Global Scientific JOURNALS

GSJ: Volume 8, Issue 2, February 2020, Online: ISSN 2320-9186

www.globalscientificjournal.com

MODELING OF LEACHATE MIGRATION FROM SOLID WASTE DUMPSITE

AGADA LIVINUS[1], ADETOLA S. ONIKU[2], OSITA C. MELUDU[2]

1. Faculty of Science, Yobe State University Damaturu, P.M.B 1144, Damaturu.
2. School of Pure and Applied Sciences, Modibbo Adama University of Technology, Yola.

Correspondence Author: agadaman1908@gmail.com

ABSTRACT

Leachate from solid waste dumpsite has become a great treat to the quality of groundwater in recent times due to its large production and poor disposal management. The evaluation of groundwater quality is very important due to the fact that most people in towns and cities depend on groundwater for their drinking water. In this study, the quality of groundwater in Gashua was evaluated using Atomic Absorption Spectrometer (AAS). The results obtained reveals that some heavy metals such as Cadmium, Chromium, Lead and Arsenic are available in the groundwater in an unacceptable proportions which constitute health hazards. One dimensional advective-dispersive model was used to evaluate the migration of the contaminants from the dumpsite into the aquifer. Lead was used as a tracer to estimate the extent of the migration of the contaminant in both space and time because of its availability in most solid waste dumpsites. The modelling results showed that the concentration of the contaminants drops fast as the distance from the dumpsite increases, but the longitudinal and transverse advection and dispersion of the contaminants will increase with time. The field results also showed that the (safe drinking) distance at which lead concentration is less than 0.01mg/L is 570m from the solid waste dumpsite. Therefore, water from boreholes situated at distances greater than 570m away from the solid waste dumpsite is safe for drinking base on both the National Agency for Food and Drug Administration and Control (NAFDAC) and World Health Organization (WHO) standards.

Keywords: Leachate, contaminant, dumpsite, metal, advection and dispersion.

INTRODUCTION

Approximately 3.4 million people die every year because of water-related diseases. In recent times, the impact of leachate on groundwater and surface water has attracted a lot of attention because of its environmental and health hazards (Uchegbulam and Ayolabi, 2014). Leachate can be defined as a liquid that passes through a landfill and has extracted dissolved and suspended matter from it. Groundwater is the major source of both domestic and industrial water in Gashua and its environs. Groundwater constitutes water from boreholes, hand-dug wells and springs. The quality of groundwater depends on the nature of aquifer and the anthropogenic activities within the surrounding area. Groundwater has a high risk of being polluted around areas near landfills and open solid waste dumpsites due to their potential source of leachate. Presently there has been suspicion that the groundwater in Gashua is contaminated and could be possibly responsible for some of the prevailing water related diseases in the area. Waziri et al., (2009), observed that both surface and groundwater in Gashua are contaminated by heavy metals, but nevertheless, sufficient study has not been conducted to determine the source of the contaminants. Solid waste generate contaminants which are transported in groundwater, and they migrate to areas far away from their sources and pollute groundwater resources. The transportation of contaminants in groundwater involves both chemical and physical processes caused by advection and dispersion. Development of analytical solutions for groundwater pollution problems has attracted many researchers over the years because of its role in understanding the mechanism of contaminant transportation and in the prediction of the movement of contaminant plume in both space and time. Contaminant transport in groundwater, soil and aquifer is mainly governed by advective-dispersive equation. A number of mathematical models describing groundwater flow and solute transport in homogeneous and heterogeneous porous domain have been developed over the years. Kumar and Yadav (2015) developed analytical solution for conservative solute transport in one dimensional heterogeneous porous medium and the solute dispersion parameter was considered uniform, while the seepage velocity was spatially dependent. Singh and Das (2015) presented an analytical solution of one dimensional scale dependent solute dispersion in semi-infinite heterogeneous porous medium. Sharma et al. (2016) presented the behavior of solute transport through mobile-immobile soil column based on the laboratory study. Singh et al. (2016) presented a solution of one dimensional solute transport with space-time dependent contaminant concentration along uniform flow in a semi-infinite homogeneous porous medium. Singh and Chatterjee (2016) presented analytical solution for non-point source of concentration in semi-infinite aquifer using Laplace transform technique.

In this study, water samples were obtained from boreholes in Gashua to determine the concentration of those heavy metals consider to be highly toxic in there elevated concentrations in drinking water. Mathematical modelling was used to determine the extent of groundwater contamination due to the migration of leachate from solid waste dumpsite into the surrounding groundwater aquifer in the area. Lead was used as a tracer to estimate the extent of the migration of the contaminant in both space and time because of its prevalence in most solid waste dumpsites. The one dimensional modeling was carried out using Excel sheets.

SAMPLE COLLECTION

Water samples were collected from twenty (25) boreholes within Gashua town and its environs. Water samples were specifically collected from boreholes which are the main source of drinking water in the study area. The samples were collected in pre-cleaned sample bottles of 0.25 liter capacity. The bottles were rinsed first with distilled water before filling, rinsed further, two or three times with the water being sampled, and then the water samples were taken. The sample locations are; Abacha, Tashar- Kuka, Low- cost, Takari, Unguwar Lawan, Katuzu, Zango, Sabon-gari, G.R.A, Unguwar kuka, Kabala and Tanda area of Gashua and its environs. The water samples were filtered through pre-washed 0.45µm Millipore nitrocellulose filters to remove any suspended material, and preserved immediately after collection with nitric acid (HNO_3) in order to avoid precipitation of the metals. The samples were stored at 4^0C in a refrigerator prior to the analysis.

