

# Permeability and void ratio influences on heterogeneous deposition of chlorobium transport in coarse formation, applying numerical modeling and simulation

## Abstract

This paper monitored the migration level of Chlorobium in coarse formation, the study applied numerical modeling, the expression of the contaminants was through numerical simulation of the derived solution, the generated simulation values produces values that fluctuates and developed exponential in some conditions, these values range from 8.5600-0.00440, 0.1520-0.6270, 0.0045-0.6951, 0.6587-0.0168, 0.0362-0.0083, these simulation considered permeability and void ratio influences on Chlorobium deposition, these formation characteristics are reflected on the behaviour of Chlorobium migration in the formation, such predominant soil deposition express the rate of Chlorobium concentration in the strata, model validation carried out expressed the authenticity of the developed system, the application of this conceptual frame work will definitely predict the behaviour of the contaminant in any other part of deltaic environment.

**Keywords:** permeability, void ratio, chlorobium heterogeneous and coarse formation

Volume I Issue 5 - 2017

 Eluozo SN,<sup>1</sup> Amagbo LG,<sup>2</sup> Afibor BB<sup>3</sup>
<sup>1</sup>Department of Civil Engineering, Gregory University Uturu (GUU), Nigeria

<sup>2</sup>Department of Chem-Petrochemical Engineering, Rivers State University of Science and Technology Port Harcourt, Nigeria

<sup>3</sup>Department of Statistics, Nigeria

**Correspondence:** Eluozo SN, Department of Civil Engineering, Gregory University Uturu (GUU)  
 Abia State of Nigeria, Email Soloeluo2013@hotmail.com

**Received:** June 24, 2017 | **Published:** December 11, 2017

## Introduction

Many parts of sub-Saharan Africa, hydrogeologic data are sparse and difficult to access. One example is the Nigeria geological formations including other countries geological history like Keta Basin of southeastern Ghana and the Coastal Sedimentary Basin of Togo. Existing data quality on groundwater flow patterns and hydrodynamic aquifer characteristics from this region is weak, and subsurface geology is poorly understood in many parts of the region. In the present study, hydrochemistry and isotope geochemistry are applied to obtain hydrogeological information from the area in spite of lack of basic data on groundwater flow patterns and aquifer characteristics.<sup>1-4</sup> In regard to permeability predictions,<sup>2,4</sup> that some researchers that modified the Kozeny - Carman equation to better represent sediment mixtures by incorporating their fractional packing model for porosity.<sup>3</sup> Measured porosity and permeability on sediment mixtures and then compared these to values predicted by the models mentioned above. These mixtures were model approximations of natural poorly-sorted sands and sandy gravels. The introduction of five possible types of packing that can occur in a sediment mixture accounts for complex packing arrangements that may be present naturally. Therefore Chapuis & Conrad CM<sup>5,6</sup> assumed that the expanded fractional packing model is generally representative of poorly-sorted sands and sandy gravels. The present study will evaluate how well the model applies to natural sediment. Taking the results and procedures into account<sup>6,7</sup> focused further on the permeability of bimodal sediment mixtures by taking measurements at small support scales.<sup>3</sup> Revising the air-based permeability procedures of other experts<sup>7</sup> is to reduce displacement of sediment by air slip-flow.<sup>3</sup> determined a sufficient depth in the sediment at which a stable representative measurement could be taken, which he termed the tip-seal burial method. He also improved upon the correction needed for the air-based measurements

