Groundwater Flow Modeling at the Source of River Ethiope, Delta State, Nigeria.

Fredrick Ogochukwu Okocha, M.Sc. and Edmund Atakpo, Ph.D.

Department of Physics, Delta State University, Abraka, Nigeria.

E-mail: fred_okocha@yahoo.co.uk

ABSTRACT

Groundwater flow modeling at the source of River Ethiope in Umuaja, Delta State, Nigeria is presented in this work with the aim of evaluating the degree of interaction between River Ethiope and the groundwater regime of the thick sandy aquifer. The local geology of the area, called the Benin formation is of Eocene to Quaternary age. Potential aquifer zone earlier delineated using the geo-electrical resistivity soundings formed the basis for groundwater flow modeling. The watershed has been modeled with a grid of 40 rows X 15 columns and with 2 layers lateral inflow from the north has been simulated with constant head near the source of River Ethiope and outflow at Imala Street (Umutu) in the South. The data obtained at some locations within the study area has been used for assigning surface water levels. Naturally recharge due to rainfall formed the main input to the aquifer system and abstraction from bore-holes, the output. A steady state groundwater simulation was carried out and calibrated using six (6) target heads, 4 in layer 1 (Northern boundary), and 2 in layer 2 (Southern boundary). The model computations have converged after 150 iterations. The results from the modeling show that abstraction is very less compared to groundwater recharge. Hence, there is the possibility for additional groundwater exploitation in the watershed through drilling of bore-holes.

(Keywords: groundwater, modeling, recharge, River Ethiope)

INTRODUCTION

The increasing industrial development in Umuaja area of Delta State, Southern Nigeria and the demand for potable water to cater for the needs of the people has prompted the present search for favorable ground water potential zones in the area (Igboekwe et al., 2005). Very few boreholes are drilled in different places in the area, and have become abortive because of lack of prior systematic scientific investigation. As a result of the limited boreholes, as well as the inadequacy of water supply from improved scheme in the intake of potable drinking water by the people. Thus the aim of the present study is to assess the River Ethiope-aquifer interaction using ground water modeling techniques. In order to achieve the above objective, the following tasks have been carried out. Characterization of the geological formations within the area through interpretation of geophysical data (mainly VES data). Hydrogeological data analysis for aquifer characteristics. Ground water flow underling of the area (Conceptual model).

Geomorphology, Geology and Hydrogeology

River Ethiope was identified to take its source from Umuaja, a town in Ukwani L.G.A of Delta State. Umutu is the closest town to Umuaja and the two towns' lies within latitude 5°40' N and longitude 6°14' E. Figure 1.0 shows the location map of the study area. The watershed is located between latitude 5°40'N and 5°51'N and between longitude 6°12'E and 6°14'E. It covers a total area of about 250sq.km. It spreads through major towns that include Obiaruku, Abraka, Sapele and empties into the Atlantic Ocean forming a Delta.

Southeast of Delta State within which the watershed is found enjoys a copious rainfall during rainy (monsoon) season. Some part gets flooded during rainy season and then remains dry during summer (Akpokodje and Etu-Efeotor, 1987).

The source of River Ethiope is generally in an upland region, where precipitation is heaviest and where there is a slope down from which the run-off can flow, which shows a dendritic drainage pattern (Goncheng Leong 1992).

The Geology of the area falls within the deltaic marine sediments of Cretaceous to Quaternary age. There are two principal geological formations in the area namely; Agbada and the Benin Formation. Whose sediments were deposited during the late Tertiary-early Quaternary period (Mbonu et al., 1991) the Benin formation comprises of fluvial gravels and sands. The formation overlies the Agbada Formation. It consists of interbedded sand and shale.

The two principal geological formations have a relative groundwater regime. They both have reliable groundwater that can sustain regional borehole prediction. The Agbada Formation has little groundwater when compared to the Benin Formation.

METHODOLOGY AND DATA ACQUISITION

In this work, ground water flow modeling is done by numerical solution using the Groundwater vistas software (Rumbaugh and Rumbaugh, 2001). The software has been developed by Environmental Simulations Inc. version 3.0 (c) 2001. Under the numerical solution, finite difference block centered technique is used.

For the purpose of this review, it should be recalled that numerical methods are divided into two (2): Finite Difference Method (FDM) and Finite Element Method (FEM). (Tyson and Weber, 1964) have described extensively the finite difference method (FDM) while (Neumann and Witherspoon, 1971; Desai and Abel, 2002) have equally described the finite element method (FEM).

