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Research article

MODELING MASS RATE OF TRANSPORT INFLUENCED BY DISPERSION AND WATER FLOW VELOCITY IN ORGANIC AND LATERITIC SOIL IN OBIO AKPOR, RIVERS STATE OF NIGERIA

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Abstract

The dispersion and water flow velocity influences on mass transport has been expressed to monitor different condition in deltaic soil. There lots of environmental influences in these types soil generating different concentration of different types of solute in deltaic environment , several experts has in different concept discus several deposition of mass transport in batch system concept, but not much has been done in applying plug flow application concept to develop and monitor mass water rate in organic and lateritic soil, theses condition could not defined the behaviour and impact from the transport system in deltaic environments. Base on these condition, the need for developing model that can monitor the rate of mass transport become imperative in soil and water environment, the developed model from generated governing equation will definitely expressed various condition in fluid flow in soil, these express various formation influences like porosity on the mass transport rate in organic and lateritic soil

Keywords: modeling, mass rate of transport, dispersion and water flow velocity

1. Introduction

As metropolitan and manufacturing development continues to increase around the world's rivers and coastlines, so does the rate of inadvertent release of pollutants to subsurface and surface waters and the require for effective evaluation of such environments (Winter, 2000). Experts like Hydrologists and other related professionals have long known that surface waters and groundwater are inherently linked systems (e.g. Glover, 1959; Cooper, 1959; clement et al., 1996; Simpson et al., 2003 Westbrook 2004). Most Areas around streams, rivers, lakes and coastal environments symbolize zones of communication and conversion between the two systems where dissolved constituents such as contaminants can be watered down, exchanged, changed or damaged. Identifying predominant processes affecting solute exchange across conversion zones is therefore, critical in evaluating pollutant fluxes to the sediment/water interface, and eventually in estimating pollutant exposures for the acceptance ecosystems. Groundwater/surface water communications in estuarine environments are influenced by a numeral of processes forming compound spatially and temporally changeable systems. Density contrasts between the typically fresh groundwater and saline to brackish, marine and estuarine surface waters leads to mixing and convective circulation at the groundwater release boundary so that the system is characterised by the interference of saltwater into the adjacent coastal aquifer (Glover, 1959; Cooper, 1959; Reilly and Goodman, 1985; Ataie-Ashtiani et al., 1999; Simpson and Clement, 2004, Westbrook, 2004). Tidal action can frequently induce a variable water table as well as penetration of surface water into sediments, forming a surficial combination zone with groundwater discharging from the adjacent aquifer (Robinson et al., 1998; Ataie-Ashtiani et al., 1999; Boudreau and Jorgensen, 2001; Acworth and Dasey, 2003). while several studies have addressed groundwater and solute inputs to surface water bodies (e.g. Harvey et al., 1987, Gallagher et al., 1996, Portney et al., 1998, Krabbenhoft et al., 1990, Lorah mand Olsen, 1999, Winter, 2000; Tobias et al., 2001), a small number of studies to date have examined near-shore groundwater release in detail. Studies of note down however, comprise those by Robinson et al. (1998); Robinson and Gallagher (1999); Smith and Turne (2001); Linderfelt and Turner (2001); Simpson et al. ,(2003 Westbrook, 2004) and the initial study by Westbrook et al. (2000) connected to the present work. Robinson et al. (1998) presented results from a field studies on unconfined groundwater release to estuarine waters at Chesapeake Bay, Virginia, showing strong tidal and seasonal controls on fresh groundwater discharge connected with penetration of surface water into tidally exposed sediments. Robinson and Gallagher (1999) additional developed a two-dimensional, field scale, finite element model based on density dependent fluid flow with water table and dynamic tidal boundary conditions. The model was able to reproduce the Chesapeake Bay field data on the movement of the near-shore water table, groundwater salt concentrations and groundwater discharge rates and patterns but was unable to replicate short-term salt fluctuations in the hyporheic zone due to the wave action of tides within the intertidal zone (Robinson and Gallagher, 1999). Simpson et al. (2003) performed transport experiments in a sand tank to study the characteristics of the seepage-face zone that exists near a groundwater/ surface water interface. Their study concluded that seepage-face zones, which are dominated by strong hydraulic gradients, play an important role in influencing the localized flow and solute transport processes in shallow unconfined aquifers.

