American Journal of Environmental Engineering 2015, 5(5): 141-145
DOI: 10.5923/j.ajee.20150505.02

Modeling Longitudinal Movement of Leachate in Soils by Means of Electrical Resistivity and Moisture Content

L. A Uneke[1], A. P. Paulinus[1,*], S. Ayagere[2]

[1]Department of Civil Engineering, Rivers State, Polytechnic, Bori, Nigeria
[2]Department of Architectural Technology, Rivers State, Polytechnic, Bori, Nigeria

Abstract Ground water and soil contamination by leachate is a serious pollution problem. Developing a simple model to monitor its movement is the object of this study. Soil electrical resistivity is an emerging technic in soil characterization. A major factor that influences it is moisture content/soil moisture density. Determinations of electrical resistivity of soil in and away from a municipal waste dump site as well as laboratory determination of soil moisture content were carried out in this study. The intent was to establish a linear relationship amongst resistivity, regression analysis. Result shows that resistivity increased as distance away from sources of leachate production increased, while moisture content decreased. The developed model showed a good coefficient of correlation of 0.975 thus validating the model.

Keywords Soil, Leachate, Electrical Resistivity, Moisture Content, Model, Monitoring

1. Introduction

Leachate is the product of decomposition of municipal solid waste by a combination of physical, chemical and biological processes and precipitation, percolation and infiltration of water into a sanitary landfill. Sanitary landfills are usually designed to prevent leaching which often contaminate ground water and other nearby water courses. Landfill leachate has very high concentration of toxic metallic contaminants which presence induce high electrical conductivity of the infiltrated soil. Soil electrical resistivity (inverse of conductivity) provides a good measure of information on soil cation contents which are good indicators of soil contamination, hence soil cation exchange capacity may be used as an assessment tool to measure future contamination (Badv etal 2007).

Soil electrical resistivity is the resistance offered by the soil to the passage of electrical current through it. It is one of the emerging techniques of soil characterization in respect of contamination of the media and consequent effect on electrical grounding systems and lightening conductors. Every soil possesses natural resistivity within certain limit deviation from which generally suggest position pollution as the contaminant may influence bulk resistivity (Achie 1942). A major factor that affects soil resistivity is moisture content and it may be used to monitor longitudinal movement of leachate in soils.

* Corresponding author:
paulynciap06@yahoo.com (A. P. Paulinus)
Published online at http://journal.sapub.org/ajee

2. Review of Literature

Not much is available in literature on the subject matter of leachate movement in soil by use of electrical resistivity of the soil. The basic principle involved in the measurement of soil electrical resistivity is that voltage drop across a pair of electrodes when current is passed through them is proportional to the electrical resistivity of the soil. Electrical conductivity (and by implication, resistivity) was first applied in geophysical logging resulting in (Achie, 1947) equation for saturated rocks and sands.

$$E_c = ar_c \sum^m \quad (1)$$

E_c apparent soil electrical conductivity, r_c is electrical conductivity of porous media, m is cementation exponent and a is an empirical constant. Equation (1) can also be written as (Rhodes 1989)

$$F_f = \frac{P_{sat}}{P_w} an^{-m} \quad (2)$$

F_f is known as formation factor, n is porosity of the media, a and m are arbitrary constants that prop up the equation to particular group of measurement.

Rhodes et al (1999) suggested that there are three pathways of current flow that contribute to electrical conductivity in soils namely liquid phase, solid-liquid phase and solid phase. They gave electrical conductance model describing the three pathway as

$$E_C = \left[\frac{(Wss+Wws)2Ewc*Ess}{Wss*Ewc+Wws*Es}\right]+(Wsc*Esc)+(Wwc*Ewc) \quad (3)$$

Where W_{ws} and W_{wc} are volumetric water contents of the soil-water pathway and in the continuous liquid pathway. W_{ss} and W_{sc} are volumetric contents of surface conductance and undulated solid phases of the soil. E_w and E_{wc} are specific electrical conductivities of soil-water pathway and continuous-liquid pathway (Cordwin et al, 2005).

Comrade Schlumberger and Frank Wenner introduced simpler methods of obtaining soil resistivity by introducing electric current into the soil through current electrodes at the soil surface and reading the flow potential from a voltmeter (Burge, 1992). Apparent soil resistivity by the Wenner method is given by

$$R_A = \frac{[4\pi \mathrm{RaRw}]}{\left[1 + \frac{2a}{\left(a^2 + 4b^2\right)^{1/2}} - \frac{a}{\left(a^2 - b^2\right)^{1/2}}\right]} \quad (4)$$

R_A, a, b, R_w are measured apparent resistivity (Ωm), electrode spacing (m), and depth of electrode respectively. Similarly, the Schlumberger formula for soil resistivity is (Agunwamba, 2008).

$$RA = \frac{\pi L 2\Delta V}{2I} \quad (5)$$

Where I, ΔV and L are current, potential difference and length between electrodes.

