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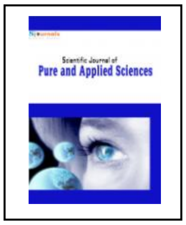

Original article

Modeling and simulation of dissolved lead in groundwater influenced by porosity and seepage velocity in homogeneous formation

S.N. Eluozo
Subaka Nigeria Limited Port Harcourt Rivers State of Nigeria.

*Corresponding author; Subaka Nigeria Limited Port Harcourt Rivers State of Nigeria.

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ABSTRACT

Modeling and simulation of dissolved lead in groundwater influenced by porosity and seepage velocity in homogenous formation has been developed. Porosity influence were considered in the study area as the major role of lead transport, seepage velocity are through the degree of porosity of the soil, this formation characteristics were thoroughly examined, the variables were applied to formulate a system, this system denoted with mathematical tools that developed a governing equation. These equations were derived and it generated a model to monitor the rate of dissolved lead influenced by porosity and seepage velocity in homogenous formation. The developed model was compared with the experimental values from other locations for validation. The model confirmed the fitness of both parameters, the validation of this model implies that the model should be applied to monitor the dissolved lead in the study location. The figures were found to be increasing gradually and rapidly in several locations, these are based on the influence of porosity and seepage velocity. It is recommended that risk assessment should be thoroughly done to reduce the type of pollution in the study area.

1. Introduction

Lead is a well-known neurotoxin. Destruction of neurodevelopment in children is the most serious effect. Exposure in utero, during breastfeeding and in early Childhood may all be responsible for the effects. Lead accumulates in the skeleton, and its mobilization from bones during pregnancy and lactation causes exposure to fetuses and breastfed infants. Hence, the lifetime exposure of woman before pregnancy is important. Epidemiological studies consistently show that effects in children are associated with blood lead (B-Pb) levels of about 100–150 µg/l. There are indications that lead is harmful even at B-Pb concentrations considerably below 100 µg/l; there may be no threshold for these effects. In many areas there have been major decreases in B-Pb levels in recent decades, mainly because of the phasing out of leaded petrol but also because of reductions in other sources of exposure. At present, the lowest average B-Pb level in several European countries is about 20 µg/l, but reliable B-Pb information from many parts of Europe is lacking. The relative contributions of sources of pollution differ depending on local conditions. Food is the predominant source of lead uptake in the general population. Ingestion of contaminated soil, dust and old lead-based paint due to hand to- mouth activities may also be important regarding lead intake in infants and young children. When tap-water systems with leaded pipes are used, lead intake via drinking-water can be an important source, especially in children. Inhalation exposure may be significant when lead levels in the air are high. Lead levels in ambient air have decreased in recent decades: between 1990 and 2003, lead levels in air in Europe fell by 50–70%. Similar decreases have been observed for atmospheric deposition. The annual lead inputs from LRTAP and from the addition of organic and inorganic fertilizers to topsoil are roughly similar in magnitude, depending on the country and the agricultural activity. Those inputs are relatively small in comparison with the existing accumulations, natural sources and resuspension. However, LRTAP may contribute significantly to the lead content of crops through direct deposition. Although uptake via plant roots is relatively small, rising lead levels in soils over the long term are a matter of concern and should be avoided because of the possible health risks of low-level exposure. Lead emissions to the atmosphere should therefore be kept as low as possible (WHO 2007).