to account for the effects of high-velocity flow. He repeated the permeability measurements taken by Conrad<sup>7</sup>, Kamann PJ<sup>8</sup> and further confirmed the applicability of the permeability model.<sup>3,7,9</sup> It was found that the air-based measurements corresponded well to the water-based measurements for both sand mixtures and sand/pebble mixtures. Thus, the air-based measurements with a small support scale were generally similar to the water based measurements with a larger support scale.<sup>5,6</sup> it is concluded that the permeability of bimodal sediment mixtures of poorly-sorted sands can be accurately measured with the air-based permeameter. He found that mixtures dominated by finer grains show only subtle differences between air- and water-based measurements.<sup>5,10</sup> Determined that the air-based permeameter captures subtle changes in poorly sorted sands better than in pebbly sands. In addition to previous,<sup>4,6,7</sup> studies it has been conducted since in the work of some researchers<sup>9,10,12</sup> that utilize models for predicting permeability.<sup>11-13</sup> presented a permeability model for bimodal sediment mixtures that is based on parameters that separate pore throat porosity from total porosity and the effective radius from the total radius of the grains,<sup>2</sup> developed permeability model using representations of the grain size distribution as well as the petrophysical properties of porosity, volume fraction of fines, and bulk density. Other research on the porosity-permeability relationship for porous media involved the modification of previous models.<sup>1,3,5,7</sup> These studies all use different models for predicting permeability but none of them utilize a fractional packing model for porosity. Model sediment mixtures and predicted porosity values are useful tools for testing the applicability of a permeability model. Therefore, the research conducted by some researchers<sup>11,12</sup> that provides results that can be applied to other permeability models. This study will take the necessary step of testing his model to determine if it is accurate for natural sediment, which will help improve confidence in its applicability.<sup>10,13</sup>

## Governing equation

The Implicit Scheme Numerical Solution

$$\frac{\partial C}{\partial t} = \frac{K}{V} \frac{\partial C}{\partial x} + D_0 \frac{\partial^2 C}{\partial x^2} + \frac{qL_{IN}}{A} C \quad (1)$$

But  $\frac{\varphi}{V}$  = Velocity, v in meter per second (m/s), and porosity [-].

Thus equation (1) becomes:

$$\frac{\partial C}{\partial t} = \frac{K}{V} \frac{\partial C}{\partial x} + D_0 \frac{\partial^2 C}{\partial x^2} + \frac{qL_{IN}}{A} C \quad (2)$$

Converting the PDE to its algebraic equivalent equation by applying the finite different approximation technique for the implicit scheme, we obtain as follows.

$$\frac{\partial C}{\partial t} = \frac{C_i^{j+1} - C_i^j}{\Delta t} \quad (3)$$

$$\frac{\partial C}{\partial x} = \frac{C_{i+1}^{j+1} - C_{i-1}^{j+1}}{2\Delta x} \quad (4)$$

$$\frac{\partial^2 C}{\partial x^2} = \frac{C_{i+1}^{j+1} - 2C_i^{j+1} + C_{i-1}^{j+1}}{\Delta x^2} \quad (5)$$

Substituting equation (3) through (5) into (2) gives:

$$\begin{aligned} \frac{C_i^{j+1} - C_i^j}{\Delta t} &= \frac{K}{V} \left[ \frac{C_{i+1}^{j+1} - C_{i-1}^{j+1}}{2\Delta x} \right] + D_0 \left[ \frac{C_{i+1}^{j+1} - 2C_i^{j+1} + C_{i-1}^{j+1}}{\Delta x^2} \right] + \frac{qL_{IN}}{A} C_i^{j+1} \\ C_i^{j+1} - C_i^j &= \frac{\Delta t}{2\Delta x} \frac{K}{V} [C_{i+1}^{j+1} - C_{i-1}^{j+1}] + \frac{\Delta t D_0}{\Delta x^2} [C_{i+1}^{j+1} - 2C_i^{j+1} + C_{i-1}^{j+1}] + \frac{\Delta t qL_{IN}}{A} C_i^{j+1} \\ C_i^{j+1} - C_i^j &= \lambda (C_{i+1}^{j+1} - C_{i-1}^{j+1}) + K (C_{i+1}^{j+1} - 2C_i^{j+1} + C_{i-1}^{j+1}) + \alpha C_i^{j+1} \\ \text{Or} \\ C_i^j + (\alpha - \lambda - 2K - 1) C_i^{j+1} + (\lambda + K) C_{i+1}^{j+1} + K C_{i-1}^{j+1} &= 0 \end{aligned} \quad (6)$$

For cases where the initial and final conditions are given, boundary condition at the first node can be expressed as:

$$C_0^{j+1} = f_0(t^{j+1}) \quad (7a)$$

Hence, first node equation is expressed as:

$$C_i^j + (\alpha - \lambda - 2K - 1) C_i^{j+1} + (\lambda + K) C_{i+1}^{j+1} = -K f_0(t^{j+1}) \quad (7b)$$

