ENVIRONMENTAL BEHAVIOR OF UNSATURATED ZONE IN AN ISLAND UNDER TIDAL EFFECT AND CLIMATIC CONDITION

Nguyen Thi Minh Hang[1]

Abstract: *The beaches with mudflats located near islands surrounded by a sea are usually characterized by cyclic variations in soil moisture due to changes in temperature, evaporation, rainfall and tidal fluctuation. These issues of the unsaturated zone and mudflat behavior under varied boundary conditions were studied by establishing a new conceptual model for a study area, which is the Trieu Duong beach of Phu Quy Island, Binh Thuan Province. The effect of the tidal fluctuation on the variability of the moisture in the mudflat was also studied. We found that seawater intrusion has been expected in the beach line area. The variation of soil moisture follows daily cycles, rather than monthly or seasonal. These studied preliminary results help us/scientist to understand the behavior of the mudflat in terms of variation in moisture content and also salinity which may help in proper ecological management of the area.*

Keywords: Variably saturated zone, coastal zone, numerical model, soil moisture, Phu Quy island

1. INTRODUCTION

Phu Quy island in Binh Thuan Province, Vietnam (Fig. 1) has the potential to become a central logistics, processing and consumption of an array of seafood fishing lasts from Truong Sa to Con Minh for offshore fishing vessels, in addition to the location on the international marine transportation, Phu Quy can be a place for boat repair services, international port services, providing services on oil and gas exploration and exploitation. The island has both mountainous and hilly features in the north and the land area in the southern region. Trieu Duong beach is one of nice beaches in Phu Quy. The beach is under tidal effects having a major influence on the behavior of the variably saturated zone. This area consists of soil with different layers which control the flow and transport.

The unsaturated zone is usually heterogeneous and characterized by cyclic fluctuations in the soil moisture as water is replenished by rainfall

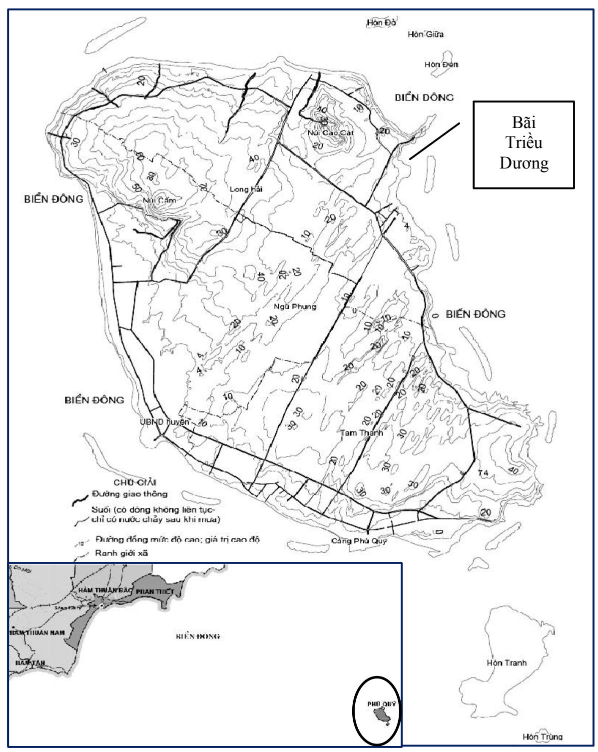

Fig 1. Phu Quy Island of Binh Thuan province

and removed by evaporation and recharge to

[1] *Faculty of the Environment, Thuyloi University.*

groundwater table. The unsaturated zones near the sea (beach-line) undergo lot of environmental changes in terms of temperature, evaporation, rainfall, tidal fluctuation etc. Some of these factors vary on hourly and daily cycle whereas some of them vary seasonally. These variations in the boundary conditions bring a lot of changes in the behavior of the soil including the variation in the moisture content and the subsurface flow. These in turn will affect the transport of natural tracer like chloride and also the unplanned disposal of contaminants by humans. Most of the earlier studies do not consider the effect of the unsaturated zone in a coastal zone.

In this paper, a new conceptual model for the above problem was developed and the effect of different types of boundary conditions such as sea effect on the right side of the domain, tidal effect on the top of the domain, rainfall and evaporation effect on the top boundary at the upland was studied. Such works on the behavior of a coastal zone with the consideration of unsaturated zone along with the effect of sea on its flow and transport behavior has not been reported so far. This problem is being addressed through the numerical modeling of the classical Richard's equation with varied initial and boundary conditions especially bringing in the tidal effect.

