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Flow Net Modeling on Uniform Silty Sand in Alluvia Coastal Area of Buguma

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Abstract

This paper monitored a structured silty soil based on the geological setting of the area. The depositions develop other formation characteristics that have been established under the influences of the geological conditions in the study location. The behaviour of flow net condition are determined by such characteristics and the study has express the behaviour of flow net in terms of effect from alluvia deposition. The predominant parameter in the flow net is the permeability of the soil, which plays major role on the direction of flow. The combination of flow lines and equipotential lines develop the flow net. From the simulation, it was observed that linearization of the flow net was predominant and these may be based on the alluvia influence based on the geological setting. Thorough expression of the flow net was expressed through development of mathematical modeling method and a model was generated to monitor the deposition of fluid flow direction in the formation. The developed model was simulated and it produced theoretical values which were compared with other measured values. Both parameters developed a favuorable fits validating the model on flow net for alluvia deposited silty formation.

Keywords: Alluvia; Flow Net; Modeling; Silty sand.

1. Introduction

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 [1,2].

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Potable water is safe for drinking, pleasant in taste and suitable for domestic purposes and must not contain any chemical or biological impurity [3]. 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. 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 [4]. 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 [5]. 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 [6]. Thus, they 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 [7,8].

Uniformity of stratum is based on geologic history and geomorphology, including the geochemistry that influences the constituent of the formations. This characteristic determines the rate of microbial migration to ground water aquifers. Rivers State is situated about 60 km from the open sea lying between longitude $6^o55'$E to $7^o10'$E of the Greenwich meridian and latitude $4^o38'$N to $4^o54'$N of the Equator, covering a total distance of about 804 km^2 [9]. In terms of drainage, the area is situated on the top of Bonny River and is entirely lowland with an average elevation of about 15m above sea level [10]. The topography is under persuading of tides which is consequence to flooding especially during rainy season [11]. Climatically, the city is situated within the sub-equatorial region with the tropical monsoon weather characterized by high temperatures, low pressure and high relative dampness all the year round. The mean annual temperature, rainfall and relative dampness are 30^oC, 2,300 mm and 90% respectively. The soil in the area is mainly silty-clay with interaction of sand and gravel while the vegetation is an amalgamation of mangrove swamp forest and rainforest [12]. Rivers state falls within the Niger Delta Basin of Southern Nigeria which is defined geologically by three sub-surface sedimentary facies: Akata, Agbada and Benin formations [13]. The Benin Formation (Oligocene to Recent) is the aquiferous formation in the study area with an average thickness of about 2100m at the centre of the basin. This consists of coarse to medium grained sandstone, gravels and clay with an average thickness of about 2100m at the centre of the basin [14]. The Agbada formation consists of alternating deltaic (fluvial coastal, fluviomarine) and shale, while Akata formation is the basal sedimentary unit of the entire Niger Delta, consisting of low density and high pressure shallow marine to deep water shale. The quantity and quality of ground water resources of any region are restricted by the climate and geology of the area. The climate through rainfall and surface water resources ensure steady supply or recharge to groundwater resources of an area in a complex hydrological cycle. The geology of the region determines the aquiferous zones where exploitable groundwater may occur and this influences the geochemical characteristics of the groundwater, amongst other factors such as human activities [15]. The geochemical characteristics of the groundwater in turn influence the quality of the groundwater resources. Earlier works by [16,17,18,19,20] have confirmed the influence of local geology on the aquifer characteristics and quality of groundwater resources of any area. Human activities may also influence the quality of groundwater in the region [21].

2. Materials and Methods

Column experiments were done using soil samples from several borehole locations. The soil samples were collected at intervals of 200mm each (0.2m). Water was introduced at the top of the column and the outflows from the lower end of the column were collected at intervals using a stopwatch to monitoring the rate of flow. At different stratum, the rate of flow and its velocity at different time and depth were determined. The results of the net flow were applied to the governing equations. The experimental net flow values were compared with the theoretical values to determine the validation of the Model.

