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Research article

MATHEMATICAL MODELING AND SIMULATION OF POLIO-VIRUS TRANSPORT ON POROUS MEDIUM IN HOMOGENEOUS COARSE SAND IN EMUOHA RIVERS STATE OF NIGERIA

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Abstract

Modeling of polio virus to determine the behavior and its transport process at different formation has been assessed. Formation characteristics such as permeability of the soil were confirmed to established an influence on the transport of the virus to ground water aquifer, physical process where observed from high concentration to low concentration, the microbes developed lag phase conditions between sixty to eighty days, lag phase establishment implies that the deposition of the virus may have been inhibited between the lag zone. The lag zones are un-confined beds influence by geologic formation in the study area. This condition explain the stationary phase of microbial behavior under the influence of variation of the soil structural disposition between the un-confined beds, the study is imperative because polio virus is a contaminant that transport to a very long distance under the influence of high degree of porosity and permeability of the formation.

Keywords: modeling and simulation of polio virus in porous medium and coarse sand

1. Introduction

The soil is at the interface between the atmosphere and lithosphere (the mantle of rocks making up the Earth's crust). It also has an interface with the hydrosphere, i.e. the sphere describing surface water, ground water and oceans. The soil sustains the growth of many plants and animals, and so forms part of the biosphere. A combination of physical, chemical and biotic forces acts on organic and weathered rock fragments to produce soils with a porous fabric that contain water and air (pedosphere). We consider soil as a natural body of mineral and organic material that is formed in response to many environmental factors and processes acting on and changing soil permanently. Soils have been cultivated intensively for at least 5500 years. About 2000 years ago some crude soil fertility relationships were proposed for crops. The need for water was clear. Most of our scientific knowledge has been accumulated in the last 70 to 90 years [Agbalabu et al 2001]. Nigeria has abundant water resources although they are unevenly distributed over the country. The highest annual precipitation of about 3,000 mm occurs in the Niger Delta and mangrove swamp areas of the south-east, where rain falls for more than eight months a year. There is a progressive reduction in precipitation northwards with the most arid north-eastern Sahelian region receiving as little as 500 mm a -1 precipitation from about 3-4 months of rainfall. Widespread flooding occurs in the southern parts of the country, while the northern parts experience chronic water shortages during the dry season when rain fed springs, streams and boreholes dry up. Water pollution in Nigeria occurs in both rural and urban areas. In rural areas, drinking water from natural sources such as rivers and streams is usually polluted by organic substances from upstream users who use water for agricultural activities. The most common form of stream pollution associated with forestry activities is increased concentrations of soil particles washed into the stream by land disturbance. The large particles sink to the bottom and increase the bed loads while, depending on the stream velocity, smaller particles remain in suspension. In the river Niger, for example, studies have shown that the suspended matter can obstruct the penetration of light and limit the photosynthetic zone to less than 1 m depth. Suspended sediments in watercourses have become a serious concern for the water supply authorities because they lead to increased water treatment costs Nigeria has a coastline that is about 1000km long with the Atlantic Ocean, bordering eight states. These are Lagos, Ogun, Ondo, Delta, Bayelsa, Rivers, Akwa Ibom and Cross River States. While the first four states are west of the River Niger, the last three states are east of the Niger with the last Bayelsa State, straddling the river. Potable water supply to inhabitants in some of the communities in the coastal belt has been a major problem due to salt water intrusion. Communities such as Burutu in Delta State and Aiyetoro in Ondo State have no potable water source as the surface water is salty while all the boreholes drilled so far have yielded saline water. The inhabitants therefore depend on rain harvesting (in the midst of numerous gas flares from oil production platforms) and purchasing water from merchants coming from the hinterland in boats. Since the mid-‘80s, many potable water programs have been carried out in Nigeria based on the development of groundwater by the Federal Government and its agencies, States and multi-lateral agencies such as UNICEF and UNDP. Unfortunately many communities in the coastal belt are not benefiting due to perceived difficulties as a result of salt water intrusion. In this paper, a review of the geology of the coastal basins is given followed by a description of the nature of salt water intrusion. The paper is concluded by discussing the constraints to the development and management of potable water in the coastal areas in Nigeria.[Lawrence,1997,Oteri,2003]

Coastal Nigeria is made up of two sedimentary basins: The Benin basin and the Niger Delta basin separated by the Okitipupa ridge. 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 [Horsfall and Spiff, 2011]. 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 [Horsfall and Spiff,2011]. 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 75,000km^2. 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 [Ehirim and Ofor,2011]. 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 [Horstall and spiff, 1998].

