Simulation of Electrical Resistivity Tomography (ERT) results to detect the subsurface layers at Thalapathkulama geotechnical investigations

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***Abstract*— Thalapathkulama is an abandon reservoir in Sri Lanka. It has been proposed to rehabilitate for the purpose of increasing ground water table inside the forest area and for irrigation purposes. The geotechnical investigations were carried out using both indirect methods and direct methods. Ground Electrical Resistivity Surveys (GERS) were carried out as indirect methods and bore hole drilling were conducted as direct methods of investigation. The results of the GERS were prepared as Electrical Resistivity Tomography (ERT) profiles and they were used to optimize the number of bore holes considering the anomalies shown in ERTs. The Gradient XL method of arrays was used in all of the GERS and additionally another two array methods (Schlumberger & Wenner) were used in one GERS. The results from GERS and borehole data were compared and this paper discusses the comparison of actual results and simulated results from GERS. The soil layer, weathered rock layer and the hard rock layer were compared with the anomalies in the ERT. It was seen that the Gradient XL method shows the anomalies with less accuracy, However Schlumberger method showed the anomalies clearly. Moreover, the study must be extended to give a more accurate result to predict the applicability of the ERT arrays to determine the subsurface layers in the geotechnical investigations.**

Keywords*— *Electrical Resistivity Tomography, Gradient XL, Schlumberger, Wenner

I. INTRODUCTION

Thalapathkulama is an abandoned reservoir located in Horowpothana area in Sri Lanka. It can be assumed that this reservoir might have been built by ancient kings to increase the ground water table inside the jungle and for the water usage for the wild animals. Additionally, the reservoir might have been used to issue irrigation water also. Geologically, the Thalapathkulama reservoir area is located at the transition zone (Fig. 1) of Wanni and highland lithotectonic boundaries.

It was noticed that few historical symbols were carved on the rock which is in the mid of the dam, which shows an archeological value of the reservoir. Under the proposed project, the reservoir will be rehabilitated. The existing bund has been breached at two locations and the existing bund height is about 7-10 meters.

Further a sluice made out of rock, called in Sinhala as "Bisokotuwa" is visible near to the right bank side. As per the villagers it is still functioning during the rainy season. A huge rock outcrop was visible at the mid of the earthen bund which is approximately 700-800m long.

Irrigation Department, Sri Lanka (IDSL) carried out Ground Electrical Resistivity Surveys (GERS) as an indirect investigation method, and borehole investigations as a direct method. Generally, Dipole-Dipole, Gradient-XL, Schlumberger and Wenner are four arrays that are used for the Two-Dimensional (2D) GERS. Even though several researchers have used some or all of these array methods to investigate subsurface profiles with comparisons, it appears that the assessment of the simulation of electrical resistivity results to determine underground subsurface layers have not been sufficiently carried out in Sri Lankan context.

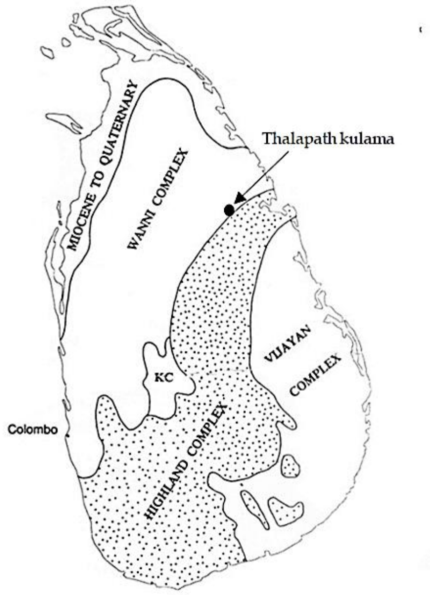

Fig. 1. Location of Thalapathkulama

The objective of this paper is to compare the drill hole results (actual results) with the 2D GERS results (simulated results) using Gradient-XL array, and to determine how well can the Gradient XL method can be used to predict the subsurface layers.

II. LITERATURE REVIEW

Ground Electrical Resistivity Survey (GERS) is a geophysical method used to investigate subsurface properties by measuring the resistance to the flow of an electric current through the ground. This technique has become widely used in civil engineering, environmental studies, and archaeological investigations. By applying electrodes to the ground and measuring the potential difference, it is possible to infer subsurface features such as variations in soil moisture, voids, fractures, and the presence of fluids.