SAMPLE ANALYSIS

The digested water samples were analyzed for the presence of lead, chromium, iron, cadmium, copper and arsenic by using Atomic Absorption Spectrophotometer. The calibration plot method was used for the analysis. Air-acetylene flame and hollow cathode lamp of the corresponding elements were used to determine the concentration of the metals respectively. The digested samples were analyzed in triplicates with the average concentration of the metal present being displayed in mg/L by the instrument after extrapolation from the standard curve.

CONTAMINANT MODELING

Simplified assumptions were used to carry out the modeling. The assumptions were used to reduce a heterogeneous medium into a simple homogeneous medium that enables the analytical solution of the transport equation to be obtained. The assumptions are:

- Doman is homogeneous and isotropic in permeability.
- Contaminant flow is horizontal
- Contaminant transport occurs in saturated zone of the aquifer.
- Contaminant flow is laminar and Darcy’s law is valid.
- Change in thickness of aquifer in response to change in head is negligible.
- Aquifer stress to strain is elastic.
- Longitudinal and transverse dispersion coefficient (D_x and D_y) are constant.
- Flow is in x- direction only and velocity is constant (uniform flow).

Formulation of contaminant transport equation

Contaminant transport equation were formulated by using the assumptions made above, boundary and initial conditions, governing laws (conservation of mass, momentum, Darcy’s law, Fick’s law) and constitutive equations. Analytical models for groundwater contaminant in isotropic and homogeneous porous formation were derived and the analytical solutions were derived using the Laplace transform technique.

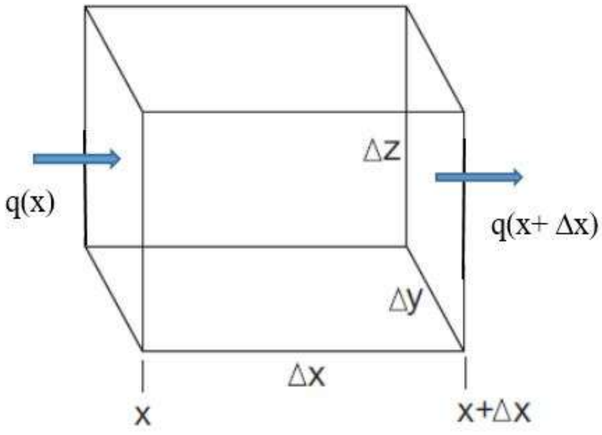


Fig.1 Control volume element within the saturated zone with fixed dimensions.

Δx, Δy and Δz.

At the saturated zone, assumed that effective porosity $n_e = \Theta$.

For a one dimensional water flow in the positive x – direction through a control volume element of length Δx and cross-sectional area perpendicular to the direction of flow A (L^2) as shown in figure 1 above. Let the rate at which water enters the control volume element along the x – direction be $q(x)$ and the rate at which it leaves be $q(x + \Delta x)$. Since the volume of the control volume element (A*Δx) remains constant, the only way water can accumulate within the control volume is either for the porosity of the medium (θ) or the density of water (ρ) to change with time. Water accumulated in the control volume along x-direction is given as,

A$\Delta x \frac{\partial(\rho\theta)}{\partial t}$, its dimensions are MT^{-1} .

The mass of water entering the control volume per unit time is $A\rho q(x)$. Where,

$q(x)$ = specific discharge at location x

$A =$ Cross sectional area through which the water enters.

$\rho =$ Water density at location x.

The mass of water leaving the control volume per unit time is $q(x + \Delta x)A\rho(x + \Delta x)$

Where, $q(x + \Delta x)$ = specific discharge at location $x + \Delta x$

$\rho(x + \Delta x)$ = Water density at location $x + \Delta x$

For a transient flow, the law of conservation of mass holds and it implies that

$$A\Delta x \frac{\partial(\rho\theta)}{\partial t} = q(x)A\rho - Aq(x + \Delta x)\rho(x + \Delta x) \qquad (1)$$

Assuming that water is incompressible and its density is constant in time and space.

Eliminating ρ from both sides of equation (3.6) and dividing through by $A\Delta x$.

We have, $$\frac{\partial\theta}{\partial t} = \frac{q(x) - q(x+\Delta x)}{\Delta x} \qquad (2)$$

Taking the limit on the right hand side of equation (2) as Δx approaches zero. We have,

$$\frac{\partial\theta}{\partial t} = -\frac{\partial q}{\partial x} \qquad (3)$$

Applying Darcy's law,

$$q = -k\frac{\partial h}{\partial x} \qquad (4)$$

We have,

$$\frac{\partial\theta}{\partial t} = k\frac{\partial^2 h}{\partial x^2} \qquad (5)$$

Assuming the change in water content with time on the left-hand side of equation (5) is proportional to the change in hydraulic head with time, equation (5) becomes

$$S_s \frac{\partial h}{\partial t} = k \frac{\partial^2 h}{\partial x^2} \qquad (6)$$

Where S_s is the specific storage whose dimension is L^{-1}. It is defined as the volume of water that a unit volume of aquifer release from storage under a unit decline in hydraulic head.

Expanding equation (6) to three dimensions, we obtain,

$$\frac{\partial h}{\partial t} = \frac{K}{S_s} \left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2}\right) \qquad (7)$$

Equation (7) is called the flow equation for a homogeneous isotropic aquifer. In a steady state (as is frequently assumed), $\frac{\partial h}{\partial t} = 0$ and the flow equation becomes,

$$0 = \left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2}\right) \qquad (8)$$

Solution of which does not depend on K and S_s. Hydraulic head as function of location (x, y and z) can be found by solving equation (8) for given boundary conditions. Porous media has two parameters; the porous compressibility α and fluid compressibility β. The compression or expansion of porous media is caused by change in effective stress σ_e.

$$d\sigma_e = -\rho g dh \qquad (10)$$

The compressibility, α of a porous media is given as

$$\alpha = -\frac{dV_w}{V}\frac{1}{d\sigma_e} = -\frac{d\theta}{d\sigma_e} \qquad (11)$$

Where V_w = volume of water

V = control volume

θ = porosity

Equations (10) and (11) yields,

$$\frac{d\theta}{dh} = \alpha\rho g \qquad (12)$$

Where, h = depth

ρ = Density

g = Acceleration due to gravity.

