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Predicting Campylobacter Transport Influenced by Permeability and Void Ratio in Partial Heterogeneous Sand Gravel Formation, Sapelle, Delta State of Nigeria

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Abstract: The study investigates the behaviour of Campylobacter in heterogeneous sand gravel formation. The rate of Campylobacter deposition was monitored in terms of its concentrations in sand gravel deposited formations. This study was found imperative because of high rate of concentration of Campylobacter at different heterogeneous strata. Such conditions were critically evaluated to determine the effect from heterogeneous deposition and migration. The developed model was generated through the derived governing equation, the simulation express slight fluctuation from theoretical values. At depth ranges of 3-39metres, 2-38metres, and 2-30metres, the concentration of Campylobacter ranges from 47.4-62.6 Mg/L, 32-62.5 Mg/L, and 1.34E-03-2.14E-02 respectively. The system generated several exponential migrating processes, but with different concentrations. The theoretical values were compared with experimental data for model validation and both parameters developed favourable fits. Hence heterogeneity of sand gravel deposition has generated various rates of concentrations reflecting on their migration processes. Experts will definitely apply this concept to observe various rates of Campylobacter concentrations in soil and water environment.

Keywords: Predictive Model, Void Ratio and Permeability, Campylobacter and Sand Gravel Formation

1. Introduction

High rate of fresh water demand globally shows its importance. It has been observed that water crisis is generating serious tension in most developing nations [1, 2, 3, and 4]. The causes of these crises are as a result of increase in population, urbanization, growing water utilization for agricultural and industrial requirements. One cannot forget the compounding issue of depletion of water resources. All these have lead to variation of climatic condition, deteriorating rain fall. This causes long-lasting drought periods, during which surface water reservoirs are no longer able to match water demand [2]. The rate of excessive groundwater abstraction has been observed to generate water table drawdown, leading to environmental challenges such as land subsidence and saltwater intrusion [5, 7, 8, and 9]. Definite environmental conditions, such as development of large urban settlements on a single river are some examples in London that provided drinking water mainly from the River Thames. Furthermore, slight landmass or mass natural aquifers therefore generates water scarcity [9, 10, and 11]. Thus surface and groundwater sources increasingly fail to provide a durable water supply [12, 13, 14 and 15]. It is noted that process water from industrial concerns or water for toilet flushing in households are mainly established today as reuse water [4, 11, 12, 14, and 15]. There is need for such reused water, so-called indirect potable water to be conserved due to its usefulness [5, 15, and 16]. However, natural waters are often an environment for existence of micro organisms, numerous of them being harmful to human health. WHO estimates that approximately 10% of the global disease burden can be prevented through provision of water supply, sanitation, hygiene and proper management of water resources [17, 18 and 19]. It was observed by some experts that pesticides were recognised as possible threats to water quality [4, 8, 12, 14 and 16].

2. Governing Equation

$$K_t \frac{d^2c}{dz^2} - aL\frac{dc}{dz} + \frac{v}{R}\frac{dc}{dz} = 0 \quad (1)$$

$$K_t \frac{d^2c}{dz^2} - \left(aL - \frac{v}{R}\right)\frac{dc}{dz} = 0 \quad (2)$$

Let $C = \sum_{n=0}^{\infty} a_n x^n$

$$C^1 = \sum_{n=1}^{\infty} n a_n x^{n-1}$$

$$C^{11} = \sum_{n=2}^{\infty} n(n-1) a_n x^{n-2}$$

$$K_t \sum_{n=2}^{\infty}(n-1) a_n x^{n-2} - \left(aL - \frac{v}{R}\right)\sum_{n=1}^{\infty} n a_n x^{n-1} = 0 \quad (3)$$