GERS is commonly employed in groundwater studies, dam seepage investigations, and other geotechnical applications. Different electrode configurations, or arrays, can be used to optimize data collection for specific geological conditions or objectives.

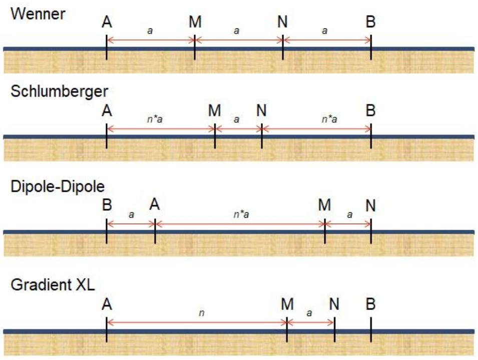

Fig. 2. Different array methods

The GERS consists of a set of electrodes placed at a significant distance apart, which will measure voltage differences. As depicted in Fig. 2, two current electrodes (A and B) are placed at a significant distance apart, with multiple potential electrodes (M and N) are spread in between or separately as per the relevant array method. The controlling instrument will select the relevant electrode. However, four other array methods are available as Gradient XL, Schlumberger, Dipole-Dipole & Wenner with different electrode arrays.

As per the results of a comparison of Wenner and dipole-dipole arrays to determine an underground cavity by Neyamadpour et.al [1], Wenner array was superior over the dipole-dipole array. However they have carried out a three dimensional electrical resistivity imaging. Three array methods were compared by Al-Saady et.al [2] in 2D resistivity survey in Iraq to determine subsurface weak zones, and have found that dipole-dipole array is more sensitive than others with large number of data. They have concluded that dipole-dipole array is the optimum for mapping subsurface weak zones. Furthermore, In Sri Lankan context, Wickramasooriya [3] has carried out a study on applicability of the available four arrays and determined that Schlumberger method is well accepted to delineate subsurface soil layers in a project at Ellewewa, Sri lanka. Moreover, Wickramasooriya et.al [4] has concluded that GERS can be applied to determine seepage paths in the earthen dams.

Himi et.al [4] has studied complementary geophysical methods including electrical resistivity tomography, seismic refraction tomography and frequency-domain electromagnetic surveys to determine seepage and mortar injected areas. Their results show areas where corrective mortar was injected and abnormal seepages. Aning et.al [5] has used electrical resistivity tomography models to locate faults and fractures and the thickness of the post impact lake sediments and the breccias. Athanasiou et.al [6] conclude in their study that, there is no single optimum array which can always give valid and useful results, independent of the target characteristics. They have used Jacobian matrices for the data sets and combined weighted inversion algorithm is proved to be a useful tool for data interpretation.

Neyamadpour et.al [7] has carried out another 3D electrical resistivity imaging survey and analysed using least squares algorithm, based on the robust inversion method. Their results show that using combined inversion method can be highly useful for the investigations. Wijesekara et.al [8] has carried out a resistivity survey to delineate a leachate plume. Their study confirms that the GERS can be effectively utilized to assess the subsurface characteristics of the open dumpsites.

III. Area Geology

As per the Geology map (Fig. 3) of Sri Lanka, the particular area mainly consists with Quartzites (pure coarse-grained ridge forming quartzites locally with less than 5% each of sillimanite, kaolinised feldspar or biotite). Due to the silica content, this rock is very resistant to chemical weathering.

This site is located at the transition zone of Wanni and highland lithotectonic boundaries. Therefore, major folds, lineation, and shear zones can be identified at both minor and major scales. Further, deformations of rock units can be occurred under high strain conditions. It can be predicted that the breaching of the bund might have been happened along the shear zone that expands from North West direction to South East.

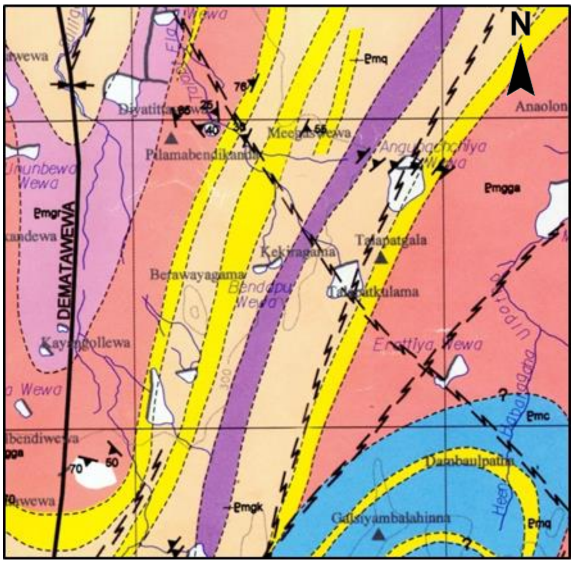

Fig. 3. Area Geology of the Thalapathkulama

(GSMB Provisional map series 1:100000 Vavuniya-Trincomalee)

