Modeling and Simulation of Groundwater for Irrigational Usage in Ede City, Rivers State, Nigeria

C. Ukpaka, [1] F. E. Ezeilo [2] and J.C. Ozota [3]

[1]Department of Civil Engineering, Rivers State University, Nigeria
[2]Jospaka Ventures Nigeria Limited, Port Harcourt, Nigeria.
[3]Department of Chemical / Petrochemical, Rivers State University, Nigeria.

Corresponding Author's Email: ezeilo.ebele@ust.edu.ng

Abstract

In this research the modified sodium absorption ratio differential equation developed for Ede City in Rivers State, Nigeria given as, $\frac{\partial SAR}{\partial t} + 0.004t$ - 0.005 = 0 were solved using the approach of finite element method and the solution gives, SAR values for different weeks as SAR_1 = 0.36, SAR_2 = 0.35, $SAR_3 = 0.34, SAR_4 = 0.33$ *and* $SAR_5 = 0.31$ and SAR values obtained by empirical model as SAR_1 = 0.36, SAR_2 = 0.35, $SAR_3 = 0.35, SAR_4 = 0.35$ *and* $SAR_5 = 0.34$. The concept of using finite element method in simulating and monitoring sodium absorption ratio was validated by comparing the relationship between results obtained by empirical model and finite element method using linear least square approach and coefficient of determination, R^2= 0.844 indicating the reliability of finite element in simulating SAR values in groundwater of the study area. Describing the suitability of groundwater for irrigation usage, the groundwater is of low sodium water (S1) can be used for irrigation on almost all soil and for all crops except those which high sensitive to sodium, such as stone fruit trees and avocado and so on.

Keywords: Sodium absorption ratio, irrigation, water, finite element method, empirical, Ede City

*Corresponding author

1 Introduction

The quality of suitable irrigation water is highly influenced by the constituents of the soil which is to be irrigated in the field. Particular water may be harmful for irrigation application on a particular soil, but good on other soils. The constituents that makes water unfit for irrigational works are sediment concentration in water, bacterial contamination, bicarbonate concentration as related to concentration of calcium plus magnesium, total concentration of sodium salts in water and ratio of sodium ions to other cations. The irrigation water should, therefore, have salts that are lower than the tolerant values of the grown crops. However, salts in excess of 700mg/l prove harmful to some crops, and more 2000mg/l are injurious to all crops. The salt concentration in irrigation water or soil extract is generally evaluated by electrical conductivity of salty water [1-10].

In terms of quality of water for irrigation, the major parameters of concern are salinity, in the form of dissolved solids and conductivity, potentially toxic trace elements, and herbicides. Furthermore, the presence of sodium is also an important parameter, the excess quantities of which can deteriorate the soils to be irrigated. High value of sodium may also damage the sensitive crops because of sodium phytotoxicity. The degree of sodium in water can be evaluated using percent sodium or sodium absorption ratio empirical models [1-6].

In this research the developed model used in monitoring and predicting sodium absorption ratio of Ede City given by Ukpaka, 2016 will be examined further, taking change in time which gives an account of environmental activities on the City as a functional parameter and the modified sodium absorption ratio model will be simulated using the concept of finite element approach and results compared sodium absorption ratio evaluated by empirical model.

1.1 Sodium absorption ratio guideline

Table 1 below described type of water and applicable irrigation usage.

Table 1: Describing Suitability of Water for Irrigation Use.

S/No	Type of Water	Use in Irrigation
1.	Low sodium water (SI) SAR value between 0-10.	Can be used for irrigation on almost al soil and for almost all crops except those which are highly sensitive to sodium, such as stone fruit trees and avocado, etc.
2.	Medium sodium water (S2) SAR value between 10-18.	Appreciably hazardous in five-textured soils, which may required gypsum etc, but may be on coarse-textured or organic soils good permeability.
3.	High sodium water (S3) SAR value between 18-26.	May prove harmful on almost all the soils, and do require good drainage, high leading, gypsum addition, etc for proper irrigation.
4.	Very high sodium water (S4) SAR value above 26.	Generally not suitable for irrigation.

