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Application of Geoelectric Resistivity to Determine Soil Moisture Distribution

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Abstract : *Agriculture plays a crucial role in the economy of Ghana. It is however observed that many farmers in Ghana, both large and small scale farmers do not do thorough subsurface moisture investigation before cultivation. This tends to make the land underused, and may not produce optimum yield due to lack of sufficient soil moisture for plant growth. The purpose of this study is to investigate the use of the geoelectric resistivity method in assessing soil moisture distribution using a vegetable farm at KNUST campus as a case study. Field tests including in-situ and gravimetric soil moisture measurements were performed and compared with geoelectric resistivity distribution. Comparing the apparent resistivity distribution to the moisture content distribution, it was observed that low resistivity areas were generally corresponding to high moisture content and vice versa. The studies showed that there was a relatively good correlation between the apparent resistivity and moisture content. It may be concluded from this study that geoelectric resistivity methods can be used to determine soil moisture distribution on a section of land although the interpretation will depend largely on the geology or soil type of the land.*

Keywords –*Apparent Resistivity, Moisture content, Geoelectric, Traverse lines, Soil, Agriculture, Farm, Land*

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I. INTRODUCTION

Ghana has about 52% of its labour force population engaged in agriculture (Oppong-Anane, 2001). Agriculture plays a crucial role in the economy of Ghana, and provides the main source of food, income and employment to the rural populations. Although peasant farmers have a higher population than the commercial farmers, both of these do not appear to carry out detailed soil moisture investigations on their farmlands before cultivation. As a result of these practices, farmlands most of the time do not yield optimum results (Youth in Agriculture, 2013). Highest crop yield can be achieved under optimum moisture conditions during the growing season while a drop in moisture conditions during the growth season may result in poor yield. The poverty of the mass of the rural population could be a consequence of the low productivity of the farming population. The low productivity leads to low incomes, i.e. little or nothing is left for savings or investment after consumption.

While the soil system is fundamental to the growth of crops, moisture is one of the most important components of plant's growth. Moisture in the soil determines crop growth and agricultural production. The germination of seeds and root development depends on the availability of water. Ample soil moisture storage also makes it possible to overcome dry spells in critical growing stages and hence, secure good yields even when rainfall is erratic. On the other hand, if soil moisture falls below a crop's wilting point, crop losses will be irretrievable.

There are various ways of determining soil moisture both in-situ and in the laboratory. The gravimetric method is a laboratory test and it involves collecting soil sample, weighing the sample before and after drying it, and calculating its original moisture content and the heatdiffusion method is based upon the principle that the heat conductivity of a soil varies with its moisture content. The absorption method, which is in-situ, works on the principle that porous points or blocks would absorb moisture from the adjacent area when installed in soil. The soil moisture is then estimated from the change in weight of the points or blocks. The penetration method involves the use of an instrument called an availameter (Allyn and Work, 1941), pushed into the soil and the force used to push the instrument is measured and related to the soil's moisture content. This is also an in-situ method.

This research seeks to provide farmers with another method of determining the distribution of moisture content on their farms using the geoelectric resistivity method. Having an idea of the moisture distribution of an area can help farmers know the type of crops to be planted at particular portions on the field. Crops that demand minimum amount of water would then be planted at areas with low moisture content whereas plants which demand high amount of water would be planted at areas with high moisture content. Also, farmers will be able to plan well for irrigation when they have enough information about the moisture distribution of the farmland.

LAND USE

Agricultural land in Ghana was last measured as 69.88% in 2011, according to the World Bank (Trading Economics, 2015). Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures. Arable land includes land under temporary crops, kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded. Land under permanent crops is a land cultivated with crops that occupy the land for long periods and need not to be replanted after each harvest, such as cocoa, coffee, and rubber. This category includes land under flowering shrubs, fruit trees, nut trees, and vines permanent pasture is land used for five or more years for forage.

SOILS

Most of the soils in Ghana are developed on thoroughly weathered parent materials, with alluvial soils (Fluvisols) and eroded shallow soils (Leptosols) common to all the ecological zones. Generally, most of the soils are plagued with inherent or human induced infertility (Oppong-Anane, 2001).

The soils in the Forest zone are grouped under Forest Oxisols and Forest Acid Gleysols(Youth in Agriculture, 2013). They are porous, well drained and generally loamy and are distinguished from those of the savannah zones by the greater accumulation of organic matter in the surface resulting from higher accumulation of biomass. They occur in areas underlain by various igneous, metamorphic and sedimentary rocks, which have influenced the nature and properties of the soil (Oppong-Anane, 2001). Soils of the Savannah zones, especially in the Interior Savannah, are low in organic matter (less than 2% in the topsoil), have high levels of iron concretions and are susceptible to severe erosion(Youth in Agriculture, 2013). Thus well-drained upland areas tend to be droughty and when exposed to severe incident sun scorch, tend to develop cement-like plinthite. These conditions make it imperative that manure can be incorporated regularly into the soils in the Savannah zones (Oppong-Anane, 2001). Table 1 shows some basic soil types and their corresponding apparent resistivity.

Table 1: Soil types and their apparent soil resistivity

Soil Type	Soil Apparent resistivity (Ohm-m)
Moist humus soil	30
Farmland loamy and clay soils	100
Sandy clay soil	150
Moist sandy soil	300
Moist gravel	500
Dry sandy or gravel soil	1000
Rocky ground	30000

SOIL MOISTURE AND ITS IMPORTANCE

Soil moisture content is the quantity of water contained in a soil. It is expressed as a ratio which can range from zero (completely dry) to the value of the soils porosity at saturation. It can be given on a volumetric or mass (gravimetric) basis (Wikipedia, 2015) Volumetric water content, θ, is defined mathematically as:

$$\theta = \frac{V_w}{V_{wet}} \quad (1)$$

Where v_w is the volume of water and$v_{wet}$is the volume of wet sample

Gravimetric water content, μ is expressed by mass (weight) as:

$$\mu = \frac{m_w}{m} \quad (2)$$

Where mw is the mass of water and $m$is the mass of the dry sample.

