again, from the data generated from the GPS and the bathymetric surveys, the cross-sectional area of the main river where flow measurement took place was obtained using Trapezoidal rule (see Equation 2).

$$Area = \Delta x \left(\frac{1}{2} y_0 + y_1 + y_2 + y_3 + \dots + \frac{1}{2} y_n \right) \dots \text{(Eq. 2)}$$

$$\Delta x = \frac{1}{n} (b - a)$$

Where $y_0, y_1, \dots, y_{n-1}, y_n$ are ordinates in the figure; a and b are the chainages of the start point and end point on the figure's baseline, n is the number of strips or trapeziums in the figure. Figure 3 illustrates

the application of Trapezoidal rule. Cross-sectional area of the river was obtained as **1568.75m²**

$$\begin{aligned} \text{Discharge} &= \text{Flow Velocity} \times \text{Cross-sectional Area} \\ &= 0.44889 \text{ m/s} \times 1568.750 \text{ m}^2 \\ &= \mathbf{704.196 \text{ m}^3/\text{s}} \end{aligned}$$

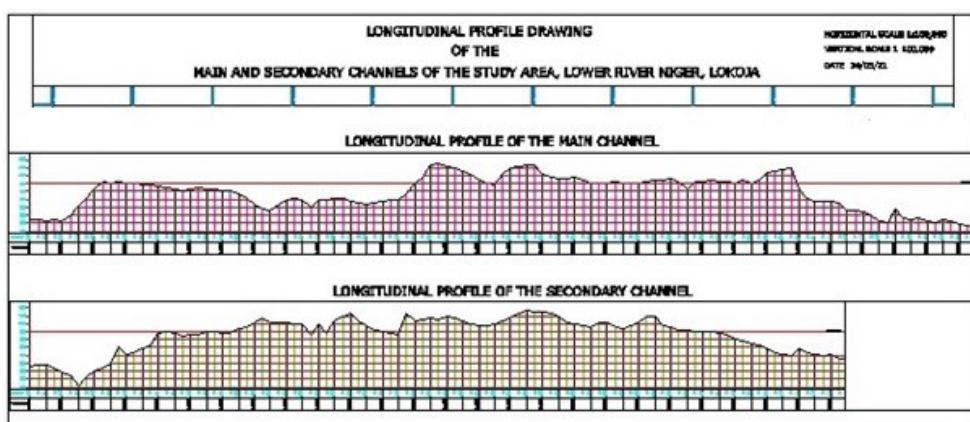


Figure 1 Longitudinal Vertical Profiles of the Main and the Secondary Channel (Authors' Concept, 2021).

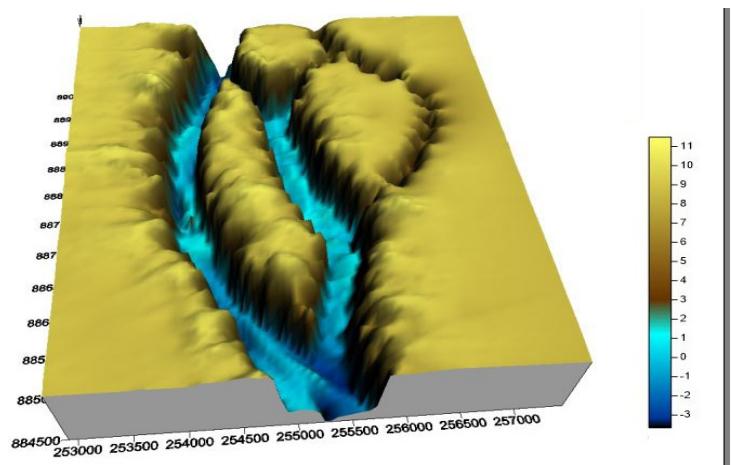


Figure 2 Digital Terrain Model (DTM) of the Study Area (Source: Model prepared by the Study).

