VERTICAL ELECTRICAL SOUNDING METHOD TO DECIPHER THE EXISTING SUBSURFACE STRATIFICATION AND ASSESS THE CAUSE LEADING TO LAND INSTABILITY: A CASE STUDY

Meripeni Ezung[1], Temsulemba Walling[2] and C. Chelladurai[3]

[1]Research Scholar (Regd. No. 1813602004), [2]Assistant Professor, [3]Professor

[1,3]*Department of Physics, St. Joseph University, Ikishe model Village, Virgin Town, Dimapur-797115, Nagaland, India*

[2]*Department of Geology, Nagaland University, Kohima campus, Meriema-797004, Nagaland, India*

[1]e-mail:m_ezung@yahoo.com

ABSTRACT

An electrical resistivity study was conducted at the selected study area to ascertain the causes leading to land instability after a portion of the area was washed away in 2005 at site 1(Officer's Hill) and in 2007 and 2008 at site 2 (Merhülietsa). The data generated through Vertical Electrical Soundings (VES) at five VES stations were analyzed and interpretation of the sounding curves indicated the presence of three to four subsurface geo-electric layers comprising of the topsoil, fractured shale layers/shale with sandstone/siltstone intercalations, and weathered shale layers with high water content. The dominance of K type curve confirms that the study area has lower saturatedbedrocks consisting of sheared, crumpled, weak, and highly weatheredrocks that are in various stages of weathering and are more prone to slope failures.

KEYWORDS:Electrical resistivity, field curves, Schlumberger configuration, vertical electrical sounding (VES)

1. Introduction

Kohima,which is the state capital of Nagaland, is located in the southern part of the state and lies geographically between 25°37'30" and 25°42'32" North latitudes and 94°04'40" and 94°07'43"East longitudes with an area coverage of about 20 sq. km. The area receives heavy rainfall during the monsoon season ranging from 1500 mm to 2200 mm and the main drainage systems that control the hydro-geology around the town area are Dzütre Rü on the west, Dzuna Rü on the east, Sanu Rü and Rhe Rü on the north.Kohima town is hydrogeologically occupied by consolidated to semi-consolidated rocks of Disang and Barail group of rocks comprising of shale, siltstone, mudstone and fine to medium sandstone, which are highly jointed, fractured and in various stages of weathering. Major portion of Kohima town is dominated by the Disang group of rocks consisting of shales, siltstone, mudstone and sandstone. The exposed shales observed are dark grey and splintery in nature with minor beds of siltstone and sandstone intercalation in some areas of the town. This type of shale, when in contact with water, becomes pulverized into blackish shale and swells, leading to slide and mudflow, thus resulting in landslides which pose great threat to the people because of the enormous generation of debris from severe infrastructure damages[1-4].

Geophysical methods are used successfully for Reconnaissance survey over the past few decades, especially in landslide investigations [5]. This method employs scientific measurement parameters to study the subsurface of the earth which enables to find the different patterns relating to its geological formation, rock types, thickness of weathered material, porosity and location of fractured zones [6-7].Among the several geophysical methods which are in use, electrical resistivity (ER) method have been broadly used, especially by field geologists for regional and local surveysdue to its theoretical, operational and interpretational ease [8-9]. This method measures the earth's resistivity by driving a direct current (DC) into the ground to give the potentials induced inside the earth. Several factors, such as moisture and clay content influence slope movement that control the electrical resistance of soils and rocks. So, variations in resistivity to current flow cause variations in the potential differences and this provides information about the subsurface[10].

2. Study area

2.1 Location

The study area is located within Kohima town andis incorporated in the Survey of India topographic sheet number 83K/2 and lies between 25°39'51.59" - 25°39'56.8" North latitudes and 94°05'40.49" - 94°05'50.12" East longitudes. The selected sites for the survey are Officer’s Hill (M1 and M2) and Merhülietsa (M3, M4 and M5) marked in Fig. 1.