Similarly, the last node boundary condition is:

$$C_l^{j+1} = f_{l+1}(t^{j+1}) \quad (8a)$$

$$C_l^j + (\alpha - \lambda - 2K - 1) C_l^{j+1} + K C_{l-1}^{j+1} = -(\lambda + K) f_{l+1}(t^{j+1}) \quad (8b)$$

For  $1 \leq x \leq 9$  and  $0 \leq t \leq 4$ ; and for the first instance, we obtain as follows:

At time=0 (i.e j=0):

$i = 1$ ,

$$\begin{aligned} C_1^0 + K C_0^1 + (\alpha - \lambda - 2K - 1) C_1^1 + (\lambda + K) C_2^1 &= 0 \\ C_1^0 + (\alpha - \lambda - 2K - 1) C_1^1 + (\lambda + K) C_2^1 &= -K f_0(t^1) \end{aligned} \quad (9a)$$

$i = 2$ ,

$$C_2^0 + K C_1^1 + (\alpha - \lambda - 2K - 1) C_2^1 + (\lambda + K) C_3^1 = 0 \quad (9b)$$

$i = 3$ ,

$$C_3^0 + K C_2^1 + (\alpha - \lambda - 2K - 1) C_3^1 + (\lambda + K) C_4^1 = 0 \quad (9c)$$

$i = 4$ ,

$$C_4^0 + K C_3^1 + (\alpha - \lambda - 2K - 1) C_4^1 + (\lambda + K) C_5^1 = 0 \quad (9d)$$

$i = 5$ ,

$$C_5^0 + K C_4^1 + (\alpha - \lambda - 2K - 1) C_5^1 + (\lambda + K) C_6^1 = 0 \quad (9e)$$

$i = 6$ ,

$$C_6^0 + K C_5^1 + (\alpha - \lambda - 2K - 1) C_6^1 + (\lambda + K) C_7^1 = 0 \quad (9f)$$

$i = 7$ ,

$$C_7^0 + K C_6^1 + (\alpha - \lambda - 2K - 1) C_7^1 + (\lambda + K) C_8^1 = 0 \quad (9g)$$

$i = 8$ ,

$$C_8^0 + K C_7^1 + (\alpha - \lambda - 2K - 1) C_8^1 + (\lambda + K) C_9^1 = 0 \quad (9h)$$

$i = 9$ ,

$$C_9^0 + K C_8^1 + (\alpha - \lambda - 2K - 1) C_9^1 = -(\lambda + K) f_{10}(t^1) \quad (9i)$$

$$\text{At time, } t = 0, C_1^0 = C_2^0 = C_3^0 = C_4^0 = C_5^0 = C_6^0 = C_7^0 = C_8^0 = C_9^0 = 0$$

Arranging equations (6a) through (6i) in vector matrix gives:

$$\begin{bmatrix} \omega & \lambda+K & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ K & \omega & \lambda+K & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & K & \omega & \lambda+K & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K & \omega & \lambda+K & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & K & \omega & \lambda+K & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & K & \omega & \lambda+K & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & K & \omega & \lambda+K & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & K & \omega & \lambda+K \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & K & \omega \end{bmatrix} \begin{bmatrix} C_1^1 \\ C_2^1 \\ C_3^1 \\ C_4^1 \\ C_5^1 \\ C_6^1 \\ C_7^1 \\ C_8^1 \\ C_9^1 \end{bmatrix} = \begin{bmatrix} -Kf_0(t^1) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ -(\lambda+K)f_{10}(t^1) \end{bmatrix}$$

Where:

$$\omega = (\alpha - \lambda - 2K - 1)$$

Hence, at any point with time, the general form of the above equation is presented as:

$$\begin{bmatrix} \omega & \lambda+K & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ K & \omega & \lambda+K & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & K & \omega & \lambda+K & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K & \omega & \lambda+K & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & K & \omega & \lambda+K & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & K & \omega & \lambda+K & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & K & \omega & \lambda+K & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & K & \omega & \lambda+K \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & K & \omega \end{bmatrix} \begin{bmatrix} C_1^{j+1} \\ C_2^{j+1} \\ C_3^{j+1} \\ C_4^{j+1} \\ C_5^{j+1} \\ C_6^{j+1} \\ C_7^{j+1} \\ C_8^{j+1} \\ C_9^{j+1} \end{bmatrix} = \begin{bmatrix} -Kf_0(t^{j+1}) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ -(\lambda+K)f_{10}(t^{j+1}) \end{bmatrix}$$

