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RESEARCH ARTICLE

MATHEMATICAL MODELING AND SIMULLATION OF SALMONELLA TRANSPORT IN A HOMOGENEOUS SILT FORMATION IN BUGUMA: RIVERS STATE OF NIGERIA.

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Abstract

Mathematical modeling of salmonella transport in a uniform silty stratum formation has been carried out, the study area is situated in a coastal environment, and it has experience different type of pollution from various sources. The model where develop to monitor the transport of salmonella at various time, the transport of the microbes where found to be fluctuating in some condition in a gradual process, thus decreasing in some region as observed in some figures, these values where compared for fitness, consequently, the model has been verified with the experimental values. The study has produced a benchmark to monitor the migration of salmonella in soil and water environment. The behaviour of the microbes in brackish aquiferious zone has been determined from the figures presented at different period, considering the influence that deposited in the study area. The model has definitely determined the rate of concentration at different velocity including constant velocity, the behaviour of the microbes at different condition that produced lag phase where also expressed, the rate of the salinity in the environment where also streamlined. The study recommends treatment of the water after construction of water well in the study area.

Introduction:-

Salmonella organisms are bacteria that can be transmitted by all animals, including humans. Their complete elimination from the general environment is unlikely. However, control on the farm is possible and can begin by following simple hygiene practices. There are over 2,000 known serotypes of salmonella but currently only about 200 are associated with foodborne infections in humans in any one year in the UK. In pigs some types of salmonellas (for example Salmonella typhimurium) are more likely than others to cause disease and produce clinical signs such as diarrhoea, dehydration, septicaemia, abortion or even death. Salmonella may be introduced onto farms in a number of ways but the major route is by the movement of clinically healthy carrier animals (i.e. those animals which are infected but show no sign of disease). Feeding stuffs and bedding contaminated with dung from infected animals are other ways by which infection may be introduced. Infection may also be brought on to a farm by domestic pets, rodents, wild birds and animals, contaminated vehicles, farm personnel, visitors or equipment. It is important that an assessment of the potential hazards is made so that appropriate controls/checks can be implemented to reduce the risk of infection entering your farm. A monitoring programme to check the salmonella status of your stock is advisable. Both should be done in consultation with your veterinary surgeon. The following key measures should be considered during the assessment (although there may well be other measures depending on the particular circumstances on your farm, which is why it is important to consult your veterinary surgeon. Salmonella sometimes causes disease and deaths in pigs, mainly after weaning, but the disease is usually short lived. Infection with salmonella does not always result in disease, but many infected animals become symptomless carriers

