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Research article

MODELING THE MIGRATION OF ENTEROMOBACTER IN ALLUVIUM SILTY AND COARSE SAND FORMATION IN ISIOKPO RIVERS STATE OF NIGERIA

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Abstract

Modeling of enteromobacter transport process has been expressed by different researchers on a particular formation on the application batch system. Their results can only be determined with the behavior of the microbes at a particular soil formation. Previous studies have not provided a platform to monitor the behavior of the enteromobacter sequentially from made/organic soil to the formation where aquiferous zones are deposited. The behavior of the enteromobacter at a particular formation cannot give an explicit result on enteromobacter behavior, but this study developed a mathematical expression that will monitor the transport of enteromobacter in alluvium soil and water environment. This expression from previous studies cannot solve or monitor the behavior of the microbes determined by formation characteristics; this is to can solve the problem of preventing enteromobacter transport to groundwater aquifers. The deltaic nature of the study area are influenced by several formation characteristics, where porosity play a role that influence the enteromobacter behavior at different stratum, The influence of the deltaic nature of the soil is a subject of concern. The model expression will definitely monitor the enteromobacter behavior sequentially as considered in the system, this will definitely to express various concentrations of the enteromobacter to groundwater aquifers. Finally, the developed model derived will definitely conquer the bacterial transport on designing of water wells in the study location. **Copyright © IJESTR, all rights reserved.**

Keywords: modeling, enteromobacter, alluvium and silty and coarse sand formation

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Introduction

Increasing environmental awareness has resulted in regulatory measures that aim to remedy past mistakes and protect the environment from future contamination and exploitation. These measures intend to preserve the environment and protect human health. Some of the pollutants of concern are chemical from pesticide, were banned when it was discovered that they were hazardous to human health. In our country, about 99 per cent of the pesticides are imported in bulk and in concentrated form (based on 1996 statistic). They are diluted and/or mixed with other chemicals by local manufacturers to obtain the formulation desired for local conditions. Unfortunately, in many cases, these compounds are also persistent in nature. Long after their use has been discontinued, these chemicals remain in soils and sediments where they can enter the food chain directly or percolate down to the water table. Once in the groundwater, these pollutants can enter drinking water wells and cause health problems indirect accumulation in higher trophic level organisms, such as mammals, may cause health problems over time because of the increasing levels of toxic compounds within the body. A degree of persistence is often desired in chemicals such as pesticides. If microorganisms degraded them as soon as they were applied, then they would not serve their desired function. There are two main reasons that these compounds persist in nature. First, the conditions necessary for their biodegradation are not present. The microorganisms that are capable of biodegrading these toxic compounds may be absent at the contaminated site (Adawiah, 2008).

Soil passage is frequently used as pretreatment in production of drinking water in several water suppliers. It is an intensive filtration process with long contact times and an effective barrier for pathogenic micro-organisms such as viruses, bacteria, and protozoa. How effective it is, however, is not known and is a question of growing interest since the introduction of quantitative microbial risk assessment for drinking water safety (Haas *et al*., 1999). In 1980 a minimum water travel time of 60 days as a protection zone around groundwater abstraction wells was formalized in The Netherlands (Anonymous, 1980). This travel time was assumed to cause sufficient die off of pathogenic bacteria from contamination sources (Knorr, 1937). In the past decades, however, viruses, and more recently protozoa like *Cryptosporidium* and *Giardia*, have been recognized as pathogens of major concern in the water industry (Craun *et al*., 1997; MacKenzie *et al*., 1994; Gerba *et al*., 1990). These organisms have been related to waterborne diseases because of their persistence in the environment, resistance to water treatment, and high infectivity. Moreover, it has become clear that die off in groundwater is not the only process that governs the transport of microorganisms. For viruses it was demonstrated that attachment to soil particles was more important than survival in the groundwater (Schijven, 2001). A number of field studies have been carried out that established either removal of indigenous micro-organisms or lab-cultured seeded microorganisms (Schijven *et al*. 1999, 2000, 2001; Van Olphen *et al*., 1993; Medema and Stuyfzand, 2002). These studies showed that soil passage poses a very effective barrier to micro-organisms, but critical situations may arise (Medema and Stuyfzand, 2002). The concentration of pathogens in the field is generally too low to assess removal, and only non hazardous model micro-organisms (*Escherichia coli*, Bacteriophages, and spores of clostridia) can be used in spiking studies (Schijven *et al*., 2000). The importance of attachment and the surface properties of bacteriophages, bacteria, and soil and of water quality parameters has been elucidated by column experiments (Burge and Enkiri, 1978; Sobsey *et al*., 1980; Bales *et al*., 1991; Jin *et al*., 1997; Goldschmid *et al*., 1972; Fletcher and Marshall, 1982; Scholl *et al*., 1990; McCaulou *et al*., 1994). More recently, transport of the oocysts of *Cryptosporidium* in soil columns was studied (Harter *et al*., 2001; Logan *et al*., 2001; Bradford and Bettahar, 2005; Tufenkji *et al*., 2004a), and results indicate the importance of straining on the removal of these larger organisms. The significance of column studies increases when results are related to field conditions of the selected soils and validated by field studies, as described for phage MS2 in dune sand by Schijven (2001).

