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Original article

Mathematical modeling and simulation of Salmonnela transport influenced by porosity and void ratio in soil and water: Eleme Niger delta of Nigeria

S.N. Eluozo

Subaka Nigeria Limited Port Harcourt Rivers State of Nigeria.

*Corresponding author; Subaka Nigeria Limited Port Harcourt Rivers State of Nigeria.

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ABSTRACT

Salmonella transport in soil and water is a serious microbial containment that is a threat to human life, salmonella containment has been found to survival in several days in soil, if there is no regeneration and that will definitely increase microbial population, more so, the microbes also increase when there is high degree of substrate utilization. Mathematical model were developed to express the behavior of the microbes and there transport process. This condition were considered as the system that where developed, considering this variables. The model were developed to monitor the growth rate of the microbes, there rate of concentration at different formation, where found to be influenced by a lots of factors, but the most depressing one where the degree of porosity of the soil, this were found to have influence on the fast migration of the microbes within a short period of time, the conditions where considered and where integrated in derived model the developed model values compared faviourably well with the experimental values, the model will definitely monitor the transport of salmonella in prelatic aquifers.

1. Introduction

The presence of microbial contamination of drinking water from human waste The use of coliforms was later expanded and adopted for ambient, recreational, and shellfish waters and continues to focus on identification of fecal contamination. Over the long history of their development and use, the current bacterial indicator approaches have become standardized, are relatively easy and inexpensive to use, and constitute a cornerstone of local, state, and federal monitoring and regulatory programs. An increased understanding of the diversity of waterborne pathogens, their sources, physiology, and ecology, however, has resulted in a growing understanding that the use of bacterial indicators may not be as universally protective as was once thought. For example, the superior environmental survival of pathogenic viruses and protozoa raised serious questions about the suitability of relying on relatively short-lived coliforms as an indicator of the microbiological quality of water. That is, while the presence of coliforms could still be taken as a sign of fecal contamination, the absence of coliforms could no longer be taken as assurance that the water was uncontaminated. Thus, existing bacterial indicators and indicator approaches do not in all circumstances identify all potential waterborne pathogens. Furthermore, recent and forecasted advances in microbiology, molecular biology, and analytical chemistry make it timely to reassess the current paradigm of relying predominantly or exclusively on traditional bacterial indicators for waterborne pathogens. Nonetheless, indicator approaches will still be required for the foreseeable future because it is not practical or feasible to monitor for the complete spectrum of microorganisms that may occur in source waters for drinking water and recreational waters, and many known pathogens are difficult to detect directly and reliably in water samples.

Water is essential to life. An adequate, safe and accessible supply must be available to all. Improving access to safe drinking-water can result in significant benefits to health. Every effort should be made to achieve a drinking water quality as safe as possible Many people struggle to obtain access to safe water. A clean and treated water supply to each house may be the norm in Europe and North merica, but in developing countries, access to both clean water and sanitation are not the rule, and waterborne infections are common. Two and a half billion people have no access to improved sanitation, and more than 1.5 million children die each year from diarrheal diseases (fenwick, 2006). According to the WHO, the mortality of water associated diseases exceeds 5 million people per year. From these, more that 50% are microbial intestinal infections, with cholera standing out in the first place. In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human or animal feces. Wastewater discharges in fresh waters and costal seawaters are the major source of fecal microorganisms, including pathogens (WHO, 2008, Fenwick2006, George, 2001, and Grabow1996). Acute microbial diarrheal diseases are a major public health problem in developing countries. People affected by diarrheal diseases are those with the lowest financial resources and poorest hygienic facilities. Children under five, primarily in Asian and African countries, are the most affected by microbial diseases transmitted through water 9 sea et al 2000). Microbial waterborne diseases also affect developed countries. In the USA, it has been estimated that each year 560,000 people suffer from severe waterborne diseases, and 7.1 million suffer from a mild to moderate infections, resulting in estimated 12,000 deaths a year (Medema et al 2003).

