A Vertical Electrical Sounding Method For Investigating The Electrical Resistivity, & Salt Content (Salinity) In The Soils Of Sites Proximal To Lekki Peninsula, Lagos.

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***Abstract*—Measurements of resistivity is based on electrical methods.**

In the present investigation, the 'vertical electrical sounding' method was used to survey a site proximal to Lekki Peninsula in Lagos. The electrical resistivity was determined to observe the variation between electrical resistivity, and salt content.

Keywords—Electrical resistivity, Apparent resistivity, VES, Electrode arrays, Salt content (salinity).

1. Introduction

Electrical methods are intensively used by geophysicists for evaluation of deep subsurface. Measurements of the electrical conductivity or resistivity have been applied for soil salinity surveys in situ for many years [1], [2], [3]. The most common method is the electrical profiling using four-electrode probes in Wenner configuration. The probes are applied on the soil surface as well as in bore-hole logging, [4], Rhoades[5], , [6]. Recently other electrical geophysical methods such as electromagnetic induction (EM) and ground penetrating radar (GPR) become increasingly popular. The methods are still applied preferentially on saline irrigated areas. Some successful applications of the methods were reported on accessing quality of forest soils [7], mapping water flow paths [8], finding perched water locations [9] , and outlining permafrost layers [10] . Despite the promising applications, methods of four-electrode profiling, EM, and GPR have some drawbacks when used for shallow soil profiles. Methods of EM and four-electrode probe can not directly measure different resistivities or conductivities of soil horizons and provide only average or bulk electrical conductivity of the soil profile [11]. GPR evaluates profile differentiation in soil electrical conductivity, but its application is limited on soils with high conductivity (salty soils, clay soils). GPR is also not easily modified for shallow subsurface measurements [12] .

VES is a straight forward electrical resistivity method usually conducted using one of two electrode arrays: Schlumberger or Wenner array(s). These are generally 4-pin resistivity survey set-ups with progressively larger spacings between the current and/or potential electrodes. Short electrode spacings measure the resistivity distribution in the shallow subsurface, while the longer spacings measure deeper into the subsurface. By taking measurements starting with a short spacing stepping to larger, a 1D measurement, termed a 'sounding', of the resistivity as a function of depth is generated through a modeling process.

Although the method of vertical electrical sounding (VES) is very popular in conventional geophysical studies, such as gas, oil, and coal exploration [13] , it is rarely used in shallow subsurface studies. Vertical electrical sounding was applied to estimate hydraulic conductivity [14] and texture [15] of the stratified soils and sediments. VES [16] was applied to a landfill outlining at a 40-m depth. However, the arrays used in these studies can not accurately evaluate very thin (3-30 cm) soil layers.

The resistivity method is used in the study of horizontal and vertical discontinuities in the electrical properties of the ground,it utilizes direct curr ents or low frequency alternating currents to investigate the electrical properties(resistivity) of the subsurface.

A resistivity contrast between the target and the background geology must exist.

2. MATERIALS AND METHODS

The vertical electrical sounding and electrical profiling methods are based on the four-electrode principle as shown in Fig. 1. The electrical current (*I*) is applied to A and B electrodes and the potential (*U*) is measured between M and N electrodes. The bulk soil electrical resistivity (*ER*) is calculated with

$$ER = K\frac{\Delta U}{I}$$

,where *K* is the geometric factor.

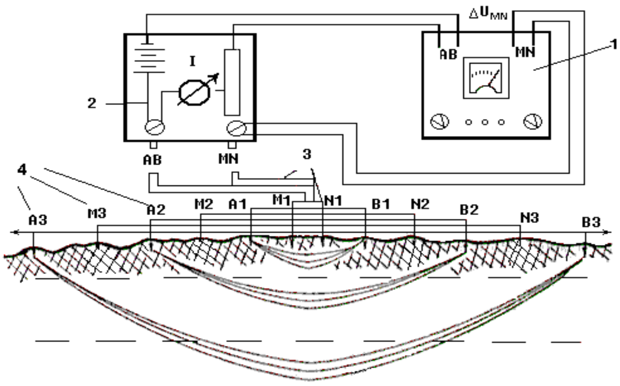

Fig. 1. Scheme of the vertical electrical sounding (VES) device: (1) auto-canceller, (2) commutator for electrodes AB and MN, (3) netted wires for different distances among electrodes AB and MN, and (4) electrodes.

Some uncertainties exist in the soil literature about the calculation of *K* and estimation of the measuring depth with different arrays [17-21]). As implied in conventional geophysics, the depth of penetration of electrical field in the media is influenced by the array geometry as well as electrical conductivity and layer organization of the media [19- 21]). Therefore, the depth of penetration can not be precisely derived from the distances between the electrodes in an array. Theoretical derivations and practical tests have shown that the approximate penetration depth can be considered as 1/6 of [*AB*] for the arrays of Schlumberger and Wenner types used on wide range of soils and grounds [23-26]. However, a depth approximation coefficient has been misused (1/3 of [*AB*]) for the four-electrode profiling with Wenner array[27-28].

