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RESEARCH ARTICLE

MATHEMATICAL MODEL TO EVALUATE THE DECAY PHASE BEHAVIOUR OF E.coli IN A SHALLOW AQUIFER AT ABUA-ODUA IN RIVERS STATE, NIGER DELTA OF NIGERIA

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ABSTRACT

This paper explains the behaviour of *E.coli* on decay phase condition in Abua-Odua in Niger Delta of Rivers State; the model shows the variation of degradation of *E.coli* in shallow aquifer. Furthermore, it is confirmed that the decay phase condition of *E.coli* migration on stratum deposition in groundwater aquifers, does not completely free it from solute, due to other influences that may cause regeneration of the microbes, increasing the level of concentration and degrade the quality of ground water. The study also explains the rate of concentration with respect to distance and duration within hundred days and thirty metres respectively. Finally, the model and the experimental results compared fits to the condition of decay phase; this implies that the model developed will be a benchmark in solving groundwater pollution transport of *E.coli* in decay phase condition in the study location.

INTRODUCTION

Microbes generate a lot of variation in behaviour depending on their types, decay level condition may also vary, and the dynamics in their types definitely affect their system of migration, regeneration and population including the duration of their death rate. The issue of E.coli in their behaviour on migration, growth rate and death rate with respect to duration are determined by the behaviour in transport of *E.coli* from one aquifer to the other. The level of migration and death rate are influenced by some depositions on the ground, its transportation has contaminated groundwater aquifers and generated lots of water related diseases, this has generate a lot of death rates in the study area (Abua - Odua) in Rivers State. In the Niger Delta Environment, this diseases called *E.coli* is of serious concern in the study location, the geological formation generated some variations in deposition, while the influence in the soil stratum influenced the decay level phase of *E.coli,* because the death rate variation compared to some other areas are based on the geological deposition and other influences, that may have caused variation in the behaviour of death rate of *E.coli* from other locations in the study area. The deposition of *E.coli* decay phase condition varies from one aquifer deposition to the other in Abua-Odua which is influenced by soil characteristic properties, including other depositions that generate the variation of decay growth rate.

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The result from the variation is that it has caused difficulties in groundwater quality in the study area, because it is a shallow aquiferious deposition. The decay in the process of E.coli transport may not degrade in a region, where it can generate self purification process, it will increase the concentration of other depositions that are not supposed to be harmful, and the reaction will make the other minerals to be toxic and contaminate groundwater quality.

The study area generated this problem of quality water from any solute, because *E.coli* reaction with other minerals and its concentration of the mineral become higher. This is a serious matter in the study location; this ugly situation makes it imperative for a serious study to generate a better solution that will tackle the problem of the variation of decay that is causing the increase in concentration of other deposited minerals that were not supposed to be toxic to groundwater quality. The reaction on *E.coli* does not degrade at the region where it will be harmless and this result to high concentration of solute. The study expresses the causes of variation in decay phase in *E.coli* transport in pheratic aquifer as these conditions degrade the quality of groundwater. Shallow aquifers experience these problems of microbe's migration as a living organism, their transport process generated these problems because of their regeneration at any region they found themselves faviourable. Especially when they see microelement deposited in that region, they increase in microbial population; therefore the decay phase level in those

regions will be slow in death rate. Moreover, where they integrate themselves with other minerals deposition and generate more toxicity to groundwater aquifers. Other microbes in the microbial world may have some behaviors in their transport contamination.

Pathogen pollution of surface waters is one of the most important environmental problems faced by society. The U.S. EPA (2004) estimates that about 13% of streams and 17% of estuaries are impaired by pathogens. In 2006, 32% of beaches had at least one advisory due to the presence of pathogen indicators (U.S. EPA 2007). Pathogens and their indicators enter surface waters from a number of sources, including sanitary, storm and combined sewer discharges, direct runoff, and others (e.g., birds, boats). After discharge the density generally decreases due to a number of processes (Thomann and Mueller 1987; Chapra 1997; Boehm *et al.,* 2005; Liu *et al., 2006*), including dilution, dispersion, settling, predation, and decay (also called die-off).

