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Research article

MODELING BACTERIOPHAGE TRANSPORT INFLUENCED BY LACUSTRINE DEPOSITION ON PORE DISTRIBUTION STRATATIFICATION IN AHOADA, RIVERS STATE OF NIGERIA

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Abstract

The behaviour of bacteriophage has been expressed in different dimension through several influences that has pressured migration and depositional condition of the microbes in different formations. Heterogeneity was predominantly confirmed in the system as it is expressed in the developed governing equation, this has reflected on different dimensions in the transport system of bacteriophage in regions where there are no inhibitors. The study also considered regions where there are substrates that will definitely increase the microbial population of bacteriophage under the influence of formation characteristics that were predominantly considered in the system. Several models were developed that expressed their functions to monitor the migration and deposition of bacteriophage depending on the region and level of predominant influence in the strata. Variations of formations play major roles at shallow depositions predominant in deltaic formation. The study is imperative because experts will definitely find it favuorable in monitoring and evaluation of bacteriophage under the influence of predominant lacustrine deposition in deltaic formation.

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1. Introduction

In the previous two decades, a number of researches have been done with batch, flowing column, and field experiments on viral performance in the subsurface. Quite a lot of processes may affect viral fate and transport in ground water, irreparable attachment, reversible attachment, and inactivation only irreversible attachment can result in permanent removal of viruses from water. The viral behavior in ground water appears to be controlled by the properties of viruses [4, 12 13, 3], the properties of the porous medium [6, 7, 10, 11], and the properties of water transporting the virus [6, 1, 7, 3]. An incomplete understanding of the processes governing virus fate and transport is achieved if the study does not consider all controlling factors from the three aspects listed. The electrostatic attraction and repulsion, van der Waals forces, and hydrophobic effects are three major forces responsible for interaction between the virus and the porous medium [1,2,9]. In particular, viral attachment was observed to be a function of water pH [1,2], the isoelectric point (pHiep) of the porous medium [6,13], and the isoelectric point of the virus [4,5, 13,14, 3]. In another development in microbial deposition in soil and water environment, Metals play an integral role in the life processes of microorganisms. Some metals, such as calcium, cobalt, chromium, copper, iron, potassium, magnesium, manganese, sodium, nickel and zinc, are essential, serve as micronutrients and are used for redox-processes; to stabilize molecules through electrostatic interactions; as components of various enzymes; and for regulation of osmotic pressure [14]. Many other metals have no biological role (e.g. silver, aluminums, cadmium, gold, lead and mercury), and are nonessential [14] and potentially toxic to microorganisms. Toxicity of nonessential metals occurs through the displacement of essential metals from their native binding sites or through ligand interactions (15, 14]. For example, Hg2+, Cd2+ and Ag2+ tend to bind to SH groups, and thus inhibit the activity of sensitive enzymes [15]. In addition, at high levels, both essential and nonessential metals can damage cell membranes; alter enzyme specificity; disrupt cellular functions; and damage the structure of DNA [16, 15, and 17]. Even though microorganisms have specific uptake systems, high concentrations of nonessential metals may be transported into the cell by a constitutively expressed unspecific system. This “open gate” is the one reason why metal ions are toxic to microorganisms [15]. As a consequence, microorganisms have been forced to develop metal-ion homeostasis factors and metal-resistance determinants 13 15, 14, 16].

2. Theoretical background

Unconsolidated sediments are deposited in different environments such as rivers and deltas by various combinations of physical processes. The sediments are all relatively young and as the name suggests, the material is still looser and groundwater is stored and transmitted through pore spaces, not fractures. They comprise a range of materials, from coarse gravel and sand to silt and clay. At one end of the scale are hundreds of metres or even kilometers thick. At the other end of the scale can be a thin covering of alluvium next to a small river. Major alluvial and coastal basin sediments form some of the most important aquifers in the world, in which very large volumes of groundwater are stored and from which large quantities of water are pumped for water supply and irrigation. Examples include the Lower Indus, Ganges-Brahmaputra, Mekong, Tigris-Euphrates and Nile valleys. Aquifers in unconsolidated strata are rarely simple homogeneous systems but typically consist of alternating permeable layers of productive sands and gravels separated by less permeable aquitard layers of clay and silt, reflecting the complex history of deposition. In such sequences, the shallow aquifers are the easiest and cheapest to exploit, but are likely to be the most vulnerable to pollution. The presence of aquitard may produce complex groundwater flow patterns, but he permeable horizons may still have a degree of hydraulic continuity, such that pumping from one layer will affect the others, producing significant vertical head gradients and consequent leakage. Deeper groundwater in thick alluvial sequences is derived from recharge several hundred to several thousand years ago, and the term fossil has sometimes been used to describe deep, old groundwater [18].

