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Research article

MATHEMATICAL MODEL OF BATCH SYSTEM APPLICATION ON KLEBSIELLA PNEUMONAE TRANSPORT ON HOMOGENEOUS LATERITIC SOIL INFLUENCE BY VOID RATIO IN OBIO AKPOR, RIVERS STATE OF NIGERIA

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Abstract

Mathematical model on klebsiella pneumonae transport influence by void ratio has been developed. The model is to predict the behaviour of the klebsiella pneumonae within a region of a uniform soil in the study location, the model were compared with experimental laboratory analysis, both values compared faviourably, the model developed has show the rate of microbes at constant velocity and void ratio in homogeneous soil and at various velocity, thus concentration at various time within a region of soil stratum, it can be attributed to the rate of substrate utilizations including variations in deposition of some other deposited minerals, the model has explained the rate of influence from void ratio that has resulted to high deposition of contaminants in some days. This is base on regeneration of these contaminants within a short period of time, finally, validation of these model with experimental values compared faviourable well, it has represent the behaviour of the klebsiella pneumonae **as** it generate high accumulation that can transport to ground water aquifer within a short period of time, the study generated a bench mark for scientists and engineers on the method to prevent soil pollution in the study area.

Keywords: mathematical model klebsiella pneumonae transport lateritic soil and void ratio

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1. Introduction

The express discovery of pathogenic bacteria and viruses, and cysts of protozoan parasites requires costly and prolonged procedures, and well-trained labor. The task would be enormous if one contemplates the monitoring of hundreds of pathogens and parasites on a schedule basis in water and wastewater treatment plants, getting waters, soils, and other environmental samples. Therefore, indicators of fecal pollution were much needed. As early as 1914, the U.S. Public Health Service (U.S.P.H.S.) adopted the coliform group as an indicator of fecal contamination of drinking water. Later on, other microorganisms were added to the list of indicators. Studies carried in the last few decades have shed some light on the fate of microbial indicators in the environment and their suitability as representatives of the hardier viruses and protozoan cysts. The criteria for an ideal indicator organism are the following (Bitton, 2005): 1. It should be a member of the intestinal micro flora of warm-blooded. The total coliform group belongs to the family enterobacteriaceae and includes the aerobic and facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose with gas production within 48 hours at 35oC (APHA, 1998). Total coliforms consist of Escherichia coli, Enterobacter, Klebsiella, and Citrobacter. These coliforms are discharged in relatively high numbers (2 x 109 coliforms/day/capita) in human and animal feces, but not all of them are of fecal origin. These indicators are useful for determining the quality of potable water, shellfishharvesting waters, and recreational waters. They are less sensitive, however, than viruses or protozoan cysts to environmental stresses and to disinfection. Some members (e.g., Klebsiella) of this group may sometimes grow under environmental conditions in industrial and agricultural wastes. In water treatment plants, total coliforms are one of the best indicators of treatment efficiency of the plant.

The presence of fecal coliforms indicates the presence of fecal material from warm-blooded animals. Some investigators have suggested the sole use of E. coli as an indicator of fecal pollution as it can be easily distinguished from the other members of the fecal coliform group (e.g., absence of urease and presence of b-glucuronidase). Fecal coliforms display a survival pattern similar to that of bacterial pathogens but their usefulness as indicators of protozoan or viral contamination is limited. Coliform standards are thus unreliable with regard to contamination of aquatic environments with viruses and protozoan cysts. Coliforms may also regrow in the environment. Detection of E. coli growth in pristine sites in a tropical rain forest, suggest that it may not be a reliable. If total coliform bacteria are confirmed in your drinking water, your water system should be inspected to find and eliminate any possible sources of contamination. Once the source is identified, it can usually be resolved by making system repairs, flushing, and adding chlorine for a short period of time. The state Health Department works with water systems and utility managers to help resolve such problems. When total coliform bacteria are confirmed in drinking water, a water system or utility is required to notify its customers within 30 days about the situation. The Health Department recommends that this notice be distributed as soon as possible. The notice will inform you of actions being taken to correct the problem, when the problem will likely be resolved, and what you may need to do until then. Coliform bacteria are organisms that are present in the environment and in the feces of all warm- loaded animals and humans. Coliform bacteria will not likely cause illness. However, their presence in drinking water indicates that disease-causing organisms (pathogens) could be in the water system. Most pathogens that can contaminate water supplies