Changes, of groundwater quality are caused directly or indirectly by various activities of man. Direct influences emanate from natural or artificial substances which are introduced by man into the geochemical cycle of the earth, and ultimately reach the groundwater zone. Indirect influences should be considered to be those changes of quality which are brought about without the addition of substances by man into hydrological, physical and biochemical processes. Transitions occur between the direct and indirect influences, e.g. when artificially recharged and bank filtered river water containing noxious constituents mixes with groundwater. Polluted groundwater may be defined as groundwater which has been affected by man to the extent that it has higher concentrations of dissolved or suspended constituents than maximum permissible concentrations fixed by national or international standards for potable, industrial or agricultural purposes. As natural groundwater (i.e. not influenced by man) may contain constituents exceeding the standard limits, pollution should be defined in these cases as any increase in the concentration of the respective constituent above its natural variations (Matthess, 1958, 1970, 1972 and 1973). Thus, the evidence of man-made changes takes as a prerequisite the investigation of natural groundwater properties and their temporal and spatial variations. The criteria for anthropogenic influences must be chosen in accordance with the prevailing circumstances and the best proof will be the identification of artificial components in groundwater. Natural processes, to which all substances are exposed, may modify the composition of groundwater on its subterranean flow path. This is the reason for the spatial and temporal limitation of areas affected by pollution or of polluted groundwater zones. However, it also creates difficulties in obtaining clear evidence of anthropogenic influences

Solution of substances in the ground is generally due to dissolution, degradation and hydration processes. The ability of water to dissolve substances is increased by inorganic and organic acids and an increase in temperature. Solution and precipitation are frequently controlled by pH and Eh. Solution of artificial solids may occur in the atmosphere (aerosols) and on and under the ground surface. Resulting concentrations are due to the solubility of the respective substances, the extent of the solid/water interface and the contact time. The solubility of numerous substances dependent on pressure, temperature and co-solutes may be studied in models with the help of chemical thermodynamics' (Garrels and Christ, 1965). This approach is valid only for electrolytic solutions, not for colloids. The basis of equilibrium thermodynamics is Gibbs' free energy AG, which is related to the equilibrium coefficient' Substances with solubilities which are dependent on pH and Eh may be precipitated by groundwater's with different pH and Eh values (e.g. mixtures of groundwater free of oxygen containing ferrous iron with oxygen-bearing groundwater). The Eh conditions may change along the subterranean flow path of the water. Oxygen-consuming processes e.g. microbial degradation of organic matter, may give rise to oxygen-free reduction zones characterized by the presence of ferrous iron, manganese, ammonia, nitrite and sulphide, the deficiency of nitrate and a diminished content or absence of sulphate (Schwille and Vorreyer, 1969,1964.; Golwer *et al,* 1970,1972 and 1973). In such reduction zones heavy metals are precipitated as suphides when sulphide ions are present. When groundwater flows into regions where oxygen supply exceeds the oxygen consumptions, the reduced inorganic materials are oxidized with the precipitation of insoluble hydroxides and oxides, especially those of iron and manganese (Georg, 1976)

2. Materials and methods

Column experiments were also performed using soil samples from several different borehole locations, the soil samples were collected at intervals of three metres each (3m). An lead solute was introduced at the top of the column and effluents from the lower end of the column were collected and analyzed for lead , and the effluent at the down of the column were collected at different days, analysis, velocity of the transport were monitored at different days. Finally, the results were collected to be compared with the theoretical values.

2.1. Governing equation

$$\frac{Vi\,\partial C}{\partial xi} = \frac{qi}{\varepsilon} = \frac{-Kih}{\varepsilon}\frac{\partial C}{\partial xi} \qquad \text{..............................} \qquad (1)$$

$$\frac{\partial C}{\partial x} = SC_{(x)} - C_{(0)} \qquad \text{..............................} \qquad (2)$$

$$\frac{\partial C}{\partial xi} = SC_{(x)} - C_{0} \qquad \text{..............................} \qquad (3)$$

$$C = C_{o} \qquad \text{..............................} \qquad (4)$$

Substituting equations (2), (3) and (4) into equation (1) yield

$$Vi\left[SC_{(x)} - SC_{(x)} - C_{(0)}\right] - \frac{qi}{\varepsilon} - \frac{Kih}{\varepsilon}\left[SC_{(x)} - C_{(x)}\right] - C_{(0)} \qquad \text{......................} \qquad (5)$$

$$Vi\ SC_{(t)} - ViSC^{1}{}_{(t)} - C_{(0)} - \frac{qi}{\varepsilon}\frac{Kih}{\varepsilon}SC_{(0)} + \frac{qi}{\varepsilon}\frac{Kih}{\varepsilon}C_{(0)} - C_{(0)} \qquad \text{..............} \qquad (6)$$