for a period. It is the animals which appear clinically normal but which may be excreting or carrying salmonella at slaughter that can be responsible for contamination of pig meat Studies in various countries have shown that a Significant proportions of pigs are carrying salmonella in their intestine or on their skin at slaughter. The high standards of hygiene at slaughter help to minimize the risk of transferring the salmonella bacteria to the carcass. However, it is not possible to eliminate completely contamination during the slaughter process so inevitably some pig meat can become contaminated especially where a high proportion of pigs in a batch are carriers. Salmonella can multiply outside the body. Even small numbers of organisms on meat can multiply during periods when it is not refrigerated or frozen resulting in a threat to public health. Outbreaks of foodborne illness caused by consumption of fresh produce contaminated with *Salmonella* or verotoxigenic *Escherichia coli* and sometimes with *Yersinia enterocolitica*, *Shigella*, or the protozoans *Cryptosporidium* and *Giardia* have become more frequent in recent years (Beuchat, 2006). According to the Centers for Disease Control and Prevention, Atlanta, GA from 1990 to 2004 there were 640 outbreaks from produce which sickened almost 32,000 persons. It is notable that the numbers of cases/outbreak involving produce were significantly higher than for any other food commodity. Of 52 outbreaks from produce caused by *Salmonella* serovars, 38 of these occurred since 2000 (Center for Science in the Public Interest, 2006; Center for Disease Control, 2004). Animal manures contaminated with zoon tic pathogens directly or indirectly may lead to transfer of the pathogens to surface, irrigation, or groundwater which may be used for horticultural production. There is a significant body of evidence showing that low temperature, presence of organic matter, higher moisture, and low numbers of competing organisms contribute to longer survival of pathogens in the environment (Beuchat, 2006). Results from several studies in the United States, Canada, Denmark, and the Netherlands have shown that nearly half (14–47%) of hogs tested either carried *Salmonella* or were seropositive and that in some cases as many as 70% of farms examined had one or more animals test positive (Kranker et al., 2003; Rajić et al., 2005; Cote et al., 2006). In an epidemiological study of an *S.* Typhimurium DT-104 outbreaks among cattle on 14 farms located within a 10 km radius in Denmark, the same pulse type by pulsed field gel electrophoresis of the pathogen was found in hogs and cattle on farms which raised one or both animal species (Langvad et al., 2006). In addition to spreading of cattle manure, contaminated equipment, transfer of infected piglets and personnel movement contributed to distribution of the organism among farms. Otherwise healthy hogs are regarded as a primary reservoir of *Yersinia enterocolitica* and the organism has been found in ≤25% of animals (Bhaduri et al., 2005; Nesbakken et al., 2006; Bowman et al., 2007). *Yersinia enterocolitica* is ranked seventh in important as a foodborne pathogen in the United States where it causes sporadic outbreaks of illness, but it has been (through consumption of contaminated, inadequately cooked pork) the major source of human yersinosis in some Scandinavian countries. Four serovars (0:3; 0:5, 27; 0:8, and 0:9) are responsible for human disease and serotype O:3 is becoming more frequent worldwide (Nesbakken, 2006). Improved hog slaughter hygiene has reduced incidents of yersinosis from pork, but animal shedding of the organism on farms is still an issue (Nesbakken et al., 2006). Although sometimes seropositive, cattle are not considered carriers of *Y. enterocolitica* (Nesbakken, 2006). Th e presence of shiga- or verocytotoxin producing *E. coli* in hogs is normally infrequent (Beutin et al., 1993). About 3 of 44 herds and 3.3% of 660 hogs were found *E. coli* O157:H7 positive in Canada (Gyles et al., 2002), and the frequency of animal contamination was ≤2% in the United States and Europe (Caprioli et al., 2005). Higher prevalence was found in Germany and Chile (7.5–10%), although recently Doane et al. (2007) found 8.9% of 570 swine samples from four farms in the United States positive for *E. coli* O157:H7. Nonetheless, hogs are not generally considered to be a reservoir of this organism.

Materials and Method:-

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 salmonella, 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.

3. Developed Mathematical Model:-

$$K C_{(x)} \frac{\partial V_{(x)}}{\partial t} = \frac{V \partial C_{(x)}}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\frac{V \partial C_{(x)}}{\partial t} = K C_{(x)} \frac{\partial V_{(x)}}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\frac{V \partial C_{(x)}}{\partial t} = -K C_{(x)} \frac{V_x}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\left(\frac{V}{V_x}\right) \frac{\partial C_{(x)}}{\partial (x)} = -\frac{K dt}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

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

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

$$\ln \frac{C_{(x)}}{C_{(x)_o}} = -K \frac{V_{(x)}}{V} \ln \frac{t}{t_o} = \ln \left(\frac{t}{t_o}\right)^{-KV_x/V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$\frac{C_{(x)}}{C_{(x)_o}} = \left(\frac{t}{t_o}\right)^{-KV_x/V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

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

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

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

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

The model can be applied to resolve the migration of E. coli influence on porosity and permeability.

Integrating both parameters into the equation will yield

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

Applying Laplace transform on (13) so that we have

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

$$\Rightarrow \quad C_{(o)}\left[KnV + S\right] = \beta$$

$$\text{i.e. } C_{(o)}\, KnV + C_{(o)}\, S - \beta = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

we can use quadratic formula on (16) so that we can have;

$$C_{(x)} = \frac{-S \pm \sqrt{S^2 + 4\beta KnV}}{2KnV} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

With $S = K\,nV$, equation (16) can be expressed as

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

Now the general solution is

$$C_{(x)} = A\exp\left[\frac{-KnV + \left(K^2n^2V^2 + 4\beta KnV\right)^{1/2}}{2KnV}\right]t + \beta\exp\left[\frac{-KnV - \left(K^2n^2V^2 + 4\beta KnV\right)^{1/2}}{2KnV}\right]t \quad (18)$$