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Nomenclature

C	-	Concentration
Q_d	-	Decay
V_O	-	Pore distribution
D	-	Dispersion number
V		Velocity
X	-	Depth
T	-	Time

$$K\frac{\partial c}{\partial t} + Q_d\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial X^2} - V\frac{\partial c}{\partial X} \qquad \text{.....................................} \qquad (1)$$

The expression above is the governing equation from the developed system that will monitor the deposition of bacteriophage under heterogeneous phase of the strata. Lacustrine depositions are known to be the influential geological structural setting in the study area. The reflection from lacustrine in the study location pressured the behaviour of bacteriophage in the study area. Such depositional microbial structure took advantage of high degree of hydraulic conductivity in some shallow phreatic zones to spread its microbial world. The developed governing equation will definitely streamline the structural influence from the strata on bacteriophage in lacustrine deposited formation.

Applying physical splitting techniques on equation (1)

$$K\frac{\partial c_1}{\partial t} = Q_d\frac{\partial c_1}{\partial t} \qquad \text{.....................................} \qquad (2)$$

$$\left.\begin{array}{l} t = 0, \quad x = 0 \\ C_{(o)} = 0 \\ \left.\dfrac{\partial c_1}{\partial t}\right| t = 0 \end{array}\right\} \qquad \text{.....................................} \qquad (3)$$

$$K\frac{\partial c_2}{\partial t} = D\frac{\partial^2 c_2}{\partial X^2} \qquad \text{.....................................} \qquad (4)$$

$$\left.\begin{array}{l} t = 0, \quad x = 0 \\ C_{(o)} = 0 \\ \left.\dfrac{\partial c_2}{\partial t}\right| = 0 \\ \qquad t = 0 \end{array}\right\} \qquad \text{.....................................} \qquad (5)$$

$$K\frac{\partial^2 c_3}{\partial t} = -\frac{V\partial c_3}{\partial X} \qquad \text{.....................................} \qquad (6)$$

$$\left.\begin{array}{l} t = 0 \\ C_{(o)} = 0 \end{array}\right| \quad t = 0 \qquad \text{.................................} \qquad (7)$$

$$D\frac{\partial^2 c_4}{\partial X^2} = -V\frac{\partial c_4}{\partial X} \qquad \text{.................................} \qquad (8)$$

$$\left.\begin{array}{l} x = 0 \\ t = 0 \\ C_{(o)} = 0 \end{array}\right\} \qquad \text{.................................} \qquad (9)$$

$$\left.\frac{\partial c_4}{\partial X}\right| \quad x = 0 \qquad \text{.................................} \qquad (10)$$

Applying direct integration on (2)

$$K\frac{\partial c}{\partial t} = Q_d C + U_1 \qquad \text{.................................} \qquad (11)$$

Again, integrate equation (11) directly, yield

$$KC = KQCt + U_1 t \quad U_2 \qquad \text{.................................} \qquad (12)$$

Subject to equation (3), we have

$$KC_o = U_2 \qquad \text{.................................} \qquad (13)$$

And subjecting equation (11) to (3)

$$at \quad \left.\frac{\partial c_1}{\partial t}\right| = 0 \quad C_{(o)} = C_o$$
$$t = 0$$

Yield

$$0 = Q_d C_o + U_2$$

$$\Rightarrow U_2 = -Q_d C_o \qquad \text{.................................} \qquad (14)$$

