Developing mass transfer model for predicting concentration profiles of contaminants in groundwater resource

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Abstract
This work involves experimental analyses on three abandoned dumpsites (Nkpolu, Oyigbo, and Elekahia) in Port Harcourt to determine the concentrations of lead, cadmium, and Iron in soil and existing tap water close to the dumpsite. Model for the prediction of lead (Pb), cadmium (Cd) and Iron (Fe) migration from abandoned dumpsite into groundwater has been developed. The model was solved and validated with experimental results. Statistical analysis was performed between the experiment and model result to determine the significant difference. The model validation showed goodness fit which was further validated by statistical analysis as there was no significant difference at $p<0.05$. The simulation performed to determine the quality of existing groundwater obtained from taps close to the abandoned dumpsites showed that the contaminants' concentration decreased as the depth from point source increased into the groundwater aquifer. At the 60 meters depth, the result obtained from predictive model showed that Pb (0.000182mg/L for Nkpolu, 0.000194mg/L for Oyigbo and 0.000482 mg/L for Elekahia dumpsites, Cd (9.77×10^{-6}mg/L for Nkpolu and 6.98×10^{-6}mg/L for Oyigbo and Elekahia dumpsites and Fe (0.000347mg/L for Nkpolu, 0.00419mg/L for Oyigbo and 0.00415mg/L for Elekahia dumpsites. The concentrations were below the international standard limit for drinking water quality (0.01mg/L for Pb, 0.003mg/L for Cd and 0.3mg/L for Fe). However, the laboratory analysis showed that only water sample collected from Nkpolu abandoned dumpsite met the international standard limit. Results showed that the increase in seepage velocity would impact negatively on the contamination of groundwater.
Keywords: Leachate, adsorption, solid wastes, heavy metals, aqueous solution, pollution.

1.0 Introduction

The management of solid waste disposal in most developing countries is a major challenging issue that has resulted to environmental problems. These solid wastes on dumpsites contain contaminants that pollute the groundwater. Studies conducted at different part of Nigeria have identified various types of contaminants present in groundwater (Okoli *et al*., 2005 and Okoli, 2007). Contaminants from the dumpsite are spontaneously transported through the soil to groundwater which constitute health hazards. Diseases such as hepatitis, diarrhea, cholera and other long term diseases such as cancer are being experience. Over-exploitation of groundwater leads to the depletion of the aquifer system and other environmental consequences such as land subsidence, water-quality deterioration and saltwater intrusion in coastal areas (Gleeson *etal*., 2012; Ujile, 2013a and USGS, 2013).

Contaminants that are present in groundwater include heavy metals, hydrocarbons, microbes and many others, depending on the source. As the population of the world continue to rise, it is obvious that more and more waste will be accumulated thereby leading to search for proper and suitable method of managing these wastes which often times, are improperly disposed of, especially in the cities.

Different types of contaminants can be found in groundwater ranging from pathogens, heavy metals and radionuclide. These materials have different solubility in groundwater therefore, some of the compounds can be found in both dissolved form and insoluble non-aqueous phase.
Recent studies have revealed that waste dumpsites can transfer significant amounts of toxic and persistent metals into the soil environment (Gurnnadha *et al*., 2011). Eventually these metals are taken up by plant parts and get incorporated into the food chain (Erah *et al*., 2002). However the rate of metal uptake by crops could be influenced by factors such as metal species, plant age and plant part (Akhionbare, 2009). According to (Ogbonna *et al*., 2008) the prevalence and levels of heavy metals, and other physicochemical constituents in sewage-impacted segment of the ecosystem is encouraged by anthropogenic activities like indiscriminate dumping of sewage and unregulated sewage standard treatment processes.

The occurrence of various heavy metals such as Mn, As, Cr, Cd, Ni, Zn, Co, Cu, and Fe in MSW dumpsites have been reported by many researchers (Amusan *et al*., 2005; Ogundiran and Osibanjo, 2008). Since these contaminants affect the environmental qualities in and around such open dumpsites, monitoring of soil qualities especially heavy metal content in dumpsite becomes necessary which can facilitate to recommend suitable remedial measures (Biswas *et al*., 2010).

Furthermore, organic and microbiological constituents of sewage can cause physicochemical changes in soil nutrients and other variables and increase pathogen levels in the groundwater (Dawes and Goonetilleke, 2001). Mass transfer of these pollutants can also cause high levels of contaminants such as ammonia, bicarbonate and chloride ions, especially in shallow groundwater and this can create toxicity in groundwater resources (Anzecc and Armcanz, 2000).

1.1 Groundwater Properties

Groundwater is characterized by its vertical and horizontal distribution. Vertically, groundwater is divided in two main parts: saturated and unsaturated zone (Duriez, 2005). These two parts are generally separated by the water table. The horizontal distribution of groundwater depends on several parameters that are characteristics of the porous medium and groundwater. These parameters determine the rate and the direction of flow.
Porosity of a medium is the ratio of the non-solid volume to the total volume of material. In the saturated zone, which occurs beneath the water table, the porosity is a direct measure of the water contained per unit volume. Porosity is a fractional value between 0 and 1, typically ranging from less than 0.01 for solid granite to more than 0.5 for peat and clay and the average value for most aquifer systems has been put to between 0.25 and 0.35 by Wikipedia, (2017).

