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Predictive model to monitor rate of dissolved chromium in soil and water influenced by permeability and linear velocity in phreatic aquifers

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ABSTRACT

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Predictive model to monitor the rate of dissolved chromium influenced by linear velocity and permeability has been developed, the model were developed to monitor the rate of traced metal chromium in phreatic aquifers, dissolved chromium were found to deposit dynamic concentration at different depth and time The influence of the migration are from the stratification of the soil influence by porosity and permeability, the theoretical values were compared with experimental results form other locations; both parameters compared favourably well. Chromium were found to dissolve with respect to change in concentration with time and distance in some locations, while in rapid increase were experienced in the last two locations. This condition implies that dynamic deposition of permeability and linear velocity influence the variation of concentration; those locations were the concentration deposit high concentration can be attributed to high degree of permeability of the formation, the model is imperative because it will monitor the rate of dissolved chromium in phreatic aquifers.

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1. Introduction

Heavy metal contamination of aquatic ecosystems is becoming a prospective global problem. Developing nations such as Nigeria, lack for mechanisms and sensitive tools to detect and observe water quality and are therefore exposed to heavy metal poisoning (Ochieng et al., 2008). Trace amounts of heavy metals are constantly

present in fresh waters from terrigenous sources such as weathering of rocks resulting into geo-chemical recycling of heavy metal elements in these ecosystems (Muwanga, 1997; Zvinowanda et al., 2009). Trace elements may be immobilized within the stream sediments and thus could be involved in absorption, co precipitation, and complex formation (Okafor and Opuene, 2007; Mohiuddin et al., 2010). Sometimes they are co-adsorbed with other elements as oxides Hydroxides of Fe, Mn, or may occur in particulate form (Awofolu et al., 2005; Mwiganga and Kansiime, 2005). Heavy metals may enter into aquatic ecosystems from anthropogenic sources, such as industrial wastewater discharges, sewage wastewater, fossil fuel combustion and atmospheric deposition (Linnik and Zubenko, 2000; Campbell, 2001; Lwanga et al., 2003; El Diwani and El Rafie, 2008; Idrees, 2009). Trace elemental concentrations in stream sediment compartments can be used to reveal the history and intensity of local and regional pollution (Nyangababo et al., 2005a). Sentongo (1998); Matagi (1998) and Kansiime et al., (1995) observed significant pollution load by organic and inorganic substances into the Nakivubo ecosystem. Some work on heavy metal loading of Lake Victoria wetlands, Nakivubo Channel and heavy metal pollution in and around Kampala was recognised (Nyangababo 2003; Nyangababo et al., 2005b; Muwanga and Barifaijo, 2006 and Nabulo et al., 2008). The objectives of the present work were to (1) assess the geochemistry of the Nakivubo stream sediments so as to establish the possibility of secondary pollution of the sediments; (2) establish the association among heavy metals and stream physico-chemical characteristics and (3) determine the source apportionment of heavy metals using cluster and factor analyses (Sekabira, et al 2010).

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

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)

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

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

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

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

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

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

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

We have

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

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

But considering the boundary condition

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

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

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

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

Applying quadratic expression, we have

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

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

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

$$C_{(t)} = A \exp \left[\frac{-\frac{Kj\epsilon p}{\mu} + \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg}}{2Vi} \right]^t - \exp \left[\frac{-\frac{Kj\epsilon p}{\mu} + \sqrt{\frac{Kj\epsilon p^2}{\mu} + 4ViPPg}}{2Vi} \right]^t \quad \dots \quad (16)$$

Subjecting equation (16) to the following boundary condition and initial values condition
 $x = 0, t > 0, C_0 = 0$ (17)

We have $B = -1$ and $A = 1$ (18)

So that our particular solution we have it this form

$$C_{(t)} = \exp \left[-\frac{Kj\epsilon p}{\mu} + \left(\frac{Kj\epsilon p^2}{\mu} - 4ViPPg \right)^{1/2} \right]^t - \exp \left[-\frac{Kj\epsilon p}{\mu} + \left(\frac{Kj\epsilon p^2}{\mu} + 4ViPPg \right)^{1/2} \right]^t \quad \dots \quad (19)$$

But $e^x + e^{-x} = 2Sin x$

Therefore, the model can be expressed as;

$$C_{(t)} = 2Sin \left[\frac{Kj\epsilon p}{\mu} + \left(\frac{Kj\epsilon p^2}{\mu} + 4ViPPg \right)^{1/2} \right]^t \quad \dots \quad (20)$$

