

Full Length Research Paper

Application of vertical electrical sounding and horizontal profiling methods to decipher the existing subsurface stratification at river Segen dam site, Tigray, Northern Ethiopia

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The study area Segen river dam site is situated in the southeastern zone of Tigray National Regional State in between Hintalo Wajirat and Enderta Weredas. It is geographically located at 37P between 541400 to 542600 UTME Latitude and 1481600 to 1482600 UTMN Longitude about 35 km southwestern part of Mekelle, the capital of Tigray National Regional State. The study was conducted having an objective of the geophysical assessment to provide important subsurface geophysical information useful in evaluating the subsurface geological formations, geological structures, cavities and others for the dam site under investigation. Ten vertical electrical sounding (VES) points along the two profile lines and a total of two horizontal profiling (EP) with a Wenner electrode array were collected. The VES results have shown that weak zones at VES 2, 3 and 4 along Profile 1 and at VES 2, 3 and 5 along Profile 2 where the depth goes not more than 20 m deep in both profiles' pseudo cross section except at VES 4 profile which extends up to 30 m deep. Similarly, the electrical resistivity profiling results also have shown that the weak zones extend not more than 20 m of depth. Hence, the result revealed that the investigation requires further core drilling investigations.

Key words: Vertical electrical sounding, electrical profiling, subsurface geophysics, Segen Dam, Tigray, Ethiopia.

INTRODUCTION

The main economic means of Tigray region, located in the northern part of the country is rain fed agriculture. The rainfall is erratic and unreliable. The topography of the area is undulating. Thus with the traditional agricultural practices, natural resources are severely degraded due to human interference as well as natural devastation; the land productivity is declining at alarming rate. As a result, because of moisture limitation and the above reasons, the region is not in a position to cover the annual food requirement of the people.

To alleviate the challenges of food insecurity in the country, promotion of irrigated agriculture was given priority in the strategy of the Nations (Mekuria, 2003). According to Abraham et al. (2005) cited in Nata and Asmelash (2007), irrigation is one of the methods used to increase food production in arid and semi-arid regions.

To avert the shortage of water and promote food security, the Ethiopian government has been involved in the construction of different surface water harvesting structures such as micro-dams, river diversion weirs and

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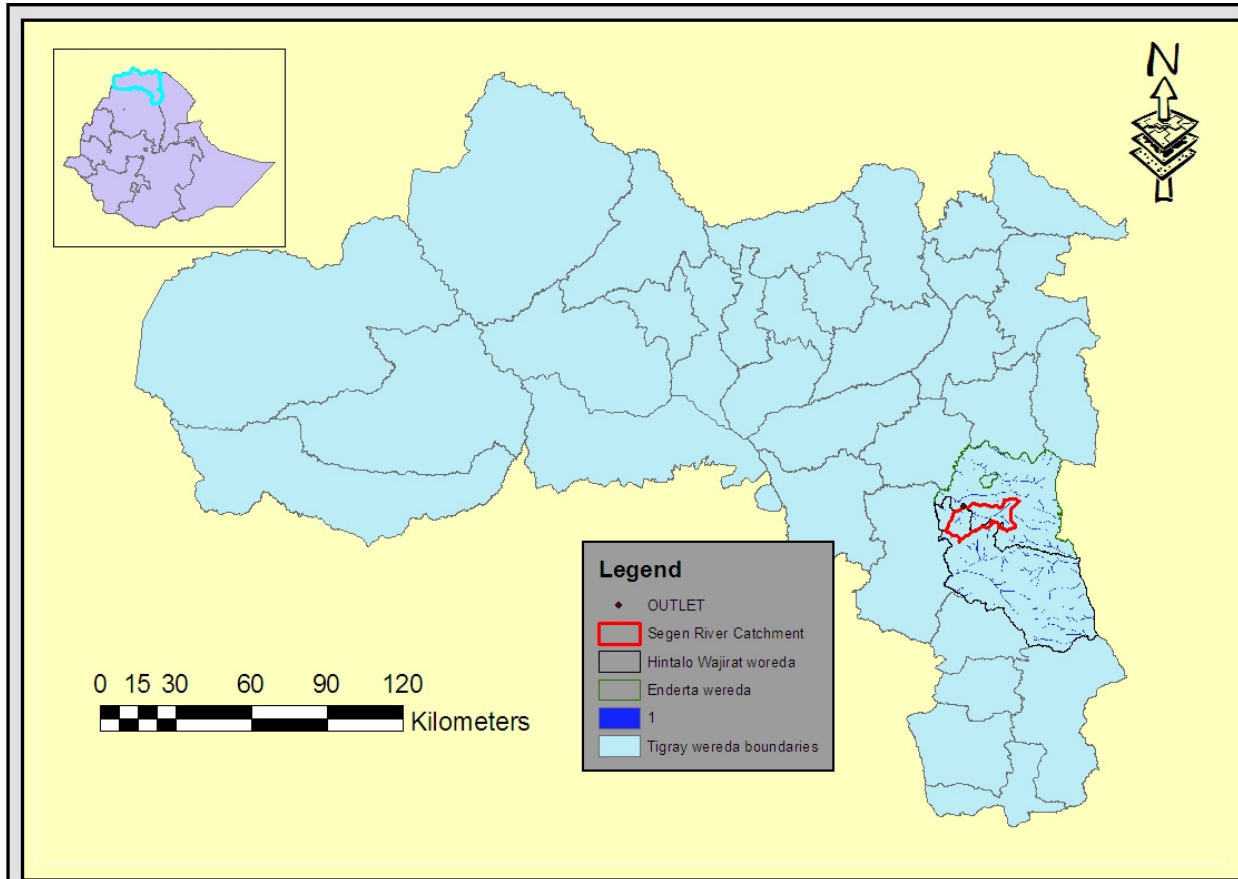


Figure 1. Location map of the Segen river dam site.

ponds in many parts of the country. In the Tigray National Regional State a number of micro-dams and several diversion weirs have been built in the last decades. Preliminary studies (Woldearegay, 2001; Mintesinot et al., 2004) indicate that the constructions of surface water harvesting schemes have economic, hydrological, and environmental benefits.

Electrical methods namely resistivity were developed in early 1900's but are more widely used since the 1970's, due primarily to the availability of computers to process and analyse the data. Electrical resistivity techniques are used extensively in the search for suitable groundwater sources, to monitor types of groundwater pollution, in engineering surveys to locate sub-surface cavities, faults and fissures, permafrost, etc, in archaeology for mapping out the area extent of remnants of buried formations of ancient buildings, amongst many other applications. It is also used extensively in down hole logging (Reynolds, 2000). The electrical resistivity technique of subsurface materials determines the composition of the overburden and depth to bedrock, and thickness of sand, gravel or metal deposits or aquifers, detect fault zones, locate steeply dipping contacts between different earth materials.

The present study intends to determine the geoelectric parameters (layer resistivity, layer thickness, transverse resistance and longitudinal conductance), delineate the weak zones, subsurface geological formations, geological structures, cavities and others.

METHODOLOGY

Location

The Segen river dam site is located about 35 Km southwestern part of Mekelle, the capital of Tigray National Regional State. The dam site is situated between two Weredas of Southeastern Zone of Tigray: the Enderta Wereda and Hintalo Wajirat. It is geographically located at 37P between 541400 to 542600 UTM Latitude and 1481600 to 1482600 UTMN Longitude. It is accessible through the Mekelle – Samre all seasons gravel pack road and seasonal rural roads (Figure 1).