2. Theoretical background

The behaviour of mass rate of transport in soil and water environment has not thorough defined especial under the condition of plug flow application, the transport of solute in a large number may not be significant in flow net of fluid in the formation, this may be as a result of soil structural setting of the formation in the system, the deposition of mass rate of transport in the system has been found to impress the rate of mass in fluid deposition, the condition of soil strata progress the direction of transport at different condition, modeling mass rate of transport influenced by dispersion and water flow velocity will be monitored to express the movement of fluid at different influential in organic and lateritic soil. Mathematical approach to monitored theses conditions in mass rate of transport will be thoroughly developed. To express the influences from mass rate through formation variation deposited are base on geological setting in the study location. The variation of velocity in the strata are the reflection or the rate of mass transport in the formation, variation of fluid flow in the strata express the rate of velocity influence on mass rate of transport in the organic and lateritic soil, the rate of mass transport of fluid has lots of challenges that should be considered in the study, the organic soil are the top soil that deposit lots of substance, several influential condition determine the condition of the soil and other minerals in the formations, mass rate of transport implies that any substance in the organic soil will definitely interact with the soil, it either develop positive of negative influences to the soil, mass rate of transport implies that there will movement of every substance in organic to lateritic soil formation, the structure of these condition determined the structural condition of the soil, this may be as a result of the structural stratification of the soil under the influences of geological condition in the study location. The structure of the study through modeling approach will definitely defined the condition of mass transport influenced by dispersion and velocity of flow in the study location.

3. Governing Equation

$$V\frac{\partial q}{\partial t} = D(x)\frac{\partial^2 q}{\partial x^2} - V\frac{\partial q}{\partial x} - \frac{\partial q\mu(x)}{\partial t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

The expression in [1] is the governing equation that will be derived to generate a model that will determine the rate of mass transport in the study area, the derive governing equation are mathematically express the study through these mathematical approach, the concepts were find suitable since there are lots of variation in the deposition of mass transport rate including variation from soil structural deposition of the formation , these conditions were considered to develop the governing equation.

Nomenclature

q = Mass Rate of Transport [LT^{-1}]

D = Dispersion coefficient in longitudinal location (MT^{-1})

μ(x) = Loss coefficient at location of x LT^{-I}

V = Void Ratio [-]

T = Time [T]

X = Distance [M]

V = Void ratio [-]

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$$V\frac{\partial^2 q_1}{\partial t} = D(x)\frac{\partial^2 q_1}{\partial x^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$\left.\begin{array}{l} t = 0 \\ x = 0 \\ C_{(o)} = 0 \\ \left.\frac{\partial C}{\partial t}\right|_{t = 0, B} = 0 \end{array}\right\} \quad \ldots\ldots\ldots\ldots \quad (3)$$

$$V\frac{\partial q_2}{\partial t} = V(x)\frac{\partial q^2}{\partial x} \quad \ldots\ldots\ldots\ldots \quad (4)$$

$$\left.\begin{array}{l} t = 0 \\ x = 0 \\ q_{(o)} = 0 \\ \left.\frac{\partial q}{\partial t}\right|_{t = 0, B} \end{array}\right\} \quad \ldots\ldots\ldots\ldots \quad (5)$$

$$V\frac{\partial q_3}{\partial t} = -\frac{\partial q_3 \mu(x)}{\partial t} \quad \ldots\ldots\ldots\ldots \quad (6)$$