Surface soil moisture is the water that is in the upper 10cm of soil, whereas root zone soil moisture is water that is available to plants, which is generally considered to be in the upper 200cm of soil (Arnold, 1999). Arnold (1999) observed that, simulations with numerical weather prediction models have shown that improved characterization of surface soil moisture, vegetation and temperature can lead to significant forecast improvements.Soil moisture information can be used for reservoir management, early warnings of drought, irrigations scheduling in crop yield forecasting (Agricultures network, 2015).

While the soil system is fundamental to the growth of living things, water is one of the most important components of plant's growth. Moisture in the soil determines crop growth and agricultural production. The germination of seeds and root development depends on the availability of water. Ample soil moisture storage also makes it possible to overcome dry spells in critical growing stages and hence, secure good yields even when rainfall is erratic. On the other hand, if soil moisture falls below a crop's wilting point, crop losses will be irretrievable.

Moisture content of a portion of soil rarely changes overtime. This is because water moves in a path of least resistance, therefore even if there is precipitation after a long drought, portions of high moisture before the drought will still have high amount of water after precipitation. This implies that when the soil moisture distribution of an area is determined, the results can be useful for a very long time.

II. MATERIALS AND METHODS USED

The study was conducted at a vegetable farm at KNUST campus inKumasi, Ghana as a case study. The site was selected because it had a gentle sloping topography and a suspected soil moisture variation due to the slope gradient. Accessibility considerations were taken into account in the selection of the study area. Also the site chosen was close to the geotechnical laboratory which made the transportation of the soil samples easier and prevented significant loss of moisture from the soil samples. Furthermore, the size of the land was also considered in the selection of the site so as to accommodate the planned number of traverse lines and stations.

A desk study was conducted to plan out the work in order to obtain the best values and also minimise the risk of encountering unseen field conditions which may affect the study. All information relevant to the understanding of this research were obtained through desk study by reviewing existing literatures and reports. Seven traverse lines as shown in Figure 1 were selected on the farmland where each traverse line lay between two risen beds. Each traverse line had 10 stations which were 5m apart and the distance between each traverse line was also 5m (Figure 1). The traverse lines run north-south in a direction parallel to the slope direction. The coordinates of the four corners of the grid were taken for referencing and easy identification and location of data points.

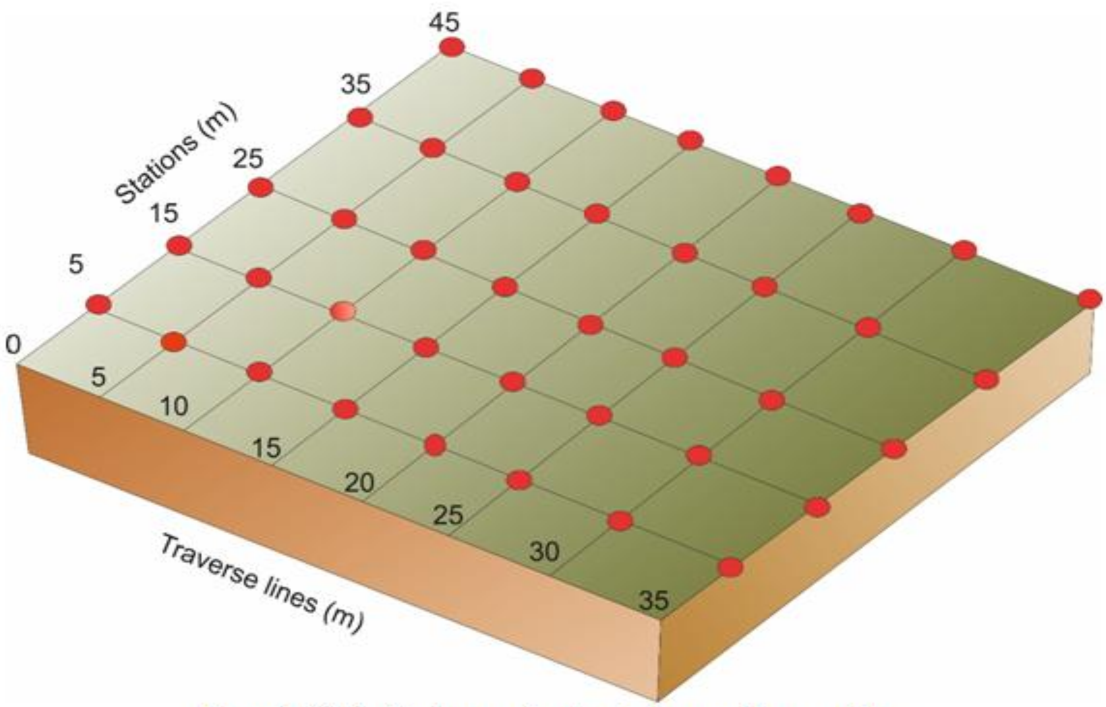

Figure 1: Grid of study area showing stations and traverse lines

SOIL RESISTIVITY MEASUREMENT

A resistivity survey to determine the apparent resistivity of the soil at all nodes of the grid was conducted on the farmland. Current was passed through the two outer electrodes and the resistance using the Mini-Res resistivity meter was measured across the two inner electrodes (L and R Instruments, 2015). The Wenner Array was used, thus the depth of investigation was assumed to be half the current electrode spread(Corrosion doctors, 2015). Vertical Electrical Sounding (VES) was carried out at each station at a depth of 30cm, 60cm and 90cm.