Data collection and analysis

Electrical methods

Both vertical electrical sounding (VES) and electrical profiling (EP) were conducted following two profile lines where one is on the

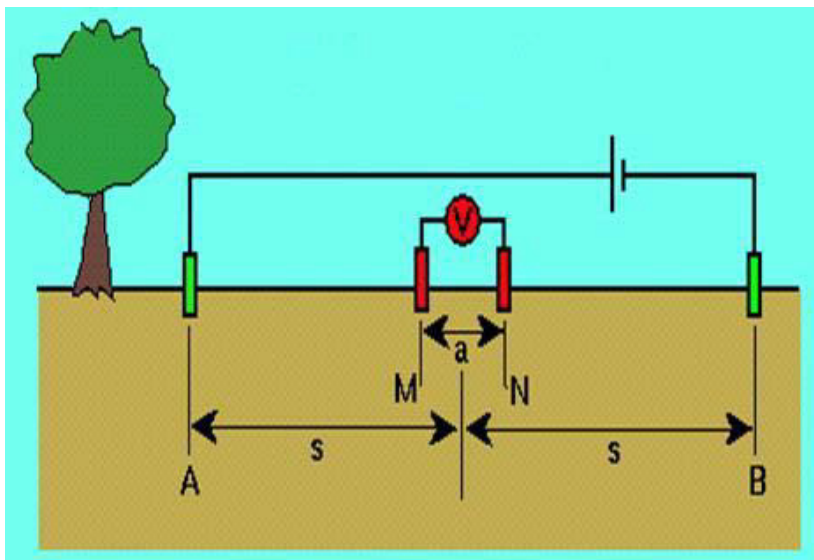


Figure 2. Electrode configurations in Schlumberger array (Mines, 2003).

proposed dam axis and the other is upper stream of the dam axis. Profile lines are aligned in the NE-SW direction. Vertical electrical sounding (VES) with the commonly used Schlumberger configuration was used for the purpose of determining the vertical variation of resistivity. The current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point (Philip and Michael, 1984). Four electrodes are placed along a straight line on the Earth surface in the same order, A M N B, as in the Wenner array but with $AB \geq 5 MN$ (Figure 2). For any linear symmetric array A M N B of electrodes, the apparent resistivity (ρ_a) applying Schlumberger array where AM is the distance on the Earth surface between the positive current electrode A and the potential electrode M. When two current electrodes A and B are used and the potential difference (ΔV) is measured between two measuring electrodes M and N, the apparent resistivity can be written in this form:

$$\rho_a = \pi \Delta V / I * [(AB/2)^2 - (MN/2)^2] / MN \text{ or } \rho_a = \pi K \Delta V / I \quad (1)$$

The value of the apparent resistivity (ρ) depends on the geometry of the electrode array used, as defined by the geometric factor (K) (Reynolds, 2000).

Electrical profiling (EP) method with Wenner array was used for determining the horizontal or lateral variation of resistivity. In the Wenner array configuration the spacing between successive electrodes remains constant and all electrodes are moved for each reading, this method can be more susceptible to near surface and lateral variations in resistivity and it is sometimes called horizontal electrical profiling (HEP). The four electrodes are collinear and the separations between adjacent electrodes are equal (a) with M, N in between A, B as shown in Figure 3 (Parasnis, 1986). The choice of electrode spacing would primarily depend on the depth of the anomalous resistivity feature (s) to be mapped (Sharma, 1986). The apparent resistivity applying Wenner array configuration can be written in the form:

$$\rho = 2\pi a \Delta V / I \quad (2)$$

Where: ρ is the apparent resistivity, $2\pi a$ is the geometric factor (K) and a is the electrode spacing, ΔV is the potential difference and I is the electric current.

Data collection

The type of instrument used for the investigation was ABEM Terrameter SAS 4000/SAS 1000 with appropriate electrodes, cables on reels, and other accessories. Four electrode Schlumberger array was chosen in the VES survey which could provide better interpretation facility and relatively fast data acquisition mechanism. The vertical electrical resistivity sounding was carried out on the profile lines which are on and on the upper stream of the dam axis with the $AB/2$ and $MN/2$ spacing ranging from 1.5 to 220 m and 0.5 to 45 m respectively. Ten VES points were collected along the two profile lines, five VES points each. The spacing between two successive VES points VES 1, 2, 3, 4 and 5 in the Profile 1 was in the order of 175, 325, 475, 663 and 783 m, respectively from the 0 station at the Teklehaimanot church. While the spacing between two successive VES points VES 1, 2, 3, 4 and 5 in the Profile 2 was in the order of 175, 325, 475, 650 and 800 m, respectively. A total of two EP with a Wenner electrode array was conducted. It was done along the two profile lines, Profiles 1 and 2 with profile length of 960 and 1025 m respectively with $a=5, 10, 20$ and 30 m along the proposed dam axis. The horizontal interval or spacing between the two profiles was approximately 50 m (Tables 1 and 2).

Data processing

Based on the fundamental principles and methodologies of the geophysical survey, the collected data are interpreted quantitatively in the case of VES and qualitatively in the case of EP to determine the thickness, nature and lateral variations of the geological formations which are used to obtain a complete geological picture of the area. VES data were entered to the computer and curves were plotted using IPI2win interpretation software. The apparent resistivity and layer thicknesses were converted into useful geological meaning using knowledge of the geological history and direct geological visual observations. EP survey data are entered into the computer and processed using Microsoft Office Excel and Golden Software Surfer V. 8 to determine the lateral variations of the geologic formations.

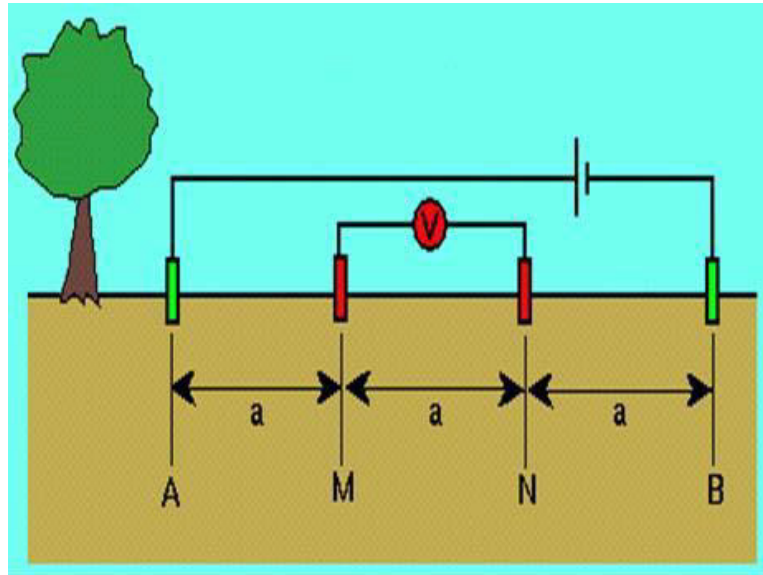


Figure 3. Electrode configurations in Wenner array (Mines, 2003).

Table 1. GPS locations of VES points at both profiles.

Designation	Along Profile 1			Along Profile 2		
	UTME	UTMN	Elevation (m)	UTME	UTMN	Elevation (m)
VES 1	542253	1482359	1852	542311	1482336	1852
VES 2	542152	1482252	1830	542215	1482238	1829
VES 3	542044	1482153	1832	542111	1482126	1829
VES 4	541900	1482038	1824	541997	1481998	1825
VES 5	541814	1481964	1839	541876	1481906	1849

Table 2. GPS location of the start and end coordinates of electrical profiling lines.