Groundwater has been described as the main source of potable water supply for domestic, industrial and agricultural uses in the southern part of Nigeria especially the Niger Delta, due to long retention time and natural filtration capacity of aquifers [Horstall and spiff, 1998,EGMA AND Terhenmen,2004 and Ogbuagu et al 2011]. Water that is safe for drinking, pleasant in taste, and suitable for domestic purposes is designated as potable water and must not contain any chemical or biological impurity [EL-Dech and Emara,2005]. Pollution of groundwater has gradually been on the increase especially in our cities with lots of industrial activities, population growth, poor sanitation, land use for commercial agriculture and other factors responsible for environmental degradation [Maratin and Frankenberger,1995]. The concentration of contaminants in the groundwater also depends on the level and type of elements introduced to it naturally or by human activities and distributed through the geological stratification of the area. It has been reported that petroleum refining contributes solid, liquid, and gaseous wastes in the environment [Decker,1981]. Some of these wastes could contain toxic components such as the polynuclear aromatic hydrocarbons (PAHs), which have been reported to be the real contaminants of oil and most abundant of the main hydrocarbons found in the crude oil mixture [Boehm et al 1981]. Once introduced in the environment, PAHs could be stable for as short as 48 hours (e.g. naphthalene) or as long as 400 days (e.g. fluoranthene) in soils [Gordon and John,2012]. They thus, resist degradation and, remain persistent in sediments and when in organisms, could accumulate in adipose tissues and further transferred up the trophic chain or web [Gordon and John,2012, Boehm et al 1981]. Groundwater has been described as the main source of potable water supply for domestic, industrial and agricultural uses in the southern part of Nigeria especially the Niger Delta, due to long retention time and natural filtration capacity of aquifers [Horstall and Spiff 1998, Egma and Terhenmen,2004 and Ogbuagu etal,2011]. Water that is safe for drinking, pleasant in taste, and suitable for domestic purposes is designated as potable water and must not contain any chemical or biological impurity [EL-dec and Emara, 2005]. Pollution of groundwater has gradually been on the increase especially in our cities with lots of industrial activities, population growth, poor sanitation, land use for commercial agriculture and other factors responsible for environmental degradation [Martin and Frankenberger, 1995]. The concentration of contaminants in the groundwater r also depends on the level and type of elements introduced to it naturally or by human activities and distributed through the geological stratification of the area. It has been reported that petroleum refining contributes solid, liquid, and gaseous wastes in the environment [Decker, 1981].Some of these wastes could contain toxic components such as the polynuclear aromatic hydrocarbons (PAHs), which have been reported to be the real contaminants of oil and most abundant of the main hydrocarbons found in the crude oil mixture [Boehm et al 1981]. Once introduced in the environment, PAHs could be stable for as short as 48 hours (e.g. naphthalene) or as long as 400 days (e.g. fluoranthene) in soils [Gordon and John, 2012]. They thus, resist degradation and, remain persistent in sediments and when in organisms, could accumulate in adipose tissues and further transferred up the trophic chain or web [Gordon and John, 2012]

2. Materials and Method

Column experiments were also performed using soil samples from several borehole locations, the soil samples were collected at intervals of three metres each (3m). An polio virus solute was introduced at the top of the column and effluents from the lower end of the column were collected and analyzed for polio virus and the effluent at the down of the column were collected at different days, analysis, velocity of the transport were monitored at different days. Finally, the results were collected to be compared with the theoretical values.

