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Research article

MATHEMATICAL MODELING OF UNSATURATED SOIL MULTIFLOW ASSESSMENT ON HYDROCARBON CONTAMINATION IN COASTAL AREA OF OKIRIKA, RIVERS STATE OF NIGERIA.

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Abstract

Hydrocarbon contamination is one of the major causes of soil degradation in deltaic environment; this type of contaminants has cause lots of pollution in soil and water environment. The soil will become infertile; the soil bear capacity will reduce the aquifer will pollute and contaminate groundwater. Rapid transports of these contaminants are caused by different factors. To monitor the rate of hydrocarbon on unsaturated soil, the system developed considered the dependent and independent variables, expressing the variable through mathematical tools, governing equation that will express unsaturated soil multiflow assessment of hydrocarbon were developed, the derived mathematical equation considered every condition that influence the system, the variables considered different phase of the soil deposition before fluid mixing with the hydrocarbon substance on the soil, the model developed also considered the geological deposition that influence the stratification of the soil. The rate of porosity and permeability were the independent variables considered because it plays a major role in the transport of these contaminants. The model developed expressed the conditions that affect the rate of this contaminant in transport process; the model will definitely monitor the rate of hydrocarbon on multiflow in unsaturated soil in the study area.

Keywords: modeling of unsaturated soil multiflow assessment, hydrocarbon and contaminants

1. Introduction

The studies of hydraulic conductivity are determined by the soil structural deposition. This influence of stratification is where variable that influence the soil matrix is expressed. The study of hydrocarbon transport spread on the soil causing environmental pollution is the focus of the study. The pollution sources are caused by some influences, which could be manmade activities or natural origin, the rate of oil exploration, without environmental risk assessment, and environmental statement are the major risk hazard, the stipulated environmental laws should as a baseline in solving environmental related problems caused of manmade activities.

This area under study is deltaic environment; there is high rate of oil exploitation and exploration. More so, as a deltaic environment, the environmental pollution from oil spillage has affected a lots of marine habitat, aquatic lifes, soil pollution; it has generated a lots of diseases, consequently reducing the life span of human settlers in the area. Considering these conditions it become imperative that model should be developed to monitor the effect of hydrocarbon transport influenced by hydraulic conductivity and porosity of soil.

Petroleum hydrocarbons (PHCs) are universal site contaminants, but they are not normally regulated as hazardous wastes. Methods for sampling and analysis of environmental media for the family of PHCs are normally thought of as TPH methods. For purposes of this profile, the expression TPH refers not only to investigative results, but also to environmental and health properties of PHCs. In part due to the difficulty of TPH mechanism themselves, little is known about their prospective for health or ecological impacts. As gross procedures of petroleum pollution, TPH consequences simply show that petroleum hydrocarbons are present in the sampled media. Measured TPH values suggest the relative potential for human exposure and, therefore, the relative potential for human health effects. The evaluation of health effects due to TPH exposure requires much more comprehensive information than what is provided by a single TPH value.

The federal government has left much of the particular regulation and oversight of crude oil manufacture refining to the states. Leaking underground storage tanks (LUST) are the most recurrent causes of federal and state governmental participation in petroleum hydrocarbon problems. Soil contamination has been a growing concern, because it can be a source of groundwater (drinking water) pollution; contaminated soils can decrease the usability of land for development; and weathered petroleum residuals may stay bound to soils for years. Affirmative TPH test results may require action on the part of land owners, local or state governments, and engineering firms called on to remove or reduce the TPH problem.

