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One Dimensional Flow through Variably Saturated Soil Profile of Guwahati City, Assam, India

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Abstract—*The flow through a variably saturated zone is complicated and it is difficult to describe it quantitatively. As there is often changes in the state and content of soil water during flow so the flow through this zone is considered to be a highly nonlinear problem. In this study two one dimensional flow models M_1 for pre-monsoon period and M_2 for post monsoon period were developed for the Pandu location of Guwahati city, Assam, India. The flow through variably saturated layered soil profile is studied using HYDRUS-1D software considering favorable climatic condition. The pressure head and water content were determined for both the models and a comparative study is carried out to see the variation of pressure head and water content during the pre-monsoon and post monsoon period. The results obtained after the simulation conclude that during pre-monsoon period the pressure head is more as compared to the post-monsoon period. In the meanwhile, for the case of water content there is a variation at different depth for both the period. This study may be used as an effective tool in the branch of agriculture and science in order to study the amount of water content that will be available for both the periods at required depth and location.*

Keywords: *nonlinear, Richard's equation, Unsaturated, HYDRUS-1D, pressure head, water content.*

1. INTRODUCTION

Unsaturated zone or variably saturated zone is the zone that lies between ground surface and groundwater table which contains solid soil particles, along with air and water. A major component of precipitation that falls on the earth surface eventually enters into the ground by the process of infiltration through the unsaturated zone and finally reaches to the ground water table. As there is often changes in the state and content of soil water during flow so the flow through this zone is considered to be a highly nonlinear problem. Transport of soil water has many applications in the field of hydrology, meteorology, agronomy, environmental protection and many more. Basically, the Richard's equation for variably-saturated water flow solved numerically. From the general review of literature it has been found that almost all the simulation problem of the unsaturated flow is done using the θ-based and h-based form of Richard's equation. With this equation form different type of finite elements and finite difference method has been used to solve this problem [3][8][11]. A mixed form of Richard's equation is also used to simulate the water flow using modified Picard's iteration method [1]. An analytical solution using exponential function is proposed to linearize the Richard's equation [10]. The computational efficient of the algorithm used by [2] is improved by developing a new convergence criteria for the modified Picard's method [5]. To account for variability in the soil properties, many modifications are made to the flow equation, such as, a sink term to account for water uptake by plant roots, and dual-porosity type flow or dual-permeability type flow to account for non-equilibrium flow.

The main objective of this study is to develop a one dimensional flow model through the unsaturated zone in Pandu location of Guwahati city, Assam, India. HYDRUS-1D is one of the computer codes based on the finite element method is used for the simulation of the flow through this zone. The work presented in this paper will describe variation of pressure head and water content at different depth for successive time period.

1.1 Governing Equation

The one- dimensional head-based form of the Richards equation given by [7] be written as-

$$\frac{\partial\theta(\varphi)}{\partial t} = \frac{\partial}{\partial z}\left[K(\varphi)\left(\frac{\partial\varphi}{\partial z} - cos\beta\right)\right] - S(\varphi) \qquad (1)$$

Where, φ is the water pressure head [L], θ is the volumetric water content [L^3L^{-3}], t is time [T], z is the spatial coordinate [L] (positive upward), S is the sink [$L^3L^{-3}T^{-1}$], β is the angle between the flow direction and the vertical axis (i.e., $\beta = 0^0$ for vertical flow) and K is the unsaturated hydraulic conductivity function [LT^{-1}]

Since in equation (1) both the water content (θ) and the unsaturated hydraulic conductivity (K) are nonlinear functions of the pressure head (φ) so there required a constitutive relationship for the solution.

Constitutive Relationships

The relationship proposed by [11] gives the relationship between $\theta - \varphi$ and $K - \theta$ as follows-

$$\theta(\varphi) = \theta_r + \frac{\theta_s - \theta_r}{(1+|\alpha\varphi|^n)^m} \quad (2)$$

$$K(\varphi) = K_s S_e^l \left[1 - (1 - S_e^{1/m})^m\right]^2 \quad (3)$$

Where, θ_r is the residual water content [L^3L^{-3}], θ_s is the saturated water content [L^3L^{-3}], α [L^{-1}], n and m (= 1 – 1/n) are unsaturated soil parameters, l is the pore connectivity parameter [-], K_s is the saturated hydraulic conductivity [LT^{-1}], and S_e = effective saturation, defined as-