3. Theoretical background

$$\frac{\phi \partial C}{\partial t} = \frac{\partial C}{\partial x}\left[\phi D \frac{\partial C}{\partial x}\right] - V\frac{\partial C}{\partial x} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

Applying Laplace transformation into equation (1) we have

$$\frac{\partial C}{\partial t} = SC_{(t)} - C_{(o)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (2)$$

$$\frac{\partial C}{\partial x} = SC_{(x)} - C_{(o)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

$$\frac{\partial C}{\partial x} = SC_{(x)} - C_{(o)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

$$\frac{\partial C}{\partial x} = SC_{(x)} - C_{(o)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (5)$$

$$C = C_{(o)} \qquad \text{…………………………….} \qquad (6)$$

Substituting equation (2), (3), (4), (5) and (6) into equation (7) yields

$$\phi\left[SC_{(t)} = SC_{(x)} - C_{(o)}\right] - \phi D\left[SC_{(x)} = SC_{(x)} - C_{(x)}\right] - VC_{(o)} \qquad \text{……} \qquad (7)$$

$$\phi SC_{(x)} - \phi S^{1}{}_{(x)} - C_{(o)} - \phi D\, SC_{(o)} - \phi D\, C_{(o)} - V\, C_{(o)} \qquad \text{…………..} \qquad (8)$$

Considering the following boundary as:

$$\text{at } t = 0,\ C^{1}{}_{(o)} = C_{o} = 0 \qquad \text{…………………………….} \qquad (8)$$

We have

$$C_{(x)}\left(\phi S - \phi S - \phi DS\right) = 0 \qquad \text{…………………………….} \qquad (9)$$

$$C_{(x)} \neq 0 \qquad \text{…………………………….} \qquad (10)$$

Considering the boundary condition

$$\text{at } t > 0,\ C(^{1}{}_{(o)} = C_{(o)} = C_{o} \qquad \text{…………………………..….} \qquad (11)$$

$$SC_{(t)} - \phi DS_{(x)} - VC_{(x)} = \phi SC_{o} + \phi D C_{o} + V C_{o} \qquad \text{…………..……} \qquad (12)$$

$$\left[\phi S - \phi D - V\right] C_{(x)} = \left[\phi S + \phi + \phi D\right] C_{o} \qquad \text{…………..……} \qquad \text{……} \qquad (13)$$

$$C_{(x)} = \frac{\phi S + \phi + \phi D}{\phi S - \phi DS + V} C_{o} \qquad \text{…………..…………………..….} \qquad (14)$$

Applying quadratic expression, we have

$$S = \frac{-b \pm \sqrt{b^{2} - 4ac}}{2a} \qquad \text{………………………………} \qquad (15)$$

Where $a = \phi$, $b = \phi D$, $c = V$

$$S = \frac{-\phi D \pm \sqrt{\phi D^{2} - 4\phi v}}{2\phi} \qquad \text{………………………………} \qquad (16)$$

$$S_1 = \frac{\phi D - \sqrt{\phi D^2 - 4\phi v}}{2\phi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (17)$$

$$S_2 = \frac{\phi D + \sqrt{\phi D^2 - 4\phi v}}{2\phi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (18)$$

$$S_1 = \phi D + \frac{\left[\sqrt{\phi D^2 - 4\phi v}\right]}{2\phi}\, S_2 = \frac{\phi D - \sqrt{\phi D^2 - 4\phi v}}{2\phi}\, \ell^{\frac{\left[\phi D + \sqrt{\phi D^2 - 4\phi v}\right]}{2\phi}\frac{V}{t}} +$$

$$\frac{\left\lfloor - \phi D \; - \phi D \sqrt{\phi D^2 + 4\phi v}\right\rfloor}{2\phi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (19)$$

Applying Laplace inverse of the equation, we obtain

$$C_t = \left[\frac{\phi}{t} + \phi + \phi D\right] \frac{\left[\phi D + \sqrt{\phi D^2 + 4\phi v}\right]}{2\phi} t + \ell^{\frac{\left[\phi D - \sqrt{-\phi D^2 + 4\phi v}\right]_t}{2\phi}} \qquad \ldots\ldots\ldots \qquad (20)$$

