UNIVERSITI PUTRA MALAYSIA

EVALUATION OF GEOLOGICAL FORMATION FOR POTENTIAL GROUNDWATER AQUIFER BY INTEGRATED GEOPHYSICAL TECHNIQUES

NOR FARHANI BINTI YUSOF

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By

NOR FARHANI BINTI YUSOF

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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June 2018

Chairman: Mohamed Azwan Mohamed Zawawi, M.S
Faculty: Engineering

Electrical resistivity method is the most popular method among geophysical techniques in groundwater exploration mainly in evaluating hydrogeological properties of the subsurface. However, electrical resistivity method can only identify the subsurface resistance specifically the subsurface structure, not the groundwater potential zone. Other than that, different hydrogeological formations have different groundwater yield potential. Thus, by using integrated geophysical technique can give a better interpretation.

The main objective is to determine the potential groundwater zone in different types of soil and rock categories. A study on 2D geo-electrical was conducted at Taiping, Perak, Serdang and Jenderam Hilir, Selangor. The technique of geophysics analysis was carried out by using two geo-electrical method of electrical resistivity and induced polarization method for better interpretations in the same area. Field works have been carried out using Terrameter SAS 4000, Electric Selector ES1064 and LUND cable with electrode. Horizontal resistivity lines were proposed with length of 400m each by using Wenner-Schlumberger configuration. Electrical current was injected into the ground and two potential electrodes are measured resulting in voltage difference for electrical resistivity and transient decay for induced polarization.

The images of 2D profile have been produced using Res2Dinv software through inversion method which provided detailed information of both the laterally and vertically geological structures based on their part. The Cluster Analysis of Hierarchical Agglomerative Clustering Analysis has been used to differentiate different types of soil and rock characteristic. The data from the

electrical resistivity result in form of numerical value have been used in XLSTAT-Pro software by using Ward Method. The characteristic of alluvium can be classified to clay, silt, fine and medium sand, coarse sand, sand and gravel, and gravel. Otherwise, rock characteristics can be differentiated based on the stages of rock weathered. Induced polarization method resulted in the value of chargeability that has potential to determine the freshwater of the subsurface.

Thus, the integration of geophysical technique and statistical analysis can identify the high potential of aquifer zone in different categories of formation. Through this study, it can save you time and cost, where groundwater potential can be determined without running the drilling process.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENILAIAN FORMASI GEOLOGI UNTUK POTENSI AKUIFER AIR BAWAH TANAH DENGAN MENGGUNAKAN TEKNIK GEOFISIK BERSEPADU

Oleh

NOR FARHANI BINTI YUSOF

Jun 2018

Pengerusi: Mohamed Azwan Mohamed Zawawi, M.S
Fakulti: Kejuruteraan

Kaedah rintangan elektrik adalah kaedah yang paling popular di antara teknik geofisik dalam penerokaan air bawah tanah terutamanya dalam menilai sifat hidrogeologi subpermukaan. Walau bagaimanapun, kaedah rintangan elektrik hanya boleh mengenal pasti rintangan bawah permukaan terutamanya struktur bawah permukaan bukan zon potensi air bawah tanah. Selain itu, pembentukan hidrogeologi yang berbeza mempunyai potensi hasil tanah air yang berbeza. Oleh itu, dengan menggunakan teknik geofizik bersepadu dapat memberikan tafsiran yang lebih baik.

Objektif utama kajian ini adalah menentukan zon air bawah tanah yang berpotensi dalam kategori tanah dan batuan yang berlainan. Satu kajian geo-elektrik 2D telah dijalankan di Taiping, Perak, Serdang dan Jenderam Hilir, Selangor. Teknik analisis geofizik telah dijalankan dengan menggunakan kaedah dua geo-elektrik rintangan elektrik dan kaedah polarisasi terinduksi untuk tafsiran yang lebih baik di kawasan yang sama. Kerja-kerja lapangan telah dijalankan menggunakan Terrameter SAS 4000, Selektor Elektrik ES1064 dan kabel LUND dengan elektrod. Garis rintangan horizontal telah dicadangkan dengan panjang 400m setiap satu dengan menggunakan konfigurasi Wenner-Schlumberger arus elektrik disuntik ke dalam tanah dan dua elektrod potensi diukur menyebabkan perbezaan voltan untuk kerintangan elektrik dan waktu transien untuk polarisasi terinduksi.

