

Research article

MODELING VERTICAL AND HORIZONTAL TRANSPORT OF ARSENIC IN LATERITIC AND SILTY FORMATION AT TRANS-AMADI LOCATION OF PORT HARCOURT METROPOLIS, NIGER DELTA OF NIGERIA

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Abstract

Vertical and horizontal migrations of arsenic were found to develop a serious hazard at trans-Amadi location of Port Harcourt metropolis. The depositions of arsenic are predominantly through manmade activities in the study location. Such conditions were confirmed through risk assessment carried out in the study location, the condition of the formation were discovered to have deposited serious pollution emanating from arsenic in the study area. The depositions of arsenic are through high settlement of industries whereby practices of various levels from the industries generate several heavy metal depositions in the study area, predominant some part under study deposited high concentration of arsenic, finding solution to prevent this substance has developed lots of challenges generating serious pollution in lateritic and silty formation, base on this factors mathematical model where find suitable to develop a model that will monitor the deposition of arsenic in the study location, the expressed model were derived base on several established conditions that influences the transport of arsenic in horizontal and vertical column. The model will be useful to experts on the field to ensure that they determined the level of arsenic concentration and prevent it from further migration.

Keywords: modeling, vertical and horizontal, transport of arsenic, lateritic and silty formation

1. Introduction

Industrial activity and natural environmental conditions have led to the introduction of nickel into soil and aquatic environments as a result of anthropogenic and geogenic sources, respectively (Duke, 1980; Richter and Theis, 1980). Nickel is a relatively minor constituent of the earth's crust having an average concentration of less than 0.01% by weight and ranking 24th in terms of abundance. Nickel is very heterogeneously distributed among crustal rocks ranging from less than 0.0001% in sandstone and granite to 4% in coveted ore deposits (Duke, 1980, Eluozo, 2013). Nickel can be found in igneous, sedimentary, and metamorphic rocks as well as nickel ores. In soils, nickel ranges from 5 – 500 mg kg⁻¹ (Lindsay, 1979). Serpentine clay-rich soils are noted for natural geogenic abundance of nickel and have been the focus for use of hyperaccumulating plants to phytomine nickel (Chaney et al., 1995). Nickel is one of the most mobile of the heavy metals in the aquatic environment. The mobility of nickel in the aquatic environment is controlled largely by competition between various sorbents to scavenge it from solution and ligands to form non-sorptive complexes. Although data are limited, it appears that in pristine environments, hydrous oxides and phyllosilicates control nickel mobility via co-precipitation and sorption. In polluted environments, the more prevalent organic compounds will keep nickel soluble by ligands complexation. In reducing environments, insoluble nickel sulfide may form. The movement of nickel in ground water will be restricted by partitioning reactions to aquifer sediments. Probable techniques' that influences nickel partitioning to subsurface solids include direct adsorption to clay minerals, adsorption and/or coprecipitation with metal oxides, complexation with natural organic particles, ion exchange with charged surfaces, and direct precipitation as an hydroxide, carbonate or sulfide (Snodgrass, 1980). The chemical speciation of nickel in solution exerts a significant influence on the extent and mechanism(s) of partitioning to aquifer sediments, which may be influenced by acid-base reactions, oxidation-reduction reactions influencing the speciation of complexing inorganic solution species (e.g., aqueous sulfate vs. sulfide), and interactions with dissolved organic compounds. In general, inorganic/organic species that form dissolved complexes with nickel tend to enhance transport of nickel in soil profiles to subsurface water (e.g., dissolved organic carbon; Christensen et al., 1996; Warwick et al., 1997; Christensen and Christensen, 2000; Friedly et al., 2002, Eluozo, 2013). Field studies on transport in the subsurface illustrate several general conditions that are anticipated to result in expanding nickel plumes, including 1) acidic conditions (Kjoller et al., 2004), 2) manganese- and iron-reducing conditions (Larsen and Postma, 1997), and 3) the presence of mobile organic compounds that form soluble nickel complexes (Christensen et al. 1996; Kent et al., 2002). Possible production concept that can be in a job for remediation of a ground-water plume containing nickel include physical removal of polluted soils or sediments that serve as a long-term source of nickel leached into ground water, extraction of the dissolved plume with some method of above-ground treatment, physical isolation of the dissolved plume, or in-situ treatment of a dissolved plume resulting in immobilization of dissolved nickel within the aquifer. Of these technologies, the use of permeable reactive barriers (PRBs) for the capture and immobilization of nickel plumes has been investigated and applied in field settings due to favorable performance and cost characteristics (Blowes et al., 2000). Both carbon- and metallic iron-based (or zero valent iron) reactive media have been employed for nickel removal from ground water. For carbon-based media, nickel removal is generally considered to occur (Eluozo, 2013)