But if $V = \frac{d}{t}$

$$\left[C[L,t] = \phi \big/ d \big/ t + \phi + \phi D\right] C_o\, \ell^{\frac{\left[\phi D + \sqrt{\phi D^2 + 4\phi v}\right]}{2\phi}\frac{d}{t}} \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (21)$$

At $C(^1{}_{(o)} = t \neq 0$

Considering the following boundary condition as:

$$\text{at } t = 0,\; C^1{}_{(o)} = 0 \quad C_o = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots. \qquad (22)$$

$$C_{(x)} = \left[\phi \big/ t + \phi + \phi D\right] C_o \left[\ell^{\frac{\left[\phi D + \sqrt{\phi D^2 + 4\phi v}\right]}{2\phi}}\right]^{\frac{d}{t}} + \frac{\left[\phi D \sqrt{\phi D^2 + 4\phi v}\right]}{2\phi}\frac{d}{t} \qquad \ldots\ldots\ldots \qquad (23)$$

at $C^1{}_{(o)} = t \neq 0$

Again $C_o = C_o$

This implies

$$C_o = [\phi + \phi D]C_o [1+1]\; i.e.\; 0 = [\phi + \phi D]2 \qquad \dots\dots\dots\dots\dots\dots\dots\dots \qquad (24)$$

$$\Rightarrow \quad \phi D + \phi D = 0 \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \qquad (25)$$

So that we have

$$C_{(x)} = \left[2 \phi\!\!\diagup_{t}\right] C_o \, \ell^{\frac{\left[\phi D + \sqrt{\phi D^2 + 4\phi v}\right]}{2\phi} + \frac{\left[\phi D + \sqrt{\phi D^2 + 4\phi v}\right]}{2\phi}} \qquad \dots\dots\dots\dots\dots\dots\dots\dots \qquad (26)$$

However, $e^x + e^{-x} = 2Cosx$

Therefore, we have

$$C_{(x)} = \left[2\phi\!\!\diagup_{t}\right] C_o \; Cos \frac{\left\lfloor \phi D + \sqrt{\phi D^2 + 4\phi v} \right\rfloor}{2\phi} t \qquad \dots\dots\dots\dots\dots\dots\dots\dots \qquad (27)$$

If $t = \dfrac{d}{V}$

$$C_{(x)} = \left[2\phi\!\!\diagup_{t}\right] C_o \; Cos \frac{\left\lfloor \phi D + \sqrt{\phi D^2 + 4\phi v} \right\rfloor}{2\phi} t \qquad \dots\dots\dots\dots\dots\dots\dots\dots \qquad (29)$$

$$\boxed{C_{(x)} = \left[2\phi\!\!\diagup_{t}\right] C_o \; Cos \frac{\left\lfloor \phi D + \sqrt{\phi D^2 + 4\phi v} \right\rfloor}{2\phi} \frac{d}{V}} \qquad \dots\dots\dots\dots\dots\dots \qquad (28)$$

4. Result and Discussion

Mathematical modeling and simulation of polio-virus transport on porous medium in homogeneous coarse sand are presented in table and figures

Table 1: Comparison of theoretical and experimental values of polio virus at various depths

Time	Theoretical values	Experimental values
10	163.53	161.75
20	63.95	62.88
30	24.44	25.57
40	2.48	2.45
50	-11.07	-11.34

60	-18.69	-18.44
70	-22.03	-23.11
80	-21.85	-21.23
90	-18.86	-17.98
100	-10.56	-10.22
110	-8.33	-8.98
120	-2.46	-2.89

Figure 2: Comparison of theoretical and experimental values of polio virus at various depths