However, densities can also increase due to growth in soil or sediments (e.g. Solo- Gabriele *et al.,* 2000). Decay varies depending on the type of pathogen or indicator and numerous environmental factors, including temperature, salinity, solar irradiance, and various water chemistry parameters. Quantitatively estimating the density decrease is important, because it controls the assimilative capacity of the receiving water, a critical component of a total maximum daily load analysis. This technical note is concerned primarily with the decay process, which first has to be defined. Fecal bacteria are traditionally enumerated by culturing, which strictly speaking does not measure "alive" but "culturable" cells. There is a difference, because many bacteria, including *E. coli*, can exist in a "viable but not culturable" (VBNC) or dormant state (Smith et al. 1994; Winfield and Groisman 2003). So quantifying density as culturable can be misleading, especially in the context of "die-off" or "decay. Also, because VBNC cells can be infective (Colwell *et al.,* 1996) this may not be the most relevant measure from a public health risk perspective. However, it is consistent with past decay studies and current monitoring practices. Therefore, alive is defined here as culturable and decay is defined as loss of culturability. The decay process is typically modeled using a first-order kinetic model, originally proposed by Chick (1908, 1910), with the rate constant a function of environmental variables (Thomann and Mueller 1987; Chapra 1997). However, numerous studies, as reviewed in the following paragraph, have found a biphasic pattern, consisting of a first period with relatively high apparent first-order rate constant and a second period with a lower constant.

Frost and Streeter (1924) analyzed field data from the Ohio River during summer and winter conditions and concluded that decay of fecal bacteria, including *E. coli*, was biphasic (Phelps 1944; Velz 1970). Orlob (1956) reviewed data from 13 experiments on the decay of *E. coli*, coliforms, and *E. typhosa under* various temperatures and experimental conditions in sea-water, about half of which exhibited a biphasic pattern. (Geldreich and Kenner 1969 Hellweger 2009) performed laboratory decay experiments infiltered storm water at two temperatures. The bacteria studied included *Streptococcus faecalis Streptococcus faecalis var. liquifaciens,Streptococcus bovis, Aerobacter aerogenes,* fecal coliform (FC), and *Salmonella typhimurium*. All of the bacteria showed a biphasic pattern in at least one of the two experiments Dutka and Kwan (1980) studied decay of *E. coli, Streptococcus faecalis* and *Salmonella thompson* using in situ membrane diffusion chambers. All riments exhibited a clear biphasic pattern. Fujioka *et al.* (1981) studied the decay of FC and fecal streptococci (FS) in river water, seawater, and phosphate buffer in dark and sunlight conditions. Decay of FC and FS in dark seawater and FC in sunlit river water was biphasic, but the other experiments did not exhibit this pattern. Smith *et al.* (1994) studied decay of *E. coli, Enterococcus faecalis, Salmonella typhimurium,* and *Yersinia enterocolitica* in diffusion chambers exposed to seawater. Culturable cells were quantified using plate counts on two different media. *E. coli* did not show a biphasic pattern, but data from at least one of the two enumeration methods showed a biphasic pattern for the other bacteria. Munro *et al.* (1995) studied the decay of *E. coli* and *Salmonella typhimurium* in filtered sterilized seawater (Hellweger 2009).

Experiments were conducted with wild type and mutants related to stress resistance from cultures at various growth conditions exponential, stationary. Several of their experiments exhibited a biphasic pattern. Bogosian et al. (1996) studied the decay of *E. coli* in sterile and nonsterile river water and sterile seawater at different temperatures. Culturable cells were quantified using plate counts and most probable number methods. All experiments showed a biphasic pattern. Medema *et al.* (1997) studied decay of *E. coli*, fecal enterococci, and *Clostridium perfingens* in sterilized and natural river water at two different temperatures. Two experiments, *E. coli* and *C. perfingens* at 15°C in natural river water, exhibited a biphasic pattern. Easton *et al.* (2005), (Hellweger, 2009) followed the densities of total coliforms, *E. coli*, and enterococci from raw sanitary sewage and pure strain *E. coli* 0157:H7 in laboratory diffusion chambers immersed in river water at two temperatures. All experiments showed a biphasic pattern. These studies demonstrate that biphasic decay is a common phenomenon. However, it is not always observed. Several of the above-referenced studies did not show an obvious biphasic pattern in all experiments. There are also numerous decay studies where a biphasic pattern is not obvious in any of the experiments e.g. Xu *et al.* 1982; Rhodes and Kator 1988 several mechanisms may be responsible for the biphasic decay pattern. There could be two subpopulations with different resistances to decay (Frost and Streeter 1924). This could simply be due to the presence of different strains. Also, as mutant populations of *E. coli* can emerge in a matter of days in stationary phase (Zambrano *et al.*, 1993; Finkel 2006), the resistant fraction could be due to recent mutation.