The fluid compressibility is defined as

$$\beta = \frac{dV_w}{V}\frac{1}{dp} \qquad (13)$$

Where, P is the pressure. The change in pressure is given as

$$dp = \rho g dh \tag{14}$$

Advective-Dispersive Equation (ADE)

The partial differential equation describing lead contaminant transport equation in space and time for uniform flow in x - direction can be written as

$$R\frac{\partial C}{\partial t} = D_x\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial x} - \text{ʎ}RC \tag{15}$$

R is retardation factor defined as

$$R = 1 + \frac{k_b K_d}{\theta} \tag{16}$$

And ʌ is a general decay constant given as

$$\text{ʎ} = \propto + \frac{\beta k_b K_d}{\theta} \tag{17}$$

V is the pore water velocity given as

$$V = \frac{q}{\theta} \tag{18}$$

Where C is the depth average plume concentration; θ is the Porosity; D is the hydrodynamic dispersion coefficient accounting for both diffusion and mechanical dispersion; q is the velocity; k_b is the porous media bulk density; K_d is a distribution or partition coefficient; $\propto$ and β are first order rate constants associated with the solid and liquid phases of the soil respectively.

Equation (15) can be solved subject to specified initial and boundary conditions. The initial condition is given by,

$$c(x,0) = c_i \tag{19}$$

Equation (19) describes the initial lead concentration values at different locations. The boundary conditions associated with the surface area are given as,

$$c(0,t) = c_0 \tag{20}$$

and $$\frac{\partial C}{\partial x}(\infty, t) = 0 \tag{21}$$

Equation (20) shows that for an active solid waste dump site, there is a continuous inflow of contaminant which replaces the outflow into the groundwater. Equation (21) shows that at very large distances the aquifer is unaffected by the contamination from the solid waste dump site. Equation (15) can be solved by using Laplace transform.

Analytical solution for one dimensional advective-dispersive equation.

Boundary Conditions

$$C(0,t) = C_0 \qquad \text{for } x = 0,\ t > 0 \tag{22}$$

$$C(L,t) = 0, \qquad \text{for } x = L = \infty,\ t = 0 \tag{23}$$

Intial Conditions,

$$C(x,0) = 0, \qquad \text{for } 0 \le x \le L = \infty,\ t = 0 \tag{24}$$

Taking Laplace Transform of the boundary conditions, initial condition and the terms in equation (15) we have,

$$\mathcal{L}\{C(0,t)\} = \mathcal{L}\{C_0\} \implies \bar{C}(0,s) = \frac{C_0}{s} \tag{25}$$

$$\mathcal{L}\{C(L,t)\} = \mathcal{L}\{0\} \implies \bar{C}(L,s) = 0,\quad L \longrightarrow \infty \tag{26}$$

$$\mathcal{L}\{C(x,0)\} = \mathcal{L}\{0\} \implies C(x,0) = 0 \tag{27}$$

$$\mathcal{L}\left\{R\frac{\partial c}{\partial t}\right\} = R\mathcal{L}\{\frac{\partial c}{\partial t}\} = R[s\bar{C} - C(x,0)] = Rs\bar{c} \tag{28}$$

$$\mathcal{L}\{D_x \frac{\partial^2 c}{\partial x^2}\} = D_x\mathcal{L}\frac{\partial^2 c}{\partial x^2} = D_x\frac{\partial^2}{\partial x^2}\int_0^\infty c(x,t)e^{-st}dt = D_x\frac{\partial^2 \bar{C}}{\partial x^2} \tag{29}$$

$$\mathcal{L}\{v\frac{\partial c}{\partial x}\} = v\mathcal{L}\left\{\frac{\partial c}{\partial x}\right\} = v\frac{\partial}{\partial x}\int_0^\infty c(x,t)e^{-st}\,dt = v\frac{\partial \bar{C}}{\partial x} \tag{30}$$

$$\mathcal{L}\{\lambda RC\} = \lambda R\mathcal{L}\{C\} = \lambda R\int_0^\infty C(x,t)e^{-st}\,dt = \lambda R\,\bar{C} \tag{31}$$

Putting the Laplace Transform of the respective terms into equation (15) we have,

$$Rs\bar{c} = D_x\frac{\partial^2 \bar{c}}{\partial x^2} - v\frac{\partial \bar{c}}{\partial x} - \lambda R\bar{C} \tag{32}$$

Rewriting equation (32) we have,

$$D_x\frac{\partial^2 \bar{c}}{\partial x^2} - v\frac{\partial \bar{c}}{\partial x} - (\lambda R + Rs)\bar{c} = 0 \tag{33}$$

The characteristic equation for equation (33) is

$$k^2 - \frac{v}{D_x}k - \frac{R}{D_X}(\lambda + S) \tag{34}$$

Comparing equation (34) with the quadratic equation

$$ax^2 + bx + c = 0 \tag{35}$$

We have,

$$a = 1,\quad b = -\frac{v}{D_x},\ \text{ and } c = -\frac{R}{D_x}(\lambda + s)$$

The solution of the characteristic equation (35) is given as

$$k_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{36}$$

Substituting the values of a , b and c into equation (36) gives

$$k_{1,2} = \frac{v}{2D_x} \pm \sqrt{\frac{R}{D_x}[\left(\frac{v^2}{4RD_x} + \lambda\right) + s]} \qquad (37)$$

Where $k_1 = \frac{v}{2D_x} + \sqrt{\frac{R}{D_x}[\left(\frac{v^2}{4RD_x} + \lambda\right) + s]}$ and $k_2 = \frac{v}{2D_x} - \sqrt{\frac{R}{D_x}[\left(\frac{v^2}{4RD_x} + \lambda\right) + s]}$

Using the coefficient of dispersion D_x without the subscript *x*.

