

Research article

# MODELING THE TRANSPORT OF DISSOLVED URANIUM IN SOIL AND WATER INFLUENCED BY LINEAR VELOCITY IN UNCONFINED AQUIFERS IN PORT HARCOURT NIGER DELTA OF NIGERIA

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## Abstract

Modeling the transport of dissolved uranium in soil and water influence by linear velocity in unconfined aquifer has been thoroughly assessed. Unconfined aquifers were found to deposit predominantly in Port Harcourt. The studies were carried out to monitor the trace of uranium found to deposit in the study area. Regeneration of this trace contaminant is from man-made activities. To prevent this source of pollution, mathematical model were developed to monitor the transport of uranium to ground water aquifer under the influence of linear velocity. Linear velocities were confirmed through hydro geological studies from the flow of ground water influenced by velocity of fluid. The study is imperative because the geological setting has thoroughly expressed the behaviour of the formation characteristics determined from the transport of the dissolved uranium. This is under the influence of formation characteristic and velocity of flow. The developed model will definitely determine the trace contaminant in ground water aquifer, and professionals will use the application of the model to determine the rate of trace contaminant at various formations and monitor the quality of ground water in the study area. **Copyright © IJEATR, all rights reserved.**

**Keywords:** modeling dissolved uranium in soil and linear velocity in unconfined bed

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## 1. Introduction

Uranium occurs as a trace element in many types of rocks. Because its abundance in geological formations varies from place to place, uranium is a highly variable source of contamination in drinking water as the uranium

concentration in the host aquifer rock, the partial pressure of CO<sub>2</sub>, the presence of O<sub>2</sub> and complexing agents in the aquifer, the pH and the nature of the contact between the uranium minerals and water (Hess et al., 1985). Uranium in water is derived from phosphate deposits and mine tailings, as well as from run-off of phosphate fertilizers from agricultural land. Greater than 99 percent of uranium transported by runoff from land to fresh water systems is in suspended particles and remains in the sediment (Cothorn and Lappenbusch, 1983 1986). Environmental pH also influences both the type and relative amount of chemical complexing agents present in solution, which are known to facilitate uranium solubility and mobility. Inhalation is a minor route of entry for uranium into humans in the general population. The use of water that contains uranium could expose an individual to uranium by dermal contact or ingestion. Human skin absorption data are not available. Percutaneous absorption has been reported as an effective route of penetration for soluble uranium compounds after application to rat skin (De Rey et al., 1983). Single or daily applications were performed with uranium compounds mixed with emulsion composed of Vaseline<sup>®</sup> and water (De Rey et al., 1983). The lowest administered dose (0.5 g/kg body weight) was orders of magnitude greater than could result from exposure to the highest levels of uranium found in potential California drinking water sources. Electron microscopy showed that the uranium penetrated into the intercellular space between the horny and granular layers of the epidermis. Adverse effects such as purulence and detachment of the horny layer were observed (De Rey et al., 1983).

Gastrointestinal absorption studies of uranium include single oral administration experiments of soluble uranium compounds to rats, dogs, hamsters, baboons, and neonatal swine. Gastrointestinal absorption is consistently lower in rats (less than 0.5 percent) than in other species studied (Wrenn et al., 1985). Fractional absorption in two-day old rats given uranyl nitrate orally was estimated as 0.01 to 0.07 (ICRP, 1995). In feeding studies, it was found that absorption was doubled in fasted rats, and increased 3.4 fold in iron-deficient rats (ATSDR, 1997). individual who worked as a "chemical operator" in a uranium processing plant for 20 years. Deposition of uranium followed the pattern: skeleton > liver > kidney, with ratios of 63:2.8:1. The rank order of uranium content was in agreement with the observations by Fisenne and Welford (1986) for New York City residents but in disagreement with the data reported for the ICRP Reference Man (ICRP, 1975 1995, 1996). The uranium order content in the Reference Man is skeleton > kidney > lung > liver or 59, 7, 1, 0.45 µg, respectively. Recently, uranium in all tissues of two whole bodies were measured and reported by the U.S. Transuranium and Uranium Registries (USTUR) (Kathrin, 1998). The data showed lung > kidney > liver in one case and kidney > lung > liver in the other. In both cases, pulmonary lymph nodes were an order of magnitude higher in uranium concentration than other soft tissues. Such differences may be due to sampling error or real differences in exposure history and individual variability. In humans, most of the uranium (approximately 90 percent) is excreted in the feces; the remainder is excreted in the urine (Wrenn et al., 1985). In rats, most of the absorbed dose leaves the body within a few days in the urine (ATSDR, 1997); half is excreted in two to six days (Durbin and Wrenn, 1975), and 98 percent is excreted within seven days (Sullivan et al., 1980a, 1980b, 1986).

