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(Research Article)

Virus transport in transient flow condition through unsaturated zone using HYDRUS-1D

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Abstract

A one dimensional numerical model is developed to study the vertical movement of the water and virus transport through homogeneous unsaturated porous media. 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 finite element scheme computer coded software, HYDRUS-1D is used to simulate the one dimensional flow equation and virus transport equation. This study is mainly carried for all type of unsaturated soil. The study uses a transient flow condition of water flow that is coupled with the convective- dispersive equation for subsurface solute transport. For simulating the partial differential equation of virus transport equilibrium solute transport model is selected with Crank-Nicholson as time weight scheme and Galerkin finite elements as space weight scheme. The viruses that is been employed in this study were the male specific RNA coliphage MS2, and the Salmonella typhimurium phage, PRD1. The result from the simulation indicates that the presence of water content has influence the transport of virus through the unsaturated zone.

Keywords: HYDRUS; Unsaturated; Crank-Nicholson; Galerkin finite element

1. Introduction

Virus transport in unsaturated porous media differs from saturated media due to soil moisture content and temperature fluctuations affecting virus sorption and inactivation. Understanding virus movement requires simulating their fate and transport, influenced by advection, inactivation, hydrodynamic dispersion, and adsorption. Virus transport in unsaturated porous media is distinguished from transport in saturated porous media, because virus sorption and inactivation are considerably influenced by the soil moisture content and subsurface temperature fluctuations (Vilker and Burge, 1980; Vilker, 1981; Thompson and Yates, 1999). In unsaturated zones, liquid-solid and air-liquid interfaces impact virus sorption. The complex, nonlinear flow and variable moisture velocity necessitate solving the flow equation before addressing virus transport. This study offers a one-dimensional numerical model to predict virus behaviour in the unsaturated zone under steady-state conditions. The main objective of this study is to prepare a one dimensional numerical model for the analysis of virus transport through a layered soil profile in the unsaturated zone under steady state condition. The present study uses HYDRUS 1D software to simulate the one dimensional flow equation and the result obtain is being used for simulating the virus transport equation. For solving the virus transport equation the partial differential equation (PDE) solver available in the MATLAB is mainly used. All the data needed for this study is taken from the literature.

HYDRUS is one of the computer codes which simulating water, heat, and solutes transport in one, two, and three dimensional variably saturated porous media on the basis of the finite element method. The Richards's equation for

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variably-saturated water flow and advection-dispersion type equations (CDE) for heat and solute transport are solved deterministically (Šimůnek, et al., 2009).