come from the feces of humans or animals. Testing drinking water for all possible pathogens is complex, time-consuming, and expensive. It is relatively easy and inexpensive to test for coliform bacteria. If coliform bacteria are found in a water sample, water system operators work to find the source of contamination and restore safe drinking water. There are three different groups of coliform bacteria; each has a different level of risk. Several factors influence the recovery of coliforms, among them the type of growth medium, the diluting solution, and membrane filter used, the presence of non-coliforms, and the sample turbidity. Another crucial factor affecting the detection of coliforms is the occurrence of injured coliform bacteria in environmental samples. These debilitated bacteria do not grow well in the selective detection media used (presence of selective ingredients such as bile salts and deoxycholate) under temperatures much higher than those encountered in the environment (Domek et al., 1984; McFeters et al., 1982). The low recovery of injured coliforms in environmental samples may underestimate their numbers. We now know that injured pathogens may retain their pathogenicity following injury (Singh and McFeters, 1987; Amadi 2011). Port-Harcourt falls within the Niger Delta Basin of Southern Nigeria which is defined geologically by three sub-surface sedimentary facies: Akata, Agbada and Benin formations (Whiteman, 1982; Amadi 2007). The Benin Formation (Oligocene to Recent) is the aquiferous formation in the study area with an average thickness of about 2100 m at the centre of the basin and consists of coarse to medium grained sandstone, gravels and clay with an average thickness of about 2100 m at the centre of the basin and consists of coarse to medium grained sandstone, gravels and clay (Etu-Efeotor and Akpokodje, 1990). The Agbada Formation consists of alternating deltaic (fluvial coastal, fluviomarine) and shale, while Akata Formation is the basal sedimentary unit of the entire Niger Delta, consisting of low density, high pressure shallow marine to deep water shale (Schield, 1978).
The topography is under the influence of tides which results in flooding especially during rainy season (Nwankwoala and Mmom, 2007). Climatically, the city is situated within the sub-equatorial region with the tropical monsoon climate characterized by high temperatures, low pressure and high relative humidity all the year round. The mean annual temperature, rainfall and relative humidity are 30oC, 2,300 mm and 90% respectively (Ashton-Jones, 1998). The soil in the area is mainly silty-clay with interaction of sand and gravel while the vegetation is a combination of mangrove swamp forest and rainforest (Teme, 2002).

2. Material and method

The soil samples were collected at intervals of three metres each (3m). An E.coli solute was introduced at the top of the column and effluents from the lower end of the column were collected for standard experimental laboratory analysis the laboratory analysis and procedures are explained bellow

Bacteriological testing of water

Methodology: Membrane filtration. (WHO, 1993, 1996, 1998)

Principle of Method: A 100ml water sample was filtered through membrane filters. The membranes, with the coliform organism (*E. coli*) on it, are then cultured on a pad of sterile selective broth containing lactose and an

indicator. After incubation, the number of colonies of coliform (*E. coli*) were counted. This gives the presumptive number of *E. coli* in the 100ml water sample.

2.1 Choice of Technique: The method is recommended for its accuracy, speed of result, and because it can be performed in the field.

Required:

1. Sterile filtration unit for holding 47mm diameter membrane filters with suction device (wagteck international)
2. Sterile grid membrane filters of 47mm diameter with a pore size of 0.45um (oxoid).
3. Sterile 47mm diameter cellulose pads (both culture medium to be added just before use).
4. Sterile Petri dishes 50-60mm diameter
5. Sterile membrane lauryl sulphate broth (lactose sodium lauryl sulphate broth)
6. Autoclaving unit, blunt ended forceps, sterile bottles, grease pencil, incubator at 44^{o}c, Bunsen burner, Petri-dish holders and oblique light source.

Procedure:

a. Assembling the Filtration Unit: The sterile broth is aseptically added to the cellulose pad in a Petri-dish. The membrane filter is aseptically removed from the sterile pack using a flame sterilized blunt forceps and placed on the filter base with the grid-side uppermost and centrally. Next, the filter lid was screwed into place.

b. Suction Filtration of water sample: 100ml of the different water samples were thoroughly mixed by inverting the bottles several times and gently poured into the assembled filtration unit.

- The water was drawn into the filter membrane by suction using the hand held pressure pump.
- A blunt-ended forceps was sterilized by naked Bunsen flame, cooled and the membranes were aseptically removed from the filtration unit after unscrewing the lid of the filtration unit.
- The membranes were placed, grid-side uppermost, on the culture medium pads in the Petri-dishes, ensuring there were no air bubbles trapped under the membranes.
- The Petri-dishes were closed and the top of the lids were labelled with the code numbers of the water samples and volumes of water used using a grease pencil.