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

We have

$$C_{(x)}\left(ViS - Vs - \frac{qi}{\varepsilon}\frac{Kih}{\varepsilon}S\right) = 0 \qquad \text{..............................} \qquad (8)$$

$$C_{(t)} \neq 0 \qquad \text{..............................} \qquad (9)$$

But considering the boundary condition

At $t > 0,\ C^{1}{}_{(0)} = C_{(0)} = C_{o}$ .... (10)

$$SC_{(x)} - \frac{qi}{\varepsilon}\frac{Kih}{\varepsilon}S_{(x)} - Vi\,Sc_{o} + Vi\,C_{o} + \frac{qi}{\varepsilon}\frac{Kih}{\varepsilon}C_{o} \qquad \text{..............................} \qquad (11)$$

$$\left[ViS - \frac{qi}{\varepsilon}\frac{Kih}{\varepsilon}S\right]C_{(x)} = \left[Vi\,S + Vi + \frac{qi}{\varepsilon}\frac{Kih}{\varepsilon}\right]C_{o} \qquad \text{..............................} \qquad (12)$$

$$\frac{C_{(x)} = Vi\,S + Vi\,\frac{qi}{\varepsilon}\,\frac{Kih}{\varepsilon}}{ViS - \frac{qi}{\varepsilon}\,\frac{Kih}{\varepsilon}S}C_o \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (13)$$

Applying quadratic expression, we have

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (14)$$

$$\frac{-\frac{qi}{\varepsilon} \pm \sqrt{\frac{qi}{\varepsilon}^{2} + 4Vi\frac{Kih}{\varepsilon}}}{2Vi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (15)$$

$$C_{(x)} = A\exp\frac{\left[-\frac{qi}{\varepsilon} + \sqrt{\frac{-qi^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}}\right]^x}{2Vi}x - \exp\frac{\left[-\frac{qi}{\varepsilon} + \sqrt{\frac{-U^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}}\right]^x}{2Vi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(16)$$

Subjecting equation (16) to the following boundary condition and initial values condition

$$x = 0,\ C_{(0)} = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (17)$$

We have *B = -1* and *A = 1* ………………… (18)

So that our particular solution, will be in this form

$$C_{(x)} = \exp^{\left[-\frac{qi}{\varepsilon} + \left(\frac{qi}{\varepsilon} - 4Vi\frac{Kih}{\varepsilon}\right)^{1/2}\right]}x = \exp^{\left[-\frac{qi}{\varepsilon} + \left(\frac{qi^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}\right)^{1/2}\right]} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (19)$$

But $e^x - e^{-x} = 2\,Sin\,x$

Therefore, the expression of (19) can be written in this form

$$C_{(x)} = 2\,Sin\left[\frac{qi}{\varepsilon} + \left[\frac{qi^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}\right]^{1/2}\right]x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (20)$$

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

Therefore, the model can be expressed as:

$$C_{(t)} = 2\,Sin\left[\frac{qi}{\varepsilon} + \left(\frac{qi^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}\right)^{1/2}\right]\frac{v}{t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (21)$$

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

$$C_{(t)} = 2\,Sin\left[\frac{qi}{\varepsilon} + \left(\frac{qi^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}\right)^{1/2}\right]x \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (22)$$

Considering (21) and (22) yield

$$\boxed{C_{(x,t)} = 2\,Sin\left[\frac{qi}{\varepsilon} + \left(\frac{qi^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}\right)^{1/2}\right]t + 2\,Sin\left[\frac{qi}{\varepsilon} + \left(\frac{qi^2}{\varepsilon} + 4Vi\frac{Kih}{\varepsilon}\right)^{1/2}\right]x} \ldots \quad (23)$$

3. Results and discussion

Modeling and simulation of dissolved lead in groundwater influenced by porosity and seepage velocity in homogeneous formation are presented in table and figures bellow.