2. Theoretical background

Modeling the migration of enteromobacter at various strata is a serious contamination difficulty in soil and water environment, enteromobacter pose serious threat to ground water aquifers, the actions of the pollutant are base on the influence deposition from formation characteristics in the transport zone, the developed system at various condition were considered, the behavior of the enteromobacter at different formation characteristics were not left behind, geological history of the study location were expressed, base on these variables, it is very important to sequentially denote all the variables with mathematical symbols ,the condition of the enteromobacter and the geological formation were one of the most important variables that were express in the system, this is to narrate other variable in terms of develop there function in the system, by expressing their connection with other parameters as regard there functions , mathematical equation were find suitable These equation are modified with all the parameters that were measured to monitor the transport of enteromobacter from on formation to another under the application plug flow system. a variety of mathematical method were considered, but the most accepted method that were found to generate a models at various condition are split method techniques, and Bernoulli's method of separation of variables, the application of the concept were found to monitor the transport of enteromobacter at different soil formation to ground water aquifers, since the bacterial are to be influenced by several soil characteristics and environmental condition, the derived mathematical equation considered all these condition before formulation of the equation, the derived mathematical model will be a able to monitor the transport of bacterial at different formation.

NOMENCLATURE

C	=	enteromobacter Concentration (cell/m^3)
S_k	=	enteromobacter concentration on kinetic adsorption (cell/g)
P_b	=	Bulk Density (g/m^2)
K_d	=	Partitioning coefficient of enteromobacter (m^3/g)
θ	=	Porosity (m^3/m^3)
D	=	Longitudinal Dispersion coefficient (m^2/sec)
X	=	Co-ordinate parallel to the flow (m)
V	=	Pore velocity (m/sec)
α	=	First order mass transfer coefficient (sec^{-1})
μ_{sk}	=	First order enteromobacter deposition coefficient (sec^{-1})

The equation expresses the enteromobacter concentration under minding there behavior under the pressure of some measured parameters that may influence the system. The situation are measured to monitor their performance at every phase, the stated nomenclature are the influential variables that express the dynamic behavior of the enteromobacter at any phase on the migration process.

$$\frac{1+fP_bK_d}{\theta}\frac{\partial C}{\partial t}=D\frac{\partial^2 C_1}{\partial x^2}-V\frac{\partial C}{\partial x}-\frac{\alpha P_b}{\theta}\left[(1-f)K_dC-S_k\right] \quad \ldots\ldots\ldots\ldots \quad (1)$$

Applying physical splitting techniques on equation (1) we have

$$D\frac{\partial^2 C_1}{\partial x^2}=D\frac{\partial^2 C_1}{\partial x^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$\left.\begin{aligned} x &= 0 \\ C_{(o)} &= C_o \\ \left.\frac{\partial C_1}{\partial x}\right|_{x=0} &= 0 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (3)$$

$$\frac{1+fP_bK_d}{\theta}\frac{\partial C_2}{\partial t}=V\frac{\partial C_2}{\partial x}-\frac{\alpha P_b}{\theta}1-f\,K_dC-S_k \quad \ldots\ldots\ldots\ldots \quad (4)$$

$$\left.\begin{aligned} C_{(o)} &= 0 \\ \left.\frac{\partial C_2}{\partial t}\right| & t=0,\ B \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (5)$$

$$D\frac{\partial^2 C_3}{\partial x^2}=-V\frac{\partial C_3}{\partial x}-\frac{\alpha P_b}{\theta}1-f\,K_d \quad \ldots\ldots\ldots\ldots \quad (6)$$

$$\left.\begin{aligned} x &= 0 \\ C_{(o)} &= 0 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (7)$$

The technique useful for this study is split the variables base on different condition influenced by the structural stratification of the formations. These expression are denoted with mathematical equation in terms of expressing their connection to each other in the system, these setting are generated through the thoughtful of various functions stated as variables and their role in the system, the parameters are denoted with mathematical symbols, boundary values were expressed to determined there limits, this is base on various variables roles on the transport system to ground water aquifers, and there relationship in the system design to solve the Enterobacter concentration at every phase. The split parameters are derived in accordance with the behavior of the microbes, including the expressed formation variable in soil and water, there behavior are denoted in mathematical expression on the system.