Subjecting equation (18) to the following conditions:

$x = 0$, $C_{(o)} = 0$ and $t = 0$, so that (18) gives a particular solution of the form

$$C_{(x)} = \exp\left[\frac{-KnV + \left(K^2n^2V^2 + 4\beta KnV\right)^{1/2}}{2KnV}\right]t - \exp\left[\frac{-KnV - \left(K^2n^2V^2 + 4\beta KnV\right)^{1/2}}{2KnV}\right]t \quad . \quad (19)$$

Using the expression $2Sinx = \ell^{x} - \ell^{-x}$, our equation (7) yield the result:

$$C_{(x)} = 2Sin\left[\frac{KnV + \left(K^2n^2V^2 + 4\beta KnV\right)^{1/2}}{2KnV}\right]t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

Results and Discussion:-

Table 1: Theoretical values of Salmonella concentration at various time at constant velocity:-

Time	Constant (V)Theoretical
10	3.80E-04
20	2.66E-06
30	2.29E-05
40	3.05E-05
50	3.82E-05
60	4.58E-05
70	5.35E-05
80	6.11E-05
90	6.88E-05
100	7.64E-05

Table 2: Theoretical values of Salmonella concentration at various time at constant velocity:-

Time	Constant (V)Theoretical
10	0.03
20	0.07
30	0.11
40	0.14
50	0.18
60	0.21
70	0.25
80	0.28
90	0.32
100	0.35

Table 3: Theoretical values of Salmonella concentration at various time at constant velocity:-

Time	Various (V)Theoretical values
10	1.22E-05
20	2.15E-05
30	6.63E-05
40	4.99E-05
50	8.90E-05
60	1.14E-04
70	1.70E-02
80	1.80E-02
90	2.27E-03
100	1.30E-02

Table4: Comparison of Theoretical and Experimental values of Salmonella concentration at various Depths at constant velocity:-

Time	Constant (V)Theoretical	Experimental
10	3.80E-04	3.73E-04
20	2.66E-06	2.80E-06
30	2.29E-05	5.78E-06
40	3.05E-05	4.34E-05
50	3.82E-05	3.77E-05
60	4.58E-05	4.69E-05
70	5.35E-05	5.48E-05
80	6.11E-05	6.17E-05
90	6.88E-05	6.82E-05
100	7.64E-05	7.53E-05

Table5: Comparison of Theoretical and Experimental values of Salmonella concentration at various Depths at constant velocity:-

Time	Constant (V)Theoretical	Experimental
10	0.03	0.04
20	0.07	0.06
30	0.11	0.15
40	0.14	0.16
50	0.18	0.21
60	0.21	0.24
70	0.25	0.28
80	0.28	0.31
90	0.32	0.34
100	0.35	0.37

Table: 6 Comparison between theoretical and experimental of salmonella at various depths:-

Time	Various (V)Theoretical values	Experimental Values
10	1.22E-05	1.25E-05
20	2.15E-05	2.44E-05
30	6.63E-05	5.60E-06
40	4.99E-05	4.77E-06
50	8.90E-05	8.78E-06
60	1.14E-04	1.24E-04
70	1.70E-02	1.89E-02
80	1.80E-02	1.78E-02
90	2.27E-03	2.34E-03
100	1.30E-02	1.20E-02