MOISTURE CONTENT DETERMINATION

In-Situ Moisture Content Survey

The James Trident T-90 Moisture Meter (James Instrument Inc., 2012) was used to determine the in-situ moisture content at alternate nodes on each traverse line. This instrument can determine the moisture content of sand, gravel, crushed stone and other fine and coarse aggregate. The instrument was calibrated to determine the moisture content of sand. A 1m hole was excavated and the prongs of the probe was inserted at the side of the hole at depths of 30cm, 60cm and 90cm and the percentage of moisture content was shown on the easy to read display instantaneously.

Gravimetric Method

Samples were taken from the 1m hole also at alternate nodes on each traverse line at depths 30cm, 60cm and 90cm. The samples where sealed air tight and double bagged to avoid moisture loss. Samples were labelled and transferred to the lab after collection.

LABORATORY WORKS

The test to determine the gravimetric soil moisture content was done in accordance with the B.S 1377:1975, as such the soil samples were sealed air tight and taken to the laboratory from the 1m hole at depths of 30cm, 60cm and 90cm. The mass of containers were weighed after which the samples were poured into the containers. The mass of the samples and the containers were weighed and oven dried for 24 hours at a temperature of 105°C. The mass of dried samples and containers were reweighed and the moisture content was calculated as a percentage of the dry sample weight (Johnson, 1962).

DATA PROCESSING

Resistivity Calculation

The mini-Res resistivity meter that was used for the field work only read resistance values. Therefore there is the need to calculate the apparent resistivity values which will be used for our analysis and this was done with the help of Microsoft Excel. Apparent resistivity, ρa, for Wenner Array is defined mathematically as:

$$\rho_a = RK \tag{3}$$

Where: ***K***=2πa, ***a*** is inter-electrode spacing and ***R*** is the resistance recorded

The depth of investigation for each station is half the total electrode span and from that, the inter-electrode spacing (a)can be calculated by dividing the total electrode span by 3. A typical example of how the apparent resistivity values were calculated is shown in Table 2 below.

Table 2: Calculation of apparent resistance values

Community:	KNUST				Traverse Line No.	30 m
Array	Wenner				Grid Reference:	
STATION	K30	1.256	K60	2.512	K90	3.768
	R30	ρ30	R60	ρ60	R90	ρ90
35	347.8	436.84	180.1	452.41	164.4	619.46
40	267.1	335.48	192.4	483.31	176.2	663.92
45	312.9	393.0	267.9	672.96	213.9	805.98
50	676.7	849.94	388.6	976.16	333.8	1257.76
55	632.5	794.42	559.5	1405.46	513	1932.98
60	1501	1885.26	1021.5	2566.00	719.9	2712.58
65	748.1	939.61	601.01	1509.74	451.6	1701.63
70	344.5	432.69	152.6	383.33	117.5	442.74
75	60.5	75.99	67.5	169.56	59.7	224.95
80	53.2	66.82	33.4	83.90s	23.3	87.79

Moisture Content Calculation

The T-90 moisture meter gives an instantaneous reading of moisture content values when the prongs are inserted into the soil therefore no calculations were involved there. The moisture meter was calibrated to pick values for sand since sand has similar particle size as the soil on our study area. The calculations for the gravimetric moisture content were done with the help of Microsoft Excel using the formula:

$$\mu = \frac{m_w}{m} \times 100\ \% \qquad (4)$$

Where: $\boldsymbol{\mu}$ is the moisture content, $\boldsymbol{m_w}$ is the mass of water and $\boldsymbol{m}$ is the mass of dry sample

A typical example of how the moisture content values were calculatedusing the gravimetric method is shown in Table 3 below.

Table 3: Moisture content calculation using gravimetric method

Community:	KNUST				Traverse Line No.	0m	
Sample No	Depth (m)	Container and Wet Sample (g)	Container and Dry Sample (g)	Mass of wet sample(g)	Mass of Dry Samples(g)	Massof Water (g)	Moisture content (%)
A35	0.3	123.16	120.09	97.48	94.41	3.07	3.25
A35	0.6	164.74	158.68	139.02	132.96	6.06	4.56
A35	0.9	N/A	N/A	N/A	N/A	N/A	N/A
A45	0.3	182.88	175.48	157.59	150.19	7.4	4.93
A45	0.6	172.64	166.09	147.28	140.73	6.55	4.65
A45	0.9	213.56	205.96	188.21	180.61	7.6	4.21
A55	0.3	204.01	195.88	178.74	170.61	8.13	4.77
A55	0.6	180.82	171.05	155.62	145.85	9.77	6.70
A55	0.9	215.14	205.75	189.91	180.52	9.39	5.20
A65	0.3	171.37	160.81	145.7	135.14	10.56	7.81
A65	0.6	237.01	219.21	211.1	193.3	17.8	9.21
A65	0.9	272.83	246.4	247.2	220.77	26.43	11.97
A75	0.3	195.19	182	169.71	156.52	13.19	8.43
A75	0.6	275.48	232.01	249.43	205.96	43.47	21.11
A75	0.9	358.17	281.97	335.46	259.26	76.2	29.39

III. RESULTS AND DISCUSSION

Soil resistance and electrode spacing were recorded on the field and apparent resistivity (ρa) for each station was calculated. Soil moisture content was measured in-situ using the T-90 moisture meter and by the gravimetric method when the soil samples were taken to the laboratory. Based on the comparisons between apparent resistivity distribution and moisture distribution for the various depths (30, 60 and 90cm), the interpretation of our findings are presented in the sections below.

GRAVIMETRIC AND IN-SITU MOISTURE CONTENT

Two different methods of determining soil moisture content were used; (i) in-situ moisture content was determined with the T-90 moisture meter (ii) the gravimetric method. A graph of the moisture content determined in the laboratory against the in-situ moisture content was plotted which can be used to calibrate the probe. A best fit line was drawn to check if there was a correlation between the two methods of determining moisture content. From Figure 2, it can be observed that the probe gave lower moisture content values compared to the gravimetric method and also, Equation 5 was derived from the plot and this is the equation used for the calibration of the probe.

$$y = 1.5987x + 3.0428\ (R^2 = 0.7896) \qquad (5)$$

Where $\boldsymbol{y}$ is the moisture content determined at the laboratory and $\boldsymbol{x}$ is the in-situ moisture content as determined with the probe.

