



Original article

Modeling the transport of shigella in silty and fine sand in shallow aquifers in Coastal area of bonny Niger delta; rivers state of Nigeria

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ABSTRACT

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Modeling the transport of shigella in silty and fine sand formation in shallow aquifer has been developed, the model were generated to monitor the transport of shigella in coastal area of bonny, as coastal environment there are lots of influence in the soil formation, the major variable were considered in the development of the theoretical model, this condition were assessed and were integrated, this variables were considered and it develop a system that generated the model equation since the microbes are found to be in exponential phase, because of high degree of porosity and permeability of the soil formation, the mathematical equation were found to consider these variables to ensure it predict the rate of deposition of shigella in silty and fine sand formation, the model developed predict the transport of shigella in the coastal area of bonny, Niger Delta area of Nigeria, the model will be one of the baseline to reduce high rate of shigella in the study area, the study has also provide a design benchmark for practicing engineers and scientist to ensure that thorough ground are provide by application of the these design model.

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1. Introduction

Water is known to be a worldwide solvent. It is also one of the natural resources tapped by man, flora and fauna and plants to meet their needs for life sustenance. The world's water resources comprise the whole range of natural waters on earth, either in vapour, liquid or solid form. Water is classified as surface water or groundwater. Surface water comprise rain water collected into rivers, lakes, reservoirs and oceans while groundwater include natural springs, well and boreholes. Groundwater is generally understood as water occupying the voids within a geologic stratum, groundwater is free from suspend matter and bacteria. It can be said to be pure, clear and colourless. Groundwater has greater quality than surface water. About 495,000 children die annually of various diseases due to drinking of water that are not properly safe and sanitize (sea, stream e.t.c.), even as population increases and industries required all over the world, most people generally required about 2.5 litres of water everyday for direct consumption. The average amount of water used domestically each day by every person is about 190 litres (Hamill and Bell, 1986). Generally, industries require approximately one quarter to one third of the public water supply under normal condition the easiest and most convenient way to meet the public demand for water is to utilize surface water resources, but unfortunately, water such as river, lake, stream e.t.c. are less plentiful than can be imagined. It can be recorded that surface water resources account for less than 2 percent of the world's fresh water. The latter fresh water available however is unevenly distributed while the sources that are available have been either contaminated or polluted.(Hamill and Bell, 1986). Groundwater accounts for about 98 percent of the world's fresh water and is fairly evenly distributed throughout the world. It provides a reasonable constant supply which is not completely susceptible to drying up under natural condition unlike surface water (World water balance and water resources of the earth UNECO Copyright 1978). All over the globe, groundwater has been a very good and important source of water supply. It has been of continuous and tremendous use in irrigation industries and urban centers, as well as in All over the globe, groundwater has been a very good and important source of water supply. It has been of continuous and tremendous use in irrigation industries and urban centers, as well as in rural communities. It is conveniently available at point of use and possesses excellent quality that requires little or no treatment in most cases. The concept which explains the ultimate destination of rainwater is the sea either directly through run off or indirectly by infiltration and subsurface flow. A system of water movement in the atmosphere or rainfall, dews, hailstones or snowfalls over land as run off. Vertical and horizontal movement underground as infiltration or subsurface and continuous movement of all forms of water is the hydrogeology cycle. In the atmosphere, water vapours condense and may give rise to precipitation. However, not all this precipitation will reach the ground surface; some are intercepted by vegetation cover or surface of building and other structures and then evaporate back into the atmosphere. The precipitation that reaches the ground surface may flow in to stream, lake and ocean, where it will either be evaporated or form seepages intruding in to the ground likewise soil moisture and further percolate downward to underline aquifer where it may be held for several years longer. Groundwater in Nigeria is restricted by the fact that more than half of the country is underlain by crystalline basement rock of pre-cambian era. The main rock types in this geological terrain include igneous and metamorphic rock such as migmatites and granite gneisses. Generally in their unaltered form, they are characterized by low porosity and permeability. Porosity in basement rocks is by induction through weathering while secondary permeability induces by tectonic activities which manifest in form of that often act as conduct path facilitating water movement. In other words, aquiferous zones in the basement terrain include fractured/weathered rocks. The yielding capacity of well, drilled within such rock are always very enormous (Kazeem, 2007).