$$\left.\begin{array}{l} t = 0 \\ C_{(o)} = 0 \\ \left.\frac{\partial q_3}{\partial t}\right|_{t = 0, B} = 0 \end{array}\right\} \quad \ldots\ldots\ldots\ldots \quad (7)$$

$$V\frac{\partial q_4}{\partial x} \quad -\frac{\partial q_4 \mu c}{\partial t} \quad \ldots\ldots\ldots\ldots \quad (8)$$

$$\begin{array}{l} x = 0 \\ t = 0 \\ C_{(o)} = 0 \\ \left.\frac{\partial C_4}{\partial x}\right|_{x = 0, B} = 0 \end{array} \quad \ldots\ldots\ldots\ldots \quad (9)$$

$$D(x)\frac{\partial^2 q_5}{\partial x^2} \quad -V\frac{\partial q_5}{\partial x} \quad \ldots\ldots\ldots\ldots \quad (10)$$

$x = 0$

$q_{(o)} = 0$ ………………………………… (11)

$$\left.\frac{\partial q_5}{\partial x}\right|_{x = 0,\ B}$$

Applying direct integration on (2)

$$V\frac{\partial q_1}{\partial t} = D(x)q + K_1 \qquad \text{………………………………… (12)}$$

Again, integrate equation (12) directly yield

$$VC = D(x)qt + Kt + K_2 \qquad \text{………………………………… (13)}$$

Subject to equation (3), we have

$$Vq_o = K_2 \qquad \text{………………………………… (14)}$$

And subjecting equation (12) to (3) we have

At $\left.\frac{\partial q_1}{\partial t}\right|_{t = 0} = 0 \quad q(o) = qo$

Yield

$$0 = D(x)q_o + K_2$$

$$\Rightarrow V_1 = D(x)q_o = K_2 \qquad \text{………………………………… (15)}$$

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

$$Vq_1 = D(x)q_{1t} - D(x)qox\, Vqo \qquad \text{………………………………… (16)}$$

$$RC_1 - D(x)q_{1x} = Vq_o - D(x)qox \qquad \text{………………………………… (17)}$$

$$q_1 = q_o \qquad \text{………………………………… (18)}$$

Hence equation (18) entails that at any given distance x, we have constant concentration of the contaminant in the system.

The deposition of any substance in soil are observed in some conditions at organic soil sample, mass rate of transport depend on what deposit in the surface of the soil at any moment, there lots of influential condition that determine the rate of mass in the soil surface, other influential conditions are the activities of manmade, consequently, several substance deposit more than the natural substance in the formation, the expression from these conditions in equation [18] where the substance deposit at the surface will definitely migrate to another formation under the influences of degree of porosity, theses variation are base on the structural deposition and the rate of release substance to the surface of the soil .the expression is under plug flow application as it is found to migrate from organic l to lateritic soil, this expressed condition within formation establish change in concentration with respect to distance.

$$V\frac{\partial q_2}{\partial t} = -V\frac{\partial q^2}{\partial x} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

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

$$q_2 = XT \quad \ldots\ldots\ldots\ldots\ldots \quad (19)$$

i.e. $$V\frac{\partial q_2}{\partial t} = XT^1 \quad \ldots\ldots\ldots\ldots\ldots \quad (20)$$

$$V\frac{\partial q_2}{\partial x} = X^1T \quad \ldots\ldots\ldots\ldots\ldots \quad (21)$$

Put (20) and (21) into (19), so that we have

$$VXT^1 = -VX^1T \quad \ldots\ldots\ldots\ldots\ldots \quad (22)$$

i.e. $$V\frac{T^1}{T} = V\frac{X^1}{X} = -\lambda^2 \quad \ldots\ldots\ldots\ldots\ldots \quad (23)$$

Hence $$V\frac{T^1}{T} + \lambda^2 = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (24)$$

i.e. $$X^1 + \frac{\lambda}{R}x = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (25)$$

$$VX^1 + \lambda^2 X = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (26)$$