Tim and Mostaghimi (1991) developed a numerical model VIROTRANS for simulating the vertical movement of water and virus through soils treated with waste water effluents and sewage sludge. Yates and Ouyang (1992) developed the VIRTUS model to predict virus fate and transport in unsaturated soils, accounting for temperature-dependent virus inactivation rates. The model, based on mass conservation principles, integrates water, virus, and heat flows through soil. It was validated against laboratory data, with predictions mostly within the 95% confidence limits. A VIRTU is useful for estimating virus contamination in groundwater and identifying key parameters for accurate experimental design. Schijven and Simunel (2002),studied the removal of bacterio-phases MS2 and PRD1 by dune recharge and removal of MS2 by deep well injection, for simulating the water flow and virus transport in the one- and two-dimensional variably saturated porous media they used the HYDRUS -1D and HYDRUS-2D.C.S.P. Ojha et al. (2012) developed a model for analyzing virus transport in the unsaturated zone by combining a mass-conservative finite difference model for moisture flow with a hybrid finite volume model for virus transport. The model's accuracy was validated against analytical solutions for advection and dispersion scenarios. Parameter estimation was performed using a nonlinear least-squares approach with the Levenberg-Marquardt algorithm, but for more than two unknown parameters, results were non-unique. Estimating two parameters was also challenging when including inactivation coefficients of sorbed phases. A priori estimation of these coefficients is recommended for unique parameter estimation. S. Bhattacharjee et al. (2002) developed a two-dimensional model to simulate virus transport in heterogeneous subsurface porous media, accounting for virus inactivation, attachment, release, and removal at solid surfaces. The model integrates both geochemical heterogeneity (e.g., metal oxyhydroxide coatings) and physical heterogeneity (e.g., variable hydraulic conductivity), considering both layered and randomly distributed heterogeneities. The upstream weighted multiple cell balance method was used to solve the governing equations. Findings indicate that subsurface heterogeneity creates preferential flow paths, significantly affecting virus mobility. While solution inactivation rates significantly influence virus transport, surface inactivation has a minimal effect. High virus release rates lead to extended breakthrough periods downstream. YounSim and Constantinos V.Chrysikopoulos (2002) developed a numerical model for one-dimensional virus transport in homogeneous, unsaturated porous media was developed. The model accounts for virus sorption onto liquid-solid and air-liquid interfaces as well as inactivation of viruses suspended in the liquid phase and viruses attached at both interfaces. The effects of the moisture content variation on virus transport in unsaturated porous media were investigated. In agreement with previous experimental studies, model simulations indicated that virus sorption is greater at air-liquid than liquid-solid interfaces. Available data from experiments of colloid transport through unsaturated columns were successfully simulated by the virus transport model developed in this study. Robert Anders and Constantinos V. Chrysikopoulos (2008) conducted laboratory-scale virus transport experiments using columns packed with sand under both saturated and unsaturated conditions. They employed the MS2 coliphage and the Salmonella typhimurium phage PRD1. Their experiments utilized a mathematical model by Simand Chrysikopoulos (2000) to fit the data, which accounts for virus removal during vertical transport in unsaturated porous media. The study found that mass transfer rate coefficients increased as saturation levels decreased for both bacteriophages. Results indicated that even under conditions unfavorable for attachment, such as a phosphate-buffered saline solution (pH=7.5; ionic strength=2mM), saturation levels significantly impact virus transport through porous media. Lance et al.[1976] and Lance and Gerba [1984] reported that decreasing the moisture content enhances virus sorption onto the solid matrix by forcing viruses to move into a thin film of water surrounding soil particles. Element et al. (1996) developed a numerical model to simulate subsurface biological processes under radial flow conditions, specifically near a nutrient injection well. Their model, which combines Euler and Lagrangian methods with reaction-operator splitting, is efficient, stable, and mass-conserving. They demonstrated its effectiveness using an in-situ bio-stimulation model with aerobic kinetics and examined how biomass distribution is affected by variations in bio-kinetic parameters. The sensitivity analysis highlighted the importance of microbial detachment and attachment processes in biomass distribution, suggesting that alternative models for these processes and their relationship to growth rates should be explored. Vilker et al. (1978) developed an 'adsorption mass transfer model' for predicting virus transport by assuming steady state flow in a homogeneous soil column and neglecting the dispersion, diffusion and inactivation (die-off). Corapcioglu and Haridas(1984) developed a generalized mathematical model for predicting the spatial and temporal distribution of concentration of microorganisms in soil assuming steady state flow. Rajib Kumar Bhattacharjya, Ambuj Srivastava, and Mysore G. Satish (2014) emphasize the importance of simulating virus transport in groundwater for predicting virus movement and devising effective remediation strategies. They identify key parameters for accurate simulation, including the linear distribution coefficient, hydrodynamic dispersion coefficient, and inactivation coefficient. Classical optimization methods often struggle with the nonlinearity and non-convexity of the error function when all parameters are considered. The study proposes a hybrid optimization approach combining genetic algorithms with the simple method, demonstrating effectiveness in solving example problems and offering a practical solution for estimating virus transport parameters. Sobsey et al (1980) and Yates et al. (1987) indicated that there is a strong relation between the virus sorption and inactivation. They showed that the viruses that are absorbed onto the soil matrix survive for a longer period as they are protected against disruption of protein coat and degradation of nucleic acid.

2. Methodology

In unsaturated zone the moisture velocity varies depending upon the degree of saturation. So in such situation it becomes very essential to solve the flow equation before solving the virus transport equation.

2.1. Water flow in the unsaturated zone

Combination of the mass balance equation with the Darcy-Buckingham law results in the Richards equation that describes water flow in variably-saturated porous media. The one- dimensional form of the Richards equation given by *D.Jacques and JirkaŠimůnek* can be written as-

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

whereφ 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 term [$L^3L^{-3}T^{-1}$], β is the angle between the flow direction and the vertical axis (i.e., $\beta = 0^0$ for vertical flow, 90^0 for horizontal flow, and $0^0 < \beta < 90^0$ for inclined 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 relationships for the solution. Only van Genuchten's (1980) functions will be used to develop the constitutive relationship.

Constitutive Relationships-

The relationship proposed by van Genuchten's (1980) gives the relationship between$\theta - \varphi$and$K - \theta$ as follows

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

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

Where,

$\theta_r$is the residual water content [L^3L^{-3}], $\theta_s$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

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad \text{.................. (4)}$$

2.1.1. Initial and boundary condition for moisture flow:

Initial condition:

The pressure head distribution and moisture content at the beginning of the simulation is considered to be the initial condition and is given as-

$$t=t_0, \varphi = \varphi_0 = -100\text{cm} \; 0 \le z \le L;\ L = 100\text{cm} \quad \text{................ (5)}$$

Where$\varphi_0$is the specific pressure head at the beginning of the simulation. Initial condition is defined assuming a constant flux of 0.16 cm day-1

Lower- Boundary condition:

A gravity drainage ($\frac{\partial\varphi}{\partial z}$ =0) boundary condition is applied at certain depth bellow the ground surface, given as

$$t > 0, (\frac{\partial \varphi}{\partial z} = 0), z=0 \ldots\ldots\ldots.(6)$$

Upper-Boundary condition:

Upper boundary condition is satisfied by assuming a constant flux of 0.16 cm day-1

2.1.2. Numerical solution

The solution proceeds in two steps.

a finite element method given byHYDRUS-1D Software(a computer codes which simulating water onedimensional variably saturated porous media) is used to solve the Eq.(1) subjected to boundary condition in Eq. (5) and (6) provides a nodal pressure head in solution domain at successive time steps.