Table 1

Comparison between theoretical and experimental values at various Depths

Depth M	Theoretical values	Experimental values
3	0.36	0.33
6	0.71	0.65
9	1.06	1.11
12	1.39	1.29
15	1.69	1.71
18	1.97	1.89
21	2.22	2.11
24	2.44	2.52
27	2.63	2.59
30	2.78	2.81

Table 2

Comparisons between theoretical and experimental values at various Times

Time	Theoretical values	Experimental values
10	0.36	0.33
20	0.71	0.65
30	1.06	1.11
40	1.39	1.29
50	1.69	1.71
60	1.97	1.89
70	2.22	2.11
80	2.44	2.52
90	2.63	2.59
100	2.78	2.81

Table 3

Comparisons between theoretical and experimental values at various Depths

Time	Theoretical values	Experimental values
10	0.036	0.042
20	0.065	0.069
30	0.11	0.13
40	0.14	0.16
50	0.17	0.21
60	0.21	0.27
70	0.25	0.29
80	0.28	0.31
90	0.32	0.35
100	0.36	0.39

Table 4
Comparisons between theoretical and experimental values at various Depths.

Depth M	Theoretical values	Experimental values
3	0.036	0.042
6	0.065	0.069
9	0.11	0.13
12	0.14	0.16
15	0.17	0.21
18	0.21	0.27
21	0.25	0.29
24	0.28	0.31
27	0.32	0.35
30	0.36	0.39

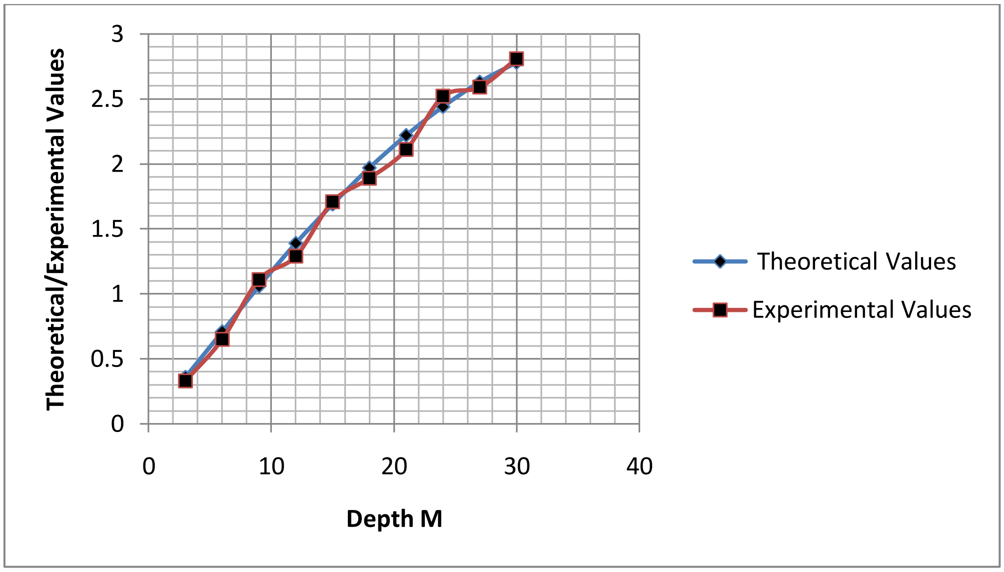

Fig. 1. Comparison between theoretical and experimental values at various Depths.