1.2 Hydraulic conductivity, Transmissivity and Intrinsic Permeability

Hydraulic conductivity is one of the soil properties that describe the ease at which water moves through the pore space of soil. However, hydraulic conductivity depends on the both permeability of material and degree of saturation. On the other hand transmissivity, is the soil property that measures how much of water an aquifer can transmit in the horizontal direction. This property depends on the saturated hydraulic conductivity and saturated thickness of the aquifer. High hydraulic conductivity in the soil structure implies that the structure has high porosity and permeability (such as sand and gravel which have higher hydraulic conductivity than clay soil). According to Bedient *et al*., (1999) typical values for aquifers are given as 10^{-4} m.s^{-1} for sand, 10^{-6} m.s^{-1} for silt and 10^{-7} cm.s^{-1} for clay. Mass movement of materials (solutes) which dissolves in groundwater is made possible via advection, diffusion or dispersion (Duriez, 2005). Tamunobereton-ari*et al*., (2010) in their studies for suitable borehole drilling capable of producing safe, potable and sustainable water supply, performed chemical analysis on three pollutants (heavy metals) which include Lead (Pb), Copper (Cu), and Nickel (Ni). They reported that good source of groundwater with low contaminant concentrations was observed from 50m to 60m.

Akudo *et al*., (2010) investigated the impact of solid waste on groundwater samples collected from three locations and reported that the concentrations of parameters analyzed (iron and acidity) were either mild or high. Otutu, (2011) also carried out similar studies on groundwater samples to investigate the level of contaminants at ten different locations in Delta State of Nigeria and recommended that boreholes with low water contaminants should be drilled to a depth of 40 - 55 m. While Ekeocha *et al*., (2012) in their investigation of resistivity, thickness and depth of solid waste dumpsite on soil and groundwater using electrical resistivity method, observed a low resistivity (between 33.9 and 55Ωm) with the depth ranging from 39.0m to 65.0m and thickness of 49.0m and concluded that groundwater around the dumpsite has been contaminated to depth exceeding 65.0m.

Investigation on groundwater quality of an open sewage dumpsite had been carried out by Edo *et al*., (2014), where parameters such as temperature, pH, conductivity, salinity and dissolved oxygen concentration, heavy metals, oil content and other physicochemical parameters were analyzed. They reported that the quality of parameters analyzed shows variation, but the levels of BOD, total coliform counts, and phosphate ion, total dissolved solids (TSS), Cu, Fe, Cr and Ni exceeded the Nigerian Federal Ministry of Environment maximum permissible limit for drinking water, indicating pollution of groundwater within the sewage disposal site.

It is worthy of note that the level of groundwater pollutants depends on location of the source of polluting agents as illustrated in the study by Keelson, (2014) while investigating the effect of heavy metals on groundwater via analysis of dumpsite and industrial waste. The researcher observed that there was a low pollution risk from chromium, lead, manganese, cobalt and zinc but the concentrations of cadmium, copper and arsenic were high enough to constitute a potential risk to groundwater as result of waste from dumpsite. Similarly, Emujakporue, (2016) investigated two environments: the subsurface in a dumpsite and a neutral environment. The researcher observed that groundwater was most vulnerable to leachate from dumpsite than in neutral environment.

Groundwater contaminants due to open dumpsite in Asian countries have been investigated by Wagh *et al*., (2014). They observed a similar trend in contaminant level as was reported in researches conducted in Nigeria. The summary of their observation is presented in table 1.

Also, studies on the management of groundwater resources have been reported (Ujile, 2013a; Nwankwoala and Ngah, 2014). Following these studies, it is imperative for deliberate efforts both from government, private and individual organizations to be put in place in the management of waste of any kind. Access to water is linked to poverty as WWAP (2015) had opined that "reducing poverty through water management is a useful framework for action, allowing for the introduction of inter-related issues of governance, water quality, access, livelihood opportunities, capacity-building and empowerment, water-related disaster prevention and management, and ecosystem management".

Thus, in managing groundwater contaminants, high capital is always involved. Therefore it becomes imperative to develop framework to reduce economic cost. To achieving this, several models have been proposed by researchers to study and predict the mass transfer of groundwater contaminants.

Macfarlane *et al*., (1983) due to inherent uncertainty in the aquifer parameter values used the Darcy equation assuming plug flow, to determine the position of the contaminants. Whereas Islam *et al*., (2001) developed a mass transfer model in contaminated soil due to biochemical processes and applied numerical method to obtain the model solution.

Groundwater flow and transport equations had been applied to experimental data by Chen *et al.*, (2016). While Ujile, (2013b) developed a mass transfer model to evaluate groundwater flow and solute transport. The analysis was able to show that bulk soil density, decay rates, aquifer characteristics affected the behaviour of groundwater contaminants.

As a key to the management of groundwater, Patil and Chore, (2014) demonstrated the usefulness of mathematical models in the study of the movement of fluids and contaminants in the subsurface environment. They compared experimental, analytical solution and numerical method in the evaluation of soil and groundwater contaminants transport. Similarly, Chawla and Singh, (2014) applied the governing equation for contaminant transport involving advection-diffusion and using the explicit finite difference method to evaluate groundwater contaminants. Part of the literatures reviewed so far have dealt with experimental determination of groundwater contaminants from dumpsites while others went further to the development of mass transfer model that predicts the level of contaminants in groundwater. However, available literature on solute migration through saturated porous media relating to Rivers State, which dumpsites are indiscriminately located, even close to boreholes: the sources of groundwater for domestic and commercial use, is limited.