From these pressure head the seepage velocity at each observation node is computed using Darcy's law applied for the unsaturated condition as given by Eq. (8). However obtaining the seepage velocity in the flow domain it used to simulate the virus transport equation as mentioned bellow in Eq. (8).

Darcy's law

According to this law the rate flow (Q) through the porous media is proportional to the head loss (Δ h) and is inversely proportional to the length of the flow path i.e

$$Q = \frac{(h_1 - h2)}{L} (7)$$

From Eq. (7)

$$\frac{Q}{A} = K\frac{(h1 - h2)}{L}$$

$$v = ki \ldots\ldots\ldots (8)$$

Where, Q is the flow rate, i.e. the volume of water that flows through the sand filter per unit time. K is the coefficient of proportionality and is termed as hydraulic conductivity of the medium, A the cross sectional area, L is the length of the flow path v is the seepage velocity and i being the hydraulic gradient.

$$i = -\frac{(h_1 - h_2)}{L} \ (9)$$

$$h_1 = Z_1 + \varphi_1 \text{ And } h_2 = Z_2 + \varphi_2$$

Z_1 and Z_2 are the datum head or elevation head

$\varphi_1$and $\varphi_1$are the pressure head

2.2. Virus Transport

Contaminants below ground are transported by diffusion, advection, and mechanical dispersion. For viruses, transport involves additional inactivation and adsorption processes. This section details these four processes-

2.2.1. Molecular diffusion

Molecular diffusion describes how a solute moves from high to low concentration, as seen when ink spreads in water. Fick's first and second laws are used to derive the diffusion equation, assuming constant diffusivity. The governing equation for time-dependent concentration changes is-

$$\frac{\partial C}{\partial t} = D(\frac{\partial^2 C}{\partial z^2}) \ldots\ldots\ldots(10)$$

This is the governing equation for the system where concentrations are changing with time.

2.2.2. Advection process

Advection is the transport of dissolved solutes with flowing groundwater. The amount of solute transported is dependent on the groundwater flow rate and solute concentration. The one-dimensional mass flux due to advection is given by-

$$F = vn_eC \text{…………..(11)}$$

'ne' is the effective porosity which is the porosity through which flow can actually occur

Therefore the one dimensional advection transport equation is given by

$$\frac{\partial C}{\partial t} = -\vartheta\left(\frac{\partial C}{\partial z}\right) \dots \dots . (12)$$

2.2.3. Mechanical dispersion

In porous media, solute dispersion occurs due to both molecular diffusion and mechanical dispersion, which are combined into a hydrodynamic dispersion coefficient. The dispersion coefficients are given by-

$$D_L = D^* + \alpha_L v_L \text{……….(13)}$$

$$D_T = D^* + \alpha_T v_L \text{………..(14)}$$

Where D_L is the hydrodynamic dispersion and α_L is the dynamic dispersivity in the longitudinal direction (L); D_T is the hydrodynamic dispersion and α_T is the dynamic dispersivity in the transverse direction (T)

The advection-dispersion equation for conservative solute transport in one dimensional flow in porous media.

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial z^2}\right) - \vartheta\left(\frac{\partial C}{\partial z}\right) \text{……..(15)}$$

2.2.4. Sorption Phenomenon

Sorption is the attachment of solutes to soil solids through processes like adsorption, absorption, chemisorptions, and ion exchange. Sorbed molecules are less mobile and not available for phase transfer, which slows their movement compared to groundwater flow and creates a retardation effect in aquifers.

As discussed earlier, the one dimensional advection dispersion equation can be written as

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial z^2}\right) - \vartheta\left(\frac{\partial C}{\partial z}\right) \qquad \text{…….(16)}$$

After adding the sorption term, the equation becomes

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial z^2}\right) - \vartheta\left(\frac{\partial C}{\partial z}\right) - \frac{\rho}{\theta}\frac{\partial s}{\partial t} \dots \dots \ (17)$$

Eq. (17) depicts for molecular diffusion, mechanical dispersion, sorption phenomenon in case of one dimensional flow. Where c is the concentration of the solute in liquid phase, D is the dispersion coefficient, v is the average linear velocity of groundwater in z- direction, ρ is the bulk density of the aquifer, s is the amount of solute sorbed per unit weight of the solid, θ is the moisture content and t is the time.