2.1 Governing Equations

Deterministic modeling techniques were used by applying analytical solution. The governing equation for the study is expressed in Equation 1:

$$V\frac{\partial q}{\partial z} = K\frac{\partial q}{\partial t} + \frac{n_f}{N_d}\frac{\partial q}{\partial z} \quad (1)$$

Where

K = Permeability

V= Velocity

q = Flow net

Z = Depth

T = Time

$\frac{n_f}{N_d}$ = Porosity of soil

$$V\frac{\partial q}{\partial z} - \frac{\partial q}{\partial z} = \frac{\partial q}{\partial z} + K + \frac{n_F}{N_d} \quad (2)$$

$$(V-1)\frac{\partial q}{\partial z} = \frac{\partial q}{\partial z} + K + \frac{n_F}{N_d} \quad (3)$$

$$(V-1)\frac{\partial q}{\partial z} = \frac{\partial q}{\partial t} \quad (4)$$

$$0 \ = \frac{\partial q}{\partial z} + K + \frac{n_F}{N_d} \tag{5}$$

i.e. $$\frac{\partial q}{\partial z} = -K + \frac{n_F}{N_d} \tag{6}$$

From (5), integrate directly

$$q \ = \ \left(-K - \frac{n_F}{N_d} \right) t + q_1 \tag{7}$$

From (6) $$(V - 1)\frac{\partial q}{\partial z} = \frac{\partial q}{\partial t}$$

Let $$q \ = \ ZT \tag{8}$$

$$\frac{\partial q}{\partial z} = Z^1 T \tag{9}$$

$$\frac{\partial q}{\partial t} = ZT^1$$

Substitute (9) and (10) into (3), we have

$$V - 1\ Z^1 T \ = \left(\ K + \frac{n_F}{N_d} \right) ZT^1 \tag{11}$$

$$V - 1 \frac{Z^1}{Z} \ = \left(\ K + \frac{n_F}{N_d} \right) \frac{T^1}{T} \tag{12}$$

$$V - 1 \frac{Z^1}{Z} \ = \phi \tag{13}$$

$$\left(\ K + \frac{n_F}{N_d} \right) \frac{T^1}{T} = \phi \tag{14}$$

From (13) $$\frac{Z^1}{Z} \ = \ \frac{\phi}{V - 1} Z \tag{15}$$

$$\text{In } Z = \frac{\phi}{V-1} Z + q_3 \tag{16}$$

$$Z = A\ell^{\frac{\phi}{V-1} Z} \tag{17}$$

$$\text{From (14)} \left(K + \frac{nf}{Nd} \right) \frac{T^1}{T} = \phi$$

$$T = \frac{\phi}{K + \frac{n_F}{N_d}} \tag{18}$$

$$\text{In } T = \frac{\phi}{K + \frac{n_F}{N_d}} t + q_3 \tag{19}$$

$$T = B\ell^{\frac{\phi}{K + \frac{nf}{Nd}} t} \tag{20}$$

Put (17) and (20) into (8) yield:

$$q_2 = A\ell^{\frac{\phi}{V-1} Z} \bullet B\ell^{\frac{\phi}{K + \frac{nf}{Nd}} t} \tag{21}$$

$$q_2 = AB\ell^{\left(\frac{Z}{V-1} + \frac{t}{K + \frac{nf}{Nd}} \right) \phi} \tag{22}$$

Hence general solution becomes

$$q[Z,T] = q_1 + q_2 \tag{22}$$

$$q[Z,T] = AB\ell^{\left(\frac{Z}{V-1} + \frac{t}{K + \frac{nf}{Nd}} \right)} \phi \tag{23}$$

3. Results

Results of the flow net of Silty sand from the column experiments at different depth and time are presented in Tables 1 and 2 while the comparison of theoretical and measured values of Silty sand at different depth and time per day are presented in Tables 3 and 4. The graphical representation of the flow net of Silty sand at different depth and time per day are presented in Figures 1 and 2 while the comparison of theoretical and measured value of the silty sand flow net at different depth and time per day are represented in Figures 3 and 4.

