



## **Geological and Geoelectrical Investigation of a Proposed Dam Site Using Vertical Electrical Sounding at Osuworowo Stream, Utughughu Arochukwu, South Eastern Nigeria**

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### **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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### **ABSTRACT**

Geophysical studies was carried out at a proposed dam site across Osuworowo stream in Arochukwu, south eastern Nigeria to investigate the depth to bedrock, possible geologic structures and foundation conditions of the dam axis. The study area is located between latitudes 5°23.58"N and 5°23.707"N and longitude 7°53.93"E and 7°53.97"E. Its elevation ranges from 90 ft to 149 ft. Six Vertical Electrical Soundings (VES) were carried out along the stream course using ABEM SAS 1000 TERRAMETER and this was done using Schlumberger configuration with maximum half current electrode separation of 55m able to reveal deep seated structures. The ip2win software was used to model the VES data to give resistivities which vary between 258 Ωm and 39000 Ωm with three and four geoelectric layer combinations of sand, sandstone, sandyshale, shalysand and ale units. The high resistivities of the geoelectric layers sand thickness and dip showing high gradient in elevation differences are indications that the site is suitable for the dam construction. The geological result shows the presence of faults this is confirmed by change in strike and dip.

**Keywords:** Investigation; dam; geoelectric layer; bedrock; construction; Osoworowo River.

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## 1. INTRODUCTION

Increasing water consumption is a great challenge facing the people of Utughughu Arochukwu area, southeastern Nigeria. This is due to rapid increase in population and their various domestic and agricultural purposes. Saving water from rainfall and groundwater have not matched the demand, therefore, it is imperative to seek for other sources hence, the construction of dams.

The evaluation of dam sites among many other parameters includes stability studies, simulation of the probable maximum flood (PMF), uplift pressures under the dam, depth to bedrock, stratigraphic continuity and structural mapping [1,2]. Studies have shown that the engineering properties of soils improved through compaction and/or addition of other soils with better properties [3,4,5]. Movement of water through soils depends on two factors: The forces acting upon the water molecules and the ease with which they can flow through the soil. These factors vary from one soil to another, depending on the amount of organic matter of the site and arrangement of mineral particles which may be irregular by size and number of pores where water can be held [6]. In soils with large, shaped sand particles, for example, large pores remain between the sand grains. Clay particles, by contrast, fit together more compactly so that the pores are smaller but numerous.

Geological studies have been largely used in the planning and designing of civil engineering structures like dams, reservoirs, tunnels, roads, bridges, building, docks, harbours, etc. These studies do help us in designing safe and economical structures with success. Without the availability of detailed geological data of a proposed construction site, and of its vicinity, no economical and safe execution of any such project can be carried out. Detailed geological surveys and investigations should be done before a project is finally planned, designed and executed.

Considering the importance of dams and reservoirs, and the excessive expenditure involved in their construction, coupled with the catastrophes likely to be generated by their failures makes the need for preliminary studies imperative. All geological problems of a dam site and its associated reservoir are usually common, because failure of the reservoir may render the dam standing useless without serving its basic functions, which also virtually amounts to the failure of the dam. But still, however, distinction has to be made between the two, as follows:

Geological investigations of a reservoir cover the entire area, over which the water is to be impounded, and relates generally to the conditions that may cause leakages. But the geological investigations of a dam site relate to a small area, with a particular stress on the strength, stability and permeability of the underlying bed-rocks, strictly speaking any leakage through the reservoir may not necessarily cause any serious damage to the dam, but any leakage through or beneath the dam may in all probability cause the sudden failure of the dam, releasing huge volume of water, wasting many lives, and destroying the costly structure itself.

## 2. LOCATION AND ACCESSIBILITY OF THE STUDY AREA

The study area is Utughughu in Arochukwu local government area. Arochukwu is bounded in the north by Ohafia, on the east by Cross river and in the south by Akwalbom state. The proposed dam area is located about 250 m N-S from east west road from Obinkita park. The axis of the proposed dam site trends east –west from north –south trending road that joins the east west road from Obinkita park. The site is readily accessible through east- west trending road, Fig. 1 the area very close to the river has the lowest height of 90 ft (Fig. 2, Table 1). The topography enhances the flow of the river which in turn harnesses a very good waterfall for the dam.