The Niger Delta is situated on the continental margin of the Gulf of Guinea (Klett *et al.,* 1997). It occurs at the Southern end of Nigeria between latitudes 30 and 60N and longitudes 30 and 90E and covers an area of about 75,000km2. Stable mega tectonic frames such as the Benin and Calabar flanks mark the northwestern and eastern boundaries of the delta respectively, while the Anambra Basin and the Abakaliki high mark the northern boundary. The delta is bounded in the south by the Gulf of Guinea. The Tertiary wedge of sediments in the Niger Delta consists of three diachronous units, which show an overall upward transition from marine prodelta shales (Akata Formation) through sand-shale paralic sequence (Agbada Formation) to continental sands and gravels (Benin Formation). The Akata Formation consists of uniform shale, which is dark grey to black with sand and silt lenses. It is under compacted in most places in the delta and is rich in microfauna, thus, suggesting deposition in shallow marine shelf. Its thickness is about 600-6000m and ranges in age from Late Eocene to Recent (Avbovbo, 1978). The Agbada Formation comprises shales interbedded with fluviatile, coastal and fluvio-marine sands, which become more prominent and thicker towards the top. Its thickness reaches about 4,500m and the sands constitute the main hydrocarbon reservoirs in the delta. The age of the formation is late Eocene to Recent (Short and Stauble, 1967). A succession of Oligocene to Recent, massive, poorly compacted sandstones, thin shales, which thicken towards the base and gravels make up the (Benin Formation). It is about 2,100m thick at the basin centre where there is maximum subsidence (Avbovbo 1978; Anakwuba et al. 2009).

2. Materials and methods

Column experiments were also performed using soil samples from forty (7) different borehole locations, the soil samples were collected at intervals of three metres each (3m). An salmonella solute was introduced at the top of the column and effluents from the lower end of the column were collected and analyzed for E.coli, and the effluent at the down of the column were collected at different days, analysis, velocity of the transport were monitored at different days. Finally, the results were collected to be compared with the theoretical values.

2.1. Developed model

$$Q\frac{\partial^2 C}{\partial x^2} = U\frac{\partial C}{\partial x} - \alpha k \quad (1)$$

Applying Laplace transformation into equation (1) we have

$$\frac{\partial^2 C}{\partial t^2} = S^2 C_{(x)} - SC_{(x)} - C_{(o)} \quad (2)$$

$$\frac{\partial C}{\partial x} = S^1 C_{(x)} - SC_{(x)} \quad (3)$$

$$C = C_o \quad (4)$$

Substituting equations (2), (3) and (4) into equation (1) yield

$$Q\left[S^2 C_{(x)} - SC_{(x)} - C_{(o)}\right] - U\left[SC_{(x)} - C_{(x)}\right]\alpha k\, C_{(o)} \quad (5)$$

$$QS^2 C_{(x)} - QSC^1{}_{(x)} - C_{(o)} - USC_{(x)} + UC_{(o)} - \alpha k\, C_{(o)} \quad (6)$$

Considering the following boundary condition at

$$t = 0,\ C^1{}_{(o)} = P_o = C_{(o)} = 0 \quad (7)$$

We have

$$C_{(x)}\left(QS^2 - QS - US\right) = 0 \quad (8)$$

$$C_{(x)} \neq 0 \quad (9)$$

Considering the boundary condition at

$$t > 0,\ C^1{}_{(o)} = C_{(o)} = C_{(o)} \quad (10)$$

$$S^2 C_{(x)} - US_{(x)} - \alpha k C_{(x)} = QSC_o + QC_o + UC_o \quad (11$$

$$\left[QS^2 - Us - \alpha k\right]C_{(x)} = \left[QS + Q + U\right]C_o \quad (12)$$

$$C_{(x)} = \frac{QS + Q + U}{\left[QS^2 - Us - \alpha k\right]}\, C_o \quad (13)$$

Applying quadratic expression, we have

$$S = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (14)$$

Where a = Q, b = -U, c = -αk

$$S = \frac{U \pm \sqrt{U^2 + 4Qakc}}{2Q} \quad (15)$$

$$S_1 = \frac{U - \sqrt{U^2 - 4Qakc}}{2Q} \quad (16)$$

$$S_2 = \frac{U + \sqrt{U^2 + 4Qak}}{2Q} \quad (17)$$

$$S_1 = \frac{U + \left[\sqrt{U^2 - 4Qak}\right]}{2Q} S_2 + \frac{U - \sqrt{U^2 + 4Qakc}}{2Q} \ell^{\frac{\left[U+\sqrt{U^2+4Qakc}\right]\frac{L}{v}}{2Q}} + \frac{\left[-U - U\sqrt{U^2 + 4Qakc}\right]}{2Q} \quad (18)$$