Imej-imej profil 2D telah dihasilkan menggunakan perisian Res2Dinv melalui kaedah penyongsangan yang menyediakan maklumat terperinci kedua-dua sisi dan menegak struktur geologi berdasarkan peranan mereka. Analisis Kluster Clustering Agregat Hierarki telah digunakan untuk membezakan pelbagai jenis

sifat tanah dan batuan. Data dari hasil kerintangan elektrik dalam bentuk nilai berangka telah digunakan dalam analisis kluster menggunakan perisian XLSTAT dalam Excel. Ciri aluvium telah dikelaskan kepada tanah liat, kelodak, pasir halus dan sederhana, pasir kasar, pasir dan kerikil, dan kerikil. Manakala, untuk ciri-ciri batu ia boleh dibeza berdasarkan pada tahap batuan yang terluluhawa. Kaedah polarisasi terinduksi mengakibatkan nilai kebolehgunaan yang berpotensi untuk menentukan air tawar bawah permukaan.

Oleh itu, integrasi teknik geofizik dan analisis statistik dapat mengenal pasti potensi tinggi zon akuifer dalam kategori pembentukan yang berbeza. Melalui kajian ini, dapat menjimatkan masa dan kos, dimana potensi air bawah tanah dapat ditentukan tanpa menjalankan proses pengerudian.

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I certify that a Thesis Examination Committee has met on (date of viva voce) to conduct the final examination of Nor Farhani binti Yusof on her thesis entitled ("Evaluation Of Geological Formation Categories For High Groundwater Aquifer Potential By Using Integrated Geophysical Techniques") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science

Members of the Thesis Examination Committee were as follows:

Abdul Rashid bin Mohamed Sharif, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Md. Rowshon Kamal, PhD
Senior Lecturer
Faculti of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ismail bin Yusoff, PhD
Professor
Faculty of Science
Universiti Malaya
(External Examiner)

RUSLI HAJI ABDULLAH, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 30 August 2018

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of the degree of Master of Science. The members of the Supervisory Committee were as follows:

Mohamed Azwan Mohamed Zawawi, M.S
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Aimrun Wayayok, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Hafizan bin Juahir, PhD
Senior Lecturer
East Coast Environmental Research Institute (ESERI)
Universiti Sultan Zainal Abidin,
(Member)

ROBIAH BINTI YUNUS, PhD
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Signature: _____
Name of Chairman of Supervisory Committee: Mohamed Azwan Mohamed Zawawi

Signature: _____
Name of Member of Supervisory Committee: Aimrun Wayayok

Signature: _____
Name of Member of Supervisory Committee: Hafizan Juahir

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LIST OF ABBREVIATIONS AND SYMBOLS

M	: meter
Ωm	: ohm.m
msec	: millisecond
mg/L	: milligrams per litre
E	: Easting
N	: Northing
TDS	: Total Dissolve Solid
USDA	: United States Department of Agriculture
WHO	: World Health Organization
RMS	: Root Mean Square
HACA	: Hierarchical Agglomerative Clustering Analysis
CA	: Clustering Analysis
RWQC	: Raw Water Quality Criteria
DWQS	: Drinking Water Quality Standard

CHAPTER 1

INTRODUCTION

1.1 General

Water has become very important nowadays especially in agriculture and industrial sectors. The treatment for surface water is now rising in cost due to the increase of pollution. Therefore, other alternatives have been used that is by using groundwater. Groundwater can be found between the pore spaces and rock aquifer. The potential of groundwater yield depends on the types of the geological formation. Thus, the physical characterization of the geological aquifer is important to be understood because it affects the discharge process for optimum groundwater supply (Bashir et. al, 2014) and to make sure of high productivity and promising well and yield (Moussa et. al, 2015).