Table 1: Flow Net of Silty Sand at Different Depth

Depth [m]	Flow Net [M/sec]
0.2	1.44E-0E
0.4	1.43E-03
0.6	1.42E-03
0.8	1.46E-03
1	1.51E-03
1.2	1.56E-03
1.4	1.58E-03
1.6	1.59E-03
1.8	1.63E-03
2	1.64E-03
2.2	1.66E-03
2.4	1.68E-03
2.6	1.73E-03
2.8	1.74E-03
3	1.76E-03

Table 2: Flow Net of Silty Sand at Different Time

Time per day	Theoretical Values[M/sec]
2	1.56E-03
4	1.57E-03
6	1.59E-03
8	1.64E-03
10	1.66E-03
12	1.68E-03
14	1.72E-03
16	1.75E-03
18	1.78E-03
20	1.81E-03
22	1.83E-03
24	1.85E-03
26	1.87E-03
28	1.89E-03
30	1.90E-03

Table 3: Comparison of Theoretical and Measured Values of Silty Sand at Different Depth

Depth [m]	Theoretical Values [M/sec]	Measured Values [M/sec]
0.2	**1.44E-03**	**1.23E-03**
0.4	**1.43E-03**	**1.27E-03**
0.6	**1.42E-03**	**1.31E-03**
0.8	**1.46E-03**	**1.34E-03**
1	**1.51E-03**	**1.36E-03**
1.2	**1.56E-03**	**1.40E-03**
1.4	**1.58E-03**	**1.43E-03**
1.6	**1.59E-03**	**1.45E-03**
1.8	**1.63E-03**	**1.46E-03**
2	**1.64E-03**	**1.48E-03**
2.2	**1.66E-03**	**1.50E-03**
2.4	**1.68E-03**	**1.52E-03**
2.6	**1.73E-03**	**1.54E-03**
2.8	**1.74E-03**	**1.56E-03**
3	**1.76E-03**	**1.58E-03**

Table 4: Comparison of Theoretical and Measured Values of Silty Sand at Different Time per Day

Time per day	Theoretical Values [M/sec]	Measured Values [M/sec]
2	**1.62E-03**	**1.26E-03**
4	**1.62E-03**	**1.28E-03**
6	**1.62E-03**	**1.29E-03**
8	**1.62E-03**	**1.32E-03**
10	**1.62E-03**	**1.34E-03**
12	**1.62E-03**	**1.36E-03**
14	**1.62E-03**	**1.38E-03**
16	**1.63E-03**	**1.41E-03**
18	**1.63E-03**	**1.44E-03**
20	**1.63E-03**	**1.46E-03**
22	**1.63E-03**	**1.48E-03**
24	**1.63E-03**	**1.51E-03**
26	**1.63E-03**	**1.53E-03**
28	**1.63E-03**	**1.56E-03**
30	**1.63E-03**	**1.59E-03**