The graph has an R^2 value of 0.7896 which can be acceptable for field work purposes. Hence, during the field work, soil samples were double bagged and placed under a shade before taken to the laboratory for testing within an hour of sampling.

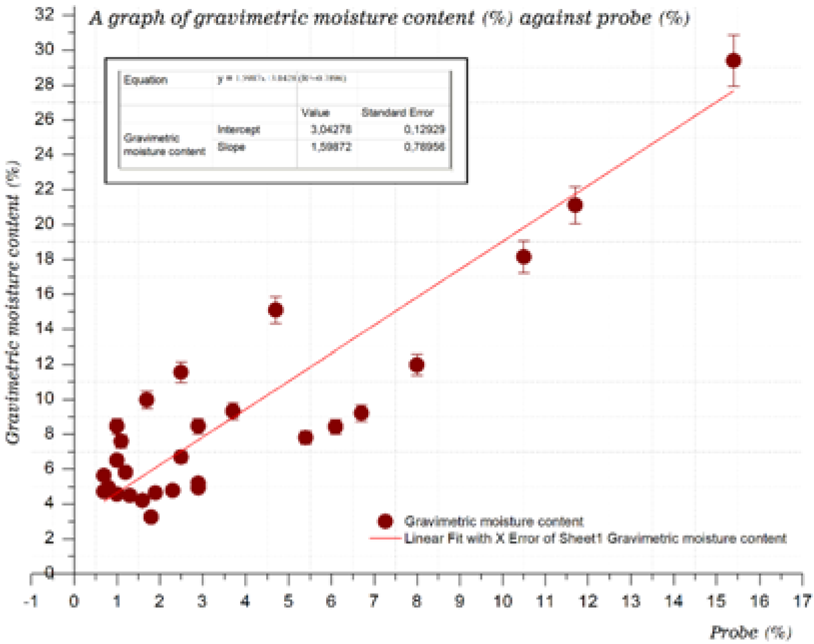

Figure 2: Comparison between gravimetric and probe methods of moisture content measurement

These meticulous measures were taken in order to reduce soil moisture loss from the samples before they were tested and because of that the difference in moisture content values using the two methods of determination could be as a result of errors in the use of the T-90 moisture meter. The T-90 moisture meter comes pre-set for sand, gravel, crushed stone and other fine and coarse aggregate. We set the probe to take readings in sand because its particle size is similar to the soil on the study area. This implies that inaccurate results might have been recorded where the soil particle size were less or more than sand, also, the inhomogeneity or non-uniformity of the soil with depth on the study area could also result in the inaccuracy of the T-90 moisture meter.

MOISTURE AND APPARENT RESISTIVITY DISTRIBUTION

It was assumed that, at the time of our survey, the lithology of the study area was homogenous hence all variations within the soil were as a result of changes in soil water content. The range of apparent resistivity values measured were between 150 and 1600 Ω-m while that of moisture content values were between 4 and 20%.

Figure 3 shows the spatial distribution of resistivity and moisture content at 30, 60 and 90 cm. Point A1 shows high apparent resistivity values, rising from 800 to 1800Ω-m. This shows a corresponding drop of moisture content values (from 6.5 to 4%) at point A2. There is also a rise in moisture content between Traverse line 10m to Traverse line 20m which corresponds to the reduction in soil apparent resistivity between Traverse line 10 to Traverse line 20m. This observation satisfies the general principle that high resistivity corresponds to low moisture content as explained in literature. This high apparent resistivity is observed between stations 20 to station 35m while low moisture content was observed between stations 0 to 30m.

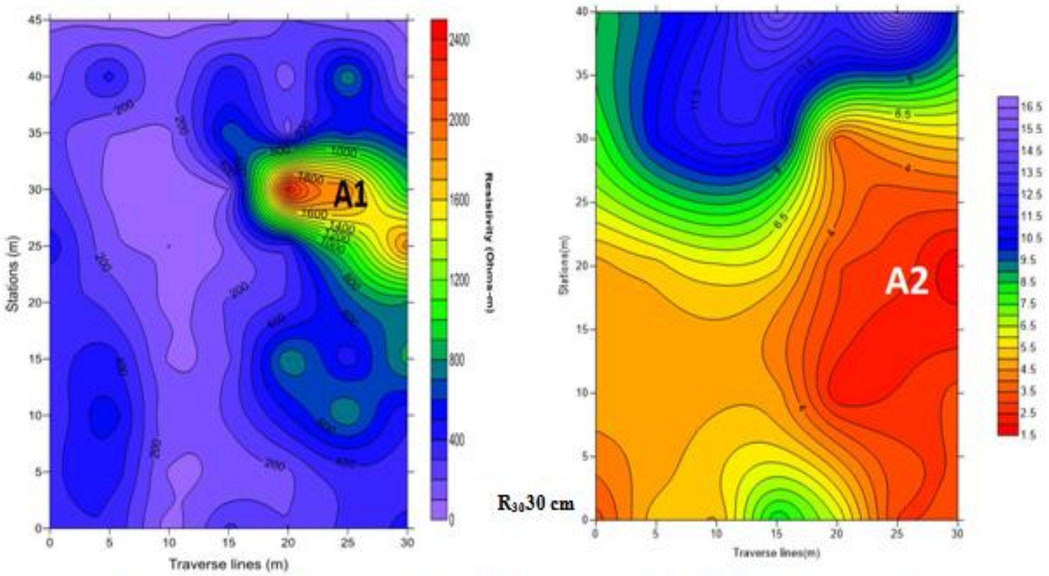

Figure 3: Spatial Resistivity (Left) and Moisture content (Right) Distribution at 30 cm