2. Theoretical Background

The deposition of arsenic in soil and water environment has been a subject on serious concern due to its health implication, this is due to its rate of toxicity in soil and water environment, the deposition of the arsenic are mostly manmade activities in the study area, such observation are from risk assessment carried out to monitor the rate of concentration at different direction in the soil formation. The formation of the study area are predominant with lateritic and silty formation were the void ratio and porosity develop slight low degree, this implies that the condition of the formation determine the rate of formation deposition, the structure of the formation are base on the geological formation, the study area examined this through risk assessment observed to deposit low degree of void ratio between lateritic and silty formation, the substance were observed to develop high concentration, this implies that the formation deposit above the silty will develop more accumulation of the substance than the silty formation, such observation implies that the stratification of the formation are influenced by formation characteristics influenced by geologic history of the study area. The deposition of arsenic at vertical and horizontal direction of fluid flow in the strata has definitely develop contaminant from arsenic in different directions, porosity and void ratio were the formation characteristics that are found to influences the directions of flow on the transport system. The study developed a system to monitor that transport arsenic in vertical and horizontal direction of the formation, the concept has been mathematically model the direction of transport in these conditions, the expressed governing are stated bellow.

3. Governing Equation

$$\phi \frac{\partial v}{\partial t} = U \frac{\partial v}{\partial x} = D \frac{\partial^2 v}{\partial y^2} + f(x, y) \quad \dots\dots\dots (1)$$

Porosity is one of the formation characteristics that that determine the movement of fluid, the system were formulated to express the transport of arsenic in two dimensional condition of transport, this deposition of this substance is of serious concern due to health implication involve. The stratifications plays major roles in the deposition of arsenic in the study area, base on these factors mathematical model were found appropriate to mathematically model the direction of these transport in silty formations, the defined governing equations are stated above.

$$\phi \frac{\partial v}{\partial t} + U \frac{\partial v}{\partial x} = f(x, y) \quad \dots\dots\dots (2)$$

Let $V = TX$

$$\frac{\partial v}{\partial t} = T^1 X \dots\dots\dots (3)$$

$$\frac{\partial v}{\partial x} = TX^1 \dots\dots\dots (4)$$

$$\phi T^1 X + UTX^1 = f \dots\dots\dots (5)$$

$$\phi \frac{T^1}{T} + U \frac{X^1}{X} = f \dots\dots\dots (6)$$

$$\phi \frac{T^1}{T} = f \dots\dots\dots (7)$$

$$U \frac{X^1}{X} = f \dots\dots\dots (8)$$

From (7), $\phi \frac{dT^1}{T} = f dt \dots\dots\dots (9)$

$$\int \frac{dT^1}{T} = \int \frac{f}{\phi} dt \dots\dots\dots (10)$$

$$\ln T = \frac{f}{\phi} t + a_1 \dots\dots\dots (11)$$

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

$$T = C_1 \ell^{\frac{f}{\phi} t} \dots\dots\dots (13)$$

$$U \frac{dX^1}{X} = f dx \dots\dots\dots (14)$$

$$\int \frac{dX}{X} = \int \frac{f}{u} dx \dots\dots\dots (15)$$

$$\ln X = \frac{f}{u} x + a_2 \dots\dots\dots (16)$$

$$X = \ell^{\frac{f}{u}x + a_2} \dots\dots\dots (17)$$

$$X = C_2 \ell^{\frac{f}{u}x} \dots\dots\dots (18)$$

But $V = TX$

$$V_1 = C_1 \ell^{\frac{f}{\phi}t} \bullet C_2 \ell^{\frac{f}{u}x} \dots\dots\dots (19)$$

$$V_1 = C_1 C_2 \ell^{\left(\frac{t}{\phi} + \frac{x}{u}\right)f} \dots\dots\dots (20)$$

$$V_1 = C \ell^{\left(\frac{t}{\phi} + \frac{x}{u}\right)f}$$

$$\dots\dots\dots (21)$$

The expression at [21] shows that at this condition, the transport of arsenic are in progressive phase, this is where the deposition are migrating direct from the point sources of discharge, although the formation developed low void ratio and it is reflected on the porosity of the soil, but the study considered the deposition influenced by climatic conditions whereby the deposition of the formation are in deltaic environment, it experiences high rain intensities pressuring the migration of the solute to where the percentage of void ratio and porosity are very high.

$$\phi \frac{\partial v_2}{\partial t} = D \frac{\partial^2 v_2}{\partial y^2} \dots\dots\dots (22)$$

Let $V = TY$

$$\frac{\partial v}{\partial t} = T^1 Y \dots\dots\dots (23)$$

$$\frac{\partial^2 v}{\partial y^2} = TY^{11} \dots\dots\dots (24)$$

$$\phi T^1 Y = DTY^{11} = \lambda^2 \dots\dots\dots (25)$$

Let $\phi \frac{T^1}{T} = D \frac{Y^{11}}{Y} = -\lambda^2 \dots\dots\dots (26)$

$$\int \frac{dT}{T} = \int \frac{-\lambda^2}{\phi} dt \dots\dots\dots (27)$$

$$\ln T = \frac{-\lambda^2}{\phi} t + a_3 \dots\dots\dots (28)$$

$$T = \ell^{\frac{-\lambda^2}{\phi} + a_3} \dots\dots\dots (29)$$

$$T = C_3 \ell^{\frac{-\lambda^2}{\phi} t} \dots\dots\dots (30)$$

$$D \frac{Y^{11}}{Y} = -\lambda^2 \dots\dots\dots (31)$$

$$\frac{d^2 y}{dy^2} + \frac{\lambda^2}{D} Y = 0 \dots\dots\dots (32)$$

Auxiliary equation is

$$m^2 + \frac{\lambda^2}{D} Y = 0 \dots\dots\dots (33)$$

$$m \pm i \frac{\lambda}{\sqrt{D}} \dots\dots\dots (34)$$

$$Y = A \cos \frac{\lambda}{\sqrt{D}} y + B \sin \frac{\lambda}{\sqrt{D}} y \dots\dots\dots (35)$$