2.2.5. Retardation due to inactivation process

The movement of viruses in groundwater can be modeled using the advection-diffusion equation. In addition to sorption, virus transport is affected by inactivation, a chemical process where viruses lose their ability to infect. This inactivation process is often approximated by a first-order rate equation-

$$\frac{\partial C}{\partial t} = -\,(t)\,C \text{………(18)}$$

Where, λ is the inactivation coefficient. It is a time dependent coefficient. However for modeling purpose sometime it is also considered as constant. Thus for the case of virus transport in porous medium, the one dimensional advection diffusion equation can be written as,

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial z^2}\right) - \vartheta\left(\frac{\partial C}{\partial z}\right) - \frac{\rho}{\theta}\frac{\partial s}{\partial t} - \lambda C \ldots\ldots\ldots \quad (19)$$

2.2.6. Governing Equation of virus transport:

The partial differential equation for virus transport through variably saturated media accounting for virus adsorption and inactivation can be written as (Ojhaet al.2012).

$$R\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial z^2}\right) - \vartheta\left(\frac{\partial C}{\partial z}\right) - \lambda C - \lambda^* \frac{\rho}{\theta} C^* (20)$$

For linear sorption the equilibrium solid phase concentration C^*(MM^{-1}) will be linearly proportional to the equilibrium liquid phase concentration C(ML^{-3});

$C^* = k_d C$, where k_d is the linear distribution coefficient………(21)

Where,R= retardation co-efficient, which can be expressed as-

$$R = 1 + \frac{\rho k_d}{\theta} \ldots\ldots\ldots\ldots\ldots\ldots(22)$$

Now using Eq. (8), (9) and Eq. (10) we can have the following equation

$$\frac{\partial C}{\partial t} + \frac{\rho}{\theta}\frac{\partial C^*}{\partial t} = D\left(\frac{\partial^2 C}{\partial z^2}\right) - \vartheta\left(\frac{\partial C}{\partial z}\right) - \lambda C - \lambda^* \frac{\rho}{\theta} C^* (23)$$

Here, D is the hydrodynamic dispersion coefficient (L^2T^{-1}); ϑ is the pore water velocity in the flow direction (LT^{-1}); ρ is the bulk density of the solid matrix (ML^{-3}); λ is the first-order inactivation rate coefficient (T^{-1}) in the aqueous viruses; λ^* is the first-order inactivation rate coefficient in the sorbed viruses (T^{-1}); k_d is the distribution coefficient; z is the Cartesian coordinate (L); and t is the time (T).

2.3. Study Area

This study mainly carried out in a one dimensional unsaturated zone of layer soil profile. The model is made upto a depth of 1m from the ground surface having seven layer of different soil materials. The one dimensional model is divided into 10 zone of depth 10 cm each. Observation node (N_n) where ,n= 1,2,…up to 10 are considered at centre of each zone such that node N_1 is at a depth of5cm, N_2 at 15 N_3 at 25….. N_{10}at 95cm from the ground surface.

The soil used in our study was a dry Spodosol, which is one of the dominant soil types in Northern Belgium considered for the disposal of low-level radioactive waste as given by D. Jacques. et.al Soil hydraulic parameters for 7 horizons in the top 1 m are listed in Table below:

Table 1 Soil hydraulic parameters for 7 horizons in the top

Material	Depth (cm)	θ_r	θ_s	Alpha	N	Ks	l	Bulk. D
1	0-10	0.065	0.48	0.016	1.94	95.04	0.5	1.31
2	10-18	0.035	0.42	0.015	3.21	311.04	0.5	1.59
3	18-32	0.042	0.47	0.016	1.52	38.88	0.5	1.3
4	32-55	0.044	0.46	0.028	2.01	864	0.5	1.38
5	55-63	0.039	0.46	0.023	2.99	1209.6	0.5	1.41
6	63-86	0.03	0.42	0.021	2.99	1209.6	0.5	1.52
7	86-100	0.021	0.39	0.021	2.99	1209.6	0.5	1.56

