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Research article

MODELING THE TRANSPORT OF PSEUDOMONAS IN HOMOGENEOUS FORMATION IN KHANA, RIVERS STATE OF NIGERIA

Eluozo, S. N.

Subaka Nigeria Limited Port Harcourt Rivers State of Nigeria
Civil and Environmental Engineering consultant, Research and Development
E-mail: Soloeluozo2013@hotmail.com
E-mail: solomoneluozo2000@yahoo.com

Abstract

Modeling the transport of pseudomonas in homogeneous formation in the study area has been expressed. The formulated equations considered the variables that transport the microbes in the system. The study location were confirmed to have experienced a contaminant trace of pseudomonas in groundwater aquifers, based on this facts, it becomes imperative that mathematical model should be developed to monitor the transport of these microbes sequentially form organic soil to groundwater aquifers. The rate of concentration can be attributed to the deltaic nature of the soil which is predominant with high degree of porosity and permeability, these conditions generates high degree of hydraulic conductivity. Such detail investigations were considered as variables that developed the mathematical equations thus resulted to derived model expression. Experts on water resources and environmental engineering will definitely find these derived models useful to monitor the rate of these microbes in homogeneous formation in the study area.

Keywords: modeling transport of pseudomonas and homogeneous formation

1. Introduction

There are many different microbes that may be of concern in source waters or within the distribution system. Developing a monitoring scheme for each would be an impossible task; therefore, another approach is needed. The food and beverage industry has used the “hazard analysis critical control point” (HACCP) approach to determine the key points within the manufacturing chain where contamination can be measured and prevented. A similar concept can be used by water utilities, to prioritize the key contamination points within the treatment and distribution system (Bryan, 1993; Sobsey et al., 1993). This approach allows utilities to focus their resources on monitoring these points and correcting any deviations from acceptable limits. The latest edition of the World Health Organization (WHO)

Guidelines for Drinking-Water Quality (WHO 2004) incorporates such an approach, providing guidance on the development of a water safety plan. The plan is developed using a water safety framework, which combines HACCP principles with water quality management and the multiple barrier concept.

Most strains of bacteria, including actinomycetes, and also fungi produce siderophores under iron limitation conditions. Siderophores are non-porphyrin, nonprotein compounds that bind iron and their synthesis is repressed when this element is abundant [Neilands 1995]. The requirement of bacterial cells is not high and averages about 3 ´ 10-7 M, but the rhizosphere does not contain sufficient free iron (III) ions to allow their survival [Budzikiewicz 1993, 1997]. These chelators, secreted by microorganisms, also play a particularly important role in regulating the amount of assimilable iron in the rhizosphere of plants, by increasing the concentration of available iron in the immediate vicinity of the plant roots. Siderophores secreted by bacteria of the genus *Pseudomonas* are the focus of particularly intense studies. It is thought that the synthesis of siderophores by these bacteria is one of the main factors inhibiting the growth and development of bacterial and fungal pathogens [Leong 1986, Sharma and Johri 2003a, Bano and Musarrat 2004]. Fluorescing strains of this bacterium secrete pyoverdin, which is also known as pseudobactin, a yellow-green pigment that is capable of chelating iron. *Pseudomonas* strains can also secrete other siderophores, the best known of which is pyochelin, a siderophore with lower affinity for iron (III) ions than pyoverdin and probably has no biological activity with regard to plant pathogens. In terms of structure, pyochelins are derivatives of salicylic acid [Cornelis and Matthijs 2002]. Pyoverdins comprise a group of siderophores with similar structure, which contain a cyclic or linear oligopeptide linked to dihydroxychinone chromophore and dicarboxylic acid or amide. Differentiation within this group of compounds involves the peptide component of a siderophore. Pyoverdins differ from other siderophores in exceptionally strong affinity for iron (III) ions and high stability of the complexes formed [Meyer 2000, Bultreys *et al.* 2001, Meyer *et al.* 2002]. The literature indicates that the secretion of siderophores can be regulated by a number of factors, including carbon source in the growth medium and temperature [Duffy and Defago 1999, Djibaoui and Bensoltane 2005]. However, the results of studies carried out so far point to the homogeneity of the mechanisms determining the level of pyoverdin secreted by bacteria belonging to the genus *Pseudomonas*. In the soil, the natural habitat of these bacteria, there are several variable factors that can modify the level of released pyoverdin. For this reason the objective of these studies was to compare the ability of six different strains of *Pseudomonas* bacteria isolated from the rhizosphere of winter wheat to synthesize siderophores under various culture conditions. In recent years growing interest in the agriculture has been observed in non-pathogenic rhizospheric strains of bacteria with properties that would allow their use as biopesticides [Handelsman and Stabb 1996, Raupach and Kloepper 1998]. Biopesticides can be an excellent alternative for the plant protection chemicals, that are both costly and damaging for the environment. The research demonstrates that their efficiency is very high. Particularly useful as the biospecimen are the natural, non-pathogenic rhizospheric microorganisms capable of secondary metabolite synthesis, including the siderophores, which have a favorable influence on the plants. Especially great attention is paid to the *Pseudomonas* strains, which synthesize the pyoverdine, because of its significant biological activity [Nagarajkumar *et al.* 2004].

