Correlation For Predicting Tds And Elecrical Conductance Of Groundwater: Using Electrical Resistivity Method

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***Abstract*—This study is aimed at developing a correlation that will assist in predicting the TDS and electrical conductance of groundwater using values of groundwater resistivity. One hundred hydrogeochemical data were gotten from 100 wells across the Basement Complex rocks of Nigeria and sedimentary rocks in some parts of Nigeria. VES was carried out close to each of these wells to determine the groundwater resistivity. Least square method was used to generate mathematical correlations for TDS, electrical conductance, and electrical resistivity. Results of the correlations were validated and found to be in agreement with experimental values when compared. Statistical analysis was further used to determine the reliability of the correlations. The correlated results for TDS and EC show multiple correlation coefficient values of 0.992 and 0.998; average absolute percentage relative error values of 0.0327 and 0.0164; and average absolute error values of 11.5 and 6.422 respectively.**

***Keywords*— TDS, electrical conductance, water quality, VES, Least Square Analysis**

INTRODUCTION

Total dissolved solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal solution) suspended form. Put differently, they are the total amount of mobile charged ions and minerals in a given volume of water, expressed in units of mg per unit volume of water (mg/L), also referred to as parts per million (ppm).
Primary sources for TDS in receiving waters are agricultural and residential runoff, leaching of soil contamination, and point source water pollution discharge from industrial or sewage treatment plants. The most exotic and harmful elements of TDS are heavy metals. Certain naturally occurring total dissolved solids arise from the weathering and dissolution of rocks and soils.
The principal application of TDS is in the study of surface water and groundwater quality. Although TDS is not generally considered a primary pollutant (e.g. it is not deemed to be associated with health effects) it is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants.
A TDS meter is based on the electrical conductivity (EC) of water. Pure H_20 has virtually zero conductivity. Conductivity is usually about 100 times the total cations or anions expressed as equivalents. TDS is calculated by converting the EC by a factor of 0.5 to 1.0 times the EC, depending upon the levels. Typically, the higher the level of EC, the higher the conversion factor to determine the TDS. In the laboratory, TDS is typically measured by gravimetric method or by multiplying electrical conductance with 2/3.
Generally, electrical conductance is used to determine TDS. The hydrogeochemical method can be used in determining the electrical conductance of surface water. This is because it is easy to estimate the actual temperature of surface water in-situ. More so, the overall conductance of such water is strongly dependent on its temperature variation.
An accurate determination of the electrical conductance of ground water requires an estimate, and use of its in-situ temperature. Regrettably, the in-situ temperature of ground water cannot be easily determined as such temperatures (i.e. of collected ground water samples) are easily influenced or altered by temperatures of other external sources. Therefore, hydrogeochemical test method is inadequate for determining the electrical conductance for ground water, and thus, cannot be used in determining TDS of groundwater.
As a bid to resolving this problem so as to accurately predict the EC and TDS of ground water, we propose a new mathematical correlation in this work that can capture the in-situ temperature of groundwater and aquifer. We are not oblivious with the fact that the Vertical electrical sounding technique has the ability to measure the electrical resistivity of groundwater at the aquifer's in-situ temperature. It is from this vantage point that we try to establish a mathematical correlation in this work between TDS and apparent resistivity; and EC and apparent resistivity of groundwater in order to be able to use apparent resistivity of groundwater to predict the TDS and EC of ground water.
There is no existing work that shows that apparent resistivity of groundwater is used to predict the TDS and EC of groundwater. However, Mehrdadi et al. [1]

and Maedeh et al. [2] have used Artificial Neural Network (ANN) to predict TDS variation in groundwater. ANN method is stressful most especially while training the network and it does not factor in the in-situ temperature. More so if proper training is not done, the true value cannot be obtained. Rhoades [3] used hydrolysis PH measurements to predict short-term bulk TDS elution potential for a given material. However, Daniels et al. [4] used PH, EC, and ions of interested ions (Ca^{2+} and $S04^{2-)}$ to predict TDS discharge in mine spoil. The short comings of these methods of TDS prediction is that they do not capture the true in-situ temperature of the groundwater which is one of the major factors that affect electrical conductivity of groundwater.