2.3 Incubation of Samples:

- The Petri-dishes were packed in Petri dish holders with lids uppermost and placed inside the incubator at 44°c for 12 – 16 hours.

Examination, count and calculation of klebsiella pneumonae colonies:

- Following incubation and using oblique lighting, the membranes were examined one after the other for yellow lactose fermenting colonies, 1-3mm in diameter. The number of colonies if any was counted. Any plink and small colonies less than 1mm in diameter were ignored. Number of colonies too numerous to count were reported as "too numerous to count" (indicative of gross contamination).

- To calculate the presumptive klebsiella pneumonae count/100ml water sample, the number of colonies counted per membrane was multiplied by 1.

2.4 Developed model for klebsiella pneumonae

Developed Model of E.coli under Progressive Condition in Groundwater The mathematical model was developed by considering the klebsiella pneumonae growth rate function to be dependent of velocity, time; distance Based on these conditions as stated above a general mathematical expression can be written as:

$$K\,C(x)\,\frac{\partial v(x)}{\partial t} = V\frac{\partial c(x)}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$V\frac{\partial c(x)}{\partial t} = K\,C(x)\frac{\partial v(x)}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$V\frac{\partial c(x)}{\partial t} = -K\,C(x)\frac{Vx}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\left(\frac{V}{Vx}\right)\frac{\partial c(x)}{\partial (x)} = -\frac{Kdt}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$V/V_{\square} - \int 1/C_{(x)}\,\partial Cx = K\int\frac{\partial t}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$V/V_{(x)}\left[\ln C(x) = -K\ln\frac{t_o}{t}\right]_{\square} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$\ln\frac{C_{(x)}}{Cx_o} = -K\frac{V_{(x)}}{V}\ln\frac{t}{t_o} = \ln\left(\frac{t}{t_o}\right) - K\frac{V_x}{V}_{\square} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$\frac{C_{(x)}}{C_{(x)_o}} = \left(\frac{t}{t_o}\right) - K\frac{V_x}{V}_{\square} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$\frac{C_{(x)}}{C_{(x)o_o}} = \ell^{-K\ln\left(t/t_o\right)V_x/V}_{\square} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

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$$C_{(x)} = C_{(x)_o} \ell^{-K \ln 1/t \, V_x/V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

$$C_{(x)} = \beta \ell^{-K \ln 1/t_o \, V_x/V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

$$\beta = C_{(x)_o} \ell^{V_x/t_v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

The system to be on this condition where it is influenced by void ratio on microbial transport.

Equation (12) will be useful; therefore the equation can be expressed integrating the parameter as

$$C_{(x)} = \beta \ell^{-\partial V t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Where ∂ is the void ratio and V is the velocity of the contaminant in *x* direction.

Take Laplace of (13) yield

$$C_{(o)} = \frac{\beta}{\partial V + S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

$$C_{(o)}\left[\partial V + S\right] = \beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

$$i.e.\ C_{(o)}\,\partial V + C_{(o)}\,S - \beta = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

Apply quadratic formula for (16) we have an expression of this form

$$C_{(x)} = \frac{-S \pm \sqrt{S^2V^2 + 4\partial\beta V}}{2\partial V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17$$

Now S = ∂V that equation (17) is of the form

$$C_{(x)} = -\partial V \pm \frac{\sqrt{\partial^2V^2 + 4\partial\beta V}}{2\partial V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

The general solution of (18) is

$$C_{(x)} = A\exp\left[-\partial V + \frac{\sqrt{-\partial^2V^2 + 4\partial\beta V}}{2\partial V}\right]t + \beta\exp\left[-\partial V + \frac{\sqrt{-\partial^2V^2 + 4\partial\beta V}}{2\partial V}\right]t \quad \ldots\ldots \quad (19)$$

Subjecting equation (19) to the following boundary conditions and initial value condition.

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$x = 0$, $C_{(o)} = 0$ and $t = 0$

we have, $\beta = -1$ and $A = 1$.