There is a fast and a slow phase of uranium excretion in humans and animals. The retention half lives of uranium in bone and kidney are of most relevance. For bone, half-lives of 883 days (Stevens et al., 1980), 180 and 360 days (Hursh and Spoor, 1973, Hursh 1989) and 800 days (Bernard, 1958) have been reported. Retention half-lives for uranium in human kidney have been reported as 30 days (Boback, 1975) and more recently as 6 days and 1,500 days for the fast and slow components, respectively (ICRP, 1979). Wrenn et al. (1985) utilized a 15-day half-life (Hursh and Spoor, 1973) and this value was incorporated into the uranium pharmacokinetic model. Numerous animal studies of the toxicity of uranium have been undertaken These studies have been reviewed by Yule (1973). More recently, the toxicology of uranium in animals has been reviewed by Durbin and Wrenn (1975) and by Wrenn et al. (1982, 1985).

## 2. Theoretical Background

Heavy metal deposition in soil and water environment has been an environmental pollution concern, when it is found to deposit in deltaic environment. Dissolved uranium is found to deposit in natural origin in deltaic environment, the areas were confirmed to deposit this type of heavy metal from natural origin. These were confirmed from the trace contaminant of uranium in some fresh water aquifer. The study area is deltaic formation; the formation is prone to generate fast migration of trace metal to ground water aquifer. The predominant unconfined bed depositing unconfined aquifers has generated shallow water table, through alluvium deposition from its predominant homogenous formation characteristics. It has significant effect on the fast migration of dissolved uranium under the influence of high degree of porosity; permeability and micropore of the soil, deltaic nature of the formation develop this influence from the formation characteristics at various degrees. Such condition are expressed from the behaviour of the trace heavy metal either from man-made activities or natural origins, the focus of this study is to develop model that will prevent the trace metal deposited between the soil strata and fluid deposition thus the soil to the ground water aquifer within a short distance. Shallow aquifer are prone to be contaminated by this trace deposited heavy metal in soil, thus it will definitely migrate through high degree of porosity and permeability deposition in deltaic soil on fast process to aquiferous zone.

To monitor the dissolved uranium in soil and water under the influence of linear velocity in unconfined bed, mathematical equation were established through the appropriate variables that should influence the system, this parameters considered develop fast migration of dissolved metal to ground water aquifers. The conceptual framework was developed to prevent the trace metal migrating to ground water aquifer in the study location. The governing equations for transport of this trace metal under the influence of linear velocity are established below:

## 3. Governing Equation

$$\frac{Vi\partial^2 C}{\partial t^2} = - \left[ \frac{Kj\epsilon p}{\mu} \right] \left[ P \frac{\partial C}{\partial x} + Pg \frac{\partial C}{\partial xi} \right] \dots \dots \dots (1)$$

Taking the Laplace transformation of (1)

Equation (1) is the formulated equation that expressed the parameters that influence the transport of uranium in soil and water from by linear velocity, the expression were considered in unconfined aquiferous zone in Port Harcourt. This study is carried out in area were man-made activities are highly practiced, i.e. industrial zone, and such trace metal found in those areas are added with the natural deposition on the study location. To model the uranium migration in soil and water environment, the equations were derived in phase to express the variations function in sequence and their influence at various formations.

$$\frac{\partial^2 C}{\partial t^2} = SC_{(0)} - SC_{(x)} - C_{(0)} \dots\dots\dots (2)$$

$$\frac{\partial C}{\partial x} = S^1 C_{(x)} - SC_{(x)} \dots\dots\dots (3)$$

Application of Laplace transformation was used as established the transport that produce from equations (1) to (3) and in equation (4) concentration with respect to distance at the initial concentration of the trace metal from the organic soil was established.

