Acidic Barren Slope Profiling using Electrical Resistivity Imaging (ERI) at Ayer Hitam area Johor, Malaysia

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Abstract. Recently, non-destructive method such as the electrical resistivity technique has become increasingly popular in engineering, environmental, mining and archeological studies nowadays. This method was popular in subsurface profiling due to its ability to replicate the images of the subsurface indirectly. The soil slope found in Batu Pahat, specifically in Ayer Hitam, is known to be problematic due to its barren condition. This location is believed to contain futile soil due to its difficulty in supporting the growth of vegetations. In the past, acidic barren slope assessment using non-destructive method was rarely being used due to several reasons related to the equipment and knowledge constraints. Hence, this study performed an electrical resistivity imaging using ABEM Terrameter LS in order to investigate the acidic barren slope conditions. Field data acquisition was based on Schlumberger and Wenner arrays while RES2DINV software was used to analyze and generate a 2-D model of the problematic subsurface profile. Based on electrical resistivity results, it was found that the acidic barren slope studied consists of two main zones representing residual soil (electrical resistivity value = 10 – 600 $\Omega$m) and shale (electrical resistivity value = 20 – 2000 $\Omega$m). The results of resistivity value were correlated with the physical mapping and the in situ mackintosh probe test for verification purposes. It was found that the maximum depth of the mackintosh probe test was 1.8 m due to its ground penetration limitation. However, the results of the resistivity section managed to achieve greater depth up to 40 m. Hence, the correlation between electrical resistivity and mackintosh probe results can only be performed at certain depth of the acidic barren slope profile in contrast with the physical mapping which able to define the whole section of the barren soil slope structure. Finally, a good match of electrical resistivity results calibrated with mackintosh and physical mapping data showed that this technique was appropriate to be applied in near-surface acidic barren slope assessment which can further compliment borehole data and other physical mapping data at a lower cost, higher speed, large data coverage and better environmental sustainability.
1. Introduction
Barren slopes along roadways have a high probability to collapse or slide due to heavy rainfall distribution. This catastrophe can cause fatal and heavy damages to our life and properties. Hence, relevant assessment related to field testing is crucial in order to determine the soil profile condition thus minimizing or preventing such disasters. Boring, drilling and excavation are traditional ways of subsurface earth exploration [1]. There are several limitations related to the traditional technique due to it being expensive, time consuming [2,3] as well as limited data coverage [4,5,6,7]. Moreover, conventional site investigation tools such as drilling pose certain difficulties in steep and hilly terrain, swampy areas, coastal regions and complex geomaterial areas which need to be investigated [1]. Furthermore, those conventional techniques are destructive methods which could lead to site damage. This is considered unsustainable in construction industry. As a result, an alternative approach able to reduce cost, save time, ensures larger data coverage and minimal ground destruction needs to be explored.

Recently, geophysical methods such as electrical resistivity, seismic method (refraction and reflection), magnetic, gravity, ground penetrating radar and etc are getting increasingly popular in engineering, environment and archeological studies. Generally, geophysical method applies the principles of physics properties in studying the earth such as resistivity, velocity, density, magnetic susceptibility and etc. Geophysical methods are able to compliment and minimize conventional method limitations due to its efficiency in terms of cost, time, data coverage [5,1,6,8,9] and sustainability [10,11,12]. Field operations require less manpower while data processing and results have become quite easy and quick to obtain compared to the conventional drilling method [12]. In the past, geophysical methods have been used as an alternative tool in many situations related to detection or characterization purposes such as leachate mapping [13,14,15], bedrock mapping [16], overburden materials [10,16,17], cavity and boulder detection [18], groundwater mapping [2,19,20,21], mining exploration [22,23] and archeological studies [24,25,26]. Generally, the process of geophysical methods involved data acquisition, data processing and data interpretation. Geophysical surveys are non-destructive methods thus able to minimize the disruption and damage to the site due to its surface technique [12]. Hence, this technique is considered sustainable since it preserves our environment during the data acquisition stages. However, according to Mauritsch et al. [7], the standard of geophysical methods depends on fundamental physical constraints such as penetration, resolution and signal to noise ratio.