Replace *n* in the 1st term by *n+2* and in the 2nd term by *n+1*, so that we have;

$$K_t \sum_{n=2}^{\infty}(n+2)(n+1) a_{n+2} x^n - \left(aL - \frac{V}{R}\right)\sum_{n=0}^{\infty}(n+1) a_{n+1} x^n = 0 \quad (4)$$

$$\text{i.e. } K_t (n+2)(n+1) a_{n+2} = \left(aL - \frac{V}{R}\right)(n+1) a_{n+1} \quad (5)$$

$$a_{n+2} = \frac{\left(aL - \frac{V}{R}\right)(n+1) a_{n+1}}{K_t (n+2)(n+1)} \quad (6)$$

$$a_{n+2} = \frac{\left(aL - \frac{V}{R}\right) a_{n+1}}{K_t (n+2)} \quad (7)$$

$$\text{for } n = 0,\ a_2 = \frac{\left(\varphi - \frac{V}{R}\right) a_1}{2K_t} \quad (8)$$

for

$$n = 1,\ a_3 = \frac{\left(aL - \frac{V}{R}\right) a_2}{3K_t} = \frac{\left(aL - \frac{V}{R}\right)^2 a_1}{2K_t \bullet 3K_t} \quad (9)$$

for

$$n = 2;\ a_4 = \frac{\left(aL - \frac{V}{R}\right) a_3}{4K_t} = \frac{\left(aL - \frac{V}{R}\right)}{4K_t} \bullet \frac{\left(aL - \frac{V}{R}\right) a_1}{3K_t \bullet 2K_t} = \frac{\left(aL - \frac{V}{R}\right)^3 a_1}{4K_t \bullet 3K_t \bullet 2K_t} \quad (10)$$

For

$$n = 3;\ a_5 = \frac{\left(aL - \frac{V}{R}\right) a_4}{5K_t} = \frac{\left(aL - \frac{V}{R}\right)}{5K_t \bullet 4K_t \bullet 3K_t \bullet 2K_t} \quad (11)$$

For

$$n;\ a_n - \frac{\left(aL - \frac{V}{R}\right)^{n-1} a_1}{K_t^{\,n-1} n!} \quad (12)$$

$$C(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + \ldots\ldots. a_n x_n \quad (13)$$

$$= a_0 + a_1 x + \frac{\left(aL - \frac{V}{R}\right) a_1 x^2}{2!K_t} + \frac{\left(aL - \frac{V}{R}\right) a_2 x^3}{3!K_t^2} + \frac{\left(aL - \frac{V}{R}\right) a_1 x^4}{4!K_t^3} + \frac{\left(aL - \frac{V}{R}\right) a_1 x^5}{5!K_t^4} + \ldots \quad (14)$$

$$C(x) = a_0 + a_1\left[x + \frac{\left(aL - \frac{V}{R}\right) x^2}{2!K_t} + \frac{\left(aL - \frac{V}{R}\right) x^3}{3!K_t^2} + \frac{\left(aL - \frac{V}{R}\right) x^4}{4!K_t^3} + \frac{\left(aL - \frac{V}{R}\right) x^5}{5!K_t^4}\right] \quad (15)$$

$$C(x) = a_0 + a_1 \ell^{\frac{\left(aL - \frac{V}{R}\right)}{K_t} x} \quad (16)$$

3. Materials and Method

Standard laboratory experiments were performed to monitor the campylobacter concentration at different formations. The soil depositions at various strata were collected in sequences according to the structural deposition at different locations. These samples collected at different locations generate variations at different depths producing different migrations of campylobacter concentration through pressure flow at lower part of the column at different strata. Experimental results were compared with the theoretical values in order to validate the model.

4. Results and Discussion

Results of laboratory experiments are presented and discussed in tables, including graphical representations of campylobacter concentrations at different depth.