$$C_{(x)} = C_{(0)} \dots\dots\dots (4)$$

Substituting equation (2), (3) and (4) into equation (1) yields

$$Vi \left[ S^2 C_{(x)} - SC_{(x)} + C_{(0)} \right] + \frac{Kj\epsilon\rho}{\mu} + [PSC_{(x)} - Pg SC_{(x)}] C_{(0)} \dots\dots\dots (5)$$

Transport concentration and the distance travel on the transport process including time were substituted with the parameters that influence the transport system which yielded equations (4) and (5).

$$Vi S^2 C_{(t)} - Vi S^1 C^1_{(t)} + C_{(0)} + \frac{Kj\epsilon\rho}{\mu} C_{(0)} + C_{(0)} \dots\dots\dots (6)$$

$$\text{Considering the following boundary condition at } t = 0, C^1_{(0)} = C_0 = 0 \dots\dots (7)$$

We have

Several limit of transport condition were established, these were expressed considering boundary values at equation (7).

$$C_{(t)} \left( Vi S^2 - Vs + \frac{Kj\epsilon\rho}{\mu} + P + Pg \right) = 0 \dots\dots\dots (8)$$

$$C_{(t)} \neq 0 \dots\dots\dots (9)$$

Considering the boundary condition with respect to time on the concentration of the trace dissolved metal, it expresses the behaviour of the metal in the system at equations (8) and (9).

But considering the boundary condition

$$\text{At } t > 0, C_{(0)}^1 = C_{(0)} = C_o \quad \dots\dots\dots (10)$$

$$S^2 C_{(t)} - \frac{Kj\epsilon p}{\mu} S C_{(x)} + P_s S C_{(x)} = Vi S C_o + Vi C_o + \frac{Kj\epsilon p}{\mu} C_o + P_g C_o \quad \dots\dots (11)$$

Boundary condition considering when the concentration at time are greater than zero express its rate of metal on the transport process in uniform state, this were expressed in equations (10 and (11). Further expression on the influence of the boundary condition were stated in equation 12

$$\left[ Vi S^2 - \frac{Kj\epsilon p}{\mu} + P + P_g \right] C_{(t)} = \left[ Vi S + Vi + \frac{Kj\epsilon p}{\mu} + P + P_g \right] C_o \quad \dots\dots\dots (12)$$

$$C_{(x)} = \frac{Vi S - Vi S + \frac{Kj\epsilon p}{\mu} + P + P_g}{Vi S^2 - \frac{Kj\epsilon p}{\mu} + P + P_g} C_o \quad \dots\dots\dots (13)$$

Applying quadratic equation, we have

$$S = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \dots\dots\dots (14)$$

Where  $a = Vi$ ,  $b = \frac{Kj\epsilon p}{\mu}$ ,  $c = PP_g$

$$S = \frac{\frac{Kj\epsilon p}{\mu} \pm \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPP_g}}{2Vi} \quad \dots\dots\dots (15)$$

$$S_1 = \frac{\frac{Kj\epsilon p}{\mu} - \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPP_g}}{2Vi} \quad \dots\dots\dots (16)$$

$$S_2 = \frac{\frac{Kj\epsilon p}{\mu} + \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPP_g}}{2Vi} \quad \dots\dots\dots (17)$$

Integration developed an expression at equations (12) to (17), their expression are with respect to time and distance under the influence of porosity, linear velocity, pressure of flow and permeability in the system. This is done in other to discretized the parameter that produce their various influences in the system in details, application of

quadratic equation were integrated, the parameters were denoted in the expression of quadratic functions as expressed on equation (14).

The detailed expression of the variation to establish their detail

$$S_1 = \frac{\frac{Kj\epsilon p}{\mu} + \left[ \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]}{2Vi} S_2 + \frac{\frac{Kj\epsilon p}{\mu} - \left[ \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]}{2Vi} \ell \frac{\frac{Kj\epsilon p}{\mu} \left[ \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]^{\frac{L}{v}}}{2Vi} +$$

$$\left[ -\frac{Kj\epsilon p}{\mu} - \frac{Kj\epsilon p}{\mu} \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right] \dots \dots \dots (18)$$

Applying Laplace inverse of the equation, we obtain

$$C_{(t)} = \left[ \frac{Vi}{t} + Vi + \frac{Kj\epsilon p}{\mu} + P + Pg \right] C_o \ell \left[ \frac{\frac{Kj\epsilon p}{\mu} \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg}}{2Vi} \right]^t + \ell \left[ \frac{\frac{Kj\epsilon p}{\mu} \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg}}{2Vi} \right]^t \dots \dots \dots (19)$$

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

$$\left[ C [d, v] = \frac{Vi}{d/v} + Vi + \frac{Kj\epsilon p}{\mu} + P + Pg \right] C_o \ell \left[ \frac{\frac{Kj\epsilon p}{\mu} + \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg}}{2Vi} \right]^{\frac{d}{v}} \dots \dots \dots (20)$$

Functions in the system are expressed from equations (15) to (18).