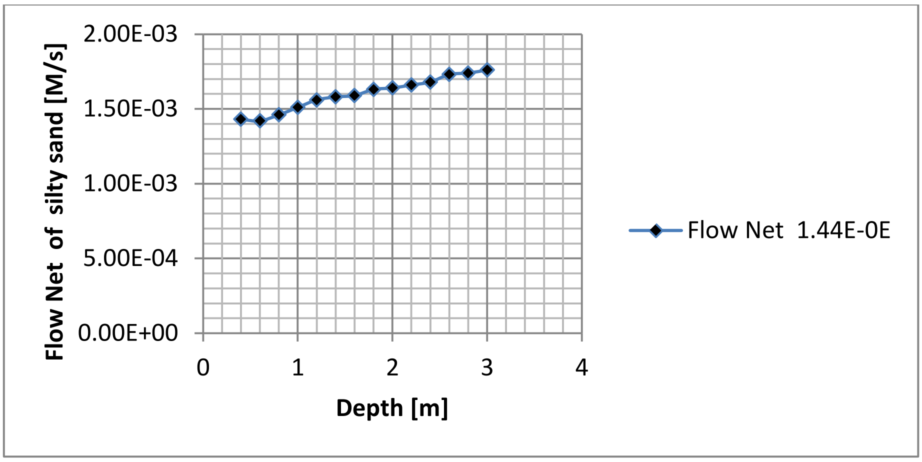

Figure 1: Graphical Representation of Silty sand Flow Net at Different Depth

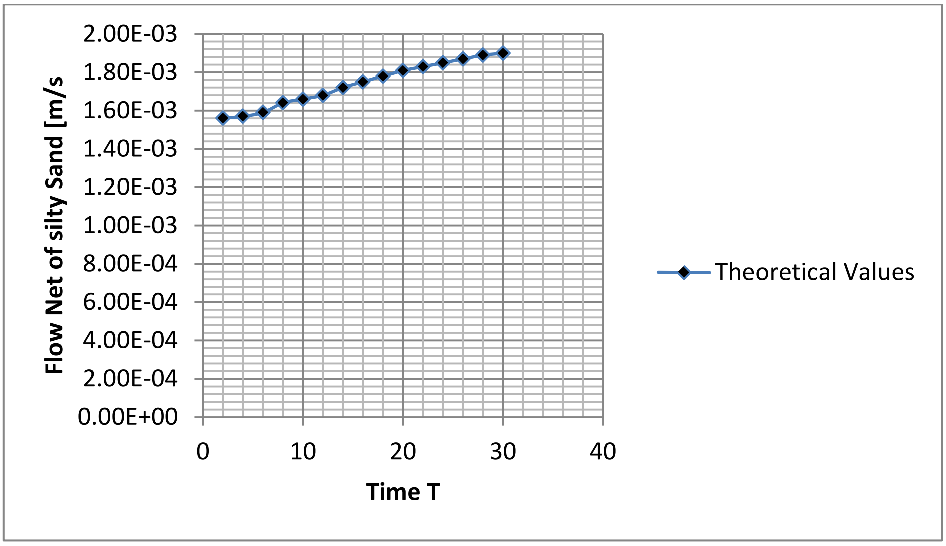

Figure 2: Graphical Representation of Silty sand Flow Net at Different Time

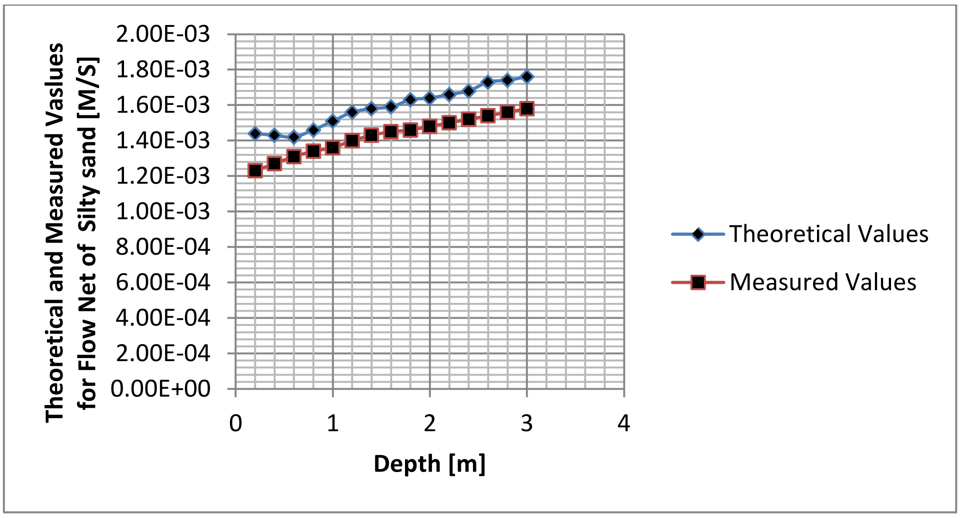

Figure 3: Comparison of Theoretical and Measured Silty sand Flow Net at Different Depth