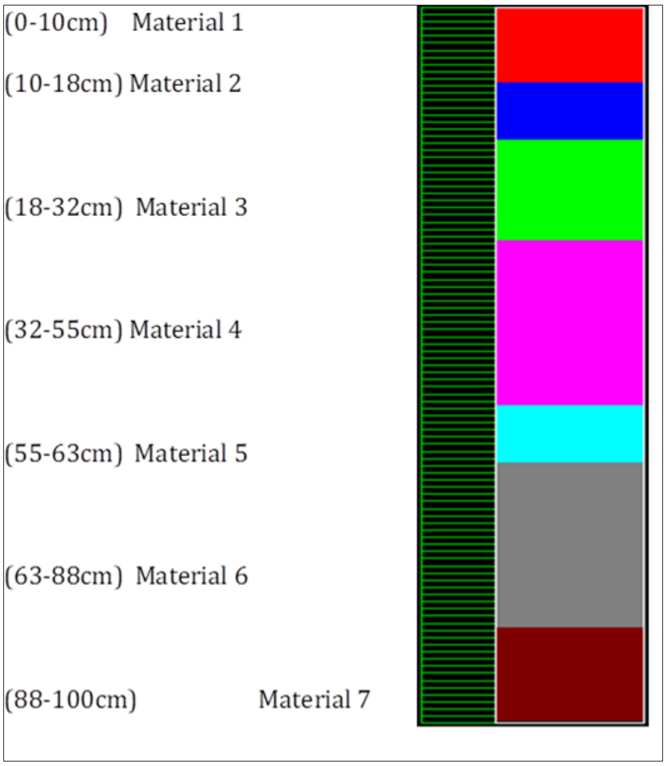

Figure 1 One dimensional vertical soil profile of seven different soil layer

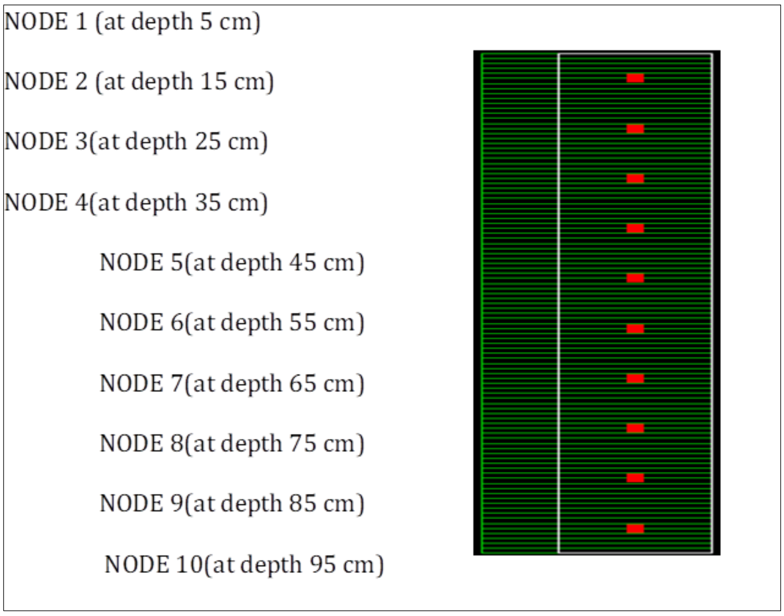

Figure 2 1-D soil profiles showing the observation node at which depth they are considered

3. Results and discussion

The solution proceeds in two steps. (i) a finite element method given by HYDRUS-1D Software(a computer codes which simulating water one dimensional variably saturated porous media) is used to solve the Eq.(1) subjected to boundary condition in Eq. (5) and (6) provides a nodal pressure head in solution domain at successive time steps. From these pressure head the seepage velocity at each observation node is computed using Darcy's law applied for the unsaturated condition as given by Eq. (8) (ii) after obtaining the seepage velocity in the flow domain it used to simulated the virus transport equation as mentioned bellow in Eq. (23).

From the above two steps mentioned the first step is being simulated till now and the results obtain is being described in detail by necessary plots. In this study the simulation of flow equation is carried out and the velocity at each observation is done using the Darcy's law. The simulation of the flow equation is done in ten time steps of 10 days each and is simulated for 100 days. The results obtain after simulating the flow equation Eq. (1) we have

- Variation of water pressure head (θ) with successive time steps for the different observation node.
- Variation of water content (θ) with successive time steps at different observation node.
- Variation of water pressure head (φ) with depth of the soil profile for different time steps.
- Variation of hydraulic conductivity (k) with depth of the soil profile for different time steps.
- Variation of water content (θ) with depth of the soil profile for different time steps.

3.1. Variation of water pressure head ($\boldsymbol{\theta}$), water content, water pressure head with successive time steps for the different observation node.

The Variation of water pressure head (θ) with successive time steps for the different observation is shown in figure 3. In this simulation step it is observed that water pressure variation with respect to time after 10 days interval is remain constant.

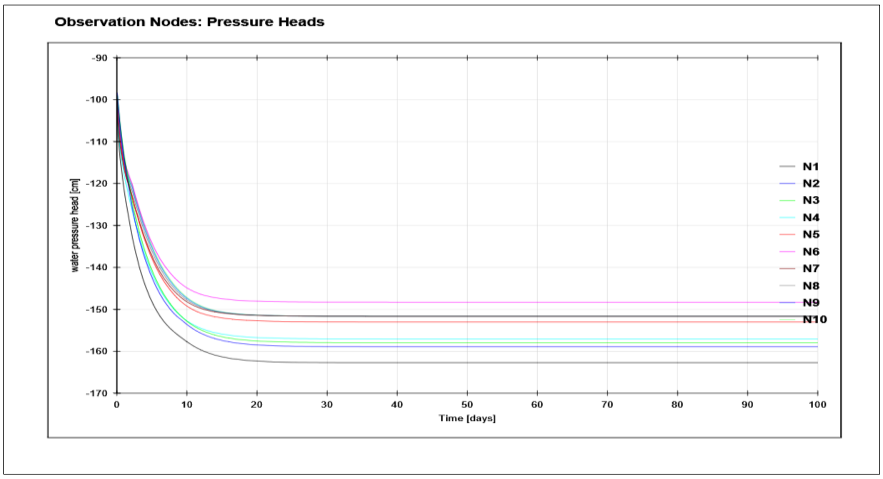

Figure 3 Variation of water pressure head ($\boldsymbol{\theta}$) with successive time steps for the different observation node