IV. Methodology

Six numbers of GERSs were conducted in four survey lines, a summary of them are given in Table 01. Four lines were surveyed (Fig.4) for the electrical resistivity. ERS line-1 (ERS- Electrical Resistivity Survey Line) was from 0+000 LB end towards the breached section at 0+120, ERS line-2 was from the breached section to the existing rock at 0+323 along the bund top, ERS line-3 was across the sluice outlet, it is from 0+350 to 0+750 RB end of the bund. ERS line 4 lies on upstream of the LB side. All the ERS lines were almost parallel to the bund or along the bund.

11 number of drill holes were drilled (Fig. 4) and only DH 1, DH 2 DH 5, DH 6, DH 7, DH 9, DH 10, & DH 11 were used for the analysis based on their locations with respect to the GERS lines. Table 02 tabulates relevant ERT for each drill hole.

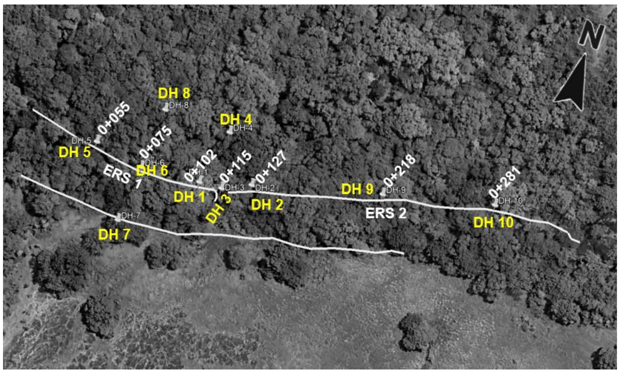

Fig. 4. Location of the boreholes

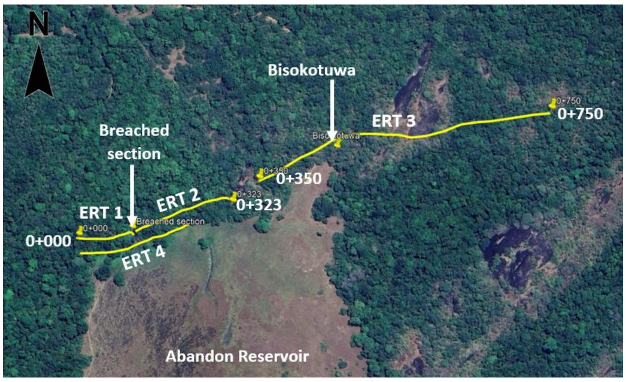

Fig. 5. Locations of GERS lines

Table 01 – Summary of the survey lines

Chainage	ERT	Length	Method
0+000 to 0+120	ERT 1	120 m	Gradient XL
0+123 to 0+323	ERT 2	200 m	Gradient XL
0+350 to 0+750	ERT 3	400 m	Gradient XL
0+350 to 0+750	ERT 3	400 m	Schlumberger
0+350 to 0+750	ERT 3	400 m	Wenner
0+020 to 0+220 (US)	ERT 4	200 m	Gradient XL

Table 02 – Summary of the drill hole locations

Chainage	Drill hole	Drilled depth	Relevant ERT
0+102	DH 1	15.45 m	ERT 1
0+127	DH 2	18.46 m	ERT 2
0+115	DH 3	15.30 m	-
0+115 , 25 m DS	DH 4	17.66 m	-
0+055	DH 5	18.40 m	ERT 1
0+075	DH 6	15.40 m	ERT 1
0+075 , 25 m US	DH 7	11.00 m	ERT 4
0+075 , 25 m DS	DH 8	17.00 m	-
0+218	DH 9	20.40 m	ERT 2
0+281	DH 10	15.05 m	ERT 2
0+625	DH 11	16.08 m	ERT 3