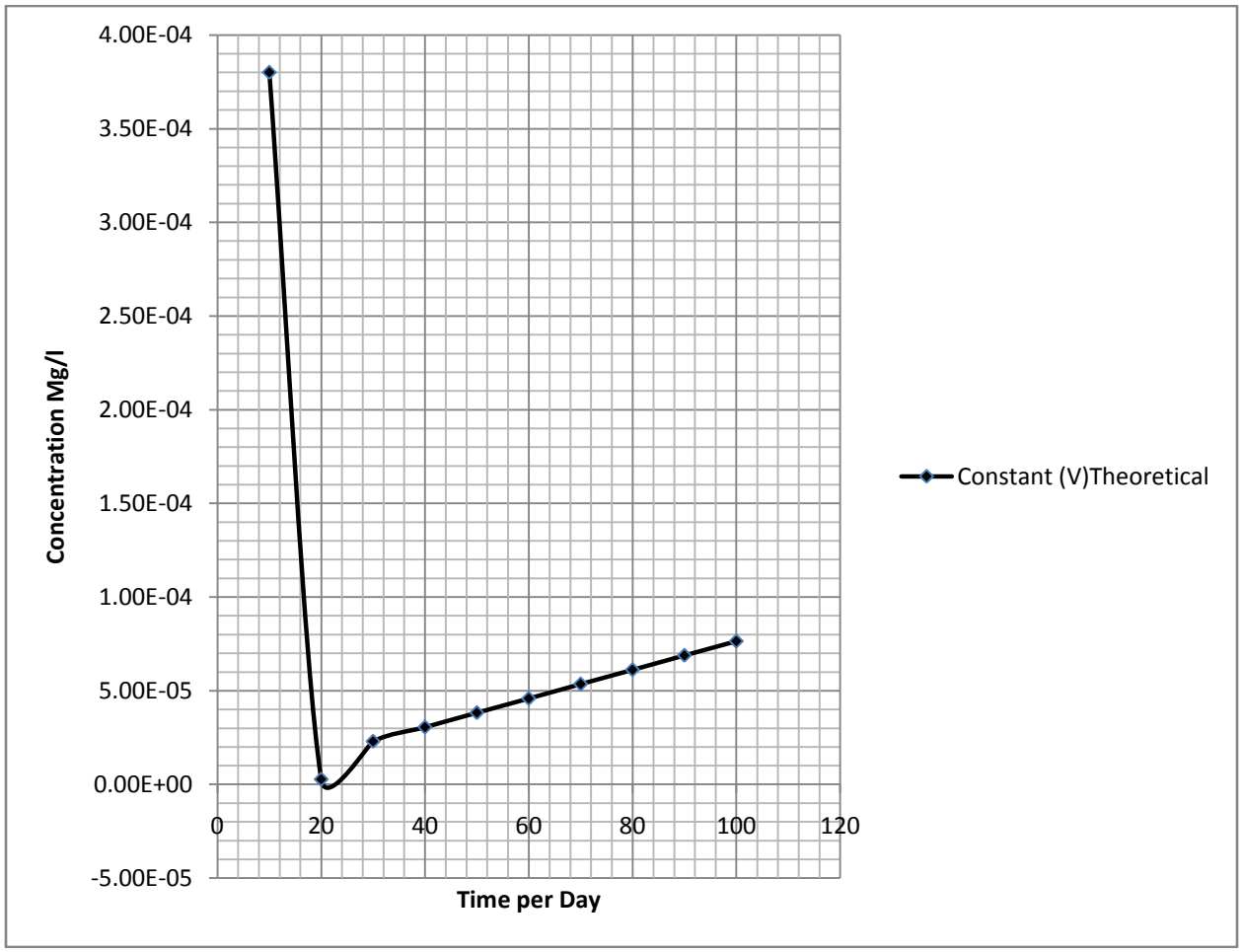

Table 1: Theoretical values of salmonella concentration at various Depths at constant velocity:-