Applying direct integration on (2)

$$\frac{1+fP_bK_d}{\theta}\frac{\partial C}{\partial t} = DC + K_1 \qquad \text{..................................} \qquad (8)$$

Again, integrate equation (8) directly, yields

$$\frac{1+fP_bK_d}{\theta} = DCx + K_1x + K_2 \qquad \text{..................................} \qquad (9)$$

Subject to equation (3), we have

$$\frac{1+fP_bK_d}{\theta}Co = K_2 \qquad \text{..................................} \qquad (10)$$

And subjecting equation (8) to (3)

$$\text{at} \quad \left.\frac{\partial C_1}{\partial t}\right|_{x = 0,\ C_{(o)} = C_o} = 0$$

Yield

$O = DCo \ K_2$

$$\Rightarrow \quad K_1 = -DC_o \qquad \text{..................................} \qquad (11)$$

So that, we put (10) and (11) into (9), we have

$$\frac{1+fP_bK_d}{\theta}C_1 - DC_1x - DCox + \frac{1+fP_bK_d}{\theta}C_o \qquad \text{.............................} \qquad (12)$$

$$\frac{1+fP_bK_d}{\theta}C_1 - DC_1x = \frac{1+fP_bK_d}{\theta}C_o - DCox \qquad \text{.............................} \qquad (13)$$

$$\Rightarrow \quad C_1(1+fP_bK_d - Dx) = Co(1+fP_bK_d - Dx)$$

$$\Rightarrow \quad C_1 = Co \qquad \text{......................................} \qquad (14)$$

Hence equation (14), entails that at any given distance, x, we have constant concentration of the contaminant in the system

$$\frac{1+fP_bK_d}{\theta}\frac{\partial C_2}{\partial t} = V\frac{\partial C_2}{\partial x}\ \frac{\alpha P_b}{\theta}\ 1-f\ K_dC - S_k \qquad \text{.............................} \qquad (4)$$

We approach this system by using the Bernoulli's method of separation of variables

$$C_2 = XT \qquad \text{......................................} \qquad (15)$$

$$\frac{\partial C_2}{\partial t} = XT^1 \qquad \text{......................................} \qquad (16)$$

$$\frac{\partial C_2}{\partial x} = X^1T \qquad \text{......................................} \qquad (17)$$

Put (16) and (17) into (15), so that we have

$$\frac{1+fP_bK_d}{\theta}XT^1 = V\frac{\alpha P_b}{\theta}V\,1-f\,K_dC-S_kX^1T \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

$$\text{i.e. } 1+fP_bK_d\frac{T^1}{T} = V\frac{\alpha P_b}{\theta}V\,1-f\,K_dC-S_k\frac{X^1}{X} = -\lambda^2 \quad \ldots\ldots\ldots\ldots \quad (19)$$

$$\text{Hence } \frac{1+fP_bK_d}{\theta}\frac{T^1}{T}+\lambda^2 = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

That is,

$$\frac{X^1+\lambda^2}{\frac{1+fP_bK_d}{\theta}}x = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

$$1-fK_d\,C-S_k\,T^1+\lambda^2T = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

$$\text{From (21), } X = \frac{A\,Cos\,\lambda}{\frac{1+fP_bK_d}{\theta}}t + \frac{B\,Sin\,\lambda}{\frac{1+fP_bK_d}{\theta}}x \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

And (16) gives

$$T = C\ell^{\frac{-\lambda^2}{Vd\frac{P_b}{\theta}V1-fK_dC-Sk}t} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (24)$$