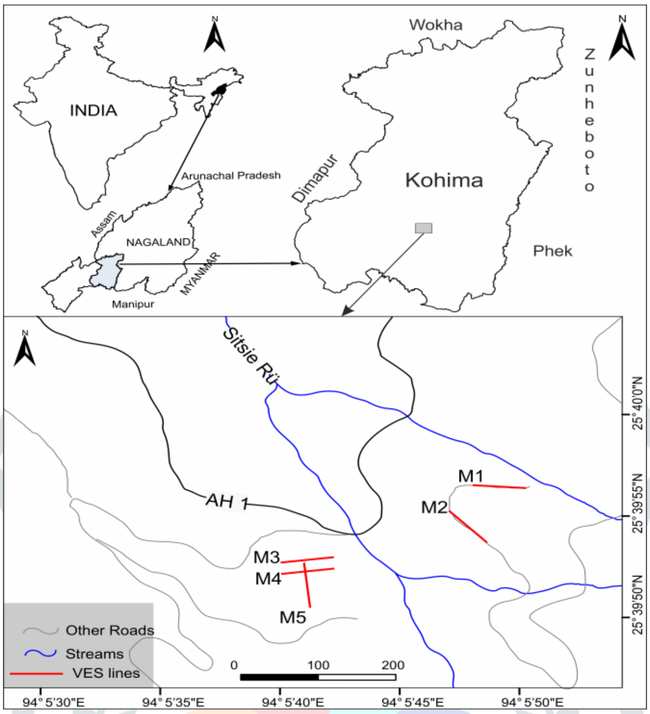

Fig. 1: Location map of the study area

(M1 = VES 1, M2 = VES 2, M3 = VES 3, M4 = VES 4, M5 = VES 5)

2.2 Lithology of the study area

The study areas are represented by Disang group of rocks that are predominantly shales intercalated with minor beds of sandstone and siltstone[11].These rock formations are more prone to weathering. The exposed rocks are sheared, fractured and weathered which allows water percolation into the subsurface to take place. Development of cracks below the surface in different parts of the selected sites led to water infiltration, especially during the monsoon season. This ledthe pore water pressure to build up on the slopes, leading to reduced strength of the slopes.Following Kusummawardani [12], it has been observed that contacts between the bedrocks that consist of weathered/sheared zones, presence of cracks, fault and overlapping of rock layersare potential geo-structures that might have encouraged instability and groundwater development in these areas. Some fieldphotographs of the study area showing fractured/weathered rocks (Fig. 2 A and B) and affected areasdue to unstable slopes (Fig. 2 C and D) are shown below:

Fig. 2: Field photographs

3. Materials and methods

Electrical resistivity method, which is based on the measurement of electrical potentials between one electrode pair with a transmitting direct current between another electrode pair, involves the measurement of the apparent resistivity of soils and rocks as a function of depth or position.An electric field is artificially induced inside the ground by means of either galvanic batteries (DC) or low frequency AC generators. The current sent into the ground by means of two grounded electrode, called the current electrodes gives the potential difference measured by two more grounded electrodes, called the potential electrodes. The resistance offered by a unit cube of the material for the flow of current through the normal surface is its electrical resistivity 'ρ', defined as:

$$\rho = RA/L \qquad (1)$$

where R is the resistance, A is its cross-sectional area and L is the length of the conductor.
The resistivity for a heterogeneous medium, which is called as the apparent resistivity of geologic formation[13] is equal to the true resistivity in which, for a given electrode configuration, the apparent resistivity 'ρ_a' is given by:

$$\rho_a = K*\frac{\delta V}{I} \qquad (2)$$

where $K = \frac{\pi}{2l}[L^2 - l^2]$ is the geometric spacing factor (AB = 2L and MN = 2l).
A resistivity meter, Aquameter CRM 500 was used for the data collection and each apparent resistivity value was computed using equation (2). Computer modelling software IPI2win was used for the quantitative analysis of the data[14-15] and resistivity with their corresponding layer thickness was obtained. Vertical electrical sounding (VES), which is based on the estimation of the electrical conductivity or resistivity of the medium was employed [16]. Here, measurements are taken at different locations for various values of current electrode separations by keeping the centre of the electrode system fixed. Variation in electrical characteristics with depth is obtained from the apparent resistivity variation with the current electrode spacing.Different electrode configurations are used for measuring the potential difference of the subsurface, the mostly used configurations for VES being the symmetrical Schlumberger configuration (Fig. 3), which was used for the present study.