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

But if

Therefore, the model can be expressed as:

$$C_{(x)} = 2\text{Sin} \left[\frac{Kj\epsilon p}{\mu} + \left(\frac{Kj\epsilon p^2}{\mu} + 4ViPPg \right)^{\frac{1}{2}} \right]^{\frac{d}{v}} \dots\dots\dots (21)$$

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

$$C_{(t)} = 2\text{Sin} \left[\frac{Kj\epsilon p}{\mu} + \left(\frac{Kj\epsilon p^2}{\mu} + 4ViPPg \right)^{\frac{1}{2}} \right]^t \dots\dots\dots (21)$$

Considering (21) and (22) yield

$$C_{(x,t)} = 2\text{Sin} \left[\frac{Kj\epsilon p}{\mu} + \left(\frac{Kj\epsilon p^2}{\mu} + 4ViPPg \right)^{\frac{1}{2}} \right]^t + 2\text{Sin} \left[\frac{Kj\epsilon p}{\mu} + \left(\frac{Kj\epsilon p^2}{\mu} + 4ViPPg \right)^{\frac{1}{2}} \right]^x \dots\dots\dots (22)$$

4. Results and discussion

Predictive model to monitor rate of dissolved chromium in soil and water influenced by permeability and linear velocity in phreatic aquifers are presented in Tables and Figures

Table1
Comparison of Theoretical Experimental values at various Depths

Depth M	Theoretical Values	Experimental Values
3	2.03E-03	2.10E-03
6	6.13E-04	5.98E-04
9	2.99E-04	3.11E-04
12	3.99E-04	4.10E-04
15	4.99E-04	5.10E-04
18	5.98E-04	5.96E-04
21	6.98E-04	6.93E-04
24	7.98E-04	7.89E-04
27	8.98E-04	8.95E-04
30	9.98E-04	9.89E-04

Table 2

Comparisons of Theoretical Experimental values at various Times

Time	Theoretical Values	Experimental Values
10	2.03E-03	2.10E-03
20	6.13E-04	5.98E-04
30	2.99E-04	3.11E-04
40	3.99E-04	4.10E-04
50	4.99E-04	5.10E-04
60	5.98E-04	5.96E-04
70	6.98E-04	6.93E-04
80	7.98E-04	7.89E-04
90	8.98E-04	8.95E-04
100	9.98E-04	9.89E-04

Table 3

Comparison of Theoretical Experimental values at various Depths

Depth M	Theoretical Values	Experimental Values
3	1.63E-03	1.67E-03
6	3.25E-03	3.77E-03
9	4.87E-03	4.75E-03
12	5.38E-03	5.62E-03
15	8.13E-03	8.44E-03
18	9.76E-03	9.78E-03
21	1.20E-02	1.40E-02
24	1.30E-02	1.40E-02
27	1.50E-02	1.60E-02
30	1.60E-02	1.70E-02

Table 4

Comparisons of Theoretical Experimental values at various Times

Time	Theoretical Values	Experimental Values
10	1.63E-03	1.67E-03
20	3.25E-03	3.77E-03
30	4.87E-03	4.75E-03
40	5.38E-03	5.62E-03
50	8.13E-03	8.44E-03
60	9.76E-03	9.78E-03
70	1.20E-02	1.40E-02
80	1.30E-02	1.40E-02
90	1.50E-02	1.60E-02
100	1.60E-02	1.70E-02