ATSDR has the responsibility for health assessment at National Priorities List (NPL) hazardous waste sites, many of which have petroleum hydrocarbon contamination. Specific contaminants that are components of TPH, such as BTEX (benzene, toluene, ethyl benzene, and xylene), n-hexane, jet fuels, fuel oils, and mineral-based crankcase oil, have been studied by ATSDR and a number of toxicological profiles have been developed on individual constituents and petroleum products. (Rando; and Lioy 1992).
Hydraulic Soil Fracturing (“HSF”) is an adjustment of conservative hydraulic fracturing, traditionally used in the oil & gas industry, to increase the effectiveness of remediation in contaminated, low permeability soils. It is a process whereby sand-laden slurry is pumped into a formation (i.e. soil or rock) at a rate and pressure high enough to

overcome the in situ confining stress and the material strength of a formation resulting in the creation of a fracture or parting. The resulting fracture contains permeable sand which keeps the fracture “propped” open and serves as a permeable pathway for the flow of fluids toward the well. Conventional Hydraulic Fracturing has been used in the petroleum industry since the late 1940’s to enhance the production of oil and gas from low yielding formations which would otherwise be uneconomical to produce. When a hydraulically fractured well is produced, the induced fractures provide permeable pathways so that fluids can flow to the well at a greater rate than would otherwise be possible. Presently, about 70% of all oil and gas wells drilled worldwide are hydraulically fractured to stimulate and enhance their production.

Hydraulic Soil Fracturing, when coupled with the appropriate remedial technology(s), as been shown to enhance the effectiveness of clean-ups in low permeability soils (ie. Hose with a hydraulic conductivity of 10-6 m/s or less). The fracturing process creates a network of sub horizontal to sub vertical fracture pathways in the contaminated soil mass. The permeable fractures created in this manner become the preferred migration Pathways for the subsequent removal or in-place degradation of contaminants. Frequently, the network of sand-filled fractures intersects natural fractures and permeable lenses in which contamination often resides. This serves to drain the contamination more effectively and generally results in an increased radius of influence and contaminant removal or treatment rate for the recovery well. Furthermore, as contaminant migration in fine-grained soils is controlled to a large degree by diffusion, the fracture network significantly lessens the time to remediate a site by reducing the length of the diffusion pathways.

Soil thermal properties to include thermal conductivity and resistivity, specific heat and thermal diffusivity are required to conduct analysis and modeling associated with numerous agricultural, hydrological and industrial applications. In addition to characterizing the soil’s physical/hydraulic properties, knowledge of the soil’s thermal properties is necessary for proper soil and water management in irrigated agriculture (e.g., Noborio et al. 1996).

Heat and water transfer are strongly coupled processes, creating transient temperature, water content and thermal conductivity distributions/gradients in unsaturated near-surface conditions. Understanding of this coupled process is limited due to a lack of thorough experimental testing thus restricting testing and refinement of coupled heat and water transfer theory (Heitman et al. 2007, Kathleen et al 2009). A number of studies have demonstrated specific processes for subsurface storm flow occurrence, including transmissivity feedback, flow through the fractured bedrock, kinematic wave routing and flow through discrete preferential pathways. Perhaps the most common mechanism for rapid subsurface flow on steep, wet hill slopes is lateral preferential flow at the soil-bedrock interface (Mosley, 1979; McDonnell, 1991, 1990; Tsuboyama et al., 1994; Weiler et al., 1998, 2003; Sidle et al., 2000).

Empirical studies of lateral preferential flow found in the literature show how lateral pipe flow controls hillslope response in steep upland forest environments, (Uchida et al., 1999 2003, 2001), nutrient flushing, (Buttle et al., 2001), and old water delivery to streams (McDonnell, 1990). Notwithstanding, few process models exist that incorporate these process findings (Jones and Connelly, 2002). Indeed the dialog between experimentalist and modeler in tackling these challenges is extremely limited. The lack of knowledge about lateral preferential flow may be the largest impediment for moving forward in catchment modeling–thus, the effect of soil pipes and other structures on the lateral flow and transport at the hillslope scale is viewed as a major control still awaiting good model-process integration (Markus et al 2005).