Application of inverse Laplace on the expression of progressive phase of the contaminant were considered, whereby equations (19) were thoroughly derived through the expression of inverse Laplace to monitor the large migration of the trace metal. In some conditions were on the process the concentration starts to reduce with respect to distance including the pressure of linear velocity. The conditions were thoroughly determined form equations (19) to (20).

Considering the following boundary conditions at

$$t = 0, C^1 = 0, C = 0 \dots \dots \dots (21)$$

Under this condition the limit of concentration from initial to final were determined through boundary conditions established at Equation (21).

$$C_{(x)} = \left[ \frac{Vi}{t} + Vi + \frac{Kj\epsilon p}{\mu} + P + Pg \right] C_o \ell \left[ \frac{\left[ \frac{Kj\epsilon p}{\mu} \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]}{2Vi} \right]^{\frac{d}{v}} + \left[ \frac{Kj\epsilon p}{\mu} \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]^{\frac{d}{v}} \dots \quad (22)$$

At  $C^1_o = t \neq 0$

These expressions subject to the parameter that are considered where applied under the limited assume condition as it is expressed in equation (22).

Again  $C^1_{(o)} = C_{(o)}$  so that  $C_o = Vi + \frac{Kj\epsilon p}{\mu} + P + Pg$   $C_o = [1+1] i.e. 0 = \left[ 0 + \frac{Kj\epsilon p}{\mu} + PPg \right]^2$  ..... (23)

$$\Rightarrow \frac{Kj\epsilon p}{\mu} + \frac{Kj\epsilon p}{\mu} = 0 \dots\dots\dots (24)$$

So that we have

$$C_{(x)} = \left[ 2\frac{Vi}{t} \right] C_o \ell \left[ \frac{\left[ \frac{Kj\epsilon p}{\mu} + \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]}{2Vi} \right]^{\frac{d}{v}} + \left[ \frac{Kj\epsilon p}{\mu} + \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]^{\frac{d}{v}} \dots\dots\dots (25)$$

Considering the boundary condition of the process, we have another equation that was established under the process in equations (23) and (24). Subject to the relation of equation (24) produced equation (25) whereby an assumption generated an expression an equation generated were expressed in detailed in equation (25).

However,  $e^x + e^{-x} = 2Cos x$  therefore, we have

$$C_{(x)} = \left[ 2\frac{Vi}{t} \right] C_o Cos \left[ \frac{\left[ \frac{Kj\epsilon p}{\mu} + \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg} \right]}{2Vi} \right]^{\frac{d}{v}} \dots\dots\dots (26)$$

Application of suncidal expression were established since the system may not be linear on the transport process, it developed the final model equation that will monitor the transport of uranium under the influence of linear velocity in the study area as it is expressed in equation (26).

#### 4. Conclusion

The study area were opportune to have a baseline known to be Niger Delta basin this consists of massive high porous sand and gravel known to be multi aquifer system. Since the geological setting in the study location are

predominant with unconfined aquiferous zone. The result from trace metal has in several occasions caused borehole abandonment, while developing of potable water is greatly hampered. Based on these factors, mathematical model were developed to monitor the trace metal to ground water aquifer. The study location is deltaic in nature and such condition developed shallow aquifers in the study area. Formation characteristics were not left behind, thus they are the major significant effect on development of this hydraulic conductivity that sustains the multi aquifer system in the study area. Formation characteristics were considered on the system as these parameters were thoroughly expressed in terms of there functions on the transport system to ground water aquifer. This study is imperative because it has expressed various conditions that trace uranium can migrate to groundwater aquifer, the conceptual framework will definitely prevent trace metal to contaminate ground water aquifer in the study area.