Table 1. *Concentrations of campylobacter at Different Depths.*

Depth [M]	Predicted Values [Mg/L]
3	4.75E+00
6	6.31E+00
9	1.30E+01
12	1.56E+01
15	2.23E+01
18	2.59E+01
21	3.36E+01
24	3.63E+01
27	4.39E+01
30	4.56E+01
33	5.22E+01
36	5.69E+01
39	6.26E+01

Table 2. *Predicted and Validated Concentration of Campylobacter at Different Depth.*

Depth [M]	Predicted Values [Mg/L]	Validated Values[Mg/L]
3	4.75E+00	4.451
6	6.31E+00	9.607
9	1.30E+01	12.963
12	1.56E+01	17.619
15	2.23E+01	22.275
18	2.59E+01	26.931
21	3.36E+01	33.587
24	3.63E+01	35.243
27	4.39E+01	43.899
30	4.56E+01	45.555
33	5.22E+01	52.211
36	5.69E+01	57.867
39	6.26E+01	60.523

Table 3. *Concentration of Campylobacter at Different Depth.*

Depth [M]	Predicted Values [Mg/L]
2	3.20E+00
4	6.31E+00
6	9.50E+00
8	1.34E+01
10	1.65E+01
12	1.76E+01
14	2.27E+01
16	2.58E+01
18	2.69E+01
20	3.21E+01
22	3.52E+01
24	3.83E+01
26	4.14E+01
28	4.45E+01
30	4.56E+01
32	4.86E+01
34	5.63E+01
36	5.79E+01
38	6.25E+01

Table 4. *Predicted and Validated Concentrations of Campylobacter at Different Depths.*

Depth [M]	Predicted Values [Mg/L]	Validated Values [Mg/L]
2	3.20E+00	2.343
4	6.31E+00	5.473
6	9.50E+00	8.813
8	1.34E+01	12.233
10	1.65E+01	15.323
12	1.76E+01	18.513
14	2.27E+01	22.559
16	2.58E+01	25.043
18	2.69E+01	27.263
20	3.21E+01	33.673
22	3.52E+01	36
24	3.83E+01	37.883
26	4.14E+01	40.203
28	4.45E+01	44.413
30	4.56E+01	46.653
32	4.86E+01	49.893
34	5.63E+01	55.123
36	5.79E+01	56.353
38	6.25E+01	60.583

Table 5. *Concentrations of Campylobacter at Different Times.*

Time Per Day [T]	Predicted Values[Mg/L]
10	6.43E-04
20	1.46E-02
30	2.14E-02
40	2.57E-02
50	3.51E-02
60	4.19E-02
70	4.68E-02
80	5.56E-02
90	6.20E-02
100	6.43E-02
110	7.61E-02
120	8.20E-02
130	8.70E-02
140	9.66E-02
150	1.12E-01
160	1.19E-01
170	1.26E-01
180	1.32E-01
190	1.39E-01
200	1.44E-01

Table 6. *Predicted and Validated Concentration of Campylobacter at Different Time.*

Time Per Day [T]	Predicted Values [Mg/L]	Validated Values[Mg/L]
10	6.43E-04	6.36E-04
20	1.46E-02	1.35E-04
30	2.14E-02	2.16E-02
40	2.57E-02	2.53E-02
50	3.51E-02	3.55E-02
60	4.19E-02	4.22E-02
70	4.68E-02	4.78E-02
80	5.56E-02	5.61E-02
90	6.20E-02	6.34E-02
100	6.43E-02	6.68E-02
110	7.61E-02	7.62E-02
120	8.20E-02	8.27E-02
130	8.70E-02	8.71E-02
140	9.66E-02	9.54E-02
150	1.12E-01	1.17E-01
160	1.19E-01	1.15E-01
170	1.26E-01	1.21E-01
180	1.32E-01	1.34E-01
190	1.39E-01	1.33E-01
200	1.44E-01	1.37E-01

Table 7. *Concentrations of Campylobacter at Different Depths.*

Depth [M]	Predicted Values [Mg/L]
2	1.34E-03
4	2.63E-03
6	4.19E-03
8	5.36E-03
10	6.73E-03
12	8.21E-03
14	9.46E-03
16	1.19E-02
18	1.26E-02
20	1.32E-02
22	1.40E-02
24	1.62E-02
26	1.72E-02
28	1.85E-02
30	2.14E-02

Table 8. *Predicted and Validated Concentrations of Campylobacter at Different Depths.*

