APPLICATION OF VERTICAL ELECTRICAL SOUNDING FOR GROUNDWATER INVESTIGATION IN THE PREMISES OF THE SABARAGAMUWA UNIVERSITY OF SRI LANKA

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ABSTRACT

Growing social, as well as development activities in the premises of Sabaragamuwa University of Sri Lanka (SUSL) and its surroundings, have reformed the natural landscape of the area. Consequently, water demand is increasing. Therefore, an understanding of the subsurface geology and their potential as beneficial aquifers help to overcome the impending water demand because surface water scares in the area. In view of assessing the groundwater potential of the area, an initial study was conducted using topographic and satellite maps followed by a geo-electrical resistivity survey, consisting of vertical electrical sounding (VES) and electrical profiling. Results revealed three subsurface layers in most places. The resistivity of the topsoil layer is ranging between about 50 to 2800 Ωm and the average thickness between 1 m to 15 m. The second layer is characterized by resistivity between about 16 to 9760 Ωm . The resistivity of the third layer ranges from about 2 to 5600 Ωm , and extending to a depth of more than 100 m. Most of the curves were identified as K type. The rest of the curves were H, Q, and A types. Out of 18 VES points, nine locations were identified as possible locations for groundwater abstraction. Groundwater could be located at a depth of between 25 to 60 m. Resistivity data indicate that the regolith mostly forms the aquifers in the area along with some weathered rock aquifers at depth. Most of the points close to or at valleys were found to be deep aquifers. Considering all the geological, structural, and morphological features, nine locations were identified as most convincing and could be recommended for test drilling.

Keywords: *Groundwater, Resistivity, Subsurface Structures, Sabaragamuwa University of Sri Lanka*

INTRODUCTION

Groundwater accounts for about 1% of the total water on the Earth and makes up to 35 times the amount of water in lakes and streams (Famiglietti, 2014). More than two billion people around the world depend on groundwater as their main water source and for cultivation, half or more of the irrigation water relies on the groundwater sources (Famiglietti, 2014).

Groundwater is significant from surface water due to several reasons. Groundwater usually free from pathogenic organisms and usually no need of purification for domestic and industrial uses. Groundwater has an approximately constant temperature which is beneficial for

heat exchange purposes. Usually, groundwater has negligible turbidity and colour. The chemical composition of the groundwater is stable. The storage of groundwater is always higher than the storage of surface water, and groundwater supplies are not severely affected by short period droughts. Biological contamination in groundwater is rare (Shankar, 1994; Siebert et al., 2010; Ojo et al., 2012).

In Sri Lanka, groundwater demand has become rapidly increased over the past few decades due to population growth, infrastructure and economic development, and shortage of rainfall. Based on the recent estimates, more than 55% of the population depend on

groundwater for their water necessities (Herath and Rathnayake, 2007).

Six major types of groundwater aquifers namely shallow karstic aquifers, deep confined aquifers, coastal sand aquifers, alluvial aquifers, lateritic (*cabook*) aquifers, and shallow regolith aquifers in the hard rock region have been delineated and identified in Sri Lanka (Panabokke and Perera, 2005). Other than these main types of aquifers, a large number of small groundwater pockets are distributed all over the country and occur either isolated spots of soil cover at top of the solid rock or in the weathered and fractured zones of the underlying metamorphic bedrock formation (Herath and Rathnayake, 2007).

Electrical prospecting is the most commonly used geophysical method for groundwater exploration as there is rapid response for the variations in conductivity of the groundwater bearing formations (Freeze and Cherry, 1979; Maheswari et al., 2013). Parameters such as amount and distribution of the water within the rock, porosity, pore size and shape, temperature, and the salinity of the water affect the electrical properties of rocks in the upper part of the Earth's crust (Zohdy et al., 1974; Todd, 1980).

The current water demand of the University and surrounding area is basically met by the supply from surface water resources, Hirikatu Oya and Kalupahana. The water supply is not adequate for the University community and the local community around the University. Also, there are issues related to the water quality and treatment process. It is challenging to maintain the demand from the current water supply during the dry periods and people face scarcity of water. Sometimes due to deteriorating the quality of surface water sources, outbreak of diseases related to the consumption of polluted water is also common during the dry season in the University area. The feasibility of the groundwater occurrences and conditions within the study area is still to be investigated. It is also important to investigate suitable locations of deep groundwater conditions and estimate possible depths for deep groundwater abstraction.