Applying Laplace inverse of the equation we obtain

$$C_t = \left[Q/t + Q + U\right] C_o \ell^{\frac{\left[U+\sqrt{U^2+4Qakc}\right]^t}{2Q}} + \ell^{\frac{\left[U-\sqrt{U^2+4Qakc}\right]^t}{2Q}} \quad (19)$$

But if $t = \frac{x}{v}$

$$\left[C\left[L,U\right] = Q/L/U + Q + U\right] C_o \ell^{\frac{\left[U+\sqrt{U^2+4Qakc}\right]^{\frac{L}{v}}}{2Q}} \quad (20)$$

Considering the following boundary conditions at

$$t = 0$$

$$C^1{}_o = 0$$

$$C_o = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

$$C_{(x)} = \left[Q/t + Q + U\right] C_o \left[\ell^{\frac{\left[U+\sqrt{U^2+4Qakc}\right]}{2Q}}\right]^{\frac{L}{v}} + \frac{\left[U+\sqrt{U^2+4Qakc}\right]^{\frac{L}{v}}}{2Q} \quad (22)$$

At $C^1{}_o = t \neq 0$

$$C^1{}_{(o)} = C_{(o)} \qquad C_o = \left[Q + U\right] C_o \left[1 + 1\right] i.e.\ 0 = \left[0 + U\right]^2 \quad (23)$$

Again so that

$$\Rightarrow \quad U + U = 0 \quad (24)$$

So that we have

$$C_{(x)} = \left[2Q/t\right] C_o \ell^{\frac{\left[U+\sqrt{U^2+4Qakc}\right]^{\frac{L}{v}}}{2Q} + \frac{\left[U+\sqrt{U^2+4Qakc}\right]^{\frac{L}{v}}}{2Q}} \quad (25)$$

However, $e^x + e^{-x} = 2Cos\, x$ therefore, we have

$$C_{(x)} = \left[2Q/t\right] C_o\, Cos\, \frac{\left[U + \sqrt{U^2 + 4Qakc}\right]^{\frac{L}{v}}}{2Q} \quad (26)$$

3. Results and discussion

Tables and figures are presented bellow. Figure one shows that the microbes gradually increase to a point where a rapid increase where experience, similar condition where experienced at experimental values, the microbes behaves the same like the theoretical values, both parameter compared favorable well. The rate of concentration observed it optimum value at hundred days, while figure three experimental and theoretical value increase in a fluctuation form from three to twenty seven meters and suddenly increase rapidly to thirty meter, where the optimum value where recorded, similar condition where found in figure four, the microbes experience fluctuation from ten to eight days, the rate of concentration from ninety to hundred experience rapid migration, the same to the experimental values, it obtained its optimum values at hundred days, both parameters compared favorably well. The microbes where found to migrate in a gradual process and suddenly increase at hundred days this condition explain the rate of inhibition between three to twenty seven meters and ten to eighty days, but rapid increase where observed between twenty seven to thirty meters and ninety to hundred days, it implies that there is deposition of substrate utilization between the region as presenting in the figure, rapid microbial growth where observed in those region, this implies that there is high rate of pollution between the stated period and at those depth the concentration varies in time base on the influence of environmental factor and stratification deposition of the stratum.

Tables 1
comparison between theoretical and experimental values at various time.

Time	Theoretical values	Experimental values
10	2.57E-60	2.45E-45
20	4.00E-55	3.77E-51
30	4.40E-43	3.40E-35
40	1.47E-39	1.55E-32
50	2.90E-30	2.78E-28
60	1.60E-25	1.77E-32
70	9.62E-16	8.87E-14
80	1.10E-20	1.12E-23
90	2.88E-11	2.77E-13
100	2.45E-06	2.23E-06

Tables 2
Comparisons between theoretical and experimental values at various depths.