As depicted in the methodology in Fig.6 the ERT results from each GERS were compared with the drilled Bore Hole (BH) results. The bore hole data were logged in log sheets and they were simplified in to three layers for the convenience of comparison. The simplified layers are;

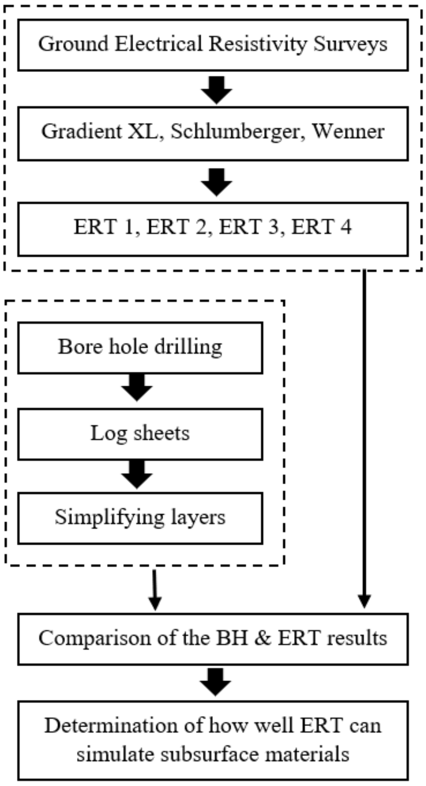

Fig. 6. Methodology

Soil layer (S) : This was considered as the layer which includes embankment filling material, soil and sand with aggregates such as pebbles & gravel etc.

Weathered rock layer (WR): This was considered as the layer which includes Completely Weathered (CW) and Highly Weathered (HW) rock layers.

Hard Rock layer (HR) : This was considered as the layer which includes Moderately Weathered (MW), Slightly Weathered (SW) and Fresh Rock (FR)

The anomalies which are shown in graphical variations in the ERT were compared with the simplified bore hole data according to the above-mentioned layers. Then, it was ascertained how well the ERT results were compatible with BH data.

V. Results & Discusion

Fig. 7 to Fig. 10 depicts the location of the boreholes in each ERT. Table 03 summarizes the results from boreholes. Fig.11 to Fig.13 show the comparison of the ERT results with the layers from bore hole results. As mentioned, ERT 1, ERT 2 & ERT 4 were carried out using gradient XL array method and ERT 3 was carried out using Gradient XL, Schlumberger & Wenner methods.

As depicted in Fig. 11, the ERT results graphically simulate the BH results in an acceptable level in DH 5 bore hole. According to the considered layers (S, WR & HW) by the authors, the gradual variation of resistivity values varies as 0 – 30 Ωm for Soil layer, 30 – 150 Ωm for Weathered Rock layer & more than 150 Ωm for Hard Rock layer. The anomalies are well depicted by the ERT simulation in DH 5.