Having identified the deficiencies in previous works, this research will focus on the determination of groundwater contaminants due to effect of dumpsites in Port Harcourt city, Obio/Akpor and Oyigbo Local Government Areas. Mass transfer model established was applied to analyze the concentration level of iron, cadmium and lead contaminants in groundwater.

Standard methods were applied in the collection and analyses of soil and borehole water samples from the three dumpsites. The locations are shown in figure 1.

The aim of this study is to evaluate/develop the mass transfer model that could predict concentrations of iron, cadmium and lead (Fe, Cd and Pb) in groundwater at some abandoned dumpsites in Rivers State Nigeria.

2.0 Methodology

2.1 Sample Collection

Soil and water samples were collected from abandoned dumpsites located at Trans-Amadi in Port Harcourt City Local Government Area; Nkpolu in Obio/Akpor Local Government Area and Oyigbo in Oyigbo Local Government Area, all of Rivers State, Nigeria. The soil samples were collected through auger at intervals of 50cm, while the water samples were collected from boreholes close to the dumpsites. The distances between the Trans-Amadi, Nkpolu and Oyigbo dumpsites and the respective boreholes where water samples were collected are 76.24, 116.56 and 80.86m respectively.

2.2 Experimental Procedure

Collected soil samples at the three dumpsites were weighed equally and prepared for analysis. 1g of the soil sample was transferred into Kjeldahl flask. Thereafter, 20ml of concentrated HNO_3 was added and the sample pre-digested by heating gently for 20 minutes. More acid was further added and digestion was continued for 30-40 minutes. Digestion was stopped when a clear digest was obtained. The flask was cooled and the content transferred into 50ml volumetric flask and made to the mark with distilled water. The resulting solution was analyzed for heavy metals using the Atomic Absorption Spectrophotometer (AAS) Model 210 VGP. The equipment absorbs the digested sample and gives the concentration of the metals present in the soil or water sample.

2.3 Development of Mass Transfer Model

The mass transfer model was developed using the principle of conservation of mass by taking material balance on a typical flow of contaminated fluid from dumpsite into potable water aquifer located beneath it. The general principle of conservation of mass is given in equation

$$\left\{\begin{array}{c}\text{Rate of}\\ \text{input of}\\ \text{mass into}\\ \text{system}\end{array}\right\} = \left\{\begin{array}{c}\text{Rate of}\\ \text{output of}\\ \text{mass from}\\ \text{system}\end{array}\right\} + \left\{\begin{array}{c}\text{Rate of}\\ \text{depletion}\\ \text{due to}\\ \text{reaction}\end{array}\right\} + \left\{\begin{array}{c}\text{Rate of}\\ \text{accumulatio}\\ \text{n of mass}\\ \text{within}\\ \text{system}\end{array}\right\} \quad (1)$$

Fig.1: Map of Rivers State showing dumpsites for the study areas

Mathematical representation of equation (1) in three dimensional flow as given by Ujile, (2017) is shown in equation (2)

$$\frac{\partial C_A}{\partial t} = -\left(v_x \frac{\partial C_A}{\partial x} + v_y \frac{\partial C_A}{\partial y} + v_z \frac{\partial C_A}{\partial z} \right) + D\left(\frac{\partial^2 C_A}{\partial x^2} + \frac{\partial^2 C_A}{\partial y^2} + \frac{\partial^2 C_A}{\partial z^2} \right) + R_A \quad (2)$$

Basic Assumptions

1. Migration of groundwater contaminants is considered only along the depth of aquifer.
2. The stream flow pattern is not altered by the presence of multiple contaminants in the soil porous media.
3. There is no variation in seepage velocity and dispersion coefficient.

For one- dimensional flow, an expression was obtained and further simplifications and considering boundary conditions of the groundwater systems, Yadaw and Jaiswal, (2011), obtained an expression shown in equation (3):

$$C(z,t) = \frac{1}{2} C_o \left\{ erfc\left[\frac{z-(v+k)t}{2\sqrt{Dt}} \right] + erfc\left[\frac{z-(v+k)t}{2\sqrt{Dt}} \right] \right\} \exp\left[\frac{v}{2D} z - \left(\frac{v^2}{4D} + k \right) t \right] \quad (3)$$

3.0 Results and Discussions

A model for prediction of lead (Pb), cadmium (Cd) and iron (Fe) in groundwater from abandoned dumpsite was developed. Experimental studies were carried out on three abandoned dumpsites (Nkpolu, Oyigbo and Elekahia) in Port Harcourt to investigate the migration of groundwater contaminants. The results obtained from laboratory analysis were tested with the developed model. Statistical analysis was performed between the experiment and model results to determine the significant difference.

3.1 Experimental Analysis of Contaminants' Concentration

Tables 1 to 3 show the laboratory results of lead, cadmium, iron and E. coli contaminants in soil samples collected from Nkpolu, Oyigbo and Elekahia dumpsites at depths 0.0 to 1.0m (100cm). While Table 4 shows the concentrations of contaminants in tap water collected from nearer borehole to the respective dumpsites. Also, waste effluent water from Oyigbo dumpsite was shown in Table 4.

