International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:14, No:3, 2020

Geophysical Investigation of Abnormal Seepages in Goronyo Dam Sokoto, North Western Nigeria Using Self-Potential Method

A. I. Augie, M. Saleh, A. A. Gado

Abstract**—**In this research, Self-Potential (SP) method was employed to locate anomalous electrical conductivity located in Goronyo area and also to determine the condition of the embankment of the dam. SP data were plotted against distance along with the profile and spacing of electrode using surfer software (version 12). High and low zones of SP values were identified along the right and left abutments of the dam reservoir. The regions with high SP values were described to be high tendency of fluid flow associate with wet sandy soil. These zones have the SP values ranging from 200 mV and above. High SP values were due to the high moisture content that may lead to the seepage of water leaking through this zone. The zones with high SP values occupied Profiles S1, S2, S3, S4 and S5 indicating the presence of potential seepage paths within the subsurface of the embankment. These regions of seepage were identified as weak zones and potential pathways through which water could be lost from the dam reservoir. The SP values for the regions range from 250 m to 400 m (S1), 306 m to 400 m (S2), 192 m to 400 m (S3), 48 m to 200 m (S4) and 7 m to 170 m (S5) with their corresponding maximum depths of 30 m, 28 m, 28 m, 30 m and 26 m respectively. However, zones of low SP values in the overburden were observed which shows the presence of intact regions, which may be due to the compactness and dryness around the dam. The weak zones were considered as geological features (such as fractures, joints, and faults) that have undermined the integrity of the dam structure, which has led to the abnormal seepage.

Keywords**—**Self-potential, subsurface, seepage, condition and dam.

I. Introduction

DAMS are valuable and represent large economic values in both local and modern society. The need for a dam is decided by the purpose(s) to which the water is being impounded [1]. In Nigeria, several needs for the construction of dams have been identified, including the production of electricity; supply of water for irrigation, industrial use and domestic consumption; and more importantly flood control. Dams can be grouped into three categories depending on the materials in-used when being constructed. We have the Earth fill dam, Rockfill dam and Concrete gravity dam [2].

The integrity of a dam embankment can be undermined by the existence of geological features, such as faults, fractures, fissures, jointed or shear zones underneath the dam axis or discontinuities in the structure itself [3]. [4]. All dams have some seepage as the impounded water seeks paths of least resistance through the dam and its foundation [1], [4].

Seepage must be controlled to prevent erosion of the embankment or foundation or damage to concrete structures [5]. Internal erosion of the materials used for construction of the embankment usually caused by seepage is known as piping. Damages resulting from internal erosion can lead to expensive remediation [5], [1]. The ability of a rock unit to conduct electrical current depends on its porosity, degree of interconnection between the pores (permeability) and degree of water saturation in the rock [6]. However, most rock-forming minerals are insulators and the electrical current flows through a permeable rock mainly by the passage of ions in pore waters presence in the rock [7]. Thus, most rocks conduct electricity by electrolytic neither by electronic processes [8].

The Goronyo Dam controlled the Rima River in Goronyo local government area of Sokoto State. It was constructed in 1984 and commissioned in 1992 by federal government. The dam is an earth-dam with a depth of 21 m and a total length of 12.5 km. The also it has a storability capacity of 976 million cubic meters. The dam usually releases water in dry season for farming systems and it is also important in controlling floods during raining season in some part of some part of Sokoto and Kebbi State [9].

In this study, SP method was employed in view to locate regions of seepage which identified as weak zones and potential pathways through which water could be lost from the dam reservoir. The study investigates the condition of Goronyo dam using SP technique. SP is a passive technique of geophysical methods that measures naturally occurring electrical potentials in the ground. It is one of the electrical techniques that respond directly to fluid flow containing in the earth materials. Water flowing through pore space of soil generates electrical current flow [10]. This electrokinetic phenomenon is called streaming potential and gives rise to SP signals that are of primary interest in dam seepage studies [11].