Geophysical method with particular reference to electrical resistivity has been widely used in soil profiling [10,17]. As mentioned previously, geophysical method with particular reference to electrical resistivity method has been used for subsurface profiling related to the soil, boulder, bedrock and groundwater mapping. However, studies related to acidic barren slope profiling based on non-destructive method are still new and need to be explored. Electrical resistivity property was determined by measuring the potential difference at points on the ground surface which caused the propagation of direct current through the subsurface [27]. Basically, the resistivity image was interpreted based on the contrast of geomaterials with verification through previous established references charts, tables, and other related data and information. Finally, a variation of resistivity distribution from the image can be interpreted and the barren soil slope profile was able to be determined successfully.

2. Materials and Methods
This study was located at the Batu Pahat area specifically in Ayer Hitam. Generally, the site of study has mixed topography of undulating hilly terrain and is located near the developing industrial areas, small town and housing area. The general geology of Malaysia has been well documented [28]. The Ayer Hitam area is located on a triassic zone (pale blue colour) which consists of a mixture between interbedded sandstone, siltstone and shale as shown in Figure 1. In general, the presence of this type of rock exhibits geological structures, namely joint, fold, fault and bedding. Those geological
discontinuities may possibly be present in the studied area thus accelerating the rate of weathering due to the surface water seepage, groundwater carriage, and water storage in soil and rock formation. During the field observation, it was found that this area consists of two major zones with particular reference to residual soil and weathered sedimentary rock which are confirmed through physical mapping at the surrounding existing rock outcrops. Moreover, during the localized physical mapping, geological structures related to bedding, fold, joint and fault could be spotted as they were exposed on the surface.

![Figure 1](image_url). Geology of the study area [28].

Electrical resistivity imaging (2-D electrical resistivity survey) was performed using ABEM Terrameter LS. A single spread line of electrical resistivity survey was performed across the problematic soil slope in this study area. The test configuration was based on Schlumberger and Wenner array using four resistivity land cables, 61 electrodes and 64 jumper cables. Equal electrode spacing of 5.0 m was used for all 61 electrodes producing total electrical resistivity for a survey length of 200 m. Schlumberger array was used during the data acquisition since it is able to provide dense near-surface coverage of resistivity data. As reported by [29], the array provides a good vertical resolution and can give a clear image of groundwater and sand-clay boundaries as horizontal structures. Furthermore, the array is able to provide greater depth of subsurface profiles within limited spaced area during the resistivity data acquisition. Meanwhile, Wenner array was performed at the same location in order to verify the Schlumberger array results. Raw data obtained from data acquisition was processed using commercialized RES2DINV software [30] to provide an inverse model that approximates the actual subsurface structure. The inversion algorithm of RES2DINV was used to process the data, as proposed by [31] in order to replicate the 2-D model of the subsurface profile. An additional test was conducted using X-Ray Fluorescence (XRF) test in order to verify the earth material with the electrical resistivity results obtained.

3. Results and Discussions

Barren soil slope outcrop mapping and electrical resistivity tomography (ERT) results from Schlumberger and Wenner array are presented in Figure 2, 3 and 4 respectively. Moreover, the electrical resistivity value specifically at the center of the ERT was extracted from Figure 4 and 5 and presented in Table 1.

According to physical mapping and Figure 2, the dotted red line indicates the presence of the black soil layer within the slope structure representing the barren geomaterial. According to Figure 3 and 4, the highest resistivity value was located at the middle of the ERT representing the middle of the slope.
structure. Moreover, the lowest resistivity value was found at both bottom flanks of the ERT. According to Figure 3 and 4, it was found that the Schlumberger array has a greater profiling depth (38 m) compared to the Wenner array result (32 m).

According to Table 1, it was found that the Schlumberger array produced higher electrical resistivity value (ERV) compared to the Wenner array. However, the resistivity contrast and distribution was found to be similar thus able to confirm that the electrical resistivity method was applicable in barren soil slope profiling. In the past, the dissimilarity of resistivity value commonly occurred due to several reasons. Basically, this factor occurred due to the different geometry factor, K, used during the field measurements [32,33,34,35]. The value of apparent ERV (pa) was greatly influenced by K factor applied in every measurement. Geometry factor, K, describes the geometry of the electrode configuration used in data acquisition. Apparent resistivity (pa) is ERV estimated based on half-pace geometry assumption which refers to the field ERV. According to [36], apparent resistivity will be equal to the true resistivity provided the current and configuration was applied over the homogeneous isotropic ground. Field ERV was determined using Schlumberger and Wenner array with a geometry factor as given in final Eq. 1 and 2 which is derived from basic Eqs. 3 and 4. Schlumberger and Wenner geometry factor, K, used in this study was derived from basic Eq. 4 based on basic four-electrode system of measurement. The schematic diagram of field array with particular reference to Schlumberger and Wenner resistivity configuration was given in Figure 5 and Figure 6 while the schematic diagram for the four electrode system is given in Figure 7. Hence due to its dissimilarity of ERV, the previous established reference charts and tables related to the resistivity value of earth materials were commonly presented in a certain range of values.