Table 1: Analysis of Contaminants in Nkpolu Dumpsite

Distance (m)	Lead (Pb) (ppm)	Cadmium (Cd) (ppm)	Iron (Fe) (ppm)	Escherichia Coli (cfu/ml)
0.00	1.30	0.05	383.00	1.5×10^5
0.50	1.22	0.03	372.00	2.0×10^4
1.00	0.99	0.02	302.00	1.0×10^4

Table 2: Analysis of Contaminants in Oyigbo Dumpsite

Distance (m)	Lead (Pb) (ppm)	Cadmium (Cd) (ppm)	Iron (Fe) (ppm)	Escherichia Coli (cfu/ml)
0.00	1.39	0.05	698.00	1.4×10^4
0.50	0.83	0.03	438.00	0
1.00	0.45	0.01	428.00	0

Table 3: Analysis of Contaminants in Elekahia Dumpsite

Distance (m)	Lead (Pb) (ppm)	Cadmium (Cd) (ppm)	Iron (Fe) (ppm)	Escherichia Coli (cfu/ml)
0.00	3.49	0.07	693.00	1.0×10^5
0.50	1.42	0.07	590.00	0
1.00	0.96	0.04	380.00	1.0×10^5

Table 4: Analysis of Contaminants in Borehole Water nearer to the Dumpsites

Dumpsite	Depth (m)	Lead (Pb) (ppm)	Cadmium (Cd) (ppm)	Iron (Fe) (ppm)	E. Coli (cfu/ml)
Nkpolu	45.72(150ft)	0.01	<0.001	<0.001	0
Oyigbo	-	0.09	0.00	<0.001	0
Elekahia	48.77(160ft)	0.05	<0.001	<0.001	4.40
Oyigbo Effluent Water	N/A	0.19	0.00	2.06	4.8×10^5

*Conversion factor: 1ft = 0.3048m

3.2 Migration of Groundwater Contaminants from Abandoned Dumpsites

Since there were no significant differences between the model and the experimental results, the leaching of groundwater contaminants from the abandoned dumpsites was further investigated at depth up to 60 meters with the aid of the model. This was done to determine the level of contaminants' concentration in groundwater and then, compared with concentrations in existing tap water samples collected from boreholes close to the dumpsites. This comparison was done to ensure if the water consumed either for domestic or industrial applications in Port Harcourt especially, from boreholes located around abandoned dumpsites, meets international standards and again, to know if the existing depth of wells are enough to obtain sustainable quality of groundwater for consumption. Figures 2 to 4 showed the profiles of contaminant's concentration along the vertical direction of flow.

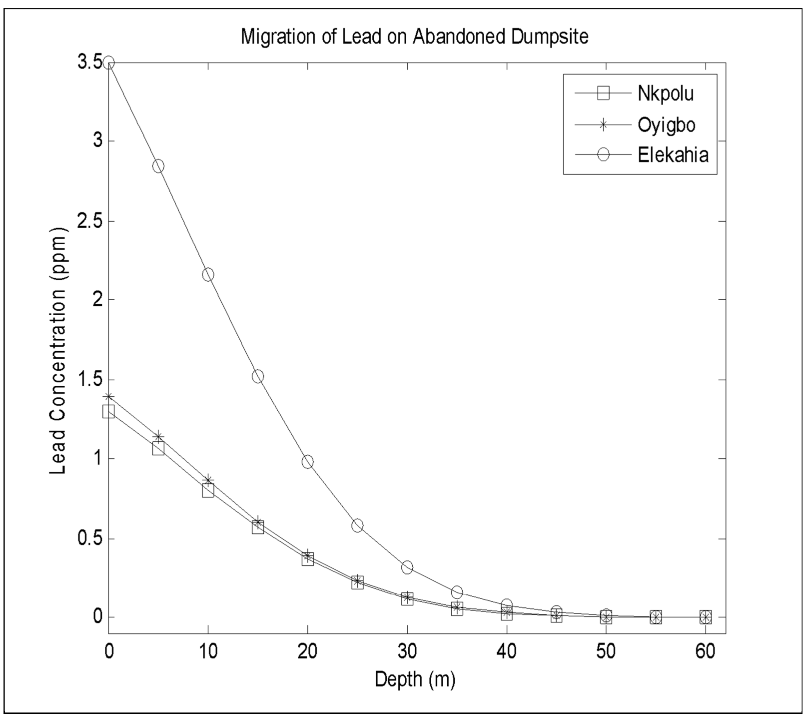

Figure 2: Leaching of Lead in abandoned Dumpsites

The concentration of lead contaminant from the abandoned dumpsites against depth at seepage velocity of 2.894×10^{-6}m/s and over a period of four years is shown in Figure 2. Although, the level of contaminant concentration in the dumpsites varied, the concentration of lead in all the dumpsites decreases as depth is increased. At depth of 60m, the corresponding lead concentrations were 0.000182ppm for Nkpolu, 0.000194ppm for Oyigbo and 0.000482ppm for Elekahia dumpsites. However, the concentration of lead from the analysis of tap water collected near the dumpsites were 0.01pmm (or 0.01mg/L) for Nkpolu at 45.72m depth, 0.09ppm for Oyoigbo dumpsite and 0.05ppm for Elekahia dumpsite at 48.77m depth. Thus, the recommended concentration of lead for drinking water quality is 0.01mg/L (0.01ppm) (WHO, 2008 and NIS, 2007). This implies that the water from boreholes located near Oyigbo and Elekahia dumpsites are not safe for consumption as the concentration of lead is above the standard maximum limit, thereby exposing those drinking it to cancer. This high concentration can be attributed to the depth of the borehole, which is expected to be in the range of 50-60m, agreeing with the work of Tamunobereton-ari*et al*., (2010).