When modeling the distribution of moisture within soil profiles and across catchment landscapes, it is important to have a comprehensive knowledge of the permeability characteristics of the soil medium. Soil permeability, however, is dependent on geological history, geomorphologic processes, and the level and nature of interaction with the biosphere. Consequently, soil permeability exhibits a high level of spatial variability (with variations sometimes exceeding 3 orders of magnitude; Rasmussen *et al.* 1993). As a result, a large number of soil permeability measurements are required to reliably characterise areas of interest. Permeability data have traditionally been obtained through *in situ* measurements using water infiltration or pore water pressure dissipation tests (Ahuja *et al.* 1976; Lunne *et al.* 1997) or have involved the transport of numerous samples back to the laboratory where the hydraulic conductivity is estimated experimentally using a permeameter or odometer (Head 1994; Holland *et al.* 2000). Both approaches are time consuming, labour-intensive, and consequently expensive, thereby making adequate collection of permeability data unlikely in practice. Soil permeabilities determined with water as the infiltrating fluid can also be affected by the presence of encapsulated air in dry soils. In partially saturated soils, changes to the soil structure during wetting can also occur as a result of the interaction between electrolytes in the water and exchangeable cations in the soil (Blackwell *et al.* 1990), or due to changes in matric suction. One alternative is to utilize pedotransfer functions such as those proposed by Jarvis *et al*. (2002) to estimate hydraulic conductivity; however, as these authors point out, direct measurements are more reliable for site-specific applications. In this study, an indirect *in situ* method of determining soil hydraulic conductivity is undertaken that uses a gas as the infiltrating fluid in place of the traditional approaches that employ water. The advantage of using gas permeabilities to determine hydraulic conductivity is that *in situ* gas permeability measurements can be undertaken much more readily than corresponding water determinations, enabling more extensive surveys to be undertaken in the field. Furthermore, the problem of electrolyte interaction with the soil is no longer an issue nor is encapsulation (as long as the soil is sufficiently drained). In a study of the removal of volatile contaminants from unsaturated soils, (Tony et al, 2006).

2. Theoretical Background

Hydraulic conductivity is the rate at which soil can hold on fluid, when the degree of saturation is very high, the rate of fluid increases to the extent that these saturation rate is high. Such soil hold water at high volume, the rate of hydraulic conductivity of the soil is determined based on the geological formation of the study area. As a deltaic environment, the rate of hydraulic conductivity and porosity of the strata are very high, these conditions allow fast migration of contaminant from in every source.

The study focused on hydrocarbon, the contaminant expedited and are distributed through distribution network of the pipe; if the pipe develops crack and spill form those leakages, Hydrocarbon will continue to transport and pollute the soil, the study area are found to have lots of hazards from hydrocarbon spillage, and the concepts were developed by Victor et al 2010, the concept were modified to suite the condition of the deltaic environment in the study location. The influences of the fast transport of the hydrocarbon are considered as a variable that denoted through the application of mathematical tools that form the system. The variables are as follows:

ϕ	=	Soil porosity [-]
Sw	=	Saturation of soil [-]
Hw	=	Water height – equivalent pressure for phase oil given by hp = pplg/pw [-]
Rw	=	Net mass transfer per unit porous media volume for oil $[M/L^3]$
g	=	gravitational acceleration $(L/T^2]$
Uz	=	Unit gravitational vector, measured positive upward [⊥]
Pw	=	Density of water $[ML^{-3}]$
Z	=	Elevation [L]
Time	=	[T]
Ko	=	Phase conductivity tensor for oil [L/T]

$$Sw\phi\frac{\partial hw}{\partial t} = \frac{\partial}{\partial z}\left[Kw\left[\frac{\partial hw}{\partial t} + PRWUz\right]\right] + \frac{\partial}{\partial z}\left[Kw\left[\frac{\partial hw}{\partial z} + PRWUz\right]\right] + \frac{Rw}{Pw} \quad \ldots\ldots \quad (1)$$

This equation was linearized in other to simplify the solution considering all the variables in the system, denoted using mathematical tools. In other to express there relationship that influence hydrocarbon transport and polluted the soil. The following expressions are applied:

Substituting hw = ZT into equation (1)

$$S\phi Z^1T = Z\left[Kw\left[Z^1T + PRWUz\right]\right] + Z^1\left[Kw\left[Z^1T + PRWUz\right]\right] + \frac{Rw}{Pw} \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$SW\phi\frac{T^1}{T} = \left[Kw\left[\frac{Z^1}{Z} + PRWUz\right]\right] + \left[Kw\left[\frac{Z^1}{Z} + PRWUz\right]\right] + \frac{Rw}{Pw} \quad \ldots\ldots\ldots\ldots \quad (3)$$

$$SW\phi\frac{T^1}{T} = \left[Kw + PRWUz\right]\frac{Z^1}{Z} + Kw\frac{Z^1}{Z} + \left[\frac{Kw + PRWUz}{ZT}\right] \quad \ldots\ldots\ldots\ldots \quad (4)$$

$$SW\phi\frac{T^1}{T} = PRWUz\frac{Z^1}{Z} + Kw + Kw\frac{Z^1}{Z} + Kw\,PRWUz + \frac{Rw}{Pw} \quad \ldots\ldots\ldots\ldots \quad (5)$$

$$SW\phi\frac{T^1}{T} = Kw + Kw\,PRWUz + \frac{Rw}{Pw} = \lambda^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$SW\phi\frac{T^1}{T} = \lambda^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$Kw\frac{Z^1}{Z} = \lambda^2 \qquad \text{……………………………. (8)}$$

$$SW\phi = \lambda^2 \qquad \text{……………………………. (9)}$$

This implies that equation can be expressed

$$KwPRWUz + \frac{Rw}{Pw} = \lambda^2 \qquad \text{……………………………. (10)}$$

This expression simplifies that some of the parameters that has major influence in the system are spitted and their relation are derived to determine their influence on the variable are expressed as:

$$Kw\frac{dy}{dz} = \lambda^2 \qquad \text{……………………………. (11)}$$

$$\frac{dy}{dz} = \frac{\lambda^2}{Sw\phi} \qquad \text{……………………………. (12)}$$

$$dy = \left(\frac{\lambda^2}{Sw\phi}\right)dz \qquad \text{……………………………. (13)}$$

$$\int dy = \int\left(\frac{\lambda^2}{Sw\phi}\right) = dz \qquad \text{……………………………. (14)}$$

$$dy = \frac{\lambda^2}{Sw\phi}dz \qquad \text{……………………………. (15)}$$

$$\int dz = \int\frac{\lambda^2}{Sw\phi}dz \qquad \text{……………………………. (16)}$$

$$y = \frac{\lambda^2}{Sw\phi}z + C_1 \qquad \text{……………………………. (17)}$$

$$0 = \frac{\lambda^2}{Sw\phi}z + C_1 \qquad \text{……………………………. (18)}$$

$$C_1 = \frac{-\lambda^2}{Sw\phi}z \qquad \text{……………………………. (19)}$$

This expression is streamlined, the variables in the system that should have a relationship with the independent variables. The major independent variables are the hydrocarbon contaminating the soil, and degree of porosity

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influence fast migration of hydrocarbon. Base on the soil condition, the derived model equation expresses at equation (19) convey the influence of porosity on hydrocarbon with respect to distance, whereby the transport is obeying the law of plug flow, migrating from one formation to another formation, influenced by porosity.

But for further expression of these parameters, the relationship in terms of variables functions of various parameters are considered, quadratic equation were adopted to relate the other variables expression, to fulfill these condition in the system, quadratic expression were mathematically articulated in this form.

$$X = \frac{-b \pm \sqrt{b^2 - 4aC}}{2a} \quad \text{……………………………………} \quad (20)$$

Where a $= \frac{\lambda^2}{Sw\phi}$, $b = C_1$.

$$X = \frac{-(C_1) \pm \sqrt{(C)^2 - 4\left[\frac{\lambda^2}{Sw\phi}\right]}}{2C_1} \quad \text{……………………………………} \quad (21)$$

$$X = \frac{-C_1 \pm \sqrt{C_1^{\ 2} - 4C_1 \frac{\lambda^2}{Sw\phi}}}{2C_1} \quad \text{……………………………………} \quad (22)$$

$$\frac{-C_1 + \sqrt{C_1^{\ 2} - \frac{4C_1\lambda^2}{Sw\phi}}}{2C_1} \quad \text{……………………………………} \quad (23)$$

$$X \ \frac{-C_1 + \sqrt{C_1^{\ 2} - \frac{4C_1\lambda^2}{Sw\phi}}}{2C_1} \quad \text{… ………………………………….} \quad (24)$$