So that the particular solution will be of this form

$$C_{(x)} = \exp\left[-\partial V + \left(\partial^2 V^2 + 4\partial\beta V\right)^{1/2}\right]t - \exp\left[-\partial V - \left(\partial^2 V^2 + 4\partial\beta V\right)^{1/2}\right]t \quad \ldots\ldots \quad (20)$$

But $\ell^x - \ell^{-x} = Sin$

Therefore, expression (20) can be expressed in this form

$$C_{(x)} = 2Sin\left[\partial V + \left(\partial^2 V^2 + 4\partial\beta V\right)^{1/2}\right]t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

3. Result and Discussion

Table and figure are presented bellow

Table: 1 theoretical values at various Time per Day

Time	Theoretical values conc mg/l
10	-1.99
20	0.32
30	1.93
40	-0.64
50	-1.83
60	0.94
70	1.67
80	-1.22
80	-1.47
100	1.46

Table: 2 theoretical values at various Times per Day

Time	Theoretical values conc mg/l
10	0.02
20	0.53
30	0.98

40	1.67
50	1.97
60	1.99
70	1.95
80	1.9
80	0.71
100	-1.21

Table: 3 theoretical values at various Times per Day

Time	Theoretical values conc mg/l
10	0.018
20	0.32
30	0.52
40	0.86
50	1.7
60	1.95
70	1.88
80	0.01
90	3.16E-03
100	0.79

Table: 4 Theoretical and Experimental values at various Times per Day

Time	Theoretical values conc mg/l	Experimental results
10	-1.99	-1.88
20	0.32	0.4
30	1.93	1.89
40	-0.64	-1.69
50	-1.83	-1.93
60	0.94	0.89
70	1.67	1.71
80	-1.22	-1.25
80	-1.47	-1.51
100	1.46	1.49

Table: 5 theoretical and Experimental values at various Times per Day

Time	Theoretical values conc mg/l	Experimental results
10	0.02	0.06

20	0.53	0.51
30	0.98	0.89
40	1.67	1.71
50	1.97	1.89
60	1.99	1.79
70	1.95	1.91
80	1.9	1.85
80	0.71	0.68
100	-1.21	-1.18

Table: 6 theoretical and Experimental values at various Times per Day

Time	Theoretical values conc mg/l	Experimental results
10	0.018	0.021
20	0.32	0.36
30	0.52	0.48
40	0.86	0.67
50	1.7	1.64
60	1.95	1.87
70	1.88	1.75
80	0.01	0.02
90	3.16E-03	3.56E-03
100	0.79	0.84