## Method of application

numerical Method were applied through the system to generate the governing equations, derived solution generated the derived model solution, this were simulated to monitor the contaminants at different depth, values of contaminant known concentration at different depth were generated, this results are within the values of concentration from other experimental values for the same contaminant by other experts validation of the method application for monitoring such microbes in deltaic environment.

## Experimental application

Standard laboratory experiment where performed to monitor the concentration of Chlorobium rate different formation, the soil deposition of the strata were collected in sequences base on the structural deposition at different locations, this samples were collected at different location, these samples generated variation at different depth producing different migration of Chlorobium concentration through pressure flow at lower end of the column, the experimental results are applied to be compared with the theoretical values to determined validation of the model.

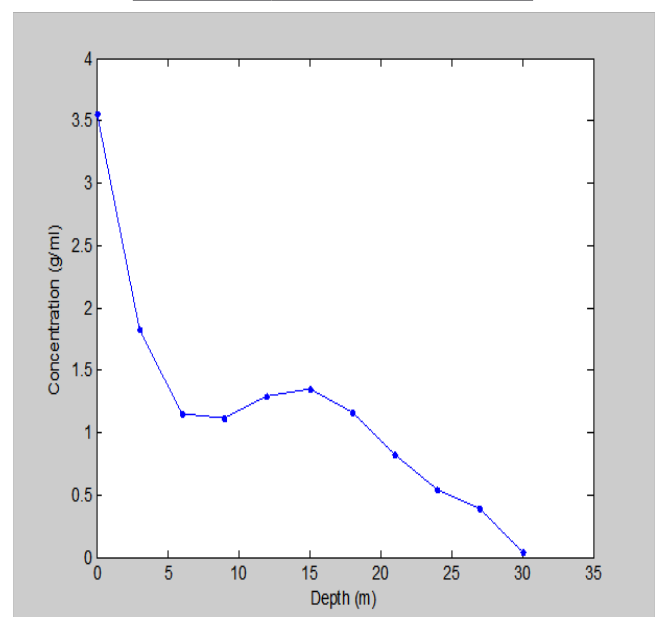
## Results and discussion

Results and discussion are presented in tables including graphical representation for Halobacterium stated below. The figure shows how the permeation of the formation influences the behaviour of the system in terms of deposition and transport at different strata (Figure 1). developed sudden growth rate in concentration between 5-10M depth

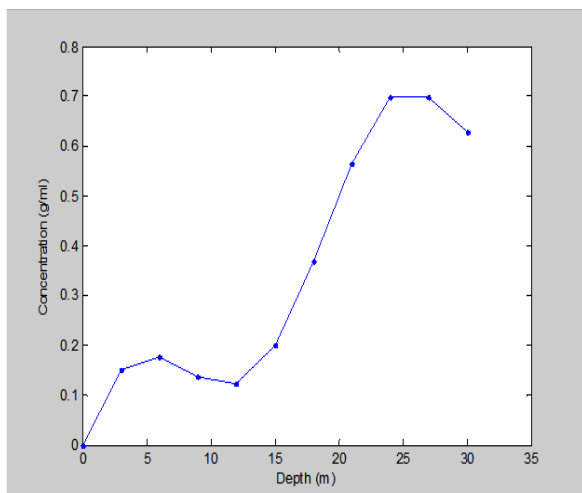
and generated fluctuation to where the lowest rate of concentration were observed at 30m, (Figure 2) express exponential phase thus developed fluctuation to the rate were optimum growth was experiences at 30m. Figure 3 in the same vein express its behaved similar to Figure 2, the growth rate rapidly migrate with slight fluctuation to maximum level recorded at 30m. Figure 4 generated sudden growth from five metres at initial concentration and experiences degradation with respect to depth to the lowest level of concentration recorded at 30m. Figure 5-10 observed vacillation while in gradual increase was experiences between 5-10m thus sudden increases were experiences at 25m and decrease to the lowest at 30m. The validation of the model with experimental values developed favourable fits, these condition shows that the systems were in line with the experimental comparison (Tables 1-10), these condition shows that the systems were in line with the experimental comparison.