The solution of equation (33) can be written in the form

$$\bar{c}\ (x, \mathrm{s}) = Ae^{k_1 x} + Be^{K_2 x} \qquad (38)$$

Therefore applying the outflow boundary condition to equation (38) gives

$$\bar{c}\,(L, s) = \bar{C}\,(\infty, S) = Ae^{k_1 \infty} + Be^{k_2 \infty} = 0$$

For convergence A = 0, equation (38) becomes

$$\bar{c}\,(x, s) = Be^{K_2 x} \qquad (39)$$

Applying the inflow boundary condition, the value of B can be obtained.

$$\bar{c}\,(0, s) = Be^{K_{2(0)}} = \mathrm{B}$$

This implies that,

$$\mathrm{B} = {}^{c_0}/_{s}$$

Substituting the value of B into equation (39) gives

$$\bar{c}\,(x, s) = \frac{c_0}{s}\left[exp\left\{\frac{v}{2D} - \sqrt{\frac{R}{D}\left[\left(\frac{v^2}{4RD} + \lambda\right) + S\right]}\right\}x\right] \qquad (40)$$

Let $\beta = \frac{v^2}{4RD} + \lambda,\ \xi = \beta + S$

Therefore,

$$S = \xi - \beta \qquad (41)$$

Substituting equation (41) into equation (40)

$$\bar{c}\,(x, s) = \frac{c_0}{s}\left[exp\left\{\frac{v}{2D} - \sqrt{\frac{R}{D}\,[\beta + S]}\right\}x\right] \qquad (42)$$

$$\bar{C}\,(x, s) = exp\left\{\frac{vx}{2D}\right\}\left[\frac{c_0}{\xi - \beta}\,exp\left\{-x\sqrt{\frac{R}{D}}\,\xi\right\}\right] \qquad (43)$$

Using the first Shift Theorem,

$$\mathcal{L}^{-1}[F(s + a)] = \mathcal{L}^{-1}[e^{-at}F(s)] = e^{-at}\mathcal{L}^{-1}[F(s)] \qquad (44)$$

Where, $a = \beta$

Hence, taking the inverse Laplace Transform of equation (43) we have,

$$\mathcal{L}^{-1}\{\bar{c}(x,s)\} = \mathcal{L}^{-1}\left\{exp\left\{\frac{vx}{2D}\right\}\left[\frac{c_0}{\xi-\beta}exp\left\{-x\sqrt{\frac{R}{D}}\xi\right\}\right]\right\} \qquad (45)$$

From equation (45) we have,

$$C(x,t) = c_0.exp\left\{\frac{vx}{2D}\right\}.exp\{-\beta t\}.\mathcal{L}^{-1}\left[\frac{1}{s-\beta}\right].exp\left\{-x\left(\sqrt{\frac{R}{D}}\right)\sqrt{s}\right\} \qquad (46)$$

But,

$$\mathcal{L}^{-1}\left[\frac{1}{s-\beta}\right].exp\left\{-x\left(\sqrt{\frac{R}{D}}\right)\sqrt{s}\right\} = 0.5exp\{\beta t\}.\left\{\begin{matrix}\exp\left\{-\frac{vx}{2D}\right\}erf\left[\frac{x}{2}\sqrt{\frac{R}{Dt}} - \sqrt{\beta t}\right]\\ +exp\left\{\frac{vx}{D}\right\}erf\left[\frac{x}{2}\sqrt{\frac{R}{Dt}} + \sqrt{\beta t}\right]\end{matrix}\right\} \qquad (47)$$

Substituting equation (47) into equation into equation (46), we obtain the Laplace Transform solution for 1Dimensional Advective Dispersive Equation as

$$C(x,t) = \frac{c_0}{2}.exp\left\{\frac{vx}{2D}\right\}.exp\{-\beta t\}.\left\{\begin{matrix}\exp\left\{-\frac{vx}{2D}\right\}erf\left[\frac{x}{2}\sqrt{\frac{R}{Dt}} - \sqrt{\beta t}\right]\\ +exp\left\{\frac{vx}{D}\right\}erf\left[\frac{x}{2}\sqrt{\frac{R}{Dt}} + \sqrt{\beta t}\right]\end{matrix}\right\} \qquad (48)$$

Substituting $\beta = \frac{v^2}{4RD} + \lambda$ into equation (48), gives

$$C(x,t) = \frac{c_0}{2}\left\{erfc\left[\frac{xR - vt\sqrt{1+\frac{4RD\lambda}{v^2}}}{\sqrt{4RDt}}\right] + exp\left\{\frac{vx}{D}\right\}.erfc\left[\frac{xR + vt\sqrt{1+\frac{4RD\lambda}{v^2}}}{\sqrt{4RDt}}\right]\right\} \qquad (49)$$

Where *C* = concentration measured in mg/L

C_0 = initial concentration

R = retardation coefficient

x = distance moved by contaminant along horizontal direction.

D = hydrodynamic dispersion coefficient

V = pore water velocity

ʎ= decay constant

t = time

Bulk Density

The bulk density of a soil sample is the weight per unit volume of the soil sample. A sample of sandy soil was obtained from one of the shallow wells in the study area, the sandy soil sample was oven dry at 105^{0}C. It was allowed to cool and it was weighed. The dried sand was carefully transferred into a cylinder by using funnel. The cylinder was properly shaken to enable the sand settle properly inside the cylinder. This was done to obtain the volume of the dry sand.