Stream sediments originate from near the surface of exposed rocks of igneous, sedimentary and volcanic origin. Some of these are easily eroded, whereas other especially the crystalline and metamorphic rocks are affected by stream only when altered in surface layers. Additional sources of stream sediments are soils which inherited their mineral content (with some alterations) from bedrock of which in the tropic may consist completely or newly formed minerals (Irion, 1987). Most streams in south-western Nigeria are derived from the Basement Complex which covers about half of the landmass of the entire Nigerian landscape. The Nigeria Basement Complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and South of the Touareg Shield. In stream sediments a whole range of known mineral can be found i.e. heavy minerals which are the most important group. Heavy minerals are known to occur in igneous, metamorphic and sedimentary rocks. These minerals are of high specific gravity and are economically valuable if they occur in sufficient large concentrations and in deposits of sufficiently large size. Stream sediments are also affected by large-scale

agricultural operation within a short period of time. A lot of literatures abound such as (Awosika et al. 1982) who conducted research on the heavy minerals in the Nigerian river sediments and concluded that the textural properties of terrigenous sediments are almost entirely controlled by transportation and deposition environment while its mineralogical composition is a function of provenance. The occurrence and abundance of heavy mineral suits are influenced by various factors such as specific gravity and hardness of individual minerals. Some minerals such magnetite, tourmaline, Zircon, rutile and sphene can form authigenically in sediments. Others include Odeyemi (1993) who also presented information on the major fold, situated a few kilometers, which he concluded it to be a NNE-SSW trending antiformal structure which was formed during the deformational phase of the Pan-African Orogeny. Oluyide (1988), gave evidence that within the basement complex, tectonic deformation has completely obliterated primary structures except in a few places where they survived deformation (Okonkwo, 1992). However, this research is aimed at carrying out geological and geochemical studies area in order to determine the underlying lithologic units in the area and to obtain baseline geochemical information about the area (Olusiji and Simeon, 2010).

Coastal Nigeria is made up of two sedimentary basins: The Benin basin and the Niger Delta basin separated by the Okitipupa ridge (Figure 1). The rocks of the Benin basin are mainly sands and shales with some limestone which thicken towards the west and the coast as well as down dips to the coast. Recent sediments are underlain by the Coastal Plains Sands which is then underlain by a thick clay layer - the Ilaro Formation and other older Formations (Jones and Hockey, 1964). The Recent Sediments and Coastal Plains Sands consist of alternation of sands and clays. The Recent Sediments forms a water table aquifer which is exploited by hand-dug wells and shallow boreholes. The Coastal Plains Sands aquifer is a multi-aquifer system consisting of three aquifer horizons separated by silty or clayey layers (Longe et al. 1987). It is the main aquifer in Lagos Metropolis that is exploited through boreholes for domestic and industrial water supply. In the coastal belt of the Benin basin, this aquifer is confined.

The Niger Delta is a coastal arcuate delta of the River Niger covering an area of about 75,000km². The subaerial Niger Delta has an extensive saline/brackish mangrove swamp belt separated from the sea by sand beach ridges for most of the coastline. Water supply problems relating to salinity are confined to the saline mangrove swamp with associated sandy islands and barrier ridges at the coast. Geologically, rocks of the Niger Delta are subdivided into three Formations which are Akata, Agbada and Benin Formations (Short and Stauble, 1967). The Benin Formation consisting predominantly of massive highly porous sands and gravels with locally thin shale/clay interbeds forms a multi-aquifer system in the delta. Many boreholes have been drilled into the aquifers of the Benin Formation yielding good quality water but many have also been abandoned due to high salinity. Oil and gas are produced from sand reservoirs in the Agbada Formation while the Akata Formation consists of uniform shale rocks (Oteri 1988 and Oteri 1990).

2. Theoretical background

Developed Model of shigella for pheratic Aquifer at progressive phase condition, Derived model equation as presented below.

The transport of heavy metal chromium in the coastal area of bonny has been a serious threat to the people of bonny, as a coastal of the Niger delta region, the study location deposited a lots of influence, but the focus of the study is the transport is microbes shigella, transport of shigella where found to contaminate the silty and fine sand formation where the aquiferious zone are deposited. The sources of pollution has pose a lots of threat to the human settlement in the study location, these sources of contaminants has developed high deposition of pollution, and there it become imperative that solution for the transport should be solved .

Mathematical model where developed to solve the transport of microbes to the aquiferious zone, the model considered the variables that lead to fast migration on the contaminants in the coastal area the model considered the major influence of the transport to ground water aquifers this variables were considered in the system through the mathematical tools as symbols that denote the variables, the material balance of the system were establish ,and it develop a mathematical equation , the equation where derived and the produced a model that will monitor the transport of heavy metal in aquiferious zone in the coastal area of bonny.