2. METHODOLOGY

2.1. Conceptual Model

Figure 2a presents the conceptual model of the soil domain near Trieu Duong beach. The finite element mesh is shown in Fig. 2b. The area of interest is the "beach line", meaning that the area in between upland and mudflat. The domain consists of several layers with the top and bottom layers being of sand type while the other layers are of the clay type. Upland is affected by rainfall and evaporation while mudflat has tidal effect. The domain considered is of size 500 m x 19 m with the detailed layering as shown in Fig. 2a. The properties of the modeled layers such as saturated hydraulic conductivity, porosity and anisotropy are summarized in Table 1.

The basic data considered in the present study such as rainfall, type and properties of the soil and the tidal data are collected from the different sources as reported in Don (2013).

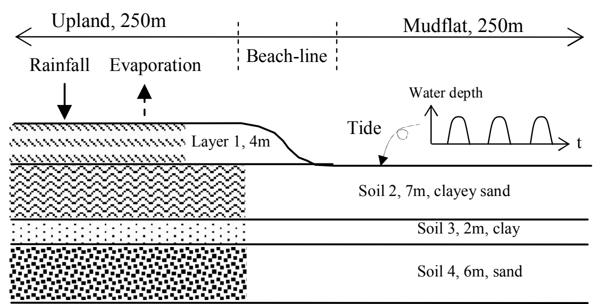

Fig. 2a Conceptual model and modeled layers

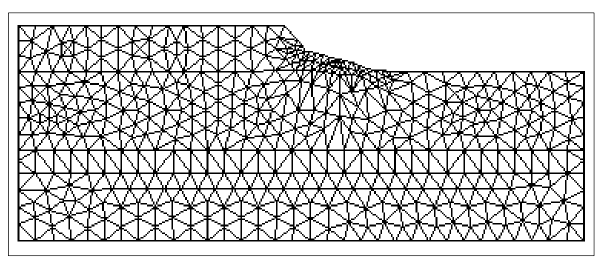

Fig. 2b Finite element meshes

Table 1 Soil properties of modeled layers

Soil layer	Parameters				
	K_s (m/s)	θ_s	θ_r	α	n
1	3.74×10^{-6}	0.4	0.1	1.2	3

2	5.57×10^{-9}	0.4	0.2	1	2
3	4.04×10^{-9}	0.4	0.2	1	2
4	9.97×10^{-6}	0.4	0.1	1.2	3

Note: K_s: saturated hydraulic conductivity
θ_r: residual volumetric moisture content
θ_s: saturated volumetric moisture content
α: van Genuchten curve-fitting parameter
n: van Genuchten curve-fitting exponent (pore size distribution index)

The right side of the domain (mudflat) is exposed to the sea while the left side (upland) is under groundwater table condition. The top boundary is exposed to the rainfall and evaporation condition and also to the tidal effect while the bottom boundary is under hydrostatic condition.

2.2. Governing Equation

The governing equation of flow in the variably saturated domain is given by the classical Richards (1931) equation,

$$\frac{\partial}{\partial x}\left\{K_{xx}(\theta)\frac{\partial \psi}{\partial x}\right\}+\frac{\partial}{\partial z}\left\{K_{zz}(\theta)\frac{\partial \psi}{\partial z}\right\} + \frac{\partial K_{zz}(\theta)}{\partial z} = S_s\frac{\theta}{\phi}\frac{\partial \psi}{\partial t}+\frac{\partial \theta}{\partial t} \qquad (1)$$

where ψ is the pressure head, K_{xx} and K_{zz} are the permeabilities in the x and z direction respectively, φ is the porosity of the soil, θ is the volumetric moisture content of the soil; S_s is specific storage of soils; x is the horizontal distance and z is the vertical height taken positive upwards. This equation represents the flow in the variably saturated zone. To complete the formulation, proper initial and boundary conditions have to be specified along the entire boundary of the domain. The boundary conditions used are of the flux type and also the Dirichlet type. It should be noted that the permeabilities, pressure head and the moisture content are related by a highly nonlinear function. Normally used equations to represent such relationships are given by van Genuchten's equation (1980),

$$\Theta = \frac{\theta-\theta_r}{\theta_s-\theta_r} = \left[\frac{1}{1+\left\|\alpha_v \psi\right\|^{n_v}}\right]^{m_v} \quad for\ \psi \le 0 \qquad (2a)$$
$$=1 \quad for\ \psi > 0$$

$$K_r = \Theta^{1/2}\left[1-\left(1-\Theta^{1/m_v}\right)^{m_v}\right]^2 \qquad (2b)$$