The express derived model at this phase shows the function of bulk density, partitioning coefficient of the enteromobacter, velocity of transport, enteromobacter concentration on kinetics adsorption including porosity of the soil, and first order mass transfer coefficient and concentration of enteromobacter were expressed in the derived model solution on the phase of the transport system.. Their function on the system details the influence on the transport of the microbes, at various conditions, denoted with various mathematical apparatus, further expression processed to equate it to a constant, the expression details the function of other parameters in the system, the established model expressed the stated phase of the bacterial with respect to time. By substituting (23) and (24) into (15), we get

By substituting (23) and (24) into (15), we get

$$C_2 = \left(\frac{A\,Cos\,\lambda}{\frac{1+fP_bK_d}{\theta}}x + \frac{B\,Sin\,\lambda}{\frac{1+fP_bK_d}{\theta}}x\right)C\ell^{\frac{-\lambda^2}{Vd\frac{P_b}{\theta}V1-fK_dC-Sk}t}$$

……………. (25)

Advancing further on the derived solution, an expressed model were thoroughly detail to accommodate other circumstances that could developed different phase in the system. it is expressed in equation [25], more so, different mathematical appliance were considered in line with the behavior of the enteromobacter, theses conditions were monitor mathematically at different phase of transport in various formation of the soil, velocity of transport were part of the parameter integrated to establish the time of distance travel from one formation to another, under the influence of plug flow applications. the behavior of the soil at different formation were considered as bulk density were included, to determine the bulk of the soil on the transport process of enteromobacter to ground water aquifers, in this context the condition of microbes are expresses with this mathematical symbols as it is derived with further expression in other to develop a model that will account for each conditions, these will express the behavior of the bacterial at different soil formation. expressed equation [25] were emerged with equation 24 to relate with derived model condition of phase two denoted as C_2 under the application of split method techniques, it developed a model that considered the expressed phase that were considered in the system, two model were found to establish a relationship as expressed in equation [25].

Subject equation (25) to conditions in (5), so that we have

$$C_o = AC \qquad \ldots\ldots\ldots\ldots \qquad (26)$$

Therefore, equation (26) become

$$C_2 = C_o \, \ell^{\frac{-\lambda^2}{Vd\frac{P_b}{\theta}V1 - fK_d C - Sk}t} \, Cos \frac{\frac{\lambda}{1 + fP_b K_d}}{\theta} x \qquad \ldots\ldots\ldots\ldots \qquad (27)$$

Again, at

$$\left.\frac{\partial C_2}{\partial t}\right|_{x = 0,\ B} = 0,\ t = 0$$

Equation (27) becomes

$$\frac{\partial C_2}{\partial t} = \frac{\frac{\lambda^2}{1 + fP_b K_d}}{\theta} C_o \, \ell^{\frac{\lambda^2}{Vd\frac{P_b}{\theta}V1 - fK_d C - Sk}t} \, Cos \frac{\frac{Sin\,\lambda}{1 + fP_b K_d}}{\theta} x \qquad \ldots\ldots\ldots \qquad (28)$$

Derived solution at this phase demonstrate descretized functions mathematically through derived equation, when the enteromobacter are on the migration process there may no deposition of substrate in the soil formation, the microbes may be slow or lag in process of migration, this may result to degradation in some region of the soil, the concept definitely considered these conditions which implies that enteromobacter may experienced degradation, if the microbes cannot adapt to the condition of the soil, migration to another soil formation will be the next action during the process of transport, the microbes may reducing it population through death.

$$\frac{\frac{C_o \; \lambda}{1+fP_bK_d}}{\theta} \neq 0 \quad \text{Considering NKP}$$

which is the substrate utilization for microbial growth (population), so that

$$0 = \frac{\frac{-C_o \; \lambda}{\sqrt{1+fP_bK_d}}}{\theta} \quad \frac{\frac{Sin \; \lambda}{\sqrt{1+fP_bK_d}}}{\theta} \; B \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (29)$$

$$\Rightarrow \frac{\frac{C_o \; \lambda}{\sqrt{1+fP_bK_d}}}{\theta} = \frac{n\pi}{2}, \; n = 1,2,3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (30)$$

$$\Rightarrow \lambda = \frac{n\pi\sqrt{1+fP_bK_d}}{\frac{\theta}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (31)$$

So that equation (27) becomes

$$C_2 = C_o \, \ell^{\frac{-n^2\pi^2\frac{P_b}{\theta}1-fK_dC-Sk}{2Vd\frac{P_b}{\theta}1-fK_dC-Sk}t} \; Cos \; \frac{\frac{n\pi\sqrt{1+fP_bK_d}}{\theta}}{\frac{2\sqrt{1+fP_bK_d}}{\theta}}x \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (32)$$

$$\therefore \Rightarrow C_2 = C_o \, \ell^{\frac{-n^2\pi^2\frac{P_b}{\theta}1-fK_dC-Sk}{2Vd\frac{P_b}{\theta}1-fK_dC-Sk}t} \; Cos \; \frac{n\pi}{2}x \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (33)$$