For the groundwater flow model, the flow equation is given by:

$$V_i = -\left(\frac{K_{ii}}{\phi}\right)\frac{\partial h}{\partial x_i} \qquad (1)$$

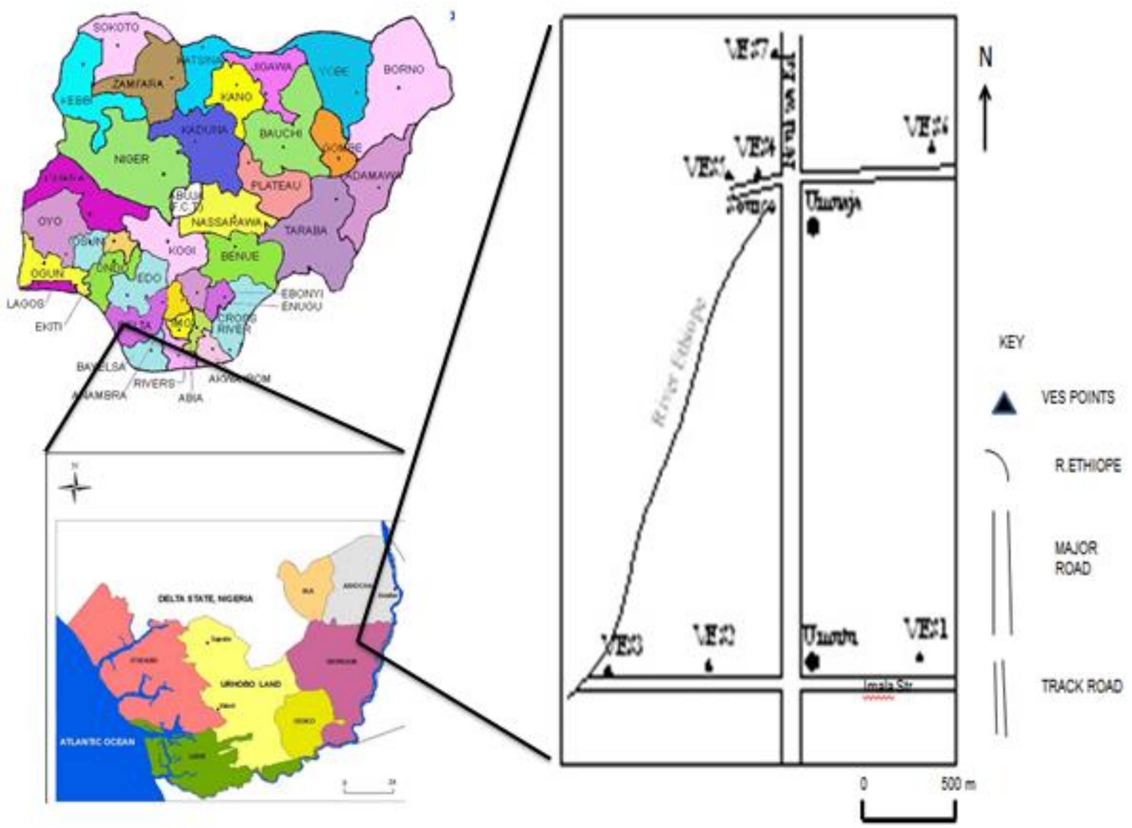

Figure 1: Location Map showing VES points.

Where:

ϕ = the porosity.

Kii = a principal component of the hydraulic conductivity tensor

h = hydraulic head.

The hydraulic head is obtained from solution of three-dimensional groundwater flow equation through MODFLOW software (McDonald and Harbaugh, 1988):

$$\frac{\partial}{\partial x_i}\left[K_{ii}\frac{\partial h}{\partial x_i}\right] + q_s = S_x\frac{\partial h}{\partial t} \qquad \textbf{(2)}$$

Where SX is the specific storage of the porous material.

The geophysical investigation carried out in the River Ethiope watershed, that include the source and its environs had provided the insight into the aquifer geometry for development of a groundwater flow model. Seven VES point was acquired using the Schlumberger resistivity configuration. The first three VES points were taken at random locations within the Umutu area, VES 4 was taken at the source of River Ethiope, VES 5 was taken about 150m from the source, while the rest were at random points in the Umuaja area. The ABEM SAS 1000 portable terrameter having an inbuilt booster was used for data acquisition. It could compute and display the apparent receptivity of the sub surface layer with the input data of the electrode configuration. The result shows that watershed consists of lateritic earth overlying a thick sandy aquifer (Figure 2).

