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Modeling the Deposition of Diplococcic and Uranium in Organic and Lateritic Soil Formation in Coastal Area of Trans Amadi of Port Harcourt Metropolis, Niger Delta of Nigeria

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ABSTRACT

Uranium and diplococcic deposition in coastal area of Amadi-Ama were found to develop lots of hazard through investigations carried out, but better solution to stop this pollution transport were not thoroughly achieved as contamination from these two parameters are found in the formation. the deposition of uranium and diplococcic has cause lots of hazards in organic and lateritic soil formation, several influences were considered to have caused these problem of high accumulation in the study location, these variables were integrated in the system that produced the governing equation, the expressed equation were derived applying mathematical method that will produce results expressing the system base on these considered conditions from transport influences. The approach of the study through the expressed governing equation were in phases, the derived solution generated model according to the conditions considered in the system, these produced results in accordance with the behavior of the contaminants in the system, The study is imperative because it has express direction of transport between both parameters reflecting several influences in the transport process, it has also showcase different formation influences that has exhibit some refection pressure on depositional level of uranium and diplococcic in the study area, experts will definitely applied this concept to monitor the deposition and migration process of both parameters to prevent further migration in the study area.

Keywords: *modeling uranium, diplococcic, organic and lateritic soil*

1. INTRODUCTION

Down whole pressure transducers—coupled with electronic data loggers—are commonly used during ground water investigations to measure and record water levels in wells for long periods at relatively short intervals. Changes in barometric pressure often induce fluctuations in water level observations (Pascal 1973). Barometric pressure applies a load to the land surface as well as to the water surface in open wells (Jacob 1940). Barometric pressure changes because water level changes because the total head in an aquifer is the sum of the water level in the well plus the barometric pressure (Nathanial J. T and Todd C. R .2007). Water level fluctuations are dependent on aquifer properties, properties of overlying materials, and the characteristics of the observation well. The lag between the water level fluctuation and the barometric stress complicates removal of barometric induced noise. Earth tides may also cause variation in water levels (Bredehoeft 1967; Hsieh 1987). These variations, which are clearly periodic, result from the elastic behavior of the aquifer skeleton. The physical deformation caused by gravitational and centripetal forces can affect the pore fluid pressure, resulting in water level changes in wells. The density and orientation of fractures are important determinants how these forces affect pore fluid pressure (Bower 1983). Rasmussen and

Rasmussen (1997) describes how barometric response changes cause a range of ground water responses. Spane (2002) evaluated this approach and demonstrated how it improves smoothed aquifer water levels. The method removes more barometric noise from the data than a constant barometric efficiency because it incorporates the transient nature of the barometric efficiency of a well. Bear (1979) presents a number of terms useful in considering soil moisture. The field capacity of a soil is the water content of the soil after all gravitational drainage has ceased. Any water content above this level, up to full saturation, is referred to as gravitational water. Marinho and Stuermer (1998) define the field capacity as ―the maximum water content a soil can hold or store under a condition of complete wetting followed by drainage.‖ Between the moisture content equal to the field capacity and that achieved when the soil is air-dried (moisture content equal to the hygroscopic coefficient), the soil water is referred to as capillary water. Within the capillary fringe, the soil retains a high degree of saturation (>75% according to Bear 1979, though most other references imply 85-90% as the minimum; for example Fredlund & Rahardjo, 1993a; Chenggang et al, 1998), but pore water pressures are negative with respect to the atmosphere. Significant groundwater flow may occur within the capillary fringe. Below the phreatic surface, pour water pressures are greater than atmospheric air pressure, and considered as positive water pressures. At the phreatic surface the pore water pressure is equal to the atmospheric pressure, and above the surface, pour water pressures drop below atmospheric and become negative. Such negative pressures are referred to as soil suction (or pore water tension). Soil suction actually has two components, matric and osmotic (or solute) (Fredlund and Rahardjo, 1993a; 1993b Richards, 1967 Eluozo, 2013). Oberg (1997) provides additional references to support this hypothesis. Thus, for _straight‘ geotechnical engineering problems such as conventional slope stability analysis, not involving environmental aspects where pollutants and chemical gradients may be present, soil suction may be considered synonymous with matric suction. Matric suction is defined as ―the difference between the pore-air and the pore-water pressures‖ (Fredlund and Rahardjo, 1993b; Fredlund and Barbour; 1992; Fredlund and Hansan;1979; Fredlund; and Hwang 1994 Eluozo, 2013), Since the height of the capillary rise is dependent on the radius of the void in which said rise is occurring, it is clear that the capillary rise that will occur within a soil will be affected by particle size and grading, since this affects the size of the voids (or pores) within the soil mass.

