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Electrical Conductivity Instrument Construction and Application for Detecting Subsurface Wood and Metal

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Abstract: The pattern of electrical conductivity of the soil with wood and metal buried in a granite gneiss pegmatite environment using Wenner array configuration was investigated with locally made instrument. The 2kW electrical conductivity instrument used has been fabricated with CD4047 based square wave oscillator, high current IRF 250 MOSFET switches, a 3kW centre tapped transformer, bridge rectifier, AC and DC capacitors and a multimeter for current measurement. Two electrodes output the low frequency high power while the other two electrodes are connected to low frequency twin T filter and a multimeter for the measurement of voltage.

The electrical conductivity data recorded from four-electrode Wenner array varied most between 0.0046S/m to 0.0108S/m on traverse 6 and maximum value of conductivity obtained also occurred on traverse 6. The result was shown on map and 3D image plots with golden Surfer 11^{TM}. The map and 3D plots show two areas of low conductivity dip where woods were actually inserted in soil. The other two zones where high conductivities are prominent are correctly interpreted as the two cylindrical iron buried locations.

Keywords: Electrical Conductivity, Traverse, Data, 3D Map, Instrument, Current, Voltage

I. INTRODUCTION

Electrical conductivity or resistivity contrast of soil varies depending on the water saturation, mineralization and various degree of dissemination of rock or soil that are intertwined between host rocks. Soil electrical conductivity is a parameter occurring due to naturally and artificially created electrical fields in soils and influenced by distribution of mobile electrical charges, mostly inorganic ions, in soils resulting from several soil-forming processes. Complex relationships can develop between electrical properties and other soil physical and chemical properties, such as texture, stone content, and bulk density, water content, ion exchange capacity, salinity, humus content, and base saturation measured in-situ and in soil samples collected.

Geophysical methods of electrical, spontaneous potential and induced polarization horizontal profiling, using four electrode probes; non-contact electromagnetic and magnetic profiling are useful for measuring soil electrical conductivity in different types of soil (Telford et al, 1990, Ernstson and Kirsch, 2006). Compared with conventional methods of soil analysis, the electrical geophysical methods allow evaluating mineralization, groundwater table, salt content, depth and thickness of soil horizons, polluted or disturbed layers in soil profiles, and stone content. The methods provide extensive data on spatial and temporal variations in soil electrical properties, which relate to the distributions of other essential soil physical properties. The electrical conductivity are being incorporated with data from conventional soil analyses to enhance the estimation of a number of soil physical and chemical properties, to assist sampling and further soil research.

Soil electrical conductivity measurements are of high importance in many human activities, such as mining, agriculture, groundwater exploration, forestry, landscaping, environmental protection, recreation, electrical engineering and civil engineering (Antony and Mohd, Abdul, 2012). Some electrical geophysical methods were used to map groundwater tables and to evaluate water content, soil temperature, texture (Banton et al., 1997), and structure (Antony, 2008). Method of four-electrode probe has been used in soil practices since 1931 for evaluating soil water content and salinity under field conditions, to locate saline seeps on croplands in USA and Canada. Rhoades (1993) developed and introduced a compact four-electrode salinity sensor into routine agricultural practices. Metal probes are useful with electrical conductivity instrument in borehole logging for nature of roads, dam reliability, oil-water contact and mineral thickness, intrusion and fault exploration (Olorunfemi, et al., 2000, Wightman et al., 2003; Antony and Ramanujam, 2010).

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The conductivity of a pegmatite rock varies with the volume and arrangement of the pores, rock fractures with its emplaced soil and amount of contained water. A simple relationship for bulk rock resistivity ρ_e was proposed by Archie (1942),

$\rho_e = a\phi^{-m}S^{-n}\rho_w$..1.1

where ϕ is the fractional pore volume (porosity), S is the fraction of the pores containing water, ρ_w is the resistivity of water, where $n \approx 2$, and a, m are constants varying as $0.5 \leq \alpha \leq 2.5$, $1.3 \leq m \leq 2.5$.

Water conductivity varies considerably, depending on the amount and conductivity of dissolved chlorides, sulfates, and other minerals present (Telford et al, 1990). Other factors that rock conductivity depends on are salinity level, cation exchange capacity (cec), depth of burial of rock, temperature and presence of clays and conductive minerals. The electrical conductivity of Earth materials can be studied by measuring the electrical potential distribution produced at the Earth's surface by an electric current that is passed through the Earth or by detecting the electromagnetic field produced by an alternating electric current that is introduced into the Earth.