If ρ1, ρ2 and ρ3 are the resistivity of the subsurface layers with ρ1 at the top followed by ρ2 and ρ3, then the four basic categories for the classification of sounding curves, depending on the resistivity values with depth are:

$\rho1 < \rho2 < \rho3$: A-type
$\rho1 < \rho2 > \rho3$: K-type
$\rho1 > \rho2 < \rho3$: H-type
$\rho1 > \rho2 > \rho3$: Q-type

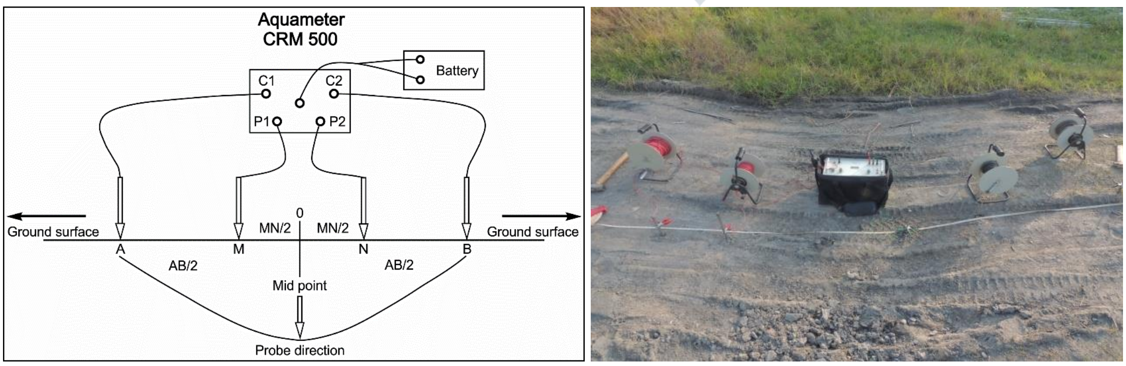

Fig. 3: Schematic diagram for the Schlumberger array

4. RESULTS AND DISCUSSIONS

Resistivity analysis for the data collected at five VES stations give the layer model interpretations in terms of its field curves (Fig. 4) and geoelectric layer parameters (Table 1).From the five VES interpreted results, three to four geoelectric layers were delineated, namely topsoil/clay,fractured shale layer/shale with siltstone/sandstoneintercalationsand saturated weathered shales with high water content[17].The sounding curves are of KQ and K types, with K type being the dominant one for the survey sites.