Traverse	GPS readings						Remark
	Start			End			
	UTME	UTMN	Elevation (m)	UTME	UTMN	Elevation (m)	
Profile 1	542344	1482485	1888	541657	1481829	1913	Each profile line is approximately 50 m away
Profile 2	542402	1482475	1892	541720	1481780	1915	

RESULTS AND DISCUSSION

Vertical electrical sounding (VES)

The VES survey data collected from different locations along the two profile lines are interpreted and presented graphically with its possible geological meanings and the resistivity value, layer thickness and depth tabulated as follows. In terms of resistivity, Igneous rocks such as granite, diorite and gabbro have the highest resistivities while Sedimentary rocks such as shale and sandstone

have a lower resistivity compared to Igneous rocks; this is due to the high fluid content in them. Metamorphic rocks on the other hand have intermediate but overlapping resistivities (Felix, 2008). The resistivity values of the 5 VES points along the Profile 1 are stated in such a way that the resistivity values in the first layer ranges from 12.94 to 106 Ohm-m and the depth ranging from 0.75 to 1.41 m. This indicates that the layer consists of clayey sand and shale formations. The second layer has an apparent resistivity values ranging from 17.6 to 214 Ohm-m and a range of depth from 2.16 to 2.91 m. This layer is

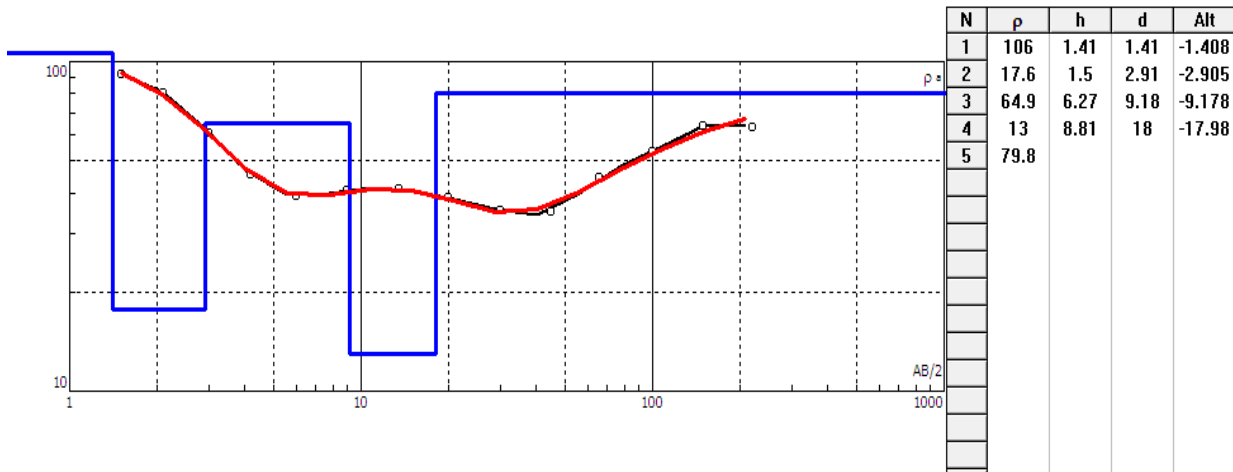


Figure 4. VES 1 on the Profile 1 (RMS = 2.29%).

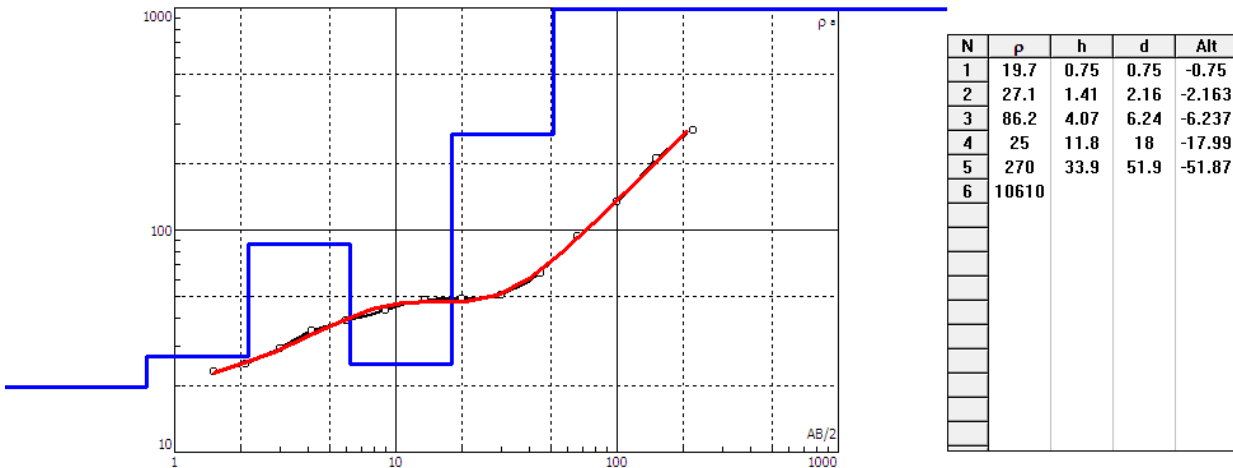


Figure 5. VES 2 on the Profile 1 (RMS = 2.42%).

weathered and fractured limestone. The third layer has an apparent resistivity between 7.191 and 86.2 Ohm-m and the range of depth is from 6.237 to 9.18 m. This layer is interpreted as water-tighted weathered and fractured limestone. The fourth layer has an apparent resistivity between 13 and 406.4 Ohm-m and the range of depth is from 17.99 to 18 m. This layer represents fresh limestone (Loke, 1999; Keller and Frischknecht, 1966) (Figures 4, 5, 6, 7 and 8).

Similarly, the resistivity values of the 5 VES points along the Profile 2 have shown that the resistivity values in the first layer ranges from 1.06 to 184 Ohm-m and the depth ranging from 0.75 to 2.884 m. This indicates that the layer consists of clay dominant sand associated with cobbles, pebbles and boulder formations. The second layer has an apparent resistivity values ranging from 15.9 to 378 Ohm-m and a range of depth from 2.16 to 6.7 m.

This layer is sand dominated clay associated with cobbles, pebbles and boulder formations. The third layer has an apparent resistivity between 16.14 and 1434 Ohm-m and the range of depth is from 6.24 to 24.35 m. This layer is interpreted as fractured limestone intercalated with shale. The fourth layer has an apparent resistivity between 11.7 and 3440 Ohm-m and the range of depth is from 18 to 94.43 m. This layer represents weathered dolerite (Loke, 1999; Keller and Frischknecht, 1966) (Figures 10, 11, 12, 13 and 14).