II. PRINCIPLES OF ELECTRICAL CONDUCTIVITY PROSPECTING

Surface electrical conductivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical conductivities and distribution of the surrounding soils and rocks. The usual practice in the field is to apply a direct electric current between two electrodes implanted in the ground and to measure the difference of potential between two additional electrodes that do not carry current. Usually, the potential electrodes are in line between the current electrodes, but in principle, they can be located differently. The current used is either direct current, commutated direct current (i.e., a square-wave alternating current), or AC of low frequency (typically about 20 Hz) but all analysis and interpretation are done on the basis of direct currents (Hazell et al., (1988) and Telford et al., 1990).

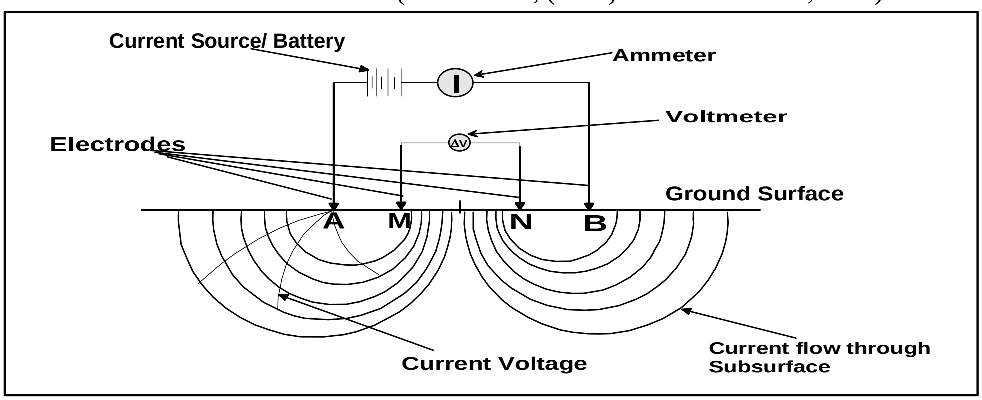

Figure 1: Current flowing through the subsurface, basic Current and Potential Electrodes Arrangement (modified from Telford et al., 1990)

III. CONDUCTIVITY INSTRUMENT AND DATA AQUISITION

The Conductivity instrument is supplied with 12V, 30 Ampere hour DC battery, one throw one pole (1T1P) for switching ON and OFF the whole instrument, CD 4047 based Oscillator circuit constructed on veroboard, has low voltage pulsed square ac output that was monitored to be 50Hz on oscilloscope before the included Schmitt trigger T unit connection. The T unit ensures prompt supply of high current at the required voltage to the M part. The M series and parallel IRFP 250 MOSFET (M) and a 3kW centre tapped transformer (Tx). When the low voltage tapping at the secondary output of the transformer was tested with the oscilloscope, the waveform was the edge up square wave due to the inductance in the transformer. A 2μF 400V ac capacitor was used to filter the AC output before the rectifier (Rct) stage. The DC current was measured with high power multimeter at the MC. The Relay low frequency Switching Swt serves as a measure to reduce Spontaneous potential and polarization in the ground was controllable with astable ciruit. The ground electrodes consisting 2 Current and 2 potential iron electrodes were used to input high power into and to measure voltage from the ground through (20Hz) low frequency twin T. Two 1mm diameter flexible cable of length 3m each were used to connect the current and potential points in the meter to the four reels containing similar flexible cables of length 120m and 25m cables for A, B and M,N current and potential electrodes respectively filter (Fig.2).

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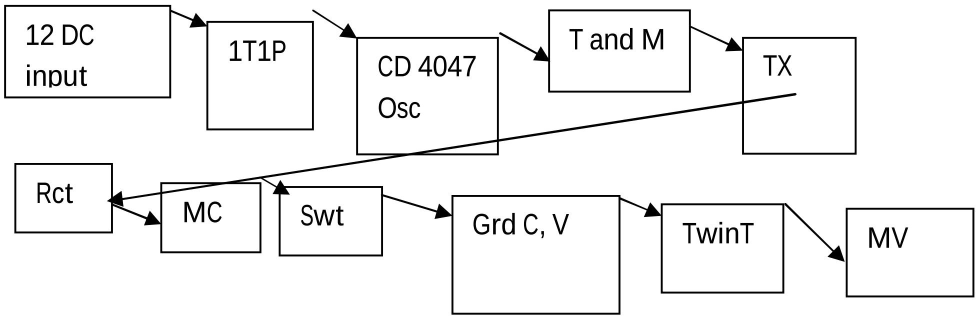

Fig. 2 Conductivity Instrument block diagram

The ground current and voltage electrodes A, B and M, N (Grd C,V,) are iron electrodes of length 1m and diameter 1.2 cm each while the conducting copper cable length is 7m each from the resistivity meter to the electrodes and distance between each electrode (a) is 0.5m while the inter traverse spacing is 1m throughout the survey.