2. THEORETICAL BACKGROUND

High deposition of diplococcic and uranium in organic and lateritic soil formation in coastal formation call for serious concern, the rate of deposition were found through some risk assessment carried out on those location, the prevention were recommended but could not be thoroughly achieved, the deposition of the these two parameters in organic and lateritic soil formation are influenced by coastal environment, because it has some slight variation through the influences of the coastal structure, the deposition of uranium and diplococcic are base on the highest predominant deposited formation influences such as porosity in the study location, thus increase the migration of the contaminants. The deposition of diplococcic with uranium are through manmade activities in the study area, some industrialized department generate this type of waste at daily bases, this condition developed high deposition of the contaminant in the study area, costal influences may have also generate dispersion of the contaminants in the strata, but one parameter are known to generate concentration more, but the case of these two parameters investigated produces almost the same concentration at every formation in the strata. The formation setting through coastal influence developed lots of variation as it is expressed in the study produced on formation reports from the risk assessment. Such condition implies that the development of low void ratio and porosity increase the concentration from pore space distribution between the grain size thus generate lower percentage of void ratio, the development of mathematical modeling on two direction of flow transport are base on the condition from the geological setting influenced by the coastal formation. The expressed derived solution will definitely produces the directions of transport from this contaminant in the system. it has establish various influenced from formation characteristics on the deposition of the two parameters in the formation, the derived solution will definitely generate various model considering various behavior of both parameters under the influences of geological setting in the study location.

2.1 Nomenclature

ϕ = Porosity [-]
V = velocity [LT^{-1}]
D = Dispersion Number
K_n = Uranium Coefficient of inhibition [ML^{-3}]
K_d = Half Concentration of substrate under Aerobic Respiration [ML^{-3}]
C = Concentration of Diplococcic [ML^{-3}]
T = Time [T]
x = Distance [L]

3. GOVERNING EQUATION

$$\phi\frac{\partial c}{\partial t} + V\frac{\partial c}{\partial x} = D\frac{\partial^2 c}{\partial y^2} - K_c\frac{\partial c}{\partial x} + K_d\frac{\partial^2 c}{\partial y} - K_n\frac{\partial^2 c}{\partial x^2} + \lambda(x,y) \quad \ldots\ldots\ldots\ldots \qquad (1)$$

The governing equations formulated the system that express the variables are denoted with mathematical symbols, the condition of the system are through investigation carried out that confirm the deposition and migration of diplococcic including uranium in coastal area of trans-Amadi in port Harcourt metropolis. Since the study locations are industrial layout, manmade activities are practice at high degree, through the exploitation of our natural resources and other construction activities. The depositions of this contaminant are in two different directions, base on this condition, the expressed governing equation are developed. The expression will be derived in accordance with the deposition influences of the substances and the microbes at different deposition of the formation.

$$\phi\frac{\partial c}{\partial t} + V\frac{\partial c}{\partial x} = \lambda[x,y] \qquad (2)$$

Let $C = TX$

$$\frac{\partial c}{\partial t} = T^1X \qquad (3)$$

$$\frac{\partial c}{\partial x} = X^1 T \qquad (4)$$

$$\phi T^1 X + VTX^1 = \lambda \qquad (5)$$

$$\phi \frac{T}{T} + V \frac{X^1}{X} = \lambda \qquad (6)$$

$$\phi \frac{T^1}{T} = \lambda \qquad (7)$$

$$V \frac{X^1}{X} = \lambda \qquad 8)$$

From (7),

$$\phi \frac{dT}{T} = \lambda dt \qquad (9)$$

$$\int \frac{dT}{T} = \int \frac{\lambda}{\phi} dt \qquad (10)$$

$$LnT = \frac{\lambda}{\phi} + a_1 \qquad (11)$$

$$T = \ell^{\frac{\lambda}{\phi} t + a_1} \qquad (12)$$

$$T \; C_1 \; \ell^{\frac{\lambda}{\phi} t} \qquad (13)$$

$$\frac{V \partial x}{x} = \lambda dx \qquad (14)$$

$$\int \frac{dx}{x} = \int \frac{\lambda}{V} dx \qquad (15)$$

$$Ln\, x = \frac{\lambda}{V} x + a_2 \qquad (16)$$

$$X = \ell^{\frac{\lambda}{V} + a_2} \qquad (17)$$

$$X = C_2 \, \ell^{\frac{\lambda}{V} x} \qquad 18)$$

But $C = TX$

$$C_1 = C_1 \ell^{\frac{\lambda}{\phi} t} \bullet C_2 \ell^{\frac{\lambda}{V} x} \qquad (19)$$