It can be observed from points B1 and B2 in Figure 4 that low resistivity values (200 Ω-m) are corresponding to low moisture content (5%). This observation can be as a result of increased clay content or salt concentration which reduces the resistivity values of the area without affecting the moisture content but because there was no soil classification test performed on the soil samples, we cannot be sure of this interpretation. Figure 4 also shows that there was an increase in the extent of the high resistivity area from station 20 to station 35 m to Station 10 to 35 m in Figure 4, but it is not so when comparing the low moisture content areas as low moisture content reduced from station 30 to Station 0m in Figure 3 (A1)to Station 25 to 0m in Figure 3 (A2). This reduction in the extent of the low moisture content areas can be as a result of increase in depth as the data points approaches the water table. High apparent resistivity values at point A1 is increased in extent at Figure 3 with the reduction of the extent of low soil moisture content area and this could be as a result of the inhomogeneity of soil on the study area with depth.

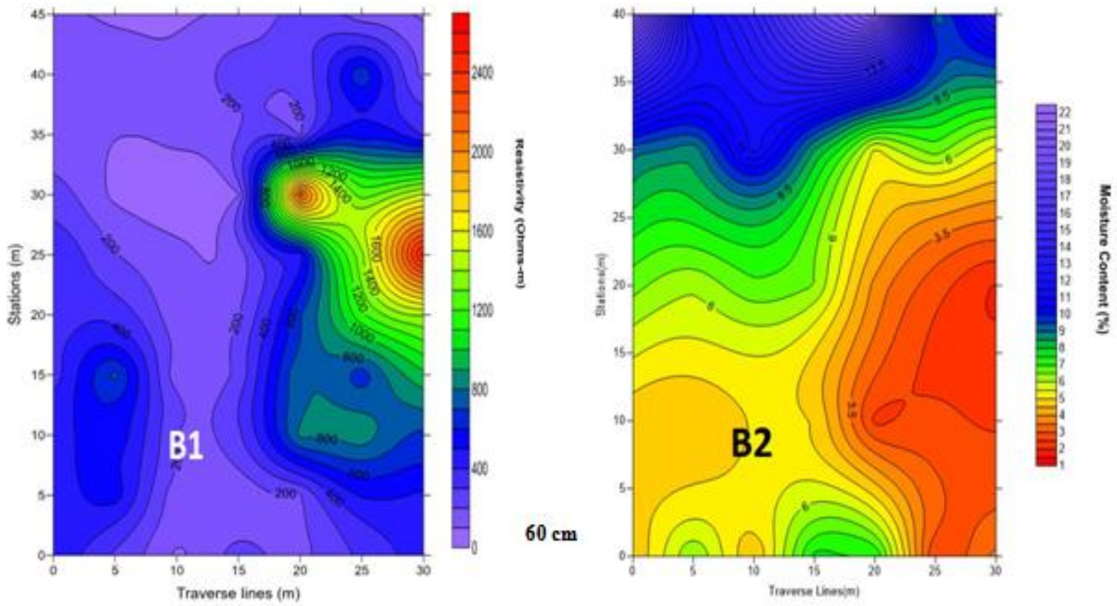

Figure 4: Spatial Resistivity (Left) and Moisture content (Right) Distribution at 60 cm

Moisture content data points were taken at alternate stations on each traverse line whiles the resistivity data points were taken at every station on each traverse line. This implies that more resistivity data points were obtained thus providing a better spatial distribution than the moisture content. This can be observed by comparing point C1 and C2 to point D on Figure 5. C1 and C2 show two distinct resistivity values but at point D, moisture content values are constant from traverse line 0m to traverse line 30m and this can be explained by the difference in the number of resistivity and moisture content data points.

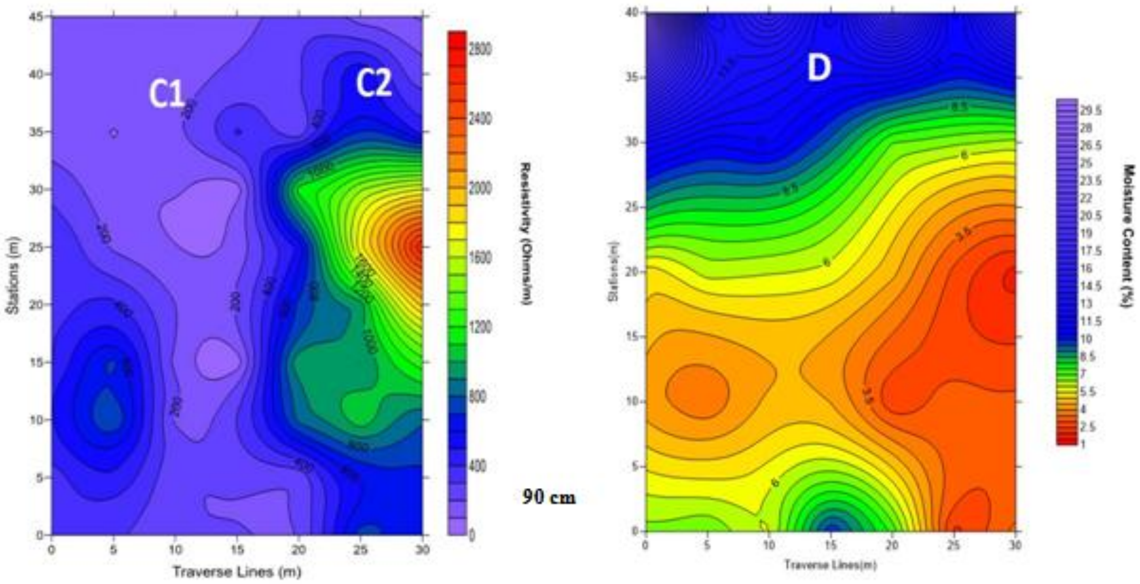

Figure 5: Spatial Resistivity (Left) and Moisture content (Right) Distribution at 90 cm