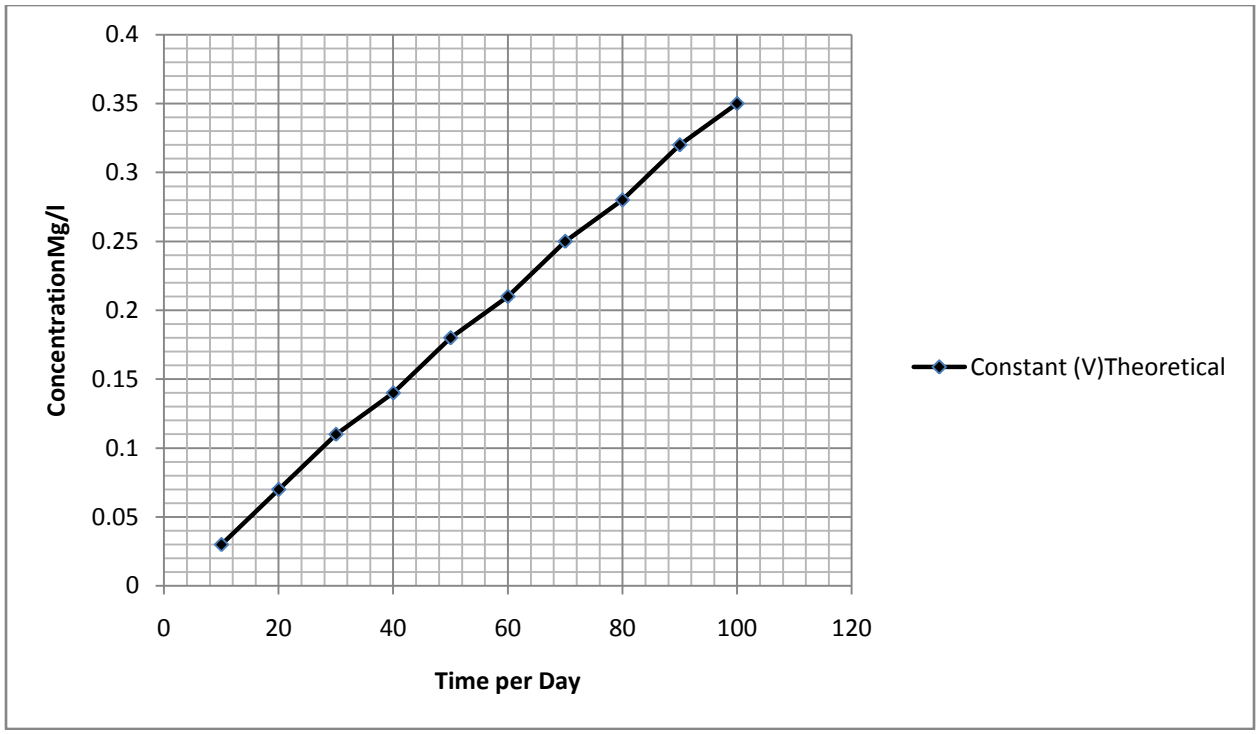

Table 2: Theoretical values of salmonella concentration at various Depths at constant velocity:-