ERT line – 01 Chainage 0+000 to 0+120

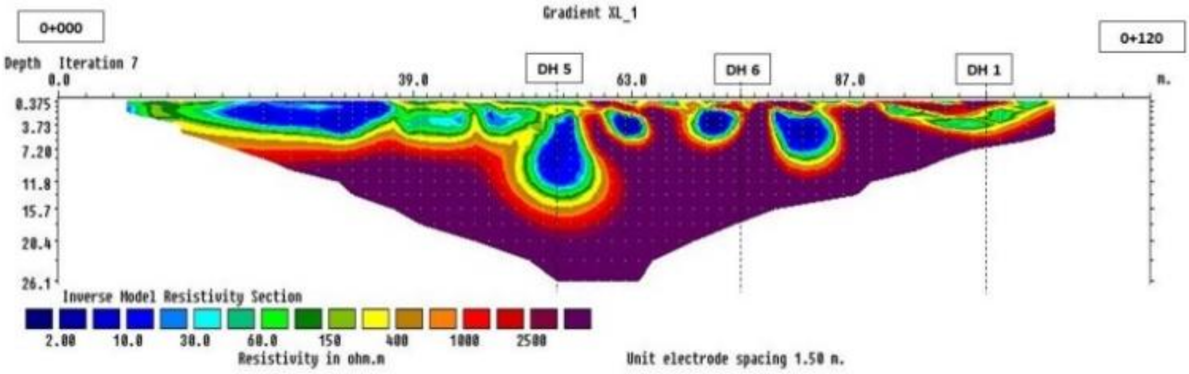

Fig. 7. Locations of DH5, DH6 & DH1 in ERT 1

ERT line – 02 Chainage 0+123 to 0+323

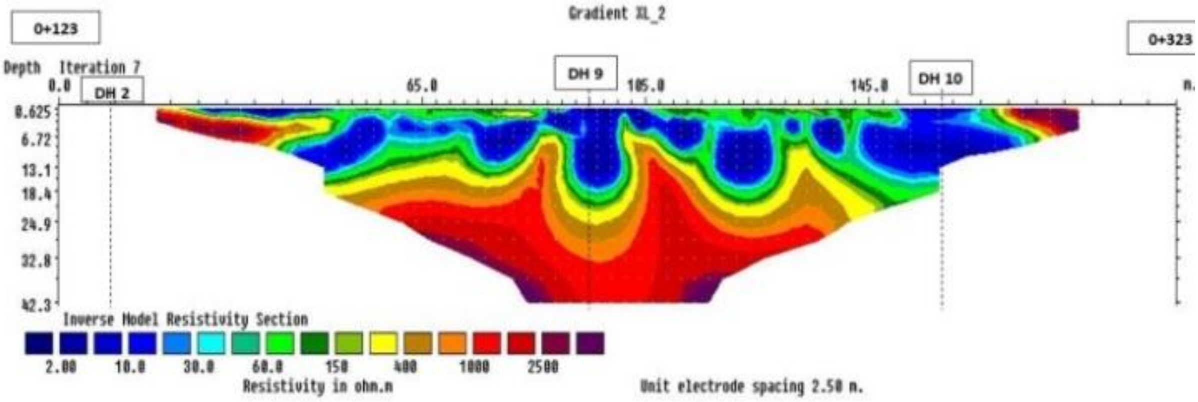

Fig. 8. Locations of DH2, DH9 & DH10 in ERT 2

ERT line – 04 Chainage 0+020 to 0+220 (5m to 20m upstream approx.)