Another possibility is nongenetic cell differentiation. For death by antibiotics, the presence of a small fraction of "persistor" cells leads to a biphasic decay pattern (Balaban *et al.,* 2004; Lewis 2007). The growth condition (e.g., exponential versus stationary phase can have a significant effect on the decay rate) (Gauthier and Hellweger, 2009) E.coli also generate from other source where their behaviour of transport may also varies just like the *Escherichia coli* (*E. coli*) isolates in water samples from site 3. Cattle, horses, and humans were the most common presumptive source of *E. coli* isolates at sites further upstream. Poultry was identified by rep-PCR as a major source of *E. coli* in Pogue Creek, a

tributary in the upper part of the study area. Results of the rep-PCR were in general agreement with the detection and distribution of trace concentrations of organic compounds commonly associated with human wastewater, such as caffeine, the antimicrobial agent triclosan, and the pharmaceutical compounds acetaminophen and thiabendazole (a common cattle anthelmintic). (John 2002).

MATERIALS AND METHOD

Sample Collection

The method of sample collection was insitu method of sample collection from a point source discharge into a drain at. Abua-Odua in Rivers State from Niger Delta Environment

COLUMN EXPERIMENTS Column experiments were performed to monitor the level of transport of *E. coli* at different deposit of soil formation.

Experiment Set up

The column was set up; the height is 1 metre of 10mm diameter steel pipe, positioned at vertical level, including a funnel of 30cm that contains 4 litres of waste water. Each sample level of average of 2000mg/l of waste water containing *E. coli* was poured inside the column. While the flow was passing through the column, a stop watch was used to monitor the speed level, to determine the level of transport of each sample of aquifer materials. The effluent 1000mg/l from the column were collected and subjected to thorough analysis to determine the level of transport of *E. coli* in each of the aquifer material, which determines the level of transport to aquiferious zone

3 developed models for decay phase condition

C = Concentration [ML^{-3}]
V = Velocity [LT^{-1}]
D_A = Dispersion coefficient dimension less
T = Time [T]
X = Distance L

$$\frac{-V}{t}\left[C_{(x)} - \frac{x\partial c(x)}{\partial x}\right] - V^2 D_{A_2}\frac{\partial c(x)}{\partial x} = \frac{V\partial c(x)}{\partial t} \quad \ldots. \quad (1)$$

If $\frac{\partial c(x)}{\partial x} + \frac{V\partial c(x)}{\partial t}$ and ..... (2)

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

$$\frac{V\partial c(x)}{\partial t} + V^2 D_{A_2}\frac{\partial c(x)}{\partial x} = \beta \quad \ldots\ldots\ldots \quad (4)$$

Such that

$$\frac{V\partial c(x)}{\partial t} = V^2 D_{A_2}\frac{\partial c(x)}{\partial x} - \beta \quad \ldots\ldots\ldots\ldots \quad (5)$$

By transformation of Equation (4.185) we have

$$C_{(x)} = TX$$

It implies that $\frac{\partial c(x)}{\partial x} = T^1 X$ ..... (6)

This can be obtained by separation of variables

$$\frac{\partial c(x)}{\partial x} = TX^1 \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

Substituting in equation (4.185) we have

$$VT^1 X - V^2 D_{A_2} TX^1 - \frac{V}{t}TX\,XTX^1 \quad \ldots\ldots\ldots \quad (8)$$

Expanding further we get

$$VT^1 X = V^2 D_{A_2}\frac{TX^1}{TX} - \frac{V}{t}TX - XTX^1 \quad \ldots\ldots\ldots \quad (9)$$

Dividing equation (4.187) by *TX* we have

$$\frac{VT^1 X}{TX} = V^2 D_{A_2}\frac{TX^1}{TX} - \frac{V}{t}\frac{TX}{TX}X\frac{TX^1}{TX} \quad \ldots\ldots\ldots \quad (10)$$

This implies that

$$\frac{VT^1}{T} - V^2 D_{A_2}\frac{X^1}{X} - \frac{V}{t}\frac{X^1}{X} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