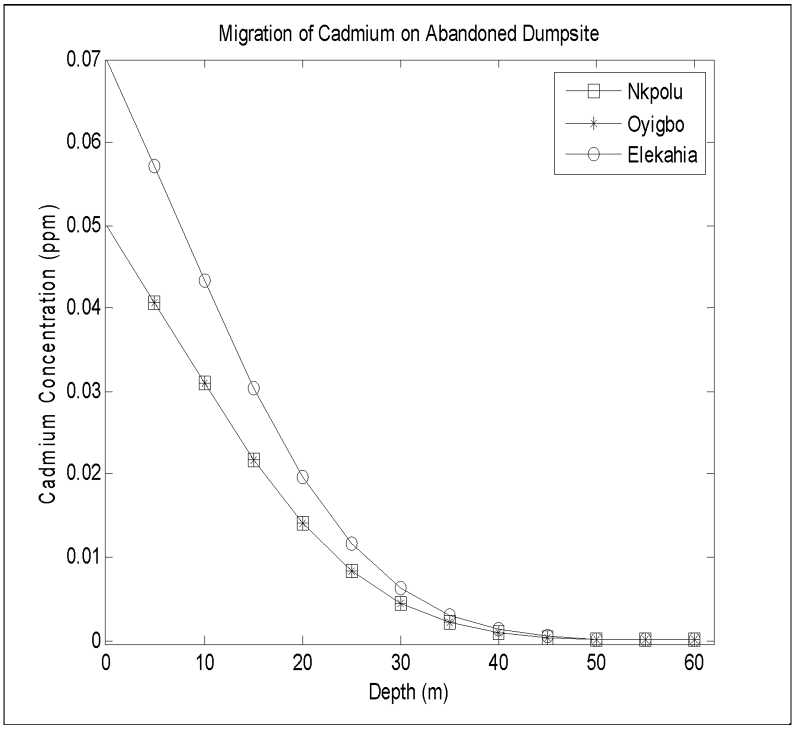

Figure 3: Leaching of Cadmium in abandoned Dumpsites

The concentration of cadmium from the abandoned dumpsites against depth at seepage velocity of 2.894 x 10^{-6}m/s is shown in Figure 3. The concentration of cadmium decreases as depth is increased. Interestingly, the concentrations of cadmium at Nkpolu and Oyigbo dumpsite are the same at all depths. Thus, at the recommended maximum limit of cadmium concentration for drinking water quality of 0.003mg/L (0.003ppm) (WHO, 2008 and NIS, 2007), the corresponding concentrations of cadmium were obtained as 0.001965 to 9.77 x 10^{-6}ppm at depth of 35 to 60m for Nkpolu dumpsite and 0.003038 to 6.98 x 10^{-6}ppm at depth of 30 to 60m for Oyigbo and Elekahia dumpsites. The concentrations of cadmium from the analysis of tap water collected near the dumpsites were less than 0.001ppm. This implies that the water from boreholes located near the dumpsites is safe from cadmium contamination.

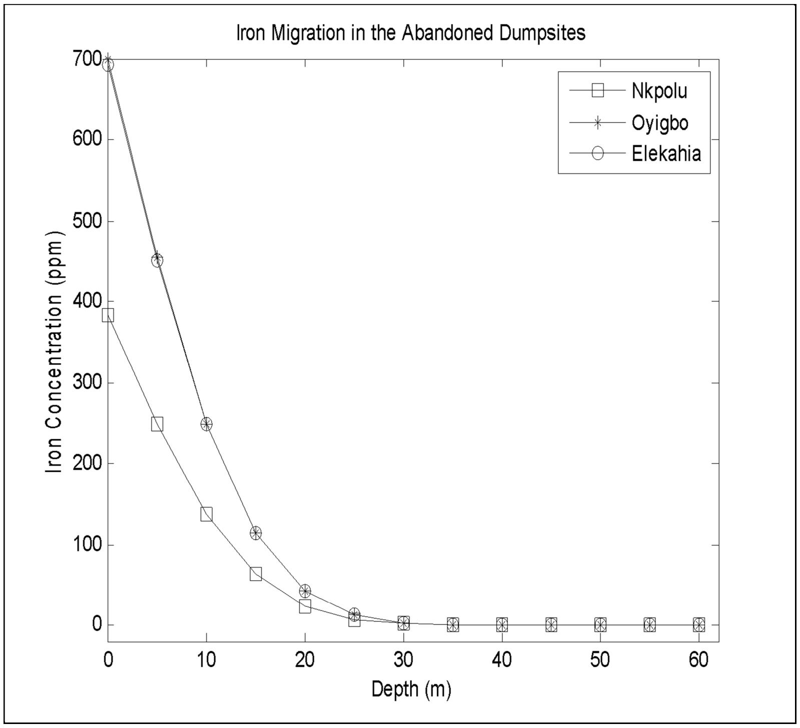

Figure 4: Leaching of Iron in abandoned Dumpsites

The concentration of iron from the abandoned dumpsites against depth at seepage velocity of 2.894 x 10^{-6}m/s is shown in Figure 4. Again, the concentration of iron decreases as depth is increased. But, there was no significant difference between the concentrations of iron at Nkpolu and Oyigbo dumpsite at all depths. At the recommended maximum limit of iron concentration for drinking water quality of 0.3mg/L (0.3ppm) (WHO, 2008 and NIS, 2007), the corresponding concentrations of iron were obtained as 0.0835 to 0.000347ppm at depth of 40 to 60m for Nkpolu dumpsite and 0.01023 to 0.00419ppm and 0.01022 to 0.00415ppm at depth of 50 to 60m for Oyigbo and Elekahia dumpsites respectively. However, the concentrations of iron from the analysis of tap water collected near the dumpsites were less than 0.001ppm, which is less than values obtained from the model. This also, showed that water from boreholes located near the dumpsites is safe from iron contamination.