VARIATION OF MOISTURE CONTENTAND APPARENT RESISTIVITY WITH DEPTH

Apparent resistivity and moisture content data points were taken at three different depths (30, 60 and 90 cm) and the results of this survey was used to generate the spatial distribution of apparent resistivity and soil moisture content (Figure 6). Since only three depths were investigated and plotted, the contours generated are not too representative of the variation of moisture content and apparent resistivity with depth although apparent resistivity is not expected to vary that much within the first 1m. Figures 6 (Right plots) shows how moisture content and apparent resistivity varies with increasing depth. Figure 6(Left plots) shows a clearer trend where moisture content remains fairly constant with increasing depth, however the variation of apparent resistivity with depth does not show any clear trend. All the contour plots in Figure 6 shows apparent resistivity values increasing with depth with an anomalous areas of high and low resistivity at points M and N.

Similar trend was observed in all the contours generated as shown in Figure 7 in appendix. Variation of Moisture content (Left) generally shows a uniform distribution (Figure 7 in appendix) with depth at Traverse Lines (0, 5, 10, 15, 20, 25 and 30 m)and this can be attributed to the gently slope nature of the study area which results in a uniform distribution of water within the subsurface soil medium. On the other hand, Apparent Resistivity (Right) generally increases with depth at Traverse Line (0, 5, 10, 15, 20, 25 and 30 m) and this can be as a results of an increase in soil density and decrease in moisture content with depth. This confirms to the general trend of apparent resistivity within different soil types as illustrated in Table 1.

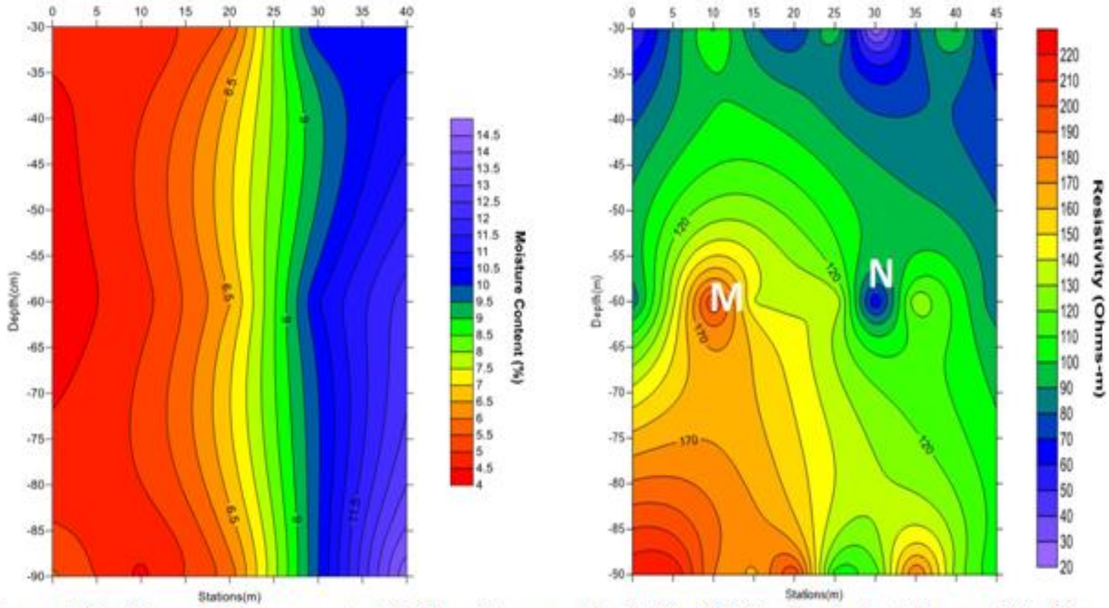

Figure 6: Variation of Moisture content (Left) and Apparent Resistivity (Right) with depth at Traverse Line 10 m

IV. CONCLUSION AND RECOMMENDATION

CONCLUSION

A geoelectric resistivity method was used to map out the distribution of the apparent resistivity of the study area and the moisture content of the area was determined using the gravimetric method and the T-90 Moisture meter. This information was used to derive a relationship between the apparent resistivity and moisture content.

Comparing the apparent resistivity distribution to the moisture content distribution, it was observed that apart from a small patch of the land, low resistivity areas were corresponding to high moisture content and vice versa. This confirms the general principle that low apparent resistivity measurements corresponds to high moisture content.

It may be concluded from this study that, geoelectric resistivity methods can be used to determine soil moisture distribution on a section of land although the interpretation will depend largely on the geology of the land.

Also an equation was derived from a graph of moisture content using the gravimetric method against the moisture content using the T-90 Moisture meter. This equation establishes a relationship between the two methods of moisture content determination and this is what is used for the calibration of the T-90 Moisture meter.

RECOMMENDATION

It will be recommended that more studies or research should be performed on the use of the T90 moisture meter since there were errors in its accuracy when the instrument was used to determine the moisture content of a heterogeneous soil.

Also, soil classification tests should be performed on the sampled soils to determine the particle size distribution of the soils. This will give more information about the type of soil encountered thus aiding in the use of the T-90 moisture meter.

Thirdly, because performing a mineralogical test on soil samples is expensive, Atterberg Limit test can also be performed on the soil to determine whether the soil is clay or not.