Source: Garg (2007)

2. Materials and Method

2.1 Regression Model of Sodium absorption Ratio (SAR)

Ukpaka, 2016, developed a SAR regression model for monitoring and predicting sodium absorption ratio value for Ede Community, Rivers state, Nigeria which is given as;

$$\text{SAR} = -0.002t^2 + 0.005t + 0.36 \quad (1)$$

And coefficient of determination of $0.70 \leq r^2 \leq 1.0$ were established.

Considering change in time as functional parameter that influences sodium absorption ratio value of Ede community and this gives account of natural activities going on in the groundwater environment and other environmental factors. Let therefore, differentiate Equation (1).

$$\frac{\partial SAR}{\partial t} = -0.004t + 0.005 \quad (2)$$

Equation (2) is rearranged as;

$$\frac{\partial SAR}{\partial t} + 0.004t - 0.005 = 0 \quad (3)$$

Equation (3) is the modified differential equation of Equation (1) considering time and environmental activities as functional parameters that changes the concentration of sodium absorption ratio of water.

2.2 Technique of finite element concept

Stage-1: Discretization and selection of Approximation function

∂t– Stretch of time of SAR were taking in consideration, elements and nodes were generated.

Stage – 2: formulation of element equations using Galerkins Weighted Residuals Method GWRM concept expressed as:

$$\int_o^T N^T [\frac{\partial SAR}{\partial t} + 0.004t - 0.005]\, \partial t = 0 \quad (4)$$

Finally assembling the solved solution of individual term in Equation (4) to predict SAR concentration.

2.3 Empirical Model of Sodium Absorption Ratio (SAR)

The ratio of sodium ions in irrigation water can monitor and controlled; and is usually evaluated using a factor called SAR, which indicates sodium hazards of water.

$$\text{SAR} = \frac{N_a^+}{\sqrt{\frac{(C_a^{++} + M_g^{++})}{2}}} \quad (5)$$

Description of range of SAR between 0 to 10; it is called low sodium water; between 10 to 18; it is called medium sodium water' between 18-26; it is called high sodium water and SAR value more than 26 is called very high sodium water as presented in Table 1.

2.4 Linear Shape Approximation Function of Finite Element

Estimating entity terms of Equation (4) can be evaluated using the linear shape functions of finite element method concept as given as:

Applying the finite element method of obtaining a solution to equation (4) the modified sodium absorption ratio (SAR) and the domains are discretized into elements. A linear shape function was chosen for this research work as given:

Step 1: Linear element approach

$$SAR(x) = N_i^e SAR_i + N_{i+1}^e SAR_{i+1} = [N][SAR] \quad (6)$$

Where,

$$N_i^e = 1 + \frac{t}{l} \quad (7)$$

And

$$N_{i+1}^e = \frac{t}{l} \quad (8)$$

Substituting Equation (6), (7) and (8) into Equation (4) to evaluate 1st Term of Equation (4)

$$\int_o^T N^T \frac{\partial SAR}{\partial t} \partial t = \int_o^T \frac{\partial SAR}{\partial t} [N][SAR] \partial t \quad (9)$$

Solving Equation (9) gives,

$$= \frac{1}{2} \begin{vmatrix} -1 & 1 \\ -1 & 1 \end{vmatrix} \begin{vmatrix} SAR_1 \\ SAR_2 \end{vmatrix} \quad (10)$$

Substituting Equation (6), (7) and (8) into Equation (4) to evaluate 2nd Term of Equation (4)

$$\int_o^T 0.004\, N^T t \ \partial t = \int_o^l 0.004t \begin{vmatrix} 1 - \frac{t}{l} \\ \frac{t}{l} \end{vmatrix} \partial t \quad (11)$$