LOCATION

Sabaragamuwa University of Sri Lanka is situated 162 km away from Colombo within the Imbulpe Divisional Secretariat division in the Sabaragamuwa province (Latitude 6.7148833°, Longitude 80.7870949°). The study area mainly covers the premises of SUSL. However, the research was extended to the nearby sites covering as a whole about 1000 acres. Geologically the area belongs to the Highland Complex and closes to the Highland-Vijayan boundary underlain by crystalline metamorphic rocks. The altitude of the area is about 800 m

Fig. 01 Study area on lithotectonic map of Sri Lanka (after Cooray, 1994)

above mean sea level in the intermediate zone with an annual rainfall of 1875-2500 mm and the average temperature of 28.3°C.

GEOLOGY

As stated before, the area belongs to the Highland Complex and close to the Highland-Vijayan boundary (Figure 01) and the rocks are mostly crystalline metamorphic rocks; Garnet sillimanite-biotite gneiss±graphite: pelitic schist or gneiss.

Fig. 02. Study area (Premises of the Sabaragamuwa University of Sri Lanka (SUSL)): Profile and VES locations

METHODOLOGY

Several groundwater investigation techniques were used to investigate the groundwater potential of the area. Those techniques include geological and geomorphologic methods, remote sensing techniques, and surface geophysical methods. First, geological and geomorphologic methods and remote sensing techniques were carried out to identify possible locations for groundwater occurrence and then electrical resistivity surveys were conducted focusing on those locations.

The geological, geomorphological, climatological, and hydrological backgrounds of an area govern the occurrence, movement, and groundwater storage. Topo-sheets, maps, reports, records, and some field observations were used to identify geological, geomorphological, climatological, and hydrological conditions of the area. Based on those sources: joints, valleys, landslide deposits, old stream beds, weak zones, and surface drainage of the area were identified,

which are essential structural features of groundwater occurrence.

The electrical resistivity method is the most commonly applied geophysical method in groundwater exploration. The electrical resistivity method is efficient in identifying water-bearing subsurface layers, and the method is simple, and field investigations are inexpensive to carry out (Zohdy et al., 1974). Two types of electrical resistivity surveys were carried out using Schlumberger electrode configuration. Electrical profiling was used to determine lateral changes in the subsurface resistivity, and vertical electrical sounding (VES) was used to determine the resistivity variation with depth.

Suitable locations for resistivity surveys were determined based on geological and geomorphological data, remote sensing data and field observations. Nine electrical profiling and eighteen vertical electrical soundings (Figure 02) were carried out within the study area. Vertical electrical soundings were carried

Fig. 03 Resistivity meters (a) ABEM Terrameter LS 2, (b) Geo-electronics resistivity meter

out based on profiling data and covering important geological formations. Electrical profiling was conducted across valleys, fracture zones, and other geological formations. VES was carried out after analysing profiling data where apparent resistivity (Ro_a) values are significantly changed. Also, several VES were carried out at locations, which are not possible to carry out profiling.

Resistivity Meter

Geo-electrical surveys were carried out using Resistivity meter (Geo-electronics) (Figure 03 (b)) verified to ABEM 1000 and compared with ABEM Terrameter LS 2 (Figure 03 (a)) for test investigations.

A paired t-test was carried out on 27 data points obtained from Geo-electronics resistivity meter and ABEM Terrameter LS 2 to determine whether there was a statistically significant mean difference in Ro_a values measured by the Geo-electronics resistivity meter and ABEM Terrameter LS 2. The measured Ro_a by the Geo-electronics resistivity meter was lower (51.84 ± 44.33) than measured Ro_a by the ABEM Terrameter LS 2 (53.13 ± 45.09). There is a statistically significant mean difference of 1.286 between the two instruments (95% CI, 2.168, 0.404) where $p < 0.006$. Since the mean difference between the two instruments is approximately equal to 1.3, we assumed that the Ro_a value measured by ABEM Terrameter LS 2 was similar to the

Table 1. Resistivity values (ρ), thickness (h) and depth (d) of subsurface layers according to ABEM Terrameter LS 2 and Geo-electronic resistivity meter

ABEM terrameter LS 2					Geo-electronic resistivity meter				
N	ρ (Ωm)	h (m)	d (m)	Alt (m)	N	ρ (Ωm)	h (m)	d (m)	Alt (m)
1	24.5	0.643	0.643	-0.6426	1	23.1	0.696	0.696	-0.6964
2	3.39	0.101	0.743	-0.7432	2	3.25	0.118	0.815	-0.8149
3	12.9	7.89	8.63	-8.632	3	12.9	7.73	8.54	-8.541
4	6536				4	6472			

Instrument Verification

Using both instruments, two vertical electrical soundings were carried out simultaneously using the same electrode configuration. Results were statistically analyzed to determine the significant difference between the instruments.