The geophysical data arising from findings formed the initial data set for groundwater flow modeling. Groundwater level monitoring and water sample collection for the modeling process have been carried out from few observation boreholes in the area. The hydraulic conductivity has been determined from pumping test at some locations with values ranging from 51m/day to 68.3m/day. The remaining values on the study area were estimated using the Hazen approximation (Uma et al, 1989).

$$K = C(D_{10})_2 \qquad \textbf{(3)}$$

Where:

K= Hydraulic conductivity

C= Grain size constant

D10=Effective grain size in mm.

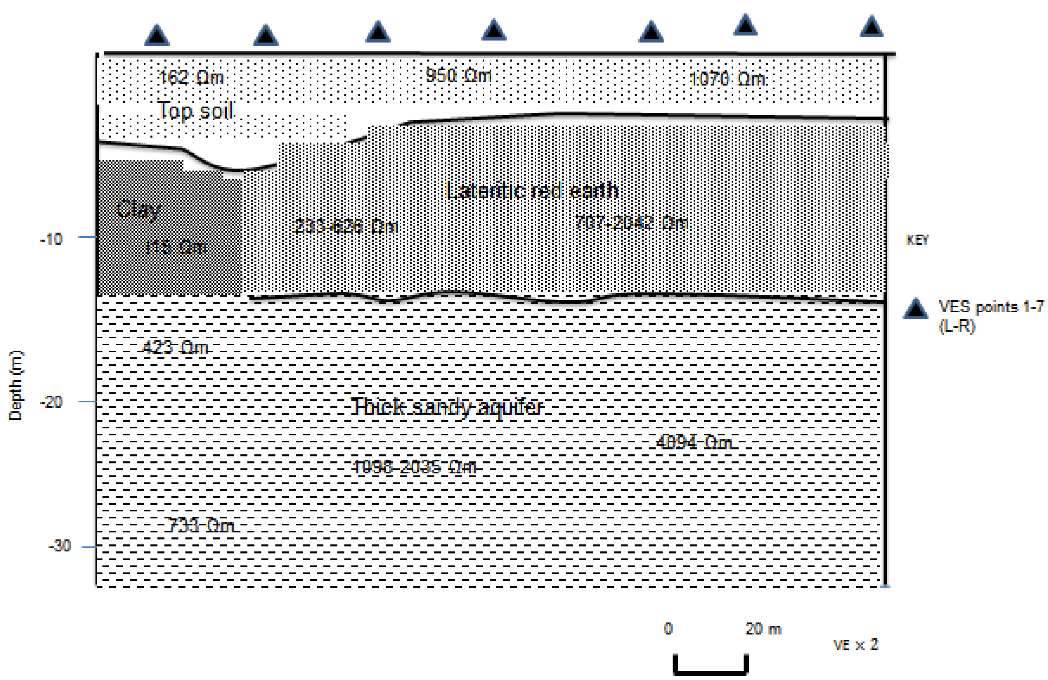

Figure 2: Geoelectric Section of Study Area.

D10 is the most important parameter among these governing the permeability of a granular medium (Marsily, 1986; Ala Edin et al., 2000). The grain size of the aquifer material ranges between 0.05 to 1.15 mm indicating that the sand size ranges between fine to medium.

MODEL CONCEPTUALIZATION

The following information was used during the conceptualization of the groundwater flow regime, groundwater recharge is mainly due to rainfall which takes place from the top layer, it is also recharged by nearby streams the continuous groundwater pumping for drinking purposes is prevalent due to the absence of sufficient surface water sources, groundwater abstraction was based on bore-holes around the area.

The water table elevation was defined by 7m (amsl) along the Northern boundary and lowest water table in the Southern boundary was defined by 4m (amsl). The simulated model domain of the watershed consists of 40 rows X 15 columns and two (2) layers covering an area of 4000 m X 3100 m (Figure 3).

The top layer mostly consists of 0.5m-5m of topsoil and laterite underlain by 15-30m of thick sandy zone. The blocks in the grid were chosen as sufficiently small as a rectangle to ensure good connection between cells represented by various hydraulic characterizations.

Groundwater recharge has been simulated to increase from 70mm/yr. in the southern boundary to 150mm/yr. in the northern boundary (Figure 4). The groundwater-pumping (abstraction) rates are varying from 150m^3/day to 200m^3/day.