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad (4)$$

1.2 Initial and boundary condition for flow:

$$\varphi(0, z) = \varphi_0 = -100\text{cm} \quad (5)$$

$$\left| -k\frac{\partial\varphi}{\partial z} - k \right| \leq E \quad (6)$$

$$\frac{\partial\varphi(t,\infty)}{\partial z} = 0 \quad (7)$$

Where, φ_0 is the initial pressure head potential and E is the maximum potential rate of infiltration or evapotranspiration under the current atmospheric conditions, h is the pressure head at the soil surface . Eq. (5) indicates that the initial pressure head potential is uniformly distributed within the medium. Whereas, Eq. (6) gives an atmospheric boundary condition with surface runoff and Eq. (7) implies a free draining bottom boundary.

2. METHODOLOGY

2.1 Study Area

Guwahati is the premier city of North-East India that lies between the river Brahmaputra and the Shillong Plateau. It straddles the valley of the river Bharalu which is a small tributary of the Brahmaputra. This extends latitudinally from $26^0 5'$ N to $26^0 12'$N and longitudinally from $91^0 24'$E to $91^0 51'$E. To the west of the city lies the Nilachal Hill on the southern banks of the Brahmaputra, to the north is the Chitrachal Hill and to the south the Narakasur Hill. To the south-west of the city lies Deepor Beel, a permanent freshwater lake with no prominent inflows apart from monsoon run-off from the hills that lie to the south of the lake. The lake drains into the Brahmaputra and acts as a natural storm water reservoir for the city. This study is mainly carried out for Pandu location of Guwahati city, Assam, India (see Fig. 1)

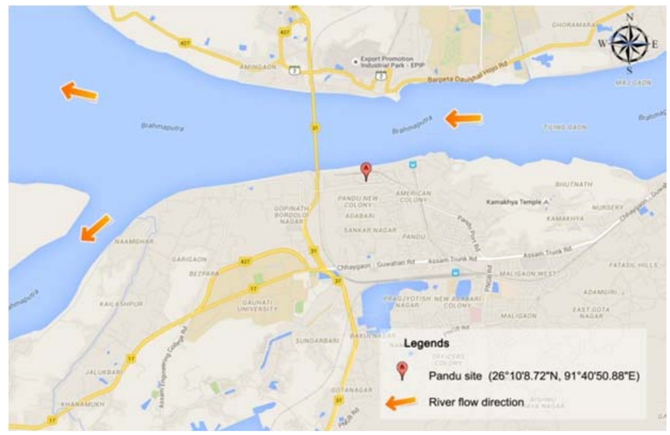


Fig. 1: Pandu location of Guwahati city, Assam, India

During pre-monsoon period the ground water table lies at a depth of 5 to 15 meters and 0.02 to 5.35 meters during post monsoon period within the greater Guwahati city [9]. So the flow models were developed considering the vertical soil profile of the unsaturated zone for a depth of 4m for model M1 and an average depth of 2m for the model M_2 for Pandu locations in Guwahati City. The data that are used in this study is taken from the soil department of Assam Engineering College, Guwahati, Assam. (see Fig. 2).

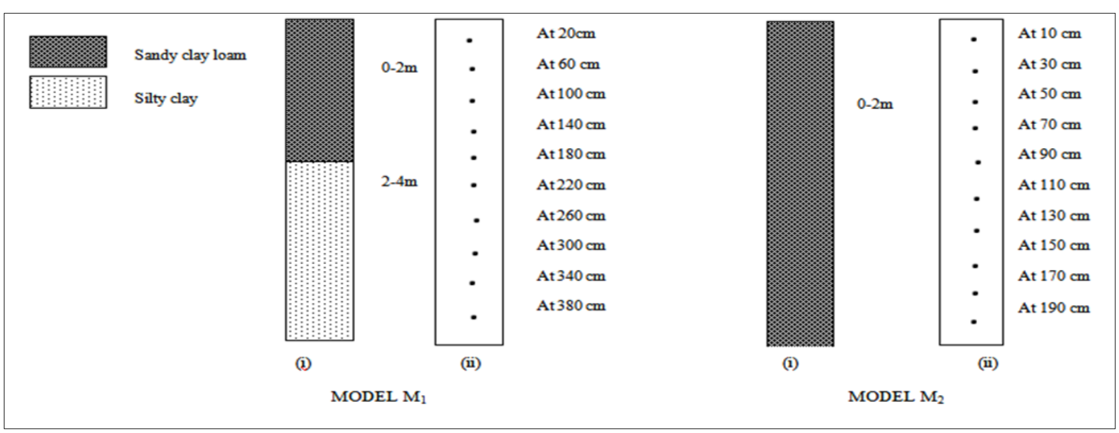


Fig. 2: Vertical soil profile for the Pandu location of Guwahati city, Assam, India (M_1 soil profile used for pre monsoon period and M_2 soil profile used for the Post monsoon period)