3. Governing equation

Developed Model of shigella for pheratic Aquifer at progressive phase condition, Derived model equation as presented below.

$$C(x) \frac{\partial v(x)}{\partial t} - D_{A1} V^2 \frac{\partial C(x)}{\partial x} = \frac{V \partial C(x)}{\partial t}$$

$$ML^{-2} T^{-2} \quad ML^{-2} T^{-2} \quad ML^{-2} T^{-2}$$

- C = Concentration [ML⁻³]
- V = Velocity [LT⁻¹]
- D_A = Dispersion Number Dimension less
- T = Time [T]
- X = Distance L

$$C_{(x)} \frac{\partial v(x)}{\partial t} - D_A v^2 - \partial c(x) = \frac{V \partial c(x)}{\partial t}$$

$$C_{(x)} \frac{\partial v(x)}{\partial t} - D_A v^2 - \partial c(x) = \frac{V \partial c(x)}{\partial t} \dots\dots\dots (1)$$

If $\frac{\partial x}{\partial t} = \frac{vc(x)}{\partial t}$

And $C_{(x)} \frac{\partial v(x)}{\partial t} = \beta \dots\dots\dots (2)$

We have $\frac{V \partial c(x)}{\partial t} + D_A v^2 \frac{\partial c(x)}{\partial x} = \beta \dots\dots\dots (3)$

Such that

$$\frac{V \partial c(x)}{\partial t} = D_A v^2 \frac{\partial c(x)}{\partial x} - \beta \dots\dots\dots (4)$$

To relate the variable influence, separation of variable where applied to see there rate of influence in terms migration by applying the law of plug flow, these method were found to explain the rate of influence on the transport in silty and fine sand formation as denoted mathematically.

By transformation of (4) we have

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

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

It can be obtained from separation of variables

$$\frac{\partial c(x)}{\partial x} = T x^1$$

Substituting in (4) we have

$$V(T^1 x) = D_A v^2 T x^1 - T x \frac{\partial v(x)}{\partial t} \dots\dots\dots (5)$$

Expanding further we get

$$VT^1 x = D_A v^2 T x^1 - T x \frac{\partial v(x)}{\partial t} \dots\dots\dots (6)$$

Dividing equation (6) by Tx we have

$$\frac{VT^1 x}{Tx} = D_A v^2 \frac{T x^1}{Tx} - T x \frac{\partial v(x)}{\partial t} \dots\dots\dots (7)$$

Then it implies that

$$\frac{VT^1}{T} = D_A v^2 \frac{x^1}{x} - \frac{\partial v(x)}{\partial t} \dots\dots\dots (8)$$

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

If $\frac{\partial c(x)}{\partial t}$

We have

$$\frac{VT^1}{T} = D_A v^2 \frac{x^1}{x} - \frac{\partial v(x)}{\partial t} = \lambda^2 \dots\dots\dots (9)$$

Solving term by term, we have

$$\frac{VT^1}{T} = \lambda^2 \dots\dots\dots (10)$$

$$VT^1 = \lambda^2 T \dots\dots\dots (11)$$

Let $T_{(o)} = 0$

$$V(ST_{(s)} - T_{(o)}) - \lambda^2 T_{(s)} = 0 \dots\dots\dots (12)$$

Considering the boundary condition, we have

$$T_{(o)} = C_1$$

Where C_1 is the initial concentration?

$$V(ST_{(s)} - VC_1) - \lambda^2 T_{(s)} = 0 \dots\dots\dots (13)$$

$$VST_{(s)} - VC_1 - \lambda^2 T_{(s)} = 0 \dots\dots\dots (14)$$

$$VST_{(s)} - \lambda^2 T_{(s)} = VC_1 \dots\dots\dots (15)$$

$$(VS - \lambda^2) T_{(s)} = VC_1 \dots\dots\dots (16)$$

Then $T_{(s)} = \frac{VC_1}{VS - \lambda^2} \dots\dots\dots (17)$

$$VS - \lambda^2 = 0 \dots\dots\dots (18)$$

$$VS = \lambda^2$$

$$S = \frac{\lambda^2}{V} \dots\dots\dots (19)$$

$$T_{(s)} = VC_1 \ell^{\frac{\lambda^2}{v} t}$$

\dots\dots\dots (20)

This condition explain that time is a major variables that determine the rate concentrations at every formations on transport process, the model can always be predicted when the time of transport are determined ,the relation between time and velocity where also expressed, the expression where able to relate the rate of concentration under the influence of time , this condition are reflected at various soil formation, this implies that at different soil formation, the time of concentration varies, reflecting it at different velocity of transport.

$$D_A v^2 \frac{x^1}{x^1} = \lambda^2 \dots\dots\dots (21)$$

Where $X_{(o)} = C_2$

$$X_{(t)} = D_A v^2 C_2 \ell^{\frac{\lambda^2}{D_A v^2} t}$$

\dots\dots\dots (22)