Fig. 3.Four electrodes placed in the ground

The place of geophysical survey lies within the longitude N7 28 201 and latitude E005 44 125 in Ogodo Agbe, Akungba Akoko, and the elevation ranges from 352m to 365m; the place is a pegmatite area with sandy silt and humus soils between fragmented stones while the major rock is granite gneiss.

The conductors used are two iron rods of length 0.8m and diameter 0.03m and are buried separately at depths of 0.4m beneath the ground surface. Two woods that are the insulators of length 1.9 m and breadth 0.1m each were buried separately at depths 0.4m beneath the ground. From the values of a, the electrode separation and using Wenner Configuration,

$K=2\pi a$……………………………………………………………………….1

K=3.147……………………………………………………………………...2

Apparent Electrical conductivity EC for all the current I and potential difference V data between M, N electrodes can be computed from

EC= (I/(3.147V))……………………………………………………………….3

Or

EC=1/(3.147R)…………………………………………………………………4

IV. RESULT AND DISCUSSION

The results of apparent electrical conductivity measurement for each traverse are presented as tables (Table1-6) while the summarized data used for 3D contour, graded grey image and coloured relief maps (Figures 4-6) are shown in Table 7.

The electrical conductivity data recorded from four-electrode Wenner array varied most between 0.0046S/m to 0.0108S/m on traverse 1 and maximum value of conductivity obtained also occurred on traverse 6.

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Table 1: Traverse 1 Electrical Conductivity Data

Distance (m)	R=V/I (Ohm)	1/R	EC=I/KV (S/m)
1.5	64.62	0.015	0.061
2.0	56.22	0.018	0.063
2.5	38.00	0.026	0.093
3.0	44.60	0.022	0.071
3.5	22.56	0.044	0.088
4.0	23.67	0.042	0.089
4.5	28.28	0.035	0.080
5.0	26.25	0.038	0.101
5.5	29.54	0.033	0.098
6.0	32.10	0.031	0.099

Table 2: Traverse 2 Electrical Conductivity Data

Distance (m)	R=V/I (Ohm)	1/R	EC=I/KV (S/m)
1.5	74.80	0.013	0.085
2.0	81.25	0.012	0.095
2.5	71.20	0.014	0.089
3.0	59.60	0.017	0.107
3.5	62.40	0.016	0.102
4.0	42.89	0.023	0.082
4.5	38.50	0.026	0.103
5.0	38.60	0.026	0.103
5.5	58.33	0.017	0.091
6.0	104.2	0.009	0.061

Table 3: Traverse 3 Electrical Conductivity Data

Distance (m)	R=V/I (Ohm)	1/R	EC=1/KR (S/m)
1.5	102.6	0.009	0.062
2.0	87.33	0.011	0.061
2.5	95.60	0.010	0.066
3.0	75.50	0.013	0.105
3.5	82.80	0.012	0.077
4.0	60.86	0.016	0.075
4.5	63.00	0.016	0.101
5.0	76.40	0.013	0.083
5.5	101	0.009	0.063
6.0	112	0.009	0.095

Table 4: Traverse 4 Electrical Conductivity Data

Distance (m)	R=V/I (Ohm)	1/R	EC=1/KR (S/m)
1.5	105.20	0.009	0.061
2.0	125.33	0.008	0.085
2.5	103.25	0.010	0.077
3.0	143.20	0.007	0.044
3.5	139.67	0.007	0.076
4.0	141.33	0.007	0.075
4.5	136.00	0.007	0.078
5.0	131.50	0.008	0.060
5.5	171.67	0.006	0.062
6.0	136.00	0.007	0.078

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Table 5: Traverse 5 Electrical Conductivity Data