**Table 1. Coordinates and elevations of the study area**

VE Point	Latitude (°N)	Longitude (°E)	Elevation (ft,m)
1	5°23 .589N	7°53.979E	105 ft(32m)
2	5°23 .619N	7°53 .973E	107 ft(32.62m)
3	5°23 .652N	7°53 .967E	90 ft(27.44m)
4	5°23 .672N	7°53 .954E	98 ft(29.88m)
5	5°23 .693N	7°53. 930E	149 ft(45.43m)
6	5°23 .707N	7°53 .970E	108 ft(32.93m)

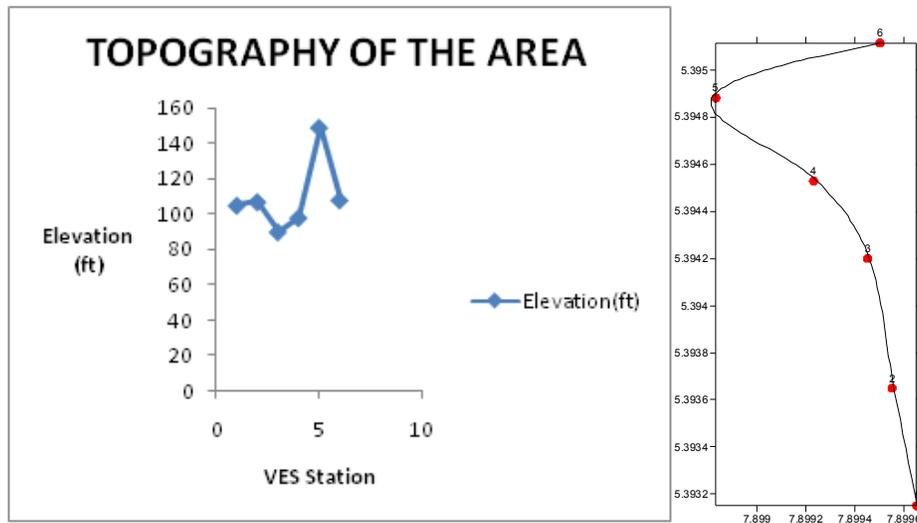


Fig. 1. Topography of the area

### 3. GEOLOGY OF THE STUDY AREA

The study area is utughugu in Arochukwu in Abia State southeastern Nigeria. It lies between latitude 05°23'589 N - 05°23 707 N' and longitude 07°53'930 E - 07°53'979 E. Its elevation ranges from 90 ft to 149 ft, Table 1. Osuworowo stream and its environs are underlain by rock units of the late Maastrichtian age (Nsukka formation). Rock units of this formation include shales, limestone, sandstones and resistant iron oxide-bearing sandstones. The outcrops of the iron oxides and iron stones of the Nsukka formation strike N40E and dip of N130S. Flaggy sandstones strikes N330°E and dips N60° South. One of the most remarkable structural features is that the river appears to be stratigraphically & structurally controlled flowing E-W which is the strike direction from observation on rock outcrop from the stream trend.

### 4. MATERIALS AND METHODS

The geological aspect involves reconnaissance survey, which helped in familiarization of the area and also in the location and observation of outcrops, sample collection and labeling, for correct identification of rock units (Fig. 4). All these geological information gathered help in interpreting the signals from geophysical records. The geophysical data helps to evaluate the structures within the subsurface in this environment. A total of six vertical electrical sounding stations were established using the Schlumberger Terrameter configuration with

ABEM SAS 4000 Terrameter. The electrode spacing (AB/2) which was constructed using the Schlumberger Equation was varied from 1.5 m to 95.0 m [7]. The spacing distances of 1.5 m, 2.0 m, 3.4 m, 4.5 m, 6.0 m, 8.0 m, 14.0 m, 18.0m, 24.0 m, 34.0 m, 42.0 m, 55.0 m, 72.5 m, and 95.0 m with cross over points or looping observed at 14.0m and 55.0m. to reduce the effect of attenuation of the current and voltage supply in order to have a consistent and reliable signals as readings in Ohm

$$\rho_a = \frac{R}{\left(\frac{a^2}{b} - \frac{b}{4}\right)} \quad (1)$$

where

$\rho_a$  = apparent resistivity in Ohm-m

a = AB/2, the Half electrode separation in metres (m)

b= Potential electrode separation in metres (m)

R = Meter reading in Ohms.