While the depth of penetration for an array varies for the different soils around 1/6 of [AB], the geometric factor (*K*) can be precisely derived from the array geometry based on the law of electrical field distribution. Using the Laplace equation in polar coordinates the electrical potential functions around the source (A and B) and measuring (M and N) electrodes was derived [29]. The geometric factor *K* can be obtained for four-electrode array of AMNB configuration as

$$K = \frac{2\pi}{\frac{1}{[AM]} - \frac{1}{[BM]} - \frac{1}{[AN]} + \frac{1}{[BN]}} \quad . (1)$$

where [*AM*], [*BM*], [*AN*], and [*BN*] are the distances (m) between the respective electrodes. For central-symmetric array, when [*AM*]=[*BN*] and [*BM*]=[*AN*], Eq. [2] can be simplified to

$$K = \pi \frac{[AM][AN]}{[MN]} \quad . . (2)$$

The VES array consists of a series of the electrode combinations AMNB with gradually increasing distances among the electrodes for consequent combinations (Fig. 1). The depth of sounding increases with the distance between A and B electrodes. The *K* factors for the combinations are calculated with Eq. [2] and used to obtain electrical resistivity from measured electrical potential and current using Eq. [1]. The result of VES measurements with central-symmetric arrays is apparent (bulk) electrical resistivity as a function of half of the distance between the current electrodes, i.e. *ER*=f(*AB/2*) [30]. The relationship between *ER* and *AB/2* can be converted into a relationship between electrical resistivity and actual soil depth through a computer interpretation. Programs for soil VES interpretations based on an updated R-function was developed [31]. The electrical resistivity measured with the method is shown to be related with salinity, texture and structure, porosity, bulk density, saturation, and hydrological conductivity of the soil [32-33]. Thus, the VES profiles can provide information on the geological structures, soil properties, and hydrological conditions in a study area.

We modified the classical geophysical VES array to obtain detailed characteristics of relatively shallow subsurface. Two array configurations are adapted for soil studies. In the first array the [*AB/2*] distances are fixed as 0.1, 0.15, 0.22, 0.3, 0.45, 0.6, 0.9, 1.2, 1.8, 2.0, 3.6, 4.0, 7.2, 10, and 15 m to ensure a thorough measurement of soil subsurface from 0.02 to 5 m [33]. In the second array we increased the [*AB/2*] distances in a geometrical progression with a coefficient $\sqrt[10]{10} \approx 1.259$, which results the sounding data distribute with an equal increment in logarithm coordinates. The distances for the second array are set up as 0.1, 0.13, 0.16, 0.2, 0.25, 0.32, 0.40, 0.5, 0.63, 0.8, 1, 1.3 m, etc. The concurrent MN electrodes are placed symmetrically within the center of [*AB*] for the both arrays (Fig. 1). Resistivity is measured by different combinations of A, B, M, and N electrodes with an automatic switch between the combinations. Since the boundaries of soil layers are often more diffusive than the boundaries of geological strata, we average 2 to 4 replications with different [*MN*] distances for a [*AB*] distance to provide a higher measurement accuracy. The second array provides a very high accuracy essential if the soil profile is relatively uniform in electrical resistivity. The accuracy provided with the first array is adequate for most soil applications. Other modifications of the traditional method include the reduced size and weight of electrodes, arrays with the fixed distances among electrodes, and automatic commutator for the electrode combinations. The equipment with such features allows measuring a detailed VES profile within 10 min using the first array and within 20 min using the second array.

To highlight the advantages of VES usage for soil survey we examined soil profiles with highly variable electrical resistivities. The modified VES method was tested in soil horizons outlining in elluvial-alluvial profiles of Spodosols and Alfisols in the humid areas of Russia. Other properties that highly influence the profile distributions of electrical resistivity in soils are salinity, stone or rock content, and pollution by oil or gasoline. Electrical resistivities of stones, rocks, and hydrocarbons such as petroleum, gasoline, bitumen, and oil are about thousand times higher than that of soils, whereas the resistivity of a saline soil can be much lower than that of a non-saline soil. The VES method was applied previously in other investigations to evaluate of saline layers and groundwater depths in the alluvial soils in some other parts of the world, such as of delta Volga, Russia, and other regions of the world.

In our own case study, we have also applied the VES method to investigate salinity in the coastal area of Lekki Peninsula, Lagos, Nigeria.

3. Discussion

3.1 Resistivity

Ohm' s law

A direct current with strength I [A] flows through a conductor of a limited size.

$I = \frac{qV}{\rho l}$,.(3)

I: current strength [A]

V: Voltage [V]

q: cross section [m²]

l: length resistivity

ρ: Resistivity

$\sigma = {}^{1}/_{\rho}$: conductivity.

This can be written alternatively in terms of field strength (E [V/m]) and current density (j [A/m²]).

$\rho = {}^{E}/_{j}\ [\Omega m]$,.(4)

Resistivity is one of the most variable physical properties.

It varies between$1.6 \times 10^{-8} < \rho < 10^{16}\Omega$m

,for native silver, and pure sulfur.