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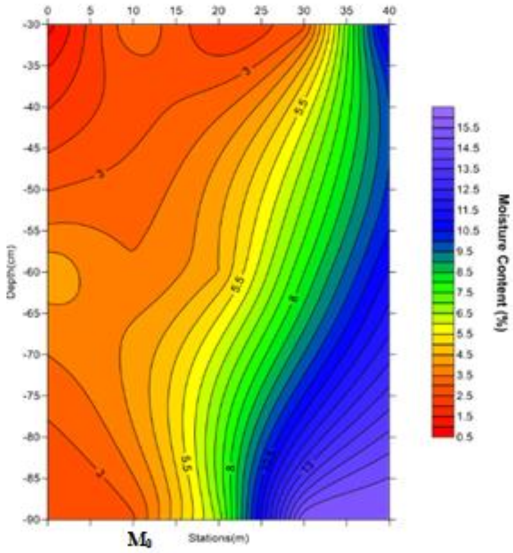
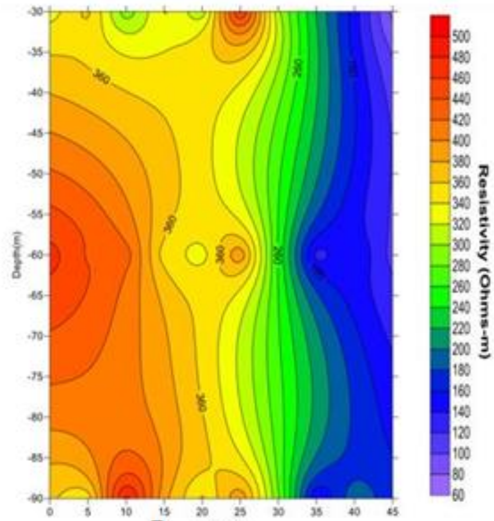
APPENDIX



M0



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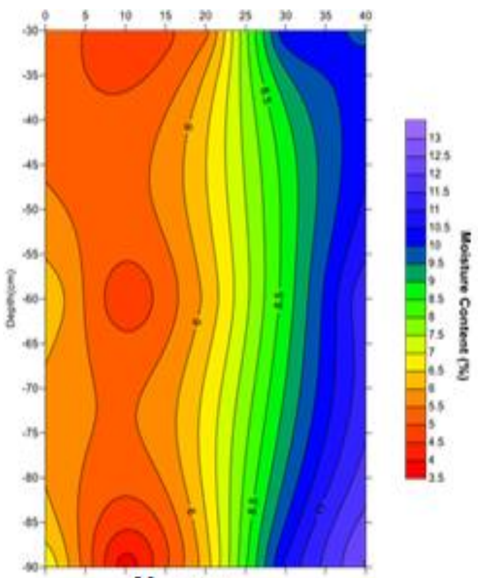

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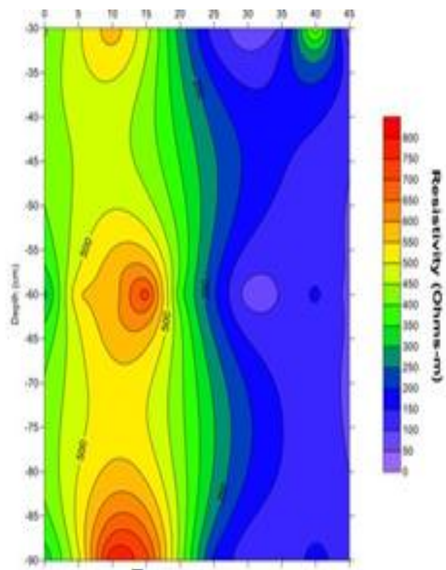
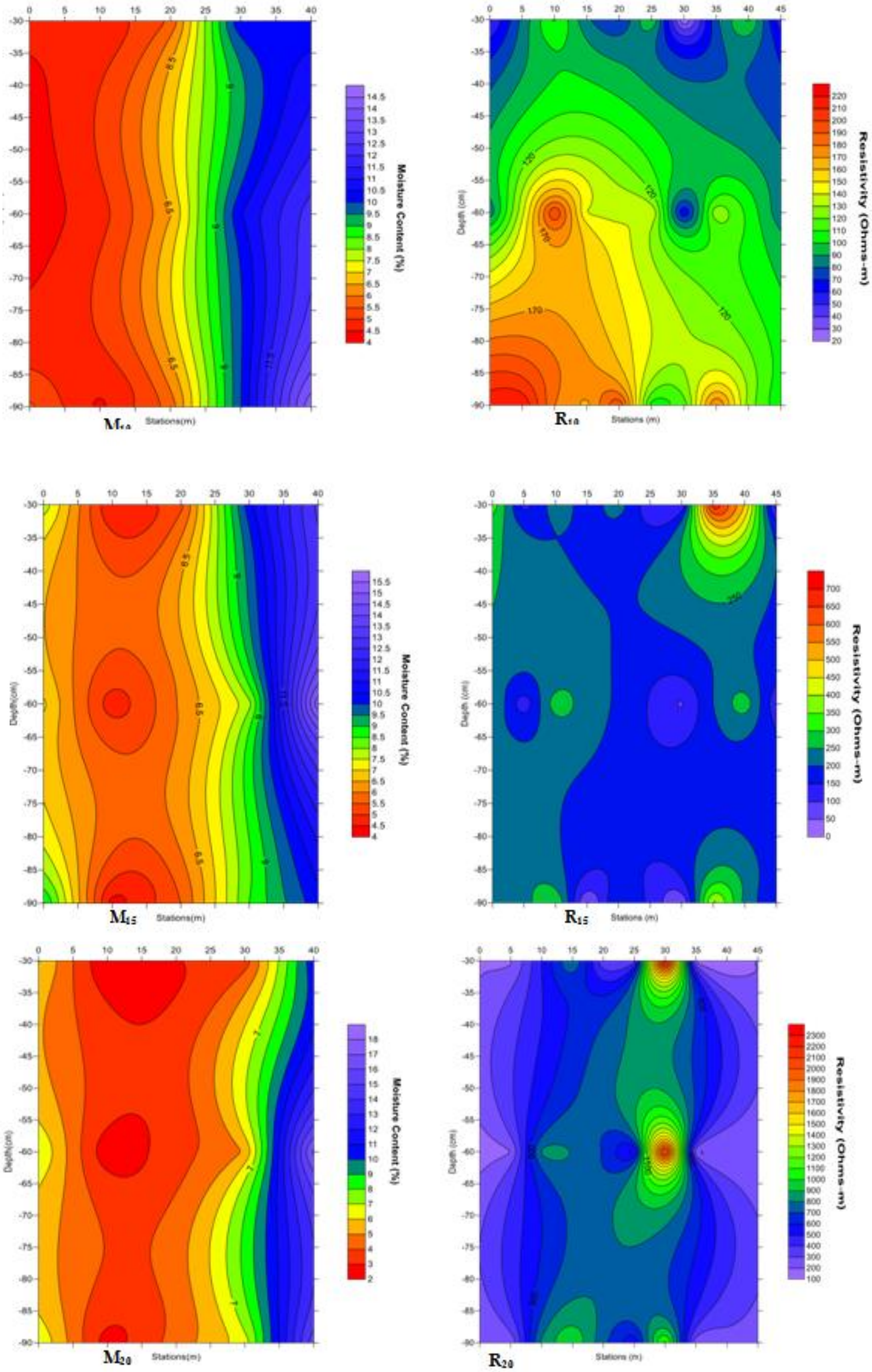