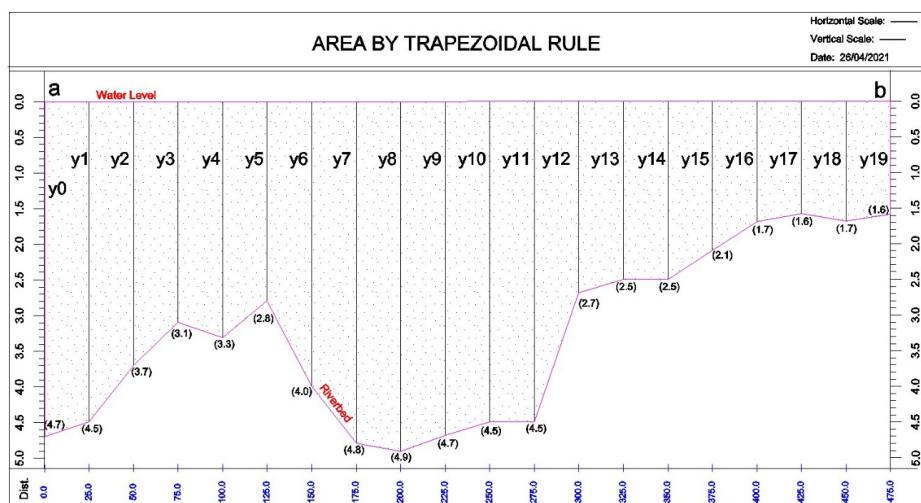


Figure 3 Illustration of Cross-Sectional Area Calculation by Trapezoidal Rule.

Discharge figure obtained is quite low because the flow velocity measurement was taken around the peak of dry season as in Table 1. Due to a wide range of water levels between dry and rainy seasons,

mean annual discharge into the lower Niger and the tropical Atlantic Ocean amounts to 5600 m³/s with peaks during September reaching 27600 m³/s and low-flow during the dry season down to 500 m³/s.⁶

Table 1 Flow Velocity Measurement Results (Authors' Concept, 2021)

Vale port 106 CM	Current Meter CM 1 (35711)	Current Meter CM 2 (35482)	Current Meter CM 3 (35096)
Positions	254291.792mE	254417.269mE	254542.746mE
	889570.194mN	889572.656mN	889574.955mN
26-02-2020	0.515	0.424	
27-02-2020	0.371	0.484	
28-02-2020	0.548	0.57	
01-03-2020	0.42	0.457	
02-03-2020	0.358	0.488	
03-03-2020	0.561	0.457	
04-03-2020	0.395	0.507	
05-03-2020	0.571	0.394	

Parameters of the diversion dam

This research looks at an embankment dam that will only block the river flow into the secondary channel for the period when water level on the main channel is too low to support navigation usually

in the dry season. Once the natural water level has risen enough to provide sufficient depth on the channel, the water flows over the dam into the secondary channel. Figure 4 gives a clearer view on how the parameters for the proposed dam are calculated. Parameters defining the proposed dam are obtained as follows:

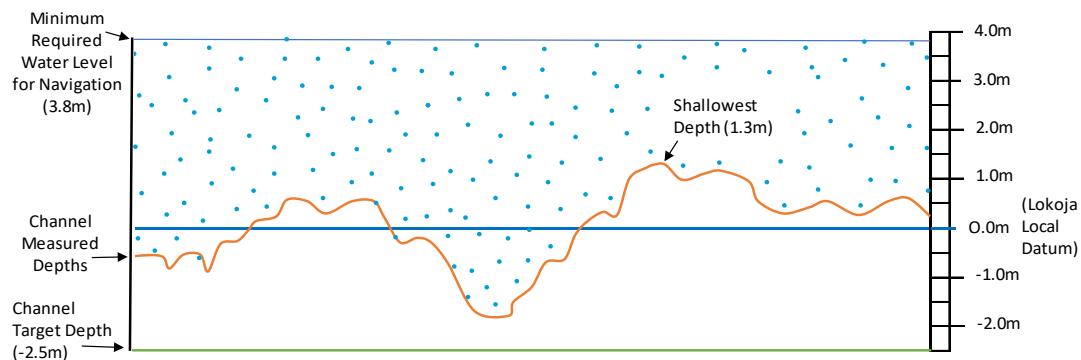


Figure 4 Illustration between Depths and Water Levels (Authors' Concept, 2021).

i. Length of dam:

$$\text{Total Length of the Diversion Dam} = 260\text{m}$$

ii. Coordinates of the two ends of dam:

$$\begin{aligned} \text{Coordinates of Dam Limits} &= (1), 254661.99\text{mE}; 888933.68\text{mN} \\ &(2), 254792.81\text{mE}; 889158.37\text{mN} \end{aligned}$$

iii. Termination level of dam

Minimum required depth on the Channel = 2.5m below LLD

Shallowest Part of the Channel = 1.3m above LLD

Level for Shallowest Part to achieve min. required depth = 3.8m above LLD

Cut off level of Diversion Dam (plus 1m tolerance) = **4.8m above LLD**

iv. Depth of dam

$$\text{Depth of Dam} = 1.7\text{m} + 2.0\text{m foundation} = \mathbf{3.7\text{m below LLD}}$$

Total height of dam structure = termination height above datum + depth of dam below datum. That is: Total height of dam = 4.8 + 3.7 = **8.5m**

v. Total force on dam

Total Force (F) acting on Dam:

$$F = \frac{1}{2}(\rho \times g \times h) \times (l \times h) \quad \dots \text{(Eq. 3)}$$