Rock types and resistivity

Igneous rocks → highest resistivities

Sedimentary rocks →
tend to be the mostconductive due to their high fluid c ontentMetamorphic rocks → have intermediate but overlapping resistivities

Age of the rock is also important for the resistivity. For example: Young volcanic rock (Quaternary) ≈ 10-200 Ωm.

Old volcanic rock (Precambrian) ≈ 100-2000 Ωm

Rock types and resistivity

Most rock-forming minerals are insulators: $10^{8} - 10^{16}\Omega m$

However, measurement in-situ:

sedimentary rocks: 5-1000 Ωm

metamorphic/crystalline rocks: $100 - 10^{5}\Omega m$

Reason: Rocks are usually porous and pores are fil led with fluids, mainly water. As the result, rocks are electrolytic conductors. Electrical current is carried through a rock mainly by the passage of ions in pore waters.

Most rocks conduct electricity by electrolyticrather t han ohmic processes.

3.2 Law of Archie

It is observed that,

$$\rho \approx {}^{1}/_{\phi^{2}}$$

,where **ϕ** is the porosity.

The empirical law of Archie is expressed as;

$\rho = a\phi^{-m}S^{-n}\rho_{w}$,.(5)

,: fractional pore volume (porosity)

S: fraction of the pore containing water

ρ_{w}: resistivity of water

$$n \approx 2$$

$$0.5 < a < 2.5$$

$$1.3 < m < 2.5$$

An increase in the number of ions in soil water (groundwater contamination) linearly decreases the soil resistivity.

4.FurtherDiscussion: Resistivity values

There is considerable overlap between different rock types.
Identification of a rock type is not possible solely on th e basis of resistivity data.
Resistivity of rocks depends on porosity, saturation, c ontent of clay and resistivity of pore water (Archie' s formula).

4.1 Current flow in a homogeneous earth

A single current electrode on the surface of a medium of uniform resistivity.
The voltage drop between any two points on the surface can be described by the potential gradient.
dV/dr is negative because the potential decreases in the direction of current flow.

Potential decay away from the point electrode

Current flows radially away from the electrode so that the current distribution is uniform over hemispherical shells centered on the source.
Lines of equal voltage (equipotentials) intersect the lines of equal current at right angles, it sinks at a large distance from the electrode.

*The geometric factor k is a crucial parameter in electrical resistivity measurement, and can be determined for various kinds of electrode set up, or spacing.

4.2 **Discussion (continuation) : True resistivity**

True resistivity of the subsurface exists, if it is homogeneous.

Where the ground is uniform, the resistivity should be constant and independent of both electrode spacin g and surface location.

When subsurface inhomogeneities exist, the resistivity will vary with the relative positions of electrodes.

The calculated value is called apparent resistivityρ_a,

$\rho_a = \frac{\Delta V_{MN}}{I} k$,.(6)

In general, all field data are apparent resistivity. They are interpreted to obtain the true resistivities of the layers in the ground.

Analysis

The table of results is presented below, and the graph is obtained.

Table 1: Salinity, & resistivity data

Depth	Total salinity	Results of interpretation		Re-calculated salinity
		Layer depth	ER	for interpretation layers
m	%	m	ohm m	%
0-0.02	0.092	0-0.17	98	0.074
0.02-0.05	0.087			
0.05-0.20	0.068	0.17-0.74	15	0.095
0.20-0.40	0.077			
0.40-0.70	0.132			
0.70-1	0.1165	0.74-2.55	12	0.117

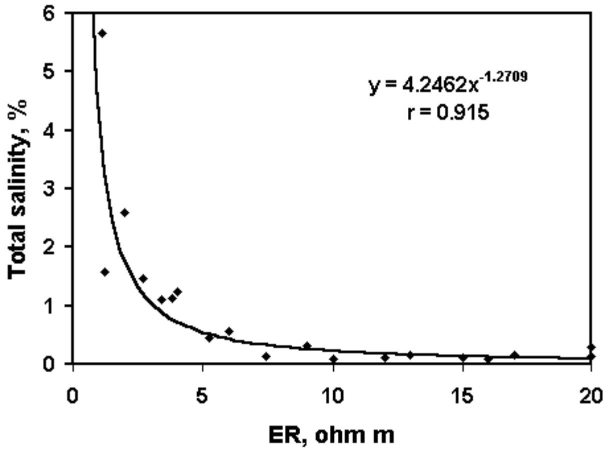

Fig. 2. The relationship between the electrical resistivity measured in-situ by VES method and the total salt content in soils site within selected zone of Lekki Peninsula, Lagos.

5. Conclusion

This study examined the vertical electrical sounding method in soil survey of the selected site in this investigation, which is also an electrical geophysical methods used to measure bulk electrical conductivity of the soil volume for the evaluation of soil salinity.

Soil electrical resistivity depends simultaneously on many soil properties, such as salt, water, humus or stone content, texture, and temperature, in many applications one or two highly variable properties can be considered as main factors influencing the profile distribution of electrical resistivity.

Generally, the VES method can be used for in-situ soil monitoring when the monitored property alone highly influences the distribution of electrical resistivity in a soil profile. The VES method can be useful for monitoring saline solution movement, defrosting, drying, or compaction of soils.

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