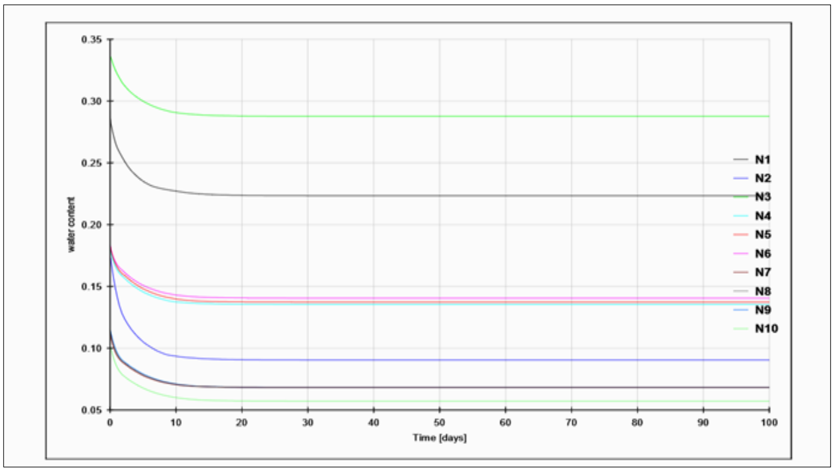

Figure 4 Variation of water content ($\boldsymbol{\theta}$) with successive time steps at different observation node

In the same way water content (θ) with successive time steps at different observation node is remain constant after 12 days. The main observation is that change of water pressure head and water contents take place only in the initial stages only. Another observation in study is that Variation of water pressure head (**φ**) with depth of the soil profile for different time steps.

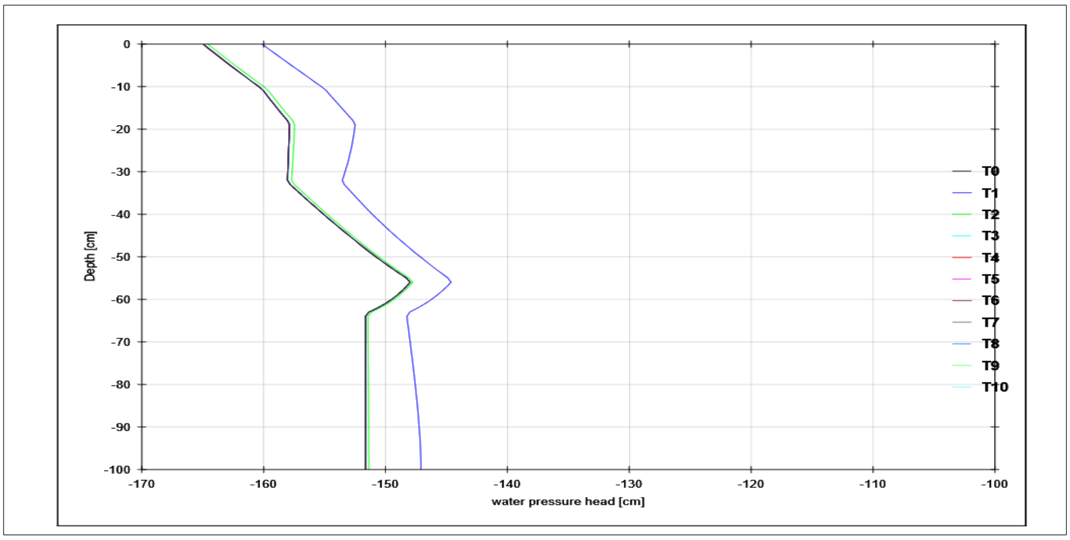

Figure 5 Variation of water pressure head (φ) with depth of the soil profile for different time steps