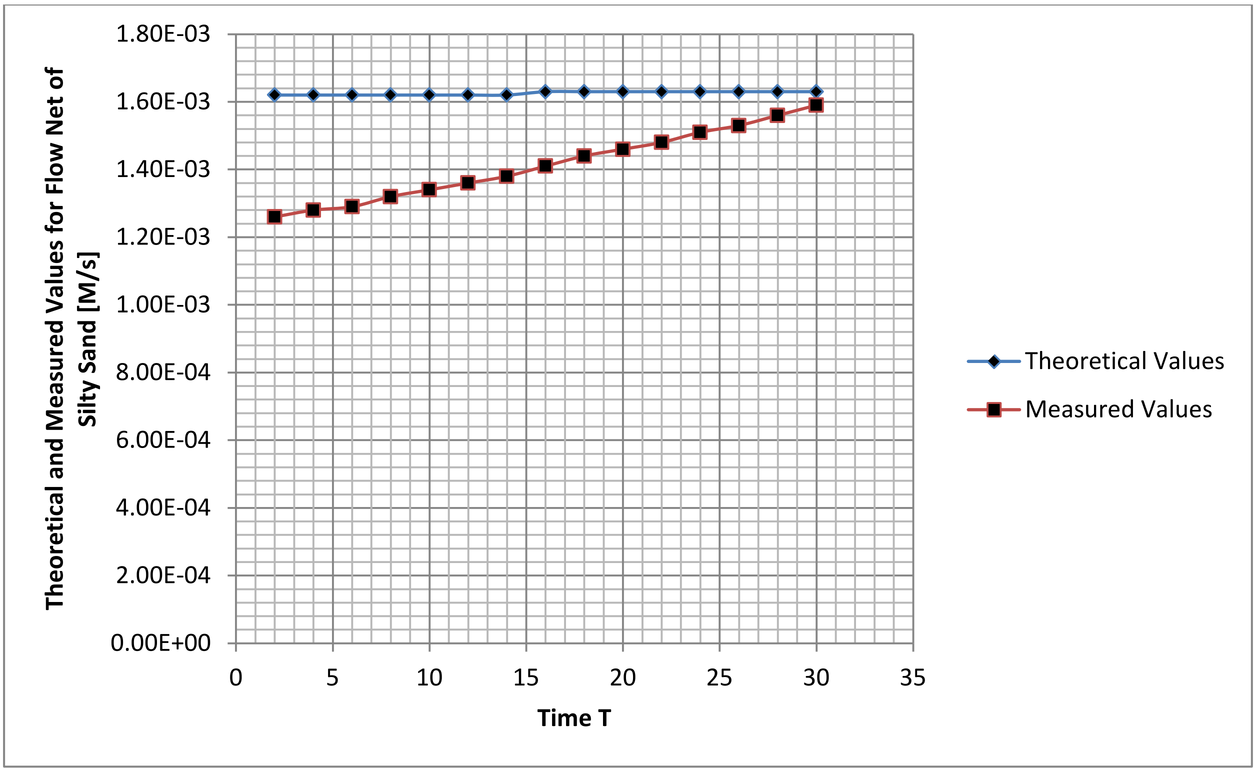

Figure 4: Comparison of Theoretical and Measured Silty sand Flow Net at Different Time

Figure 1 shows the behaviour of flow net in the study area. These are basically on linear direction as shown in the formation. Rapid rate of flow was observed and these were influences from lithology of the study environment. Moreover, it can be attributed to the structure of the geological deposition in the study area. The structural setting of the formation determined the flow direction under the influences of formation characteristics.

Similar condition was observed in Figure 2. The flow net was determined with respect to time and a linear increase was observed with slight fluctuation. This can also be attributed to slight heterogeneity in disintegrations of structured sediment deposition through the macrospores of the silty formation.

However, Figure 3 expressed the comparison between the theoretical and measured values at different depth. Both parameters observed linear direction of flow with slight vacillation in few depths. Figure 4 also expressed the comparison between the theoretical and measured values with respect to time and this maintain similar trend but expressed linearization to a point were both parameter developed an intercept. Subject to this relation, the behaviour of flow net through the piezometric head corresponds to the equipotential lines. In most cases, it is through the direction of seepage from the flow channels per unit length perpendicular to the vertical section through the permeable layers. The expression in the system monitored it in vertical direction in the flow elements. These were completely drowned as approximate square and the drop of piezometric level between any two adjacent equipotential lines is the same as the potential drops the behaviour of the system. These were based on the expressed flow condition under the influences of formation variation deposited in the strata.

5. Conclusions

Theoretical values generated from the developed model were compared with experimental values for validation of the model. The behaviour of the flow in uniform strata implies that the development of the flow was influenced by the deposited Alluvia setting of the formation as it is expressed from the results. Predominant formation characteristic was permeability which was expressed at homogeneous setting applied in uniform silty formation. The developed governing equation expressed derived solution which was generated from the model. This model was applied for simulation. The study has actually streamlined the behaviour of the fluid flow direction under the influences of various predominant deposition of permeability in the study area. The developed model considered the parameters that definitely influence the system which is expressed in the governing equation. The model developed will actually generate the rate of flow net in homogeneous structural setting of silty formation.

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