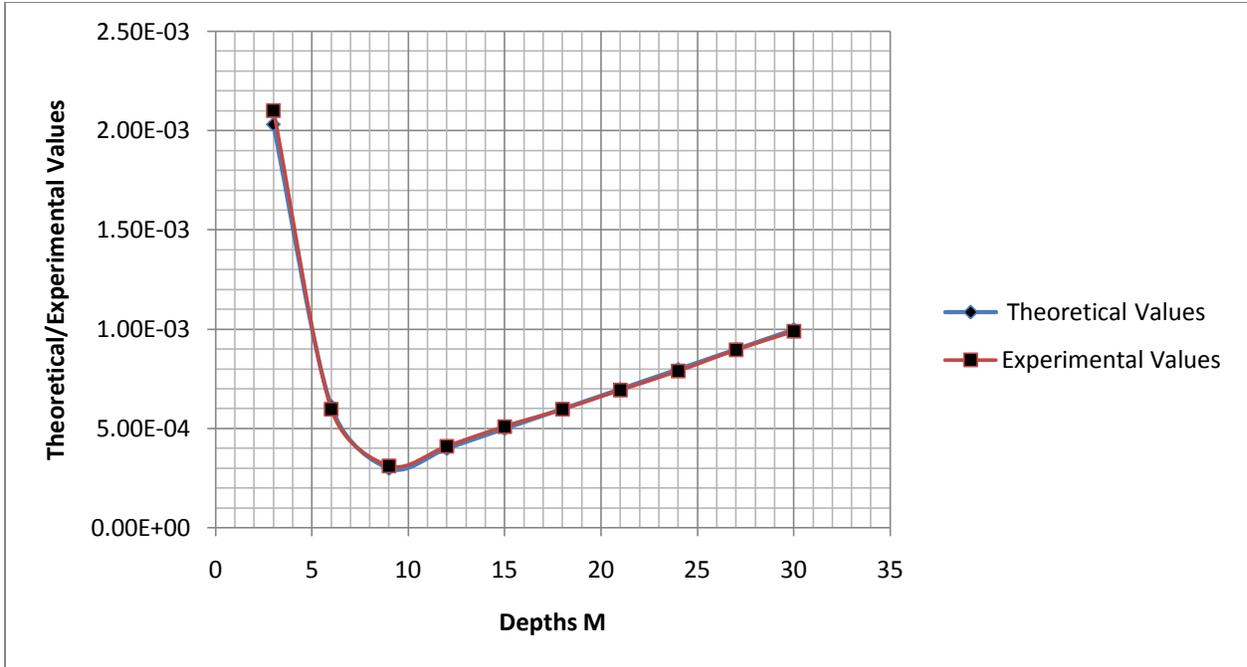


Fig.1. comparison of Theoretical Experimental values at various Depths

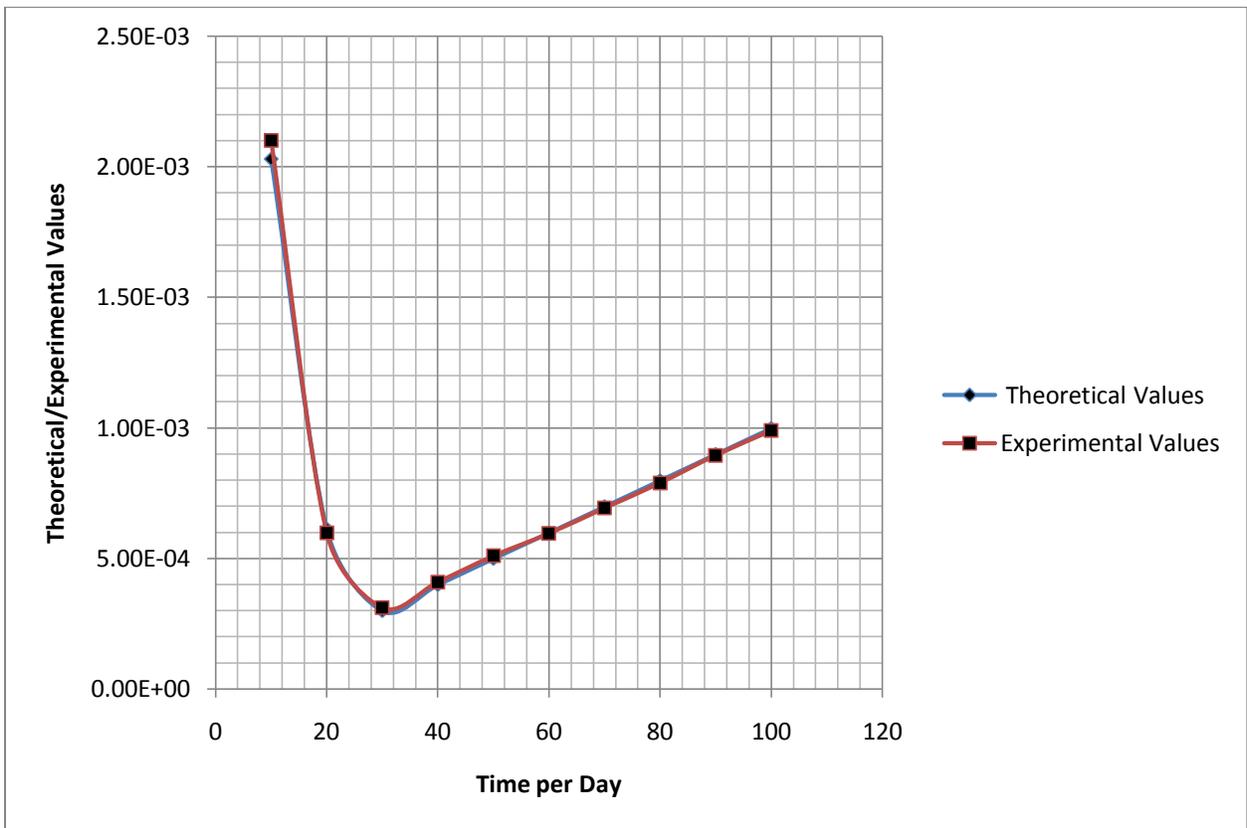


Fig. 2. comparison of Theoretical Experimental values at various Times

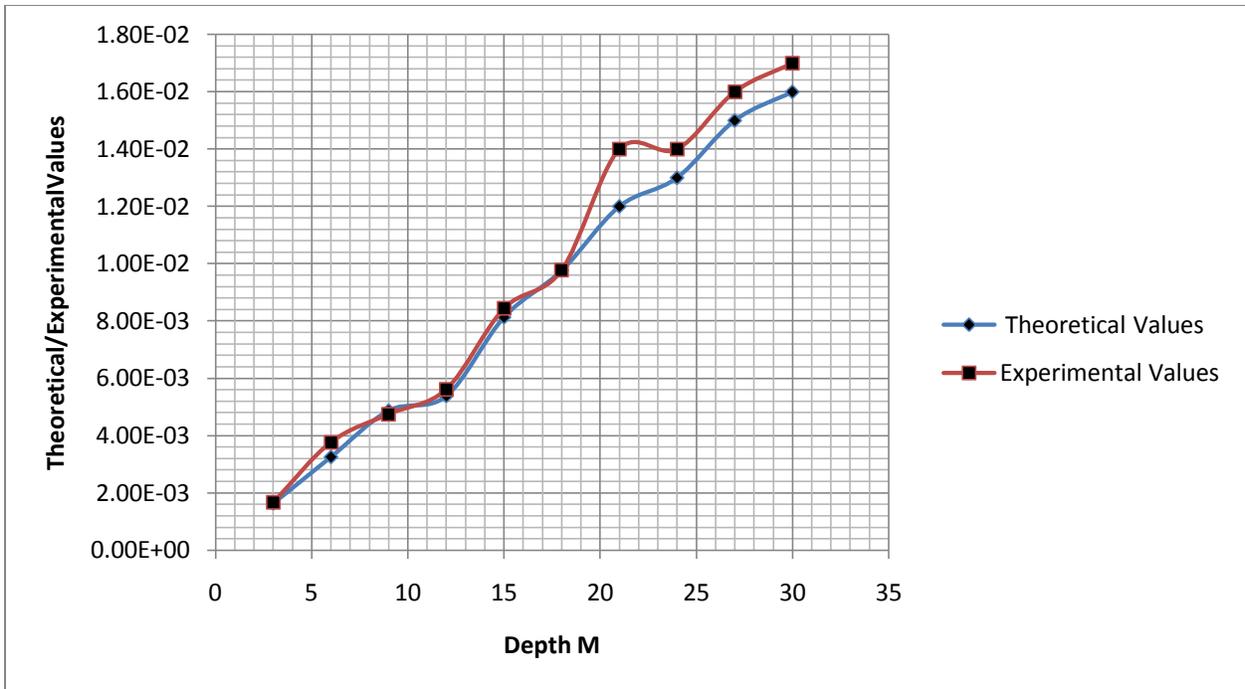


Fig.3. comparisons of Theoretical Experimental values at various Depths

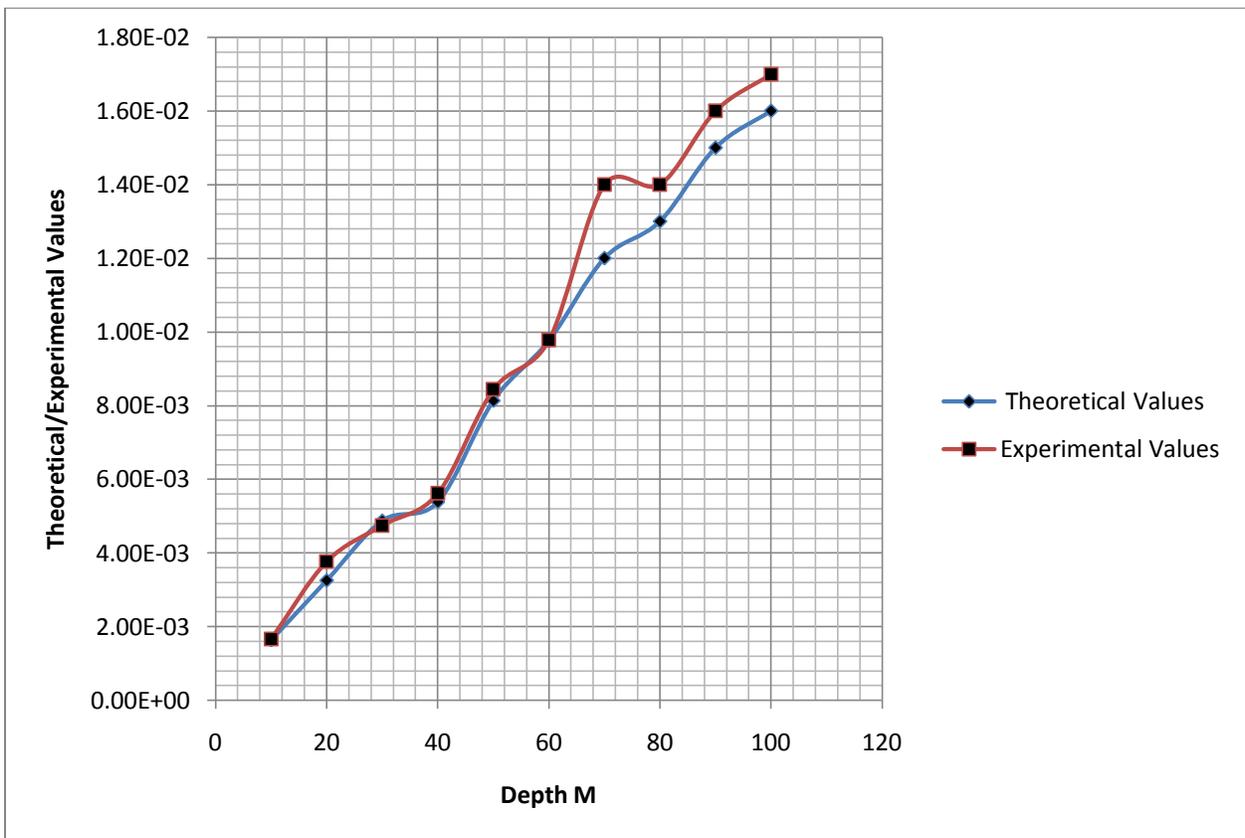


Fig. 4. Comparison of Theoretical Experimental values at various Depths

Figure 1 shows that the contaminant rapidly increased at three metres where the maximum levels of concentration were recorded suddenly decrease where observed to where the lowest were recorded at twelve

metres. Finally it developed a slight increase from fifteen to thirty metres; similar conditions were observed on the experimental values the optimum level where recorded at three metres, the lowest at twelve metres, suddenly it experienced slight increase from fifteen to thirty metres respectively.

Figure 2 were monitored with respect to various rate of concentration at different periods, highest concentration were experienced at ten days, sudden decrease were observed to the lowest level at forty days and finally it experienced slight increase from fifty to hundred days. The experimental values maintained the same rate of concentration; the