Several physical and chemical factors that affect soil resistivity include moisture content/bulk density, temperature and ionic concentrations of soluble salt, porosity, pore structure, grain size distribution among others (Abu - Hassanein et al, 1996. The most important of these factors in monitoring leachate movement is moisture content because the cation content of the leachate is transfer through it.

3. Materials and Method

The fall of potential method is adopted in this work for measurement of electrical resistivity. The materials include an ammeter, a voltmeter, earth electrodes, 1.5mm thick cable and a 9-volt battery. All these were arranged to form the resistivity meter. The usual moisture content apparatus including moisture content cams, oven, and weigh balance were used for the tests.

The dump site used was located in Bori urban, a suburb of Port Harcourt city capital of Nigeria’s south-south state of Rivers, on latitude of 4’1’ north and longitude of 7’2’ East. The soil composition at a depth of 1.0m was 94% sand and 6% clay. Test points were spaced at 15.0m intervals from center of dump.

The three electrodes were interconnected by 1.5mm cables to the voltmeter and ammeter which gave the voltage and current values receptively in the experiment.

Resistivity was calculated using

$$R = \frac{2\pi S v}{l} \quad (6)$$

Where R, S, v and I are soil resistivity, electrode spacing, voltage and current respectively. Moisture content was determined by standard procedure. The desired equation was obtained by multiple repression procedure using resistivity, moisture content and distance away from centre of dump as variables, to give equation of the form.

$$\mathrm{Rs} = \mathrm{Ax} + \mathrm{Bm_c} + \mathrm{c} \quad (7)$$

Where R, M_C and x are Resistivity, Moisture content and distance away from centre of dump respectively. A and B are coefficient while c is a constant.

4. Model Development

It is assumed that the soil profile is uniform further down the site and longitudinally. The resistivity and moisture content are assumed to be good enough tools to predict leachate movement because water is a good conductor of electricity. An intrinsic relationship may be established between resistivity on one side and moisture content and distance away from point of leachate production in the other side. With such a relationship leachate concentration changes can be monitored as a function of moisture content.

From table (1) regressing resistivity against moisture content gave

$$\mathrm{R} = 9.051 \times 10^2\ \mathrm{M_c} + 17.491 \quad (8)$$

Similarly regressing resistivity against distance away from dump yielded

$$\mathrm{R} = 0.295\mathrm{x} + 10.598 \quad (9)$$

The regressions were combined in the following manner.

$$\sum \mathrm{R} = \mathrm{nc} + \mathrm{M}\sum \mathrm{x} + \mathrm{b}\sum \mathrm{k} \quad (10)$$

$$\sum \mathrm{Rx} = \mathrm{c}\sum \mathrm{x} + \mathrm{M}\sum \mathrm{x}^2 + \mathrm{b}\sum \mathrm{x}\,\mathrm{M_c} \quad (11)$$

$$\sum \mathrm{RM_c} = \mathrm{c}\sum M_c + \mathrm{M}\sum M_c\mathrm{x} + \mathrm{b}\sum M_c^{\,2} \quad (12)$$

Using Gaussian elimination method for resolution of unknowns gave final result as

$$\mathrm{R} = 0.173\mathrm{x} + 0.471 M_c + 24.482 \quad (13)$$

Equation (13) is the desired relationship. The equation gives a simple and quick means of determining leachate movement in soils. Cation content of the leachate is higher at the dump site and should reduce away from it. Hence resistivity increases away from the dump. Evaporation is less at the dump, hence its higher moisture content. The model developed predicts the true situation of the dump as observed in the foregoing.

5. Results and Analysis

Results of resistivity and moisture content are presented in tables (1) and (2) respectively. Estimated centre point of dump had lowest resistivity value of 9.32Ωm while lowest resistivity value of 26.38Ωm was recorded 60m away. These shows that resistivity decreased with increase in distance from point of leachate production while moisture content decreased. Thus leachate concentration decreased away from source. Leachate increases moisture content and salt concentration of the soil.

The increase in resistivity away from source is as a result of increase in the salt content of the soil resulting from dissolution of metallic elements in the waste. The above observation confirms the results obtained by Yoon et al (2002).

Table 3 is the result of resistivity obtained from equation (13). High coefficient of correlation of 0.975 implies that the equation is reliable.