Time	Theoretical values	Experimental values
10	89.2	87.23
20	34.88	35.1
30	13.48	13.56
40	1.35	1.78
50	-6.01	-6.23
60	-10.31	-10.56
70	-11.46	-12.57
80	-11.57	-12.22
90	-9.64	-10.1
100	-7.67	-7.88
110	-4.54	-5.1
120	-1.35	-1.22

Figure 3: Comparison of theoretical and experimental values of polio virus at various depths

Time	Theoretical values	Experimental values
10	241.59	241.98
20	94.48	94.87
30	36.24	35.98
40	3.67	4.1
50	-16.45	-16.22
60	-27.72	-28.44
70	-32.61	-34.44
80	-31.79	-30.99
90	-27.01	-27.88
100	-20.79	-19.89
110	-12.31	-12.77
120	-3.65	-4.1

Figure 4: Comparison of theoretical and experimental values of polio virus at various depths

Time	Theoretical values	Experimental values
10	174	173
20	85.31	85.75
30	54.03	57.03
40	38.7	37.4
50	28.49	29.1
60	21.34	20.89
70	16.16	16.34
80	12.04	13.2
90	8.6	7.99
100	5.72	6.1
110	3.29	2.99
120	1.22	1.12

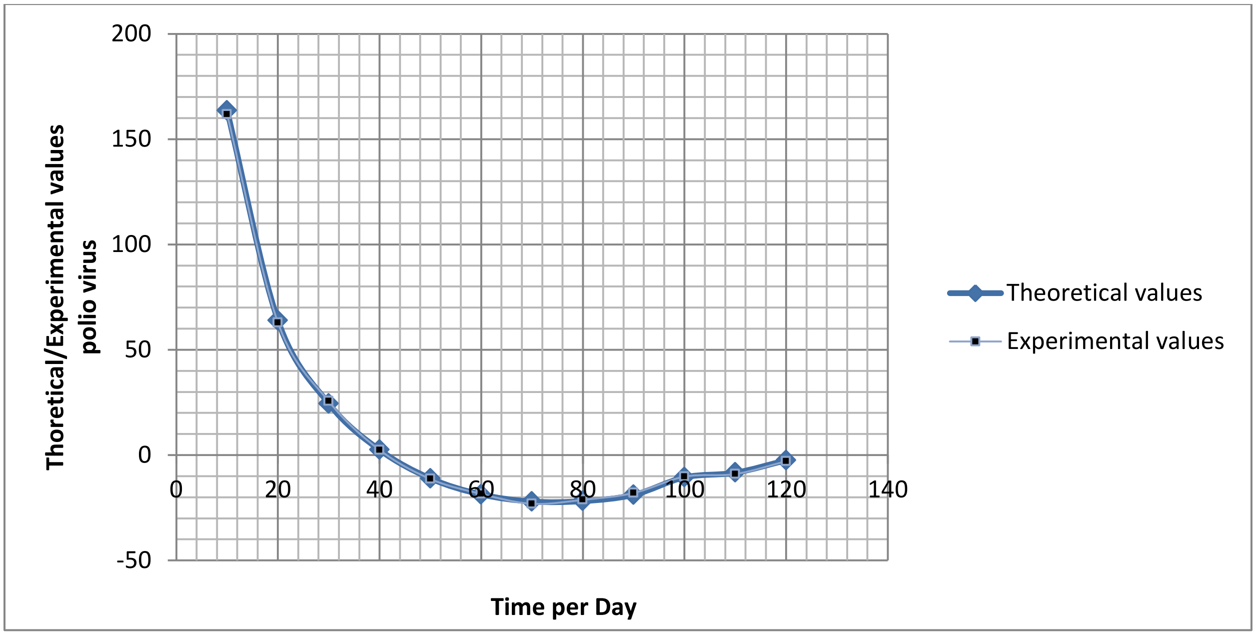

Figure 1 : Comparison of theoretical and experimental values of polio virus at various depths