Depth m	Theoretical values	Experimental values
3	2.57E-60	2.45E-45
6	4.00E-55	3.77E-51
9	4.40E-43	3.40E-35
12	1.47E-39	1.55E-32
15	2.90E-30	2.78E-28
18	1.60E-25	1.77E-32
21	9.62E-16	8.87E-14
24	1.10E-20	1.12E-23
27	2.88E-11	2.77E-13
30	2.45E-06	2.23E-06

Similar condition where observed in figure eight where by the microbes gradually increase to where the optimum value were recorded, it is influenced by degree of porosity in the soil that result to fast migration of microbes, the micro pole of the soil are one of the influence of rapid increase as observed

from the figure presented, this condition ca be attributed to the other environmental factor through man made activities.

Tables 3
comparisons between theoretical and experimental values at various depths.

Depth m	Theoretical values	Experimental values
3	8.25E-03	8.11E-03
6	0.12	0.15
9	0.19	0.17
12	0.25	0.3
15	0.32	0.29
18	0.38	0.41
21	0.44	0.39
24	0.5	0.53
27	0.57	0.57
30	1.12	1.14

Tables 4
comparisons between theoretical and experimental values at various time.

Time	Theoretical values	Experimental values
10	8.25E-03	8.11E-03
20	0.12	0.15
30	0.19	0.17
40	0.25	0.3
50	0.32	0.29
60	0.38	0.41
70	0.44	0.39
80	0.5	0.53
90	0.57	0.57
100	1.12	1.14

Table 5
Theoretical vales at various depth.

Depth m	Theoretical values
3	2.57E-60
6	4.00E-55
9	4.40E-43
12	1.47E-39
15	2.90E-30
18	1.60E-25
21	9.62E-16
24	1.10E-20
27	2.88E-11
30	2.45E-06

Table 6
Theoretical vales at various time.

Time	Theoretical values
10	2.57E-60
20	4.00E-55
30	4.40E-43
40	1.47E-39
50	2.90E-30
60	1.60E-25
70	9.62E-16
80	1.10E-20
90	2.88E-11
100	2.45E-06

Table 7
Theoretical vales at various time.

Time	Theoretical values
10	8.25E-03
20	0.12
30	0.19
40	0.25
50	0.32
60	0.38
70	0.44
80	0.5
90	0.57
100	1.12

Table 8
Theoretical vales at various depth.

Depth m	Theoretical values
3	8.25E-03
6	0.12
9	0.19
12	0.25
15	0.32
18	0.38
21	0.44
24	0.5
27	0.57
30	1.12