3.3 Effect of Seepage Velocity on Groundwater Contaminant Migration

Hydraulic conductivity and porosity causes irregularities in the seepage velocity resulting to additional mixing of groundwater pollutant (Ujile, 2013b). The rate of groundwater contaminant transport from the surface of abandoned dumpsite is determined by the seepage velocity and the dispersion coefficient. In order to study the effect of seepage velocity on contaminant's flow, three values of seepage velocities had been chosen according to Yadav and Jaiswal, (2011) and Kourakos and Harter, (2014) for groundwater contaminants, though, it depends on the soil type. The investigation of seepage velocity impact on contaminant flow into the groundwater is shown in Figures 5 to 7.

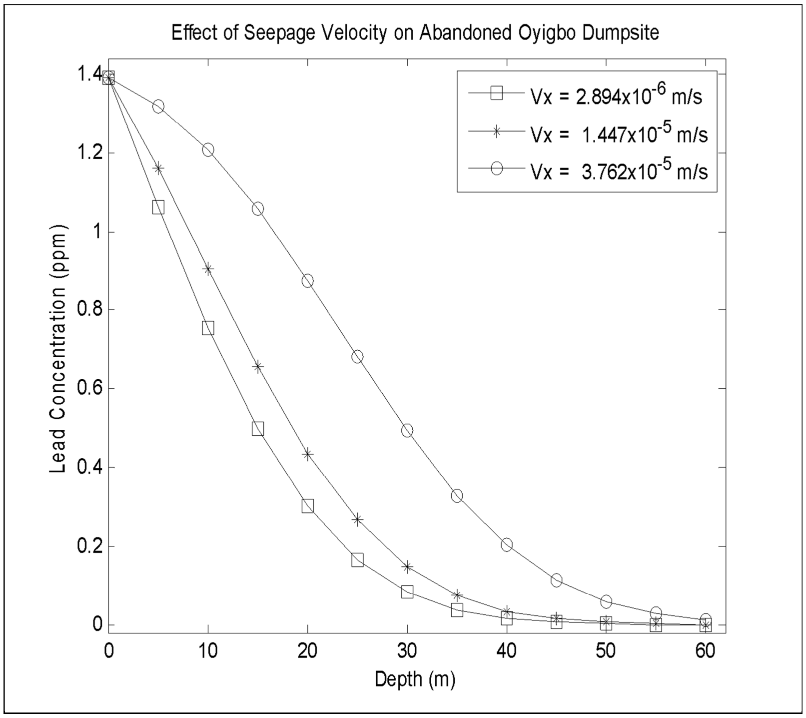

Figure 5: Effect of Seepage Velocity on Lead Migration in Oyigbo Dumpsite

Figure 5 shows the impact of seepage velocity on the migration of lead into groundwater via soil from Oyigbo abandoned dumpsite. Although, concentration of lead decreases with increase in depth, the amount of lead concentration in groundwater depends greatly on the seepage velocity. Thus, the amount or level of impact of lead on groundwater increases as the seepage velocity is increased. This is because the contaminant particles which are supposed to be retained or trapped by the soil, forced their way into bulk of the flowing fluid due to high flowing velocity. The model result showed that the concentrations of lead at 60m are 0.000194ppm at seepage velocity of 2.894 x 10^{-6}m/s, 0.000607ppm at seepage velocity of 1.447 x 10^{-5}m/s and 0.011984ppm at seepage velocity of 3.762 x 10^{-5}m/s. However, the depth required to access quality drinking in terms of lead can be obtained from 45 to 60m and 50 to 60m at seepage velocities of 2.894 x 10^{-6}m/s and 1.447 x 10^{-5}m/s respectively. While at 3.762 x 10^{-5}m/s seepage velocities, the concentration of lead at depth up to 60 m was above international accepted limit.