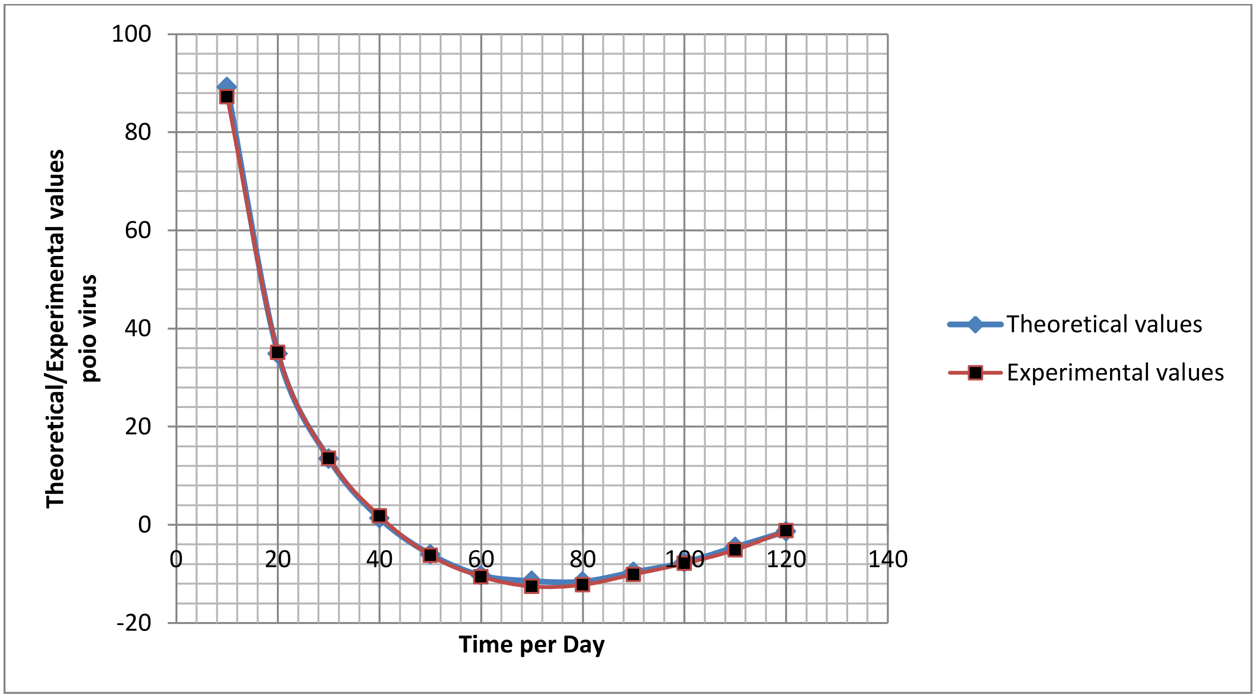

Figure 2: Comparison of theoretical and experimental values of polio virus at various depths