Solving Equation (11) gives,

$$= 0.004t^2 \begin{vmatrix} 0.17 \\ 0.33 \end{vmatrix} \quad (12)$$

Substituting Equation (6), (7) and (8) into Equation (4) to evaluate 3rd Term of Equation (4)

$$\int_o^T 0.05 N^T \partial t \quad (13)$$

Solving Equation (13) gives,

$$= \frac{0.05}{2} \begin{vmatrix} 1 \\ 1 \end{vmatrix} \quad (14)$$

Assembling Equation (10), (12) and (14) gives,

$$= \frac{1}{2}\begin{vmatrix} -1 & 1 \\ -1 & 1 \end{vmatrix}\begin{vmatrix} SAR_1 \\ SAR_2 \end{vmatrix} + 0.004t^2 \begin{vmatrix} 0.17 \\ 0.33 \end{vmatrix} - \frac{0.05}{2}\begin{vmatrix} 1 \\ 1 \end{vmatrix} = 0 \quad (15)$$

Where,

SAR_1 = Sodium absorption ratio evaluated for week 1, SAR_2 = Sodium absorption ratio evaluated for week 2 and t= discretized interval of assessment.

Taking equal spacing of t = 1.25 and substituting SAR_1 = 0.36 which is the SAR obtained first of assessment and using it to simulate SAR values for other weeks using Equation (15) gives;

$$\begin{vmatrix} SAR_1 \\ SAR_2 \\ SAR_3 \\ SAR_4 \\ SAR_5 \end{vmatrix} = \begin{vmatrix} 0.36 \\ 0.35 \\ 0.34 \\ 0.34 \\ 0.31 \end{vmatrix}$$

3. Results and Discussion

Table 2: Empirical and finite element SAR value determined.

Weeks	Empirical Method, SAR value	Finite Element Method, SAR value
1	0.36	0.36
2	0.35	0.35
3	0.35	0.34
4	0.35	0.33
5	0.34	0.31

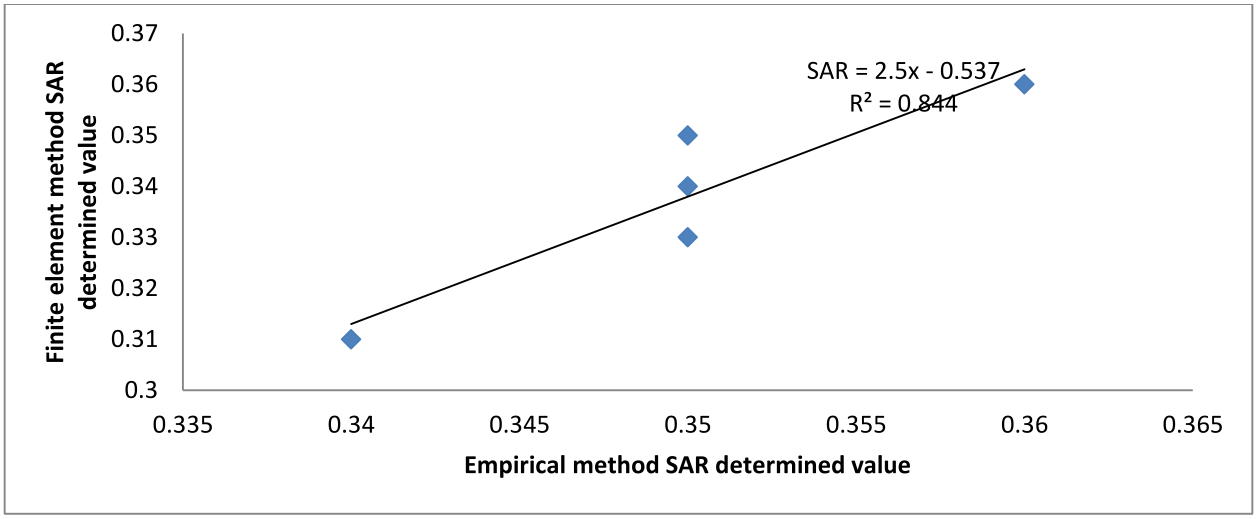

Figure 1: Plot of empirical method SAR determined value against finite element method SAR determined