Distance (m)	R=V/I (Ohm)	1/R	EC=1/KR (S/m)
1.5	108.25	0.009	0.073
2.0	111.60	0.009	0.057
2.5	157.33	0.006	0.067
3.0	158.00	0.006	0.067
3.5	201.00	0.005	0.079
4.0	151.50	0.007	0.105
4.5	228.00	0.004	0.070
5.0	230.33	0.004	0.046
5.5	309.00	0.003	0.103
6.0	294.00	0.003	0.107

Table 6: Traverse 6 Electrical Conductivity Data

Distance (m)	R=V/I (Ohm)	1/R	EC=1/KR (S/m)
1.5	82.67	0.012	0.064
2.0	127.0	0.008	0.063
2.5	114.0	0.009	0.070
3.0	138.2	0.007	0.046
3.5	224.0	0.004	0.071
4.0	222.0	0.004	0.072
4.5	208.0	0.005	0.076
5.0	198.7	0.005	0.053
5.5	320.0	0.003	0.100
6.0	297.0	0.003	0.108

Table 7: Conductivity data for all traverses

Distance (m)	EC1=I/KR (S/m)	EC2=1/KR (S/m)	EC3=1/KR (S/m)	EC4=1/KR (S/m)	EC5=1/KR (S/m)	EC6=1/KR (S/m)
1.5	0.061	0.085	0.062	0.061	0.073	0.064
2.0	0.063	0.095	0.061	0.085	0.057	0.063
2.5	0.093	0.089	0.066	0.077	0.067	0.070
3.0	0.071	0.107	0.105	0.044	0.067	0.046
3.5	0.088	0.102	0.077	0.076	0.079	0.071
4.0	0.089	0.082	0.075	0.075	0.105	0.072
4.5	0.080	0.103	0.101	0.078	0.070	0.076
5.0	0.101	0.103	0.083	0.060	0.046	0.053
5.5	0.098	0.091	0.063	0.062	0.103	0.100
6.0	0.099	0.061	0.095	0.078	0.107	0.108

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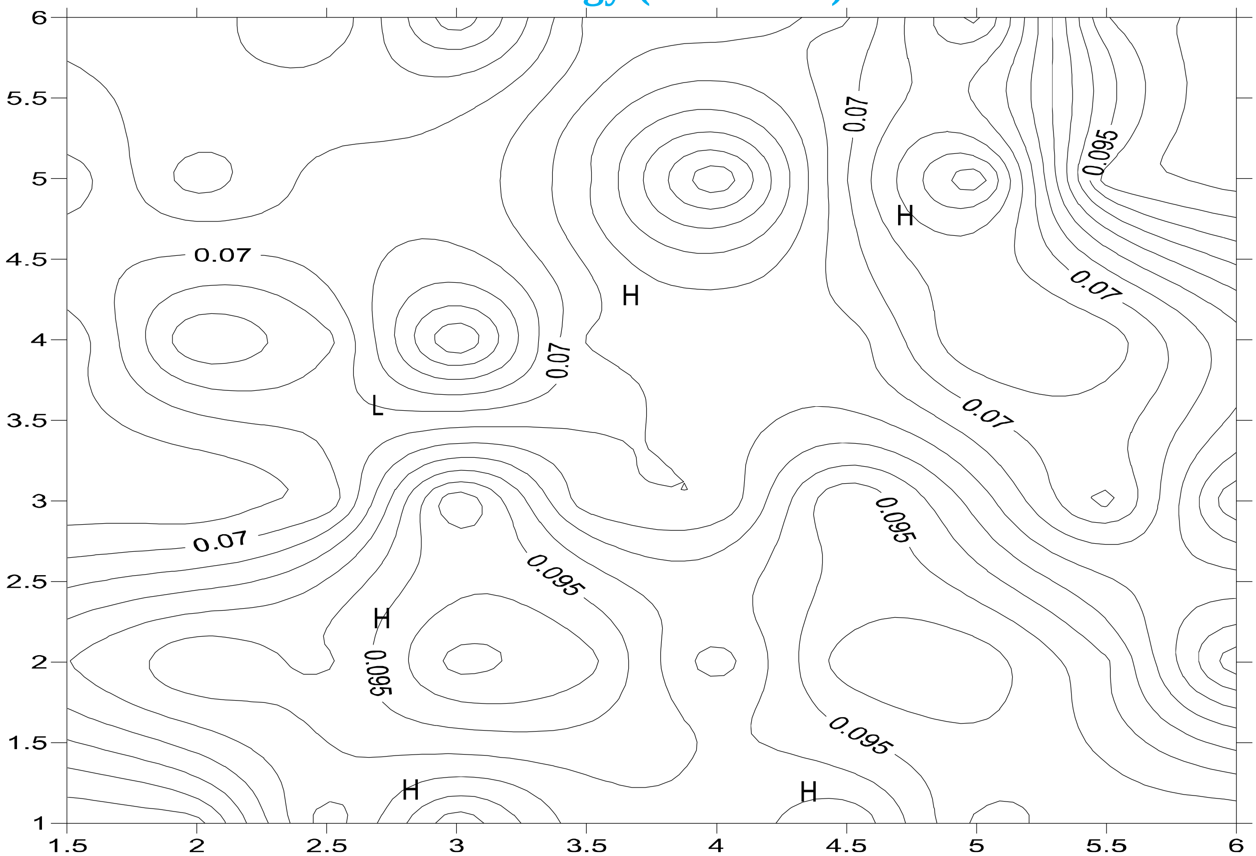