Steady-State Calibration

The result of the water level in the area indicates that the hydraulic gradient do not change significantly with time, thus the groundwater was assumed to be in a steady state.

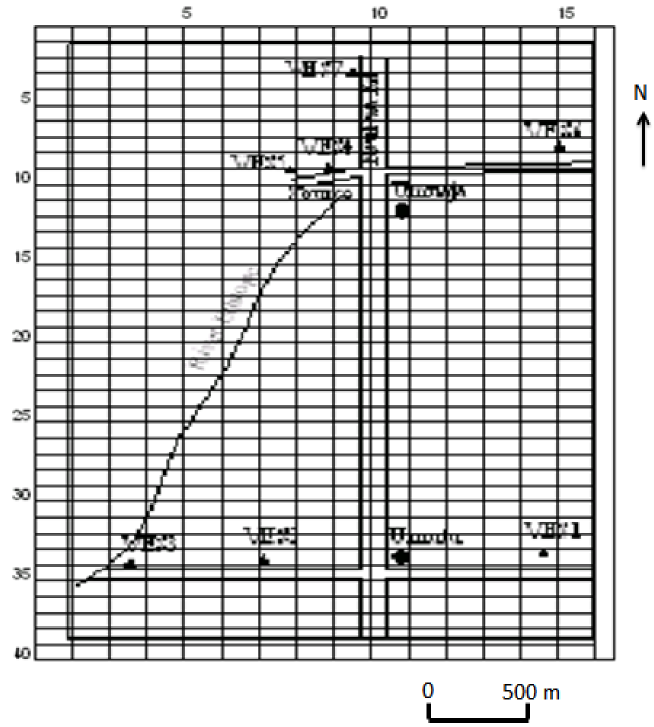

Figure 3: Grid Map of the Simulated Model Domain.

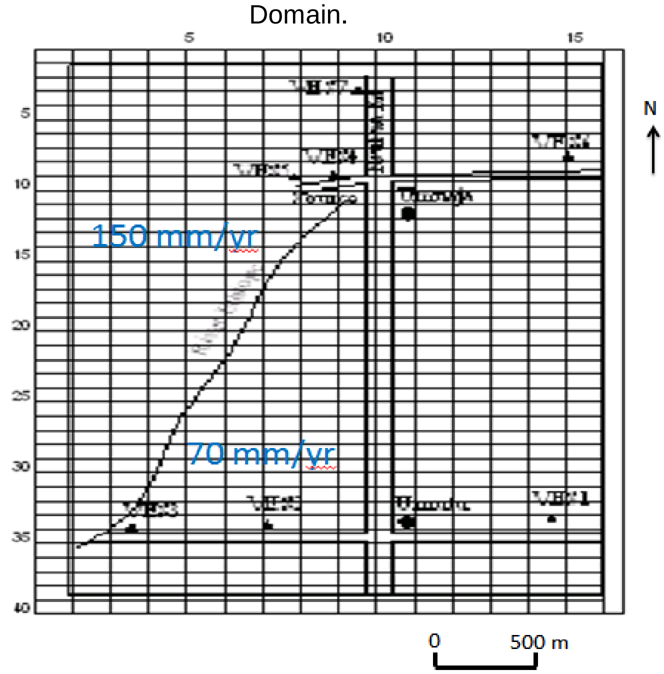

Figure 4: Simulated Recharge Distribution of the Study Area

The groundwater flow model has been constructed for computation of hydraulic head distribution. The groundwater head in the aquifer model was computed by using Groundwater Vistas (Rumbaugh and Rumbaugh, 2001). ESI solver package of MODFLOW has been used. The solver checked for the maximum change in the solution at every cell after completion of every iteration. If the maximum change in the solution was below a set convergence tolerance then the solution has converged and the solver stopped. The head change for convergence is 0.001. The model computations have converged after 150 iterations.

The flow model was calibrated by adding calibration targets to the model; in this work we define six (6) locations; 4 in layer (1) and 2 in layer (2). A graph of observed vs. computed head (Figure 5) shows a straight line this means observed values should equal or approximate the simulated value, Also the accuracy of the target values can be determined from the mean square error (Anderson and Woessner, 1992). However by keeping the hydraulic conductivity close to the estimated value, it was expected that simulated hydraulic heads and resulting velocity field represented the flow system reasonably well. The maximum groundwater velocity at the source of River Ethiope is estimated to be 0.92m/day (≈336m/yr.).