Depth [M]	Predicted Values [Mg/L]	Validated Values[Mg/L]
2	1.34E-03	1.37E-03
4	2.63E-03	2.77E-03
6	4.19E-03	4.21E-03
8	5.36E-03	5.44E-03
10	6.73E-03	6.88E-03
12	8.21E-03	8.22E-03
14	9.46E-03	9.55E-03
16	1.19E-02	1.16E-02
18	1.26E-02	1.24E-02
20	1.32E-02	1.29E-02
22	1.40E-02	1.42E-02
24	1.62E-02	1.71E-02
26	1.72E-02	1.77E-02
28	1.85E-02	1.91E-02
30	2.14E-02	2.16E-02

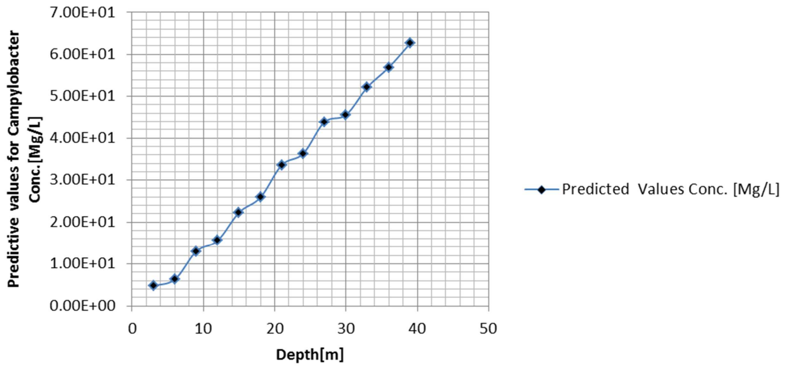

Figure 1. *Concentrations of Campylobacter at Different Depths.*

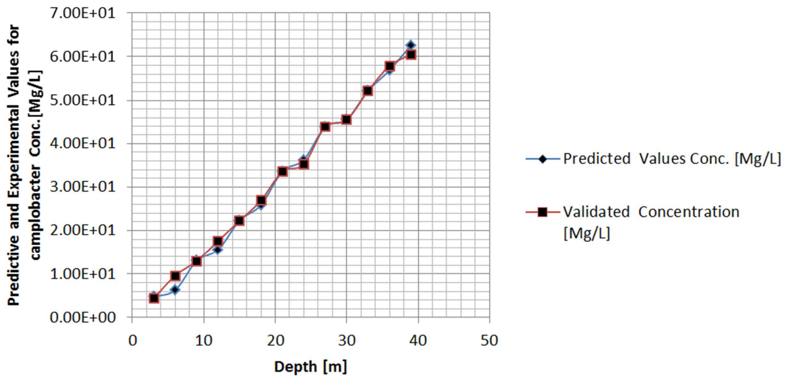

Figure 2. *Predicted and Validate Concentrations of Campylobacter at Different Depths.*