Ro_a value measured by the Geo-electronics resistivity meter.

Table 1 shows the resistivity values, thickness values, and depth of each subsurface layer according to the VES carried out from the ABEM Terrameter LS 2 and Geo-electronics

resistivity meter respectively. It is clear that resistivity values and corresponding thickness and depth values of each subsurface layer are almost similar to each other from the results of

and K ($\rho_1 < \rho_2 > \rho_3$), respectively. VES 01 was conducted at a point middle of a small valley. VES 1 indicates the most probable curve shape for groundwater conditions. According to the

Fig. 04. Vertical electrical sounding curve (a) ABEM Terrameter LS 2 (b) Geo-electronics resistivity meter

each instrument. Also, VES curves (Figure 04) for data obtained for each instrument were similar to each other.

RESULTS AND DISCUSSION

All nine electrical profiles were carried out at distinct locations within the University premises and nearby areas (Figure 02). Profiling data confirmed that small valleys would be possible points of groundwater occurrence. In most of the profiles, readings were obtained at the AB/2 values of 15, 30, and 40 m with the distance between two adjacent points of 10 m. Ro_a values were changed between 10 Ω m to 1500 Ω m.

Profile 01 (Figure 05 (a)) shows lower Ro_a values at the stations of 3 (AB/2: 15, 30, 40 m: 236.2, 269.2, 383.1 Ω m) and 7 (AB/2: 15, 30, 40 m: 466.5, 409.7, 392.5 Ω m) comparing to the adjacent stations. In between stations 3 and 7, station 5 shows highest Ro_a values (AB/2: 15, 30, 40 m: 544.3, 828.9, 848.1 Ω m). Based on the results of profile 01 (Figure 5 (a)), three 1D VES were conducted at station 3 (VES 1), 5 (VES 2), and 7 (VES 3). When comparing three VES curves, three subsurface layers can be identified (Table 2). The curves of VES 1, 2, and 3 (Figure 6 (a), (b) and (c)) can be categorized according to the resistivity values of each layer as A ($\rho_1 < \rho_2 < \rho_3$), K ($\rho_1 < \rho_2 > \rho_3$),

curve (Figure 6 (a)), three subsurface layers could be identified. The soil layer extends to the depth of 7.5 m. Then soft rock region continues about to the depth of 35 m and after the hard rock. Groundwater conditions could be identified to a depth of 50 m. However, the VES 2 and 3 (Figure 6 (b) and (c)) show hard rock closer to the surface (around 0.5-1 m) and no significant variation after penetration depth of 10 m.

The station 07 in profile 02 (Figure 05 (b)) shows the overall lower Ro_a values (AB/2: 4.5, 15, 30, 40 m: 257.1, 245.9, 392.5, 209.9, 104.4 Ω m). According to the profile 2 (Figure 05 (b)), station 7 was identified as a possible point of good groundwater conditions. Therefore VES 4 was carried out at the station 7 of profile 2. Results revealed that three major subsurface layers. Depending on the Ro_a values of each layer, the curve could be categorized as K ($\rho_1 < \rho_2 > \rho_3$) type. VES 4 conformed that good aquifer condition from the depth of 40 m to about 75 m which will be highly weathered or fractured zone. According to the curve (Figure 06 (d)), good groundwater conditions could be identified from the depth of 40 m, and the point could be proposed for a deep tube well.

Fig. 05. (a-i) Resistivity profile curves along profile line 1 to line 9 respectively. Data were acquired at 10 m distance between stations except profile 03 which was 5 m interval between stations.

Fig. 06.(a-r) Vertical Electrical Soundings curves of VES points (X axis - $AB/2$ (m), Y axis – Apparent resistivity (Ωm)) (a) VES 1 (b) VES 2 (c) VES 3 (d) VES 4 (e) VES 5 (f) VES 6 (g) VES 7 (h) VES 8 (i) VES 9 (j) VES 10 (k) VES 11 (l) VES 12 (m) VES 13 (n) VES 14 (o) VES 15 (p) VES 16 (q) VES 17 (r) VES 18