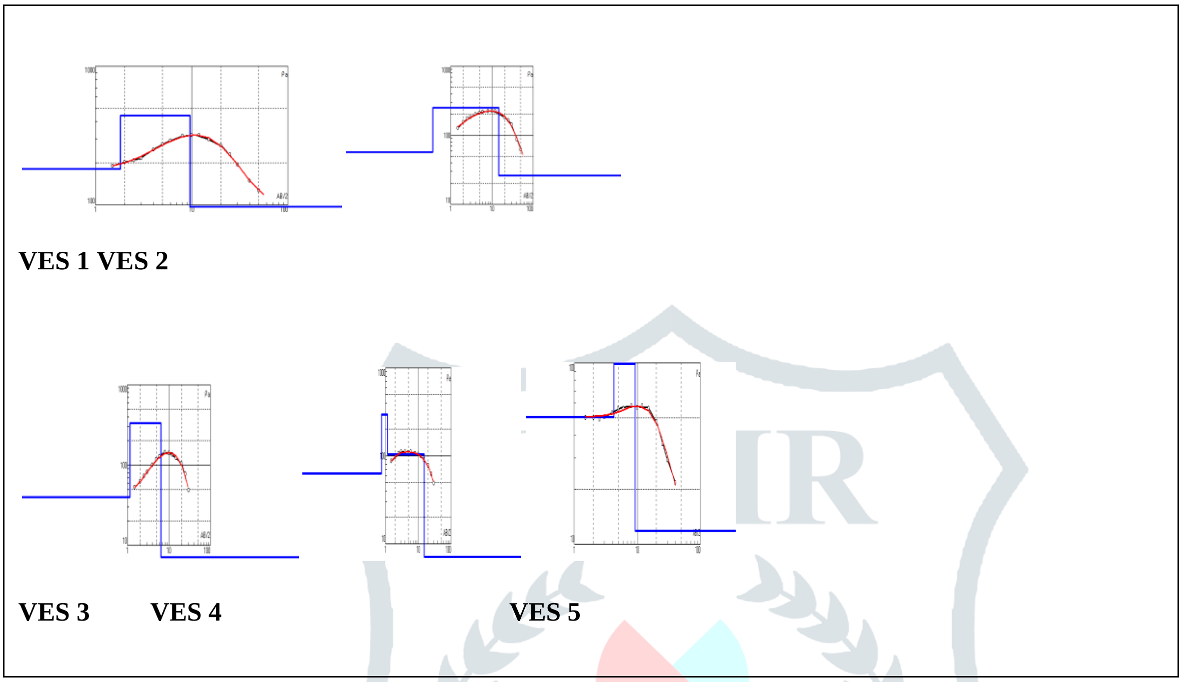

Fig. 4: VES field curves

Sounding data of VES 1, VES 2, VES 3 and VES 5 (Table 1) show resistivity value rising to a maximum and then decreasing ($\rho 1 < \rho 2 > \rho 3$) indicating that the intermediate layer has higher resistivity value compared to the top and bottom layers. Such type of curve dominance indicates that the area has a lower saturated weathered rock[18- 20]. The resistivity of the first layer (top soil) ranges between 40.1 Ωm to 182.7 Ωm with thickness of 0.37 m to 4.26 m. In the second layer, high resistivity values ranging from 106 Ωm to 442.2 Ωm with thickness of 4.97m – 14.1 m was observed which may contain the fractured bedrock layer. The third layer has lower resistivity value ranging from 0.582 Ωm to 97.25 Ωm which could be due to the presence of saturated weathered rock. From the inferred nature of the lithounits, these areas show a good potential for groundwater prospecting [21-25].

Table1: Layer parameters for the VES points

Station	ρ1 (Ωm)	ρ2	ρ3	ρ4	h1 (m)	h2	h3	h4	d1 (m)	d2	d3	d4	Curve type
VES 1 (M1)	182.7	442.2	97.25	-	1.82	7.81	-	-	1.82	9.63	-	-	K
VES 2 (M2)	56.7	249	26.2	-	0.37	14.1	-	-	0.37	14.5	-	-	K
VES 3 (M3)	40.1	332	0.582	-	1.15	5.23	-	-	1.15	6.38	-	-	K
VES 4 (M4)	63.5	297.8	103.4	1.043	0.76	0.399	14.13	-	0.76	1.162	15.29	-	KQ
VES 5 (M5)	50.3	106	11.8	-	4.26	4.97	-	-	4.26	9.23	-	-	K

VES-vertical electrical sounding: ρ-layer resistivity: h–layer thickness: d–layer depth:Ωm-ohm meter: m - meter

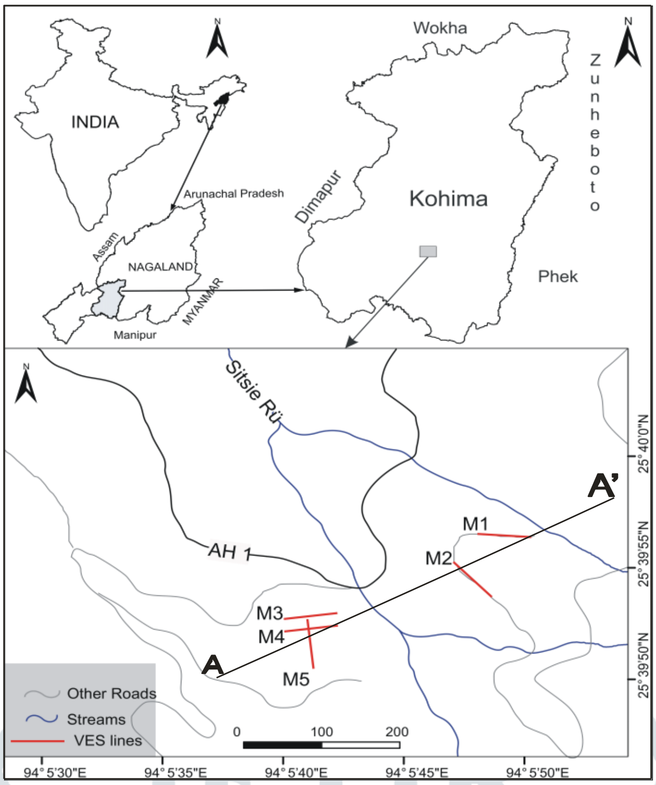

Fig. 5: Sections of resistivity and pseudo cross sections

In order to understand the underlying subsurface condition, the section AA' is plotted along the SW-NE direction (Fig. 5) with the VES stations M1, M2, M4 and M5. From the resistivity and pseudo cross sections (Fig. 6), it was observed that a low resistivity zone of less 60 Ω-m is seen at M5, which continues towards M4 at a depth of 30 m below ground level. This indicates that the area has a saturated layer revealing the high water content. In M1, layer of high resistivity (> 250 Ω-m) at a depth from 5 to 20 m (approximately) is observed, which are indicative of the presence of possible weathered or fractured zones [26].