Since 1920s, geophysical methods have been used with earliest uses primarily in mineral, hydrocarbon and later in water exploration (Fowler and Ayubcha, 1986). This is because geophysical method is very simple, low cost and time saving, compared to drilling method. Mostly all of the geophysical techniques will identify the physical properties of subsurface to the flow of the current (Bery et al, 2012). The technique can be beneficial in finding the boundaries and structure between the different formations. In addition, by applying the geophysical exploration, the elastic properties of different elements can be identified and types of formation can be explored. Many geophysical methods are available such as gravity, magnetic, self-potential, electrical resistivity, induced polarization and etc. These methods have respective advantages and disadvantages depending on the target study area and the type of the area (Abdelwahab, 2013).

The integration of geophysical method has been widely used in determine the geological, hydrological and environment solution (Goldman and Neubauer, 1994). The combination of different types of geophysical method can give a more accurate and useful information of the hydrogeological information. The understanding of the site geology is very important in order to obtain a successful survey on groundwater exploration (Koening, 2008).

1.2 Problem Statement

In the past, drilling method that has been used to determine aquifer properties faced serious problem in a large scale project which is related to the time and cost (Hazreek et. al, 2014). The most direct method of obtaining subsurface data is by drilling observation and water supply wells, but it is expensive, costly

and therefore often inefficient (Goldman and Neubauer, 1994). Usually, the technique of drilling will be conducted in a way to get the site subsurface characterization. However, drilling method will only cover the small area. So, many boreholes are needed if the large area is needed to be covered, which will increase the cost and time (Hazreek et al, 2015). Thus, instead of searching for groundwater directly, other technique is needed to be apply for a better understanding of the lithology (Goldman and Neubauer, 1993)

Other than that, geological formation needs to be characterized individually for an appropriate assessment of its engineering behavior because different geological formation has different groundwater yield potential (Akanmu and Adewumi, 2016). However, there are some serious limitations in such investigations as they fail to distinguish the formations of similar resistivity (Mathiazhagan et. al, 2015). This is due to previous electrical resistivity value, geomaterial reference charts and tables are not easily adaptable and always exposed to the limitation due to its wide range of variation in the parametric values and the overlapping values between different formations. The results of electrical resistivity values were always subjected to a long discussion and debate among the related parties (Hazreek et al, 2015).

However, electrical resistivity sometimes fails for resistive groundwater location, (Robert, 2012) because electrical resistivity method allows only mapping contrasts of electrical resistivity of the subsurface structure (Brian et. al, 2004) of physical property of soils and rocks (Kiberu, 2002) but not subsurface materials. However, this will make be a limiting factor and ambiguity in the geological interpretation (Dahlin et al, 2002). For this reason, another geophysical technique is needed to be conducted in the same area (Yadav, 2015).

1.3 Objectives

The main objective of this study is to identify the groundwater potential zone of different types of geological formation by using integrated geophysical techniques. The specific objectives of this study are:

1. To obtain the resistivity and chargeability value for different types of geological formation using inverse polarization method with Wenner-Sclumberger array.
2. To differentiate the weathering process classification of all geological formation analysis by using cluster analysis
3. To evaluate the groundwater potential aquifer value of each geological formation.

1.4 Focus of the Study

This study is more focus on to identify the good groundwater potential aquifer that limit to quantity and quality (freshwater) through the geological formation. The characteristic of the subsurface is very important to be identified because it will affect the amount of water and groundwater behavior. The research has been carrying out at the different types of rock types that are alluvium, sedimentary rock (shale), igneous rock (granite) and metamorphic rock area (quartzite). Integrated method has been applied to obtain more accurate result.

REFERENCES

Abdelwahab, H. (2013). Comparison of 2D and 3D resistivity imaging methods in the atudy of shallow subsurface structures. *Greener J. Phys. Sci*, *3*(4), 149-158.

Adamovič J. (2011). Sedimentary rocks. *Institute Of Geology, Academy Of Sciences, Czech Republic . Earth System: History And Natural Variability* - Vol. I *adapted from* https://www.eolss.net/sample-chapters/c12/e1-01-02-07.pdf

Ahamad, F., Latif, M. T., Tang, R., Juneng, L., Dominick, D., & Juahir, H. (2014). Variation of surface ozone exceedance around Klang Valley, Malaysia. *Atmospheric Research*, *139*, *116-127*.