II. Geology and Location of the Study Area

Crystalline basement rocks underlain one-third of the land area in Sokoto State. These outcrop in the southern part of the area as well as in the east [12]. However, the major part of the area is underlain by younger sedimentary rocks consisting mainly of sandstones, siltstones, clays shale's, limestone and laterites [13]. The sedimentary rocks in the mapped area can be grouped into four major rock types: siltstone (with fine-grained sandstone), medium to coarse-grained sandstone,

A. I. Augie, is with the Department of Applied Geophysics, Federal University Birnin Kebbi, Kebbi State, P.M.B 1157 Nigeria (corresponding author, phone: +2348137330559; e-mail: ai.augie@fubk.edu.ng).

shale and limestone. In a sedimentary basin, it is very uncommon to have one type of rock occupying a large geographical area and stratigraphic thickness. The Goronyo dam area lies in the northern part of the Sokoto basin and is underlain by sedimentary rocks [3]. The area is bounded on the north by Niger Republic, in the south by latitude 13^{0}40'0"N to 13^{0}44'0"N, in the east by longitude 5^{0}14'0"E to 5^{0}17'0"E (Fig. 1). The sedimentary basin in northwestern Nigeria is known as the Sokoto Basin and the total thickness of the sediments in the Sokoto Basin is about 2 km [13].

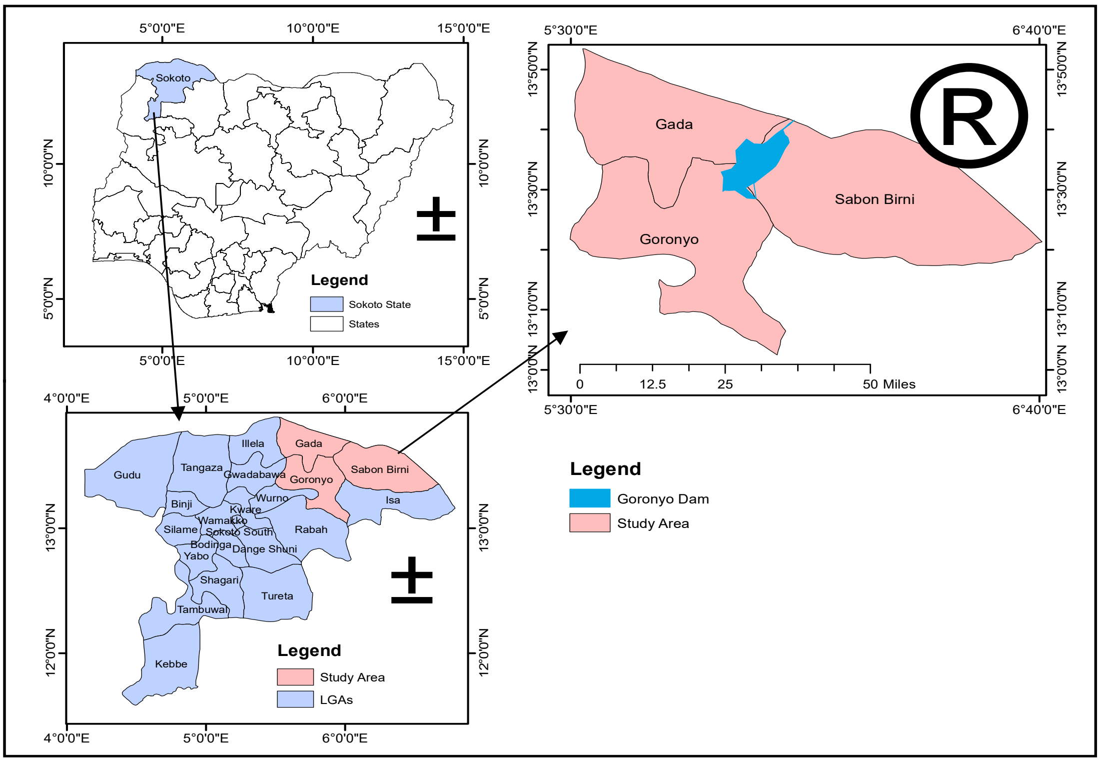

Fig. 1 Map Showing Disposition of Goronyo Dam

III. Materials and Method

SP field survey was carried out around the Goronyo dam in Sokoto State Nigeria using Ohmega (Resistivity meter) during which the SP data were acquired (Fig. 2). Measurements were done at increased electrode spacing's in multiple of 3 m. The more the increase in the electrode spacing, the more of the injected current flows to greater depths and consequently apparent resistivity and SP values at different depths are obtained. The electrode spacing varied from 3 m, 6 m, 9 m, 12 m, 15 m, 18 m, 21 m, 24 m, 27 m up to 30 m to unravel the formations at different depths in a comprehensive way.