$$C_1 = C_1 \, C_2 \, \ell^{\left(\frac{\lambda}{\phi} + \frac{x}{V}\right)\lambda} \qquad (20)$$

$$C_1 = C \, \ell^{\left(\frac{\lambda}{\phi} + \frac{x}{V}\right)\lambda} \qquad (21)$$

The expression here is the exponential phase model; the derived solution establish this phase of the system under the pressure of the soil geological setting in the environment, formation characteristics such as porosity and void ratio influences the structure of the deposited strata, the generation of the exponential phase condition in the system express high concentration of the pollutant at these phase, formation influences are base on the deposited structure of the formation.

$$\phi \frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial y^2} \qquad (2)$$

Let $C = T^1 Y$

$$\frac{\partial c}{\partial t} = T^1 Y \qquad (22)$$

$$\frac{\partial^2 c}{\partial y^2} = TY^{11} \qquad (23)$$

$$\phi T^1 Y = DTY^{11} = \theta^2 \qquad (24)$$

Let

$$\phi \frac{T^1}{T} = D \frac{Y^{11}}{Y} = -\theta^2 \qquad (25)$$

$$\int \frac{dT}{T} = \int \frac{-\theta^2}{\phi} dt \qquad (26)$$

$$LnT = \frac{-\theta^2}{\phi} t + a_3 \qquad (27)$$

$$T = \ell^{\frac{-\theta^2}{\phi} t + a_3} \qquad (28)$$

$$T = C_3 \, \ell^{\frac{-\theta^2}{\phi} t} \qquad (29)$$

$$D\frac{Y^{11}}{Y} = -\theta^2 \tag{30}$$

$$\frac{\partial^2 y}{\partial y^2} + \frac{\theta^2}{D} y = 0 \tag{31}$$

Auxiliary equation

$$M^2 + \frac{\theta^2}{D} = 0 \tag{32}$$

$$M = \pm i \frac{\theta}{\sqrt{D}} \tag{33}$$

$$\therefore Y = ACos\frac{\theta}{\sqrt{D}} y + BSin\frac{\theta}{\sqrt{D}} y \tag{34}$$

Combine (29) and (34), we have

$$C_2 = TY$$

$$C_2 = C_3 \ell^{\frac{-\theta^2}{\phi} t} ACos\frac{\theta}{\sqrt{D}} y + ASin\frac{\theta}{\sqrt{D}} y \tag{35}$$

Similar condition were also considered in these phase of the derived solution of the system. The developed model of these phase in [35] shows the progressive phase of the condition, but are influenced by some deposited minerals that may inhibit both parameters in the study location, the derived model in [35] showcase the condition base on the stratification influences that were considered in the phase of the derived model solution.

Considering

$$\phi\frac{\partial c_3}{\partial t} = K_c \frac{\partial c_3}{\partial x} \tag{3}$$

Let $C_3 = TX$

$$\frac{\partial c_3}{\partial t} = XT^1 \tag{36}$$

$$\frac{\partial c_3}{\partial x} = X^1 T \tag{37}$$

$$\phi T^1 X = KX^1 T \tag{38}$$

$$\phi\frac{T^1}{T} = K_c \frac{X^1}{X} = \varphi^2 \tag{39}$$

$$\phi\frac{T^1}{T} = \varphi^2 \tag{40}$$

$$\frac{T^1}{T} = \frac{\varphi}{\phi} \tag{41}$$

$$LnT = \frac{\varphi^2}{\phi} t + a_4 \tag{42}$$

i.e. $T = C_4 \ell^{\frac{\varphi^2}{\phi} t}$ (43)

$$T = \ell^{\frac{\varphi^2}{\phi} t} \tag{44}$$

$$\phi\frac{T^1}{T} = K_c \frac{X^1}{X} = \varphi^2 \tag{45}$$

$$\frac{dx}{dx} - \frac{\varphi^2}{Kc} x = 0 \tag{46}$$

Auxiliary equation

$$M^2 - \varphi^2 = 0 \tag{47}$$

$$M = \pm i \frac{\varphi}{\sqrt{Kc}} \tag{48}$$

$$X = K_c \ell^{\frac{\varphi}{Kc} x} + E \ell^{\frac{-\varphi}{Kc} x} \tag{49}$$