Weight of oven dried sand = 600g

Internal radius of cylinder = 3.5cm

Height of dry sand in cylinder = 6.5cm

The volume of the dry sand was obtained by using the relation,

Volume of cylinder = $\pi r^2 h$

Taking $\pi = {}^{22}/_{7}$, we have,

Volume of dry sand = 3.142 x 3.5^2 x 6.5

= 250.25cm^3

Bulk density = $\frac{mass\ of\ dry\ sand}{volume\ of\ dry\ sand} = \frac{600}{250.25}$ = 2.397g/cm^3 = 2397kg/m^3

Since the particle density of most mineral solids lies between 2500 and 2700kg/m^3 (Freeze and Cherry, 1979, assuming that the porosity of the dry sand is 2700kg/m^3,

Porosity = $(1 - \frac{k_b}{\rho_d})$ x$\frac{100}{1}$, where k_b = bulk density of sand and ρ_d = particle density of sand.

Porosity = (1- $\frac{2397}{2700}$) x $\frac{100}{1}$ = 11%.

Two wells in the study area separated by a distance of 100m were found to have a head difference of 0.49m. Therefore, the hydraulic gradient is given as,

$\beta = \frac{dh}{dl} = \frac{0.49}{100}$ = 0.0049

Taking the hydraulic conductivity of the sandy aquifer to be 0.55 (Taigbenu and Rusinga, 2005).

We have,

Darcy's velocity q = k$\frac{dh}{dl}$ = 0.55 x 0.0049 = 0.002695m/day

Pore water velocity v = $\frac{q}{\theta} = \frac{0.002695}{0.11}$ = 0.0245m/day.

Assuming a longitudinal dispersivity a_L = 185m (Rowe, 1987), we have,

Hydrodynamic dispersion coefficient D = pore water velocity x longitudinal dispersivity.

= 0.0245 x 185 = 4.5325m^2/day.

Retardation Factor (R)

Retardation processes remove contaminants from the groundwater during transportation and it makes the concentration of the arriving contaminant at any point at a certain time to be less than it would have been for a conservative (non-retarded) contaminant. Retardation factor (R) is a function of partition coefficient (K_d) and porous media bulk density (k_b). It is expressed as

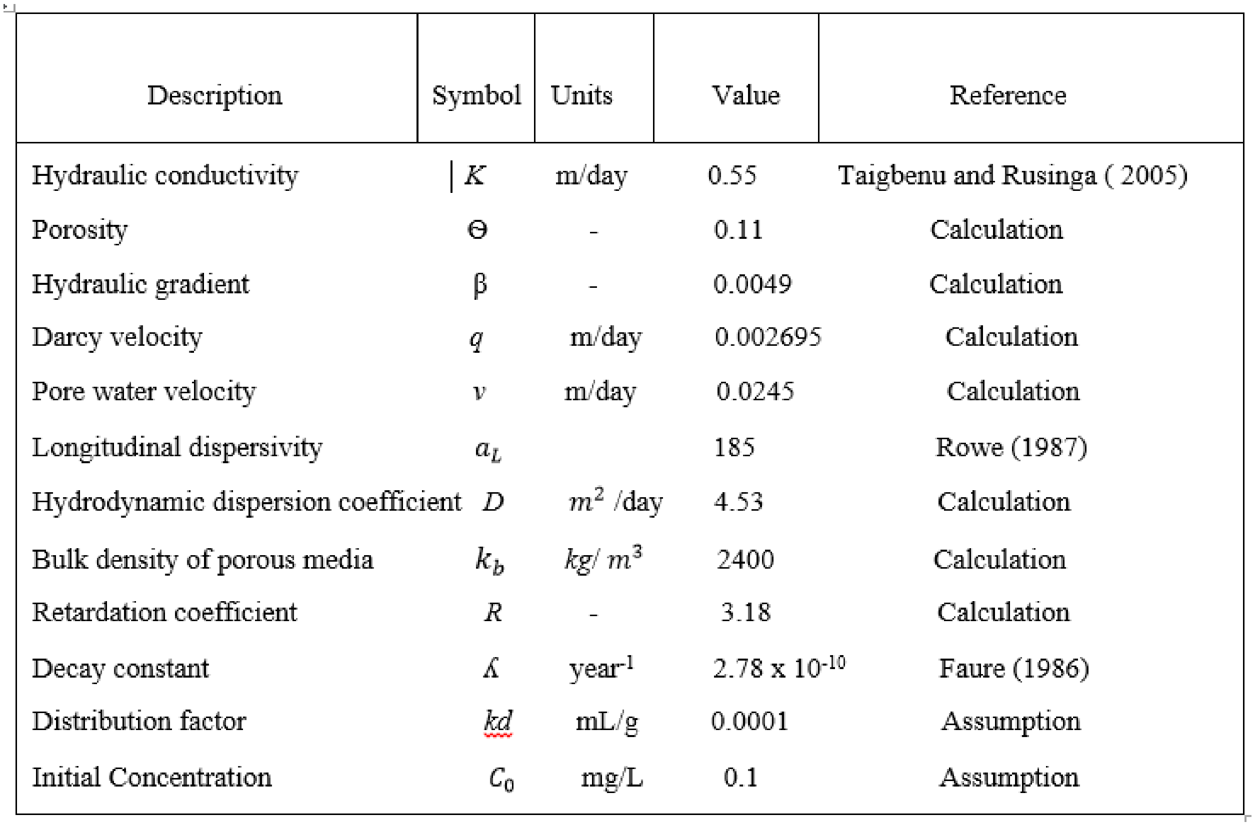
$$R = 1 + \frac{k_b K_d}{\theta}$$

Where θ = volumetric moisture content or porosity. Assuming a partition coefficient (K_d) value of 0.0001L/kg for the lead contaminant in the sandy aquifer, we have,