2. Theoretical background

Soil is designed in a system whereby it will serve as a living filter with potential for self purification through biological process that reduces microbial concentration. From different observations it has been observed that microbes can migrate to significant distance through soil in vertical and horizontal directions. The ability of microbes to transport through soil increasing the probability of water contamination, this implies that the contaminant will definitely increase further if the microbes have the ability to survive for a long period of time. Formation characteristics are one of the influences that determine the microbial transport to a very long distance. The behaviour of the microbes are also influenced by this formation characteristics such as deposited minerals in the soil, these minerals determine the state of the microbial growth either by increase or by inhibition. But for the benefit of this study, it has been confirmed that the soil formation are deltaic in nature whereby it deposits a shallow fresh and homogenous aquifer. This condition expressed the transport system of the microbes in the study location. Based on this detail study on transport behaviour, mathematical equations were formulated that monitor the rate of the microbes on homogeneous formations, depositing and unconfined bed expressed high concentration rate of microbes in shallow aquifers. The study is imperative because the expressed mathematical equation from variables expressed the behaviour of the transport system, this will definitely generate a model that will monitor the migration of pseudomonas in homogeneous formation.

3. Governing Equation

$$\frac{1+fP_bK_d}{\theta}\frac{\partial C}{\partial t} = D\frac{\partial^2 C_1}{\partial x^2} - V\frac{\partial C}{\partial x} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

Nomenclature

C	=	pseudomonas Concentration (cell/m^3)
S_k	=	pseudomonas concentration on kinetic adsorption (cell/g)
P_b	=	Bulk Density (g/m^2)
K_d	=	Partitioning coefficient of bacteria (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 bacterial deposition coefficient (sec^{-1})

Applying physical splitting techniques on equation (1) we have

The equations express the pseudomonas concentration taking into consideration there behaviour under the influence of some considered variables that influence the system. These conditions are measured to monitor there behaviour at every phase, these are stated in the nomenclature, the influence from theses parameters are express through dynamic behaviour of the microbes at any phase on the transport process.

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

$$\left.\begin{array}{l} x = 0 \\ C_{(o)} = C_o \\ \left.\dfrac{\partial C_1}{\partial x}\right| = 0 \\ \qquad x = 0 \end{array}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

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

$$\left.\begin{array}{l} t = 0 \\ x = 0 \\ C_{(o)} = 0 \\ \left.\dfrac{\partial C_2}{\partial t}\right| \quad t = 0,\ B \end{array}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

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

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

The method applied is to split the variable in terns of expressing there relationship to each other in the system, these conditions are developed through the understanding of various functions of all the variables and there role in the system, the variables are denoted with mathematical tools, boundary conditions were expressed, base on various parameter roles on the transport system to ground water aquifers, and there relationship in the system are design to solve the microbial concentration at every phase. The splited parameters are derived in accordance with the behaviour of the microbes, including the expressed formation variable in soil and fluid behaviour as mathematically expressed on the system.

Applying direct integration on (2)

$$\frac{1+fP_bK_d}{\theta}\frac{\partial C}{\partial t} = DC + K_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Again, integrate equation (8) directly, yields

$$\frac{1+fP_bK_d}{\theta} = DCx + K_1x + K_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Subject to equation (3), we have

$$\frac{1+fP_bK_d}{\theta}Co = K_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

And subjecting equation (8) to (3)

$$\text{at } \left.\begin{array}{l} \frac{\partial C_1}{\partial t} = 0 \\ x = 0,\ C_{(o)} = C_o \end{array}\right.$$

Yield

$O = DCo\ K_2$

$$\Rightarrow \quad K_1 = -DC_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

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

$$\frac{1+fP_bK_d}{\theta}C_1 - DC_1x - DCox + \frac{1+fP_bK_d}{\theta}C_o \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

$$\frac{1+fP_bK_d}{\theta}C_1 - DC_1x = \frac{1+fP_bK_d}{\theta}C_o - DCox \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

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

$$\Rightarrow \quad C_1 = Co \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

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

The rate of microbial behaviour determine the degree of migration in soil and water environment, the parameters are considered according to the rate of influence that are found on the transport system, the derived expression on the this transport state considered the boundary values that accommodate the behaviour of the microbes in those condition as expressed in equation 14, formation characteristics were considered in the state of microbial migration from one region to the other, this is under the influence of plug flow application on the transport process in these phase of migration in soil and water environment.