Table 1. Distance, Resistivity are moisture content

Distance (x) (m)	**Resistivity (R) (Ωm)**	**Moisture Content (M_c)%**
0	9.32	33.19
7.5	11.62	30.05
15	14.60	22.91
22.5	20.12	21.83
30	22.15	18.75
37.5	23.09	17.99
45	24.79	17.22
52.5	25.36	16.84
60	26.38	16.46

Table 2. Resistivity measured and predicted by equation (13)

Distance (x) in (m)	**Resistivity measured (Ωm)**	**Resistivity predicted by equation (13) (Ω+m)**	**Moisture Content (M_c)%**
0	9.32	8.85	33.19
7.5	11.62	11.63	30.05
15	14.60	16.84	22.91
22.5	20.12	18.07	21.83
30	22.15	20.84	18.75
37.5	23.09	22.50	17.99
45	24.79	24.16	17.22
52.5	25.36	25.63	16.84
60	26.38	27.11	16.46

Table 3. Model Validation Figures

R	$\hat{R}$	$R - \bar{R}$	$\hat{R} - \bar{R}$	$[R - \bar{R}]^2$	$\sum[\hat{R} - \bar{R}]^2$
9.32	8.85	-0.47	-10.47	100	109.62
11.62	11.63	-1.69	-7.09	59.27	59.61
14.60	16.84	-1.69	-3.05	22.78	9.31
20.12	18.07	-1.45	-0.75	0.64	0.56
22.15	20.84	1.31	1.52	8.01	2.31
23.09	22.50	0.59	3.18	14.21	10.11
24.79	24.16	0.64	4.84	29.92	23.39
25.36	25.63	0.29	3.61	36.48	39.82
26.38	27.11	0.73	7.79	49.84	60.68