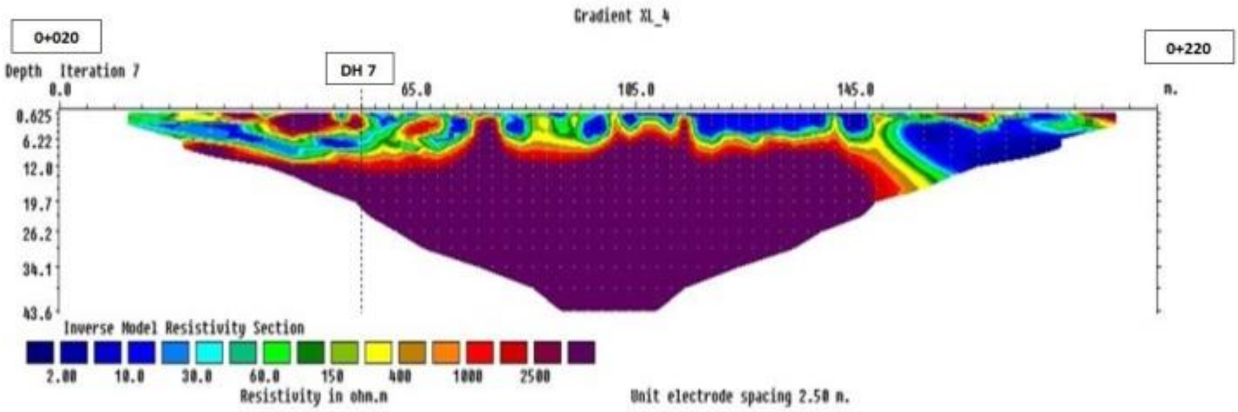

Fig. 9. Locations of DH7 in ERT 4

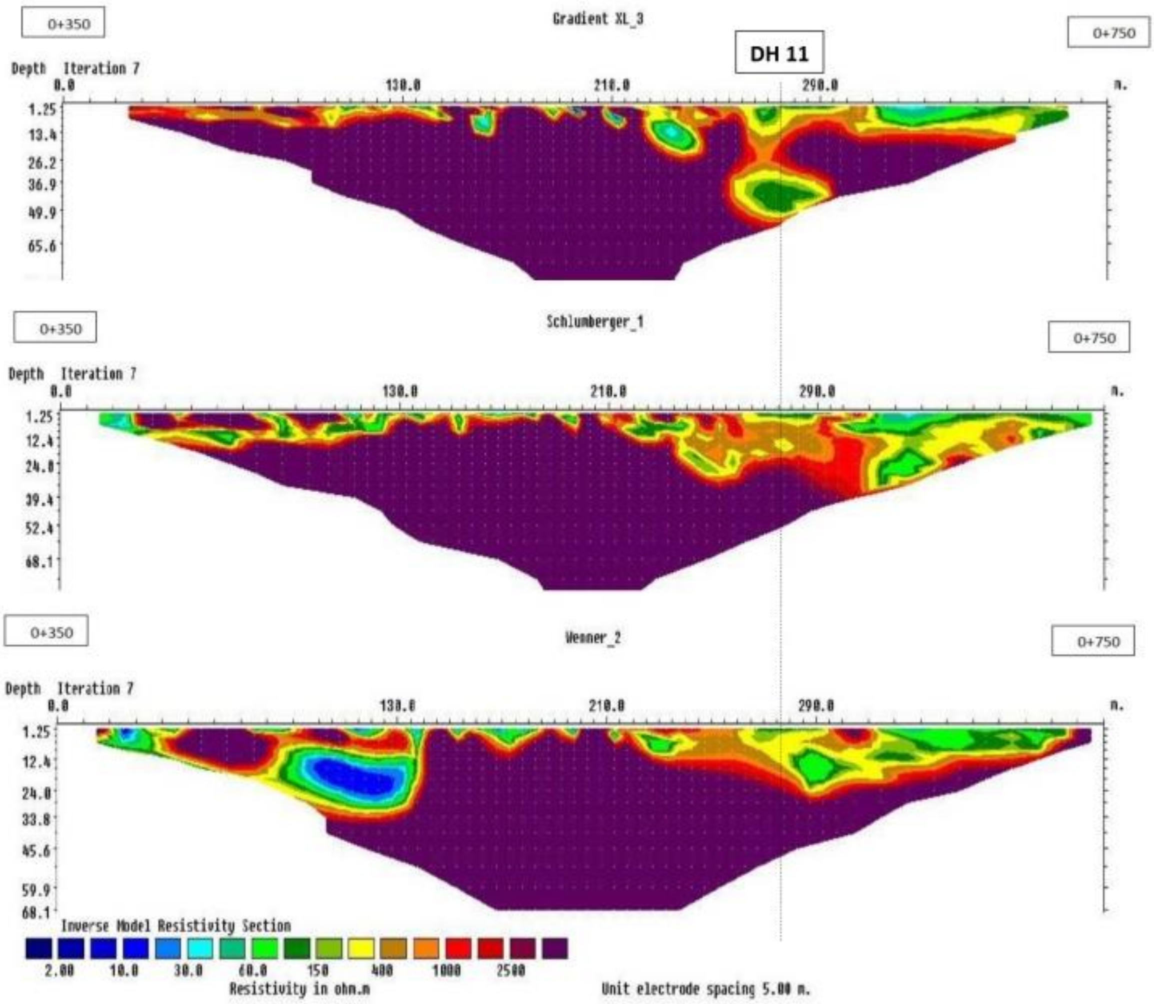

Fig. 10. Locations of DH 11 in ERT 3 using Gradient XL, Schlumberger & Wenner methods

Table 03 – Summary of the drill hole results

ERT	DH	Soil layer (m)	Weathered Rock layer (m)	Hard Rock layer (m)
ERT 1	DH 5	0-11.00	11.00-14.00	14.00-18.40
	DH 6	0-6.20 6.70-7.75	6.20-6.70 7.75-8.00	8.00-15.40
	DH 1	0–8.15	8.32-8.50	8.15-8.32 8.50-15.45
ERT 2	DH 9	0-13.25	-	13.25-20.40
	DH 10	0-7.80	-	7.80-15.05
ERT 3	DH 11	0-5.30	-	5.30-16.08
ERT 4	DH 7	0-3.78	3.78-5.38	5.38-11.00

However, an acceptable variation was not shown by ERT profile for DH 6 & DH 1 in ERT 1 profile (Fig 11). Even though the profile could scan the subsurface materials in DH 6, the GERS could not capture DH 1 up to a sufficient depth.

As depicted in Fig.12, even though the ERT results for DH 9 does not match with BH results in a highly acceptable level, it can be accepted moderately in DH 9. As in DH 1 in ERT 1, the ERT results in DH 10 were not scanned up to a considerable depth since it is located near to the edge of the profile.