If $\frac{V\partial c(x)}{\partial t} = \lambda^2$

We have

$$\frac{VT^1}{T} = V^2 D_{A_2}\frac{X^1}{X} - \frac{V}{t}\frac{X^1}{X} = \lambda^2 \ldots\ldots\ldots\ldots \quad (12)$$

Solving term by term

$$\frac{VT^1}{T} = \lambda^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

$$VT^1 = \lambda^2 T \quad \ldots\ldots\ldots\ldots\ldots \quad (14)$$

Let $T_{(o)} = 0$

$$V\left(ST_{(s)} - T_{(o)}\right) - \lambda^2 T_{(s)} = 0 \quad (15)$$

Considering the boundary condition we have

$$T_{(o)} = Cz_1 \quad \ldots\ldots\ldots\ldots\ldots \quad (16)$$

Where Cz_1 is the initial concentration

$$V(ST_{(s)} - VCz_1) - \lambda^2 T_{(s)} = 0 \quad \ldots\ldots\ldots \quad (17)$$

$$VS\,T_{(s)} - VCz_1 - \lambda^2 T_{(s)} = 0 \quad \ldots\ldots\ldots \quad (18)$$

$$VS\,T_{(s)} - \lambda^2 T_{(s)} = VCz_1 \quad \ldots\ldots\ldots \quad (19)$$

Then $T_{(s)} = \frac{VCz_1}{VCz_1 - \lambda^2}$ ..... (20)

$$VS - \lambda^2 = 0$$

$$VS = \lambda^2 \quad \ldots\ldots\ldots\ldots\ldots \quad (21)$$

$$S = \frac{\lambda^2}{V} \quad \ldots\ldots\ldots\ldots \quad (22)$$

$$\boxed{TS = VCz_1\,\ell^{\lambda^2/V^t}} \quad \ldots\ldots\ldots \quad (23)$$

$$V^2 D_{A_2}\frac{X^1}{X} = \lambda^2 \quad \ldots\ldots \quad (24)$$

$$Xt = V^2 D_{A_2}\,Cz_2\,\ell^{\frac{\lambda^2}{V^2 D_{A2}}t} \quad \ldots\ldots\ldots \quad (25)$$

$$V^2 D_{A_2}\frac{v}{t} - \frac{X^1}{X} = \lambda^2 \quad \ldots\ldots\ldots \quad (26)$$

$$SV_{(s)} = V_{(o)} = \lambda^2 \quad \ldots\ldots\ldots\ldots \quad (27)$$

Integrating the initial concentration for which

$$V_{(o)} = Cz_3$$

$$SVs = Cz_3 = \lambda^2$$

Multiplying *Vs* the subject relations gives

$$Vs = \frac{\lambda^2 + Cz_3}{S} \quad \ldots\ldots\ldots \quad (28)$$

Using Laplace universe we obtain

$$Vt = \lambda^2 + Cz_3 \quad \ldots\ldots\ldots \quad (29)$$

$$\lambda^2 + \frac{Vt}{Cz_3} \quad \ldots\ldots\ldots \quad (30)$$

If $\frac{VT^1}{T} = -V^2 D_{A2} \frac{X^1}{X} = \frac{-V}{t} \frac{X^1}{X} = \lambda^2$ (31)

If we let $C_{(x)} = TX$ we have

$$\frac{VT^1}{T} = V^2 D_{A2} \frac{X^1}{X} - \frac{V}{t} \frac{X^1}{X} \quad (32)$$

Integrating the both sides gives

$$VC_1 \ell^{\frac{\lambda^2}{V}t} = V^2 D_{A2} Cz_2 = \ell^{\frac{\lambda^2}{V^2 D_{A2}}t} \quad (33)$$

$$C_{(x)} = VC_{Z_1} \ell^{\frac{\lambda^2}{V}t} = V^2 D_{A2} Cz_2 \ell^{\frac{\lambda^2}{V^2 D_{A2}}t} \quad (34)$$

But if $\lambda^2 = \frac{Vt}{Cz_3}$

We get

$$C_{(x)} = VC_{Z_1} \ell^{\frac{\lambda^2}{Cz_3}t} = V^2 D_{A2} Cz_2 \ell^{\frac{vt}{CZ_3}t} \quad 35)$$

$$C_{(x)} = T_{(x)} = T_{(x)} \; X_{(t)}$$

$$C_{(x)} \left(VC_{Z1} \ell^{\frac{\lambda^2 t}{V}} \right) \left(V^2 D_{A2} \; Caz_2 \ell^{\frac{\lambda^2 t}{V^2 D_{A2}}} \right) \quad (36)$$