Here θ_s and θ_r are the full and residual saturations and α_v and m_v are the fitting parameters and K_r is the relative permeability. Equations (1) along with (2) with proper initial and boundary conditions close the mathematical problem for flow.

The transport of a conservative tracer through the variable saturated porous media is given by,

$$\frac{\partial C}{\partial t} = \frac{\partial C}{\partial x}\left(\theta D_{xx}\frac{\partial\left(C/\theta\right)}{\partial x}-q_{xx}c\right) - \frac{\partial C}{\partial z}\left(\theta D_{zz}\frac{\partial\left(C/\theta\right)}{\partial z}-q_{zz}c\right) \qquad (3)$$

where, c is the concentration of the solute in liquid phase and $C = \theta c$; q_{xx} and q_{zz} are Darcy's fluxes; $v_{xx} = q_{xx} / \theta$ and $v_{zz} = q_{zz} / \theta$ are pore water velocities; D_{xx} and D_{zz} are the dispersion coefficients in x and z directions respectively; x and z are horizontal and vertical spatial dimensions; and t is the time. Along with proper initial and boundary conditions, Eq (3) is amenable for numerical solution. In a flow and transport problem such as the present one, both

Eqs. (1) and (3) have to be solved together at each time step.

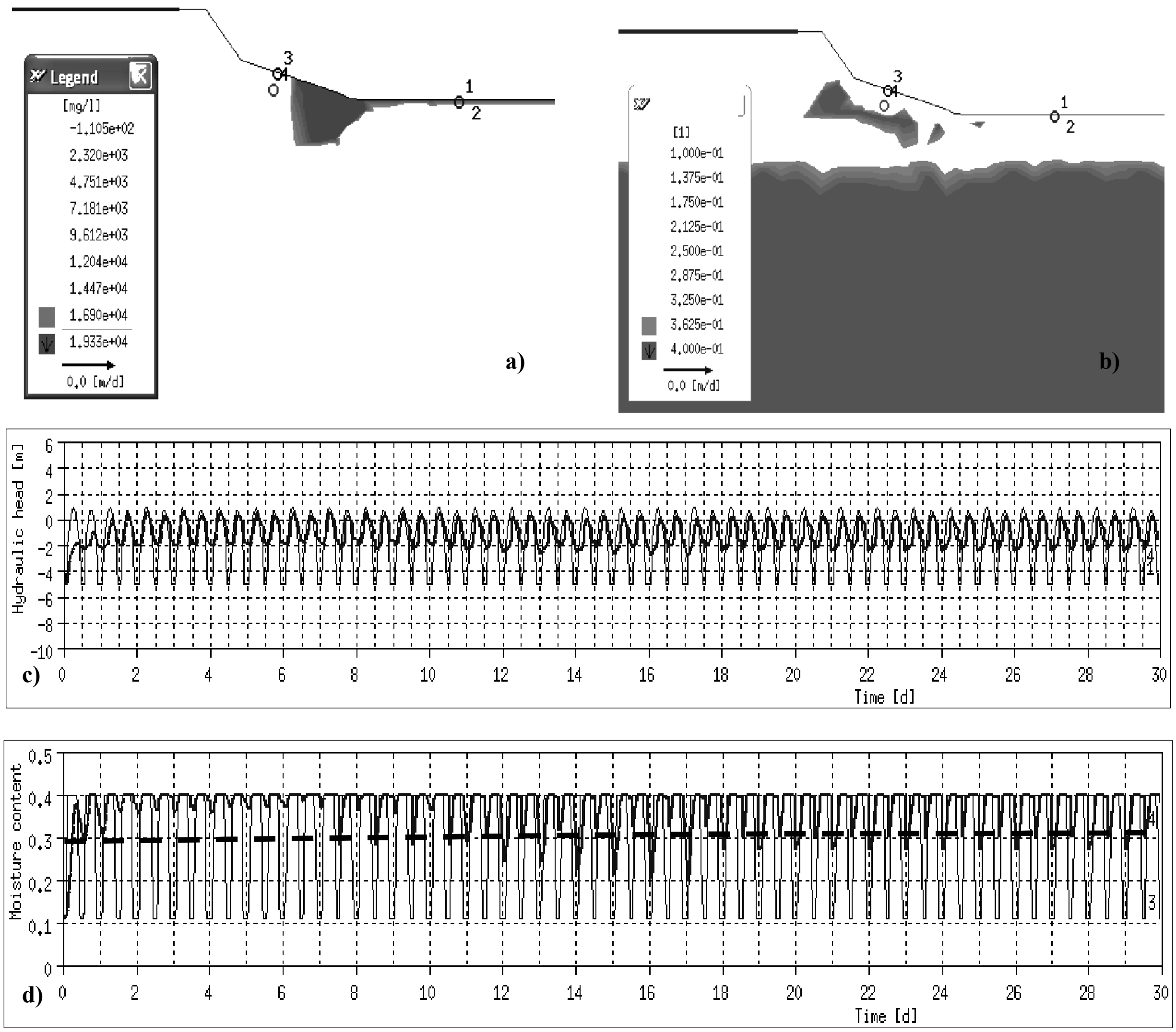

Fig. 3 Distribution of a) Chloride concentration, b) Moisture content; and Time variation of c) Hydraulic head, d) Soil moisture content

3. NUMERICAL APPROACH

The approach adopted is the numerical method with both the governing equations along with boundary conditions being approximated using finite element method and the resulting matrix equations solved using iterative solvers such as the standard preconditioned conjugate gradient iterative solver. The *novelty* of the present model is the consideration of both the unsaturated zone in the upland and also the sea effect on the right side of the domain.

4. RESULTS AND DISCUSSION

A case is conducted for low groundwater table. Most of the simulations are done for a total time of a month and in some cases a seasonal simulation of a year is done. The external boundary conditions are varied to account for rainfall, evaporation, tidal effect and also sea water intrusion. Along with this the internal boundary condition such as groundwater table and also the variation in domain properties are considered in terms of layered heterogeneity and anisotropy. All these are considered to see the relative effect of these on the flow and transport in the domain under consideration.