Initially, four electrodes were used. 1st electrode was used as the 1st current electrode (C1) at 0 m, 2nd electrode as the 2nd potential electrode (P1) at 3 m, 3rd electrode as the 2nd potential electrode (P2) at 6 m and 4th electrode as the 2nd current electrode (C2) at 9 m (Fig. 2) then, SP values were recorded.

Second measurement, 2nd, 3rd, 4th and 5th electrodes were used for C1 at 3 m, P1 at 6 m, P2 at 9 m and C2 at 12 m respectively. This was continuously done along the profile one (S1) of 400 m using 1*a* spacing so also for 3*a,* 4*a,* 5*a,* 6*a,* 7*a,* 8*a,* 9*a* and 10*a* spacing measurement were obtained. This was repeated down the profiles S2 (400 m), S3 (400 m), S4 (200 m) and S5 (200 m) of 400 m. At each measurement, SP data were obtained. In Table I, the x-locations stands for the location of the position of the first electrode for a particular electrodes setting.

IV. Results and Interpretation

A. SP Profile 1 (S1)

Fig. 3 gives the results of SP data plotted against x-distance and a-spacing using surfer software (version 12). The length of the profiles is 400 m and measurement commenced from the west side of the profile spotted with the bottom of the deepest layer appearing at 30 m. Observing this map very closely under position 120 m along the profile of the layer having high SP values ranging from 200 mV and above spotted with the bottom of the deepest layer appearing at 30 m. These points with high SP values (200 mV and above) with a depth of 30 m indicate points with high flow, which extended to regions ranging from 120 m to 200 m and also from 250 m to 400 m along the profile at the depth ranging from 23 m to 30 m. This region shows that there is an indication of the presence of weak zones, which may be due to high moisture content resulting from the seepage of water leaking through this layer. These weak zones are considered risky when they extend deep into the bedrock as they could provide micro-channels for seepage of water from the lake under the effect of the hydraulic gradient.