Aizebeokhai A. P. (2010), 2D and 3D geoelectrical resistivity imaging: theory and field design, *Scientific Research and Essays Vol. 5(23),* pp. 3592-3605

Akanmu, T. O., & Adewumi, A. J. (2016) Geophysical characterization of aquifer parameters within basement complex rocks using electrical sounding data from the Polytechnic, Ibadan, Southwestern Nigeria*. International Journal of Scientific Research in Knowledge, 4(5),* pp. 112-126, 2016

Aliman, S., Komoo, I., & Pereira, J. J. (2009). Kelestarian pembangunan sumber batu kapur di negeri Perak. *Bulletin of the Geological Society of Malaysia*, 55, 87-93.

Alisiobi, A. R., & Ako, B. D. (2012, April). Groundwater investigation using combined geophysical methods. In *Poster Presentation at AAPG Annual Convention and Exhibition*

Alwan, I.A. K., (2013). Comparison between conventional arrays in 2d electrical resistivity imaging technique for shallow subsurface structure detection of the University of Technology, *Engineering & Technology Journal, Vol. 31 (10, Part A) 1817-1824*

Andrew T, Wiebenga W.A(1965) Two layer resistivity curves for the wenner and schlumberger electrode configurations. Bureau of mineral Resources, *Geology and Geophysics, Department of National Development*

Andrews, H. E., Besancon, J. R., Gore, P. J. W., & Thompson, M. D. (1997). Sedimentary rocks, processes and environments. *Laboratory Manual In Physical Geology. Prentice Hall, Upper Saddle River*, 69-92.

Barker, R. D. (1990). Investigation of groundwater salinity by geophysical methods. *Geotechnical and Environmental Geophysics*, *2*, 201-211.

Bashir, I. Y., Izham, M. Y., & Main, R. (2014). Vertical electrical sounding investigation of aquifer composition and its potential to yield groundwater in some selected towns in Bida basin of North Central Nigeria, *Journal of Geography and Geology 6(1), 60–69.*

Baculakova, K., & Gress, M. (2015). Cluster analysis of creative industries in the EU. *Економічний часопис-XXI*, (9-10), 15-18.

Bahrudin, N. F. D. B., & Hamzah, U. (2016, November). Geological and structural interpretation of Peninsular Malaysia by marine and aeromagnetic data: Some preliminary results. In *AIP Conference Proceedings* (Vol. 1784, No. 1, p. 060040). AIP Publishing.

Bery, A. A., Saad, R., Mohamad, E. T., Jinmin, M., Azwin, I. N., Tan, N. M. A., & Nordiana, M.M. (2012). Electrical resistivity and induced polarization data correclation with conductivity for iron ore exploration. *The Electronic Journal of Geotechnical Engineering,* 17, 3223-3233*.*

Binley, A., & Kemna, A. (2005). DC resistivity and induced polarization methods. in hydrogeophysics (pp. 129-156)*. Springer Netherlands.doi: 10.1007/1-4020-3102-5_5*

Bleil. D. F (1953), Induced polarization : A method of geophysical prospecting, *Geophysic, 18(3),636-661*

Bruvold, W. H., & Ongerth, H. J. (1969). Tasti quality of mineralized water. *Journal (American Water Works Association)*, 170-174.

Cardimona, S. (2002). Electrical resistivity techniques for subsurface investigation. *Department of Geophysics, University of Missouri Rolla-Mo*.

Chapman, D. V., & World Health Organization. (1996). Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring, Chapter 9 - Groundwater *ISBN 0 419 21590 5 (HB) 0 419 21600 6 (PB)*

Chaudhary, P., & Shukla, K. (2015). Status of physico-chemical parameter of ground water of Gorakhpur City UP India. *International Journal of Scientific & Technology Research*, *4*(8), 233-237.

Dablool, A. S., Elawad, M. A., Ahmed, A. A., & Mosa, O. F. (2011). Assesssment of chemical parameters of ground water in Holly Makkah. *Inter J of Inn Res in Sci Eng and Tech*, *2*(11), 5965-5970.