Given the constraint below

Since $t = 0 \; x = 0 \; C_{(x)} = C_m$ (37)

We have $C_m = C_{Z_1} C_{Z_2}$

Such that $= C_{Z_1} = \frac{C_m}{C_{Z_2}} \quad \ldots \quad (38)$

Integrating through we have

$$C_{(x)} \left(\frac{VC_m}{Cz_2} \ell^{\frac{Vt^2}{Cz_3}} \right) \left(V^2 D_{A_2} C_{z_2} \ell^{\frac{Vt^4}{Cz_3}} \right) \quad (39)$$

By indices, it simplifies it as

$$C_{(x)} = V^3 V^2 D_{A_2} C_m \ell^{\frac{\lambda^2 t}{V} + \frac{\lambda^2 t}{V^2 D_A}} \quad \ldots \quad (40)$$

But if $V = \frac{\partial}{t}$ we have

$$C_{(x)_t} = \frac{d^3}{t^3} V^2 D_{A_2} C_m \ell^{\left(\frac{\frac{\lambda^2 t}{d}}{t} + \frac{\frac{\lambda^2 t}{V^2 D_A d^3}}{t^3} \right)} \quad \ldots\ldots \quad (41)$$

$$C_{x_d} = \frac{d^3}{t^3} V^2 D_{A_2} C_m \ell^{\left(\frac{\frac{\lambda^2 t}{d}}{t} + \frac{\frac{\lambda^2 t}{V^2 D_A d^3}}{t^3} \right)} \quad \ldots\ldots\ldots \quad (42)$$

Or

$$C_{(x)} = \frac{d^3}{t^3} V^2 D_{A_2} C_m \ell^{\left(\frac{\lambda^2 t^2}{d} + \frac{\lambda^2 t^3}{V^2 D_{A_2}} d \right)} \quad \ldots\ldots \quad (43)$$

RESULTS AND DISCUSSION

From the figure presented the concentration of *E.coli* migrates in an oscillation form, to a point where an optimum value was recorded at hundred days, this explains the decay phase condition from the developed model considering the behaviour of *E.coli* in the system, this implies that the death rate including the degradation of *E.coli* and its with respect to its duration and distance varies it does not take place at the same time or the same distance, because the microbial population in some region are high due to deposition of micronutrients which they feed from and regenerate. That is why in some area the microbes cannot die entirely, the best fit line equation is displayed on the graph.

Table 1. Concentration at various Distances

Distance	Decay Level Constant Velocity initial conc.
3	9.60E-09
6	3.99E-08
9	3.37E-08
12	1.82E-07
15	3.26E-06
18	2.60E-07
21	4.70E-07
24	9.60E-07
27	5.14E-06
30	9.60E-06

Table 2. Concentration at various Times

Time Per DAY	Decay Level Constant Velocity initial conc.
10	9.60E-09
20	3.99E-08
30	3.37E-08
40	1.82E-07
50	3.26E-06
60	2.60E-07
70	4.70E-07
80	9.60E-07
90	5.14E-06
100	9.60E-06

From the figure it shows that concentration increase in fluctuation form to a point where an optimum value where obtained at thirty metres, this condition can be attributed to the behaviour of the microbes, with respect to the condition of decay phase, the influence from other minerals including the stratum deposition in some instance cause the degradation of *E.coli* variation in death rate, because the influence from other deposition on the soil will not allow the microbes to die entirely, so the remnant migrate and on the process regenerate

Table 3. Comparison of theoretical value and experimental result versus Distance

Distance	Exp Result Conc. M/L	Theoretical model initial Result Conc. M/L(CV/DY/a
3	0.000000955	9.60E-09
6	0.000000396	3.99E-08
9	0.000000334	3.37E-08
12	0.000000178	1.82E-07
15	0.00000321	3.26E-06
18	0.000000245	2.60E-07
21	0.000000465	4.70E-07
24	0.000000887	9.60E-07
27	0.0000059	5.14E-06
30	0.0000079	9.60E-06