**Table 1** Simulation Values from Chlorobium Concentration at Different Depth

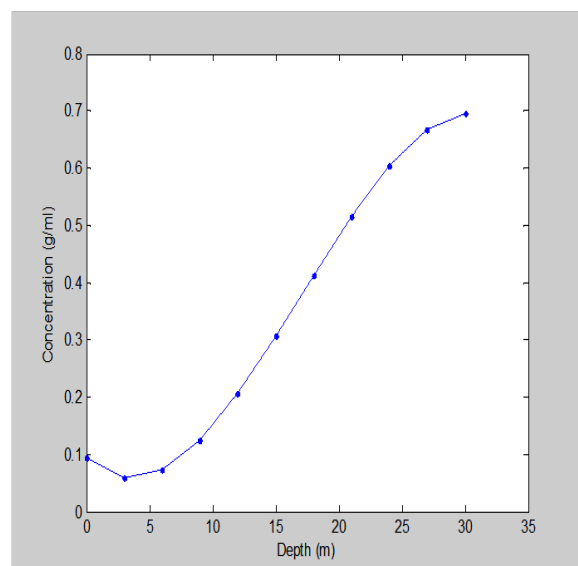
Depth(m)	Concentration(g/ml)
0	3.56
3	1.8358
6	1.1475
9	1.1192
12	1.2978
15	1.3512
18	1.1631
21	0.8277
24	0.5407
27	0.39
30	0.044



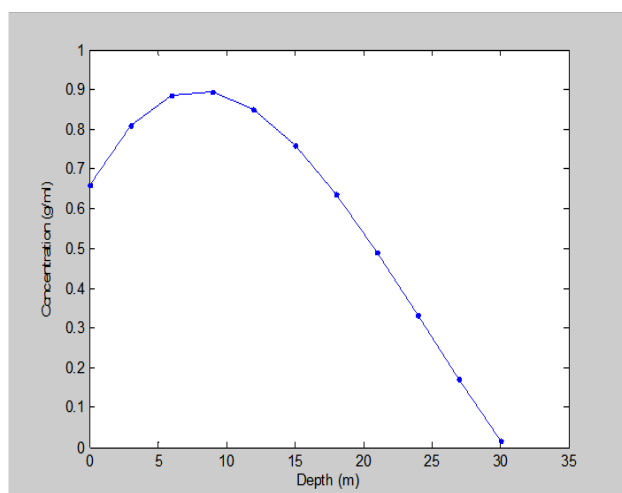
**Figure 1** Simulation Values from Chlorobium Concentration at Different Depth.



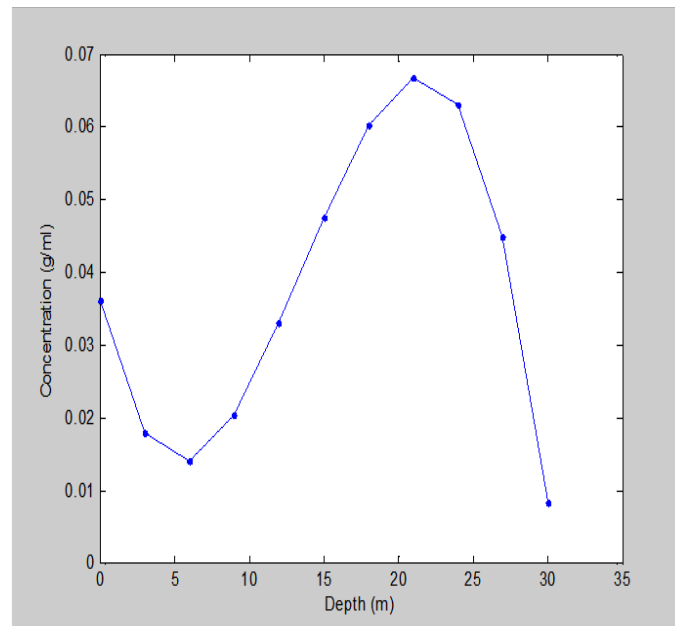
**Figure 2** Simulation Values from Chlorobium Concentration at Different Depth.



