Spatial Resistivity Mapping of Ureje Dam Floor, Southwestern Nigeria

Prostorsko upornostno kartiranje dna jezua Ureje, JZ Nigerija

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Abstract

Ureje Dam, Ado-Ekiti has witnessed drastic reduction in the water storage capacity of its reservoir. It became imperative to determine the possible cause(s) of the reduction in storage capacity. Geophysical investigation involving the vertical electrical sounding technique of the electrical resistivity method was conducted in the upstream part of the dam. Five lithologic units that include the mud/suspended materials, such as sandy clay, clay, weathered/fractured bedrock and fresh bedrock, were delineated. The respective resistivity and thickness range of the units are 2–19 ohm-m; 147–206 ohm-m, 2–38 ohm-m; 47–236 ohm-m and 455–1516 ohm-m and 0.4–1.9 m; 0.5–2.5 m; 1.0–12.2 m; 7.3–16.4 m and ∞ . The thickness of suspended materials, resistivity/thickness of weathered layer and the presence of near-surface impervious layer were used as the main indices for the spatial demarcation of the dam axis in terms of vulnerability to loss of impounded water. Using the cumulative response of the indices, the study concluded that the eastern to southeastern parts of the dam axis showed the highest indications of vulnerability to loss of impounded water.

Key words: Drastic reduction, vulnerability, spatial demarcation, impounded water.

Povzetek

Jez Ureje na območju Ado-Ekiti se sooča z drastičnim zmanjšanjem kapacitete zadrževanja vode. Določitev mogočih vzrokov za zmanjšanje kapacitete zadrževanja je postalo nujno. V gor-vodnem delu jezua so bile izvedene geofizikalne preiskave z navpičnim električnim sondiranjem. Razmejenih je bilo pet litoloških enot, ki so vključevale blato/suspendirane materiale; peščeno glino; glino; preperelo/razpokano podlago in svežo podlago. Pripadajoče upornosti in debeline plasti za omenjene enote so 2–19 ohm-m; 147–206 ohm-m, 2–38 ohm-m; 47–236 ohm-m in 455–1516 ohm-m ter 0.4–1.9 m; 0.5–2.5 m; 1.0–12.2 m; 7.3–16.4 m in ∞ . Debelina suspendiranih materialov, upornost/debelina preperle plasti in prisotnost neprepustne plasti blizu površine so bili uporabljeni kot glavni indeksi za prostorsko razmejitev osi jezua v smislu ranljivosti glede izgube zajezone vode. Z uporabo kumulativnih odzivov indeksov preiskava zaključuje, da vzhodni do jugovzhodni deli osi jezua kažejo najvišje znake ranljivosti na izgubo zajezone vode.

Ključne besede: drastično znižanje, ranljivost, prostorska razmejitev, zajezena voda.

Introduction

Ureje dam, Ado-Ekiti was constructed over 50 years ago with the sole aim of providing potable water for the populace of Ado-Ekiti and its environs. At construction, the dam lake had an initial production capacity of 10,000 m³ volume of water per day. The production capacity has, however, dwindled over the years and has reduced abysmally in recent times. This research aims to investigate the possible cause(s) for the reduction in reservoir water, which has negative impact on the living standard of the people. Dam lake floors are susceptible to the accumulation of sediments after several years of construction. This is due to the transportation of sediments through the streams and rivers that serve as feeders to the lake. The volume of sediments deposited is a function of the rate of flow of the streams and the progressive deposition increases the volume of sediments in the dam lake floor [1].

The initial storage capacity and functions of the dam reservoir have been compromised by the increase in the volume of sediments with the attendant reduction in the production capacity of the dam. Unpublished reports from local fishermen at the Ureje dam site indicate that there has been a rise in the level of the dam floor in some portions of the dam lake. This rise in the level of the dam floor could be attributed to the appreciable deposition of sediments. Apart from the accumulation of sediments, the nature of subsurface materials and anomalous seepages may contribute to the loss of dam reservoir water [2–4]. Subsurface geologic structures such as faults, fracture zones, basement depressions, and so on, if present beneath, a dam reservoir floor may also inhibit the storage capacity of the dam reservoir [5–8].