Dahlin, T., Leroux, V., & Nissen, J. (2002). Measuring techniques in induced polarisation imaging. *Journal of Applied Geophysics*, *50*(3), 279-298.

Daniels F. and Alberty R. A. (1996) *Physical chemistry*, John Wiley and Sons, Inc

Department of Engineering (DOE). 2000. National standard for drinking water quality, engineering services division *Ministry of Health Malaysia*

Ferreira, L., & Hitchcock, D. B. (2009). A comparison of hierarchical methods for clustering functional data. *Communications in Statistics-Simulation and Computation*, *38*(9), 1925-1949.

Fowler, J. W., & Ayubcha, A. M. I. N. (1986, October). Selection of appropriate geophysical techniques for the characterization of abandoned waste sites. In *Proc. Surface and Borehole Geophysical Methods and Ground Water Instrumentation Conf. and Exp., National Water WeU Association, Dublin, OH* (pp. 625-656).

Goldman, M., & Neubauer, F. M. (1994). Groundwater exploration using integrated geophysical techniques. *Surveys in geophysics*, *15*(3), 331-361

Groundwater Engineering (2016), *Report on groundwater exploration study using inverse polarization method with wenner-schlumberger electrode array at Pengerang, Johor Darul Takzim.* (Unpublished report, Hydrogeological Research Team). Soil And Water Conservation Lab, Department Of Biological & Agricultural Engineering, Faculty Of Engineering,Universiti Putra Malaysia.

Gülağız, F. K., & Şahin, S. (2017) Comparison of hierarchical and non-hierarchical clustering algorithms. *International Journal of Computer Engineering and Information Technology,* (Vol.9, No 1, January 2017, 6-14)

Hadian, M. S. D., Azy, F. N., Krismadiyanti, I., Arfani, D. L., Sofyan, E. T., & Prayogi, T. E (2015) Groundwater quality assessment for suitable drinking and agricultural irrigation using physico-chemical water analysis in the Rancaekek-Jatinangor District, West Java, Indonesia.*6th International Conference on Environmental Science and Technology Volume 84 of IPCBEE (2015), V84.10*

Han, P., Wang, J., Ma, Z., Lu, A., Gao, M., & Pan, L. (2011). Application of fuzzy clustering analysis in classification of soil in Qinghai and Heilongjiang of China. *Computer and Computing Technologies in Agriculture IV*, 282-289.

Harter, T. (2003). *Basic concepts of groundwater hydrology*. UCANR Publications. Harter, T. (2003). *Groundwater quality and groundwater pollution*. UCANR Publications.

Hazreek, Z. A. M., Aziman, M., Azhar, A. T. S., Chitral, W. D., Fauziah, A., & Rosli, S. (2015). The behaviour of laboratory soil electrical resistivity value under basic soil properties influences. In *IOP Conference Series: Earth and Environmental Science* (Vol. 23, No. 1, p. 012002). IOP Publishing.

Hazreek, Z. A. M., Rosli, S., Chitral, W. D., Fauziah, A., Azhar, A. T. S., Aziman, M., & Ismail, B. (2015). Soil identification using field electrical resistivity method. In *Journal of Physics: Conference Series* (Vol. 622, No. 1, p. 012030). IOP Publishing

Hazreek, Z. A. M., Azhar, A. T. S., Aziman, M., Rosli, S., Fauziah, A., & Chitral, W. D. (2015). Integral analysis of laboratory and field electrical resistivity for soil density prediction. In *Proc. The 3rd Int. Conf.on Applied Geophysics (Hong Kong)*

Hot, E., & Popović-Bugarin, V. (2015, November). Soil data clustering by using k-means and fuzzy k-means algorithm. In *Telecommunications Forum Telfor (TELFOR), 2015 23rd* (pp. 890-893). IEEE.

Huat, B. B., Ali, F. H., & Abdullah, A. (2005). Shear strength parameters of unsaturated tropical residual soils of various weathering grades. *Electronic Journal of Geotechnical Engineering*, *10*, 6.