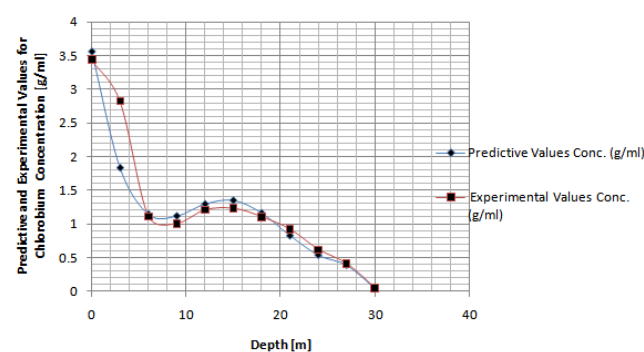
**Figure 3** Simulation Values from Chlorobium Concentration at Different Depth.



**Figure 4** Simulation Values from Chlorobium Concentration at Different Depth.



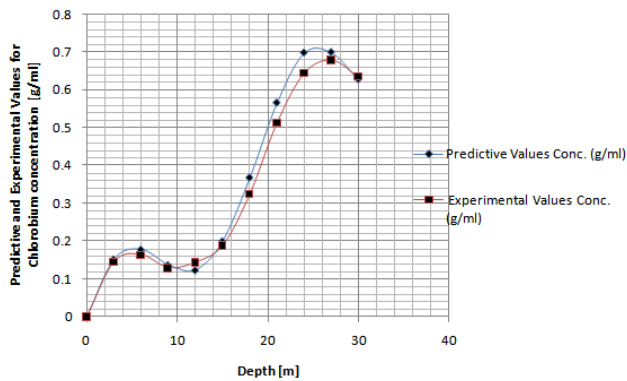
**Figure 5** Simulation Values from Chlorobium Concentration at Different Depth.



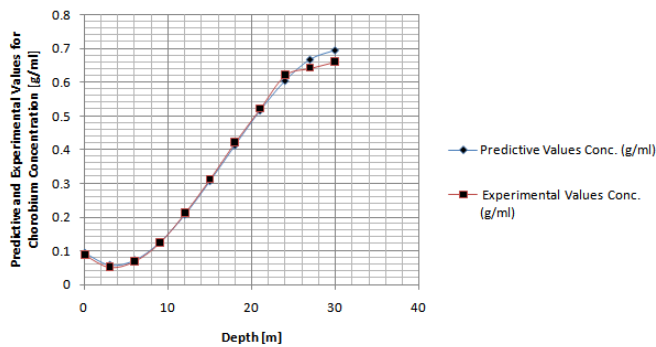
**Figure 6** Predictive and Experimental Values for Chlorobium Concentration at Different Depth.

**Table 2** Simulation Values from Chlorobium Concentration at Different Depth

Depth(m)	Concentration(g/ml)
0	0
3	0.152
6	0.1777
9	0.1368
12	0.123
15	0.1996
18	0.3678
21	0.5654
24	0.6976
27	0.6989
30	0.627



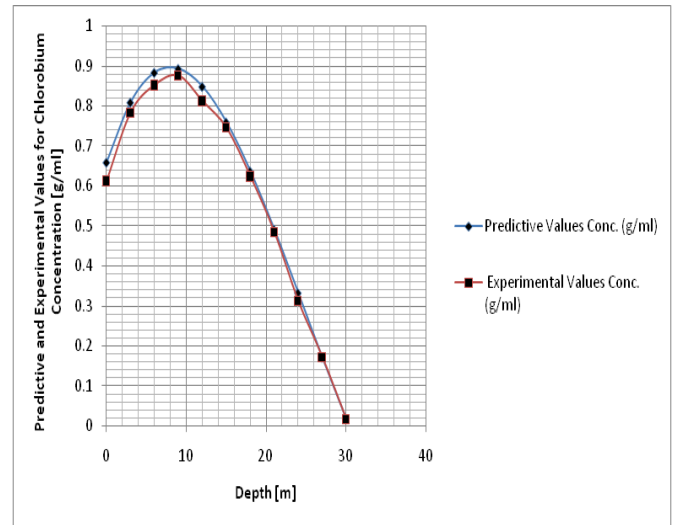
**Figure 7** Predictive and Experimental Values for Chlorobium Concentration at Different Depth.