highest at ten days while the lowest at forty days and finally experienced slight increase from fifty to hundred days. Figure 3 experienced rapid increase fluctuating to the maximum level recorded at thirty metres, while the experimental maintained the same rate of concentration, but developed more fluctuations between twenty-seven and thirty metres. Similar condition were recorded in figure 4, the concentration experienced rapid increase with vacillation concentration at different time to the maximum level at hundred days, while the experimental values observed the same level of concentration, but were more severe between seventy and hundred days. The rate of concentration from figure 1 and 2, shows that the dissolved chromium deposit its optimum at three metres and within the period of ten days and suddenly experienced change in concentration with respect to change in distance and time, the rate of flow dynamic can be attributed to change in time and the structural deposition of the soil with respect of depth in the transport process, this where found to influence the concentration in other locations as presented in figure 3 and 4 that experienced rapid increase in concentration. This condition can be attributed to the regeneration of the contaminant as a result of man made activity, the variation in permeability that influence the rate of concentration are on based on regeneration experienced in the study location. This also influenced the concentration with respect to time.

5. Conclusion

Chromium is one of the heavy metals that if found in the groundwater is a threat to human life. This has been a serious life threatening contaminant in the study location; this is a serious concern to environmental health condition of the people, and need serious and urgent attention. Based on this ugly scourge, it became imperative that solution to this problem should be generated. To solve this problem, a mathematical model were developed to monitor this trace metal in groundwater, the model were developed considering the stratification of the formation and their formation characteristics, this influence the migration of this metal to phreatic aquifers. The model was simulated and theoretical value were compared with the experimental values from other locations, both parameter compared favourably well, this condition validate the model for application of the model to solve this threatening life contaminants. The application of this model in design of groundwater system will reduce the rate of water pollution in the study area.

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