## References

- [1] George V. Alexeeff, 2001 Public Health Goal for uranium In Drinking Water public health goals for chemicals in drinking water Agency Secretary California Environmental Protection Agency Winston H. Hickox
- [2] Hursh, J.B., Neuman, W.F., Toribara, T., Wilson, H., Waterhouse, C. (1969). Oral ingestion of uranium by man. *Health Phys.* **17**, 619-621
- [3] Hursh, J.B., Spoor, N.L. (1973). Uranium data on man. In: *Handbook of Experimental Pharmacology*. Edited by Hodge, H.C., Stannard, J.N., Hursh, J.B. Berlin. Springer-Verlag. **36**, 197-239
- [4] ATSDR. (1997). Toxicological Profile for Uranium. Draft for Public Comment. Agency for Toxic Substances and Disease Registry, CDC, Atlanta, Georgia
- [5] Boback, M.W. (1975). A review of uranium excretion and clinical urinalysis data in accidental exposure cases. In: *Conference on Occupational Health Experience with Uranium*. Edited by M.E. Wrenn. Arlington, Virginia. ERDA **93**, 225-243.
- [6] De Rey, B.M., Lanfranchi, H.E., Cabrini, R.L. (1983). Percutaneous absorption of uranium compounds. *Environ. Res.* **30**, 480-491.
- [7] ICRP (1975). Report of the Task Group on Reference Man. ICRP Publication 23. International Commission on Radiological Protection, Pergamon Press, Oxford
- [8] ICRP (1995). Age-Dependent Doses to Members of the Public from Intake of Radionuclides, Part 3. ICRP Publication 69. International Commission on Radiological Protection, Pergamon Press, Oxford.
- [9] ICRP (1996). Age-Dependent Doses to Members of the Public from Intake of Radionuclides, Part 5. Compilation of Ingestion and Inhalation Dose Coefficients. ICRP Publication 72. International Commission on Radiological Protection, Pergamon Press, Oxford
- [10] Sullivan, M.F. and Gorham, L.S. (1982). Further studies on the absorption of actinide elements from the gastrointestinal tract of neonatal animals. *Health Phys.* **43**, 509-519.
- [11] Sullivan, M.F. (1980a). Absorption of actinide elements from the gastrointestinal tract of rats, guinea pigs, and dogs. *Health Phys.* **38**, 159-171.
- [12] Sullivan, M.F. (1980b). Absorption of actinide elements from the gastrointestinal tract of neonatal animals. *Health Phys.* **38**, 173-185.
- [13] Sullivan, M.F., Ruemmler, P.S., Ryan, J.L., Buschbom, R.L. (1986). Influence of oxidizing or reducing agents on gastrointestinal absorption of uranium, plutonium, americium, curium, and promethium by rats. *Health Phys.* **50**, 223-232.

- [14] Wrenn, M.E., Durbin, P.W., Howard, B., Lipsztein, J., Rundo, J., Still, E.T., Willis, D.L. (1985). Metabolism of ingested uranium and radium. *Health Phys.* **48**, 601-634.
- [15] Wrenn, M.D., Singh, N.P. (1982). Comparative distribution of uranium, thorium, and plutonium in human tissues of the general population. In: *Natural Radiation Environment*. Edited by Vohra, K.C. Wiley Eastern Ltd., New Delhi, pp. 144-154.
- [16] Hess, C.T., Michel, J., Horton, T.R., Prichard, H.M. and Coniglio, W.A. (1985). The occurrence of radioactivity in public water supplies in the United States. *Health Phys.* **48**, 553-586
- [17] Lam, R.H.F., Brown, J.P., Fan, A.M., Milea, A. (1994). Chemicals in California drinking water: source contaminants, risk assessment, risk management, and regulatory standards. *J. Hazard. Materials* **39**, 173-192.
- [18] Cothorn, C.R., and Lappenbusch, W.L. (1983). Occurrence of uranium in drinking water in the U.S. *Health Phys.* **45**, 89-100.
- [19] Cothorn, C.R., Lappenbusch, W.L. (1986). Drinking water contribution to natural background radiation. *Health Phys.* **50**, 33-47.
- [20] Yuile, C.L. (1973). Animal experiments. In: *Handbook of Experimental Pharmacology*. Edited by Hodge, H.C., Stannard, J.N., Hursh, J.B. Volume 36. Springer-Verlag, Berlin, pp. 165-196.