2.2. Development of Model:

2.2.1. Input Data

Meteorological data (Evapotranspiration and Precipitation):

As evapotranspiration varies with day and season so for this study the daily evapotranspiration is obtained using Hargreaves formula considering the solar radiation, maximum and minimum temperature [4].The daily precipitation and the data for calculating evapotranspiration are taken from the Indian Meteorological department for the month of February and October, 2013.

Soil Parameters:

Using the Meteorological data and soil parameters model

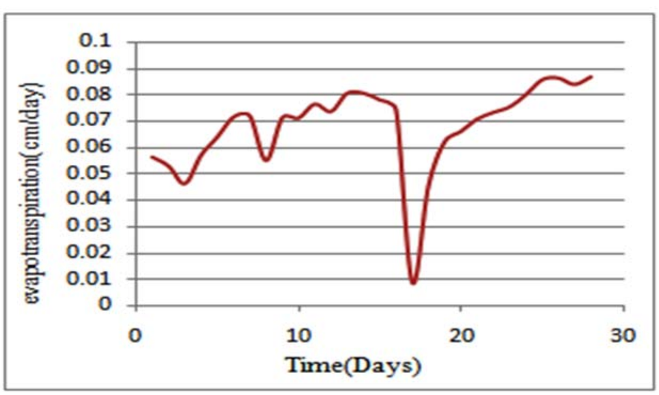
$M_1$and M_2 are developed for Pandu location with their

The different soil parameters which are considered in this study are given in the Table 1.

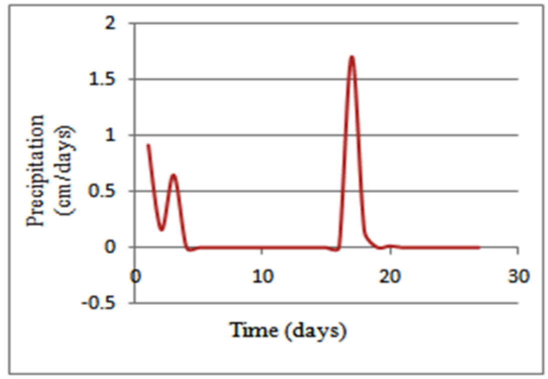
Table 1: Soil parameter for different soil type that is used in this study

Type	Sandy clay loam	Silty clay
K_S	1.68	0.48
θ_r	0.089	0.07
θ_s	0.43	0.36
α	0.01	0.005
N	1.23	1.09
L	0.5	0.5

respective soil profile (see Fig. 2). The flow equation given by Eq. (1) is simulated for 28 days considering the boundary condition as given in Eq. (5), (6) and (7). The result obtain will provide the pressure head and water content for four successive time period that is for 7, 14, 21, 28 days.

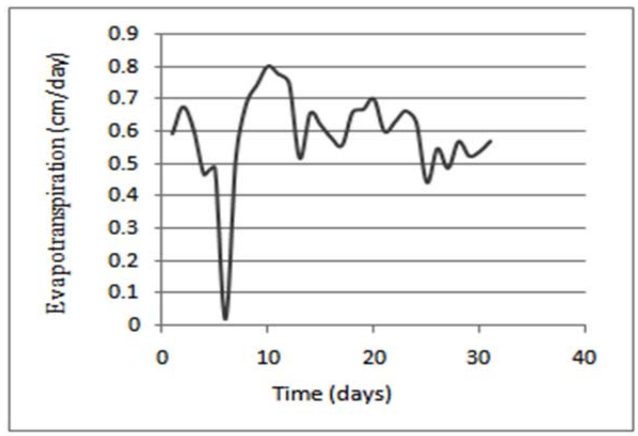


(a)



(b)

Fig. 3: Daily evapotranspiration(a) (cm/day) and precipitation(b) (cm/day) for the pre-monsoon period (February, 2013)