Hutchison, C. S. T., & Denis, N. K. (2009). Geology of Peninsular Malaysia (Mesozoic stratigraphy): *The University of Malaya and The Geological Society of Malaysia*. *Kuala Lumpur, Malaysia*.

Ishaku Yakubu Bashir, Mohamad Yusoff Izham and Rindam Main (2014) , Vertical electrical sounding investigation of aquifer composition and its potential to yield groundwater in some selected towns in Bida Basin of North Central Nigeria,*Journal of Geography and Geology; Vol. 6, No. 1*

Isiyaka, H. A., & Juahir, H. (2015). Analysis of surface water pollution in the Kinta River using multivariate technique. *Malaysian Journal of Analytical Sciences*, *19*(5), 1019-1031.

Jabatan Mineral dan Geosains Malaysia, (2010). "Kajian hidrogeologi daerah Kerian, Selama dan Larut Matang, Perak

Jasin, B., & Harun, Z. (2007). Stratigraphy and sedimentology of the chert unit of the Semanggol Formation. *Geol Soc Malaysia Bull*, *53*, 103-109.

Jones F. (2007), Introduction to Induced polarization surveying, applied geophysics learning objects, UBC Earth & Ocean Science retrieved from https://www.eoas.ubc.ca/ubcgif/iag/methods/meth_2/index.htm

Jayeoba, A., & Oladunjoye, M. A. (2015). 2-D electrical resistivity tomography for groundwater exploration in hard rock terrain. *International Journal of Science and Technology*, *4*(4).

Juahir, H., Zain, S. M., Yusoff, M. K., Hanidza, T. T., Armi, A. M., Toriman, M. E., & Mokhtar, M. (2011). Spatial water quality assessment of Langat River Basin (Malaysia) using environmetric techniques. *Environmental monitoring and assessment*, *173*(1-4), 625-641.

Juanah, M. S., Ibrahim, S., Sulaiman, W. N. A., & Latif, P. A. (2013). Groundwater resources assessment using integrated geophysical techniques in the Southwestern region of Peninsular Malaysia. *Arabian*

Journal of Geosciences, *6*(11), 4129-4144.

Jasin, B., & Harun, Z. (2007). Stratigraphy and sedimentology of the chert unit of the semanggol formation. *Geol Soc Malaysia Bull*, *53*, 103-109.

Keller, G. V., & Frischknecht, F. C. (1966). Electrical methods in geophysical prospecting.

Khoo, T. T., & Tan, B. K. (1983, September). Geological evolution of Peninsular Malaysia. In *Proceedings of Workshop on Stratigraphic Correlation of Thailand and Malaysia* (Vol. 1, pp. 253-290).

Kiberu, J. (2002). Induced polarization and resistivity measurements on a suite of near surface soil sampless and their empirical relationship to selected measured engineering parameters. *MSc Thesis Submitted at ITC, Enschede, 2002*.

Kumar, D. V., Ramadass, G., & Jagadish, S. V. (2015). Delineation of groundwater potential zones through electrical resistivity parameters in hard rock terrain , Osmania University Campus, Hyderabad, Telangana State, India, *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 3, Issue 6 Ver.II (Nov. - Dec. 2015), PP 01-10* http://doi.org/10.9790/0990-03620110

Lisa Koening (2008). Application of geophysical methods for site characterization, *Technical Guidance Manual for Groundwater Investigatio, (August). State of Ohio Environmental Protection Agency. Division of Drinking and Groundwaters*

Loke, M. H. (1999). Electrical imaging surveys for environmental and engineering studies. *A practical guide to*, *2*.

Lumetzberger M., Engesgaard, P. K., Nielsen, L., & Dahlin, T., (2004). Master's thesis 3-D and 2-D resistivity and IP mapping of geology and chlorinated aliphatics at Färgaren 3 , Kristianstad, Faculty of Science, University of Copenhagen

Marchant, D. (2015). *Induced polarization effects in inductive source electromagnetic data* (Doctoral dissertation, University of British Columbia).

Lozán, J. L., Brabi, H., Hupfer, P., Menzel, L., & Schonwiese, C. D. (2007). *Global change: enough water for all?* (No. P10-48).