From (25), $$X = ACos\frac{\lambda}{R}X + BSin\frac{\lambda}{\sqrt{R}}X \quad \ldots\ldots\ldots\ldots\ldots \quad (27)$$

And (20) gives

$$T = C\ell^{\frac{-\lambda^2}{V}t} \quad \ldots\ldots\ldots\ldots\ldots \quad (28)$$

And (20) gives

$$\boxed{C_2 = \left(ACos\frac{\lambda}{V}t + BSin\frac{\lambda}{\sqrt{V}}t\right)C\ell^{\frac{-\lambda^2}{V}x}} \quad \ldots\ldots\ldots\ldots\ldots \quad (29)$$

Subject to equation (29) to conditions in (5), so that we have

$$q_o = AC \quad \ldots\ldots\ldots\ldots\ldots \quad (30)$$

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Equation (30) becomes

$$q_2 = q_o \ell^{\frac{-\lambda^2}{V}x} \; Cos \frac{\lambda}{\sqrt{V}}t \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (31)$$

Again, at

$$\left.\frac{\partial q_2}{\partial t}\right| \begin{matrix} = 0, \; x = 0 \\ t = 0, \; B \end{matrix}$$

Equation (31) becomes

$$\frac{\partial q_2}{\partial t} = \frac{\lambda}{\sqrt{V}} q_o \ell^{\frac{-\lambda}{V}x} \; Sin \frac{\lambda}{\sqrt{V}}t \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (32)$$

i.e. $0 = -\frac{qo\lambda}{\sqrt{V}} \; Sin \frac{\lambda}{V} 0$

$Co\frac{\lambda}{V} \neq 0$ Considering NKP

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

$$0 = qo\frac{\lambda}{\sqrt{V}} \; Sin \frac{\lambda}{\sqrt{V}} B \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (33)$$

$$\Rightarrow \frac{\lambda}{R} = \frac{n\pi}{2} n, 1, 2, 3 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (34)$$

$$\Rightarrow \lambda = \frac{\lambda}{V} = \frac{n\pi\sqrt{R}}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (35)$$

So that equation (31) becomes

$$\Rightarrow q_2 = qo \, \ell \, \frac{-n^2\pi^2 R}{2} t \; Cos \frac{n\pi\sqrt{R}}{2\sqrt{R}} x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (36)$$

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$$\Rightarrow q_2 \;=\; qo\,\ell\,\frac{-n^2\pi^2 R}{2}t\;Cos\frac{n\pi}{2}x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (37)$$

Now, we consider equation (7), we have the same similar condition with respect to the behaviour

$$v\frac{\partial q_3}{\partial t} = -\frac{\partial q_3 \mu(x) q}{\partial t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

$$q_3 \;=\; XT^1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (38)$$

$$\frac{\partial q_3}{\partial t} \;=\; XT^1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (39)$$

i.e. $V\frac{\partial q_3}{\partial t} \;=\; XT^1$ ………………………….. (40)

Put (20) and (21) into (19), so that we have

$$VXT^1 = -XT^1\mu(x)q \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (41)$$

i.e. $V\frac{T^1}{T} = -\frac{T^1}{T}\mu(x)q - \lambda^2$ ………………………….. (42)

$$V\frac{T^1}{T} + \lambda^2 \;=\; 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (43)$$

$$X^1 \;+\; -\frac{\lambda}{V}t \;=\; 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (44)$$

And $VT^1 + \lambda^2 t = 0$ ………………………….. (45)

From (44), $t \;=\; A\,Cos\frac{\lambda}{V}t \;+\; B\,Sin\frac{\lambda}{\sqrt{V}}t$ ………………….. (46)

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and (39) give

$$T = C\ell \frac{-\lambda^2}{\mu(x)q} t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (47)$$