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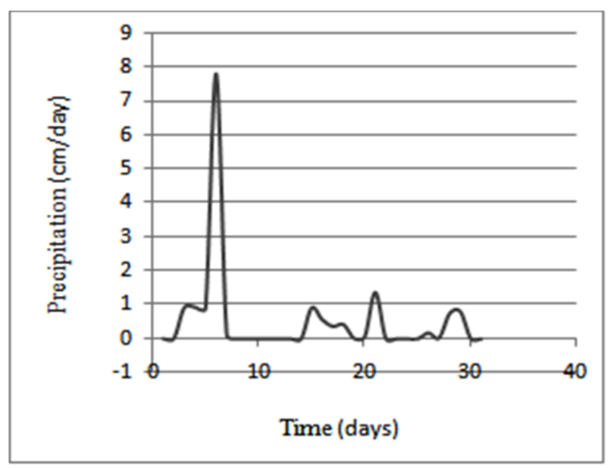
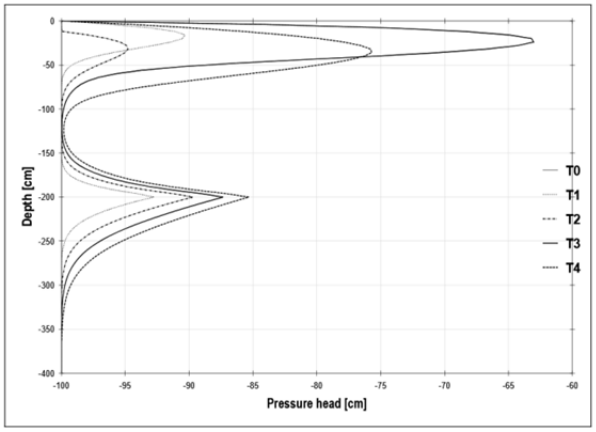


(b)

Fig. 4: Daily evapotranspiration (a) (cm/day) and precipitation(b) (cm/day) for the post-monsoon period (October, 2013).

3. RESULTS AND DISCUSSION:

From the simulation variation of pressure head and water content for both the model is seen at time steps T1=7days, T_2= 14 days, T_3 = 21days and T_4 = 28days.



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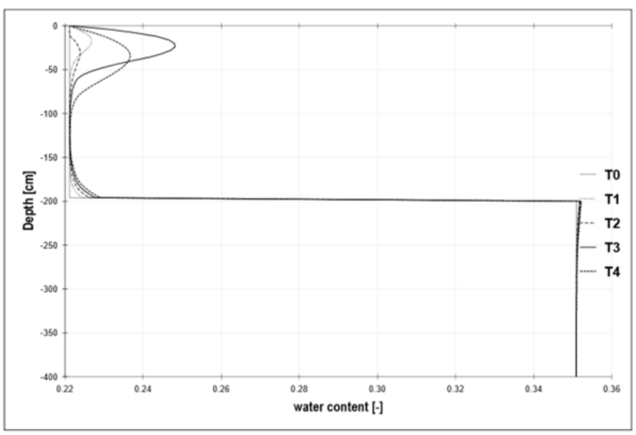

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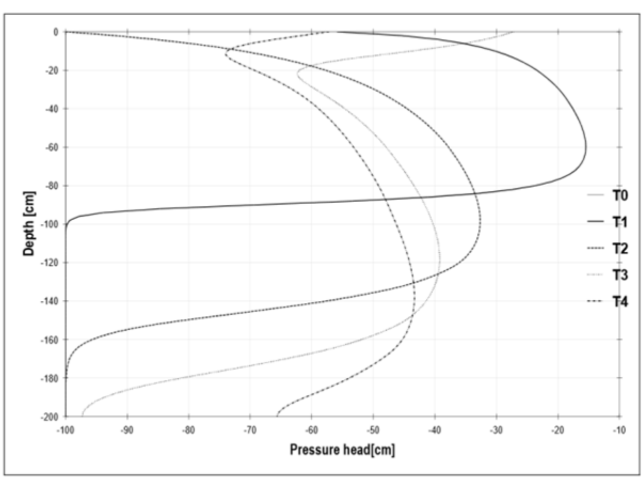