Combining (44) and (49) yield

$$C_3 = TX$$

i.e. $C_3 = C_4 \ell^{\frac{\varphi}{\phi} t} \left(K_c \frac{\varphi}{\sqrt{Kc}} x + E \ell^{\frac{-\varphi}{\sqrt{Kc}} x} \right)$ (50)

The developed model at this phase shows the rate of inhibition that may be found on the process of deposition in some region of the formation, it may deposit transient flow base on the slight low deposition of porosity reflecting on the velocity of transport flow. Degree of porosity in these condition determine the rate of inhibition from uranium on diplococcic at this phase of the transport process, the influences from degree of porosity determined the deposition of uranium and other substances inhibiting microbes in the formation.

Let $C = TY$ (51)

$$\frac{\partial c}{\partial t} = T^1Y \qquad (52)$$

$$\frac{\partial^2 c}{\partial y^2} = TY^{11} \qquad (53)$$

$$\phi T^1Y = K_d TY^{11} = \alpha^2 \qquad (54)$$

$$\int \frac{dT}{T} = \int \frac{-\alpha^2}{\phi} dt \qquad (55)$$

$$LnT = \frac{-\alpha^2}{\phi} t + a_5 \qquad (56)$$

$$T = \ell^{\frac{-\alpha^2}{\phi} t + a_5} \qquad (57)$$

$$T = C_4 \ \ell^{\frac{-\alpha^2}{\phi} t} \qquad (58)$$

$$K_d \frac{Y^{11}}{Y} = -\alpha^2 \qquad (59)$$

$$\frac{\partial^2 y}{\partial y^2} + \frac{\alpha^2}{K_d} y = 0 \qquad (60)$$

Auxiliary equation is

$$M^2 + \frac{\alpha^2}{K_d} = 0 \qquad (61)$$

$$M = \pm i \frac{\alpha}{\sqrt{K_d}} \qquad (62)$$

$$\therefore Y = ACos \frac{\alpha}{\sqrt{K_d}} y + BSin \frac{\alpha}{\sqrt{K_d}} y \qquad (63)$$

Combine (58) and (63), we have

$$C_4 = TY$$

$$C_4 = C_5 \ \ell^{\frac{-\alpha^2}{\phi} t} \left(ACos \frac{\alpha}{\sqrt{K_d}} y + ASin \frac{\alpha}{\sqrt{K_d}} y \right) \qquad (64)$$

Porosity continues to play foremost roles in the migration system, but at this stage, micronutrients are established to play it roles by displaying their functions on the deposition through the transport system. The influences from micronutrients are found to express thorough deposition, but may be established to deposit an average performance due to its rate of concentration. The expressions in [64] establish the role of half concentration of micronutrients in the transport system.

Considering

$$K_d \frac{\partial^2 c_5}{\partial y^2} = K_n \frac{\partial c_5}{\partial x} \qquad (5)$$

Let $C_5 = YX$

$$\frac{\partial c_5}{\partial y} = Y^{11}X \qquad (65)$$

$$\frac{\partial c}{\partial x} = X^1Y \qquad (66)$$

$$K_d Y^{11}X = -K_n X^1 Y \qquad (67)$$

$$K_d \frac{Y^{11}}{Y} = -K_n \frac{X^1}{X} \qquad (68)$$

$$K_d Y^{11}X = -K_n X^1 Y = -Z^2 \qquad (69)$$

Let $K_d \frac{Y^{11}}{Y} = -K_n \frac{X^1}{X} = Z^2$ (70)

$$K_d Y^{11} = -Z^2 \qquad (71)$$

$$Y^{11} + \frac{Z^2}{K_d} = 0 \qquad (72)$$

Auxiliary equation

$$M^2 + \frac{Z^2}{K_d} = 0 \qquad (73)$$

$$M = \pm i \frac{Z}{\sqrt{K_d}} \qquad (74)$$

$$\therefore Y = ACos \frac{Z}{\sqrt{K_d}} y + BSin \frac{Z}{\sqrt{K_d}} y \qquad (75)$$