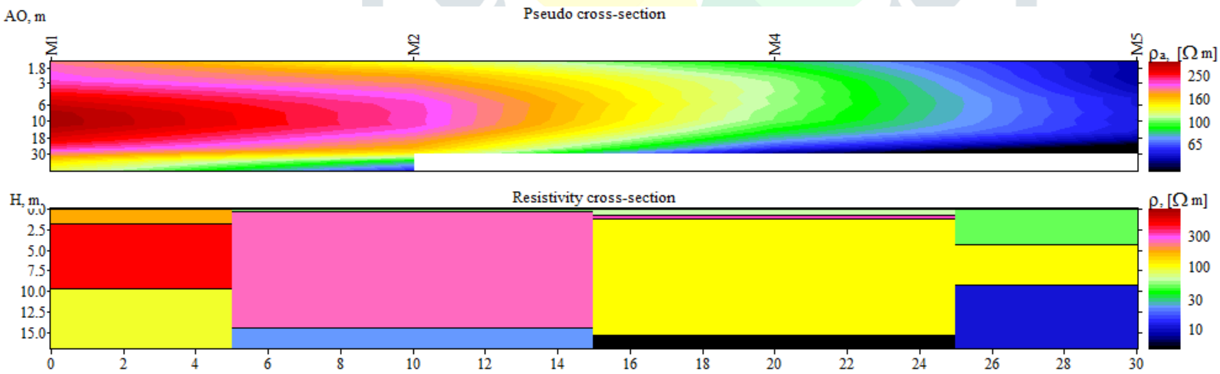

Fig. 6: Pseudo cross section and Resistivity cross section along AA'

5. Conclusion

Electrical resistivity survey of the selected sites show the presence of three to four geoelectric layers, namely topsoil/clay,fractured shale layers/shale with siltstone/sandstoneintercalations and weathered shale layers with high water content. The VES sounding curves are of KQ and K types, with K type being the dominant one, indicating that the area has a lower saturated weathered bedrock layer.The subsurface geologic materials mainly consist of sheared, crumpled, weak, highly weatheredand fractured rocks. During monsoon season, the excess water infiltrated through these fractured and weathered zones makes the shales to swell causing water pressure to build up on the slopes. These might have been some of the factors that led tofailure of the slope. The results suggest that the selected survey sites are situated in a geologically disturbed area that are highly susceptible to weathering and slope failures.

6. Acknowledgement

The authors wish to acknowledge Mr.C. Nokendangba Chang, Mr. Mehilo Apon and Mr. Notoka, Research scholars, Department of Geology, Nagaland University for the help during the field works.