Combine (6) and (7), we have;

$$V_2 = TY$$

$$V_2 = C_3 \ell^{\frac{-\lambda^2}{\phi} t} \left(A \cos \frac{\lambda}{\sqrt{D}} y + A \sin \frac{\lambda}{\sqrt{D}} y \right) \dots\dots\dots (36)$$

Considering

$$U \frac{\partial v_3}{\partial x} = D \frac{\partial^2 v_3}{\partial y^2} \dots\dots\dots (37)$$

Let $V_3 = XY$

$$\frac{\partial v_3}{\partial x} = X^1 Y \dots\dots\dots (38)$$

$$\frac{\partial^2 v_3}{\partial y^2} = XY^{11} \dots\dots\dots (39)$$

$$UX^1 Y = DXY^{11} \dots\dots\dots (40)$$

$$U \frac{X^1}{X} = D \frac{Y^{11}}{Y} = \rho^2 \dots\dots\dots (41)$$

$$U \frac{X^1}{X} = \rho^2 \dots\dots\dots (42)$$

$$\frac{X^1}{X} = \frac{\rho^2}{U} \dots\dots\dots (43)$$

$$\ln X = \frac{\rho^2}{U} x + a_4 \dots\dots\dots (44)$$

$$\text{i.e. } X = \ell^{\frac{\rho^2}{U} x + a_4} \dots\dots\dots (45)$$

$$X = C_4 \ell^{\frac{\rho^2}{U} x} \dots\dots\dots (46)$$

$$D \frac{Y^{11}}{Y} = \rho^2 \dots\dots\dots (47)$$

$$\frac{d^2 y}{dy} - \frac{\rho^2}{D} Y = 0 \dots\dots\dots (48)$$

Auxiliary equation is

$$m^2 - \frac{\rho^2}{D} = 0 \dots\dots\dots (49)$$

$$m = \pm \frac{\rho}{\sqrt{D}} \dots\dots\dots (50)$$

$$Y = D\ell \frac{\rho}{\sqrt{D}} y + E\ell \frac{-\rho}{\sqrt{D}} y \quad \dots\dots\dots (51)$$

Combining (46) and (51), yield;

$$V_3 = XY$$

i.e.

$$V_3 = C_4 \ell \frac{\rho^2}{U^x} \left(D\ell \frac{\rho}{\sqrt{D}} y + E\ell \frac{-\rho}{\sqrt{D}} y \right) \quad \dots\dots\dots (52)$$

Combining (5), (8) and (11), yield;

$$V(x, y) = V_1 + V_2 + V_3$$

$$V(x, y) = C\ell \left(\frac{t+x}{\phi+u} \right)^f + C_3 \ell \frac{-\lambda^2}{\phi^t} \left(A \cos \frac{\lambda}{\sqrt{D}} y + A \sin \frac{\lambda}{\sqrt{D}} y \right)$$

$$V_3 = C_4 \ell \frac{\rho^2}{U^x} \left(D\ell \frac{\rho}{\sqrt{D}} y + E\ell \frac{-\rho}{\sqrt{D}} y \right) \quad \dots\dots\dots (53)$$

The expression here is the final developed model for vertical and horizontal direction of flow in silty formation, the study was carried out in Trans -Amadi location of port Harcourt metropolis , this location are were manmade activities are carried out to the optimum level, the formation are between the deltaic environment whereby there lots of formation influences in the study area, vertical and horizontal direction of flow were carried out to ensure the direction of arsenic transport are monitored in the study area , this will easier to determined the rate of spread and it concentration comparing the two direction of flow in the formation.

4. Conclusion

Vertical and horizontal direction of flow are centre for monitoring the transport of arsenic in the study location, health implication of arsenic deposition in lateritic and silty formation was expressed on the developed system to generated the governing equation for the study, the study area are predominantly industrialized location of port Harcourt metropolis, such development has generated lots of heavy metal deposition in various strata, the deposition of arsenic has lots of health implication in lateritic and silty formation, therefore it implies that the migration will definitely proceed to aquiferous zone. Developing a better solution to monitor the rate of concentration in two direction of transport were imperative for the study area, the prevention of the substances from further migration is a serious challenge, the development of mathematical model were fine suitable to ensure

that the rate of transport are determined, this will develop a base line to prevent the transport to shallow deposited aquifer in the study area.

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