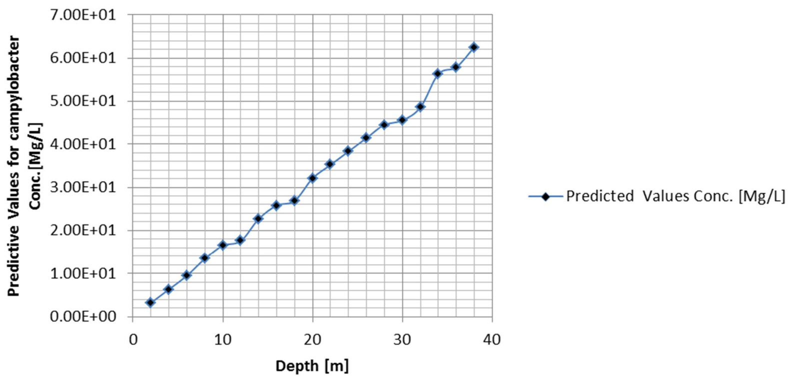

Figure 3. *Concentrations of Campylobacter at Different Depths.*

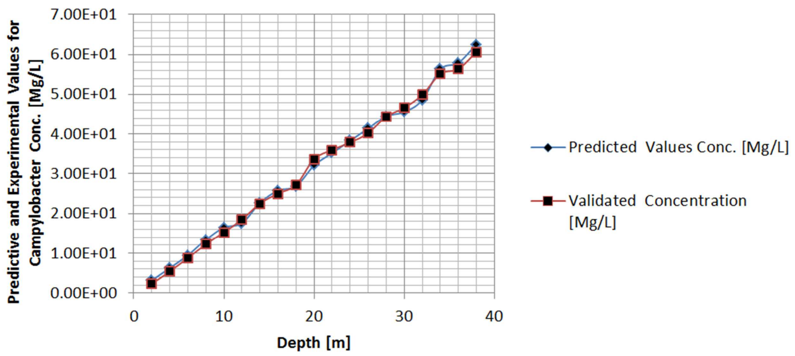

Figure 4. *Predicted and Validated Concentrations of Campylobacter at Different Depths.*

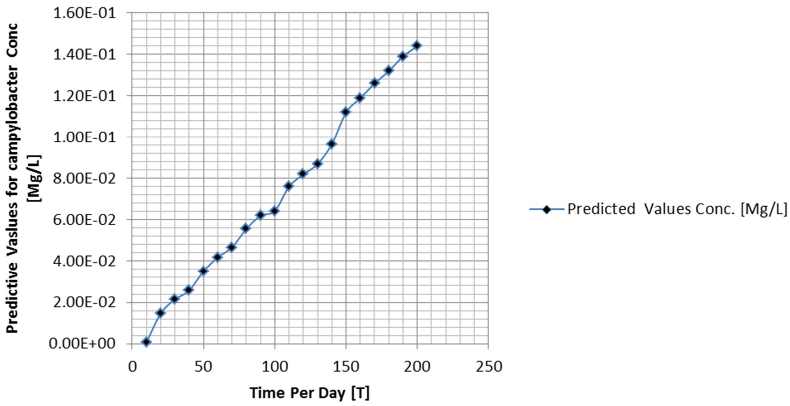

Figure 5. *Concentrations of Campylobacter at Different Depths.*

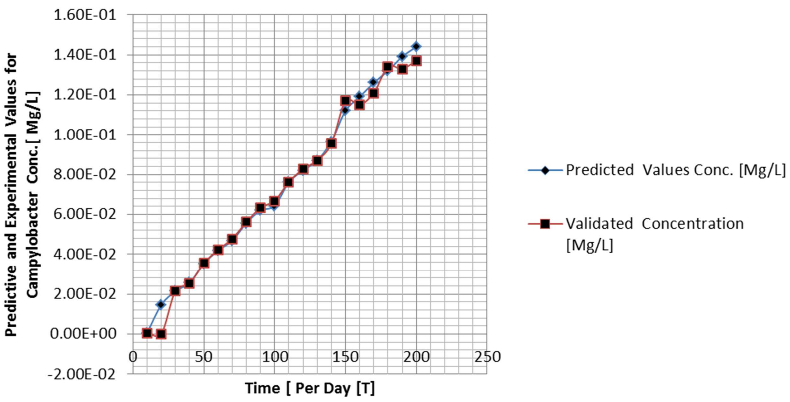

Figure 6. *Predicted and Validated Concentrations of Campylobacter at Different Depths.*