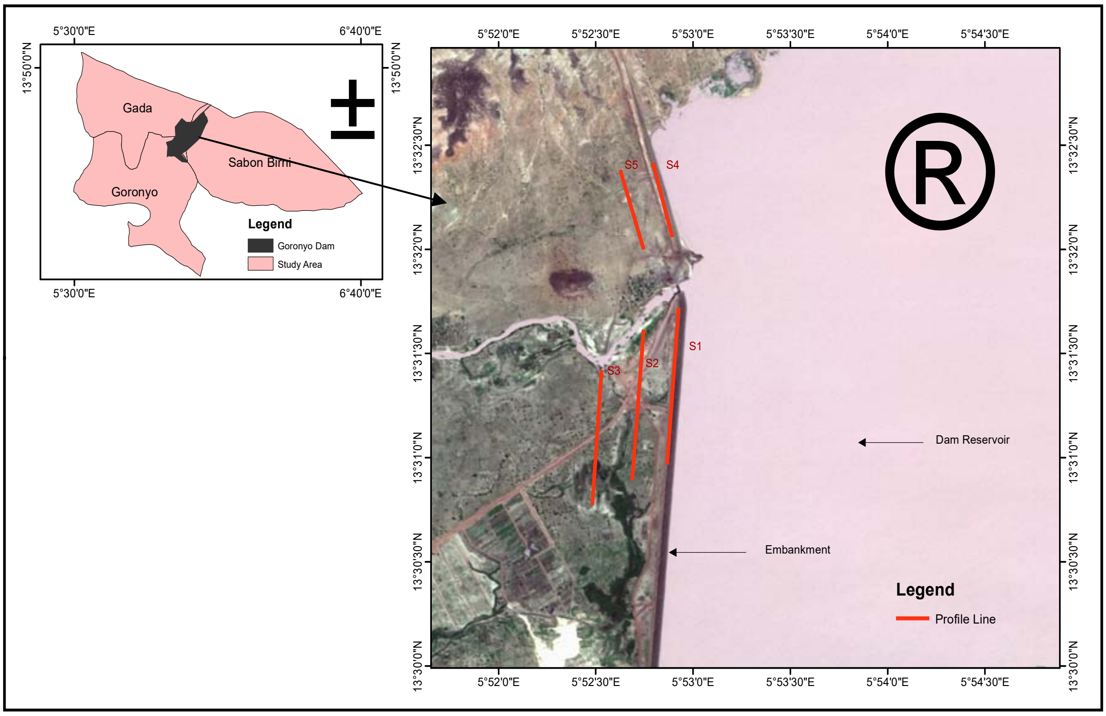

Fig. 2 Field Survey Layout Using Wenner Electrode Configuration

TABLE I
TYPICAL FIELD DATA FOR PROFILE 1

S/No	x-Location (m)	Spacing (*a*) (m)	SP (mV)
1	0	3	45.41
2	3	3	51.23
3	6	3	95.35
4	9	3	167.6
5	12	3	142.2
6	15	3	164.3
7	18	3	223.4
8	21	3	65.22
9	24	3	286.2
10	27	3	223.4
11	30	3	87.23
12	33	3	43.43
13	36	3	306.6
14	39	3	73.03
15	42	3	32.23
16	45	3	43.56
17	48	3	82.32
18	51	3	79.69
19	54	3	36.55
20	57	3	73.76
21	60	3	24.26
22	63	3	57.45
23	66	3	86.83
24	69	3	34.63
25	72	3	51.41
26	75	3	212.0
27	78	3	162.1
28	81	3	134.3

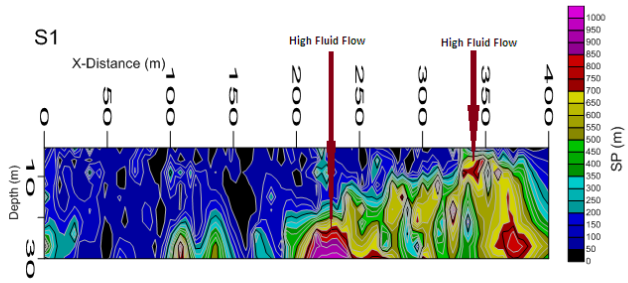

Fig. 3 2D Section for Profile 1 (S1)

B. SP Profile 2 (S2)

The contours of high and low SP values were shown in Fig. 4. Regions with high SP values indicated the direction of dip of a conducting body which are identified to be weak zones. However, the zones of low SP values in the overburden show the presence of intact regions that are usually associated with partially weathered basement complex rocks within the embankment of the dam.

Looking at Fig. 4 very carefully under positions of 164 m to 199 m and also from 306 m to 400 m along the profile with the corresponding depth ranging from 23 m to 30 m and also from 10 m to 30 m of the segment, the regions indicated high SP values ranging from 200 mV and above. High SP values were due to the high fluid flow and the regions with high SP values indicated areas where the host rock has been altered by faulting and/or fracturing and thus contains water, making the area less resistive to electrical current as shown in Fig. 4.

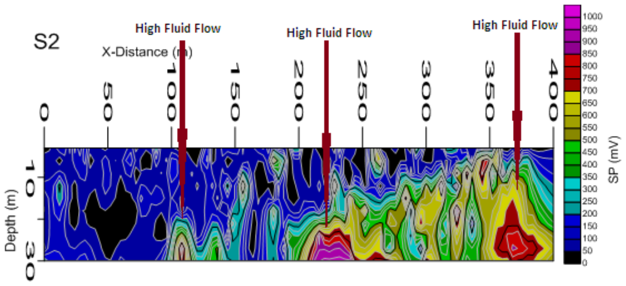

Fig. 4 SP 2D Section for Profile 2 (S2)

C. SP Profile 3 (S3)

The measured SP values and the results for the profile 3 are given in Fig. 5. The result was used to identify weak zones which are the possible regions of leakage of water through the embankment. The regions covering the positions of 95 m to 150 m and also 192 m to 400 m along the profile at the depth ranging from 23 m to 30 m and 11 m 30 m show high SP values. Thus these regions were identified as geologic weak zones through which water from lake could leak out by seepage which could affect the storage capacity of the dam as well as the competence of the embankment.