The pseudo cross section along the Profile 1 shows that the weak zones mainly stretches from VES 2 to 4 from the surface level to about 5 m deep at VES 2 to 3 and to about 100 m deep at VES 3 to 4 (Figure 9). The pseudo cross section along the Profile 2 has also shown that weak zones at VES 2 to 3 and 5. Vertically under VES 3, there exists a hole-like weak zone which extends

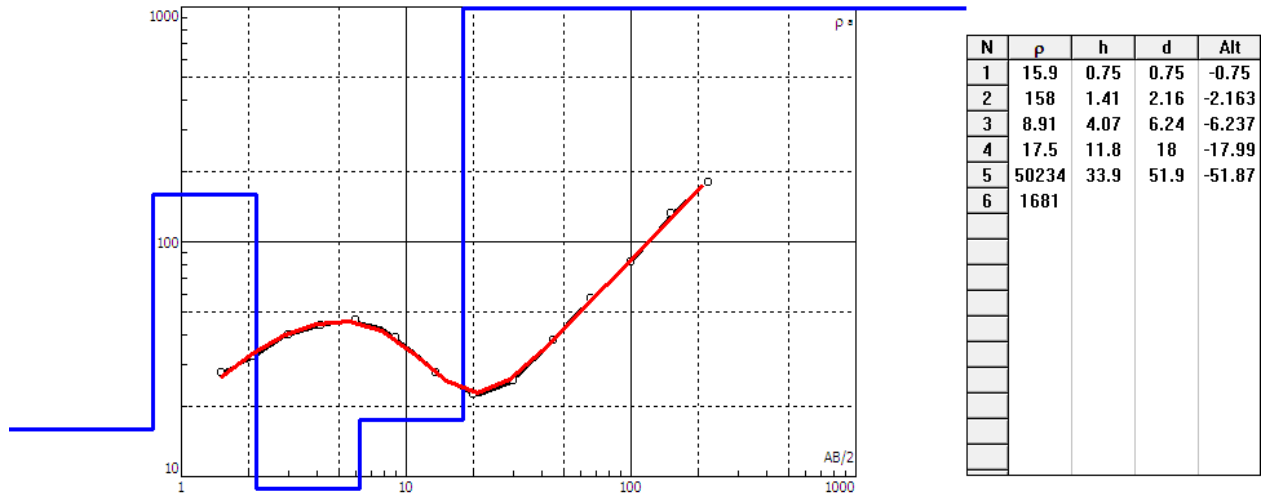


Figure 6. VES 3 along the Profile 1(RMS = 2.5%).

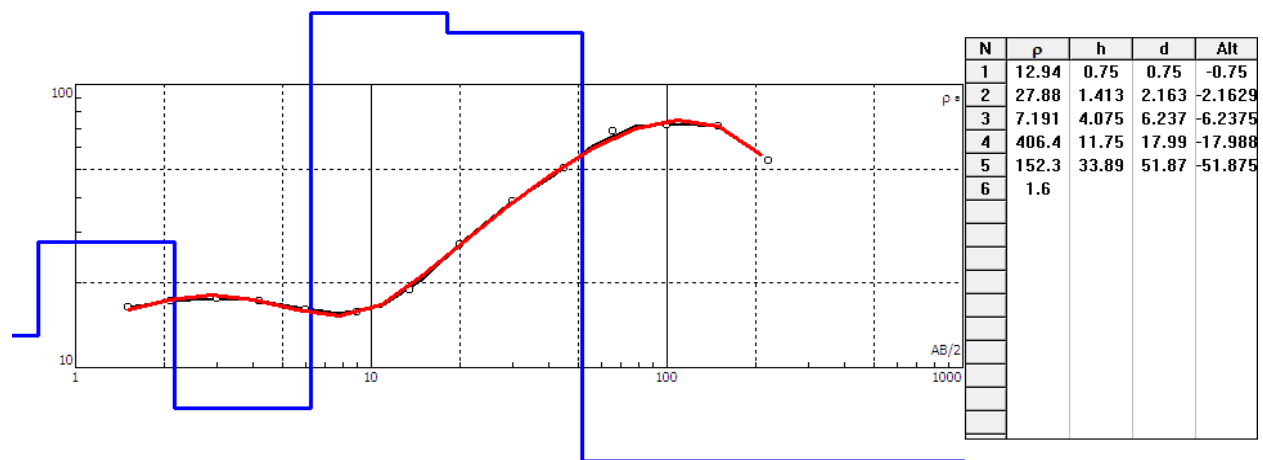


Figure 7. VES 4 along the Profile 1(RMS = 1.85%).

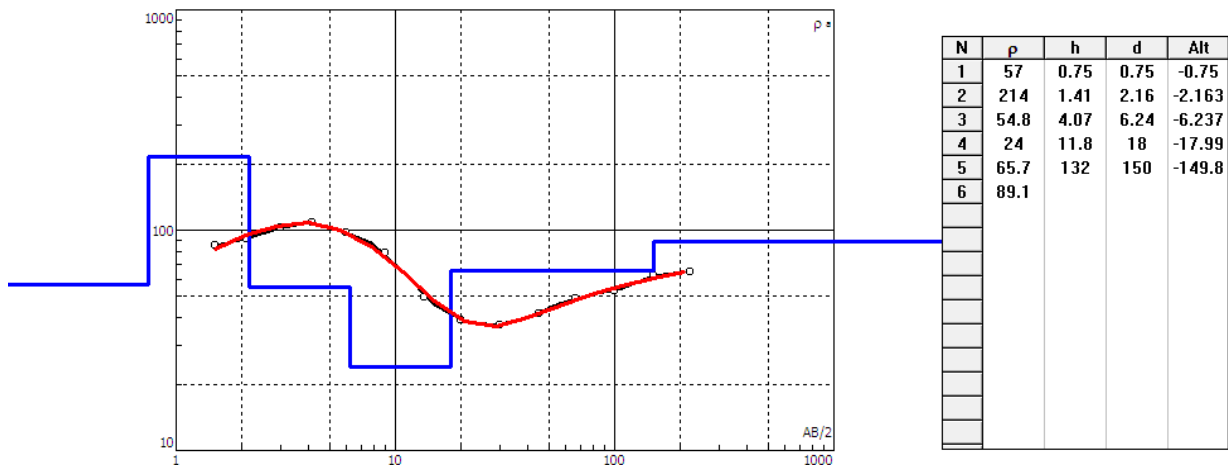


Figure 8. VES 5 along the Profile 1(RMS = 2.56%).

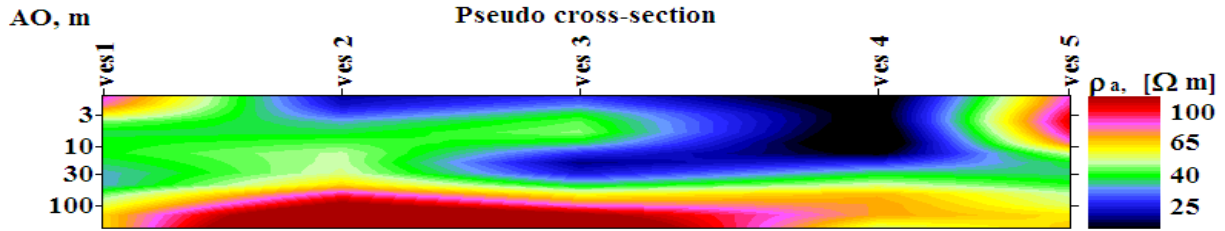


Figure 9. Pseudo cross-section along the Profile 1.