Where F is the total force measured in Newton (N), ρ is the density of water, g is the acceleration due to gravity, h is the height of water and l the length of the dam.

$$\text{Density of Water } (\rho) = 1000\text{kgm}^{-3}$$

Acceleration due to Gravity (g)	=	9.81ms ⁻²	Expressed F in Tonnage (M)	=	F ÷ g (where g is acceleration due to gravity)
Height of Water (h)	=	8.5m (same as height of dam)	Mass (M)	=	92,140,425 ÷ 9.81
Length of Dam (l)	=	260m (already given above)		=	9,392,500 Kg
Total Force on Dam (F)	=	1/2(1000 x 9.81 x 8.5) (260 x 8.5)		=	9,392.5 Ton
	=	92,140,425 N			

Dam estimates

Figure 5 is the geometric cross-section of the proposed diversion dam (which is a rock filled embankment dam). Natural gradient of 1:2 along the sides is assumed.

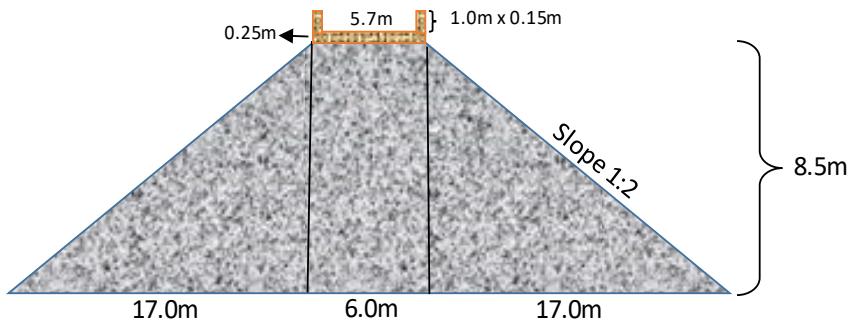


Figure 5 Cross-Section of Research Embankment Dam (Source: Prepared by the Study).

Table 2 Dam Calculation and Cost Estimate (Authors' Concept)

DAM CALCULATION AND COST ESTIMATE					
Information					
Project Description: Diversion dam located on Lower River Niger, downstream of Jameta Bridge, Iokoja, Kogi State, Nigeria					
Project Location: Lokoja, Kogi State, Nigeria					
Dam Location:  Southern End 254661.99mE 888933.68mN Northern End 254792.81mE 889158.37mN					
Scope Statement: The dam is to serve to divert water flow from the secondary channel to the main channel. This is to enhance water depths on the main channel in order to improve navigation.					
Dimensions of Dam: Length: 260 m Height: 8.5 m Width: Top 6.0 m Down 40.0 m					
Other Information: A research work					
Total Force Acting on Dam					
Acceleration due to Gravity: 9.81 ms ⁻²	Density of Water (a): 1000 kgm ⁻³	Height of Water (h): 8.5 m			
Total Force on Dam: $F = 1/2(a \times g \times h) (L \times h)$	= 1/2(1000 x 9.81 x 8.5) (260 x 8.5)	= 92,140,425.0 N			
Total Force on Dam: $F = mg$, therefore $m = Fg^{-1}$ (where m is total Mass of Dam)	\therefore Mass = 9,392,500 Kg	= 9,392.5 Tons			
Other Information: Total Force on Dam (F) = $1/2(a \times g \times h) (L \times h)$, is also expressed in term of mass (weight of Dam) = Mg , hence Mass can be obtained. This is the mass enough to withstand the force.					
Elements of Dam					
Cross-sectional Area of Dam: 195.5 m ²	Volume of Dam: 50,830 m ³	Weight of Boulder Rock: 137,241 Tons			
Volume of Graded Granite: 10,166 m ³	Weight of Graded Granite: 24,398 Tons	Total Weight of Dam: 161,639 Tons			
Cross-sectional Area of Capping: 1.8 m ²	Volume of Capping: 468 m ³				
Cost Estimates					
Project Item Description	Quantity	Unit	Rate (₦)	Amount (₦)	Remarks
Project Preparations					
Project's Survey and Design		Lump Sum		11,500,000.00	
Environmental Impact Assessment (EIA)		Lump Sum		28,000,000.00	
Site Clearing	100,000	m ²	140	14,000,000.00	
Access Road Construction					
Grading	2200	m	105,000	231,000,000.00	
Hardcore					
Main Construction					
Cost of Materials - Boulders	137,241	Ton	8,000	1,097,928,000.00	
Cost of Materials - Graded Rock	24,398	Ton	10,000	243,980,000.00	
Equipment	270	Days	1,015,000	274,050,000.00	Total daily rates for 1 year
Capping					
Grade M20 Concrete	468	m ²	100,000	46,800,000.00	
Reinforcement Rods	260	m	40,000	10,400,000.00	Rate per crosssectional area
Supervision/Consultancy		Lump Sum		322,609,050.00	15% of contract sum
SUBTOTAL				2,280,267,050.00	
RISK (CONTINGENCY)	5%			114,013,352.50	
TOTAL COST ESTIMATE				₦ 2,394,280,402.50	