Figure 2. The acidic barren slope studied at Ayer Hitam.

Figure 3. Electrical resistivity tomography (ERT) based on Schlumberger array.

Figure 4. Electrical resistivity tomography (ERT) based on Wenner array.
Table 1. Resistivity data at central of resistivity line (100m from the initial point).

| Depth (m) | Resistivity (Ωm) |
|----------|------------------|
|          | Schlumberger     | Wenner         |
| 0.94     | 352.11           | 343.885        |
| 2.91     | 428.485          | 390.075        |
| 5.07     | 751.825          | 546.175        |
| 7.45     | 1441.65          | 804.30         |
| 10.07    | 3037.35          | 1303.20        |
| 12.96    | 2705.15          | 1129.15        |
| 16.13    | 1679.70          | 748.26         |
| 19.62    | 980.41           | 471.365        |
| 23.45    | 624.355          | 312.40         |
| 27.67    | 422.47           | 227.25         |
| 32.31    | 344.05           | 186.535        |
| 37.42    | 368.595          |                |

\[ \rho_s = 2\pi r^* R \]  \quad (1)

where \( R \) is a resistance term given by \( R = \Delta V/I \)

\[ \rho_s = (2\pi \Delta V/I)^*(-(1/(1/r1 - 1/r2) - (1/r3 - 1/r4))) \]  \quad (2)

where \( r_1 = (L - x), r_2 = (L + x), r_3 = (L - x) \) and \( r_4 = (L + x) - 1 \)

\[ \rho_s = K^*(R) \]  \quad (3)

where \( R \) is a resistance term given by \( R = \Delta V/I \), \( K \) is geometry factor based on pole-dipole electrode configuration

\[ \rho_s = (2\pi \Delta V/I)^*(-(1/(1/r1 - 1/r2) - (1/r3 - 1/r4))) \]  \quad (4)

where \( K = ((1/(1/r1 - 1/r2) - (1/r3 - 1/r4)) \)

Figure 6. Wenner electrode array arrangement.
A 2-D resistivity model was compared with the geological map as shown in Figure 1 to display the similarities between both findings. Overall lithology comparison explains that the study area consists of sedimentary rock with particular reference to shale situated at the bottom of the slope structure. According to [37], shale has a resistivity value from 5 – 1000 Ωm. Hence, both ERT from Figure 3 and Figure 4 have reached some good agreement based on physical mapping, geological map and previous reference of ERV. Moreover, it is widely known that the composition of shale consists of a large portion of silica (SiO2). Hence, this study performed an X-Ray Fluorescence (XRF) test which found that the minerals dominant in Ayer Hitam samples is silica with a concentration of 70.6 % as shown in Table 2.

| Formula | Concentration (%) |
|---------|-------------------|
| CO₂     | 0.10              |
| SiO₂    | 70.60             |
| Al₂O₃   | 21.00             |
| K₂O     | 4.75              |
| SO₃     | 1.08              |
| Fe₂O₃   | 1.01              |
| TiO₂    | 0.67              |
| Na₂O₃   | 0.26              |
| MgO     | 0.20              |
| Zr      | < LLD             |
4. Conclusion
The problematic subsurface profile with particular reference to acidic barren slope was successfully investigated using electrical resistivity imaging (ERI). The electrical resistivity value was largely influenced by the variations of sedimentary earth materials beneath the ground surface. The result obtained from the study area consists of two zones, which are residual soil zone with a resistivity of $10^{-600}$ Ωm and shale zone with a resistivity of $20-2000$ Ωm. This finding has proved that this method is able to predict the slope condition in order to complement conventional borehole data. ERI successfully mapped the acidic barren slope and surface information was extended using the physical mapping technique. The mechanics and physical characteristics of the slope can be easily recognized. The determination of shape, depth and geomaterial stiffness of the problematic slope is relatively easier and cheaper than the conventional borehole method. This geophysical method is suitable for our sustainable ground investigation since it can save time, money and complement other conventional methods especially using its 2D surface technique of investigation. To conclude, the application of ERI in conjunction with geological and borehole information was effectively applied for acidic barren slope assessment.