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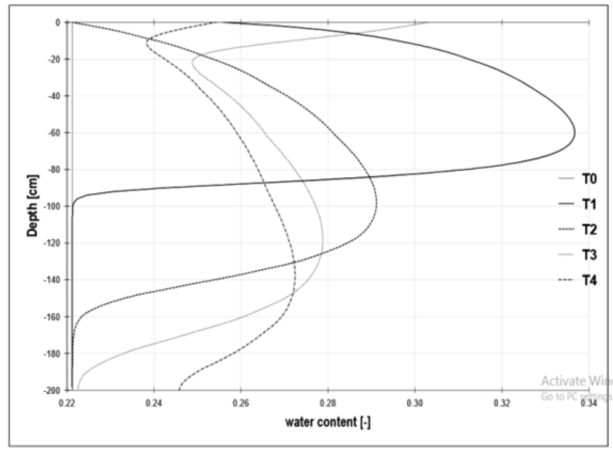
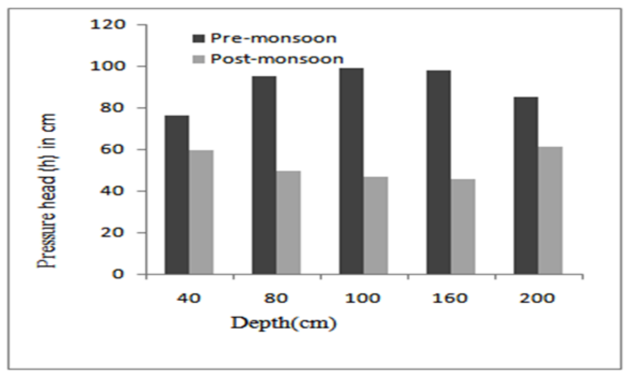


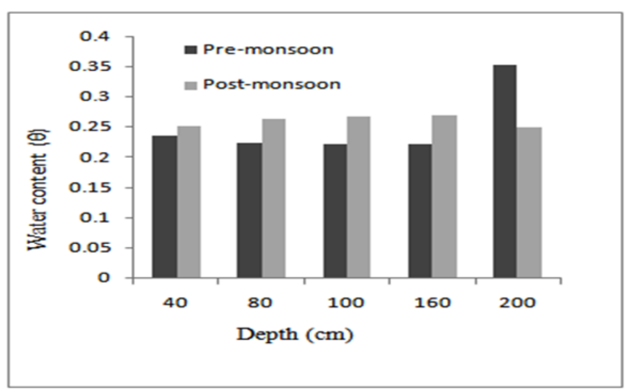
(d)

Fig. 5: Variation of Pressure head (h) and water content (theta) with depth for successive time steps T_n for Model M_1 (a,b) and model M_2 (c,d)

3.1 Comparative study of the flow Model M_1 and Model M_2:



(a)



(b)

Fig. 6: The comparative study of the Model M_1 and Model M_2 at different depth after 28 days of simulation for the Pandu location.

We can have a clear view how the pressure head at different depth is more in pre-monsoon period than the post monsoon period (See Fig. 5 and 6). This is because the amount of flux flowing through the model M_1 is more compared to the model M_2 (See Fig. 3and 4).In case of water content we can see that during pre- monsoon period the water content is less as compared to the post monsoon period, but at 200 cm of depth water content in pre monsoon period becomes higher than post monsoon period. As in the model M_1 the unsaturated zone is considered up to 4m of depth and there is a change in soil type at depth 2m so this may be the reason behind this increase in water content.

4. CONCLUSION

In this study two numerical models M_1 for pre-monsoon period and M_2 for post monsoon period were developed for the Pandu location of Guwahati city, Assam, India to study the flow through unsaturated layered soil profile under favorable climatic condition. For this study HYDRUS-1D software which is based on the finite element method is used to study pressure head and water content at different depth of the soil profile. The results obtained after the simulation conclude that From during pre-monsoon period the pressure head is more as compared to the post-monsoon period. This is because the amount of flux flowing through the Model M_1 is more compared to the model M_2(see Fig. 3 and 4). In case of water content we can see that during pre- monsoon period the water content is less as compared to the post monsoon period, but at 200 cm of depth water content in pre monsoon period becomes higher than post monsoon period as there is a change in soil type. The infiltration rate of the silty clay is less than the sandy clay loam which may be the reason for the increase in water content. There are different season crops, which require presence of a particular moisture content for their proper grown. Thus, this may be used as an effective tool in the field of agriculture and science in order to study the moisture content at required depth and location. If we try for different simulation periods for different soil profile and characteristics a comparative study can be develop in order to discover the worst downward migration scenario.

5. ACKNOWLEDGEMENT

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