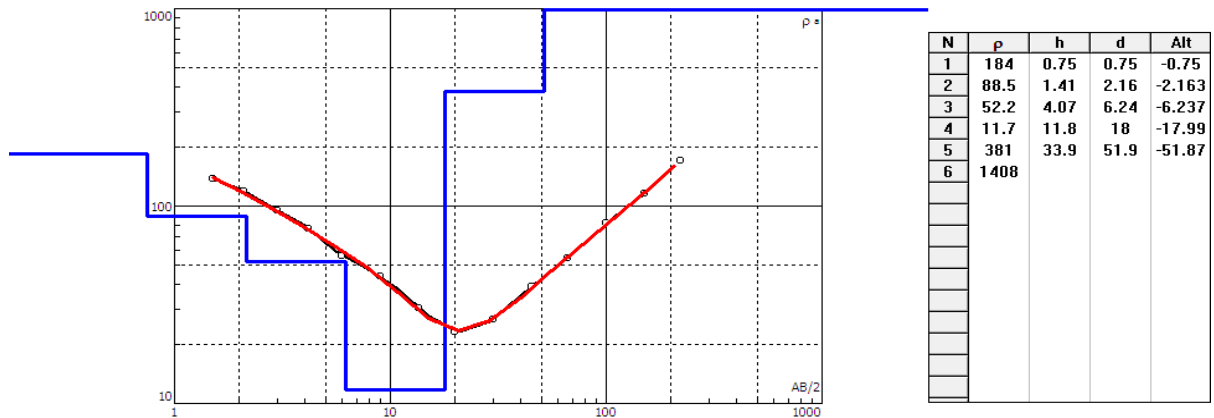


Figure 10. VES 1 on Profile 2(RMS = 2.27%).

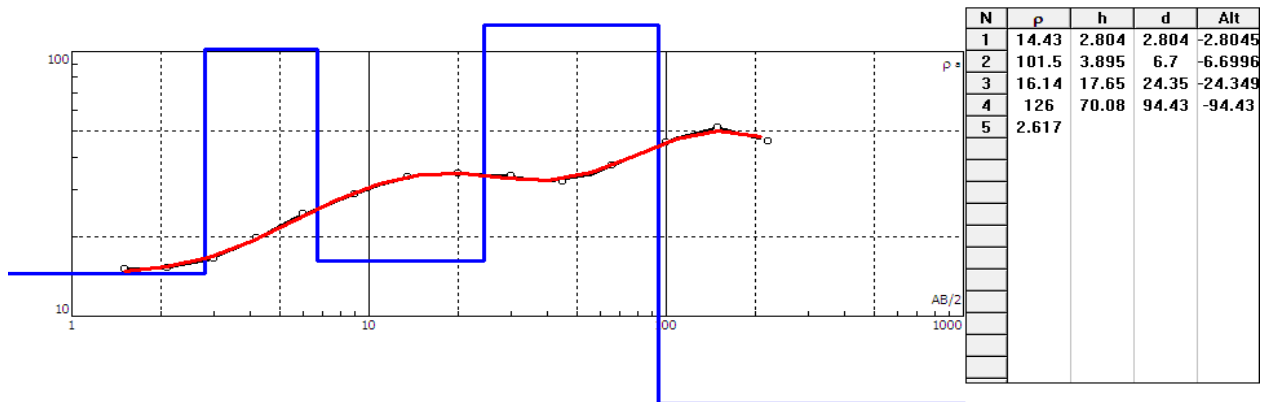


Figure 11. VES 2 on profile 2(RMS = 1.58%).

approximately from 20 to about 100 m below surface (Figure 15).

Electrical profiling (EP)

Electrical profiling (EP) survey was conducted in the area across the Segen river with Profile 1 on the proposed dam axis with profile length of 960 m and Profile 2 on

proposed upper stream of the dam axis with profile length of 1025 m with sampling intervals of 5, 10, 20 and 30 m along NE-SW direction. The main target of the EP survey is to identify the relative position and orientation of geological structures and lithologic contacts which may have an importance for the dam construction.

Electrical profiling contour map plotted for Profile 1 at 30 m depth (AB/3 = 30 m) is characterized by heterogeneous resistivity. It shows high resistivities

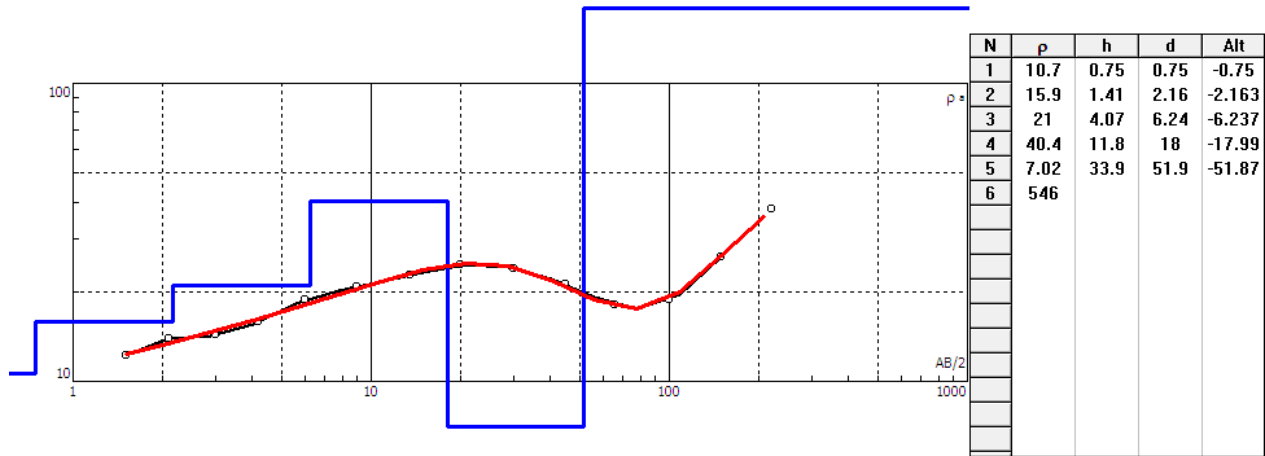


Figure 12. VES 3 on Profile 2(RMS = 2.03%).

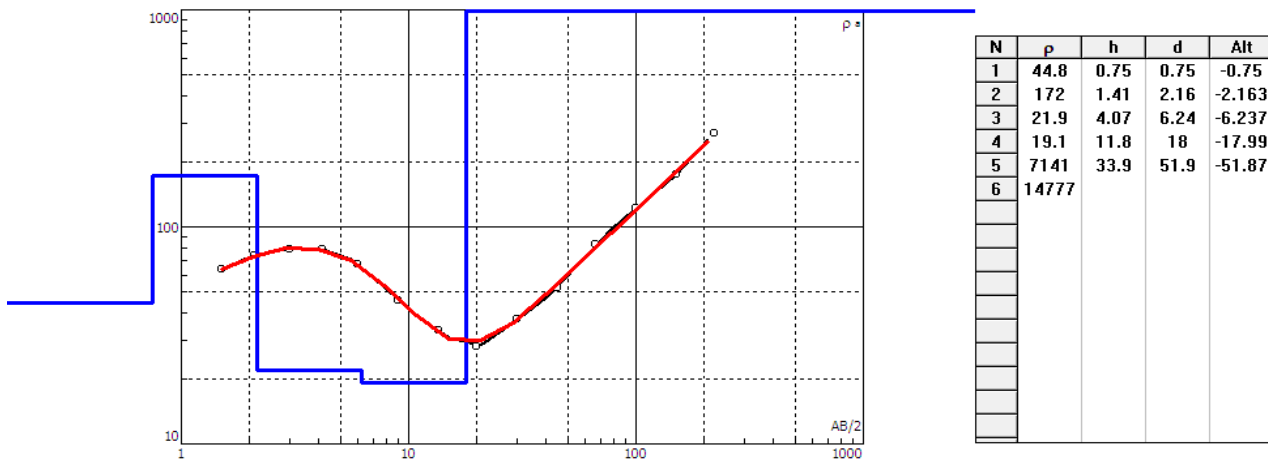


Figure 13. VES 4 on Profile 2(RMS =2.3%).