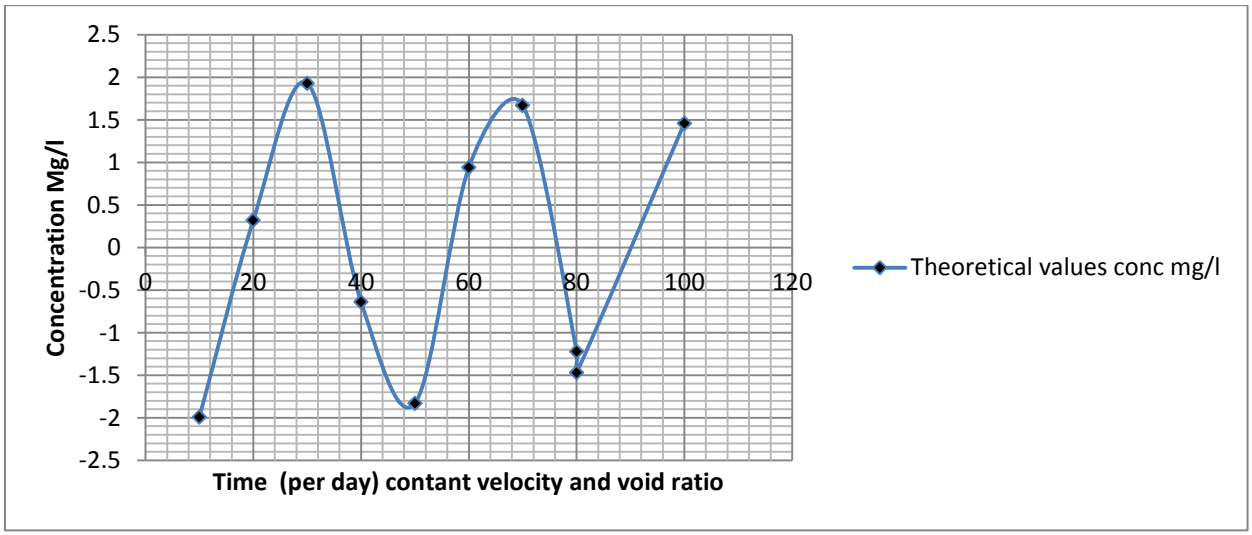

Figure: 1 Theoretical and Experimental values at various Times per Day

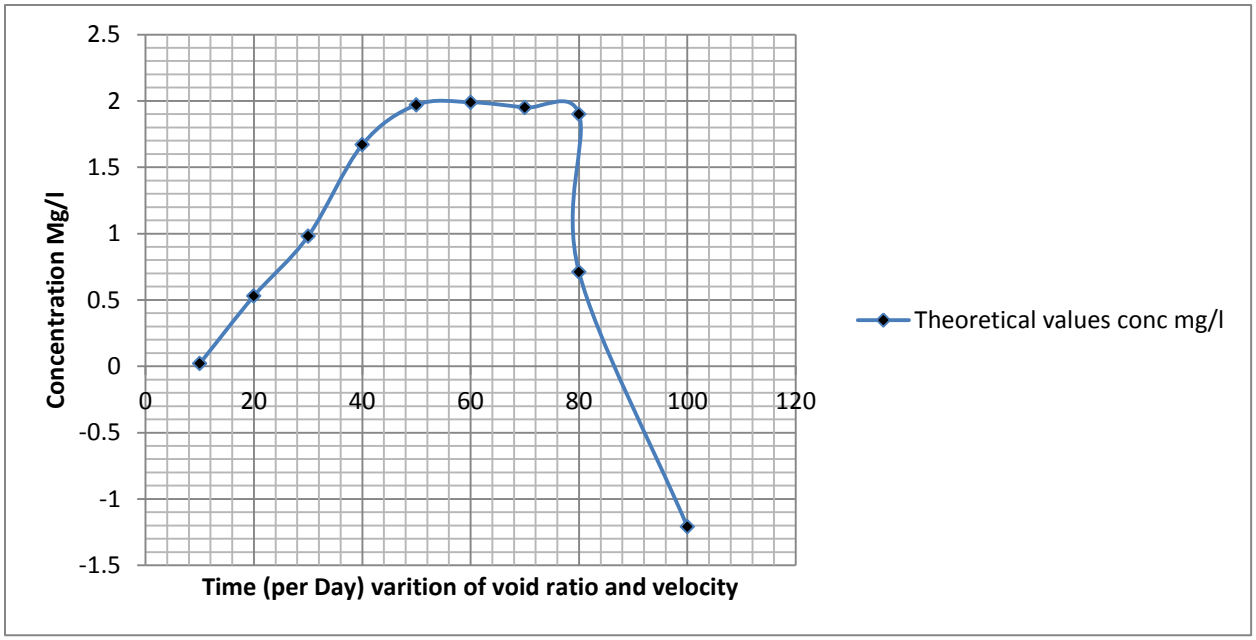

Figure: 2 Theoretical and Experimental values at various Times per Day