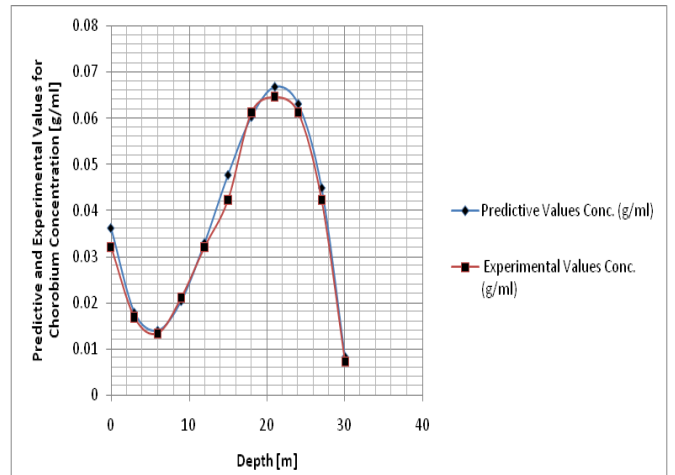
**Figure 8** Predictive and Experimental Values for Chlorobium Concentration at Different Depth.

**Table 3** Simulation Values from Chlorobium Concentration at Different Depth

Depth(m)	Concentration(g/ml)
0	0.0945
3	0.0585
6	0.0725
9	0.1257
12	0.2074
15	0.3068
18	0.4133
21	0.5161
24	0.6045
27	0.6677
30	0.6951



**Figure 9** Predictive and Experimental Values for Chlorobium Concentration at Different Depth.



**Figure 10** Predictive and Experimental Values for Chlorobium Concentration at Different Depth.

**Table 4** Simulation Values from Chlorobium Concentration at Different Depth

Depth(m)	Concentration (g/L)
0	0.6587
3	0.8087
6	0.8834
9	0.8931
12	0.8484
15	0.7595
18	0.6368
21	0.4908
24	0.3319
27	0.1704
30	0.0168

**Table 5** Simulation Values from Chlorobium Concentration at Different Depth

Depth(m)	Concentration(g/ml)
0	0.0362
3	0.0179
6	0.014
9	0.0204
12	0.033
15	0.0477
18	0.0603
21	0.0668
24	0.0631
27	0.0449
30	0.0083

**Table 6** Predictive and Experimental Values for Chlorobium Concentration at Different Depth

Depth(m)	Predictive Values Conc.(g/ml)	Experimental Values Conc.(g/ml)
0	3.56	3.44
3	1.8358	2.8234
6	1.1475	1.1153
9	1.1192	1.0103
12	1.2978	1.2123
15	1.3512	1.2351
18	1.1631	1.1104
21	0.8277	0.92345
24	0.5407	0.62341
27	0.39	0.41222
30	0.044	0.0534

**Table 7** Predictive and Experimental Values for Chlorobium Concentration at Different Depth

Depth(m)	Predictive Values Conc.(g/ml)	Experimental Values Conc.(g/ml)
0	0	0
3	0.152	0.1453
6	0.1777	0.1634
9	0.1368	0.12878
12	0.123	0.1434
15	0.1996	0.18795
18	0.3678	0.3245
21	0.5654	0.51234
24	0.6976	0.64352
27	0.6989	0.67821
30	0.627	0.63412

**Table 8** Predictive and Experimental Values for Chlorobium Concentration at Different Depth

Depth(m)	Predictive values conc.(g/ml)	Experimental values conc.(g/ml)
0	0.0945	0.0876
3	0.0585	0.05123
6	0.0725	0.06892
9	0.1257	0.12345
12	0.2074	0.21112
15	0.3068	0.31214
18	0.4133	0.42113
21	0.5161	0.52121
24	0.6045	0.62112
27	0.6677	0.64212
30	0.6951	0.66113