So that, put (13) and (14) into (13), we have

$$KC_1 = Q_d C_1 t - Q_d C_o t + KC_o \qquad \text{.................................} \qquad (15)$$

$$KC_1 - Q_d C_1 t = KC_o - Q_d C_o t \qquad \text{.................................} \qquad (16)$$

$$\Rightarrow C_1 (K - Q_d t) = C_o \quad (k - Q_d t) \qquad \text{.................................} \qquad (16)$$

$$\Rightarrow C_1 = C_o \qquad \text{.................................} \qquad (17)$$

The derived solution in (17) established the rate of concentration of bacteriophage deposited in the formation. At this level of concentration, it will definitely experience change in concentration with respect to depth under the influence of continuous migration within the intercedes at different strata. Such expressions are noted in the formation whereby the structural setting develop predominance or pore distribution system at high degree. Therefore, the influence for such formation characteristics may pressure the concentration varying from initial to final under change of depth with respect to variation of bacteriophage deposition.

Hence, equation (16) entails that at any given distance *x*, we have constant concentration of the contaminant in the system. Now we consider equation (4) which is the progressive phase of the system.

$$K\frac{\partial c_2}{\partial t} = D\frac{\partial^2 c_2}{\partial X^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Approach this system using the Bernoulli's method of separation of variables

i.e. $$C_2 = XT \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

i.e. $$K\frac{\partial c_2}{\partial t} = XT^1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

$$\frac{\partial^2 c_2}{\partial X^2} = X^{11}T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

Put (19) and (20) into (18), so that we have

$$KXT^1 = DX^{11}T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

i.e. $$\frac{KT^1}{T} = \frac{DX^{11}}{X} = -\lambda^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

Hence $$\frac{KT^1}{T} + \lambda^2 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

$$X^{11} + \frac{\lambda^2}{K} = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (24)$$

And

$$DX^{11} + \lambda^2 T = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (25)$$

From (24) $$T = A\,Cos\,\frac{\lambda}{K}t + B\,Sin\,\frac{\lambda}{K}x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (26)$$

And (19) gives:

$$T = C\ell^{\frac{-\lambda^2}{K}t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (27)$$

By substituting (25) and (26) into (18) we get:

$$C_2 = \left[A\,Cos\,\frac{\lambda}{\sqrt{Q_d}}t + B\,Sin\,\frac{\lambda}{\sqrt{Q_d}}x\right]C\ell^{\frac{-\lambda^2}{K}t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

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The developed model in (28) expressed time predominance of concentration in exponential phase. The influences from permeability were considered at high degree, whereby the derived solution expressed the pressure from permeability on the migration rate of bacteriophage in lacustrine influential depositional formation. Such deltaic formation developed a transition from Benin to sombrero, establishing lacustrine stratification in the study location.

Subject equation (28) to condition in (5), so that we have

$$C_o = AC \quad \text{..................................} \quad (29)$$

Equation (29) becomes:

$$C_2 = C_o \ell^{\frac{-\lambda^2}{D}t} Cos \frac{\lambda}{\sqrt{k}} x \quad \text{..................................} \quad (30)$$

Again at $\left.\frac{\partial c_2}{\partial t}\right| = 0, \quad x = 0$

$$t = 0, B$$

Equation (30), becomes:

$$\frac{\partial c_2}{\partial t} = \frac{\lambda}{\sqrt{K}} C_o \ell^{\frac{-\lambda^2}{D}t} Sin \frac{\lambda}{K} x \quad \text{..............................} \quad (31)$$

i.e. $0 = -C_o \frac{\lambda}{\sqrt{K}} \; Sin \frac{\lambda}{\sqrt{K}} 0$ .... (31)

$C_o \frac{\lambda}{\sqrt{K}} \neq 0$ Considering NKP

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

Micronutrients are normally found to deposit within any region of the formation in deltaic location. Such conditions normally influence the increase in microbial population as it serve as energy and substrate utilization to the microbes. In line with this condition, the deposition of micronutrients cannot be objected as it should be considered in a system expressing it in the derived solution. The geological setting determines the region where such parameters should be considered under the influence of formation level of variation through heterogeneous condition.

$$0 = -C_o \frac{\lambda}{\sqrt{K}} \; Sin \frac{\lambda}{\sqrt{K}} B \quad \text{..................................} \quad (32)$$

$$\Rightarrow \frac{\lambda}{\sqrt{K}} = \frac{n\pi}{2}, \; n, 1, 2, 3 \quad \text{..................................} \quad (33)$$

$$\Rightarrow \lambda = \frac{n\pi\sqrt{K}}{2} \quad \text{................................} \quad (34)$$