Mathiazhagan, M., Selvakumar, T., & Madhavi, G. (2015). Groundwater abstraction and contamination studies at Thiruvidanthai Village, Along East Coast Road In Chennai using electrical resistivity method with geochemical analysis. *Journal of Coastal Sciences*, *2*(1), 12-8.

Mibei, G. (2014). Introduction to types and classification of rocks. *001374011*.

Mondal, N. C., Rao, A. V., & Singh, V. P. (2010). Efficacy of electrical resistivity and induced polarization methods for revealing fluoride contaminated groundwater in granite terrain. *Environmental monitoring and assessment*, *168*(1-4), 103-114.

Mooi, E., & Sarstedt, M. (2010). Cluster analysis (pp. 237-284). *Springer Berlin Heidelberg.*

Morrison, J. M., Goldhaber, M. B., Ellefsen, K. J., & Mills, C. T. (2011). Cluster analysis of a regional-scale soil geochemical dataset In Northern California. *Applied Geochemistry*, *26*, S105-S107.

Morgan, R. P. C. (1970). An analysis of basin asymmetry in the Klang Basin, Selangor. *Bulletin No 3, Geological Society of Malaysia, Marsh 1970, pp. 17-26*

Moussa, O., Marc, P., & Véronique, D. (2015). Hydrogeophysical characterization of bedrock aquifers : The case of the white bandama upstream watershed (Northern Ivory Coast) caractérisation hydrogéophysique des aquifères de socle : Exemple Du Bassin Amont Du Bandama Blanc (nord de la Côte d ' Ivoire)

National Hydraulic Research Institute of Malaysia (NAHRIM) (2011). 9th malaysian plan penyelidikan pengurusan air tanah: (Project Code: P2317000 014 0001 Report No: Nahrim/Pkg/2/2011)

Nelson S. A. (2015). Physical geology: Sediment and sedimentary rocks adapted from http://www.tulane.edu/~sanelson/eens1110/sedrx.htm, 1–10.

New Zealand Geotechnical Society (2005) Field description of soil and rock: Guideline for the field classification and description of soil and rock for engineering purposes, *NZ Geotechnical Society INC*

Neyamadpour, A., Abdullah, W. W., & Taib, S. (2010). Use of four-electrode arrays in three-dimensional electrical resistivity imaging survey. *Studia Geophysica et Geodaetica*, *54*(2), 299-311.

Obi, J. C. (2012). The use of electrical resistivity tomography (ERT) to delineate water-filled vugs near a bridge foundation.

Oduduru, P. I., & Mamah, L. I. (2014). Integration of electrical resistivity and induced polarization for subsurface imaging around Ihe Pond, Nsukka, Anambra Basin, Nigeria (Doctoral dissertation*). The Pacific Journal of Science and Technology, Vol 15. Number 1. May 2014*

Omowumi, O. (2012). Electrical resistivity imaging survey for shallow site investigation at *University Of Ibadan Campus Southwestern Nigeria, 7(2), 187–196.*

Ouedraogo Moussa, Pessel Marc, Durand Veronique, Marlin Christelle & Savane Issiaka (2015), Hydrogeophysical characterization of bedrock aquifers : The case of the white bandama upstream watershed (Northern Ivory Coast) , *Vingtiemes journees techniques du Comite Francais d'Hydrogeologie de l'Association Internationale des Hydrogeologues*

Pietrzyk-Sokulska, E. (2012). Geological environment as an important element of the reclamation and revitalization of the quarries. *AGH Journal of Mining and Geoengineering*, *36*(1), 267-274.

Premises, H. A. (2007). Imaging of the ahmadu bello university teaching by inichinbia sonny msc / sci / 44893 / 2004-05 being a research thesis submitted to the postgraduate school , In partial fulfilment of the requirements for The Award of Master ' S Degree (M . Sc .) *In Applied Geophysics . Faculty Of Science*.

Rahardjo, H., Aung, K. K., Leong, E. C., & Rezaur, R. B. (2004). Characteristics of residual soils in Singapore as formed by weathering. *Engineering Geology*, *73*(1), 157-169.