k_b = 2397kg/m^3, K_d = 0.0001L/kg and θ = 0.11. Therefore,

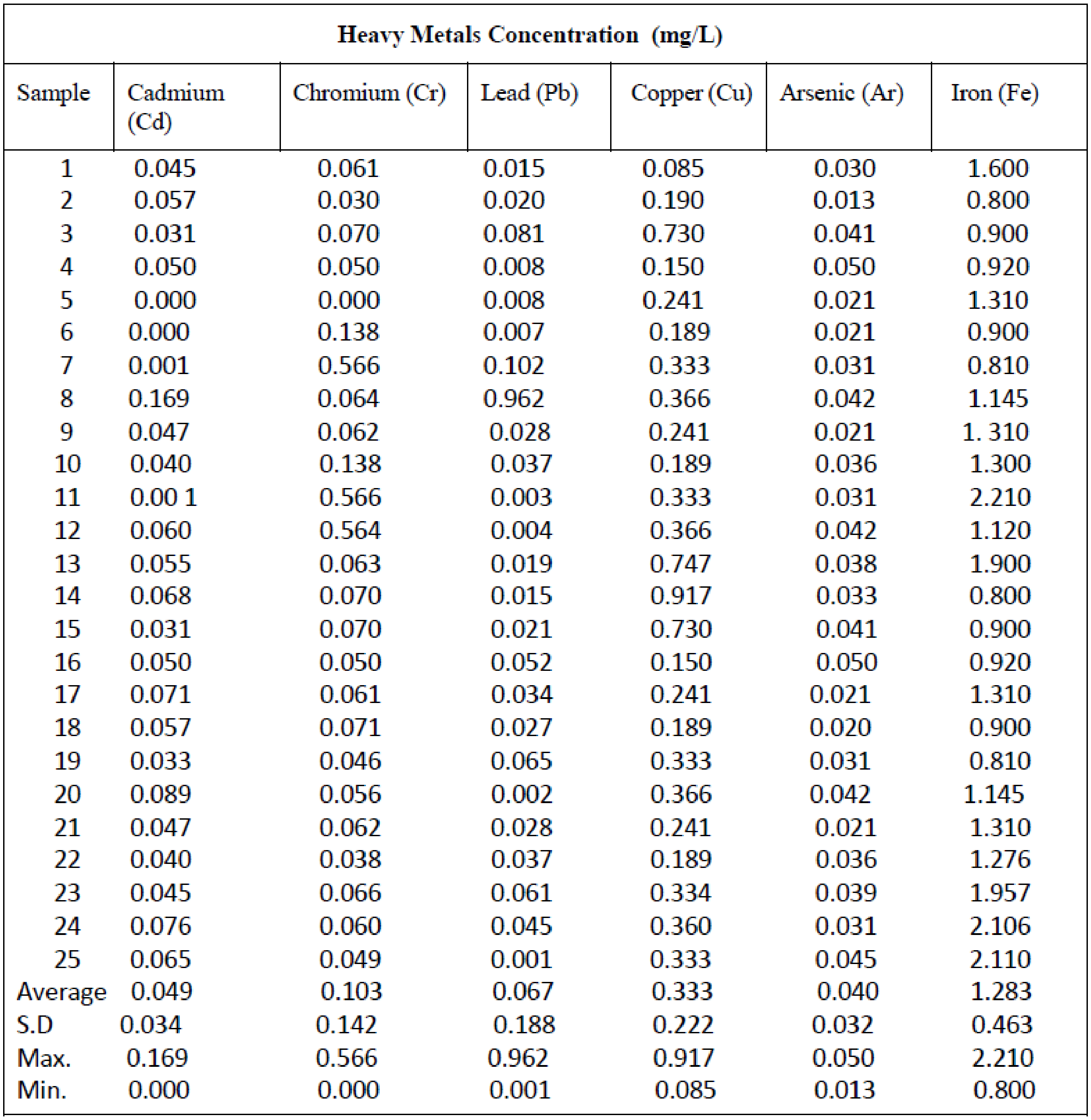
$$R = 1 + \frac{2397\text{x}0.0001}{0.11} = 1+2.18 = 3.18$$

Table 1. Summary of the Parameters used for 1D modeling.



Description	Symbol	Units	Value	Reference
Hydraulic conductivity	K	m/day	0.55	Taigbenu and Rusinga (2005)
Porosity	Θ	-	0.11	Calculation
Hydraulic gradient	β	-	0.0049	Calculation
Darcy velocity	q	m/day	0.002695	Calculation
Pore water velocity	v	m/day	0.0245	Calculation
Longitudinal dispersivity	a_L		185	Rowe (1987)
Hydrodynamic dispersion coefficient	D	m^2 /day	4.53	Calculation
Bulk density of porous media	k_b	$kg/\,m^3$	2400	Calculation
Retardation coefficient	R	-	3.18	Calculation
Decay constant	λ	year^{-1}	2.78 x 10^{-10}	Faure (1986)
Distribution factor	kd	mL/g	0.0001	Assumption
Initial Concentration	C_0	mg/L	0.1	Assumption