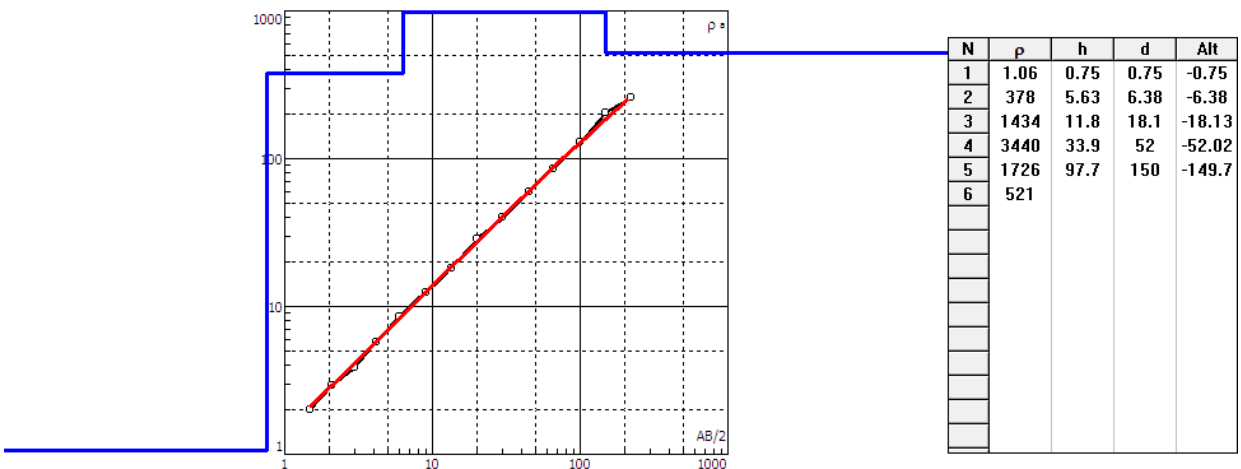


Figure 14. VES 5 on Profile 2(3.65%).

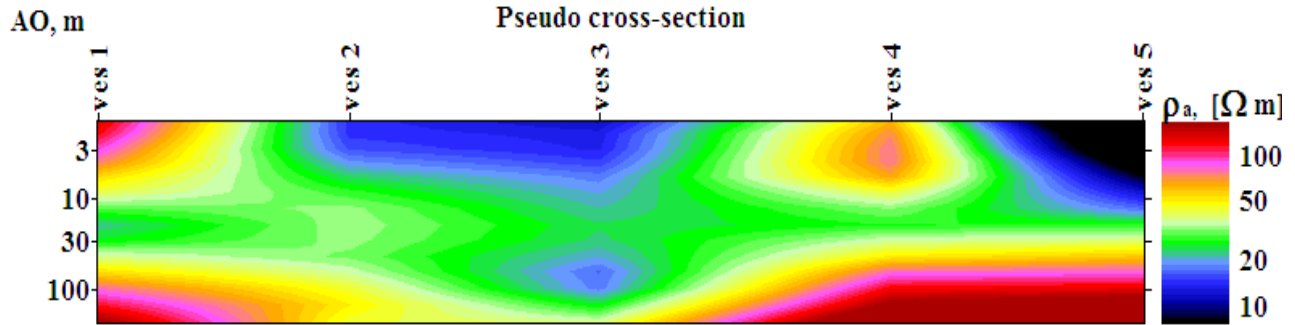


Figure 15. Pseudo cross-section along the Profile 2.

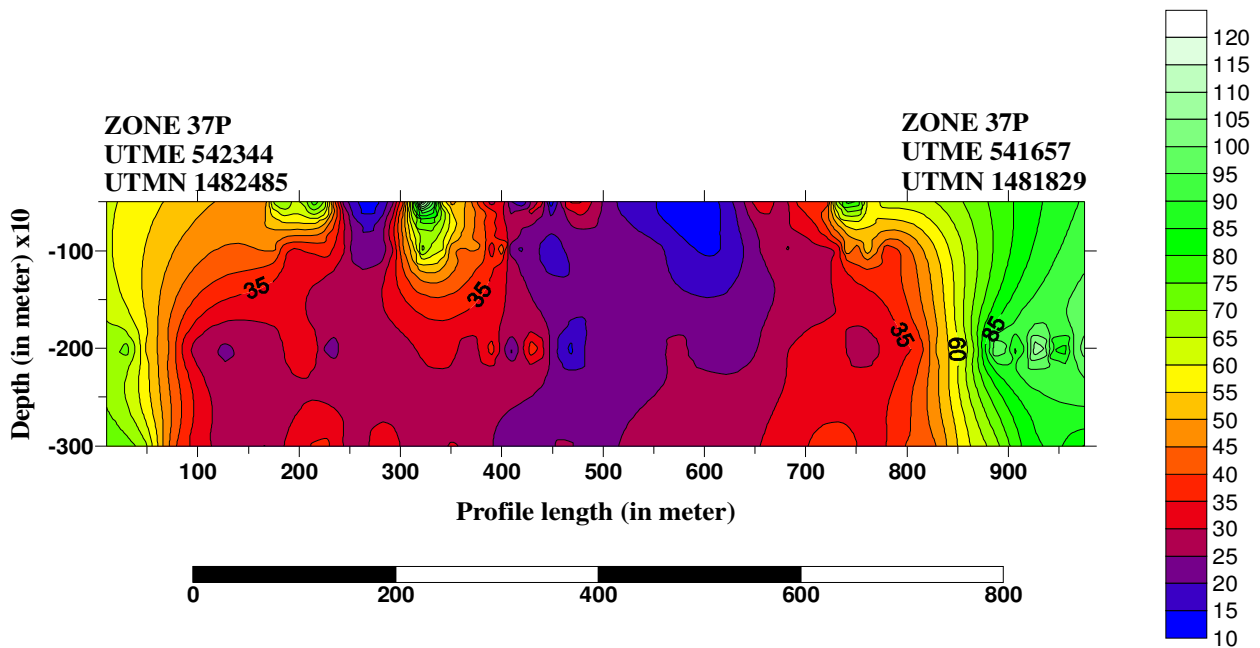


Figure 16. Apparent resistivity contour map of EP Profile 1 showing the lateral variation.

ranging from 35 to 120 Ohm-m at both corners of the profile line. While the resistivity values at the middle of the profile declines from 35 to 10 Ohm-m with the exception of the resistivity of the profile line at 300 to 400 m from the Teklehaimanot church shows a resistivity value of greater than 35 Ohm-m. The contour map of the Profile 1 shows a “graben-like” boroundary between the NE – SW direction (Figure 16).

The electrical profiling contour map plotted for Profile 2 at 30 m depth is also charaterized by heterogeneous resistivity: highest resistivity values at the corners and smallest resistivity values at the middle of the profile line (Figure 17). The horizontal or surfacial contour maps plotted between the Profiles 1 and 2 at a = 5, 10, 20 and 30 m also shows that smallest resistivity values at the middle while the highest values are obtained at the

corners of the profile lines with a “graben-like” structure at the center (Figures 18, 19, 20 and 21).