Table 4. Comparison of theoretical value and experimental result versus Time

Time	Exp Result Conc. M/L	Theoretical model initial conc. Result Conc./L(CV/DY/a
10	0.000000955	9.60E-09
20	0.000000396	3.99E-08
30	0.000000334	3.37E-08
40	0.000000178	1.82E-07
50	0.00000321	3.26E-06
60	0.000000245	2.60E-07
70	0.000000465	4.70E-07
80	0.000000887	9.60E-07
90	0.0000059	5.14E-06
100	0.0000079	9.60E-06

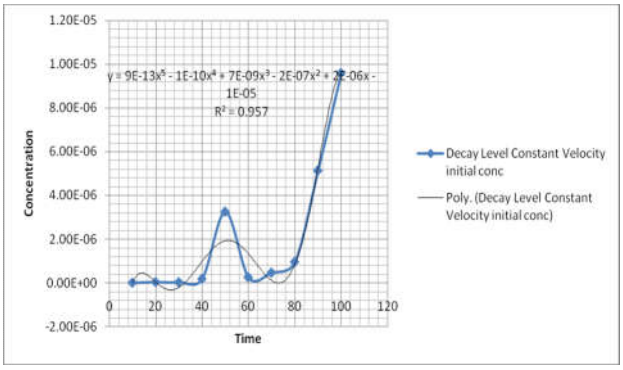

Fig. 1: Concentration of E. coli various duration

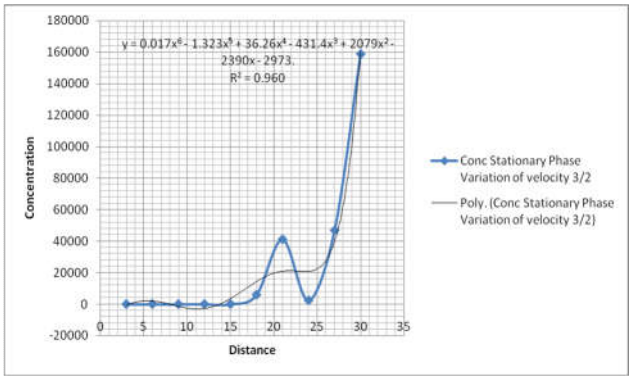

Fig. 2: Concentration of E. coli various Distance

as a result of deposition of micronutrient, which is substrate utilization to the microbes, therefore this condition may increase the toxicity of groundwater aquifers as the regeneration of this microbes may be at the aquiferious zone, it will definitely increase the level of contaminants, this shows that decay phase condition of *E.coli* transport Will not completely degrade, where it can generate self purification process in the stratum deposition in those aquiferious zone, as it for seen in the graph in all the study locations, Were the concentration is high at thirty metres, the study from this dimension explained that groundwater aquifers are not entirely free from solute, when the microbes are in decay phase condition. The figure explain that the concentration of the theoretical value result displayed in vacillation form, where it obtained its optimum value at thirty metres, while that of experimental result maintained the same form of concentration and also obtained its optimum value at thirty metres, but that of the theoretical value is higher than experimental result, the comparative analysis of both value result fits, showing that the model has explain the behaviour of E.coli in decay level condition, the variation of the degradation of the microbes in decay level condition can also be attributed to environmental factors from manmade activities or natural origin. The best fit line equations are displayed on the graph.

The figure presented shows that the concentration of theoretical value migrate in an instability form to a point where it obtained its optimum value at hundred days, while that of the experimental value produce the same form of concentration and also obtained its optimum value at the same time of hundred days, the model from every point of indication fit in with the experimental result as for seen from the figure presented, this also explain the variation of the death rate under decay phase condition with respect to duration of hundred days as presented in the graph, the regeneration of the microbes base influence the variation of the degradation of the microbes with respect to time base on other deposition in the groundwater aquifers. The best fit line equations are displayed on the graph.

Conclusions

The decay level condition from the model developed have explain the behaviour of *E.coli* on its level of degradation including the variation of its death rate with respect to time and distance, in the issue of time it has explained from the graph that the degradation of the microbes does not have a constant time the same to distance , the degradation may take place at any distance , this implies that if the microbes did not degrade in a certain stratum where it can reduce its concentration to be harmless to groundwater aquifer , it means that it will increase its concentration to extend increase its microbial population, therefore the condition of decay phase does not completely ascertain the quality of groundwater aquifers.

The experimental result produced shows the physical behaviour of the system in terms of degradation of the microbes in the system, the comparison of both parameters shows that the model developed with all the consideration fit to the system, therefore the model for decay level condition will be a bench mark for the solution of groundwater pollution in that study location

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