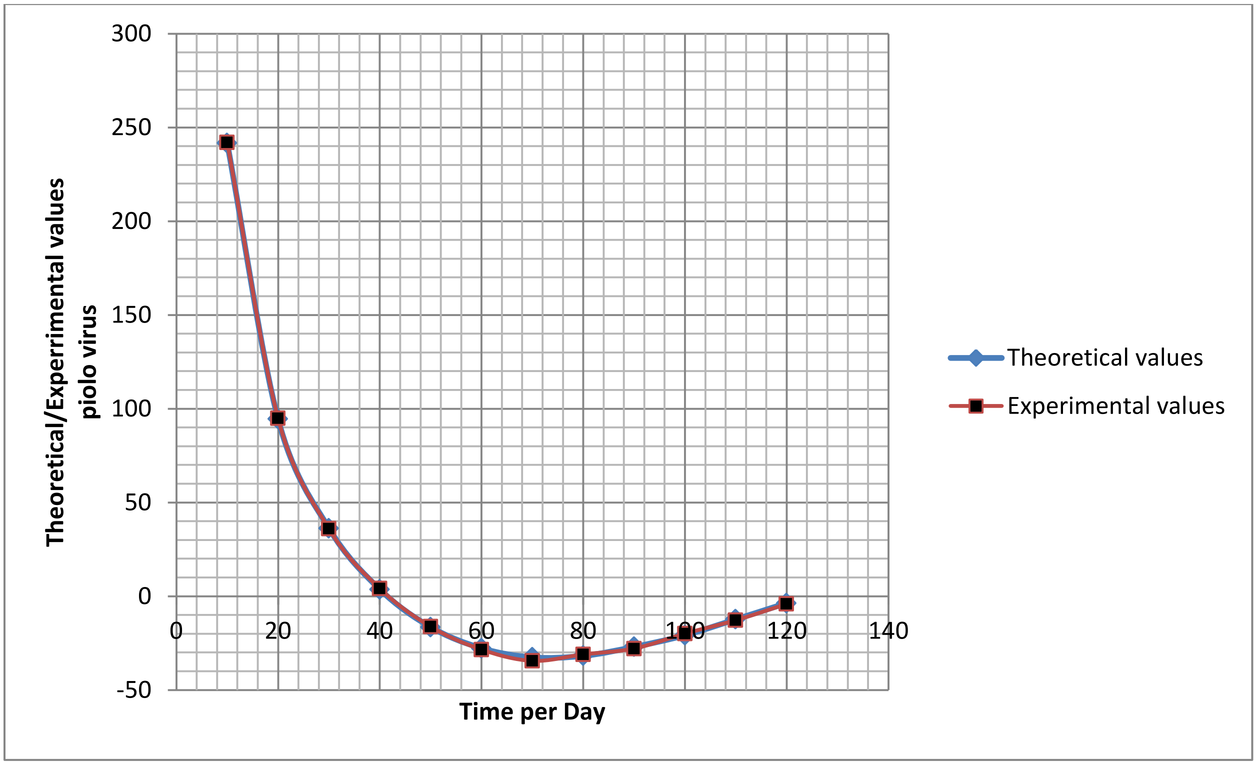

Figure 3 : Comparison of theoretical and experimental values of polio virus at various depths