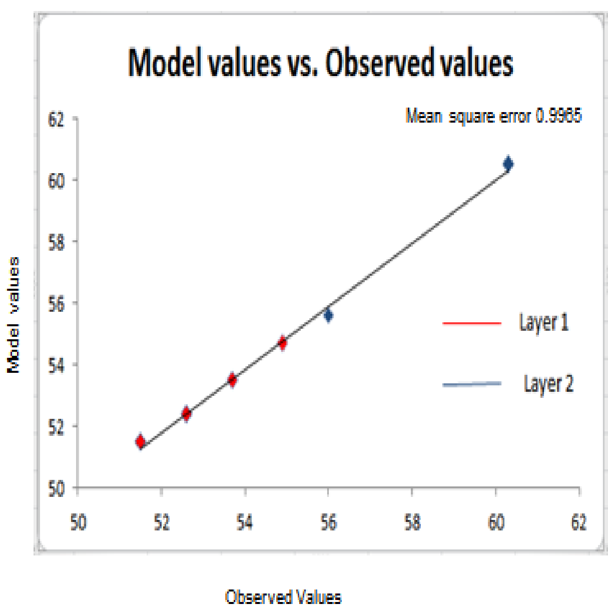

Figure 5: Comparison of Modeled and Observed Values.

RESULTS AND DISCUSSION

The hydrodynamics of groundwater flow regime in River Ethiope was controlled by three (3) factors: The abstraction (pumping rates), groundwater recharge during the rainy season, and the groundwater effluence to River Ethiope. The groundwater balance has been calculated in different zone under steady state condition (Table 1).

Natural recharge to the aquifer system is estimated to be 39263m^3/day and groundwater abstraction is 18484m^3/day. Thus the groundwater balance indicates that the net contribution from River Ethiope to the groundwater system is about 5268m^3/day.

Much of the effluence is however taking place during the rainy season and very little takes place during the dry season. Lateral inflow entering the confined aquifer from the Northern boundary also goes out as lateral outflow through the Southern boundary. The perennial flow of River Ethiope is maintained by the effluence from the aquifer system. The magnitude of the velocity field vectors is 0.92m/day (≈336m/yr.). At Umutu, the direction of the velocity field vectors is in the south-east direction (Figure 6).

Run-off is high and recharge is less, north of the study area, while southwards run-off is low and recharge is high.

Input(m^3/day)	Output(m^3/day)
Recharge 39263	Pumping 18484
	Groundwater to river 1818
	Lateral inflow 18961
Total 39263	Total 39263

Table 1: Calculated Groundwater balance at the source of R. Ethiope.

CONCLUSION

The hydrogeological and modeling studies have been carried out at the source of River Ethiope with the sole aim of determining the aquifer-river interaction within the study area. The surface water flow direction is from North to South. The aquifer geometry had earlier been delineated by carrying out geophysical investigation at seven (7) locations.

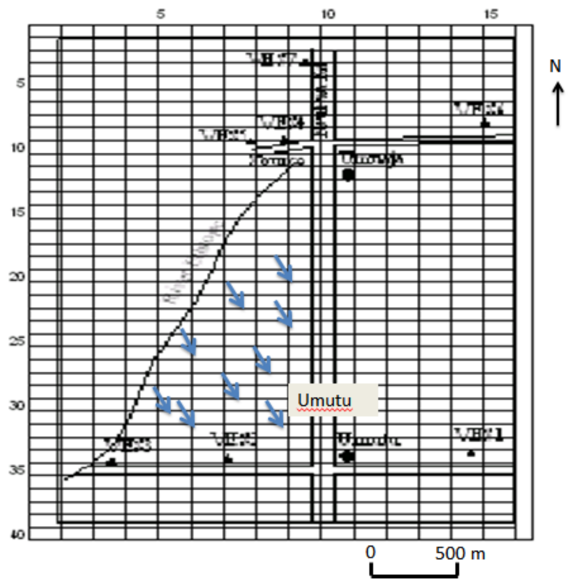

Figure 6: Direction of Water Flow (showing S-E direction around Umutu Area).

The subsurface lithology was deciphered from the geo-electric section covering the watershed. The average depth to water level ranged from 5-7m in the recharge area (Uplands) and from ground level to about 4m in valley bottom in the south. Generally water table has a configuration similar to that of land surface, however, depth to water levels are greater in upland areas (recharge areas) than in the southern boundary.