By substituting (46) and (47) into (38), we get

$$C_3 = \left(A\,Cos \frac{\lambda}{V} t + B\,Sin \frac{\lambda}{\sqrt{V}} t \right) C\ell \frac{-\lambda^2}{\mu(x)q} t \qquad \ldots\ldots\ldots\ldots \quad (48)$$

Subject equation (48) to conditions in (7), so that we have

$$qo = AC \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (49)$$

Equation (49) becomes

$$q_3 = qo\,\ell \frac{-\lambda^2}{\mu(x)q} t\ Cos \frac{\lambda}{q} t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (49)$$

Again, at $\left.\frac{\partial q_3}{\partial t}\right|_{t\ =\ 0,B} = 0 \quad t = 0$

Equation (50) becomes

$$\frac{\partial q_3}{\partial t} = \frac{\lambda}{V} Co\,\ell \frac{-\lambda}{\mu(x)q} t\ Sin \frac{\lambda}{V} t \qquad \ldots\ldots\ldots\ldots\ldots \quad (51)$$

i.e. $0 = qo \frac{\lambda}{V}\ Sin \frac{\lambda}{V} 0$

$qo\frac{\lambda}{V} \neq 0$ Considering NKP again

Due to the rate of growth, which is known to be the substrate utilization of the microbes we have

$$0 = -qo\frac{\lambda}{\sqrt{V}} \; Sin\frac{\lambda}{\sqrt{V}}B \qquad \text{..............................} \qquad (52)$$

Organic soil are the initial deposition of any substance concentration, mass transport at this stage considered the deposition of micronutrients in the soil, the deposition of substrate are considered in several conditions, since the deposition may observe variation at different structural deposition of organic and lateritic soil in the study location, there it is imperative that substrate deposition condition should be in generally analyzed in the study at anywhere the derived solution are considered, therefore substrate condition are expressed because other solute like microbes are usually faivoured at any region of the soil micronutrients deposit.

$$\Rightarrow \frac{\lambda}{V} = \frac{n\pi}{2}n,1,2,3 \qquad \text{..............................} \qquad (53)$$

$$\Rightarrow \lambda = \frac{n\pi\sqrt{R}}{2} \qquad \text{..............................} \qquad (54)$$

So that equation (50) becomes

$$q_3 = qo\,\ell\,\frac{-n^2\pi^2R}{2\mu(x)q}t\; Cos\frac{n\pi}{2}t \qquad \text{..............................} \qquad (55)$$

Now, we consider equation (8), we have

$$V\frac{\partial q_4}{\partial x} - \frac{\partial q_4\mu(x)q}{\partial x} \qquad \text{......................} \qquad (8)$$

Using Bernoulli's method, we have

$$C_4 = XT \qquad \text{..............................} \qquad (56)$$

$$\frac{\partial q_4}{\partial x} = X^1T \quad \text{.............................} \quad (57)$$

$$\frac{\partial C_4}{\partial t} = X^1T \quad \text{.............................} \quad (58)$$

Put (57) and (58) into (56), so that we have

$$VX^1T = -X^1T \ \mu(x)X^1T \quad \text{......................} \quad (59)$$

$$\text{i.e. } V\frac{X^1}{X} = -\frac{X^1}{X}\mu(x) \quad \text{......................} \quad (60)$$

$$V\frac{X^1}{X} = \varphi \quad \text{.............................} \quad (61)$$

$$\frac{X^1}{X}\mu(x)q = \varphi \quad \text{.............................} \quad (62)$$

$$X = A\,\ell\,\frac{\varphi}{V}x \quad \text{.............................} \quad (63)$$

Put (62) and (63) into (56), gives

$$C_4 = A\,\ell\,\frac{\varphi}{\mu(x)} \bullet B\,\ell\,\frac{-\varphi}{\mu(x)}x \quad \text{.............................} \quad (64)$$

$$C_4 = AB\,\ell^{(t-x)}\frac{\varphi}{\mu(x)} \quad \text{.............................} \quad (65)$$