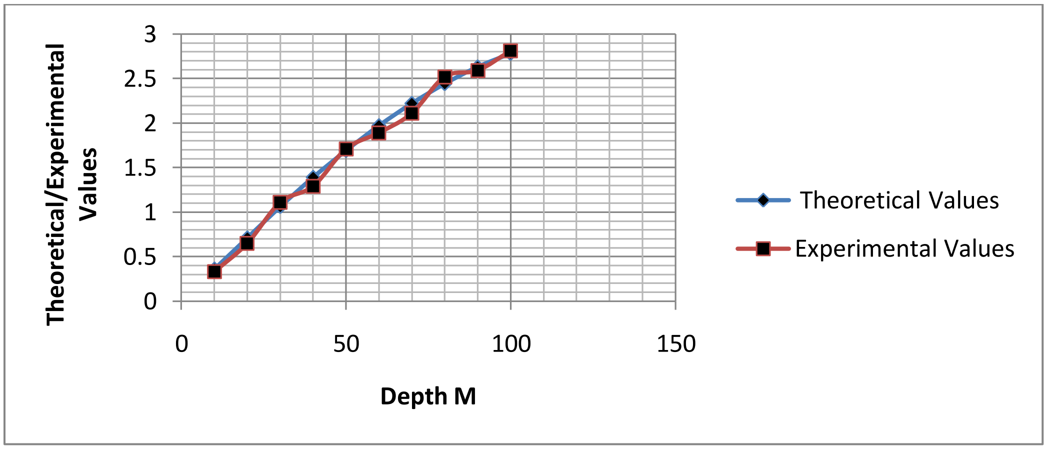

Fig.2. Comparisons between theoretical and experimental values at various Depths.

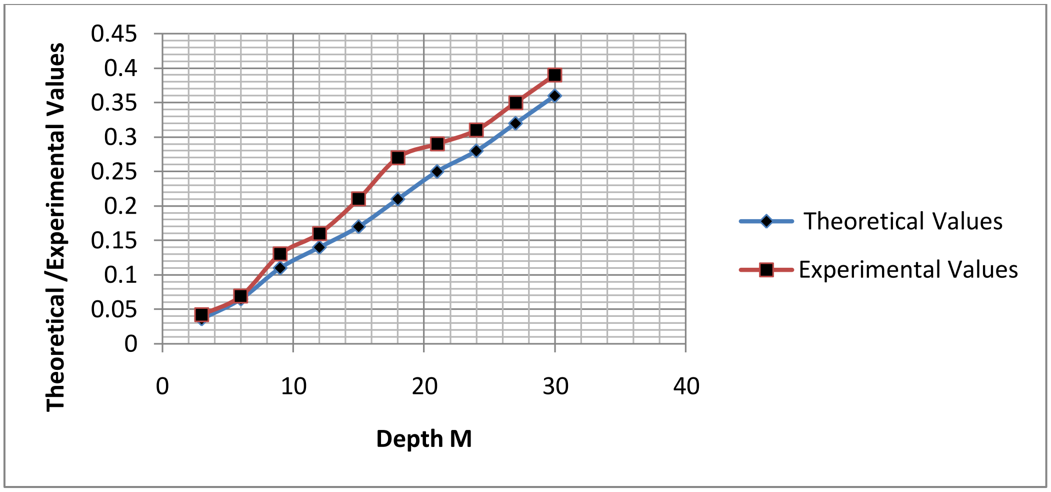

Fig. 3. Comparisons between theoretical and experimental values at various Depths.