Table 2. Results of the Heavy Metal Analysis of the Water Samples

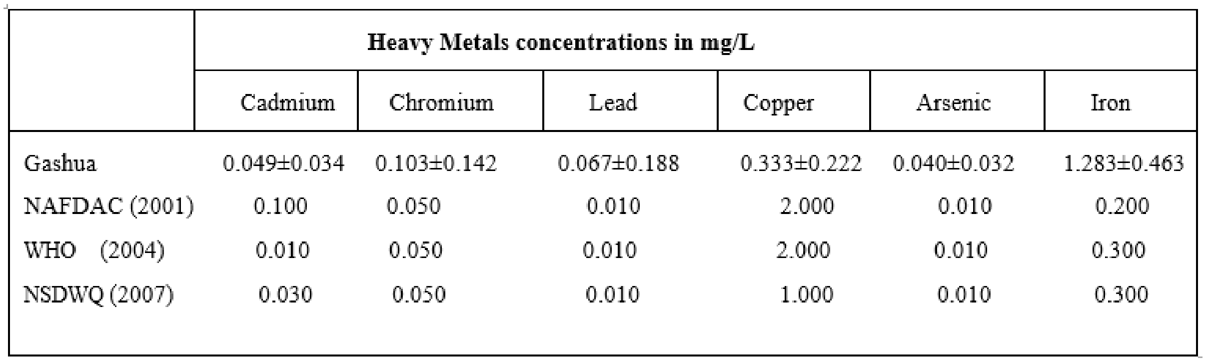


Heavy Metals Concentration (mg/L)						
Sample	Cadmium (Cd)	Chromium (Cr)	Lead (Pb)	Copper (Cu)	Arsenic (Ar)	Iron (Fe)
1	0.045	0.061	0.015	0.085	0.030	1.600
2	0.057	0.030	0.020	0.190	0.013	0.800
3	0.031	0.070	0.081	0.730	0.041	0.900
4	0.050	0.050	0.008	0.150	0.050	0.920
5	0.000	0.000	0.008	0.241	0.021	1.310
6	0.000	0.138	0.007	0.189	0.021	0.900
7	0.001	0.566	0.102	0.333	0.031	0.810
8	0.169	0.064	0.962	0.366	0.042	1.145
9	0.047	0.062	0.028	0.241	0.021	1. 310
10	0.040	0.138	0.037	0.189	0.036	1.300
11	0.00 1	0.566	0.003	0.333	0.031	2.210
12	0.060	0.564	0.004	0.366	0.042	1.120
13	0.055	0.063	0.019	0.747	0.038	1.900
14	0.068	0.070	0.015	0.917	0.033	0.800
15	0.031	0.070	0.021	0.730	0.041	0.900
16	0.050	0.050	0.052	0.150	0.050	0.920
17	0.071	0.061	0.034	0.241	0.021	1.310
18	0.057	0.071	0.027	0.189	0.020	0.900
19	0.033	0.046	0.065	0.333	0.031	0.810
20	0.089	0.056	0.002	0.366	0.042	1.145
21	0.047	0.062	0.028	0.241	0.021	1.310
22	0.040	0.038	0.037	0.189	0.036	1.276
23	0.045	0.066	0.061	0.334	0.039	1.957
24	0.076	0.060	0.045	0.360	0.031	2.106
25	0.065	0.049	0.001	0.333	0.045	2.110
Average	0.049	0.103	0.067	0.333	0.040	1.283
S.D	0.034	0.142	0.188	0.222	0.032	0.463
Max.	0.169	0.566	0.962	0.917	0.050	2.210
Min.	0.000	0.000	0.001	0.085	0.013	0.800

S.D = Standard deviation, Max = Maximum, Min = Minimum

Table 3. Comparison of the heavy metal concentration values obtained with the

National and international set standards.



	Heavy Metals concentrations in mg/L					
	Cadmium	Chromium	Lead	Copper	Arsenic	Iron
Gashua	0.049±0.034	0.103±0.142	0.067±0.188	0.333±0.222	0.040±0.032	1.283±0.463
NAFDAC (2001)	0.100	0.050	0.010	2.000	0.010	0.200
WHO (2004)	0.010	0.050	0.010	2.000	0.010	0.300
NSDWQ (2007)	0.030	0.050	0.010	1.000	0.010	0.300