Subject equation (24) to the following boundary condition and initial values condition

$$t = 0, \ hw = 0 \quad \text{……………………………………} \quad (25)$$

Therefore,

$$Z_{(z)} = C_1 \ell^{-M_1 z} + C_2 \ell^{-M_2 z} \quad \text{…………………………………….….. } (26)$$

$$= \quad C_1 \, Cos \, M_1 z + C_2 \, Sin \, M_2 z \qquad \ldots\ldots\ldots\ldots \quad (27)$$

Solving equation (19) gives

$$C_1 = \frac{\lambda^2}{Sw\phi} z$$

$$hw(z,t) = \left(C_1 \, Cos \; M_1 \frac{\lambda^2}{Sw\phi} z + C_2 \, Sin \, M_2 \frac{\lambda^2}{Sw\phi} z \right) \qquad \ldots\ldots\ldots\ldots \quad (28)$$

But if $z = \frac{v}{t}$

$$hw(z,t) = \left(C_1 \, Cos \; M_1 \frac{\lambda^2}{Sw\phi} \frac{v}{t} + C_2 \, Sin \, M_2 \frac{\lambda^2}{Sw\phi} \frac{v}{t} \right) \qquad \ldots\ldots\ldots\ldots \quad (29)$$

The model established is to monitor the unsaturated soil multiflow assessment on hydrocarbon contaminant, the soil unsaturated are contaminated by hydrocarbon, reciprocally carry its natural structure deposition and decreasing lot of soil values. But when hydrocarbon were introduced through pipe spillage on the unsaturated horizon of soil the pollution is confirm to reduce the bearing capacity including fertility of the soil and it other characteristics, the rate of contamination is determined through soil stratification, based on the soil matrix. It is known also to be influenced by other environmental factors e.g. climatic condition of the study area. The location under study is prone to high rain densities, the rate of unsaturation will rapidly decrease due to high rain intensities. The conditions allow rapid migration of hydrocarbon spillage from the distribution network.

Hydrocarbon in this study is found to mix together with the fluid from the soil, and rapidly contaminated the entire soil in the study area. Other factors will definitely increase high rate of migration, the rate of diffusion and dispersion; these variables are some of the influences that cause increase in migration. The final model equation also considered these parameters that are insignificant influence on the system, but focus more on the variables that expresses the major problem in the system.

Mathematical model expression considered the variables because the parameters are integrated in the system found to influence hydrocarbon in unsaturated soil and migrate to other region of the soil; this reduced the bearing capacity; fertility and minerals that will be good or productivity to the country at large.

Considering the required parameters that influence the soil migration, it is based on the established relationship in their migration process to other regions in the soil formation. The expressed model developed will assess the hydrocarbon in unsaturated soil through multiflow that influence contaminated hydrocarbon; the model can be applicable for simulation and model validation.

4. Conclusion

Unsaturated soil in multiflow assessment from hydrocarbon contaminant is a serious problem in the study; the deltaic environment is prone to spillage of hydrocarbon, through pipeline Vedas, high rate of economy sabotage has cause a lots of hydrocarbon pollution in the deltaic environment, contaminant mixed with fluid that deposited on the soil will definitely generate high pressure transport of the hydrocarbon influence through soil structural deposition. The influence of the system considered these variables including fast diffusion and dispersion, it has also increase high concentration of hydrocarbon on the soil formation, such characteristics are the basic causes of contaminants at rapid rate. The developed model considered different conditions based on the geologic history in the study location, the study area has been suffering from infertility of the soil from pollution of hydrocarbon contaminating groundwater aquifer, surface water like creeks are prone to serious environmental hazard emanating from hydrocarbon pollution. The development model that considered the basic cause as independent variables were thorough the expression in the system, deriving the mathematical equation, the model was developed. Model that can be applied to monitor the rate of hydrocarbon contaminant in unsaturated soil, migrating through multiflow in the soil and water environment.

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