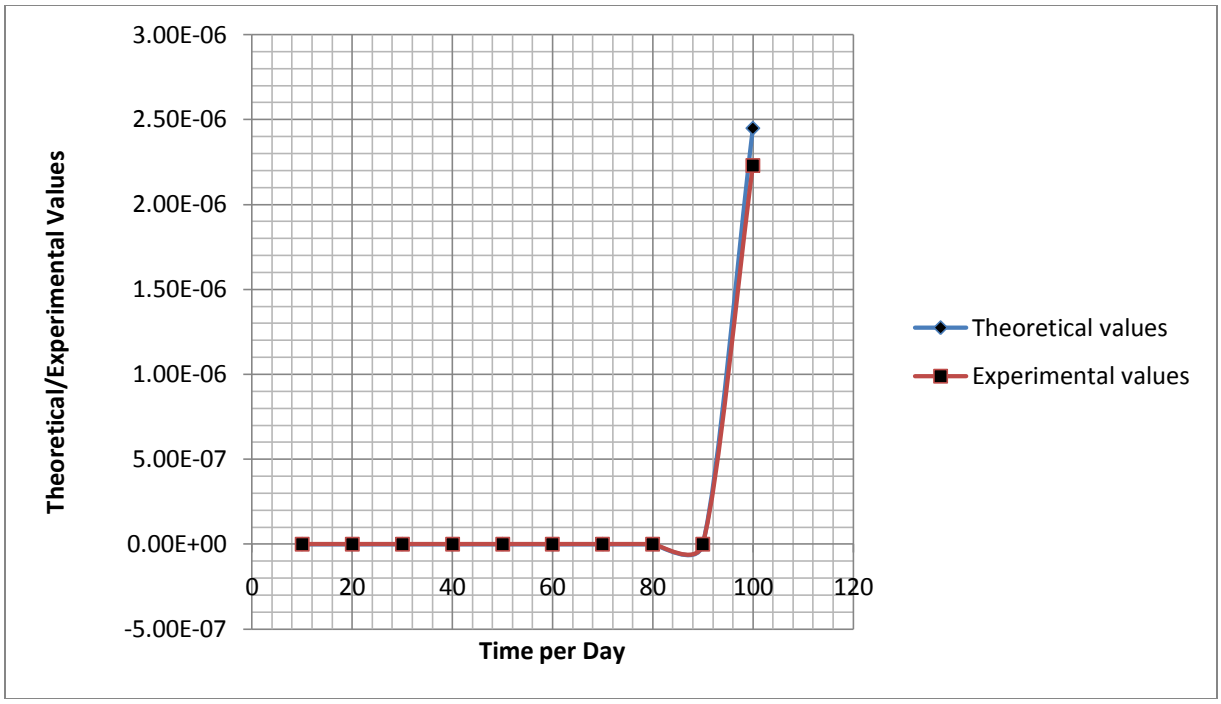

Fig. 1. comparisons between theoretical and experimental values at various time.

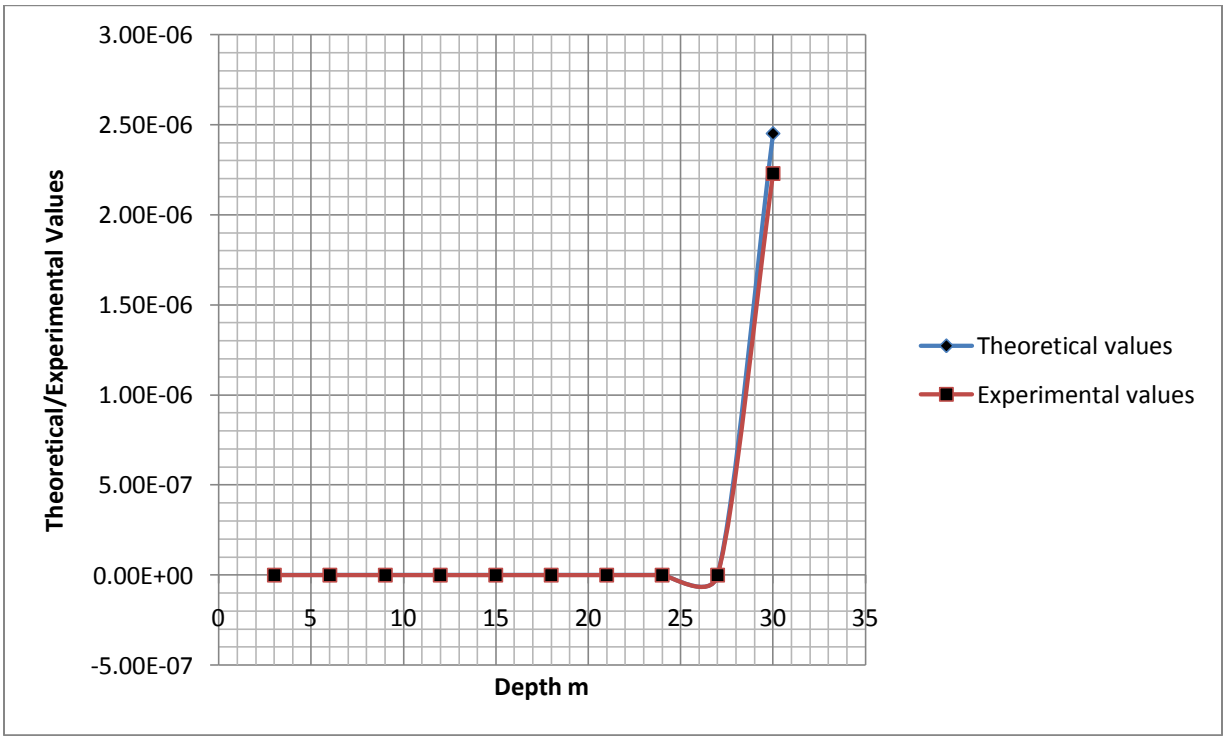

Fig. 2. comparisons between theoretical and experimental values at various depth.