Conclusion

The vertical electrical resistivity sounding and the electrical resistivity profiling data collected and interpreted above have shown similar trends which is the resistivity values goes inclining from center of the river bed towards both abutments/flanks. The VES results have shown that weak zones at VES 2, 3 and 4 along Profile 1 and at VES 2, 3 and 5 along Profile 2 where the depth goes not more than 20 m deep in both profiles’ pseudo cross section except at VES 4 profile which extends up to 30 m deep. Similarly, the electrical

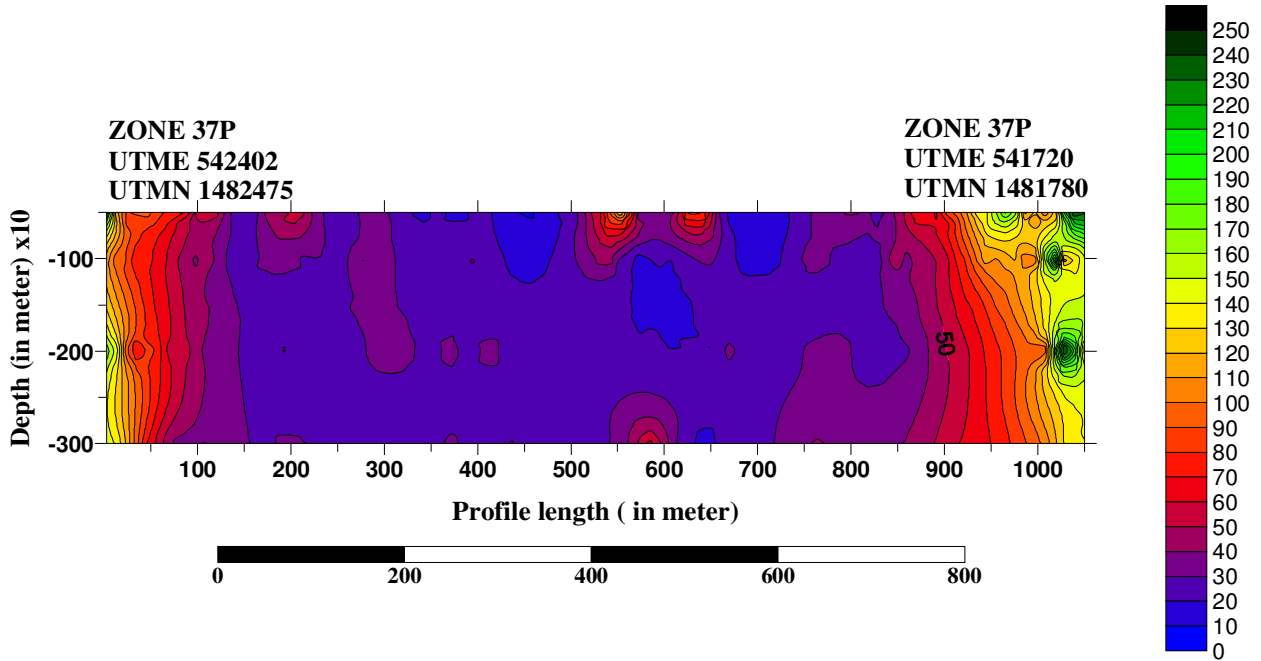


Figure 17. Apparent resistivity contour map of EP Profile 2 showing the lateral variation.

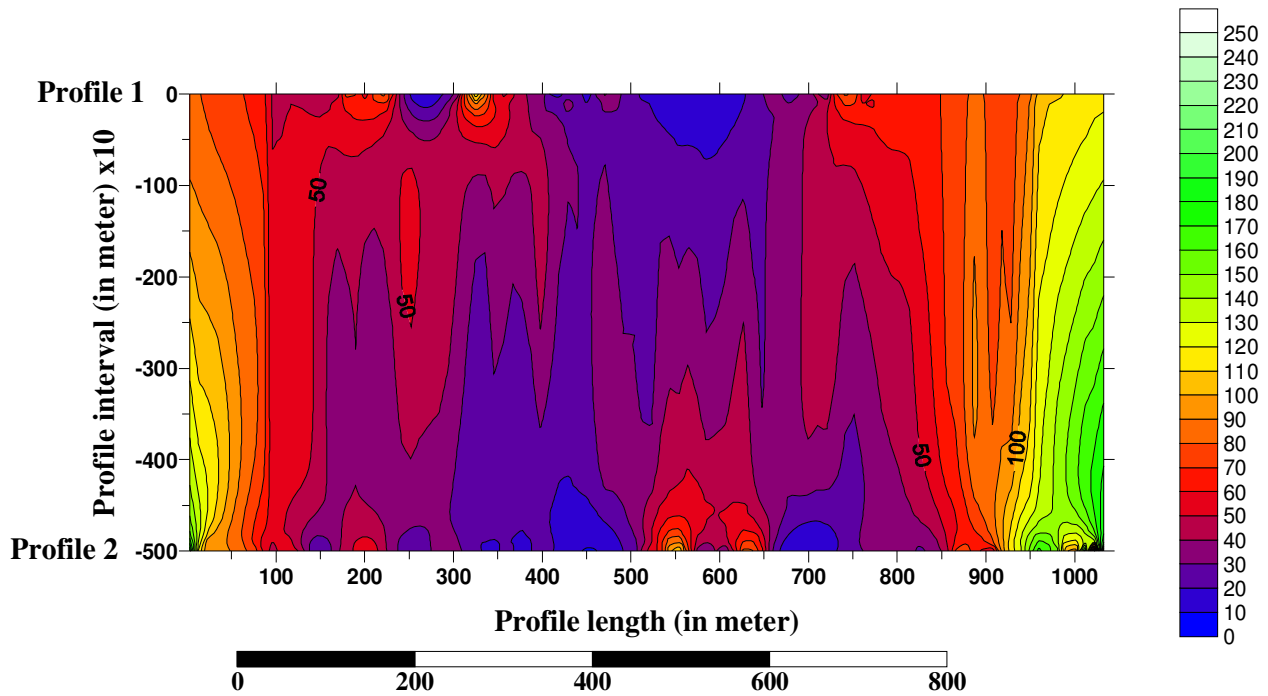


Figure 18. Apparent resistivity contour map between EP Profile 1 and 2 at 5m depth.

resistivity profiling results also have shown that the weak zones extend not more than 20 m of depth. This requires further core drilling investigation before construction is commenced.

RECOMMENDATIONS

Core drilling should be conducted in the proposed dam axis and upper stream of the dam axis where the VES