So that equation (30) becomes

$$C_2 = C_o \ell^{\frac{-n^2\pi^2 V}{2D}t} \; Cos \frac{n\pi\sqrt{K}}{2\sqrt{K}} x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (35)$$

$$C_2 = C_o \ell^{\frac{-n^2\pi^2 K}{2D}t} \; Cos \frac{n\pi}{2} x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (36)$$

The expression from the developed model [36] is the reflection of dispersion under the influences of permeability in the formation, such condition were to monitor the behaviour of the microbes under the influences of these two parameters, the deposition in shallow depth were noted including the time of transport including variation of the strata. The behaviour from the two parameters were considered in line with it s influential condition to the microbes in the study location.

We consider equation (6)

$$K \frac{\partial c_3}{\partial t} = -V \frac{\partial c_3}{\partial X} \qquad \ldots\ldots\ldots\ldots\ldots \qquad (6)$$

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

$$C_3 = X^1 T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (37)$$

$$\frac{\partial c_3}{\partial t} = X T^1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (38)$$

$$\frac{\partial c_3}{\partial X} = X^1 T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (39)$$

Again, we put (38) and (39) into (37), so that we have

$$V X T^1 = V X^1 T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (40)$$

i.e. $\dfrac{KT^1}{T} = \dfrac{VX^1}{X} = -\lambda^2$ ……………………………….. (41)

Hence $\dfrac{KT^1}{T} + \lambda^2 = 0$ ……………………………….. (42)

i.e. $X^1 + \dfrac{\lambda^2}{V} X = 0$ ……………………………….. (43)

And $KT^1 + \lambda^2 T = 0$ ……………………………….. (44)

From (44) $X = ACos \dfrac{\lambda}{\sqrt{V}} X + BSin \dfrac{\lambda}{\sqrt{V}} X$ ……………………………….. (45)

And (38) give

$$T = C\ell^{\frac{-\lambda^2}{K}t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (46)$$

By substituting (45) and (46) into (37), we get

$$C_3 = \left(ACos\frac{\lambda}{\sqrt{V}}x + BSin\frac{\lambda}{\sqrt{V}}x \right) C\ell^{\frac{-\lambda}{K}t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (47)$$

Subject (47) to conditions in (9), so that we have

$$C_o = AC \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (48)$$

$\therefore$ Equation (48) becomes:

$$C_3 = C_o\ell^{\frac{-\lambda^2}{K}t} Cos\frac{\lambda}{\sqrt{V}}x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (49)$$

Again, at $\left.\frac{\partial c_3}{\partial t}\right| = 0, \quad t = 0$

$$t = 0, B$$

Equation (49) becomes:

$$\frac{\partial c_3}{\partial t} = \frac{\lambda}{\sqrt{K}}C_o\ell^{\frac{-\lambda^2}{D}t} Sin\frac{\lambda}{V}x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (50)$$

i.e. $0 = \frac{-C_o\lambda}{\sqrt{K}} Sin\frac{\lambda}{V}0$

$C_o\frac{\lambda}{\sqrt{K}} \neq 0$ Considering NKP

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

$$0 = -C_o\frac{\lambda}{\sqrt{K}} Sin\frac{\lambda}{\sqrt{V}}B \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (51)$$

$$\Rightarrow \frac{\lambda}{\sqrt{V}} = \frac{n\pi}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (52)$$

$$\Rightarrow \lambda = \frac{n\pi\sqrt{V}}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (53)$$

So that equation (30) becomes

$$C_3 = C_o\ell^{\frac{-n^2\pi^2K}{4D}t} Cos\frac{n\pi\sqrt{V}}{2\sqrt{V}}x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (54)$$

$$\Rightarrow C_3 = C_o\ell^{\frac{-n^2\pi^2K}{4D}t} Cos\frac{n\pi}{2}x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (55)$$

Furthermore, the expression from substrate influence was determined since it is found in some parts of the soil deposition. Based on this condition, there is a tendency of continuity consideration of substrate as it is an influential parameter that increased the microbial population without the deposition of inhibitors. The expressed model at this phase considered permeability and dispersion influence with respect to migration at various time and depth in the formation. This implies that the exponential migration with increase in microbial population does not have any inhibitors depositing in any of the regions where such exponential phase are experienced.