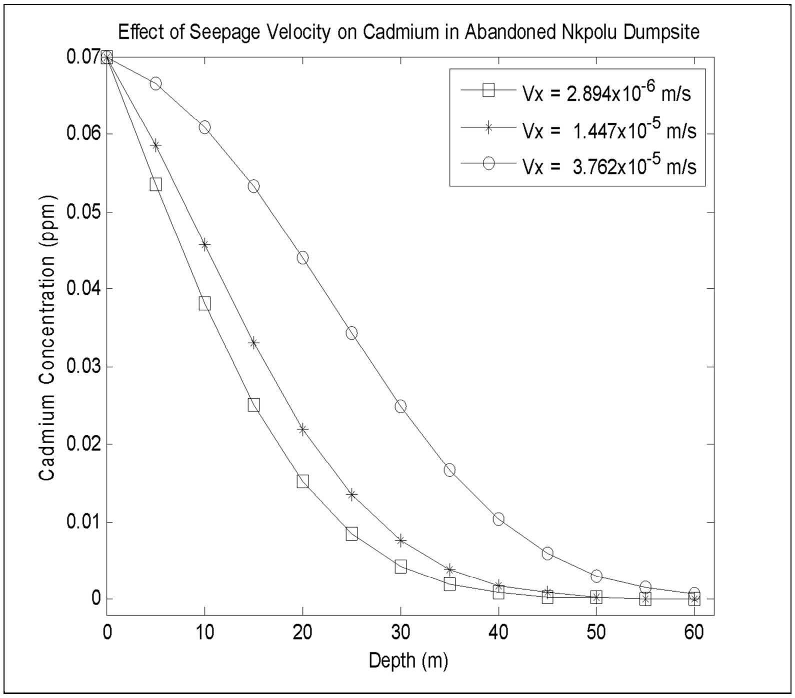

Figure 6: Effect of Seepage Velocity on Cadmium Migration in Nkpolu Dumpsite

Figure 6 shows the effect of seepage velocity on the migration of cadmium into groundwater from Nkpolu abandoned dumpsite. The level of impact of cadmium on groundwater increases as the seepage velocity is increased. The model result showed that the concentrations of cadmium at 60m are 9.77 x 10^{-6}ppm at seepage velocity of 2.894 x 10^{-6}m/s, 3.06 x 10^{-5}ppm at seepage velocity of 1.447 x 10^{-5}m/s and 0.000604ppm at seepage velocity of 3.762 x 10^{-5}m/s. From results, the depth required to access quality drinking in terms of cadmium can be obtained from 35 to 60m, 40 to 60m and 50 to 60m at seepage velocities of 2.894 x 10^{-6}m/s, 1.447 x 10^{-5}m/s and 3.762 x 10^{-5}m/s respectively.

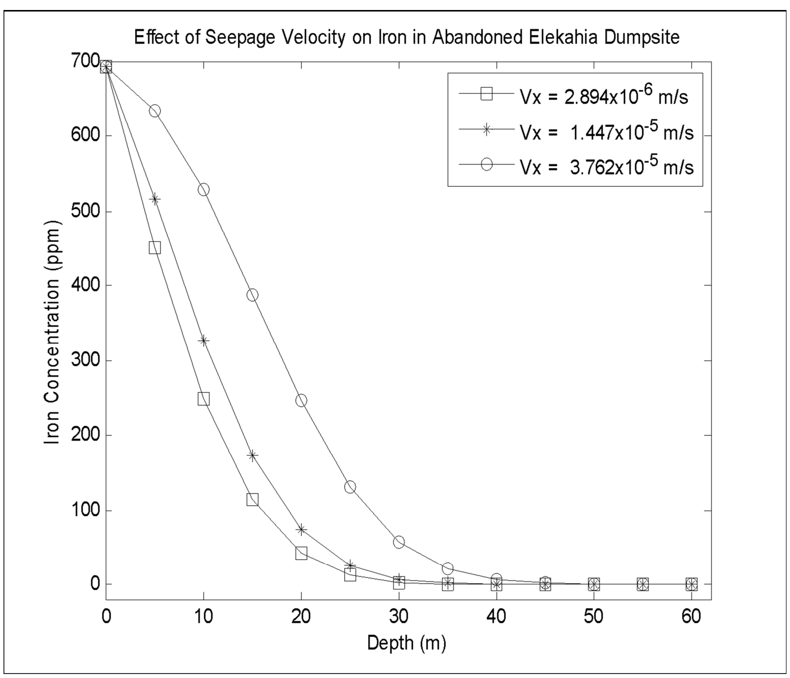

Figure 7: Effect of Seepage Velocity on Iron Migration in abandoned Elekahia Dumpsite

The effect of seepage velocity on the migration of iron into groundwater from Elekahia abandoned dumpsite is shown in Figure 7. Like lead and cadmium, the amount of iron in groundwater increases as the seepage velocity is increased. Thus, at the 60m depth, the model result showed that the concentrations of iron were 0.004154ppm at seepage velocity of 2.894 x 10^{-6}m/s, 0.0333ppm at seepage velocity of 1.447 x 10^{-5}m/s and 0.3946ppm at seepage velocity of 3.762 x 10^{-5}m/s. From these results, the depth required to access quality drinking in terms of iron can be obtained from 50 to 60m and 55 to 60m at seepage velocities of 2.894 x 10^{-6}m/s and 1.447 x 10^{-5}m/s respectively. Again, at 3.762 x 10^{-5}m/s seepage velocities, the concentration of iron at depth up to 60 m was above international accepted limit, hence, sinking of borehole for drinking water around Elekahia abandoned dumpsite should go beyond 60 meters.

3.4 Statistical analysis of Experiment and Model Results

The degree of agreement between the experimental and model results were statistically analyzed using one way ANOVA (single factor) as shown in Tables 5 to 7. This was done to determine the applicability of the developed model to the study of groundwater contaminants in abandoned dumpsites. The analysis was performed at significant difference of 0.05 (P<0.05) for all the contaminants investigated in each dumpsite.