**Table 9** Predictive and Experimental Values for Chlorobium Concentration at Different Depth

Depth(M)	Predictive values conc. (G/MI)	Experimental values conc.(G/MI)
0	0.6587	0.61234
3	0.8087	0.78323
6	0.8834	0.85234
9	0.8931	0.87564
12	0.8484	0.81234
15	0.7595	0.74561
18	0.6368	0.62412
21	0.4908	0.48453
24	0.3319	0.31216
27	0.1704	0.17231
30	0.0168	0.01734

**Table 10** Predictive and Experimental Values for Chlorobium Concentration at Different Depth

Depth(M)	Predictive values conc.(G/MI)	Experimental values conc. (G/MI)
0	0.0362	0.03211
3	0.0179	0.01687
6	0.014	0.01342
9	0.0204	0.02111
12	0.033	0.03211
15	0.0477	0.04231
18	0.0603	0.06123
21	0.0668	0.06453
24	0.0631	0.06123
27	0.0449	0.04231
30	0.0083	0.00734

## Conclusion

The study has express the permeability influences on Chlorobium deposition in coarse formation, the behaviour were monitored Applying numerical modeling approach, the system experiences other formation characteristics such as soil void ratio as its reflecting in the rate of Chlorobium concentration, the study has express the variation of Chlorobium concentration pressures, application of numerical techniques was to monitor the system thoroughly in other to express the concentration in sequences, this application were base on the type study area, the developed model experienced fluctuation and exponential phase in different condition that the system were monitored. The system with its authenticity expresses it through model validation with experimental validations.

## Acknowledgments

None.

## Conflicts of interest

Author declares that there is no conflict of interest.

## References

1. Barr DW. Coefficient of permeability determined by measurable parameters. *Ground Water*. 2001;39(3):356–361.
2. Boadu FK. Hydraulic conductivity of soils from grain-size distribution: new models. *Journal of Geotechnical and Geoenvironmental Engineering*. 2000;126(8):739–746.
3. Tina H. Environmental Isotopic and Hydrochemical Characteristics of Groundwater from the Cretaceous-Eocene Limestone Aquifer in the Keta Basin. Denmark: Ghana, and the Coastal Sedimentary Basin of Togo Ph.D. Thesis, Geological Institute Faculty of Science, University of Copenhagen. 2006.
4. Chapuis RP. Predicting the saturated hydraulic conductivity of sand and gravel using effective diameter and void ratio. *Journal of Canadian Geotechnology*. 2004;41(5):787–795.
5. Chapuis RP, Aubertin M. On the use of the Kozeny-Carman equation to predict the hydraulic conductivity of soils. *Journal of Canadian Geotechnology*. 2003;40(3):616–628.
6. Conrad CM. Air-based measurement of permeability in pebbly sands. *Ground water*. 2006;46(1):103–112.
7. Conrad. Air-based measurement of permeability in pebbly sands. (Unpublished). Permeability-porosity relationship: A reexamination of the Kozeny- Carman equation based on a fractal pore-space geometry assumption. *Geophysical Research Letters*. 2007;33:1–5.
8. Kamann PJ. *Porosity and permeability in sediment mixtures*. USA: Master's Thesis, Department of Geological Sciences, Wright State University. 2004. p. 1–35.
9. Koltermann CE, Gorelick SM. Fractional packing model for hydraulic conductivity derived from sediment mixtures. *Water Resources Research*. 1995;31(12):3283–3297.
10. Revil A, Cathles LM. Permeability of shaly sands. *Water Resources Research*. 1999;35(3):651–662.
11. Revil A, Grauls D, Brévert O. Mechanical compaction of sand/clay mixtures. *Journal of Geophysical Research*. 2002;107(11):11–15.
12. Peter MP. Porosity and permeability of bimodal sediment mixtures using natural sediment. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, USA; 2005.
13. Eluozo SN. Model prediction to monitor the influence of porosity effect on Shigella transport to ground water aquifers in Elele rivers states of Nigeria. *Scientific Journal of Pure and Applied Sciences*. 2013;2(3):151–160.