Profile 3 was a much detailed investigation with the 5 m distance between two adjacent stations and data was obtained for 6 AB/2 values. In the curve (Figure 05 (c)) low Ro_a values can be observed at the station 1 (AB/2: 4.5, 8, 25, 30, 40, 50 m: 421.3, 578, 496.1, 466.6, 546.4, 577.1 Ω m) and 3 (AB/2: 4.5, 8, 25, 30, 40, 50 m: 738, 709.1, 584.5, 601.9, 491.3, 483.9 Ω m). Ro_a values at deeper layers show uniform distribution among stations. VES 5 was conducted at the station 3 of the profile 3, and three subsurface layers could be identified from the results. The curve could be categorized as H ($\rho_1 > \rho_2 < \rho_3$) according to the Ro_a values of each layer. From the curve of VES 5 (Figure 06 (e)), groundwater conditions could be identified from 25 m to 60 m. VES 6 was conducted at a point close to the profile 3, and the curve (Figure 06(f)) was identified as H ($\rho_1 > \rho_2 < \rho_3$) type.

Location of the profile 4 was a small mountain ridge where would not be possibility of groundwater, considering the geological aspects around the area. In the profile 4 (Figure 05 (d)) several low resistivity points were identified, and VES 7 and VES 8 were carried out at station 3 and station 10. However, the Ro_a values (Table 02) were highly changed between some adjacent layers showing unusual distribution. This may be due to several reasons; low penetration of the current as a result of very dry soil of the area. However, any possible groundwater condition would not be identified from the curves.

Table 2. Resistivity values (ρ), thickness (h) and depth (d) of subsurface layers at VES 1 to VES 18

VES 1					VES 2					VES 3				
N	ρ (Ω m)	h (m)	d (m)	Alt (m)	ρ (Ω m)	h (m)	d (m)	Alt (m)		ρ (Ω m)	h (m)	d (m)	Alt (m)	
1	240	1.48	1.48	-1.48	49	0.575	0.575	0.575		143	0.379	0.379	-0.379	
2	404	12.6	14.1	-14.1	9760	2.6	3.18	-3.179		469	28	28.4	-28.44	
3	594				126					326				
VES 4					VES 5					VES 6				
N	ρ (Ω m)	h (m)	d (m)	Alt (m)	ρ (Ω m)	h (m)	d (m)	Alt (m)		ρ (Ω m)	h (m)	d (m)	Alt (m)	
1	413	6.86	6.86	-6.86	1487	13.1	13.1	-13.1		566	1.98	1.98	-1.985	
2	1073	4.55	11.4	-11.41	120	10.9	24	-24		118	2.68	4.66	-4.664	
3	49.2				5602					616				
VES 7					VES 8					VES 9				
N	ρ (Ω m)	h (m)	d (m)	Alt (m)	ρ (Ω m)	h (m)	d (m)	Alt (m)		ρ (Ω m)	h (m)	d (m)	Alt (m)	
1	180	1.21	1.21	-1.206	598	11.3	11.3	-11.3		1403	3.67	3.67	-3.675	
2	61.2	4.06	5.26	-5.262	135	39.8	51.1	-51.1		973	30	33.7	-33.66	
3	367				24.8					1.56				
VES 10					VES 11					VES 12				
N	ρ (Ω m)	h (m)	d (m)	Alt (m)	ρ (Ω m)	h (m)	d (m)	Alt (m)		ρ (Ω m)	h (m)	d (m)	Alt (m)	
1	165	2.65	2.65	-2.651	315	2.66	2.66	-2.661		193	5.07	5.07	-5.066	
2	1611	3.92	6.57	-6.572	539	30.4	33.1	-33.11		814	26.5	31.6	-31.61	
3	115				91.2					1.93				
VES 13					VES 14					VES 15				
N	ρ (Ω m)	h (m)	d (m)	Alt (m)	ρ (Ω m)	h (m)	d (m)	Alt (m)		ρ (Ω m)	h (m)	d (m)	Alt (m)	
1	799	13.8	13.8	-13.83	623	7.92	7.92	-7.921		204	12.3	12.3	-12.33	
2	374	86.2	100	-100	194	92.1	100	-100		570	12.5	24.8	-24.8	
3	1.93				1.93					16.8				
VES 16					VES 17					VES 18				
N	ρ (Ω m)	h (m)	d (m)	Alt (m)	ρ (Ω m)	h (m)	d (m)	Alt (m)		ρ (Ω m)	h (m)	d (m)	Alt (m)	
1	554	100	100	-100	2793	13.4	13.4	-13.4		583	13.9	13.9	-13.9	
2	15.1				104	86.6	100	-100		15.7	12	25.9	-25.91	
3					737					731				