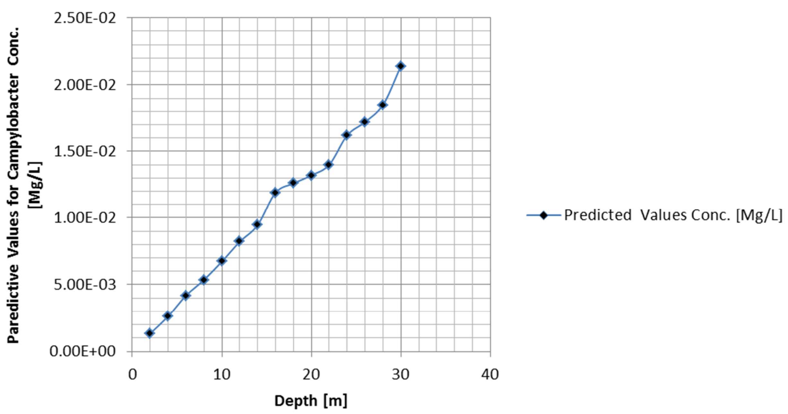

Figure 7. *Concentrations of Campylobacter at Different Depths.*

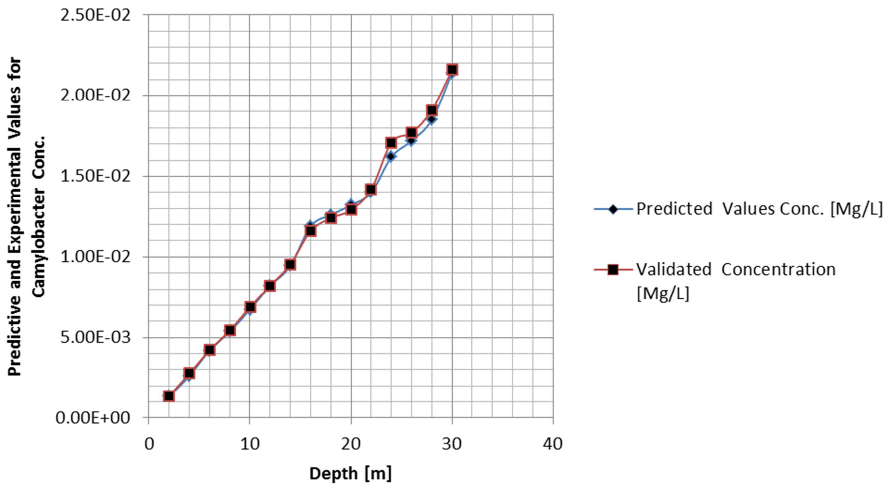

Figure 8. *Predicted and Validated Concentrations of Campylobacter at Different Depths.*

The figures presented show the behaviour of Campylobacter deposition in soil and water environment under the effect of high degree of permeability and void ratio. The deposition of Campylobacter indicates the rate of concentration at various strata. It has been observed that microbes migrate with various levels of influences. Therefore the depositions of this type of microbial species are critically assessed in the system, such as litho stratification variation based on the geological setting influences. This includes deposition of other minerals observed to react which hinder their migration and increase their population. Figures one to four show the migration process in exponential phase, based on condition of regeneration of the contaminant in the study environment with some slight vacillations, these are reflected on the deposited strata variation in their heterogeneous setting. Predominant deposited sand gravel locations that shows slight fluctuations under the influence of heterogeneity of the particles size reflecting on the migration process, these are through Tuotorsity direction of flow. The behaviour of the microbes shows the rate of concentration, as observed in figure one to six, the rate of transport with respect to time were monitored to examine the rate of concentrations at different days, but the heterogeneity setting of the formation were expressed through the geological structural deposition influences. The time of concentration show a slight fluctuation, but are reflected on the deposited strata generating exponential phase, these include the period it takes to migrate at different formations. Figures seven and eight experiences such similarity, these are through the concentrations observed to migrate in exponential phase. This can be attributed to the change in concentration with respect to depth, including fluctuations of the rate of inhibited deposited minerals in the environment. The migration process in various locations where compared with simulated results that were observed to experienced slight fluctuation. This expressed the rate of strata heterogeneity in the study area. It has been observed that the effect reflect directly on the migration process of the contaminant

5. Conclusion

The behaviour of the Campylobacter has been evaluated through the developed model for the study; the system has expressed the behaviour of the Campylobacter in terms of formation characteristics and mineral influences reflecting on the rate of concentration. The transport process is reflected on the increase in concentrations under the pressure of structural heterogeneity in such deltaic environment. The developed model monitored the contaminant in exponential phase, these are base on the geological setting as is reflected on the formation characteristics at various phase of the strata. The developed model shows that some parameters were found predominant in the study area.. It also integrated their relationship in the system to generate the derived governing equation for the study. Experts will definitely apply this resolved solution as a bench mark to solve other transport problems by applying this type of developed concept in the study location.

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