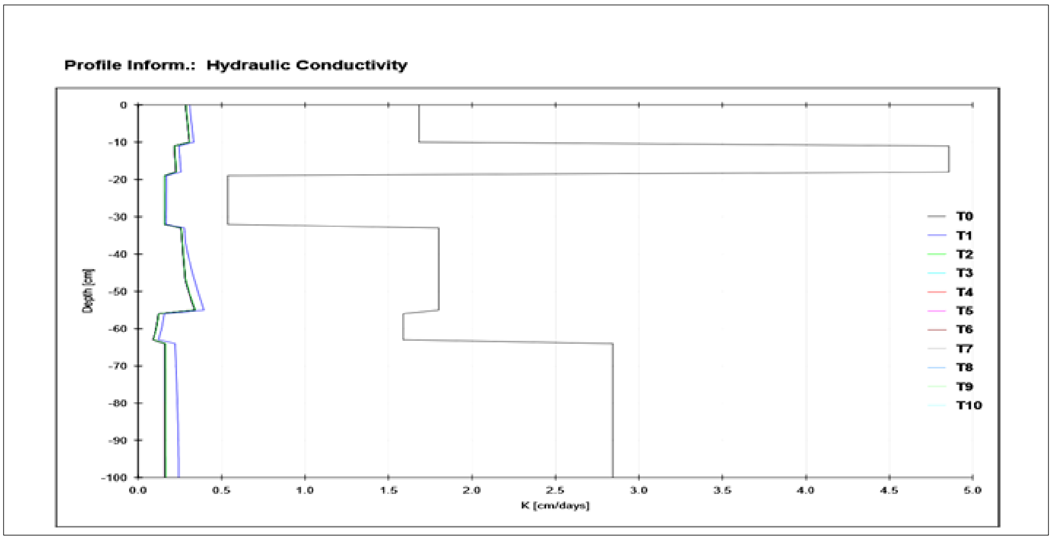

Figure 6 Variation of hydraulic conductivity (k) with depth of the soil profile for different time steps

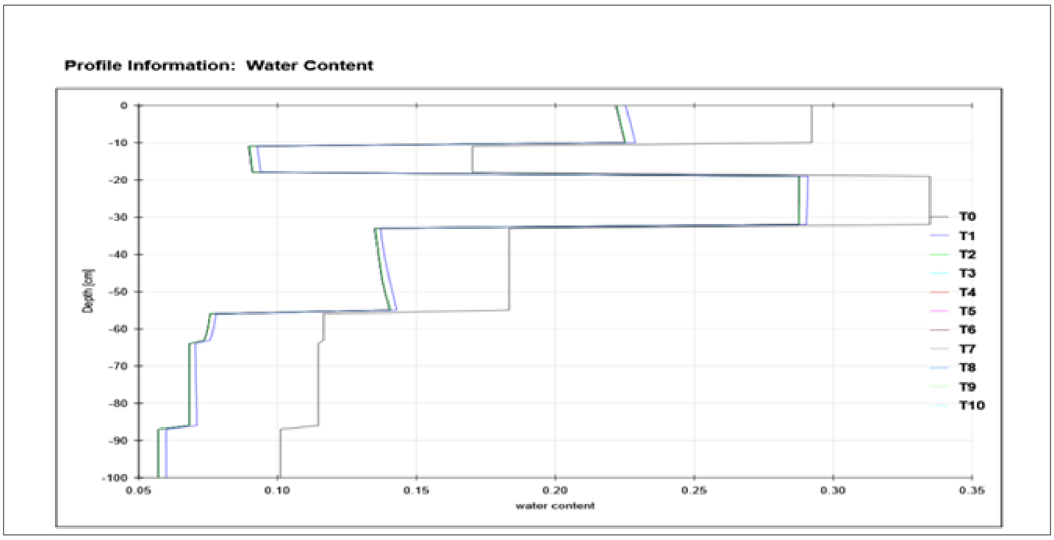

Figure 7 Variation of water content ($\boldsymbol{\theta}$) with depth of the soil profile for different time steps

From the above results the total pressure head is obtained at each node and the seepage velocity is obtained by using the Darcy's law. In this study the result obtained for time period of 10 days is considered to calculate the seepage velocity.

Table 2 Total pressure head (h) and seepage velocity at different depth

Depth(z) (cm)	**Water pressure head(φ(cm)**	**Total pressure head(h) (cm)**	**Change in pressure head(Δh) (cm)**	**Length between the**	**Hydraulic conductivity(k) (cm/day)**	**Seepage velocity(v) =$k\frac{\Delta h}{l}$(cm/day)**
0	-160.14	-160.14				
-5	-157.72	-162.72	-2.58	0.321	-5	0.165636
-15	-153.61	-168.61	-5.89	0.251	-10	0.147839
-25	-152.84	-177.84	-9.23	0.169	-10	0.155987
-35	-152.74	-187.74	-9.9	0.279	-10	0.27621
-45	-149.22	-194.22	-6.48	0.326	-10	0.211248
-55	-144.87	-199.87	-5.65	0.393	-10	0.222045
-65	-148.2	-213.202	-13.332	0.224	-10	0.298637
-75	-147.77	-222.766	-9.564	0.232	-10	0.221885
-85	-147.38	-232.384	-9.618	0.238	-10	0.228908
-95	-147.13	-242.132	-9.748	0.24	-10	0.233952

The pressure head and seepage velocity at each node after 10 days of simulation is obtained from table 2 and it is shown with the following two plots.