Raupeeh, N. M. B. (2009). Geophysics research using 2-dimensional resistivity method for groundwater investigation. *Univeristi Teknologi Malaysia*

Robert, T. (2012). Geophysical identification, characterization, and monitoring of preferential groundwater flow paths in fractured media *(Doctoral dissertation, Université de Liège, Liège, Belgium).*

Robert, T., Dassargues, A., Brouyère, S., Kaufmann, O., Hallet, V., & Nguyen, F. (2011). Assessing the contribution of electrical resistivity tomography (ERT) and self-potential (SP) methods for a water well drilling program in fractured / karsti fi ed limestones. *Journal of Applied Geophysics*, *75*(1), 42–53.

Sambamoorthi, N. (2003). Hierarchical cluster analysis: Some basics and algorithms. *CRMportals Inc., Englishtown*.

Sarma, V. S. (2014). Electrical resistivity (ER), Self potential (SP), Induced polarisation (IP), Spectral induced polarisation (SIP) and Electrical resistivity tomography (ERT) prospection in NGRI for the past 50 years-A Brief Review. *J. Ind. Geophys. Union*, *18*(2), 245-272.

Schonlau, M. (2004). Visualizing non-hierarchical and hierarchical cluster analyses with clustergrams. *Computational Statistics*, *19*(1), 95-111.

Scrivenor, J. B.,& Jones, W. R. (2013). The geology of South Perak, North Selangor, and the Dindings with a geological sketch-map

Shamshuddin, J., & Darus, A. (1979). Mineralogy and genesis of soils in Universiti Pertanian Malaysia, Serdang, Selangor [Malaysia]. *Pertanika*. *2(2), 141-148*

Sharma, P.V (1997). Environmental and engineering geophysics, Cambridge University Press

Singh, R. J., & Bushee, J. (1977). The rock cycle. *Journal of Geological Education*, *25*(5), 146-147.

Singhal, B. B. S., & Gupta, R. P. (2010). *Applied hydrogeology of fractured rocks*. Springer Science & Business Media.

Suntharalingam, T. (1984). Quaternary stratigraphy and prospects for placer tin in the Taiping—Lumut area, Perak. *a a*, *3*, 3.

Suntharalingam, T. (1984). Studies on the quaternary geology of Peninsular Malaysia. *Warta Geologi*, *10*(3), 101-110.

Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). *Applied geophysics* (Vol. 1). Cambridge University Press

Tóth, J. (2009). Groundwater in igneous metamorphic and sedimentary rocks. *Groundwater-Volume I*, 67.

United States Department of Agriculture (USDA) (2012), Chapter 4: Engineering classification of rock materials, *part 631 geology national engineering handbook, (210–VI–NEH, Amend. 55)*

USGS (2016) Groundwater Information: Aquifer Basic, Retrieved 8 Dec 2016 from http://water.usgs.gov/ogw/aquiferbasics/index.html

Wong, I. F. T. (1970). Reconnaissance soil survey of Selangor. *Bull. Minist. Agric. Lds, Malaysia.*, *122*.

Yadav, G. S.(2015), Detection of groundwater saturated fractures using geoelectrical techniques of gradient profiling in the rgsc of Banaras Hindu University, India. Int. Jl*. General Engg. Tech. (IJGET), vol. 4(3), pp. 21-30*

Yin, E. H. (1976) Geological map of Kuala Lumpur. *Geological Survey of Malaysia.*

Young, F. J., & Hammer, R. D. (2000). Defining geographic soil bodies by landscape position, soil taxonomy, and cluster analysis. *Soil Science Society of America Journal*, *64*(3), 989-998.

Zaini, N. N., Osman, R., Juahir, H., & Saim, N. (2016). Development of chromatographic fingerprints of eurycoma longifolia (Tongkat ali) roots

using online solid phase extraction-liquid chromatography (SPE-LC). *Molecules*, *21*(5), 583.

Zawawi, M. A. M., Toridi, N. M., & Wayayok, A. (2015). Detection of fractured aquifer using combination of resistivity and induced polarization analysis. *Jurnal Teknologi, 76(15), 119-124.*