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

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

$$C_2 = XT \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

$$\frac{\partial C_2}{\partial t} = XT^1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

$$\frac{\partial C_2}{\partial x} = X^1 T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

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

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

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

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

That is,

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

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

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

And (16) gives

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

The model expressed concentration of the microbes migrating from one region to the other under the influence of time, but the concentration varies depending on time, this condition are determine on the state of the formation, the condition of this formation implies that the structural strata are base on the geological setting, the migration of the microbes may be mobile or immobile, this influence time of transport based on this condition of migration at different formation, these varies expressed on the model. Soil with different micropoles are with different hydraulic conductivity of fluid, this generate different time as express on the model phase of the studies

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

$$C_2 = \left(\frac{A Cos\lambda}{\frac{1+fP_bK_d}{\theta}}{}^x + \frac{B\,Sin\lambda}{\frac{1+fP_bK_d}{\theta}}{}^x\right) C\ell^{\frac{-\lambda^2}{Vd\frac{P_b}{\theta}V1-fK_dC-Sk}t} \quad \ldots\ldots\ldots\ldots\ldots \quad (25)$$

Expressing the subject relations through the substitution of (24) and (26) into (15), the model expression are correlated to interact with other variables under the influence of exponential conditions of the microbes with respect to time and distance, subject to these conditions determine the microbes on the rate of concentration influenced by the formation characteristics between the soil strata and groundwater aquifers.

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

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

Therefore, equation (26) become

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

Again, at

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

Equation (27) becomes

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

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

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

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

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

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

So that equation (27) becomes

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

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

The model in (33) expresses the transport phase when the microbes deposit substrate in the system, the formation deposit the substrate on the transport process, the deposited substrate become source of energy for the microbe, the rate of substrate deposition determine the rate microbial growth in the system, this condition generate high concentration of microbes, this expressed model handle this condition in this transport phase of the study, but formation characteristics such porosity at different degrees determine the rate of deposition of the contaminant in the system, other variables are expressed in the model stated in equation 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

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

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

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

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

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

That is,

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

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

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

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

And

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

The model examine steady state flow of the concentration, this is expressed on the transport phase of the system as the model is stated in (42),in most condition the contaminant may experience lag phase, this state of microbial behaviour are influenced by the rate permeability of the soil, such condition determine the state of the microbial migration to ground water aquifers, the developed model in this transport phase express the role of the soil formation in the system by considering the state of microbial migration .

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

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

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

Subject equation (44) to (7), yield

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

So that equation (45), becomes

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

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

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

Substrate are known to be the mineral that increase microbial growth rate in there deposition, but on this condition an expression considered when at steady state substrate deposition are not found in the soil, then it implies that there may be less contaminant in those formation, or at those aquiferious zone ground water quality may be abstracted for human utilization, so the expression at equation 47 were found to be zero, this explain that there is no deposition of substrate ,more so if it is at ground water aquifers there is the tendency of quality water at those formation.

Therefore, solution of the system is of the form

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

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

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

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

The final models define the rate at which the transport of pseudomonas in homogeneous formations is expressed. These models were derived in phases considering the behaviours of the microbes influenced by several formation characteristics; these expressed geological settings in the study area. The final model equations are the integrals of all other derived models that expressed several conditions considered on the transport of the microbes in the study location.

4. Conclusion

Modeling the transport of pseudomonas in homogeneous formation has been expressed from the derived mathematical models. Formulated mathematical equations were derived in phases considering different variables that influence the system on the transport process. The study was carried out in Khana Local Government Area of Rivers State considering its geological formation. The variables that influenced the system expressed their functionality in the system, this ascertain the microbial behaviour based on the formation characteristics that made the variables. The derived mathematical equations are splited in phases through the application of split method techniques and separation of variables. These mathematical concepts were appropriate as it expressed several conditions that influenced the behaviour of microbial transport to groundwater aquifer. Finally, the developed models were coupled together to formulate the final derived mathematical model that will monitor the transport of the microbes in homogenous formation.

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