The data obtained is usually plotted as a graph of apparent resistivity against half electrode spacing. The electrode spacing at which inflection occurs on the graph provides an idea of the depth to the interface. A useful approximation is that the depth of the interface is equal to two thirds (2/3) of the electrode spacing at which the point of inflection occurs [8]. This approximation has found useful applications in computer iterative modeling. Parameters such as apparent resistivity and thickness obtained from both partial curve matching were used as input data for computer iterative modeling [9,10].

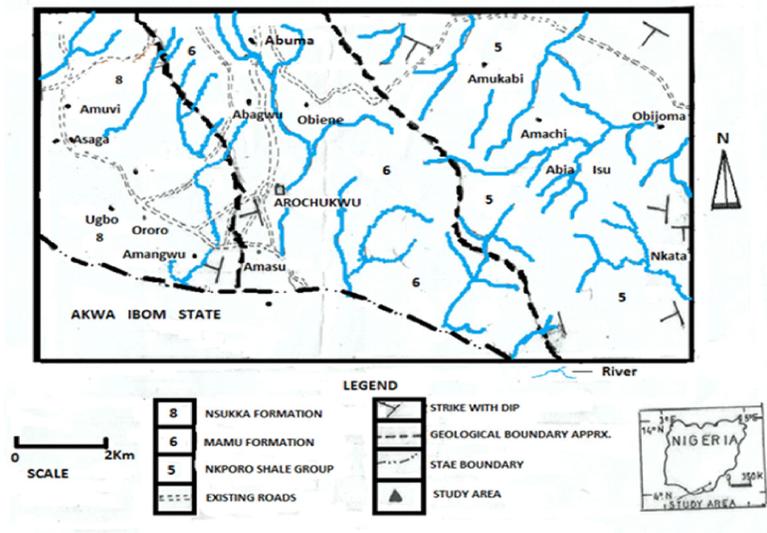


Fig. 2. Geological map of the study area



Fig. 3. Topographic profile along the dam axis showing VES points

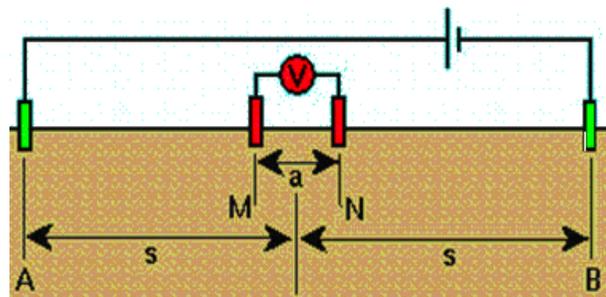


Fig. 4. Typical schlumberger array. M and N; potential electrodes, A and B; current electrodes

The raw data (as below) acquired from vertical electrical sounding using the Schlumberger array were further processed and interpreted using a combination of curve matching and computer iterative modeling. Detailed quantitative interpretation was done using Fortran Resistivity 2-D

Inverse Computer Program. The VES data are finally presented as sounding curve (Figures) and the results used to prepare geoelectric sections with the appropriate geo-software (surfer 12). Correlated probable litho-sections in a profile along the dam axis was drawn using the coordinates of the various VES points measured with the aid of GPS unit, "GARMIN 76CSx, USA".

## 5. RESULTS AND DISCUSSION

### 5.1 Geophysical Results

The results of vertical electrical sounding were presented as field curves (Fig. 5.1-5.6), and geoelectric sections (Table 2, Fig. 5). The VES curves are composed of K, KQ and KHK types with three and four geoelectric layer combinations. The K curve type predominates by 50.0%, KQ constitutes 33.3% and the KHK type is about 16.7% of the total.