$$K_n \frac{X^{11}}{X} \;=\; +Z^2$$

$$\int \frac{dx}{x} \;=\; \int \frac{+Z}{K_n} dx \qquad (76)$$

$$LnX \;=\; \frac{+Z^2}{K_n} x + a_6 \qquad (77)$$

$$X \;=\; C\ell^{\frac{+Z}{K_n}x} \qquad (78)$$

$$C_5 \;= C\ell^{\frac{+Z^2}{K_n}t}\left(ACos\frac{Z}{\sqrt{K_d}}y \;+\; BSin\frac{Z}{\sqrt{K_d}}y \right) \qquad (79)$$

The behavior of arsenic and micronutrients were considered lastly at this stage of the modeling approach, the structure at this phase were to observed the deposition of micronutrients and arsenic as an inhibitor in the deposition at diverse path of the formation, such circumstance are expressed to determine their behavior at two diverse path of flow influenced by porosity and velocity in the transport system. The derived solution established a model to monitor the behavior of both parameters in the system as it is established in the developed model of [79]. The expressions may develop higher concentration because it is set up to deposit motionless phase of the formation in the developed model Combining (21), (35), (50), (64) and (79) yield

$$C = \;(x,y) \;=\; C_1 + C_2 + C_3 + C_4 + C_5$$

$$C = \;(x,y) \;= C\ell^{\frac{t}{\phi}+\frac{x}{v}\lambda} + C_3\,\ell^{\frac{-\theta}{\phi}t}\left(ACos\frac{\theta}{\sqrt{D}}y \;+\; Sin\frac{\theta}{\sqrt{D}}y \right) +$$
$$\ell^{\frac{\varphi^2}{\phi}t}\left(A\,Cos\,\frac{\varphi}{\sqrt{Kc}}x \;+\; BSin\frac{\varphi}{\sqrt{Kc}}y \right) + \ell^{\frac{-\alpha}{K_d}}\left(ACos\frac{\alpha}{\sqrt{K_d}}y \;+\; BSin\frac{\alpha}{\sqrt{K_d}}x \right)$$
$$C\ell^{\frac{+Z^2}{K_n}x}\left(ACos\frac{Z}{\sqrt{K_d}}y \;+\; BSin\frac{Z}{\sqrt{K_d}}y \right) \qquad (80)$$

But if $t = \frac{x}{v}$, we have

$$C = \;(x,y) \;-\; C\ell^{\left(\frac{t}{\phi}+\frac{x}{v}\lambda\right)\frac{x}{v}} + C_3\,\ell^{\frac{-\theta}{\phi}t}\left(ACos\frac{\theta}{\sqrt{D}}y \;+\; BSin\frac{\theta}{\sqrt{D}}y \right)\frac{x}{v} +$$
$$C_5\,\ell^{\frac{-\varphi^2}{\phi}t}\left(A\,Cos\,\frac{\varphi}{\sqrt{Kc}}x \;+\; BSin\frac{\varphi}{\sqrt{Kc}}y \right)\frac{x}{v}\;C\ell^{\frac{+Z^2}{K_n}x}\left(ACos\frac{Z}{\sqrt{K_d}}y \;+\; BSin\frac{Z}{\sqrt{K_d}}y \right)$$
$$C_5\,\ell^{\frac{-\varphi^2}{\phi}t}\left(A\,Cos\,\frac{\varphi}{\sqrt{Kc}}x + BSin\frac{\varphi}{\sqrt{Kc}}y \right)\frac{x}{v}\;C_6\,\ell^{\frac{\alpha}{K_d}}\left(ACos\frac{\alpha}{\sqrt{K_d}} \;+ BSin\frac{\alpha}{\sqrt{K_d}} \right)\frac{x}{v} +$$
$$C\ell^{\frac{-Z^2}{K_n}x}\left(ACos\frac{Z}{\sqrt{K_d}}y \;+\; BSin\frac{Z}{\sqrt{K_d}}y \right)\frac{x}{v} \qquad (81)$$

Several phase were considered in the transport system of the study, the direction of flow were considered at different condition base of the geological environment of the study, the direction of transport flow were monitor in two different deposition, this implies that the flow net are in different direction as it is state in the governing equation, it may definitely experience different rate of deposition influenced by formation characteristics, formation deposited influences were found to play major roles in these condition of the study, therefore the function of various parameters were detailed at every stage of the developed model . Such conditions are to ensure that the influenced parameters are detailed in the derived solution as it is expressed from various phase of the transport system. The final expressed model were combined together to showcase the developed model together for the transport system of the study as it is expressed in [81].