Subject equation (66) to (8)

$$q_4\ (o) = qo \quad \text{.............................} \quad (66)$$

So that equation (67) becomes

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$$q_4 = qo\ell^{(t-x)}\frac{\varphi}{\mu(x)q}$$ …………………………..(67)

Considering equation (10), we have

$$D(x)\frac{\partial^2 q_5}{\partial x^2} - V\frac{\partial q_5}{\partial x}$$ ………………… (10)

$$q_5 = X^{11}T$$ …………………………..(68)

$$\frac{\partial^2 C_5}{\partial x^2} + X^{11}T$$ …………………………..(69)

$$\frac{\partial q_5}{\partial x} + X^1 T$$ …………………………..(70)

Put (69) and (70), so that we have

$$D(x)X^{11}T - VX^1 T$$ …………………………..(71)

$$D(x)\frac{X^{11}}{X}T - V\frac{X^1}{X}$$ …………………………..(72)

$$D(x)\frac{X^{11}}{X} = \varphi$$ …………………………..(73)

$$V\frac{X^1}{X} = \varphi$$ …………………………..(74)

$$X^1 = A\ell\frac{\varphi}{D(x)}x$$ …………………………..(75)

Put (74) and (75) into (68), gives

$$q_5 = A\ell \frac{\varphi}{V} \bullet B\ell \frac{-\varphi}{V} x \qquad \text{.............................} \qquad (76)$$

$$q_5 = AB\ell^{(x-x)} \frac{\varphi}{V} \qquad \text{.............................} \qquad (77)$$

Subject (76) to (10)

$$q_5 \ (o) = Co \qquad \text{.............................} \qquad (78)$$

So that equation (78) becomes

$$q_5 = qo\,\ell^{(x-x)} \frac{\varphi}{V} \qquad \text{.............................} \qquad (79)$$

Now, assuming that at the steady flow, there is no NKP for substrate utilization, our concentration here is zero, so that equation (79) becomes

$$q_5 = 0 \qquad \text{.............................} \qquad (80)$$

Therefore, $C_1 + C_2 + C_3 + C_4 + C_5$ .... (81)

We now substitute (18), (37), (55), (67) into (81) so that we have the model of the form

$$q = qo + qo\,\ell \frac{-n^2\pi^2 R}{2V} x \ Cos \frac{n\pi}{2} t \bullet Co\,\ell \frac{-n^2\pi^2 R}{2\mu(x)} t \ Cos \frac{n\pi}{2} t +$$

$$qo\,\ell^{(t-x)} \frac{\varphi}{\mu C} \qquad \text{.............................} \qquad (82)$$

$$\Rightarrow q = qo + 1 + \ell \frac{n^2\pi^2 V}{2V} x \ Cos \frac{n\pi}{2} \bullet Co\,\ell \frac{-n^2\pi^2 V}{2\mu(x)} t \ Cos \frac{n\pi}{2} t +$$

$$Co\,\ell^{(t-x)} \frac{\varphi}{\mu(x)} \qquad \text{.............................} \qquad (83)$$

The expression in [83] is the final derived model to monitor mass rate of transport, this expression is to establish several condition that has resulted to variation of mass rate of transport in organic and lateritic soil, the stratification of the formation determined the variation of mass transport, and this is base on the deposition of degree of porosity of the soil formation, therefore mass transport are determined by these influential conditions the derived model considered these condition in developing the governing equation the generated the derived model .

4. Conclusion

Modeling mass rate of transport influenced by dispersion and water flow velocity in organic and lateritic soil has been developed. The systems were formulated to be expressed with some mathematical approach that will showcase several deposition of mass transport rate in soil and water environment in the study formation area. The derived model considered several formation deposition influences in the soil, the stratification soil formation express degree of porosity at several variation of mass transport rate in soil and water environment. Velocity and dispersion rate in soil are through the degree of porosity in soil, the model establish integrated the degree of soil formations including the dispersion rate in the soil formation.

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