This case is considered in which the water table is assumed to be 7 m below the upland surface. This would happen due to excessive pumping in the island. Figure 3 a *and* b show the distribution of chloride concentration and moisture content at the end of 30 days simulation time. Time variation of hydraulic head and soil moisture content are shown in Fig. 3c and 3d (at the points 1, 2, 3, 4 indicated in Figs 3a and 3b), respectively.

Under a high gradient, saltwater in terms of chloride intrudes the area near the sea to a certain depth. As expected, there is more area exposed to unsaturated zone in the beach-line. Due to the tidal effect, hydraulic heads at the surface of the mudflat and beach-line follow a cyclic pattern (the thick line in Fig. 3 c). The movement of the soil moisture also follows a cyclic variation. Mudflat and beach-line become saturated during high tides due to ponding and unsaturated during low tides. As seen in Fig. 3c (the thin line), in the beach-line, during a tide, surface soil gets saturated (water content = 0.4) and becomes very dry (water content = 0.12) in response to tidal changes. On the other hand, moisture content of soils in deeper depths also change with tide but with a smaller magnitude (water content ranges from 0.3 to 0.4).

In the mud flat area, at a certain depth below the soil surface, water content increases with a very small rate (the dash-thick line in Fig. 3d). Because the clay layers do not easily transmit water, a deeper zone exhibits a relatively muted response to tidal changes. In contrast, the more permeable soil in the top zone of upland and beach line transmits water very easily, which exhibits a much greater response to tidal cycles. Figure 4 shows the distribution of moisture content along an indicated section (A - A). The unsaturated zone is about 5m depth. Within the unsaturated depth (0-5m), soil moisture change gradually, from initial water content to the maximum (0.4). The lower layer has lower hydraulic conductivity than the above, making a decline change in the soil moisture curve. Below that depth (at 5m), all soil layers get fully saturated therefore the soil moisture curve became constant.