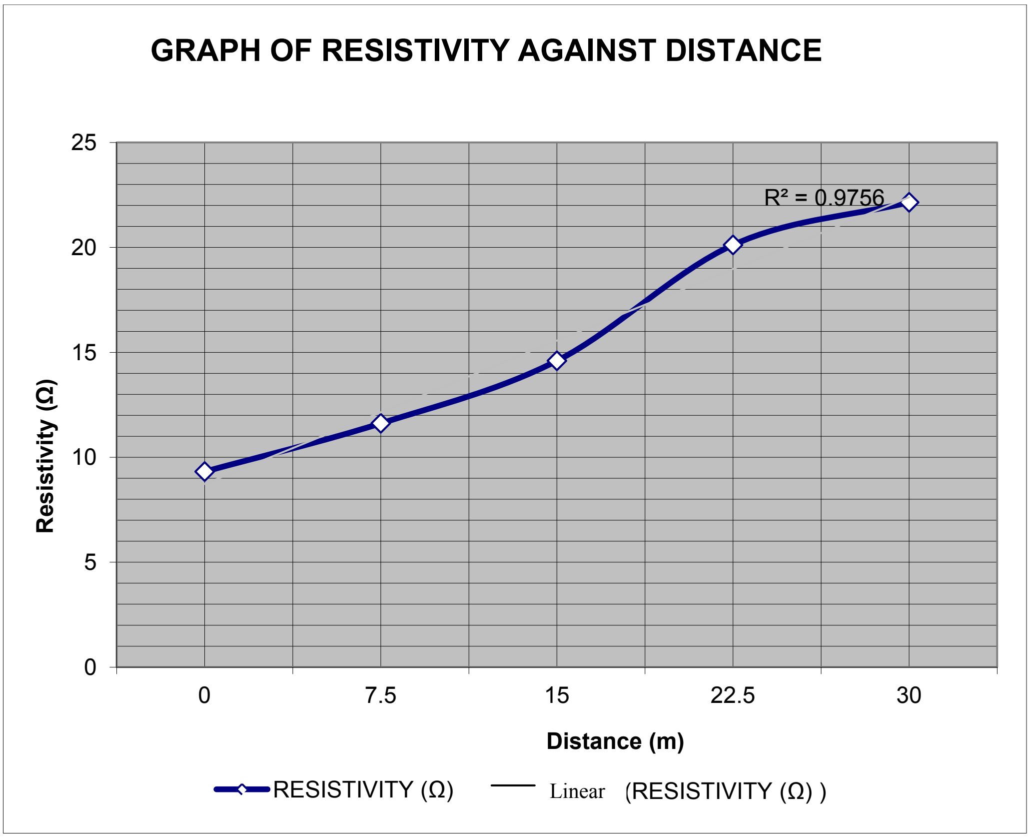

Figure 1. Plot of Resistivity against distance

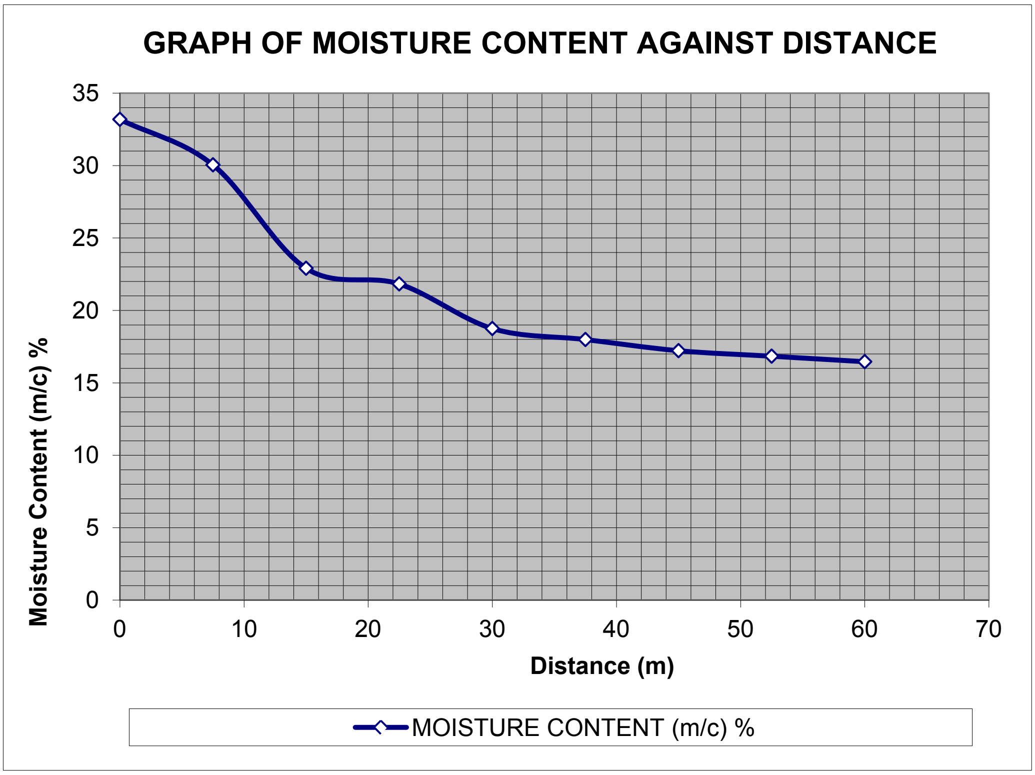

Figure 2. Plot of moisture content against distance

6. Conclusions

A basic linear relationship has been established amongst soil resistivity, moisture content and distance away from point of leachate production. This is as stated in equation (13). The equation may be used in monitoring longitudinal movement of leachate by simply determining the moisture content along the path of interest. Leachate concentration/moisture content has been confirmed to vary with distance away from point of production. Equation (13) offers a simple and quick means of determining these variations. Use of wells may serve only as a confirmatory test.

Where, R = Resistivity measured $\hat{R}$ = Resistivity predicted

$\bar{R}$ = 19.32

$\sum[\hat{R} - \bar{R}]^2$ = 315.41

$\sum[R - \bar{R}]^2$ = 321.12

Coefficient of correlation r^2

$$= \frac{\text{Explained variation}}{\text{Total variation}}$$

$$= \frac{315.41}{321.12} = 0.98$$

REFERENCES

[1] Abu-Hasanein, Z.S; Benson Colt and Boltz L.R; (1996). Electrical resistivity of compacted clay. Journal of Geotechnical Eng; 122, (5), 397-406.

[2] Agunwamba, J.C (2008): Water engineering systems, De-adroit innovation, Ogui N/L, enugu, Nigeria 35.

[3] Archie. G.E; (1942). Electrical resistivity log as an aid in determining some reservoir characteristics. Trans. Am Inst. Min. Metaill. Pet-Eng 146, 54-62.

[4] Badv. K and Omidi, A (2007), Ranian Journal of Science and Technology. Transaction B, Engineering, 31 (5), 535 – 545.

[5] Burger, H.R (1992). Exploration Geophysics of shallow surface. Prentice Hall PTR, Upper Saddle River, NJ.

[6] Corwin, D.L and Lesch S.M (2005) apparent soil electrical conductivity measurement in agriculture comp. and electronics in agric 46, 11-43.

[7] Rhodes, J.D; Corwin, D.L and Lesch S.M (1999 a). Geospatial measurement of soil electrical conductivity to assess soil salinity and diffuse salt loading from irrigation. In: Corwin, D.L Loague, K and Ellsworth, T.R (Eds). Assessment of non-point source pollution in vadose zone. Geophysical monograph 108. American Geophysical Union, Washington D.C USA, 197-215.

[8] Rhodes J.D, Manteghi, N.A; Shouse P.T and Alves, W.J (1989). Soil electrical conductivity and soil salinity: New formulations and calibrations. Soil science society Journal 53. 433 – 439.

[9] Yoon, G.L; Oh JH and Park, J.B. (2002) Laboratory study of landfill leachate effect on resistivity in unsaturated soil using cone penetration. Journal of environmental geology 43, 18-28.