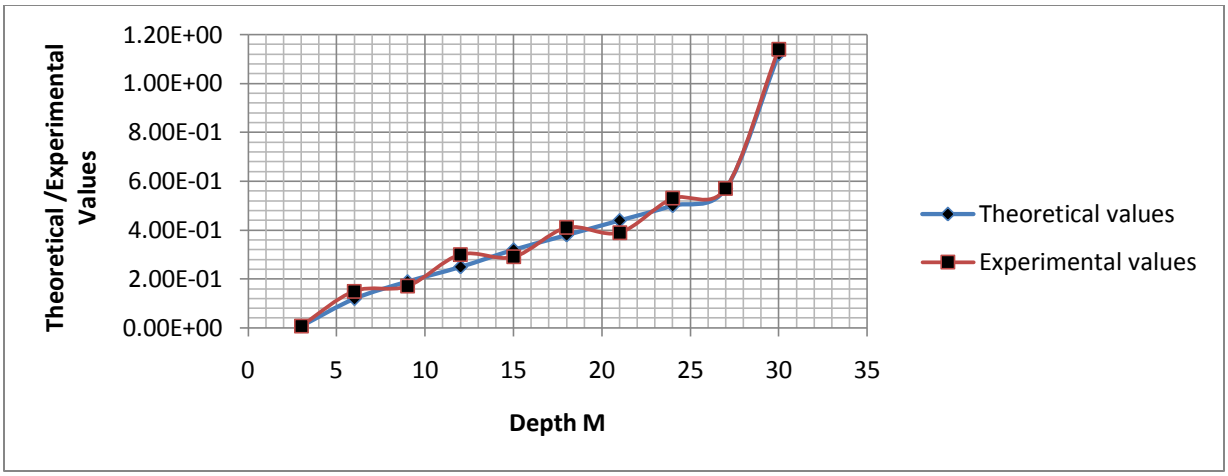

Fig. 3. Comparisons between theoretical and experimental values at various time.

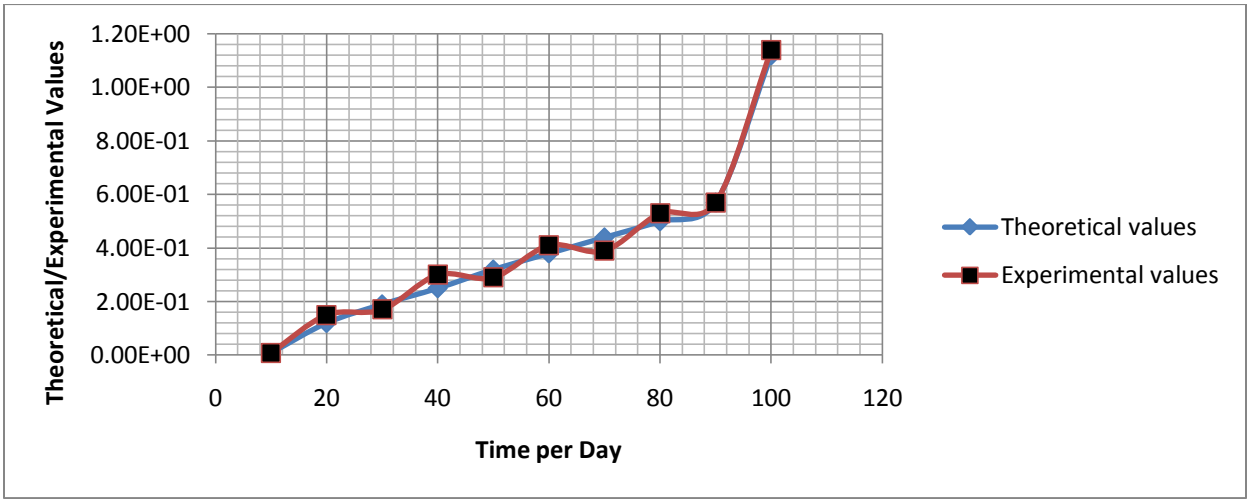

Fig. 4. Comparisons between theoretical and experimental values at various time.