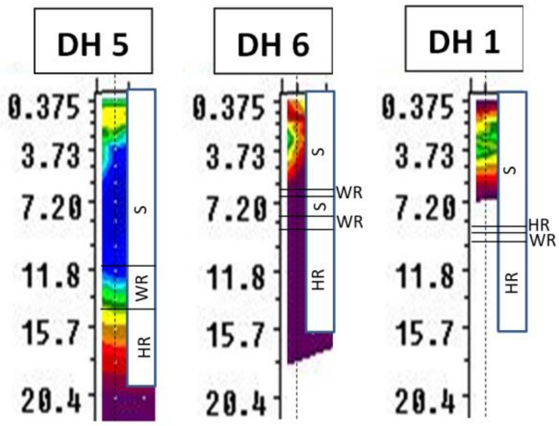

Fig. 11. Comparison of borehole data with ERT results in ERT1

As depicted in Fig. 13, the anomaly in Soil layer can be assumed as the anomalies in the filling material in DH7, and the WR and HR layer matches well with the ERT simulation. As depicted in Fig. 14, among the three array methods, Schlumberger and Wenner methods matches with BH data in DH 11 up to an acceptable level. This verifies the results obtained by Wickramasooriya [3] in Ellewewa project in Sri Lanka.

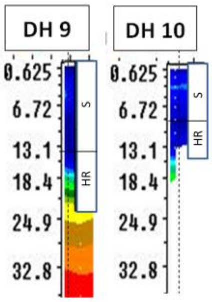

Fig. 12. Comparison of borehole data with ERT results in ERT2

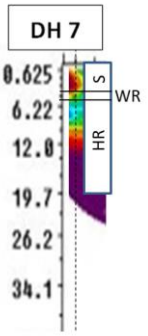

Fig. 13. Comparison of borehole data with ERT results in ERT 4

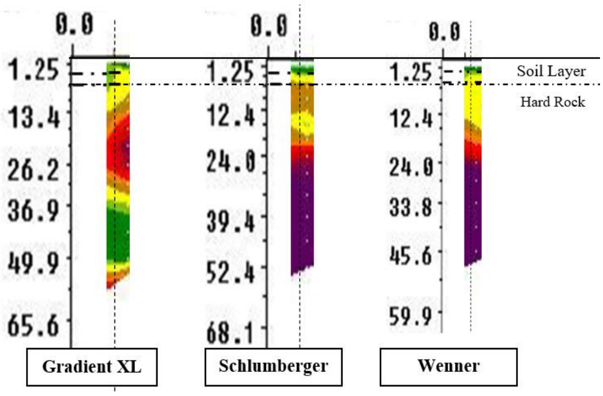

Fig. 14. Comparison of borehole data (DH11) with ERT results in ERT 3

The causes for the existing anomalies in the Soil layer in DH 7 may be due to the anomalies in the filling material, because it is not formed by a natural phenomenon.

GERS can be considered as an economical method of indirect investigations and it depends on the data interpretation based on the resistivity values while BH drilling is based on the physically drilling the earth. Further, the GERS method provides 2D or 3D resistivity profiles of the subsurface, offering spatially continuous data and drilling BH provides information about the subsurface materials at specific point. Greater depths in GERS require wide electrode spacing which might reduce resolution at shallower levels, and the depth of BH drilling is limited by the drilling equipment. Both cost and consuming time will be less in GERS compared to traditional drilling BHs, and it will be environmentally friendly method.

VI. CONCLUSIONS

The following conclusions can be suggested based on the study.

- ERT method is less suitable for estimating the soil details at the edges of the ERT profile.
- Further improvements can be carried out for the studies on applicability of the array methods out of Dipole-dipole,Gradient XL,Schlumberger & Wenner , to delineate the soil sub surface profiles.
- Gradient XL method was less capable to predict the Soft soil layers, Hard soil layers & Rock layers. However, GERS can be applied as an alternative approach for geotechnical investigations.

VII. FUTURE DEVELOPMENTS

The followings can be recommended as future studies that can be carried out for the development of this study area.

- Application of Image analysis software or Numerical analysis software to compare the GERS results with bore hole data.
- Study on combined algorithm of the GERS results using different arrays.

ACKNOWLEDGMENT

The authors would like to acknowledge The Irrigation Department, Director of Irrigation (Engineering Geology) and Drilling investigation team lead by Mr.I.C.Gunasinghe

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