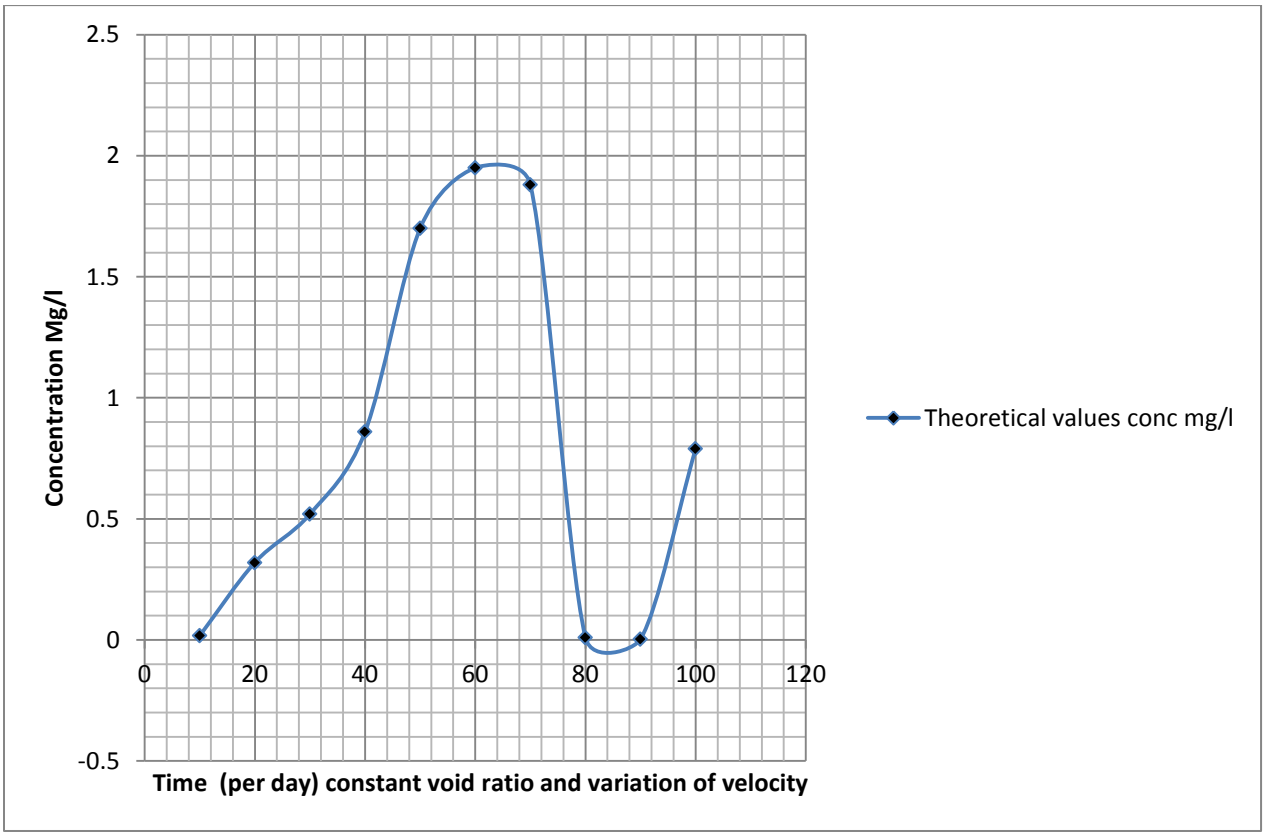

Figure: 3 Theoretical and Experimental values at various Times per Day

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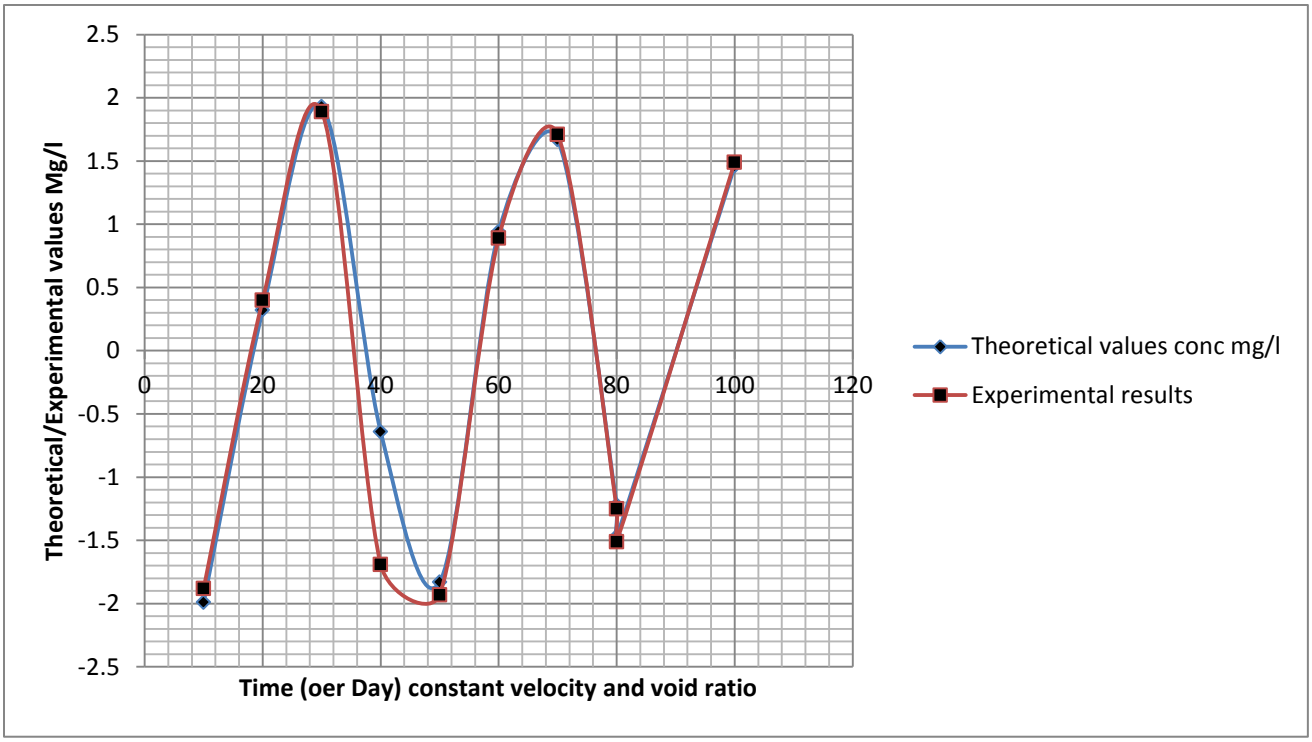