- Variation of pressure head with respect to the depth of the soil profile.
- Variation of seepage velocity with respect to the depth of the soil profile.

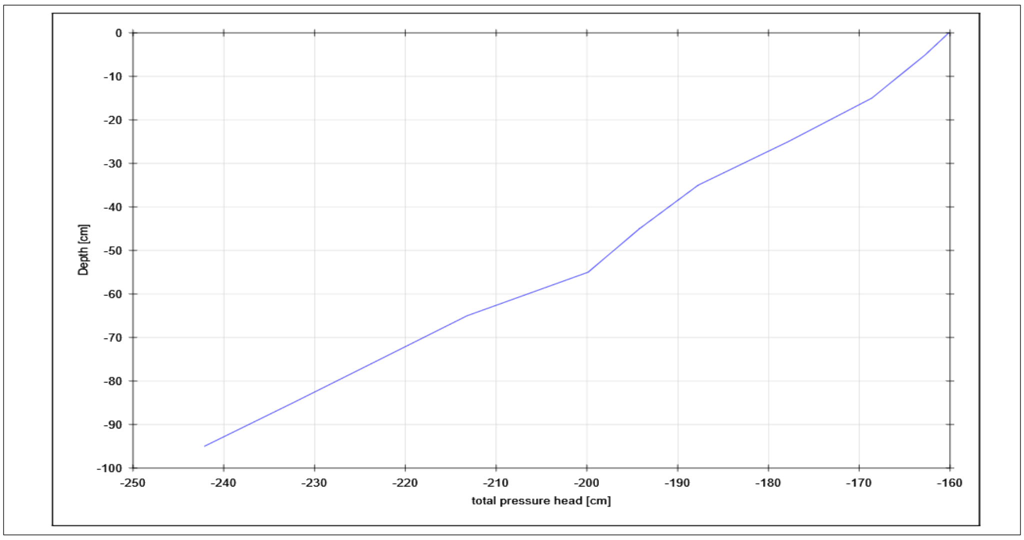

Figure 8 Pressure head with respect to the depth of the soil profile

In this study all the models are used to simulate for unsaturated phase in vertically for each layer.

It is observed that the virus transport in unsaturated porous media is affected by the pressure head with respect to time and depth. Here it is observed that total pressure head and water content change with respect to depth. So movement of virus in unsaturated porous media can change during the simulation period. Figure 3 to 8 shows water pressure head, water content, hydraulic conductivity, and pressure head with respect to depth. In all the simulation phase, it is observed that all the parameter changes vertically for each node.

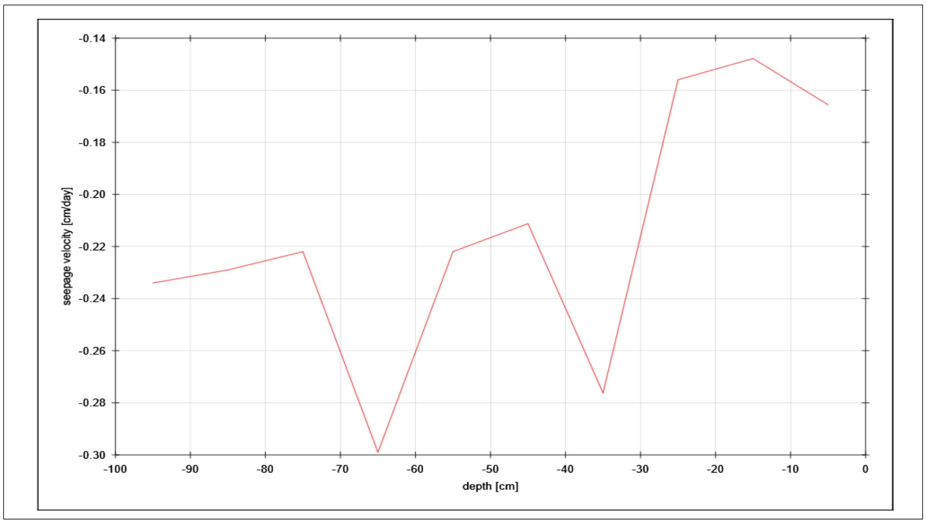

Figure 9 Seepage velocities with respect to the depth of the soil profile

4. Conclusion

This study is mainly concerned to develop a one dimensional numerical model to simulate the one dimensional flow equation using HYDRUS 1-D software. After the simulation water pressure head at each node is being analyzed and it has being observed that there is variation in water pressure head which may be due to the effect of different saturation hydraulic conductivity of different soil material. The total pressure head and seepage velocity is obtained and thus we can concluded from the Fig .9 that when the flow moves beneath the ground surface along the vertical direction the pressure head decreases with the decrease in depth of the soil profile. This flow model is simulate many times to observe the flow path of virus which can be helpful for selecting the drinking source of water

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