Table 5: One-Way ANOVA for Lead Migration in the Abandoned Dumpsite

Source of Variation	*SS*	*df*	*MS*	F_{cal}	*P-value*	F_{crit}
Nkpolu Dumpsite	0.000244	1	0.000244	0.009096	0.928606	7.708647
Error	0.107252	4	0.026813			
Total	0.107496	5				
Oyigbo Dumpsite	1.69E-05	1	1.69E-05	7.67E-05	0.993432	7.708647
Error	0.880314	4	0.220078			
Total	0.880331	5				
Elekahia Dumpsite	0.009753	1	0.009753	0.005712	0.943382	7.708647
Error	6.82954	4	1.707385			
Total	6.839293	5				

*Significant (p<0.05); SS-Sum of Squares; MS-Mean Square; df-Degree of Freedom

Table 5 showed the statistical analysis of model and experimental results for lead. From the analysis, the F_{crit} was greater F_{cal} in all the three abandoned dumpsites investigated and there was no significant difference between the model and the experimental results. The P-value which showed the percentage of the experiment that had been explained by the model were 0.9286 (92.86%) for Nkpolu dumpsite, 0.9934 (99.34%) for Oyigbo dumpsite and 0.9434 (94.34%) for Elekahia dumpsite. Thus, the model compared satisfactorily with the experimental results and its use in this study was justified.

Table 6: One-Way ANOVA for Cadmium Migration in the Abandoned Dumpsite

Source of Variation	*SS*	*df*	*MS*	F_{cal}	*P-value*	F_{crit}
Nkpolu Dumpsite	2.2E-06	1	2.2E-06	0.00977	0.926018	7.708647
Error	0.000903	4	0.000226			
Total	0.000905	5				
Oyigbo Dumpsite	6E-08	1	6E-08	0.000157	0.990607	7.708647
Error	0.001529	4	0.000382			
Total	0.001529	5				
Elekahia Dumpsite	4.76E-06	1	4.76E-06	0.017254	0.901837	7.708647
Error	0.001103	4	0.000276			
Total	0.001108	5				

*Significant ($p<0.05$); SS-Sum of Squares; MS-Mean Square; df-Degree of Freedom

Table 6 showed the statistical analysis of model and experimental results for cadmium migration into groundwater. From the analysis, it showed that there was no significant difference between the model and the experimental results for cadmium. The P-value were 0.9260 (92.60%) for Nkpolu dumpsite, 0.9906 (99.06%) for Oyigbo dumpsite and 0.9018 (90.18%) for Elekahia dumpsite. This model therefore, compared satisfactorily with the experimental.

Table 7: One-Way ANOVA for Iron Migration in the Abandoned Dumpsite

Source of Variation	*SS*	*df*	*MS*	F_{cal}	*P-value*	F_{crit}
Nkpolu Dumpsite	97.33984	1	97.33984	0.050814	0.832701	7.708647
Error	7662.379	4	1915.595			
Total	7759.719	5				
Oyigbo Dumpsite	107.0965	1	107.0965	0.004277	0.950995	7.708647
Error	100161.3	4	25040.32			
Total	100268.4	5				
Elekahia Dumpsite	9.99635	1	9.99635	0.00042	0.984636	7.708647
Error	95266.99	4	23816.75			
Total	95276.99	5				

*Significant ($p<0.05$); SS-Sum of Squares; MS-Mean Square; df-Degree of Freedom

Table 7 is the statistical analysis of model and experimental results for iron migration into groundwater. Again, the analysis showed that there was no significant difference between the model and the experimental results for iron, with the P-value given as 0.8327 (83.27%) for Nkpolu dumpsite, 0.9510 (95.10%) for Oyigbo dumpsite and 0.9846 (98.46%) for Elekahia dumpsite. The model again, agreed with the experimental results obtained for iron concentration from the three dumpsites.

4.0 Conclusion

Transport model for prediction of lead (Pb), cadmium (Cd) and iron (Fe) from abandoned dumpsite into groundwater has been developed. Experimental studies were carried out on three abandoned dumpsites (Nkpolu, Oyigbo and Elekahia) in Port Harcourt to investigate the migration of, Pb, Cd and Fe into groundwater. The model was solved and validated with the results obtained from laboratory analysis. Also, statistical analysis was performed between the experiment and model results to determine the significant difference.

The experimental analysis carried out showed that contamination of groundwater by contaminants from abandoned dumpsite varied from dumpsite to dumpsite. This could be attributed to type and volume of accumulated wastes on the dumpsite.

Validation of model with the experimental results showed good fit and thus was used for prediction of the investigated contaminants. This was further justified by the statistical analysis carried out between the experiment and model results.

The simulation performed showed that profiles of the investigated contaminants agreed with existing profiles for groundwater contaminants which were indicated by the decreasing characteristics of contaminant's concentration from point source as it migrates into groundwater aquifer. However, to obtained concentrations of Pb, Cd and Fe at level below the international standard limits for drinking water quality, a depth of about 60 meters is required for boreholes around the dumpsites as predicted by the model. Also, the model showed that the increase in seepage velocity will impact negatively on the contamination of groundwater.

5.0 Nomenclature

C_A	Conc. of the contaminant A at time t, mg/cm^3
C_o	Initial concentration of the contaminant, mg/L
Dx, Dy	Directional hydrodynamic dispersion coefficients, m^2 / s
erfc	Complimentary error function
exp	exponent
K_d	Distribution coefficient.
K_l,K_s	First order decay rate in the liquid phase and soil respectively, 1/s
K	Overall first order decay rate, 1/s
R_A	Rate of depletion
t	Process time, or time since the start of the simulation, s.
Vx, Vy, V_Z	Directional seepage velocity components, m/s

6.0 References

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