Scale: 1.5cm to 0.5m in x axis, 1.2 cm to 0.5m on y axis Contour interval is 0.005S

Fig. 4. 3D Electrical conductivity Contour Map

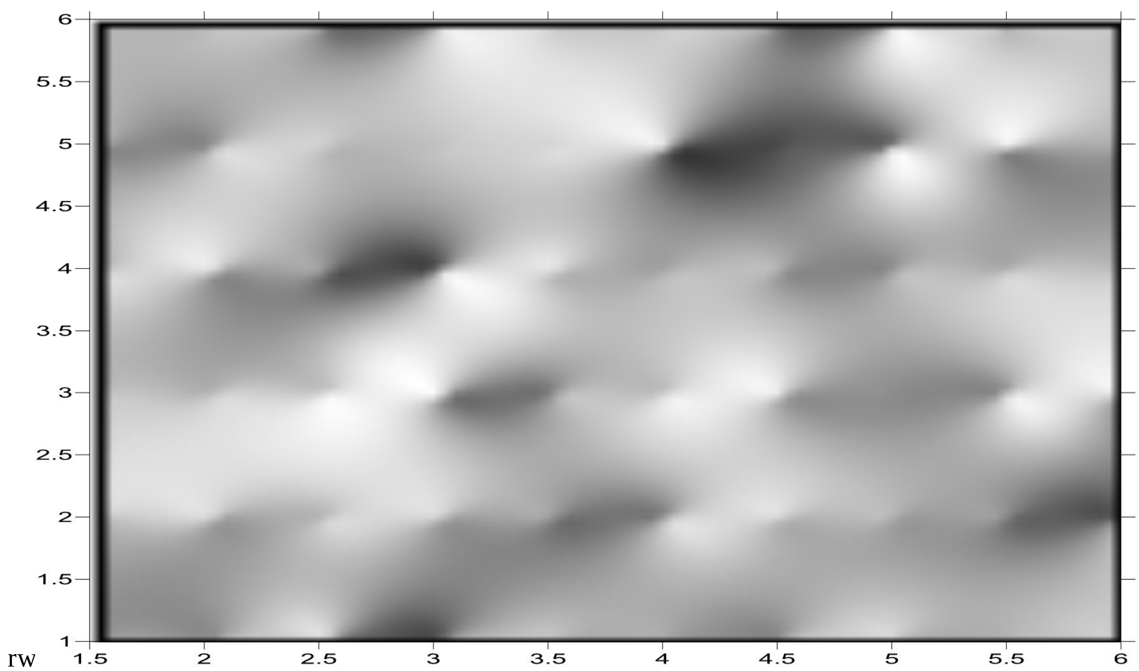

Fig. 5 3D Grey Image map of Conductivity

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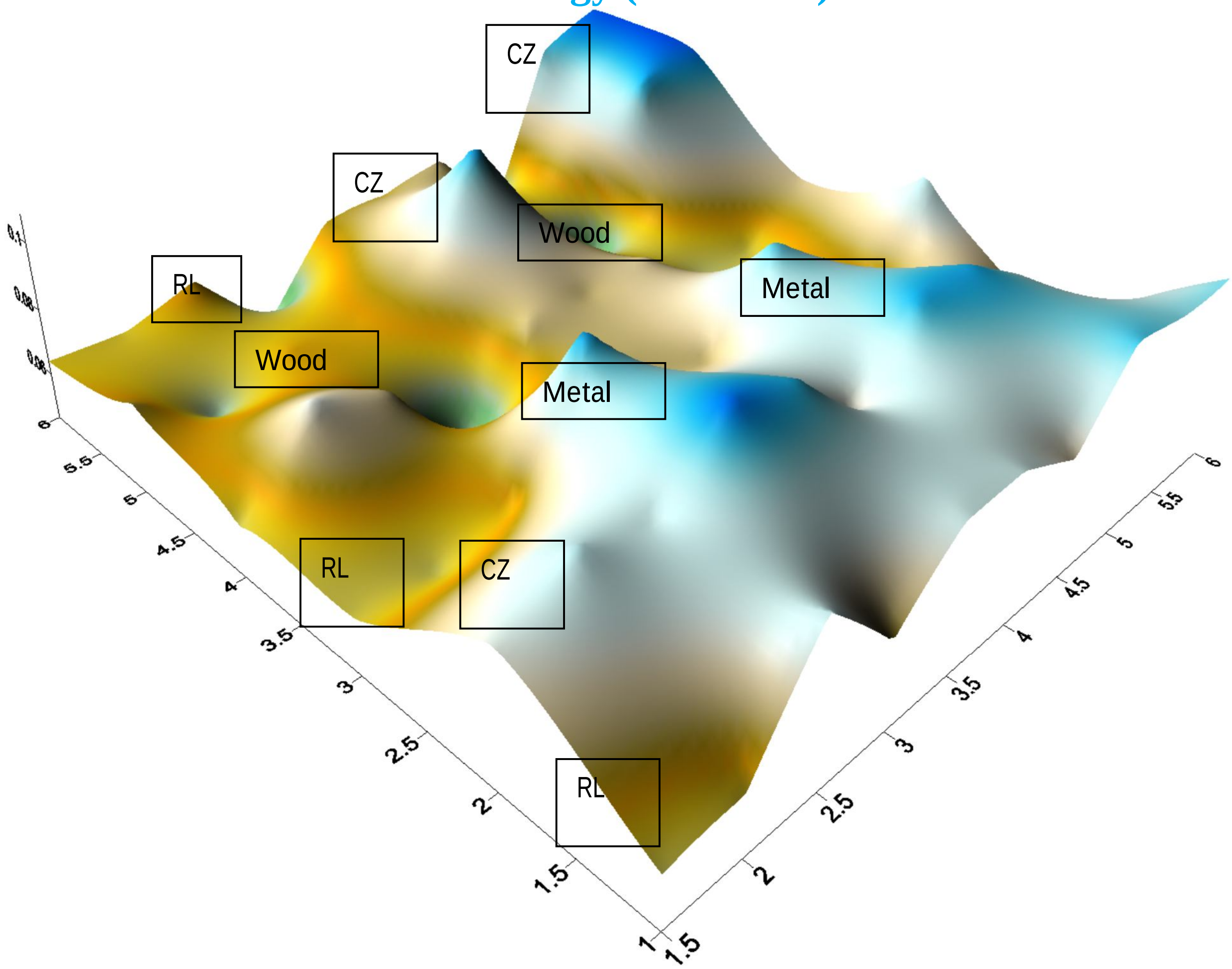

Fig. 6 3D Conductivity Relief Map

Figures 4, 5 and 6 show the apparent electrical conductivity variation in places where the electrical survey was done. The middle NW-SE part and upper Northern part also trending NW-SE have prominent low conductivities these places correspond to the places of submerged wood (indicated as Wood in Fig. 6) in the soil. The instrument sensed two parallel prominent high conductivity places in the middle trending NW-SE and up the Eastern part trending SE. Some rocks of low conductivities in RL indicated portions of the relief map while some isolated high conductivity zones are shown as CZ where soil and plant roots of high conductivity are present. Groundtruthing shows that a prominent plant roots are within the uppermost Northern zone of the maps.

V. CONCLUSION

The DC-AC 2kW electrical conductivity instrument was constructed locally with CD4047 oscillator and several components. The rectified high voltage was oscillated with a switching relay to reduce polarization and spontaneous potential errors in current and voltage. A twin T filter with frequency matched to the final relay frequency was used to filter the potential data from the ground for collecting correct voltage data. Geophysical measurement with this locally made electrical conductivity instrument using Wenner configuration accurately indicated the two woods and two cylindrical irons bars that were covered with soil after interpreting 3D maps made with Surfer 11^{TM}.

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