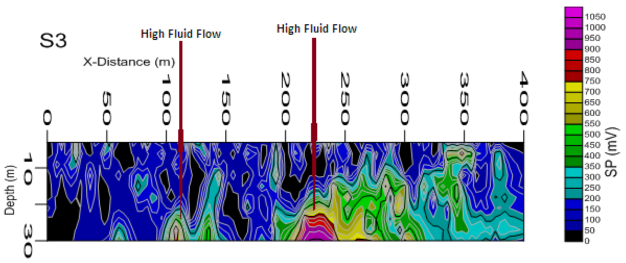

Fig. 5 SP 2D Section for Profile 3 (S3)

D. SP Profile 4

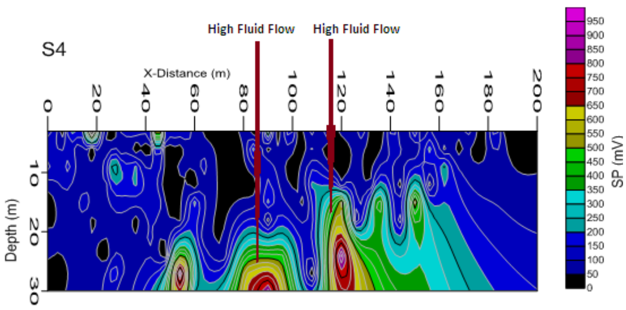

Fig. 6 SP 2D Section for Profile 4 (S4)

SP 2D Section for profile 4 was given in Fig. 6. The results of SP data plotted against x-distance and a-spacing show the high SP values ranging from 48 m to 200 m along the profile with a corresponding depth ranging from 23 m to 30 m. These regions of high SP values (≥ 200 mV) were due to high fluid flow and the regions were regarded as weak zones and potential dam water seepage locations. However, there are also zones of low SP values in the profile which may be due to evapotranspiration and/or animal movements that may lead to consolidation.

E. SP Profile 5 (S5)

Interpreted SP 2D section for profile 5 (S5) is given in Fig. 7 and the result shows lithology and anomaly of interest (weak zone within bedrock). Observing this figure very closely under the regions ranging from 7 m to 170 m along the profile at the corresponding depth ranging from 23 m to 30 m shows the high SP values ranging from 200 mV and above.

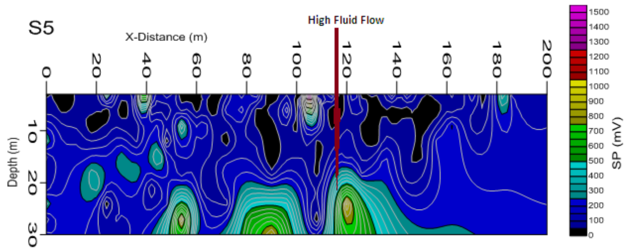

Fig. 7 SP 2D Section for Profile 5 (S5)

High SP values (≥ 200 mV) in this profile was due to high fluid flow which depends on its porosity, degree of interconnection between the pores (permeability) and degree of water saturation in the rock. These regions were considered to be weak zones.

V. Discussion

The SP 2D Section for profiles S1, S2, S3, S4 and S5 show high SP values ranging from 250 m to 400 m (S1), 306 m to 400 m (S2), 192 m to 400 m (S3), 48 m to 200 m (S4) and 7 m to 170 m (S5) with corresponding maximum depths of 30 m, 28 m, 28 m, 30 m and 26 m respectively. The regions with high SP values (200 mV and above) were identified as regions of high tendency of fluid flow associated with Wet Sandy Soil. High SP values were due to porosity, permeability and degree of water saturated presence in the rock associate with moisture content of earth materials that result in the seepage of water leaking through the regions around the Goronyo dam. These weak zones occupying most of the profiles thereby considered risky by extending deep to the bedrock as they could provide micro-channels for seepage of water from the lake under the effect of the increased in hydraulic gradient with depth. Thus these regions were identified as geologic weak zones through which water from lake could leak out by seepage, which may affect the storage capacity of the dam. However, this may have also contributed to high resistivity values in the overburden. However, the zones of low SP values were considered to be the regions that were free-associate with seepages due to the presence of partially Weathered Basement Complex Rocks, which are probably due to compactness and dryness around the dam. The dryness and compactness of the topsoil may be due to evapotranspiration and/or animal movements that may lead to consolidation.

VI. Conclusion

In conclusion, five profiles line (on right abutment having 3 profiles of length 400 m and on left abutment having 2 profiles of length 200 m) was identified the regions of weak zones (i.e. potential seepage paths). These zones were observed within the subsurface under which the dam was constructed at the deepest layer of 30 m. This weak zone may be due to the faults that have a subtle geomorphic expression in the area which is relatively young in its deposits at the surface. It is recommended that study should be repeated at regulated interval. Thus a routine scientific assessment should be established to ascertain safety level as well as the storability of the dam. This is very important as the supporting structures of the dam weaken with age of the dam.

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