Groundwater model has been prepared based on lithological information and vertical cross section interval from resistivity interpretation. The hydraulic connection (transmissivity) between the river and the aquifer was assumed to be 550m^2/day.

The hydraulic conductivity values have initially been taken from pumping test data. During the flow model calibration the values have been slightly modified to achieve a good match between computed and observed targets. The comparison of computed and observed targets graph helped in deciding the goodness of fit.

The computed hydraulic heads (gradient) and the effective porosity values have been used for computation of groundwater velocity. The maximum groundwater velocity has been 0.92m/day (336m/yr.) along the source of River Ethiope. The groundwater balance is a preliminary one since the accurate groundwater withdrawal information is not available. However the estimate serves as a first-order value for groundwater balance. The predominant groundwater flow is towards South.

In general, the net contribution of River Ethiope to the ground water is high, about 5286m^3/day, indicating less abstraction and continuous recharge. Hence, there is the possibility for more boreholes in the area.

REFERENCES

1. Akpokudje, A. and J.O. Eru.Efeotor. 1987. "The Occurrence and Economic Potential of Clean Sand Deposits of the Niger Delta". *Journal of Africa Earth Science*. (6):61-5.

2. Ala Eldin, M.E.H., M. Ahmed Sanu, V.S. Gurunadha, and R.L. Dhar. 2000. "Aquifer Modeling of Ganga Mahawa Sub-basin, India". *Hydrological Processes*. 14:297-315.

3. Anderson, M.P. and W.W. Woessner. 1992. *Applied Groundwater Modeling-Simulation of Flow and Adjective Transport*. Academic Press: San Diego, CA.

4. Desai, C.S. and J.F. Abel. 2002. *Introduction to the Finite Element Method. A numerical Method for Engineering Analysis*. CBS Publishers and Distributors: New Delhi, India.

5. Gon chen Leong. 1992. *Certificate Physical and Human Geography*. University Press: Ibadan, Nigeria. 50-51.

6. Igboekwe, M.U., V.S. Gurunadha, and E.E. Okwueze. 2005. "Groundwater flow Modeling of Kwa Ibo River Watershed, SouthEastern Nigeria". *Global Journal of Geological Sciences*. 3(2):169-177.

7. Marsily, G. 1986. *Quantitative Hydrogeology*. Academic Press: Orlando, FL. 440.

8. Mbonu, P.D., J.O. Ebeniro, and A.S. Ikwe. 1991. "Geo-Electric Sounding for the Determination of Aquifer Characteristics in Parts of the Delta Area of Nigeria". *Bull.* (56):284-91

9. McDonald, M.G. and A.W. Harbaugh. 1988. "A Model Three-Dimensional Finite Difference Groundwater Flow Model". USGS. Chap A1. pp 586.

10. Neumann, S.P. and P.A. Witherspoon. 1971. "Analysis of Non-Steady Flow with a Free Surface using the Finite Element Method". *Water Resources Research*. 7:611-23.

11. Rumbaugh, J.O. and D.B. Rumbaugh. 2001. "Groundwater Vista". Environmental Simulations Inc.: Virginia.

12. Tyson, H.N. and E.M. Weber. 1964. "Groundwater Management for the Nations future Computer Simulation of the Groundwater Basins". *Jour. Hydraulic Div. Amer. Soc. Civil Engr*. 90:59-77.

13. Uma, K.O., B.C.E. Egbaoka, and K.M. Onuoha. 1989. "New Statistical Grain-Size Method for Evaluating the Hydraulic Conductivity of Sand Aquifers". *Journal of Hydrology*. 108:343-366

ABOUT THE AUTHORS

Fredrick Ogochukwu Okocha, M.Sc., is an Assistant Lecturer in the Department of Physics, Delta State University, Abraka, Nigeria. His research interests focus on petroleum geophysics and EM methods for Hydrocarbon exploration.

Edmund Atakpo, Ph.D., is a Senior Lecturer in Department of Physics, Delta State University, Abraka, Nigeria. His research focus is on environmental geophysics, groundwater modeling and hydrogeology.

SUGGESTED CITATION

Okocha, F.O. and E. Atakpo. 2013. "Groundwater Flow Modeling at the Source of River Ethiope, Delta State, Nigeria". *Pacific Journal of Science and Technology*. 14(2):594-600.

Pacific Journal of Science and Technology