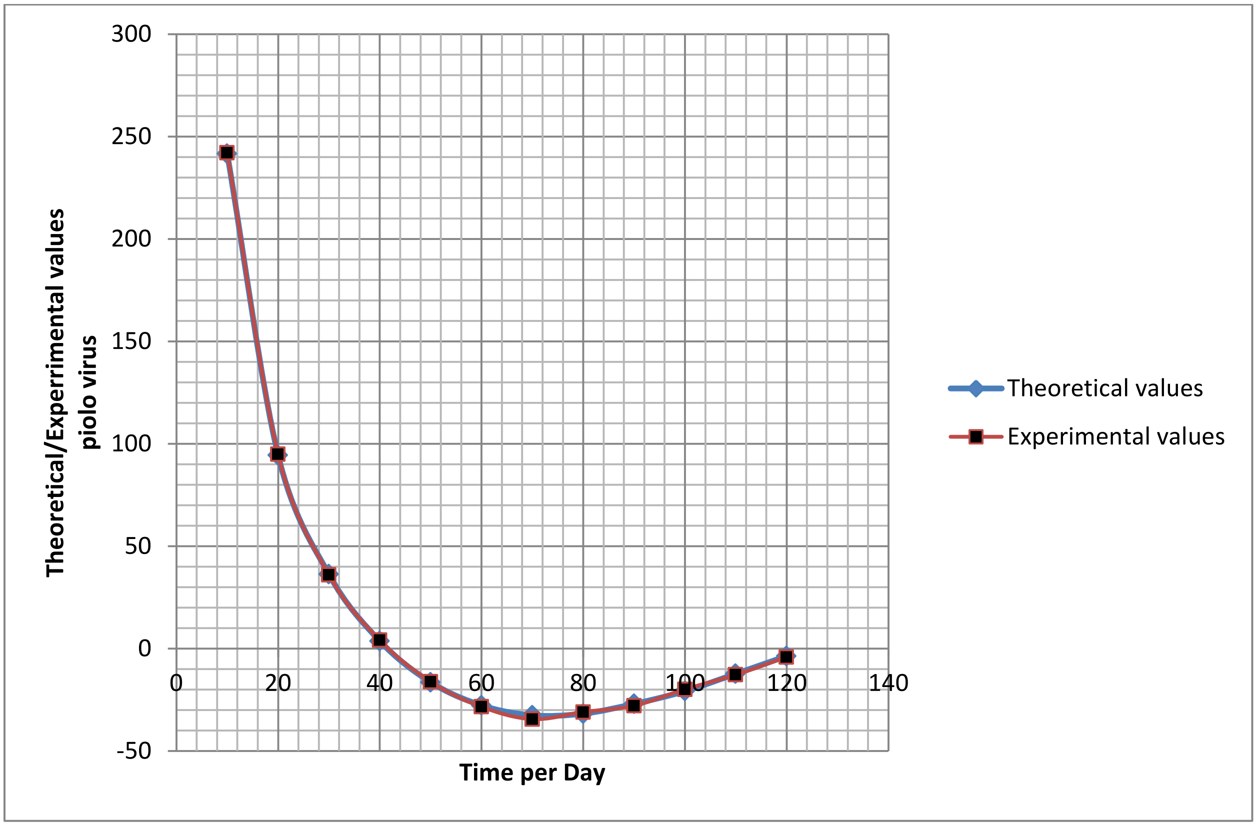

Figure 4: Comparison of theoretical and experimental of polio virus at various depths

Figure one shows that high concentration of polio virus is established at ten days, sudden increase were observed between twenty to forty days, lag phase were experienced between sixty t o twenty one days, while the experimental values in the same vein maintained similar condition as the highest concentration were recorded at ten days. Lag phase were experienced between forty and hundred days, this condition can be attributed to change in concentration with respect to distance, including environmental condition and stratification variation of the formation. Figure two observed high degree of concentration between ten and twenty days, gradual decrease were observed between fifty days, stationary phase were experienced between seventy and hundred days, while the experimental values maintained the same condition on migration as expressed from the figure. Figure three experienced fast migration of the microbes at ten days, sudden decrease were observed between twenty and forty days, stationary phase were observed between sixty and hundred days with slight migration recorded at one twenty. Experimental values expressed the highest concentration at ten days. Sudden decreases were recorded between twenty and thirty days while lag phase were experience between fifty to and eighty days, ninety to hundred. Figure four observed a rapid increase at ten days and suddenly decrease where experienced from twenty days to sixty days, where stationary phase was observed. Slight increase were experienced between eighty to hundred days, while experimental values obtained it maximum concentration at ten days, sudden decrease were observed where lag phase were experienced between sixty and eighty days, gradual increase were recorded from ninety to hundred days, the virus are one of the contaminant that transport to a very long distance in soil and water environment, rapid increase were recorded between the made and lateritic soil, this condition can be attributed to rapid generation of waste by the activity of man. Formation characteristics such as porosity and high degree of saturation influence by high rain intensity were confirmed to play a major role in transport of virus, lag phase were observed between sixty and ninety meters under the influence of variation of soil deposition in the stratum. Environmental conditions play some roles on the deposition of the virus as presented in the figures. Lag phase condition can be attributed to the regeneration of biological waste and different temperature of the soil.

5. Conclusion

Mathematical model to monitor the rate of polio virus in soil and water has been establish, the model were establish to predict the behavior and deposition of polio virus in soil and water environment. Geologic histories were confirmed to play a major role on the rate of transportation of this contaminant to ground water aquifer. Stationary phase were observed between sixty to ninety days that can be attributed to the degree of substrate deposition at the period of transportation between those soil formation, this condition does not imply that contaminant were not deposited, but the virus only experience lag in those period under the influence of environmental conditions and other inhibitors deposited in the formation. The generation of the microbes may be possible if the substrate are found to deposit more in other formation, it is recommended that polio virus should be traced in those location that develop high rate of generation of virus transporting down to ground water aquifers as presented in the figures.

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