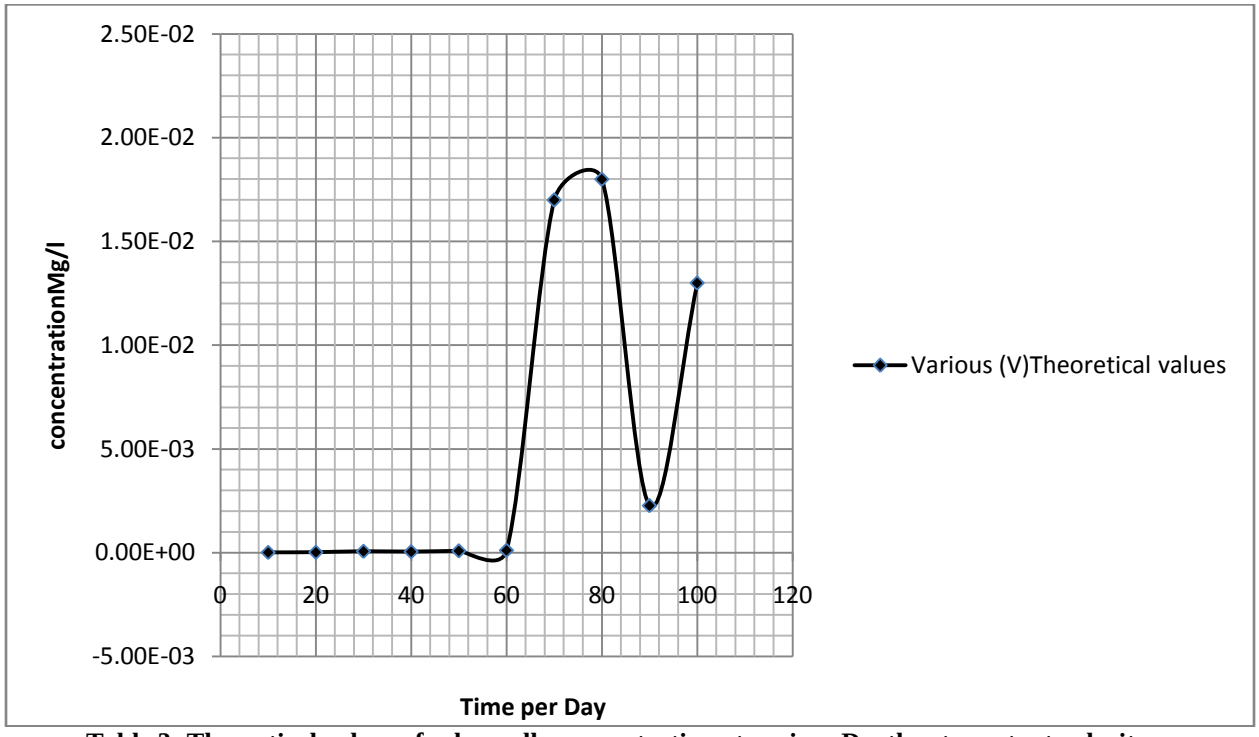

Table 3: Theoretical values of salmonella concentration at various Depths at constant velocity:-

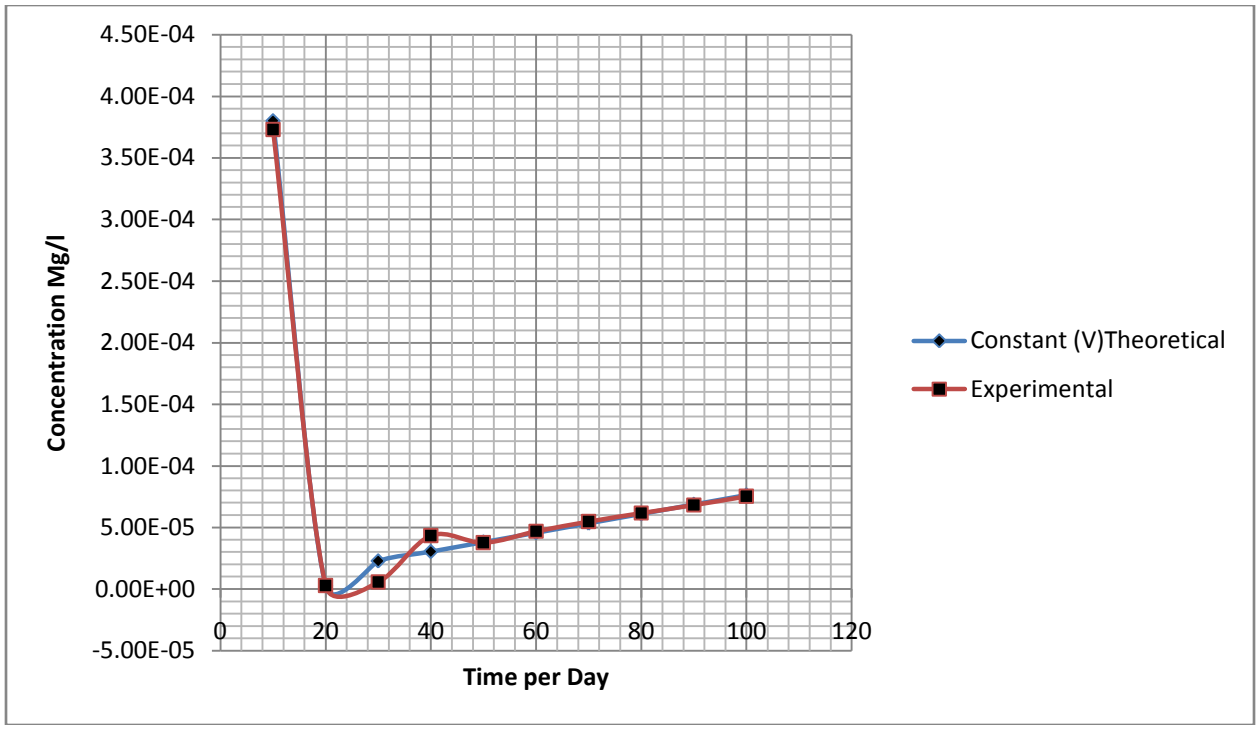

Figure 4 : Comparison of Theoretical and Experimental values of Salmonella concentration at various Depths at constant velocity:-