Geophysical methods, especially the electrical resistivity (ER) method, have been used in dam site investigation [2, 3, 9, 10, 11]. ER method is a non-destructive technique that is capable of detecting internal erosion processes and detection of anomalous seepage [12–14] during pre-construction feasibility studies, post-construction integrity assessment and post-failure investigations. ER method has proven its performance and adequacy in the characterization of the potential paths of water seepage from

dams [10, 12]. For example, [15] successfully carried out geophysical surveys at the Marathon Dam site near Athens, Greece, to detect possible degraded areas that are potentially liable to water infiltration or leakage. They also evaluated the dynamic properties of the subsurface materials and evaluated the quality of the concrete in the dam interior using this technique. [16] employed geoelectrical measurement to identify seepages through embankments and dams. [17] successfully used electrical resistivity tomography (ERT) technique at Abu Baara earth dam in northwestern Syria to delineate potential pathways of leakage that occur through the subsurface structure close to the body of the dam. [18] investigated water seepage of earth dams in Cordeirópolis, São Paulo in Brazil using the direct current ERT technique with Wenner electrode array configuration.

This study, therefore, aims at investigating the upstream part of the Ureje dam floor to unravel the subsurface features that may be undermining the production capacity of the dam.

Location, Geology and Geomorphology

Ureje Earth Dam is located in Ado-Ekiti, Ado Local Government Area of Ekiti State, Southwestern Nigeria. The geographic coordinates of the dam site are between latitude 7° 35.74' and 7° 36.26' N of the equator and longitude 5° 12.45' and 5° 13.01' E of the Greenwich meridian (Figure 1).

Geologically, the dam site lies on charnockite (Figure 2), a member of the Precambrian Basement Complex rocks of Southwestern Nigeria. Although the rock is concealed within the immediate vicinity of the dam, charnockites are classified in terms of structures as gneissic charnockites, foliated charnockites and coarse-grained charnockites [19].

The topography at the site is gently undulating with elevation above mean sea level varying between 400 m and 418 m. The surrounding hills roll towards the dam artificial lake. The area surrounding the dam site is covered with thick vegetation typical of the tropical rain forest vegetation belt of Nigeria. Two seasons occur in the area, namely the wet season

Figure 1: Location Map of the Study Area.

Figure 2: Geological Map of the Area Around Ado-Ekiti Showing the Ureje Dam site (After [20]).

(April–October) and the dry season (November–March).

Methodology

The ER method of geophysical prospecting was used in this study. The vertical electrical sounding (VES) technique, which involved the use of the Schlumberger electrode array, was adopted. Twenty-five (25) VES stations were occu-

pied (Figure 3) and the half current electrode spacing ($AB/2$) varied from 1 to 50 m. The geographic coordinates of the VES locations were taken using the Garmin® Global Positioning System (GPS). All measurements were taken on the dam floor with the aid of three wooden canoes on which measuring apparatus was

Figure 3: Geophysical Data Acquisition Map.

mounted. VES data were processed by plotting apparent resistivity against half-current electrode spacing ($AB/2$). The resulting depth sounding curves were interpreted qualitatively by visually inspecting them for classification. The quantitative interpretation involved segment-by-segment matching of field curves with master curves and auxiliary point charts. The parameters obtained from that process were used to constrain the 1-D computer-aided forward modelling on the IPI2Win® platform. The smoothed geoelectric parameters obtained from the iteration process were thereafter used to generate 2-D geoelectric sections in which deduced geoelectric/lithologic units were cor-

related. The same parameters were also spatially interpolated, and relevant maps were generated.

Results and Discussion

Depth Sounding Curves

The interpreted depth sounding curves (Figure 4a–d) in the dam lake shows that they are characterised by 3–5 geoelectric layers. The lithology is generally made up of mud/suspended materials, sandy clay, clay, weathered/fractured bedrock and fresh bedrock. The curve types include A, K, KH and KHA with A-type

Figure 4: Typical Depth Sounding Curves. (a) A – Type, (b) K – Type, (c) KH – Type and (d) KHA – Type.