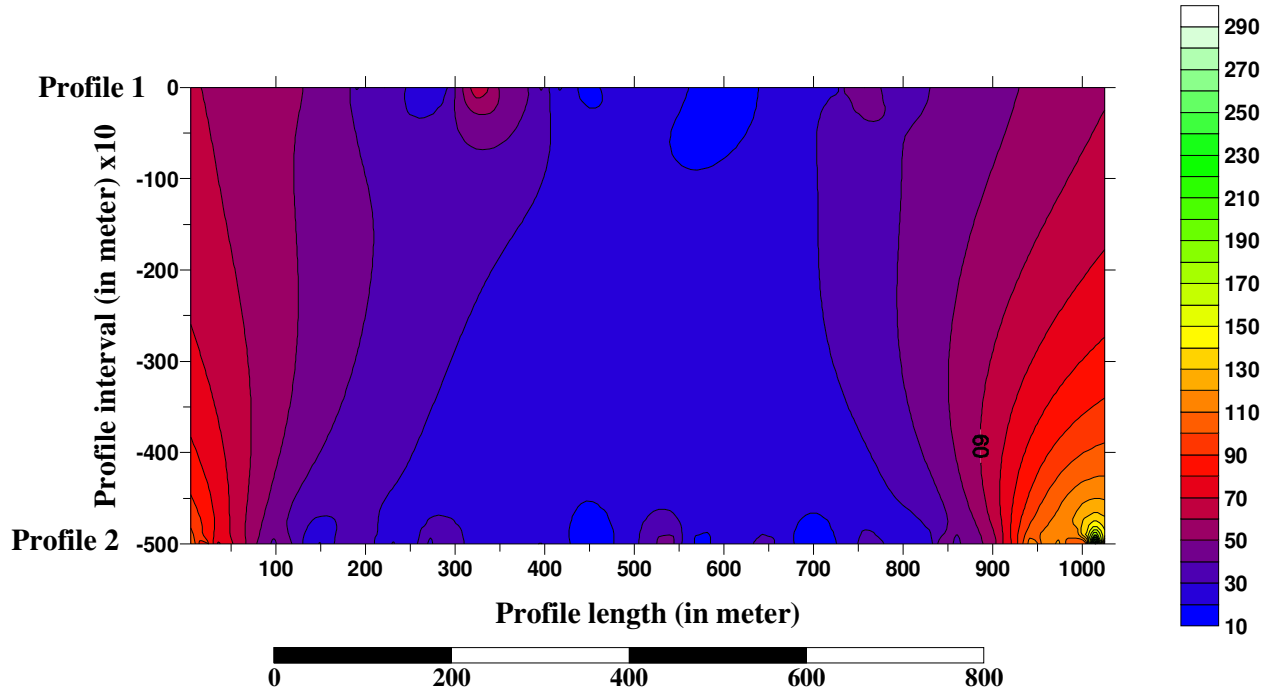


Figure 19. Apparent resistivity contour map between EP Profile 1 and 2 at 10 m depth.

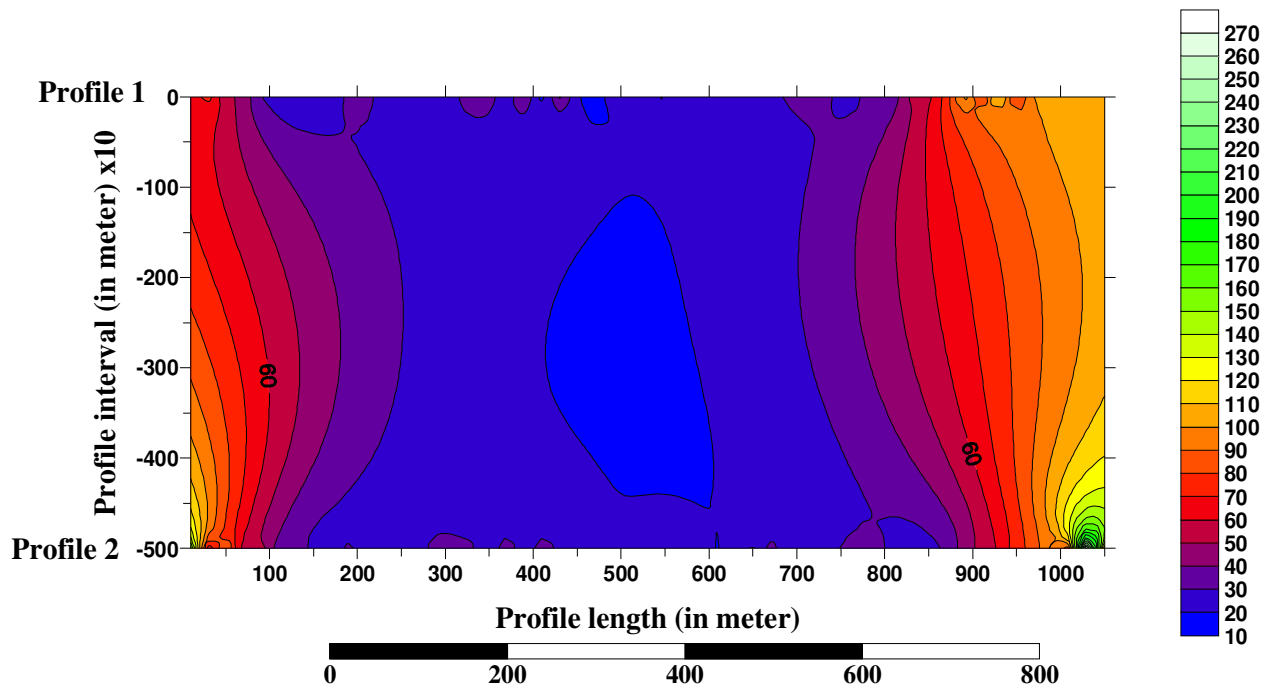


Figure 20. Apparent resistivity contour map between EP Profile 1 and 2 at 20 m depth.

and electrical resistivity profiling were conducted. Specifically, through Profile 1 at VES 2, 3 and 4 which are located at 325, 475 and 663 m and through VES 2,

3 and 5 which are also located at a distance of 325, 475 and 800 m from the starting point at the Teklehaimanot church.

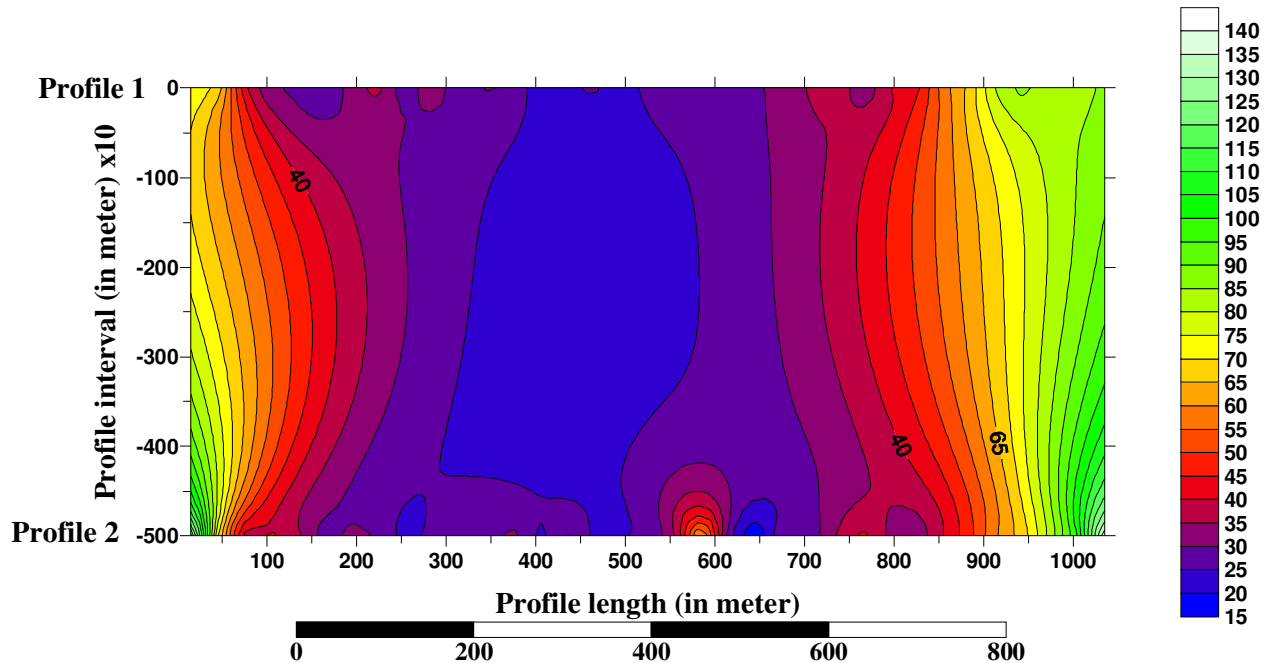


Figure 21. Apparent resistivity contour map between EP Profiles 1 and 2 at 30 m depth.

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