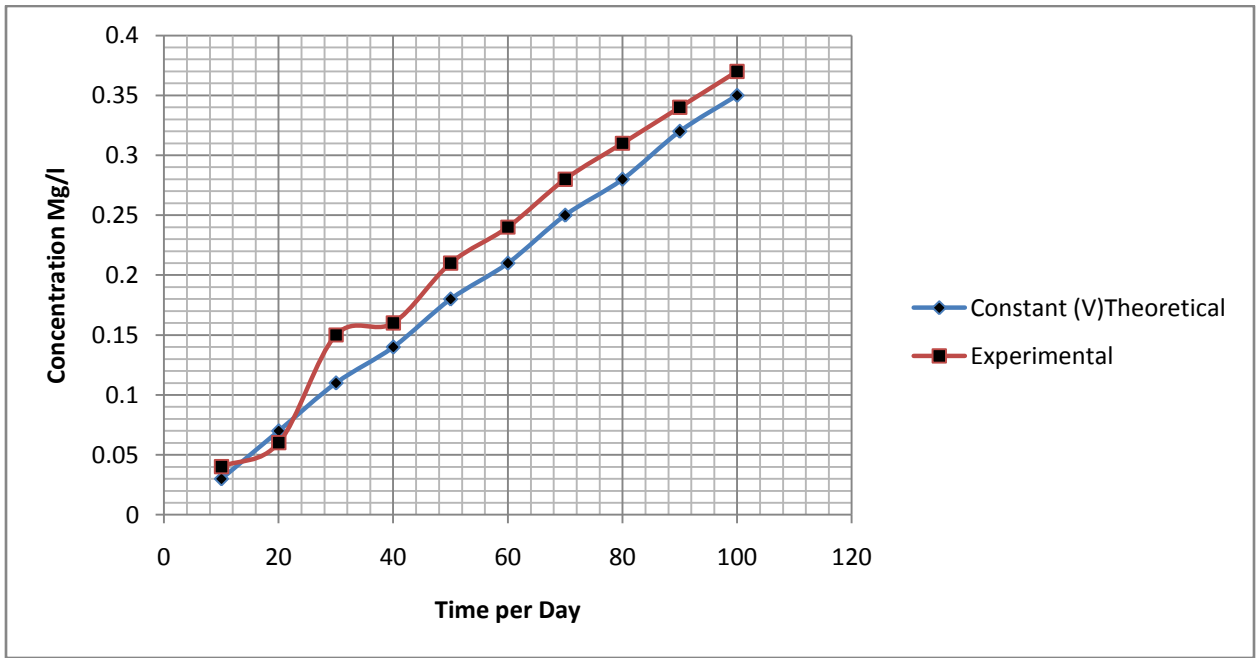

Figure 5 : Comparison of Theoretical and Experimental values of Salmonella concentration at various Depths at constant velocity:-