Now, we consider equation (6) which is the steady-flow state of the system

$$\frac{\partial C_3}{\partial x^2} = \frac{V\partial C_3}{\partial x} - d\frac{P_b}{\theta}1-fK_d$$

Applying Bernoulli's method, we have

$$C_3 = XT \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (34)$$

$$\frac{\partial^2 C_3}{\partial x^2} = X^{11}T \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (35$$

$$\frac{\partial C_3}{\partial x} = X^1T \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (36)$$

Put (35) and (36) into (6), so that we have

$$DX^{11}T = Vd\frac{P_b}{\theta}1-fK_dC-Sk\,X^1T \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (37)$$

That is,

$$\frac{DX^{11}}{X} = -Vd\frac{P_b}{\theta}1 - fK_dC - Sk\frac{X^1}{X} = \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (38)$$

$$\frac{DX^{11}}{X} = \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (39)$$

$$-Vd\frac{P_b}{\theta}1 - fK_dC - Sk\frac{X^1}{X} = \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (40)$$

That is $X = A\ell^{\frac{\varphi}{D}x}$ ………………………………… (41)

And

$$T = B\ell^{\frac{-\varphi}{D}t} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (42)$$

Put (41) and (42) into (34), gives

$$C_3 = A\ell^{\frac{\varphi}{Vd\frac{P_b}{\theta}1 - fK_dC - Sk}x} \bullet B\ell^{\frac{-\varphi}{Vd\frac{P_b}{\theta}1 - fK_dC - Sk}x} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (43)$$

$$C_3 = AB\ell^{(t-x)\frac{\varphi}{Vd\frac{P_b}{\theta}1 - fK_dC - Sk}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (44)$$

Subject equation (44) to (7), yield

$$C_3 = (0) = C_o \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (45)$$

So that equation (45), becomes

$$C_3 = C_o\,\ell^{(t-x)\frac{\varphi}{Vd\frac{P_b}{\theta}1 - fK_dC - Sk}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (46)$$

Now assuming that at the steady state flow, there is no NKP for substrate utilization, our concentration here is zero, so that equation (46) become

$$C_3 = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (47)$$

Therefore, solution of the system is of the form

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$$C_3 = C_1 + C_2 + C_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (48)$$

We now substitute (14), (33) and (47) into (48), so that we have the model

$$C = C_o + C_o\,\ell^{\frac{-n^2\pi^2\frac{1+P_bK_d}{\theta}}{2Vd\frac{P_b}{\theta}1 - fK_dC - Sk}t}\; Cos\frac{n\pi}{2}x \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (49)$$

$$C = C_o 1 + \ell^{\frac{-n^2\pi^2 \frac{P_b}{\theta} 1 - fK_d C - Sk}{2Vd \frac{P_b}{\theta} 1 - fK_d C - Sk} t} \; Cos \frac{n\pi}{2} x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (50)$$

Further mathematical expression were establish as other condition of the microbial behavior were integrated according to the formation variation that were considered in developing system, since the bacterial developed, various behavior under the influence of the formation characteristics This include environmental condition that descretize, the expressed equation developed considered this situation. The Bernoulli's method of separation of variables and split method application, they were found to be the correct method that can thoroughly expressed the transport of the bacterial at different condition.

4. Conclusion

Mathematical model to predict the migration of cryptosporidium in homogeneous formation in Obio/Akpor has been developed. Different parameters were considered noted to be the variables that may influence the microbial transport to groundwater aquifer. The variables considered are bacterial concentration, bacterial concentration on kinetic adsorption, bulk density, partition coefficient of bacteria, porosity, longitudinal dispersion coefficient, coordinate parallel to the flow, pore velocity, first order mass transfer coefficient, first order bacterial deposition coefficient. These variables were considered in formulating the mathematical equation denoted by mathematical tools. The model equations were derived applying split techniques and Bernoulli's method of separation of variables. The split method was applied to descretize the function of the parameters to express their functions on the system at different conditions, under the influence of the microbial behavior. The model will definitely monitor the behavior of the bacteria at different formations of the soil.

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