### 5.2 Geoelectric Sequence and Comprising the Top Soil, Sandstone, Sandshale

The geoelectric sections identified maximum of four geoelectric/geologic subsurface layers. VES

1, 2, 3, 5 and 6 have three geoelectric layers while VES 4 has four layers (KHK curve type). The first layer is the top soil which extends to 2.7m at VES 4. The resistivity ranges from 465  $\Omega$ m to 6360  $\Omega$ m and are interpreted as sandy clay and sandy top soil. The second layer terminates at 4.1 m at VES 2 and 21.5 m at VES 1. The resistivity values are highest in the range of 970  $\Omega$ m to 39000  $\Omega$ m. The composition of rock units are sand, sandstone and clayey sands respectively. The third layer is composed of sand/silt, sand and clay. The fourth layer occurs only at VES 4 from 26.5m which is interpreted as clayey sand. There seems to be discontinuity in the trend at VES 2 and VES 4 where there is alternating sequence of clay and sand units. This may be the river bed and geologic boundary.

The VES data were acquired in a profile, from left to right of River Osoworowo. The top soil of various VES locations are interpreted as layer 1. This is modeled as dry silty top soil with base at 2.0 m and resistivity of 1710 ohm-m, at VES 1. At VES 2, the topsoil has a thickness 0.6 m and resistivity of 465 ohm-m. For VES 3, this is modeled as dry top soil with base at 0.7m and resistivity of 1060 ohm-m.

**Table 2. Summary of the geoelectrical interpretation along the dam axis**

Location	Layer no.	Curve type	Resistivity (Ohm-m)	Depth interface (m)	Layer thickness (m)	Inferred lithology
VES 1	L <sub>1</sub>	K	1710	2.0	2.0	Dry silty top soil
	L <sub>2</sub>		7770	21.5	19.5	Dry sandy soil
	L <sub>3</sub>		1780	35	13.5	Shaly sands
VES 2	L <sub>1</sub>	K	465	0.6	0.6	Dry topsoil
	L <sub>2</sub>		39000	4.1	3.5	Sandstone
	L <sub>3</sub>		258	35	30.9	Dry shale
VES 3	L <sub>1</sub>	K	1060	0.7	0.7	Silty Topsoil
	L <sub>2</sub>		39000	3.2	2.5	Dry sandstone
	L <sub>3</sub>		1870	35	31.8	Sand/Silt
VES 4	L <sub>1</sub>	KHK	1800	2.7	2.7	Silty Topsoil
	L <sub>2</sub>		970	6.2	3.5	SandyShale
	L <sub>3</sub>		2240	26.6	20.4	Sandstone
	L <sub>4</sub>		990	35	8.4	ShalySand
VES 5	L <sub>1</sub>	K	1700	1.5	1.5	Silty Topsoil
	L <sub>2</sub>		4730	13.7	12.2	Sandstone/ Sand
	L <sub>3</sub>		703	35	21.3	SandyShale/ Shale
VES 6	L <sub>1</sub>	K	6360	0.9	0.9	Sandy Topsoil
	L <sub>2</sub>		29500	7.2	6.3	Sandstone
	L <sub>3</sub>		2330	35	27.8	Sand