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References
[1] Khatri R, Shrivastava V K and Chandak R 2011 Correlation between vertical electric sounding and conventional methods of geotechnical site investigation. *Int. Journal of Advanced Engineering Sciences and Technologies*. 4 042-053
[2] Zainal Abidin M H, Baharuddin, M F T, Zawawi M H, Ali N, Madun and Azhar A T S 2015 Groundwater Seepage Mapping using Electrical Resistivity Imaging. *Applied Mechanics and Materials*. 774 1524–1534
[3] Osman F I S and Osman, S B A S 2012 Integrating geo-electrical and geotechnical data for soil characterization. *International Journal of Applied Physics and Mathematics*. 2 104-106
[4] Hazreek Z A M, Aziman M, Azhar A T S, Chitral W D, Fauziah A and Saad R 2015 The Behaviour of Laboratory Soil Electrical Resistivity Value under Basic Soil Properties Influences. *IOP Conference Series: Earth and Environmental Science*. 23 1-9
[5] Abidin M H Z, Ahmad F, Wijeyesekera D C, Saad R and Baharuddin M F T 2013 Soil Resistivity Measurements to Predict Moisture Content and Density in Loose and Dense Soil. *Applied Mechanics and Materials*. 353-356 911-917
[6] Godio A, Strobbia C and De Bacco G 2006 Geophysical Characterisation of a Rockslide in an Alpine Region. *Engineering Geology*. 83 273-286
[7] Mauritsch H J, Seiberl W, Arndt R, Römer A, Schneiderbauer K and Sendlhofer G P 2000 Geophysical Investigations of Large Landslides in the Carnic Region of Southern Austria. *Engineering Geology*. 56 373-388
[8] Liu C and Evett J B 2008 *Soils and Foundation* (New Jersey: Pearson International)
[9] Cosenza P, Marmet E, Rejiba F, Jun Cui Y, Tabbagh A and Charley Y 2006 Correlations between geotechnical and electrical data: A case study at Garchy in France. *Journal of Applied Geophysics*. 60 165-178
[10] Hazreek Z A M, Rosli S, Chitral W D, Fauziah A, Azhar A T S, Aziman M and Ismail B 2015 Soil Identification using Field Electrical Resistivity Method. *Journal of Physics: Conference Series*. 622 1-7
[11] Abidin M H Z, Aziman M, Azhar A T S, Chitrwal W D, Fauziah A and Saad R 2015 The Influence of Basic Physical Properties of Soil on its Electrical Resistivity Value under Loose and Dense Condition. *Journal of Physics: Conference Series*. 495 1-13

[12] Abidin M H Z, Saad R, Ahmad F, Wijeyesekera D C and Baharuddin M F T 2012 Seismic Refraction Investigation on Near Surface Landslides at the Kundasang area in Sabah, Malaysia. *Procedia Engineering*. 50 516 – 531

[13] Abdullahi N And Osazuwa I 2011 Geophysical imaging of municipal solid waste contaminant pathways. *Environmental Earth Sciences*. 62 1173-1181

[14] Frid V, Liskevich G, Doudkinski, D and Korostishevsky N 2008 Evaluation of landfill disposal boundary by means of electrical resistivity imaging. *Environmental Geology*. 53 1503-1508

[15] Abu-Zeid N, Bianchini G, Santarato G and Vaccaro C 2004 Geochemical characterisation and geophysical mapping of Landfill leachates: the Marozzo canal case study (NE Italy). *Environmental Geology*. 45 439-447.