Table 1: Colour Chart of the Distribution of the Depth Sounding Curves.

VES LOCATIONS			KEY	
1	10	19	$p_1 > p_2 > p_3$	= A-Type Curve
2	11	20	$p_1 < p_2 > p_3$	= K-Type Curve
3	12	21	$p_1 < p_2 > p_3 p_4$	= KH-Type Curve
4	13	22	$p_1 < p_2 > p_3 < p_4 < p_5$	= KHA-Type Curve
5	14	23		
6	15	24		
7	16	25		
8	17			
9	18			

curve being the dominant curve. The summary of the VES type-curves and their distribution within the 25 sounded positions are presented in Table 1.

Geoelectric Sections

The geoelectric sections (Figure 5a–c) generated from approximately linearly existing VES locations show that there are a maximum

Figure 5: Goelectric Sections Beneath the Dam Floor (a) Section A – B (b) Section C – D, (c) Section E – F.

of five (5) goelectric units beneath the Ureje dam lake. The goelectric units were calibrated in terms of apparent resistivity and five litho-

logic units were identified. The lithologic units, in order of their occurrence, include mud/suspended materials, sandy clay, clay, weathered/

fractured bedrock and fresh bedrock. Each of the lithologic units has their implication(s) on the overall storage capacity of the dam reservoir. The mud/suspended materials is characterised by resistivity values generally less than 20 ohm-m and its thickness varies from 0.4–1.9 m. An increase in the cumulative volume of the mud/suspended materials could inhibit the storage capacity of the reservoir.

The sandy clay layer with resistivity values greater than 100 ohm-m present in VES 12, 14 and 15 (Figure 5a) and VES1 and 5 (Figure 5c) constitutes a liability to the reservoir. This is because the relatively high porosity associated with sandy clay materials can enhance the seepage of impounded water into the subsurface. On the other hand, the clay unit where significantly thick, (Figure 5a and 5b) is advantageous to the dam reservoir as it will inhibit the percolation of water into the subsurface due to very poor permeability characteristics of the clay materials.

The weathered/fractured bedrock unit is a threat to any engineering structure/facility due to its incompetent nature. The threat becomes greater when it is near the surface and is not overlain by any impervious medium as found in Figure 5c and some portions of Figure 5b. Also, the weathered/fractured bedrock is an aquiferous unit in a typical Basement Complex environment, and as such, the Ureje dam lake may be losing water to the groundwater in zones associated with near-surface weathered/fractured bedrock and without overlying impervious layers.

The fresh bedrock is a relatively resistive layer with impervious characteristics. The bedrock ordinarily has the capacity to support the foundation of any engineering structure especially containment facilities such as dams. However, the potential could be inhibited if it is deeply seated and with undulating topography – most especially depressions. The basement bedrock beneath the Ureje dam as seen in Figure 5a to 5c is generally deeply seated with exceptions of VES 18 and VES 23. The depth of occurrence of the bedrock varies between 7 m and 18 m and as such has minimal importance as far as the containment of impounded water is concerned.

Spatial Vulnerability Indices

The general vulnerability of the Ureje dam lake to reduction in volume/loss of impounded water was assessed using three main indices [9, 10] which include:

- i. the thickness of suspended materials,
- ii. the resistivity of weathered layer,
- iii. the presence of near-surface impervious (clay) layer.

The dam lake was demarcated based on the thickness of suspended materials, such that areas having thicknesses less than the mean thickness (0.77 m) of suspended materials under the bluish colour band in Figure 6 are classified as having a low vulnerability to the reduction in volume/loss of impounded water. Areas having thickness values greater than 0.77 m (identified by the reddish colour band) are classified to be highly vulnerable to loss of impounded water.

As shown in Figure 7, areas within the dam lake characterised by weathered layer resistivity values greater than 100 ohm-m are classified to have a higher vulnerability to the loss of impounded water due to the sandy nature of the weathered materials inferred from the resistivity values. However, areas under the greenish colour band associated with relatively low resistivity values possess low vulnerability to loss of impounded water.