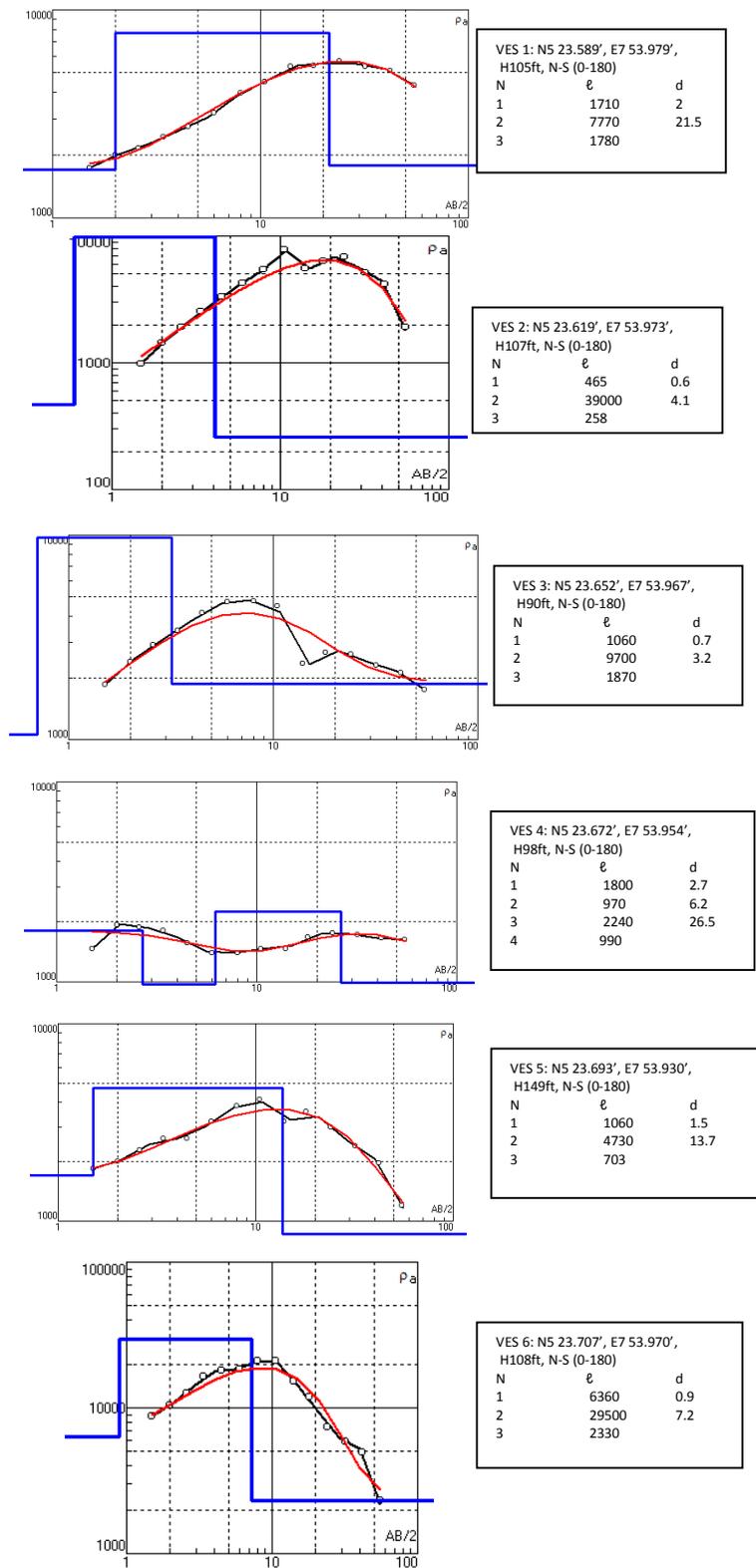


Fig. 5. Field curves of VES measurements

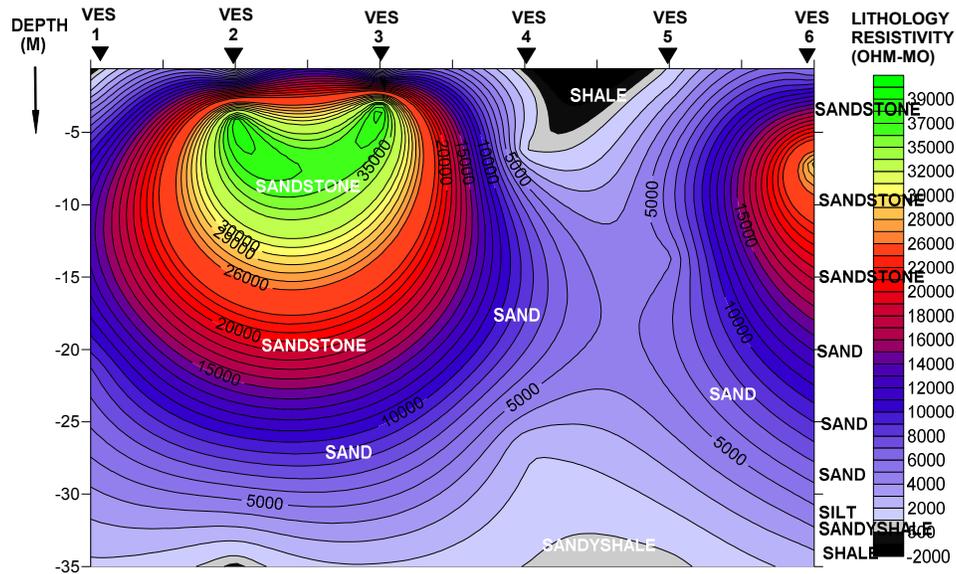


Fig. 6. Profile of the lithology of the study area showing the resistivity of the layers

## 6. CONCLUSION

From the results of the geological and geophysical studies we see that geologically the area is underlain by sandstone, cemented iron oxide, silty sands and shale. This is confirmed from the high resistivity geophysical results that represent sandstone and silty sands and low resistivity values for shales and clays. Also geophysical results indicate presence of faults confirmed via the change in strike and dip and stream appears to be structurally and stratigraphically controlled.