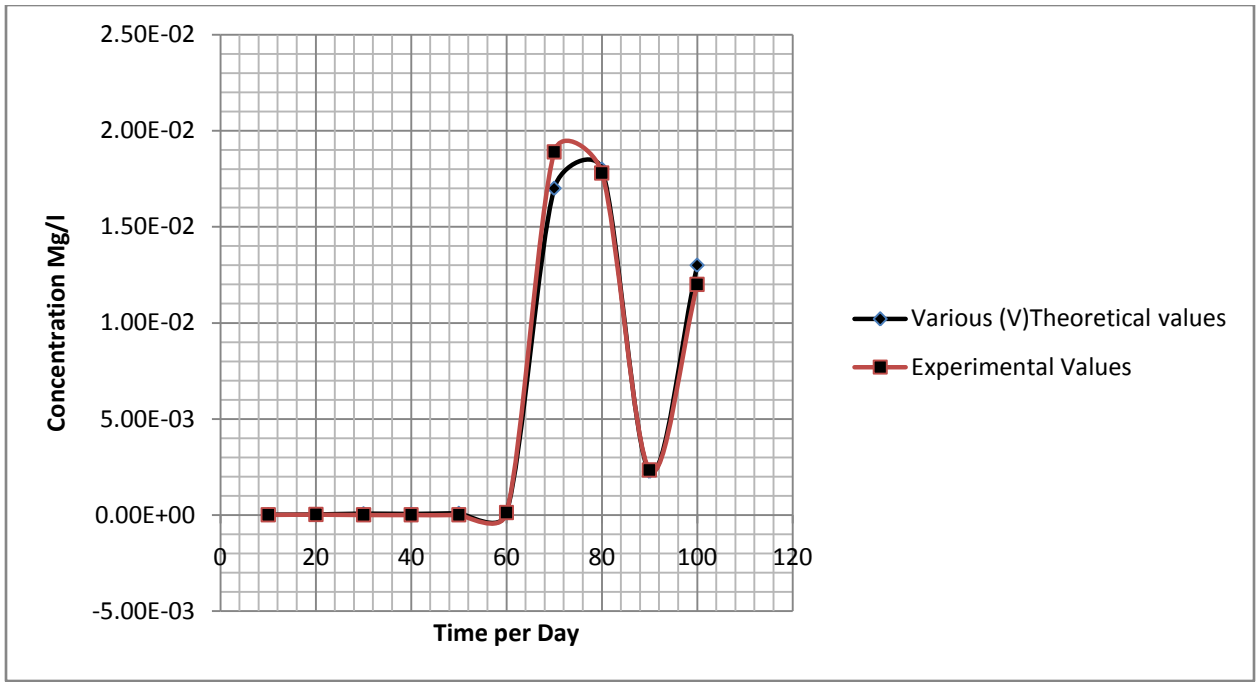

Figure 6: Comparison of Theoretical and Experimental values of Salmonella concentration at various Depths at constant velocity:-

Figure 1 shows that the concentration rapidly increased at ten days, and suddenly decreased from twenty days in a linear condition, but experienced slight increase from thirty days to hundred days, at constant velocity. Figure two where found to experienced gradual increase from ten days to hundred days where the optimum values where recorded. figure three where also found to be different from figure one and two, because the microbes experienced lag phase condition, between eighty and ninety days, gradual decrease where observed between ten to sixty days, sudden increase where also observed between seventy and eighty days, and at ninety days the microbes experienced a gradual decrease and finally experienced slight increase at hindered days. Figure four theoretical and experimental values compared faviourably well as observed. Both parameters experienced the physical process from high concentration to low concentration between ten to hundred days respectively, slight increase where also observed, the level of fitness between the theoretical and experimental values expressed the model validation. Figure five experienced a continuous increase between the theoretical and experimental values, this condition assess the model verification base on the compared parameters. Figure six where found to experience lag phase at some certain period, the theoretical and experimental values were in a good fitness as compared, the optimum values were recorded between seventy and eighty days, fluctuation between eighty and hindered days where obtained. The sixth figure were at constant and also at various velocity of transport, it has shows the level of microbial behaviour at different period in the system, there influence are from the deposition of the stratum in coastal area of Buguma , it has a lots of influence where the concentration of salmonella experienced rapid increase at different period, theses condition are base on the influence from the soil matrix, the influence of microbial transport in coastal environment where found to develop a lots of influence from environmental factors, as observed in silty stratum formation developing brackish aquiferious zone. The level of tidal effect in such coastal environment generate salinity influence where brackish aquifer is deposited, this condition may have cause short fresh water in the costal environment.

Concussion:-

Mathematical modeling where developed to monitor the behaviour of salmonella transport in homogeneous silty formation, this study where carried out in the coastal area of Buguma. Such deltaic environments are predominant with salinity in surface and ground water, the developed model where to determine the behaviour of the microbes at different period. Both at constant and various velocity of transport. Experimental values from column experiment where thoroughly carried out, and the values where compared with the theoretical values, both parameters developed a fitness expressing the model validation. The behaviour of the microbes at different period express there the rates of

transport at various formations of the soil, the values of both parameters experienced fluctuation and linear increase and decrease at constant velocity at different period, as presented in the figures. Gradual degradation of the microbes where also observed, this condition are base on the influence of the geological characteristics in coastal environment, influenced by deltaic formation. The study shows that the fresh water aquifers are shallow depth, this condition are cause by the stated influence by developing short fresh water aquifer in the study area.

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