As mentioned earlier, the presence of a near-surface impervious (clay) layer beneath a dam lake has the potential to inhibit the percolation of impounded water into the subsurface. Zones devoid of clay substratum (purple colour band) in Figure 8 are classified to possess high vulnerability. Other areas are potentially less prone to loss of impounded water due to the presence of clay.

Cumulative Spatial Vulnerability Assessment

The indices earlier discussed were spatially overlaid to generate the cumulative index map (Figure 9) of the dam lake to assess its general vulnerability to loss of impounded water. The map shows that the eastern to southeastern portions of the dam lake constitute zones with the highest indications of high vulnerability to loss of impounded water. Such zones are also present in other locations within the lake. It is interesting to note that the zones are mainly as-

Figure 6: Spatial Vulnerability Assessment from Thickness of Suspended Materials.

Figure 7: Spatial Vulnerability Assessment from Resistivity of Weathered Layer.

Figure 8: Spatial Vulnerability Assessment from Presence of Near-surface Clay Substratum.

Figure 9: Cumulative Spatial Vulnerability Map.

sociated with the boundaries of the lake with most occurring around the water intake section through which the river straddles. On the other hand, areas under the bluish colour band rep-

resent zones adjudged to be less prone to the loss of impounded water as far as the indices deployed are concerned.

Conclusions

The cause of the drastic drop in the quantity of impounded water in the Ureje dam lake in Ado-Ekiti southwestern Nigeria has been investigated using the ER method of geophysical prospecting. The VES field technique was deployed via the Schlumberger electrode array. Twenty-five locations were depth sounded within the dam lake, and three geoelectric sections were constructed to cut across a sizeable number of VES locations for correlating their resistivity parameters. Five subsurface geoelectric layers were delineated within the lake. These include the mud/suspended materials, sandy clay, clay, weathered/fractured bedrock and the fresh bedrock. The thickness of the suspended materials, weathered layer resistivity and the presence of near-surface clay substratum were used as the main indices for the loss/reduction in the volume of impounded water. Areas classified as having high vulnerability to the loss of impounded water are those having attributes such as the thickness of suspended materials greater than the mean thickness of 0.77 m; weathered layer resistivity greater than 100 ohm-m and absence of near-surface clay substratum. On the other hand, zones characterised by a thickness of suspended materials less than the mean thickness of 0.77 m; low resistivity values and presence of clay substratum were considered to be less prone to the loss of impounded water. The general characteristics of the vulnerability indices indicated that the eastern-southeastern axis and some localised zones of the dam lake possess the highest cumulative vulnerability to the loss/reduction in the quantity of impounded water. Conclusively, therefore, the Ureje dam lake may have been losing most of its impounded water in the eastern-southeastern areas of the dam lake.