Material estimates

Height of dam	=	8.5m (defined)
Top width of dam for machines)	=	6.0m (wide enough
Base of dam plane figures)	=	40.0m (geometry of
Length of Dam	=	260.0m (defined)
Cross-sectional Area of Dam 8.5	=	0.5 x (6.0 + 40.0) x
	=	195.5m²
Volume of Dam x Length	=	Cross-sectional Area
	=	195.5 x 260
Therefore, Volume of Dam	=	50,830m³
Tonnage of material expected to build the dam structure.		
Mass	=	Density x Volume
Using density of 2.7ton/m ³ for boulder rock,		
Mass	=	137,241 Tons
Addition of 20% of total volume for graded impervious material with 2.4ton/m ³		
Tonnage of graded granite	=	20% x 50,830 x 2.4
	=	24,398 Tons.
Total tonnage of material required to construct the dam:		
137,241 + 24,398	=	161,639 Tons

Cost estimates for dam

Discussion of findings

Although the length covered by the study area is barely 1% of the total length of the Lower River Niger. Total length of Lower River Niger from Warri in Delta State to Baro in Niger State is 572km.⁷ The focus of this research is on improving depths along the navigation channel through diversion of river flow from secondary channel to the main channel. Its application is therefore peculiar to sections of the LRN where the river braided to more than one channels. Depth values are prepared in hydrographic mode. Considering the average depth on the main channel, which is the navigation channel, there is a wide short fall between the depth and the required (designed) depth of -2.50m for navigation (Clause 10.4, Technical Specification, Dredging of the Lower River Niger, 2005). The difference gives: -2.50 - (-0.21) =-2.29m. This is the face difference between the required depth and the existing depth.⁸⁻¹¹

Applying this face difference on a channel width of 60m for a length of 5.94km (i.e., within the study area) the result gave 816,156m³. That is, on the navigation channel within the study area, only this amount of material ought to be excavated (dredged) from the channel to be deemed navigable. Longitudinal vertical profiles of the study area were produced. This is a two-dimensional (2D) chart which displays the change in the elevation of the channel bed (usually the center alignment) over distance along a river. The two profiles as shown in figure 1 are prepared with the chainage (distance) on

the horizontal axis and the depth on the vertical axis. Embankment dams are constructed with enough weight to counteract the force of the water pushing on them. The research is able to demonstrate that estimated total weight of the proposed dam is far bigger compared to the weight the dam requires to withstand the force pushing on it.

Total Weight of Dam = 161,639 Ton

Total Weight the Dam must possess to withstand the Force = 9,392.5 Ton

This is a confirmation that the proposed dam has weight in excess to withstand the force that would act on it. It will be a stable dam. A short simulation clip to demonstrate the interactions between the main channel and the secondary channel after the dam has been installed was developed to bring clarity to what is expected on the two channels. The water regime is altered with more volume of flow on the main channel. The simulation shows the water levels for a year with the dam effect as compared to without the dam. It can also be observed that the trained secondary channel had water all through the seasons. The simulation can be accessed through the link below.

<https://drive.google.com/file/d/13E1NYNyCrIavWUBaY602Ossi0Ynx3RtP/view?usp=sharing>

Conclusion

During the reconnaissance stage for this study, no farmland or any direct use of the river was found; meaning that the river was not directly impacting on humans within the stretch of the study area. However, to minimize the impact generally on the wider environment and also putting in mind the United Nation's Sustainable Development Goals (SDG), the following characteristics are considered in the siting and choice of the embankment dam. The study area is more suited for the research, particularly, with the presence of other minor channels through which water still flows into the secondary channel even when the secondary channel is blocked. Secondly, the secondary channel is not a distributary but branched out of the river and returned back to the river downstream. When the channel is blocked, there is backflow downstream from the main channel into the secondary channel (fluid mechanics). Hence, at no time of the year will there not be water in the secondary channel. Thirdly, the proposed embankment dam will be a typical rock filled earthen dam. The rock will be dropped directly into the river along the dam alignment. That is, there will be no excavation of any kind during the construction, and therefore the environment will be least disturbed. Finally, the dam is designed to block the channel during low water season from January to June, after this period the water level on the main river goes above the dam, and flowing into the secondary channel resumes.

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

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