5. CONCLUSIONS

A model to simulate the behavior of a region at Trieu Duong beach, Phu Quy Island (Binh Thuan province) under the influence of unsaturated zone and tidal effect has been developed. We found that seawater intrusion is expected in the beach line area. A clayey layer could slow down the intrusion process of saltwater. Soil moisture variation of soil layer in the beach line areas follows daily cycles, rather than monthly or seasonally. Because of short time variation, such changes are not much dependent on other weather conditions (rainfall, evaporation) that prominently affect the upland areas. Tidal effect is very clearly felt in the mud flats and beach line areas. The sea effect is the maximum at high tides. Layering and anisotropy do not play a major role in the flow behavior. This study shows the results which have to be strengthened by field monitoring and data gathering. In this sense, this model may help in planning of detailed field experiments for the study area.

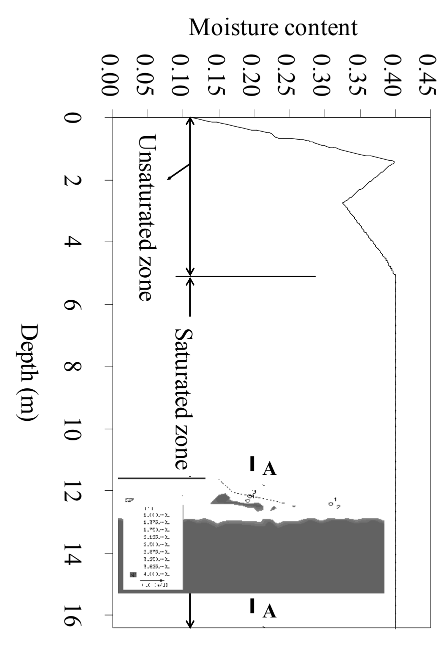

Fig. 4 Moisture content distribution along the indicated section (A - A)

REFERENCES

[1]. Richards, L.A. (1931). *Capillary conduction of liquids through porous mediums*, Physics 1, 318-333.

[2]. Van Genuchten, M.T. (1980). *A closed-form equation for predicting the hydraulic conductivity of unsaturated soils*. Sci. Soc. Am. J. 44: 892-898.

[3]. Nguyễn Cao Đơn (2013). Báo cáo tổng hợp đề tài KC.08.TN01/11-15 "*Nghiên cứu xây dựng đập dưới đất để trữ nước ngầm nhằm phát triển bền vững tài nguyên nước ở các khu vực thường xuyên bị hạn, các vùng ven biển và hải đảo*".

Tóm tắt:

DIỄN BIẾN MÔI TRƯỜNG ĐẤT VÙNG BÁN NGẬP VEN BIỂN DƯỚI TÁC ĐỘNG CỦA THỦY TRIỀU VÀ CÁC YẾU TỐ THỜI TIẾT

Nhiều bãi biển ven các hòn đảo có biển bao quanh thường được đặc trưng bởi các biến động có tính chu kỳ về độ ẩm của đất do sự thay đổi về nhiệt độ, bốc hơi, mưa và thủy triều. Những biến động này của vùng chưa bão hòa dưới tác động của các điều kiện biên khác nhau đã được nghiên cứu bằng cách thiết lập một mô hình toán cho một khu vực nghiên cứu là bãi biển Triều Dương của đảo Phú Quý, tỉnh Bình Thuận. Ảnh hưởng do sự lên xuống của thủy triều đến sự thay đổi của độ ẩm trong các bãi bồi cũng đã được nghiên cứu. Kết quả cho thấy sự xâm nhập mặn đã và đang xảy ra ở khu vực đường bờ. Sự biến động về độ ẩm của đất theo chu kỳ hàng ngày, chứ không theo chu kỳ tháng hoặc theo mùa. Những kết quả ban đầu giúp làm rõ ứng xử về mặt môi trường của các bãi biển về sự thay đổi độ ẩm và độ xâm nhập mặn, từ cũng trợ giúp trong việc ra quyết sách quản lý sinh thái thích hợp của khu vực.

Từ khóa: Vùng đất không bão hòa, vùng ven biển, mô hình số, độ ẩm, đảo Phú Quý.

BBT nhận bài: 13/4/2015

Phản biện xong: 21/5/2015