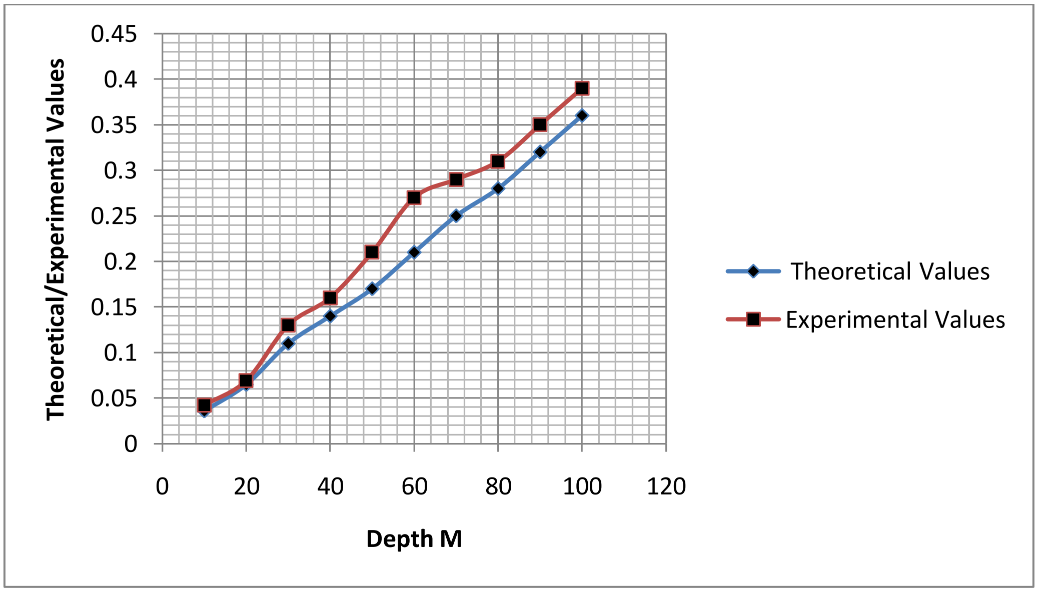

Fig. 4. Comparisons between theoretical and experimental values at various Depths.

Figure 1 shows that the microbes linearly increase to where the optimum value were recorded at thirty metres, while the experimental value maintained the same trend, but with slight fluctuation in some regions, both parameters were found to compare favourably well. Similar conditions were recorded in figure 2; the theoretical value experienced a gradual increase to the point where the optimum values were recorded at hundred days, while the experimental values observed the same trend and recorded its optimum value at thirty metres. Figure 3 developed a slight different increase compared to previous figures, fluctuations were observed from the theoretical values between the coarse formation, within fifteen and thirty metres where the optimum values were recorded, while the experimental values experienced similar conditions from three to ninety metres. Figure 4 confirmed change in concentration with respect to variation in period, the concentration experienced fluctuation between fifty and ninety days while the theoretical values experienced sight fluctuation, that cannot be compared with the experimental values.

The contaminants experience fast migration in a continuous process, the law of plug flow were observed in the transport process as presented in the figures, the rate of concentration shows that the deposition of the contaminant were not hindered by any mineral on the soil, the rate of concentration can also be attributed to combination of man made activities and natural origin. The formation of the soil also played a major role in the transport process; the soil structural stratification of the sediments generated high degree of void in the soil, it definitely influenced high concentration and fast migration of the contaminant. Finally, this condition as presented in the figure shows that aquiferious zone deposited at thirty metres is highly contaminated with lead pollution and that means that groundwater from such aquifer is a death trap to human and should not be used for human consumption in the study area.

4. Conclusion

The transport of lead to groundwater aquifer is a serious problem in the study location; lead poison is a death trap to human settlement in the study area. High concentration of this contaminant were found to be influenced by the environmental condition and natural origin deposition, the area under study were found to deposit high concentration from nine to thirty metres. The rate of concentration confirms the influence of homogenous soil structural deposition, generating fast migration of the contaminant at shallow aquiferious zone and with a short period of time. Change in concentration can also be attributed to increase in degree of porosity from the homogenous formation. The rate of migration where found to be predominant with linear migration, this condition can be attributed to the sedimentation of the sand stone and the method of disintegration of the rocks. Several conditions were considered when the system was formulated; the derived equation generated a model to monitor the rate of this heavy metal in the study area. Based on this factor, I recommend that there should be thorough risk assessment and installation of the treatment plant on any borehole design in the study area.

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