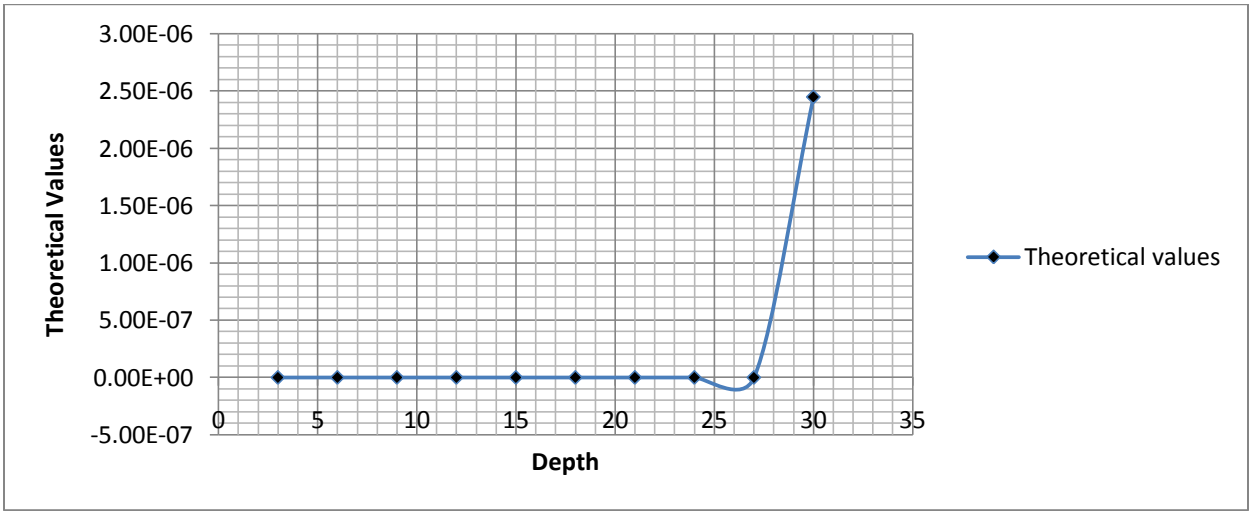

Fig. 5. Theoretical values at various times.

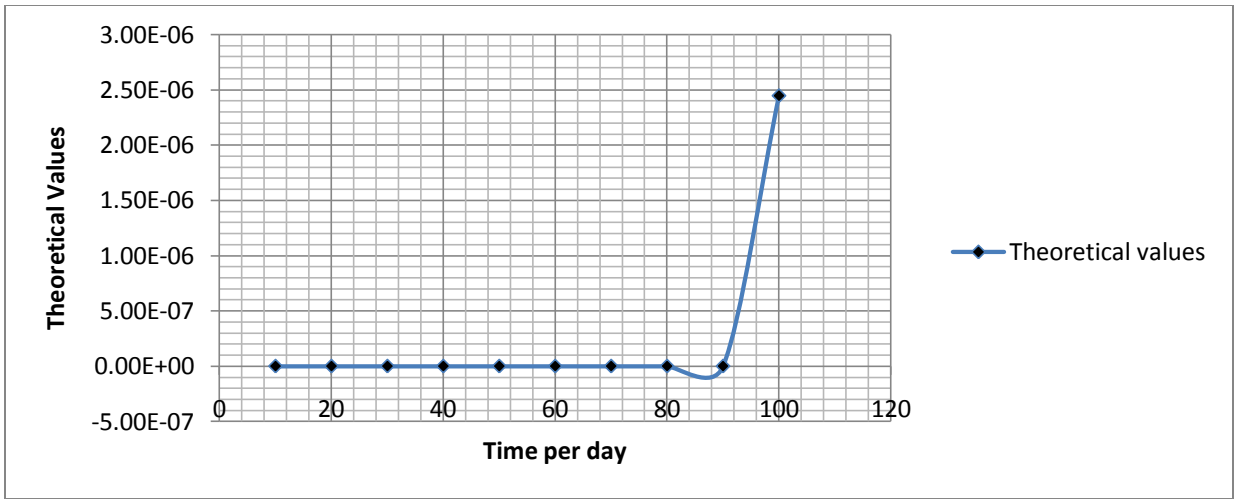

Fig. 6. Theoretical values at various Times.