MATERIAL AND METHODS

Samples of groundwater were collected from 100 wells across some Basement Complex Rocks and sedimentary terrain in Nigeria and taken to laboratory for hydrogeochemical analysis in order to determine the TDS and EC through the conventional method. The TDS was determined using gravimetric method while the EC was determined using electrometric method. Vertical electrical sounding (VES) was carried out at the sides of the 100 wells to the depth of the aquifer in each well. The data from the VES were later processed with res1Dinvers in order to determine the resistivity of the groundwater. Statistical analysis was used to determine the relationship between the resistivity of groundwater, TDS, and EC. The least square method was used to provide estimators a_o, a_i, and the fitted value to generate equation (1) as

$$y = a_0 + a_i x \quad (1)$$

The residual sum of the square of differences for all n is given by

$$S = \sum_{i=1}^{n} (y_i - a_o - a_i x_i)^2 \quad (2)$$

Values of a_o and a_i have to be determined so that S shall be a minimum

$$\frac{\partial S}{\partial a_o} = 0 \quad (3)$$

$$\frac{\partial S}{\partial a_i} = 0 \quad (4)$$

Therefore equations (3) and (4) can be written as equations (5) and (6) respectively as

$$\frac{\partial s}{\partial a_o} = -2\sum_{i=1}^{n} (y_i - a_o - a_i x_i) = 0 \quad (5)$$

$$\frac{\partial s}{\partial a_i} = -2\sum_{i=1}^{n} x_i (y_i - a_o - a_i x_i) = 0 \quad (6)$$

Equation (5) gives:

$$\sum_i^n y_i - a_o - a_i \sum_i^n a_i = 0 \quad (7)$$

$$a_o n + a_i \sum_i^n x_i = \sum_i^n y_i \quad (8)$$

While equation 6 gives:

$$\sum_i^n x_i y_i - a_o \sum_i^n x_i - a_i \sum_i^n x_i^2 = 0 \quad (9)$$

$$a_o \sum_i^n x_i + a_i \sum_i^n x_i^2 = \sum_i^n x_i y_i \quad (10)$$

Equation (9) and (10) can be equated into equation (11) and (12) for all n given pairs of values

$$a_o n + a_i \sum x = \sum y \quad (11)$$

$$a_o \sum x + a_i \sum x^2 = \sum xy \quad (12)$$

Thus the specific values of a_o and a_i can be determined by equations (13) and (14) respectively or by solving equation (11) and (12) simultaneously.

$$a_o = \frac{1}{\Delta^\circ}[(\sum(x_i^2)(\sum y_i) - (\sum x_i)(\sum x_i y_i)] \quad (13)$$

$$a_i = \frac{1}{\Delta^\circ}[n\sum(x_i y_i) - (\sum y_i)] \quad (14)$$

Where

$$\Delta^\circ = n\sum(x_i^2) - (\sum x_i)^2$$

One hundred data of hydrogeochemical and apparent resistivity from hundred wells across Nigeria Basement Complex and sedimentary terrain were gathered and used to determine which parameter(s) has/have correlation with apparent resistivity out of all the hydrogeochemical parameters tested for by using multiple correlation coefficients. Results of the multiple correlation coefficients indicated that TDS has the strongest correlation. Thus, equations (11), (12), (13), and (14) were used to generate correlation that relates TDS of groundwater to apparent resistivity of groundwater as:

$$GW_{TDS} = 2400\rho^{-1} + 159.8 \quad (15)$$

Where

GW_{TDS}= Total dissolved solid of groundwater

ρ = Apparent resistivity of groundwater

Similarly, mathematical correlation that relates electrical conductance measured from hydrogeochemical test of groundwater with apparent resistivity of groundwater is given as:

$$EC_{geoch} = 236.8e^{8.868\rho^{-1}} \quad (16)$$

Where

EC_{geoch}= Electrical conductance calculated from hydrogeochemical parameters of groundwater

ρ = Apparent resistivity of groundwater

In order to properly identify the effectiveness and the performance of the equations (15) and (16), statistical error analysis was used as follows:

$$AAE = \frac{1}{N}\sum_{i=1}^{n} |Exp_i - Pred_i| \quad (17)$$

$$AAPRE = \frac{1}{N}\sum_{i=1}^{n} \left|\frac{Pred_i - Exp_i}{Exp_i}\right| \quad (18)$$

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{n}(Exp_i - Pred_i)^2}{\sum_{i=1}^{n}(Exp_i - Pred_{avg})^2}\right) \qquad (19)$$

Where
AAE= Average Absolute Error
AAPRE= Average Absolute Percentage Relative Error
R^2 = Multiple Correlation Coefficient

RESAULT AND DISCUSSION

Shown in table 1 are experimental results of TDS and EC obtained from previous study of ten wells across Nigeria with both wells drilled in the Basement Complex and sedimentary terrains. The table also displays results of the predicted TDS and EC obtained in this study.
Previous experimental results show a range of value of TDS and EC from 227.3gm/l to 543gm/l and 303Us/cm to 962.2Us/cm respectively (Table 1).