This condition is with respect to distance of the contaminant, the rate of contaminant are reflected on the distance travel, establishing the relation between distance and time were expressed in terms of migration at different distance, this variation of distance in some condition influence the concentration of the contaminant .

$$\frac{\partial v(x)}{\partial t} = \lambda^2 \dots\dots\dots (23)$$

$$SV_{(s)} - V_{(o)} = \lambda^2$$

Integrating the initial concentration for which $V_{(o)} = C_3$

$$SV_s - C_3 = \lambda^2 \dots\dots\dots (24)$$

$$SV_s = \lambda^2 + C_3 \dots\dots\dots (25)$$

Making V_s the subject relation gives

$$V_s = \frac{\lambda^2 + C_3}{S} \dots\dots\dots (26)$$

Using Laplace inverse we obtain

$$V_t = \lambda^2 + C_3$$

$$\lambda^2 = \frac{Vt}{C_3} \dots\dots\dots (27)$$

$$\text{If } \frac{VT^1}{T} = D_A v^2 \frac{x^1}{x} = - \frac{\partial v(x)}{\partial t} = \lambda^2 \dots\dots\dots (28)$$

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

$$\frac{VT^1}{T} = D_A v^2 \frac{x^1}{x} - \frac{\partial v(x)}{\partial t} \dots\dots\dots (29)$$

Integrating both sides gives

$VC_1 \ell^{\frac{\lambda^2}{v}} = D_A v^2 C_2 = \ell^{\frac{\lambda^2}{D_A v^2}}$ (30)
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$C_{(x)} = VC_1 \ell^{\frac{\lambda^2}{v}} = D_A v^2 C_2 \ell^{\frac{\lambda^2}{D_A v^2}}$ (31)
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The relation of the independent variables were integrated, both parameter considered as the in depended variables are expressed in terms of showing their contribution on the transport of shigella in the coastal area of bonny ,the silty and fine sane sand formation where the rate of contaminants are found to deposit at a high degree of concentrations. The study areas were found to have deposited shigella in natural origin in some part of the study location. The relationship expresses the condition of the microbes in terms of rate of migration with respect to time and distance

$$\lambda^2 = \frac{Vt}{C_3}$$

If
We get

$$C_{(x)} VC_1 \ell^{\frac{\lambda^2 t}{v}} = D_A v^2 C_2 \ell^{\frac{vt^2}{C_2}} \dots\dots\dots(32)$$

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

$$C_{(x)} = VC_1 \ell^{\left(\frac{\lambda^2 t}{v}\right)} \left(D_A v^2 C_2 \ell^{\frac{\lambda^2 t}{D_A v^2}} \right) \dots\dots\dots (33)$$

Given the constraints below

Since

$$t = 0, \quad X = 0 = C_m$$

$$C_m = C_1 C_2$$

$$\text{Such that } C_1 = \frac{C_m}{C_2} \dots\dots\dots (34)$$

$$C_{(x)} = \left(\frac{VC_m \ell^{\frac{\lambda t^2}{v}}}{C_2} \right) \left(D_A v^2 \ell^{\frac{\lambda^2 t}{D_A v^2}} \right) \dots\dots\dots (35)$$

By indices, it simplifies to

$$C_{(x)} = V^3 D_A C_m \ell^{\left(\frac{\lambda^2 t}{v} + \frac{\lambda^2 t}{D_A v^2} \right)} \dots\dots\dots (36)$$

The developed mathematical equation considered all the variables, the derived model will monitor the transport of shigella to the aquiferous zone, which is the silty and fine sand formation, the microbes are found to deposit at the shallow depth, this model developed will accommodate the progressive phase condition of the microbial transport, the study location is a coastal alluvium deposition with high rate of saline deposition whereby the fresh water environment are deposited either in shallow or in a very deep depth, this condition make quality ground water to be very difficult to abstract, all the depth at shallow aquiferous zone are not good for human consumption, because the fresh water aquifer in most instant are prone to saline intrusion, the developed model focus on the microbial transport, and to monitored the microbial transport with respect to time and distances, the model will always satisfied the predictive rate of concentration of shigella.

4. Conclusion

The model developed were able to considered all the variables in the system and this is done through the integration of all the variable as they relate in terms of developing the influence of fast migration of shigella in silty and fine sands, the model will monitor the transport of microbes to the aquiferous zone, silty and fine sand formation are found to be in its exponential level, this implies that due to high rate of porosity including the substrate that may have deposited in those formation definitely generating fast microbial growth in the shallow aquifer, this condition from the model has explain the reason why there is high rate of shigella in silty and fine sand formation, high concentration of shigella deposition in silty and fine sand formation at coastal area of bonny is a serious threat to human life. The models were able to detail the causes of fast migration of shigella in the study location.

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