From the results presented in the forms of resistivity and depth values of various layers, outcrops observed along the dam axis and adjoining areas stratigraphic relations and a short reconnaissance trip to the north of the profile line, a number of facts come out very clearly which reveals that:

\*From the geological map and the geoelectric sections there are symmetrical sections of the same rock type repeat in reverse order from the river valley.

\*The stream is structurally and stratigraphically controlled. Towards the extreme of the stream between VES 5 and VES 6 there is a fault. This is confirmed by change in strike and dip direction from North-South to NW—NE direction.

\*Geology-- there is overriding sandstones and shaly sands in the area. The resistivities show

that clayey matter is not encountered in the dam area. The sandstone range from top loose dry sandstone to porous sandstone and the stream flows along the strike and through the porous layer. Thus the stream flow is stratigraphically controlled.

\*Topography--- Height differential up to 149ft occurred between the highest point along the geophysical profile (VES 5) and stream bed between VES 3 and VES 4. There is height difference between northern and southern ends of the axis to the tune of 44ft (Fig. 2). This shows that the northern side is higher than the southern ends.

\*The extremes of the proposed dam seem to anchor on very component iron-oxide-cemented sandstone as cap ranging in thickness from 0.9 m to in the North. It is proposed that the greater thickness of this material is informed by the higher topography to the South.

\*No structures that will be of deleterious effect were observed in all the VES points. However results show high degree of porosity, cross bedded and dips 40-330 and strike 40. The stream flows along the bedding planes and does not leave any fine matter at the bank of the stream. So much sand is generated from the upstream area. Thus much arenaceous matter comes in from the sandy units upstream. No faults were detected down to the depth of 35m. However, the hanging aquifer typical of all Nsukka formation units must be taken care of

and soil test shows that the area has high bearing capacity.

## 7. RECOMMENDATION

From the results and the field observation we conclude that the proposed dam axis is underlain by highly sands, sandstone and little shaly matter. Because sands and sandstone there is high porosity and potentially ripe for great infiltration. Also great sandy matter is bound to be brought in from the upstream equally rich in arenaceous matter. We recommend as follows:

1. High see page is expected in the area.
2. The swing of the stream from North –South trending road to East –West direction may suggest the presence of a fault component. This must be borne in mind.
3. Due to the 44ft height difference between the North and South, more blanket material may be required in the northern end. More blanket matter: Due to the expected high see page, it is necessary to plan for the blanket material.
4. The geophysical studies as seen in the interpreted curves show 3 to 4 layers corresponding to the lithologic units indicated by the geologic mapping and general geology of the area.

Most sandstone do not support dam failure when they act as abutment ends because they are non-plastic, not susceptible to plastic deformation, not subject to rapid surface deterioration on exposure, not easily compacted and do not slip.

Shale can be used for making embankment and reservoir floor in dam construction because of their impermeable nature. This makes them to be very useful in dam construction. Layers interbedded with shale may constitute potential sliding surface. The shale is in the part of our study area and would also be good abutment end because it is embedded with traces of sandstone as revealed by the VES results.

From our study, we found that the sandstone near the Osuworoworo River has intermediate plasticity, low angle of internal friction, not susceptible to rapid surface deterioration on exposure to weathering, will serve as good abutment end.

On the other hand, the other part of the river is slightly composed of shale and will be best for the foundational since it is impermeable.

## 8. SUGGESTION FOR FURTHER WORK

- It is expected that the high bearing capacity shall characterize the rock units. However the absence of shales means high infiltration in a sandy environment. Efforts should be made to some suitable blanket materials for the dam.
- Sedimentation/siltation: Great sandy matter is brought in from both Utughughu and Obinkita areas these must be checked and the mechanism for desilting put in place.
- Chemical and biological tests: Water from the river should be tested and chemical/ biological data used as baseline data for future studies when dam is in use.

We hereby recommend more studies on blanket material, structural features and complete mapping /leveling of the dam area

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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