References

1. Aier. I, Singh. M.P, Thong. G.T, Ibotombi. S. *Instability analyses of Merhülietsa slide, Kohima, Nagaland*. Nat Hazards, 2012, 1347 – 1363.
2. Roccati. A, Faccini. F, Luino. F, Ciampalini. A, Turconi. L. *Heavy rainfall triggering shallow landslides: A susceptibility assessment by a GIS-approach in a Ligurian Apennine Catchment (Italy).* Water *11*, 2019, 1-28, 605.
3. Aristizabal. E, García. E, Martínez. C. *Susceptibility assessment of shallow landslides triggered by rainfall in tropical basins and mountainous terrains.* National Hazards *78*, 2015, 621-634.
4. Senthilkumar. V, Chandrasekaran. S.S, Maji. V.B. *Rainfall-induced landslides: Case study of the Marappalam landslide, Nilgiris district, Tamil Nadu*, India. Int J Geomech *18(9)*, 2018, 05018006.
5. Mc. Cain. D.M, Foster. A. *Reconnaissance geophysical methods in landslide investigations.* Engineering Geology, 29(1), 1990, 59-78.
6. Plummer. C. C, D. Mc. Geory, Carlson. D. H. *physical Geology*. 8th Edition (McGraw Hill Co. Inc., New York, 1966) 48-56.
7. Singh. K.K.K, A.K.S. Singh, K.B. Singh, A. Singh. *2D resistivity imaging survey for siting water-supply tube well in metamorphic terrains: A case study of CMRI campus, Dhanbad, India.* The leading Edge, *25*, 2006, 1458-1460.
8. Bogoslovsky. V.A, Ogilvy. A.A. *Geophysical methods for the investigation of landslides.* Geophysics,*42(3)*,1977, 562-71.
9. Denis. J, Stephane. G. *Geophysical investigation of landslides. A review*. Bulletin Societe Geeologique de France,*178(2)*, 2007, 101-112.
10. Rainer. B, Jan-Erik. K, Alejandro. G, Thomas. G, Andreas. H. *Subsurface investigations of landslides using geophysical methods- geoelectrical applications in the Swabian alb (Germany)*.Geographica Helvetica Jg., 2006, 61.
11. E. Kikon, Katiwaba Ao. *Groundwater development in Hilly Terrain: Case studies in and around Kohima, Nagaland, Directorate of Geology and Mining, Dimapur.*
12. Kusumawardani. R, Upomo. T.C, Faizal. M. Back-analysis of hoek-brown criterion: Rock slide case in Manado. J. Geomate, 11(27), 2016.
13. Telford. W.M, Geldart. L.P, Sherrif. R.E. *applied Geophysics* (2nd edn. Cambridge University Press, 1990).
14. Gopinath. V.S.T, Vinodh. K, Gowtham. B, Arulprakasam. V. *Geolectrical characterization of substrata by using Geoelectrical Imaging Technique in Gagilam river sub basin, Tamilnadu, India.* International Journal of Scientific Engineering and Applied Science (IJSEAS), *1(6)*, 2015, 451-457.
15. Vender Velpen .B.P.A. *A computer processing package for DC Resistivity interpretation for IBM compatibles*, ITC J, *4*, 1998, 1-4.
16. Ganesh. R, Gowtham. B, Manive. T, Senthilkumar. S, Sundrajan. M. *Application of Resistivity methods in landslide investigations along Mettupalayam to Coonoor highway, NilgirisDistrict, Tamilnadu, India.* Scholars Journal of Engineering and Technology (SJET), *5(11)*, 2017, 661-667.
17. Loke. M.H, Barker. R.D. *Practical techniques for 3D resistivity surveys and data inversion. Data inversion*. Geophysical Prospecting, *44*, 1996, 499-523.
18. Sultan. A.S, Santos. F.A.M.*1D and 3D resistivity inversions for geotechnical investigation*. J Geophys Eng *5, 2008*, 1-11
19. Gouet. D.H, Meying. A, Nkoungou. H.L.E, Assembe. S.P, Nouck. P.N, Mbarga. T.N.*Typology of sounding curves and lithological 1D models of mineral prospecting and groundwater survey within crystalline basement rocks in the east of Cameroon (Central Africa) using electrical resistivity method and Koefoed computation method.* Int J Geophys, 2020, https://doi.org/10.1155/2020/8630406
20. Umar. D.U, Igwe. O. *Geo-electric method applied to groundwater protection of a granular sandstone aquifer.* Applied Water Science, 2019, 9-112.

21. Manimegalai. M.K, Gowtham. B, Vinodh. K. *Investigation of subsurface and groundwater state at Gadilam river sub-basin, Tamil Nadu, India*. Int. J. Modn. Res. Revs. *5(10)*, 2017, 1632-1638.

22. Hassan. E, Rai. J. K, Anekwe. U. O. *Geoelectrical survey of groundwater in some parts of Kebbi state, Nigeria, a case study of Federal Polytechnic bye-pass Birnin Kebbi and Magoro Primary health centre Fakai local Government*. Geosciences, *7(5)*, 2017, 141-149.

23. Bairu. A, Yirgale. G/her, Gebrehiwot. *Application of vertical electrical sounding and horizontal profiling methods to decipher the existing subsurface in river Segan dam site, Tigray, Northern Ethiopia.* Journal of Environment and Earth Science, *3(10)*, 2013, ISSN 2224-3216.

24. Alile. O.M, Amadasun C. V. O, Evbuomwan. A. I. *Application of vertical electrical sounding method to decipher the existing subsurface stratification and groundwater occurrence status in a location in Edo north of Nigeria. International Journal of Physical Sciences,3(10)*, 2008, 245-249.

25. Kana. J. D, Djongyang. N, Dadjé. A, Raïdandi. D. *Vertical electrical soundings for subsurface layers and groundwater investigations in the Mayo Kani area in Cameroon. International Journal of Science and Research (IJSR),* ISSN (Online): 2319-7064.

26. Brijesh. V.K, Balasubramanian. A. *Hydrogeological studies and groundwater modelling, Bharathapuzha basin, Kerala, India.* Scholar's Press, Germany, ISBN: 978-3-639-71113-4, 2014, 129-154.