4. CONCLUSION

The developed model in the system from the governing equation were derived in different phase considering various condition from formation characteristics influences and microbial behavior in the soil formations, diplococcic developed it behavior as usual but with slight different from other microbes, the behavior of the microbes were considered in the developed system that produces the governing equation, such condition were thoroughly considered in the system producing some influential variables in the study, mathematical modeling approach were found suitable through this type of mathematical method, this concept were found to express all the parameters that generate the results, this represents the deposition and migration of uranium and diplococcic in soil and water environment, the expression accommodates every parameters according to their function base on various behavior of the parameter at different direction of flow. The study has express every condition that may have influences the direction of flow on the transport system of uranium and diplococcic in the study location through the final derived model solution for the study.

REFERENCES

Eluozo S.N. 2013 Fluid pressure model to predict the influence of void ratio and permeability in alluvium predominant deposition in rivers state, Nigeria International Journal of Applied Chemical Sciences Research Vol. 1, No. 8, September 2013, PP: 121 - 130

[1] Nathanial J. T and Todd C. R 2007 Removal of Barometric Pressure Effects and Earth Tides from Observed Water Levels ground water computer (pages 101–105).

[2] Pascal, B. 1973. The Physical Treatises of Pascal. New York: Octagon Books.

[3] Spane, F.A. 2002. Considering barometric pressure in groundwater flow investigations. Water Resources Research 38, no. 6: 1078.

[4] Bower, D.R. 1983. Bedrock fracture parameters from the interpretation of well tides. Journal of Geophysical Research 88, no. 6: 5025–5035.

[5] Bredehoeft, J.D. 1967. Response of well-aquifer systems to earth tides. Journal of Geophysical Research 72, no. 12: 3075–3087

[6] Rasmussen, T.C., and L.A. Crawford. 1997. Identifying and removing barometric pressure effects in confined and unconfined aquifers. Ground Water 35, no. 3: 502–511.

[7] Eluozo S. N Model 2013 establishments and calibration of degree of saturation influencing the transport of cryptosporidium parvum in lateritic soil in coastal area of Degema Scientific Journal of Pure and Applied Sciences (2013) 2(2) 79-86

[8] Chenggang, B., Biwei, G., Liangtong, Z., 1998. ‗Properties of unsaturated soils and slope stability of expansive soils'. Proceedings of the second international conference on unsaturated soils, 27-30 August 1998, Beijing, China. Volume 2, pp71-98.

[9] Fredlund, D.G., 1998. ‗Bringing unsaturated soil mechanics into engineering practice.' Proceedings of the second international conference on unsaturated soils, 27-30 August 1998, Beijing, China. Volume 2

[10] Fredlund, D.G., Barbour, S.L., 1992. 'Integrated seepage modelling and slope stability analyses: A generalised approach for saturated/unsaturated soils'. Chapter 1 in Geomechanics and water engineering in environmental management; ed R.N. Chowdhury. Balkema.

[11] Fredlund, D.G., Hasan, J.U., 1979. 'One dimensional consolidation theory: unsaturated soils'. Canadian Geotechnical Journal, vol 16, pp521-531.

[12] Bear, J., 1972. Dynamics of fluids in porous media. Dover Publications Inc

[13] Bear, J., 1979. Hydraulics of Groundwater. McGraw-Hill

[14] Chenggang, B., Biwei, G., Liangtong, Z., 1998. ‗Properties of unsaturated soils and slope stability of expansive soils'. Proceedings of the second international conference on unsaturated soils, 27-30 August 1998, Beijing, China. Volume 2, pp71-98.

[15] Öberg, A.L., 1997. Matrix suction in silt and sand slopes. PhD thesis. Chalmers University of Technology, Sweden.

[16] Hawksley, W., 1993. ‗Pak Kong water treatment works. Ground movement affecting O Long village. Final Report. May 1993