References

- [1] Snyder, N.P., Rubin D.M., Alpers C.N., Childs J.R., Curtis J.A., Flint L.E., Wright S.A. (2004): Estimating accumulation rates and physical properties of sediment behind a dam: Englebright Lake, Yuba River, northern California. *Water Resources Research*, 40(11), W11301, doi:10.1029/2004WR003279.
- [2] Aina, A., Olorunfemi, M.O., Ojo, J.S. (1996): An Interpretation of Aeromagnetic and Electrical Resistivity Methods in Dam Site Investigation. *Geophysics*, 61(2), pp. 349–356.
- [3] Eluwole, A.B., Olorunfemi, M.O. (2012): Time-Lapsed Geophysical Investigation of the Mokuro Earth Dam Embankment, Southwestern Nigeria, for Anomalous Seepages. *Pacific Journal of Science and Technology*, 13(1), pp. 604–614.
- [4] Olorunfemi, M.O., Idornigie, A.I., Fagunloye, H.O., Ogun, O.A. (2004): Assessment of Anomalous Seepage Conditions in the Ope Dam Embankment, Ile-Ife, Southwestern Nigeria. *Global Journal of Geological Sciences*, 2(2), pp. 191–198.
- [5] Johri M., Zoback M.D., Hennings P. (2014): A scaling law to characterize fault-damage zones at reservoir depths. *AAPG Bulletin*, 98(10), pp. 2057–2079.
- [6] Mansour K., Omar K., Ali K., Zaher M.A. (2018): Geophysical characterization of the role of fault and fracture systems for recharging groundwater aquifers from surface water of Lake Nasser. *NRIAG Journal of Astronomy and Geophysics*, 7(1), pp. 99–106.
- [7] Song S., Feng X., Rao H., Zheng H. (2013): Treatment design of geological defects in dam foundation of Jinping I hydropower station. *Journal of Rock Mechanics and Geotechnical Engineering*, 5, pp. 342–349.
- [8] Wieland M., Brenner R.P., Bozovic A. (2008): Potentially active faults in the foundations of large dams part i: vulnerability of dams to seismic movements in dam foundation. In: *The 14th World Conference on Earthquake Engineering*, Beijing, China.
- [9] Ajayi, O., Olorunfemi, M.O., Ojo, J.S., Adegoke-Anthonny, C.W. (2006): Integrated geophysical and geotechnical investigation of a damsite on River Mayo Ini, Adamawa State, Northern Nigeria. *Africa Geoscience Review*, 12 (3), pp. 179–188.
- [10] Olorunfemi, M.O., Ojo, J.S., Sonuga, F.A., Ajayi, O., Oladapo, M.I. (2000): Geoelectric and Electromagnetic Investigation of the Failed Koza and Nassarawa Dams Around Katsina, Northern Nigeria. *Journal of Mining and Geology*, 36 (1), pp. 51–56.
- [11] Sjudahl, P., Dahlin, T., Johansson, S. (2003): Resistivity Monitoring for Leakage Detection at Hallby Embankment Dam. In: *9th Meeting of Environmental and Engineering Geophysics*, Prague, Czech Republic.
- [12] Cho I.K., Yeom J.Y. (2007): Cross line resistivity tomography for the delineation of anomalous seepage pathways in an embankment dam. *Geophysics*, 72(2), pp. G31–G38, doi: 10.1190/1.2435200.
- [13] Lin C.P., Hung Y.C., Wu P.L., Yu Z.H. (2014): Performance of 2-D ERT in investigation of abnormal

- seepage: a case study at the Hsin-Shan earth dam in Taiwan. *Journal of Environmental and Engineering Geophysics*, 19(2), pp. 101–112.
- [14] Sjö Dahl P., Dahlin T., Johansson S. (2010): Using the resistivity method for leakage detection in a blind test at the Røssvatn embankment dam test facility in Norway. *Bulletin of Engineering Geology and Environment*, 69(4), pp. 643–658.
- [15] Karastathis V.K., Karmis P.N., Drakatos G., Stavrakakis G. (2002): Geophysical methods contributing to the testing of concrete dams. Application at the Marathon Dam. *Journal of Applied Geophysics*, 50, pp. 247–260.
- [16] Benes, V., Tesar M., Boukalova, Z. (2011). Repeated geophysical measurement—The basic principle of the GMS methodology used to inspect the condition of flood control dikes. *Trans. Ecol. Environ.*, 146, pp. 105–115.
- [17] Al-Fares W. (2014). Application of Electrical Resistivity Tomography Technique for Characterizing Leakage Problem in Abu Baara Earth Dam, Syria. *International Journal of Geophysics*, 2014, 9 pages, doi:10.1155/2014/368128.
- [18] Camarero P.L., Moreira C.A. (2017): Geophysical investigation of earth dam using the electrical tomography resistivity technique. *REM: Int. Eng. J., Ouro Preto*, 70(1), pp. 47–52.
- [19] Rahaman, M. (1988): Recent Advances in the Study of the Basement Complex of Nigeria. *Precambrian Geology of Nigeria*, pp. 11–41.
- [20] Talabi, A., Tijani, M. (2013): Hydrochemical and Stable Isotopic Characterization of Shallow Groundwater System in the Crystalline Basement Complex Terrain of Ekiti Area, Southwestern Nigeria. *Applied Water Science*, 3(1), pp. 229–245.