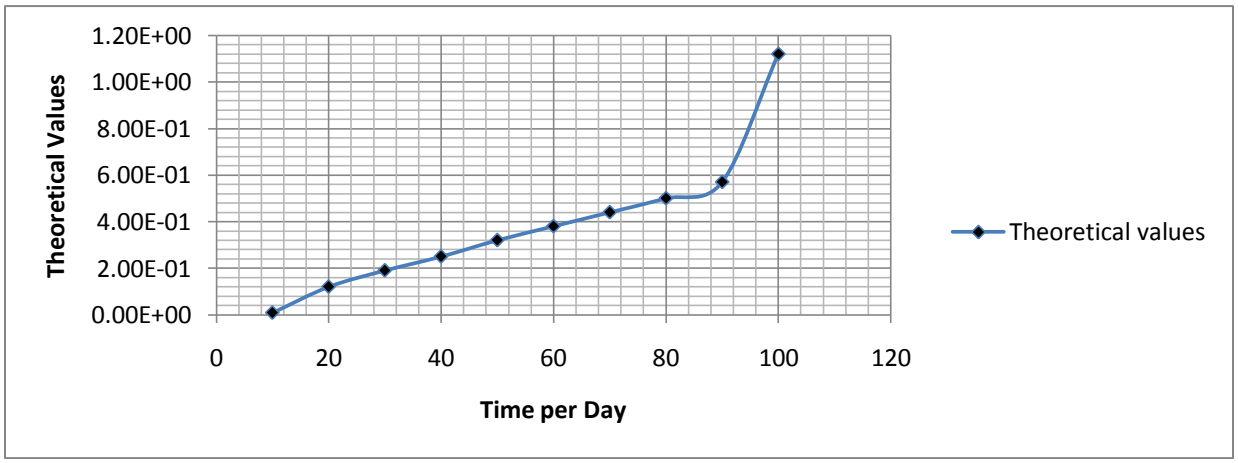

Fig. 7. Theoretical values at various times.

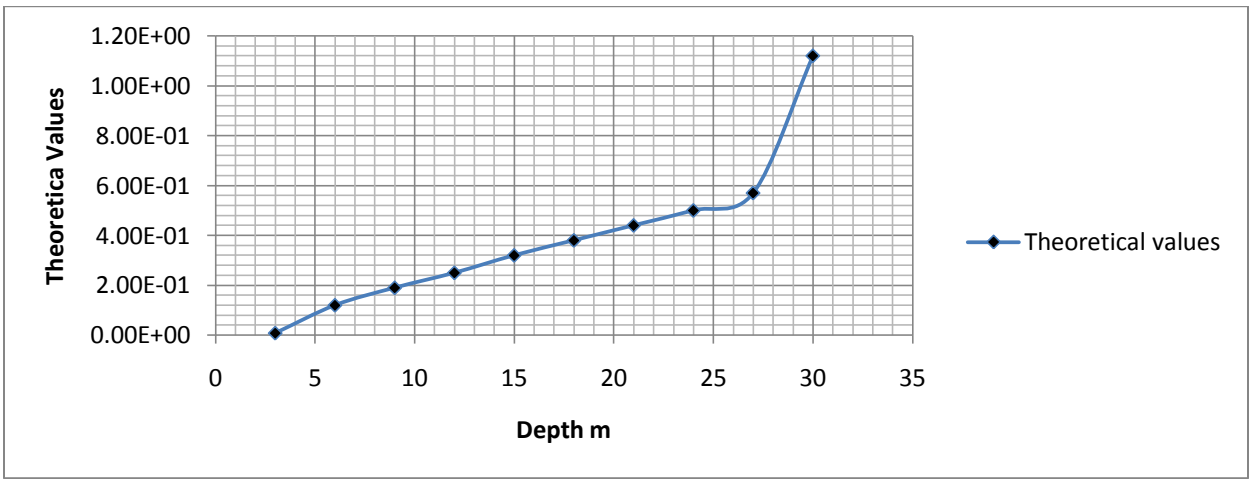

Fig. 8. Theoretical values at various times.

5. Conclusion

The transport of salmonella influence by porosity and void ration has been assessed, mathematical models were developed considering the major variable that contribute the rapid increase of salmonella to ground water aquifer, high degree of porosity and void ratio where found to generate from the rate of disintegration of the sediment, the stratification are deposited base on the deposition through intercedes of the soil, this condition can also attributed to geomorphology and geochemistry condition of the stratum, the study well definitely produce a baseline for consulting engineer and scientist to have a concrete frame work to conceptualize the design of improving design and construction quality of ground water that is free from salmonella containment in the study area.

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