Now, we consider equation (8), which is the steady flow rate of the system

$$\frac{D\partial^2 c_4}{\partial X^2} = -V\frac{\partial c_4}{\partial X} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

Using Bernoulli's method, we have

$$C_4 = XT \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (56)$$

$$\frac{\partial c_4}{\partial X^2} = X^{11}T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (57)$$

$$\frac{\partial c_4}{\partial X} = X^1 T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (58)$$

Put (57) and (58) into (8), so that we have

$$DX^{11}T = -VX^1 T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (59)$$

i.e. $$\frac{DX^{11}}{X} = \frac{VX^1}{X} = \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (60)$$

$$\frac{DX^{11}}{X} = \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (61)$$

$$\frac{-VX^1}{X} = \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (62)$$

$$X = A\frac{\varphi}{D}x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (63)$$

And $$X = B\ell^{\frac{-\varphi}{V}x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (64)$$

Put (63) and (64) into (56), gives

$$C_4 = A\ell^{\frac{\varphi}{V}x} \; B\ell^{\frac{-\varphi}{V}x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (65)$$

$$C_4 = AB\ell^{(x-x)\frac{\varphi}{V}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (66)$$

Subject equation (66) and (67) yield

$$C_{(4)} = (o) = C_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (67)$$

So that, equation (68) becomes

$$C_4 = C_o\ell^{(x-x)\frac{\varphi}{V}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (68)$$

The expression in (68) monitor the system based on the velocity of flow as an influential parameter that may be determined through the pore distribution system of the strata within the intercedes at different formations. Such condition is in line since the velocity of solute are expressed through the rate of pore distribution system of the strata influenced by geological setting in the deltaic formation. The exponential phases are also influenced by the rate of velocity through the micropores of the formation in the study location.

Now assuming that, at the steady flow, there is no NKP for substrate utilization, our concentration here is zero, so that equation (68) becomes

$$C_4 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (69)$$

Therefore solution of the system is of the form

$$C = C_1 + C_2 + C_3 + C_4 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (70)$$

We now substitute (17), (36), (55) and (69) into (70), so that we have the model of the form

$$C = C_o + C_o \ell^{\frac{-n^2\pi^2 K}{2D}t} \bullet {}^{\frac{n^2\pi^2 V}{4D}x} \, Cos \frac{n^2\pi^2}{4} x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (71)$$

$$\boxed{\Rightarrow \; C = C_o \left[1 + \ell^{\frac{-n^2\pi^2 K}{2D}t} \bullet {}^{\frac{n^2\pi^2 V}{4D}x} \, Cos \frac{n^2\pi^2}{4} x \right]} \qquad \ldots\ldots\ldots\ldots \quad (72)$$

Shallow depositions through the floodplains less than 100 metres wide and less than 10 metres sediment are known to be a valuable resource since there is underlining bedrocks with little potential groundwater but in deltaic formation, the rate of phreatic deposition develop high yield formation under the influence of deltaic nature structured through the formation characteristics influence as is observed in the study location. The expressed model was critically evaluated through the formation variables including the behaviour of bacteriophage subjecting to the influence of lacustrine deposition influence in Ahoada. Such situations were structured in the system that developed the derived model equation that will monitor the migration and deposition of bacteriophage in lacustrine influential deposition.

4. Conclusion

Pore distribution influence was found to be the major predominant pressure of bacteriophage migration in the study location. The study details the behaviour of the microbes in lacustrine stratification deposition transiting from Benin to sombrero formation. This geological variation setting experienced in the study location no doubt pressure the behaviour of microbial migration in the study area. Such conditions were considered in the system through the governing equation expressed at various derived solutions, developing various models at different considered phase of the transport system. The study is imperative because lacustrine influence has never been noted in detail on its influence on migration of microbes in deltaic formation. This conceptual framework has exposed the level of influence from lacustrine deposition developing high percentage of heterogeneous formation reflecting the behaviour of microbial transport system in the study area.

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