R5


M10
Stations(m)
Moisture Content (%)
R10
Stations (m)
Depth (cm)
Resistivity (Ohms-m)
M15
Stations(m)
Depth(cm)
Moisture Content (%)
R15
Stations (m)
Depth (cm)
Resistivity (Ohms-m)
M20
Stations(m)
Depth(cm)
Moisture Content (%)
R20
Stations (m)
Depth (cm)
Resistivity (Ohms-m)

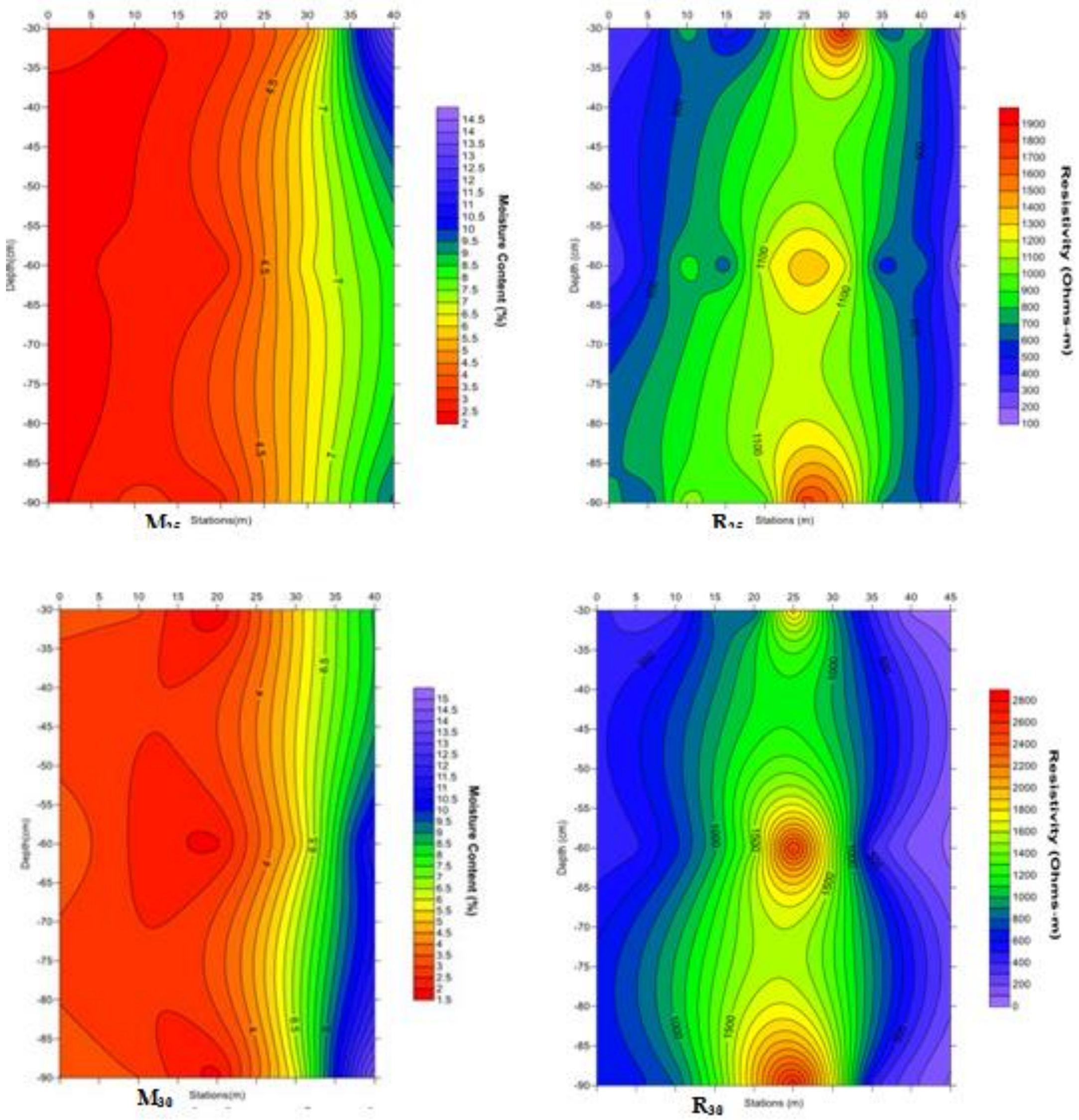


Figure 7: Variation of Moisture content (Left) and Apparent Resistivity (Right) with depth at Traverse Line (0, 5, 10, 15, 20, 25 and 30 m)

Williams, E. "Application of Geoelectric Resistivity to Determine Soil Moisture Distribution"American Journal of Engineering Research (AJER), vol. 7, no. 5, 2018, pp.113-124.