Table 1: Results of VES, TDS, Electric conductance (EC) from wells across Nigeria

Well	VES (Ωm)	TDS (gm/l)	EC Geoch (Us/cm)	Predicted EC (Us/cm)	Predicted TDS (gm/l)
1	16	324.8	433	412.18	309.8
2	20	257.3	343	368.93	279.8
3	40	227.3	303	295.57	219.8
4	5.7	589	1122	1121.77	580.76
5	7.92	478	725	725.13	462.68
6	6.32	542	962.2	961.37	539
7	6.42	543	942.3	942.8	539.72
8	13.72	351	452	452	334.76
9	7.27	499	801	798.02	488.6
10	11.24	387	516	521.37	373.4

As observed from the above table, there is a close agreement between previous experimental results of TDS and EC and those predicted in this study. The comparison plots for the experimental TDS against predicted TDS; and experimental EC against predicted EC also show similar trends (see Figures 1 and 2).
The multiple correlation coefficients for the two correlations are 0.992 (Fig. 3) and 0.998 (Fig. 4) respectively. This shows that the two correlations are very close to the experimental values. The statistical error analysis for the two correlations shows that the AAE and AAPRE for the predicted TDS are 11.5 and 0.0327 respectively (Table 2); and for the predicted EC are 6.422 and 0.0164 respectively (Table 2). These values give strong evidence that the present correlations predict very close to the experimental values with low minimal error.

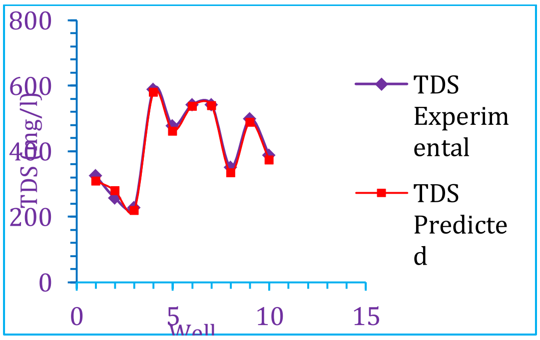

Fig.1: Comparison plots for predicted TDS

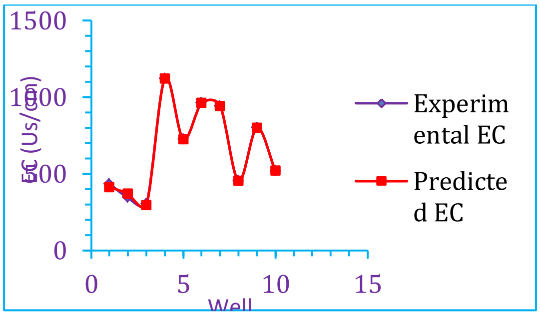

Fig.2: Comparison plots for predicted EC

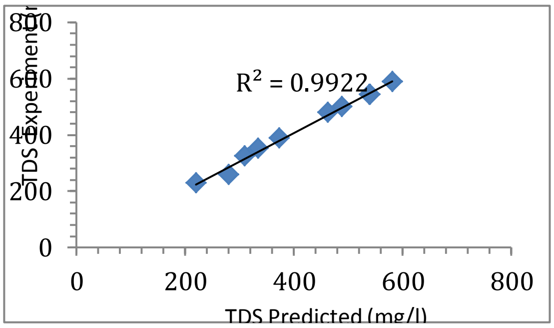

Fig.3: Multiple correlation coefficients for predicted TDS

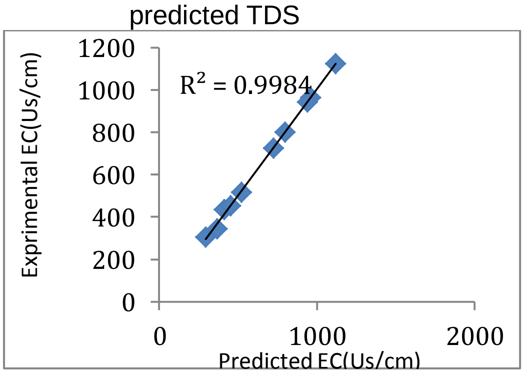

Fig.4: Multiple correlation coefficients for predicted EC

Table 2: Result of statistical analysis

Statistics Analysis	TDS (gm/l)	EC Us/cm
AAE	11.5	6.422
AAPRE	0.0327	0.0164
R^2	0.992	0.998

CONCLUSION

Correlations for predicting the TDS and EC of groundwater using electrical resistivity values of groundwater have been developed. These correlations are capable of capturing the true in-situ temperature of groundwater and require only groundwater resistivity. The proposed correlations have been successfully validated and consistent with experimental values when compared. The development of these present correlations was spurred by unavailability of large volumes of data for more accurate correlation of TDS and EC.

Instead, try “R. B. G. thanks.”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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