Figure: 4 Theoretical and Experimental values at various Times per Day

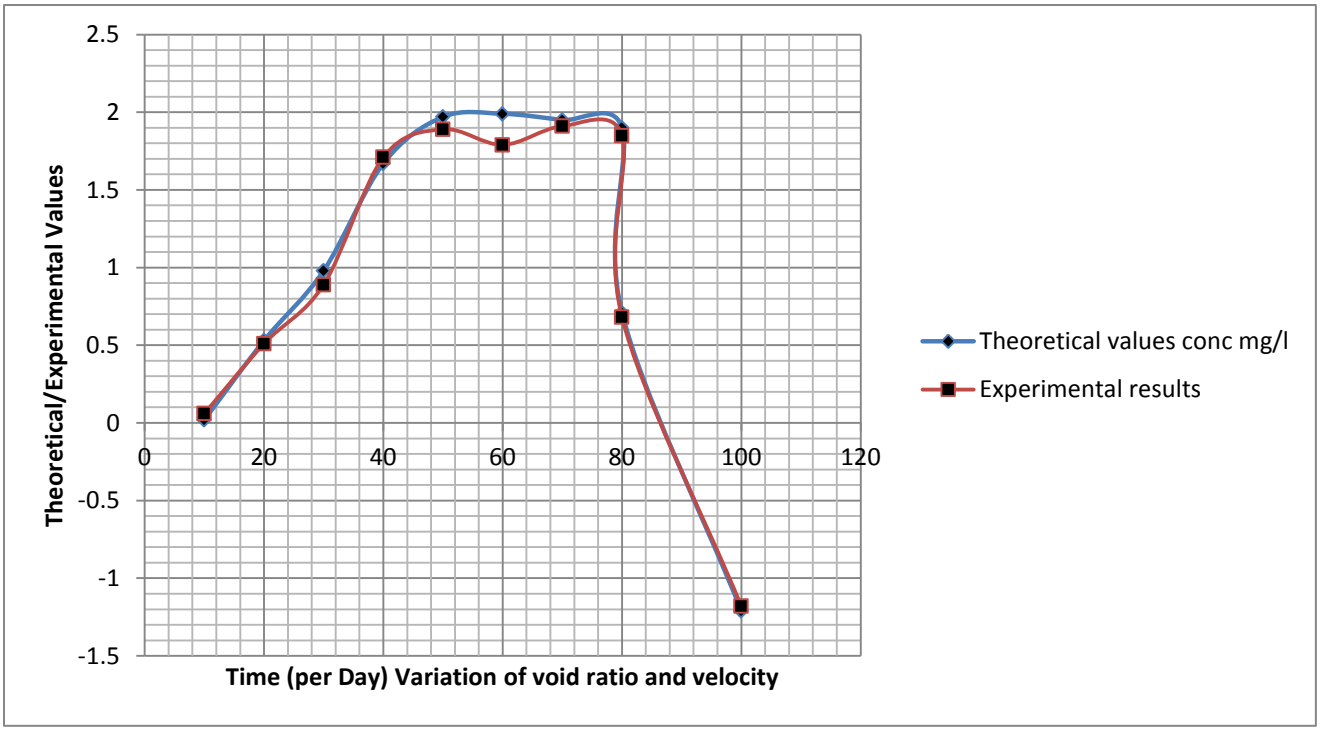

Figure: 5 Theoretical and Experimental values at various Times per Day

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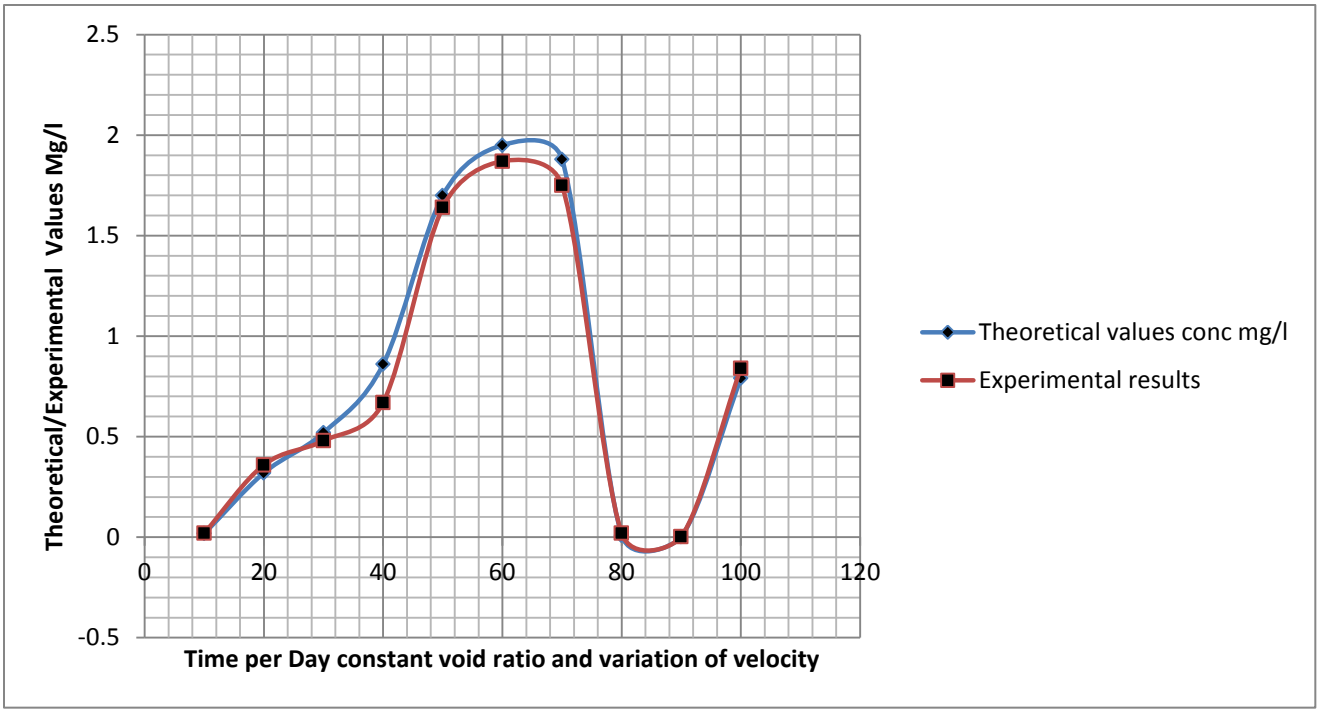

Figure: 6 Theoretical and Experimental values at various Times per Day

The figures presented shows that the region experience lag phase in some days, because of the level of depositions on the formation, another reason may be as a result of fluctuation in the generation of the contaminants, base on the formation characteristics in the soil structures, therefore the microbes may experience degradation for some time, and when the deposition of there substrate utilizations are available in the soil it will generate energy for them, and they migrate faster as well as increase in there microbial population, thus this process fluctuation are experienced. Meanwhile at various void ratio of the soil and at different velocity, an increase in microbial growth were experienced to the point were an optimum value were recorded at eighty days and finally decrease with time to the lowest at hundred day, showing the rate of degradation at certain time within the region. Similarly at constant void ratio of the soil and at different velocity, the microbes experienced a gradual increase base on the regeneration of the substrate utilization that may have regenerate in the soil. But to a certain extent it experience a rapid decrease as the substrate decrease and the microbes could not adopt, so they experience degradation for some days, but at ninety days there was a little regeneration of micronutrients and that allowed for little increase of the contaminants at hundred days. The model developed were compared with an experimental laboratory analysis, both parameters compared faviourably, the rate of void ratio influence on uniform soil are applied to be a batch system, it has definitely explained the rate of contamination on the soil, the rate of these microbial transport can be attributed to the geological formation on the study location as presented in the figures. High degrees of void ratio on the deltaic soil definitely cause fast migration of the microbes within a short period of time.

4. Conclusion

The rate of microbial transport influence by void ratio within a region as a batch system has explained thus the behaviour of microbes within a certain region of a soil. The model developed has thoroughly explained the rate of microbial transport, the cause of growth and degradation as presented from the figures. The model compared faviourably with the experimental laboratory analysis, this validate the model of microbial transport within a region of a soil with respect to time, the study has also explain the influence of formation characteristics and other

deposition either of man made activities or natural origin, finally the study is imperative because of high deposition of microbes in soil that may accumulate and finally transport to ground water aquifer. The rates of regeneration of the microbes continue to increase in the study location, this condition will definitely cause more pollution in ground water aquifers influenced by deltaic environment on the study location.

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