[16] Saad R, Muztaza, N M and Mohamad E T 2011. The 2D Electrical Resistivity Tomography (ERT) Study for Civil and Geotechnical Engineering Purposes. *Electronic Journal of Geotechnical Engineering*. 16 1537-1545

[17] Yamakawa Y, Kosugi K. I, Masaoka N, Sumida J, Tani M and Mizuyama T 2011 Combined geophysical methods for detecting soil thickness distribution on a weathered granitic hillslope. *Geomorphology*. 145–146 56-69

[18] Jusoh Z 2010 Application of 2-D resistivity imaging and seismic refraction technique in subsurface investigation for civil engineering, M.S. thesis, Sch. Physics, Science Univ., Penang, Malaysia

[19] Saad R, Nawawi M N M and Mohamad E T 2012 Groundwater Detection in Alluvium Using 2-D Electrical Resistivity Tomography (ERT). *Electronic Journal of Geotechnical Engineering*. 17 369-376

[20] Juanah M E, Ibrahim S, Sulaiman W and Latif P 2012 Groundwater resources assessment using integrated geophysical techniques in the southwestern region of Peninsular Malaysia. *Arabian Journal of Geosciences*. 1-16

[21] Zawawi M H, Syafalni and Abustan I 2011 Detection of Groundwater Aquifer Using Resistivity Imaging Profiling at Beriah Landfill Site, Perak, Malaysia. *Advanced Materials Research*. 250-253 1852-1855

[22] Saad R, Adli I and Mohamad A S 2012 The Study of Iron Ore Prospect using 2-D Resistivity and Induced Polarization (IP) Method. *Electronic Journal of Geotechnical Engineering*. 17 2981-2988

[23] Karimi N S, Hojat A, Kamkar-Rouhani A, Akbari J H and Maknooni S 2011 Successful Use of Geoelectrical Surveys in Area 3 of the Gol-e-Gohar Iron Ore Mine, Iran. *Mine Water and the Environment*. 30 208-215

[24] Saad R, Saidin M M, Muztaza N M, Ismail N A and Ismail, N E H 2011 Subsurface Study Using 2-D Resistivity Imaging Method for Meteorite Impact at Bukit Bunuh, Perak. *Electronic Journal of Geotechnical Engineering*. 16 1507-1513

[25] Batayneh A 2010 The use of magnetometry and pole-dipole resistivity for locating Nabataean Hawar archeological site in the SW-Jordan. *Archaeological and Anthropological Sciences*. 2 151-156

[26] Fabrizio T G 2007 Identifying geological and geotechnical influences that threaten historical sites: A method to evaluate the usefulness of data already available. *Journal of Cultural Heritage*. 9 302-310

[27] Burger H R, Sheehan A F and Jones C H 2006 *Introduction to Applied Geophysics* (New York: W.W. Norton & Company)

[28] Mineral and Geoscience Department Malaysia, *Geological Map of Peninsular Malaysia* 1985, eighth edn., Ministry of Natural Resources and Environment
[29] Hamzah U, Yaacup R, Samsudin A and Ayub M 2006 Electrical imaging of the groundwater aquifer at Banting, Selangor, Malaysia. Environmental Geology. 49 1156-1162

[30] Loke M H, Acworth I, and Dahlin T 2003 A comparison of smooth and blocky inversion methods 2-D electrical imaging surveys. Exploration Geophysics. 34(3) 182–187

[31] Loke M H and Barker R D 1996 Rapid least squares inversion of apparent resistivity pseudosection using a quasi-Newton method. Geophysical Prospecting. 44(3) 131–152

[32] Hazreek Z A M, Saiful A T S, Aziman M, Rosli S, Wijeyesekera D C and Fauziah A “Integral analysis of laboratory and field electrical resistivity for soil density prediction.” Proc. The 3rd Int. Conf. on Applied Geophysics (Hong Kong 2015)

[33] Abidin M H Z, Saad R Wijeyesekera D C, Ahmad F and Ismail N A 2014 The Influence of Electrical Resistivity Array on its Soil Electrical Resistivity Value. Applied Mechanics and Materials. 510 185-192

[34] Abidin M H Z, Saad R, Wijeyesekera D C and Ahmad F, 2013 Soil Resistivity Influence due to the Different Utilization of Electrical Resistivity Array. Electronic Journal of Geotechnical Engineering. 18 5643–5654

[35] Abidin M H Z, Saad R, Wijeyesekera D C and Ahmad F “Integral Analysis of Laboratory and Field Electrical Resistivity Value for Soil Moisture Content Prediction,” Proc. The 3rd Int. Conf. on Applied Geophysics (Sarawak, Kuching Malaysia. 2013)

[36] Telford W M, Geldart L P and Sheriff R E 1990 Applied Geophysics (Cambridge: Cambridge University Press)

[37] Griffith D H and King R F 1981 Applied Geophysics for Geologist and Engineers (Oxford: Pergamon Press)