VES 9 and VES 10 were conducted at the station 5 (AB/2: 15, 30, 40 m: 132.6, 77.6, 105.9 Ω m) and 8 (AB/2: 15, 30, 40 m: 61.1, 43.2, 80 Ω m) of the profile 5 (Figure 05 (e)) respectively. According to the Ro_a values of each layer, the curves of VES 9 and VES 10 (Figure 06 (i) and (j)) could be categorized as Q ($\rho_1 > \rho_2 > \rho_3$) and K ($\rho_1 < \rho_2 > \rho_3$) type respectively. Three major subsurface layers could be identified in the area. VES 9 (Figure 06 (i)) expresses the possibility of groundwater. From the curve, a continuous decrease of Ro_a values can be observed from the depth of 20 m. There may be a fracture zone in the rock. However, these fractures may be wet or dry. Therefore in order to better interpretation, further investigations should be performed.

Low Ro_a values were observed at the station 5 (AB/2: 15, 30, 40 m: 138.9, 207.5, 154.7 Ω m), 8 (AB/2: 15, 30, 40 m: 26.6, 116.9, 101.2 Ω m) and 10 (AB/2: 15, 30, 40 m: 305.2, 388.7, 345 Ω m) of the profile 6 (Figure 05 (f)). Hence VES 11, 12 and 13 were conducted at the station 5, 8 and 10 respectively. Depending on the Ro_a values of each subsurface layer, the curves of VES 11 and 12 (Figure 06 (k), (l) and (m)) could be categorized as K ($\rho_1 < \rho_2 > \rho_3$) type and 13 as Q ($\rho_1 > \rho_2 > \rho_3$) type. From three VES soundings, point of VES 11 and VES 13 (Figure 06 (k) and (m)) could be identified as possible locations for groundwater abstraction.

VES 14 was conducted at the station 4 (AB/2: 15, 30, 40 m: 421.3, 329.9, 293.6 Ω m) of the profile 7 (Figure 05 (g)) where low Ro_a values were observed. Based on the results, three subsurface layers could be identified.

Fig. 07. Suitable VES locations for tube wells

Depending on the Ro_a values (Table 02) of subsurface layers, the curve could be identified as Q ($\rho_1 > \rho_2 > \rho_3$) type. In the curve (Figure 06 (n)) low resistivity zone could be identified from about the depth of 20 m to 40 m, which would be a possible zone of groundwater. VES 15 was conducted at a point close to the profile 7, and the curve (Figure 06 (o)) was identified as K ($\rho_1 < \rho_2 > \rho_3$) type.

In the profile 8 (Figure 05 (h)) sudden decrease of Ro_a values could be observed at the station 5 (AB/2: 15, 30, 40 m: 425.9, 333.4, 309.5 Ωm) where the VES 16 was conducted. The shape of the curve (Figure 06 (p)), reflects two subsurface layers and uniform distribution of the Ro_a values could be identified from the depth of 8 m. The shape of the curve considers as a good indication of the presence of groundwater.

VES 17 (Figure 06 (q)) was conducted without performing a profile. Three subsurface layers can be identified from the table (Table 2). According to the distribution of Ro_a values of each subsurface layer the curve type could be H ($\rho_1 > \rho_2 < \rho_3$) type. The hard rock region could be identified from the depth of 35 m. Groundwater conditions could be expected from about a depth of 45 m. Therefore deep tube well will be optimum for the location. The depth of the well should be about 60 m. VES 18 was conducted along a mountain ridge and resistivity values show a very unusual distribution. The curve (Figure 06 (r)) was identified as K ($\rho_1 < \rho_2 > \rho_3$) type.

CONCLUSION

Three subsurface layers could be observed in the majority of the VES curves. The resistivity of the top layer ranging between 50 Ωm - 2800 Ωm and the average thickness between 1 m to 15 m. The second layer has resistivity values between 16 Ωm - 9760 Ωm and the maximum thickness of 92.1 m was recorded at VES 14. The resistivity of the third layer ranges from 2 Ωm - 5600 Ωm . Most of the curves were identified as K type. The rest of the curves were H, Q and A type. Out of eighteen VES points, nine locations were identified as possible locations for groundwater abstraction. Groundwater could be located at a depth of 25 - 60 m. Resistivity data indicate that the

aquifers in the area as regolith type aquifers along with deep weathered rock aquifers. Most of the points close to or at valleys prevail deep groundwater aquifers. Considering all the geological, structural, and morphological features, we suggest locations at VES 1, VES 4, VES 5, VES 9 VES 11, VES 13, VES 14, VES 16, and VES 17 (Figure 07) as most convincing for test drilling. Moreover, the resistivity data could also be used to interpret subsurface conditions for engineering purposes.

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