Table 2 presents the sodium absorption ratio computed using empirical method and finite element method evaluated for different weeks. The usefulness of using finite element method in simulating regression sodium absorption ratio model modified in this research work were validated with the empirical determined sodium absorption ratio as shown in Figure 1 using linear least square method, an acceptable coefficient of correlation R = 0.92. All natural waters having soluble inorganic irons mainly from the weathering of soil and rocks minerals. These minerals on weathering release simpler radicals or irons asCa^{2+}, Mg^{2+}, Na^{+}, K^{+}, $HCO_3{}^{-}$, $SO_4{}^{2-}$, Cl^{-} and so on. Among these are Ca^{2+}, $HCO_3{}^{-}$ and H^{+} and also Mg^{2+}also are mainly controlled by the dissolution of carbonate rocks being easily weather able and the source of extent, is from the weathering of silicate minerals which are in contact with the groundwater and the streams and this process in groundwater may tend to increase the concentration of Ca^{2+}, Mg^{2+} and Na^{+}which are functional parameters in evaluating sodium absorption ratio using empirical model, Equation (5). From Table 2 it is observed that from first week of investigation to the last week there is variation in the determined sodium absorption ratio for Ede City both by empirical model and finite element method. These variations of SAR in the groundwater can be attributed to natural weathering of soils and rocks minerals process underground/surface that releases radicals or ions of Ca^{2+}, Mg^{2+}, Na^{+} and so on.

4. Conclusion

The solution of the modified differential equation, $\frac{\partial SAR}{\partial t}$ $+ 0.004t$ - 0.005 = 0 were analyzed using finite element method (FEM) and sodium absorption ratio value for different weeks was predicted using FEM approach and the values gotten are within low sodium water which can be applied for irrigation. Validation of results were carried out by comparing results obtained by empirical method and finite element method using least square regression method and high value of coefficient of determination were established indicating fitness of finite element method in predicting and monitoring sodium absorption ratio of Ede City. Study revealed the Ede City groundwater is fit for irrigation work in terms of SAR.

5. References

1. Ashley, R. P. and Misstear, B.D. (1990): Industrial development: the threat to groundwater quality, paper presented to Institution of Water and Environmental Management, East Anglia Branch.
2. Eluozo, S.N; Ukpaka, C.P. and Udeh, N. (2012). Predictive Model to Monitor the Spread of Crude Oil in Water surface Environment. *International Journal of Current Research.* vol.4, no.2, pp. 204 – 209.
3. Gajendran, C., Jayapriya, C., Diana, Y., Oshin, V. and Christian, J. (2013). Assessment of groundwater quality in Tirunelveli District, Tamil Nadu, India, International Journal of Environmental Sciences, Vol. 3, No. 6, pp. 71-80.
4. Garg, S. K. (2007). Hydrology and Water Resources Engineering, Fourteenth Revised Edition, Khonna published, Dedhi, pp. 300-897.
5. Goel, P. K. (2006). Water pollution, causes, effects and control, New Age International (p) Ltd, publishers. p. 1-267.
6. Ukpaka, C.P and Pele A. (2012). Elemental Analysis of soil Characteristics due to municipal Solid Waste in Port Harcourt City. *International Research Journal of Engineering,* Science, *Technology and Innovation (IRJESTI),* vol.1, no.5, pp. 130-141.
7. Ukpaka, C.P. (2012). The effect of functional parameters on microbial characteristics in crude oil degradation. *Journal of Research in Environmental Science and technology.* Vol.1, no.4, pp. 66-90.
8. Ukpaka, C.P. (2012). Characteristics of produced Water from an Oil terminal in Niger Delta Area of Nigeria. *Journal of Research in Environmental, Science and technology.* Vol.1, no.5, pp. 115-130.
9. Ukpaka, C.P; Eluozo, S.N and Orji, C.U. (2011). Impact of road construction dust on Plantain Vegetable in Port Harcourt Rivers State, Nigeria. *International Journal of Current Research,* vol.3, no.10, pp. 92-98.
10. Ukpaka. C.P**;** Orji, C.U and Nwofor, T.C (2011). Studying of proportional integral (Reset) control on flow characteristics on Orifile plate of different fluid system. *International Journal of Current Research,* vol.3, no.10, pp.082–088,
11. C.Ukpaka and F.E.Ezeilo (2017): Comparative Evaluation of Groundwater Parameters Simulation by Method of Linear & Quadratic Shape Function .SSRG International journal of Civil Engineering. Vol. No. pp