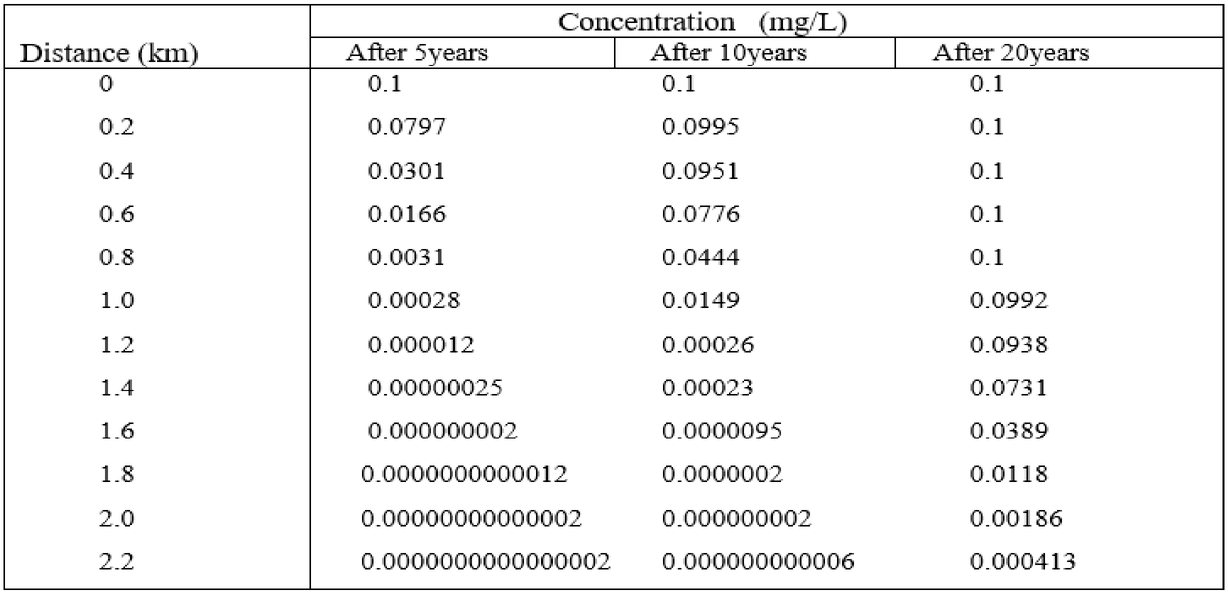
Table 1. Shows the results of the heavy metal analysis of the water samples obtained from the study area. The results were compared with the international set standards in table 2. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement of iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50mg/day. In this study the concentration of iron in the groundwater ranges from 0.80 to 2.21mg/L as shown table 1. The regulatory limits for iron in drinking water by WHO, NSDWQ and NAFDAC are 0.3mg/L, 0.3mg/L and 0.2mg/L respectively. The average iron content in the groundwater in the study area is 1.283 ± 0.463mg/L as shown in table 2 above. High concentration of iron is associated with undesirable taste, laundry staining, scaling in pipes, vomiting, teeth staining and cardiac problems. The groundwater is therefore polluted with iron, leachate from the dumpsites might have enhanced the enrichment of iron concentration in the groundwater. At appropriate concentration, copper is an essential mineral in human body but at high concentration it becomes toxic to the body system. High levels of copper can cause a bitter metallic taste in water and result in blue green stains on plumbing fixtures. The concentration of copper in the study area ranges from 0.021 to 0.917mg/L. The regulatory limits for copper in drinking water by both WHO and NAFDAC is 2mg/L, and by NSDWQ it is 1mg/l. The average copper content in the groundwater in the study area is 0.333 ± 0.222mg/L as shown in table 2. Therefore, the groundwater is not polluted in terms of its copper content. The primary sources of copper in drinking water are corroding pipes and brass components of household piping systems. The amount of copper in drinking water also depends on the hardness and PH of the water. High concentration of copper in human body can cause anemia, liver and kidney damage, stomach and intestinal irritation (Agada et al., 2011). Generally, heavy metals are naturally occurring substances which are often present in the environment in small amount, but in large amount they

constitute health hazards. Leachates from dumpsites are known for contributing heavy metals into groundwater as they migrated from their source and infiltrate into the subsurface. Lead can be present in in drinking water as a result of dissolution from natural sources, contamination from leachate into the groundwater or from household systems containing lead. It is a toxic metal which got spread through the burning of fossil fuel, mining, improper solid waste disposer and manufacturing processes. The concentration of lead in the ground water in the study area range from 0.007 to 0.962mg/L as shown in table 1. The average concentration of lead in the groundwater in the study area was 0.067± 0.188mg/L (table 2). The regulatory limits for lead in drinking water by WHO, NSDWQ and NAFDAC are 0.010mg/L respectively as shown in table 2 above. The groundwater in the area is polluted by lead. Lead can affect every organ in the body, long term exposure to lead can severely damage kidneys and the organs responsible for male reproduction. It was observed that Kidney infection was on the rise in the study area and its environs. Lead has been classified as carcinogen by the Environment Protection Agency (EPA, 1999). In some cases, long term exposure to lead can cause weakness in fingers, wrists, waist, ankles, small increase in blood pressure and anemia. Children who are exposed to high levels of lead may experience slow cognitive development, reduced growth, and other health effects (Akan et al., 2011).

Chromium is found in rocks, chemicals, plants and soil and it can be a liquid, solid or gas. The concentration of chromium in groundwater in the study area range from 0.000 to 0.566mg/L. The average concentration of chromium in the study area is 0.103 ± 0.142mg/L. The WHO, NSDWQ and NAFDAC regulatory limits for chromium in drinking water are 0.050mg/L respectively. The drinking water is polluted by chromium. Chromium and its compounds are known to cause cancer of the lung, nasa cavity, paranasal sinus, and it is suspected to cause cancer of the stomach and Larynx (ATSDR, 2000). Chromium (iii) has been classified as an essential nutrient that helps the body to use sugar, protein, and fat (Hati et al., 2005). However, under certain environmental conditions and certain metallic transformations, chromium (iii) may readily be oxidized to chromium (VI) compounds that are toxic to human health (ATSDR, 2000).

Cadmium is a very toxic metal, it could be found in coal, rocks and leachate from dumpsite. The concentration of cadmium in the study area ranges from 0.000 to 0.566mg/L as shown in table 1 above. The average concentration of cadmium the study area is 0.049±0.034mg/L as shown in table 2. The WHO, NAFDAC and NSDWQ regulatory limits for cadmium in drinking water are 0.010mg/L, 0.010mg/l and 0.030mg/l respectively. The groundwater is polluted by cadmium. Cadmium metal is used mainly as anticorrosive and electroplated on steel. Cadmium sulphide and selenite are commonly used as pigments in plastics. Ingesting very high levels of cadmium irritates the stomach, leading to vomiting and diarrhea. Long term exposure to lower levels leads to a buildup in the kidneys and possible kidney disease, lung damage and fragile bones. Arsenic could be introduced into groundwater through both natural and anthropogenic sources. Arsenic occurrence in water is caused by the weathering and dissolution of arsenic bearing rocks; minerals and ores or leachates. Fossil fuel combustion is a source of arsenic to the environment through atmospheric deposition. The concentration of arsenic in the groundwater in the study area range from 0.013 to 0.185mg/L. The WHO and NAFDAC regulatory limits for drinking water are 0.01 and 0.05mg/L respectively as shown in table 2. The average concentration of arsenic in the groundwater in the study area is 0.040 ± 0.032mg/L. By NAFDAC regulation, the groundwater is safe for drinking. Arsenic is odorless and tasteless. It can be found in paints, dyes, metals, drugs, soaps and semiconductors. Inorganic arsenic is a known carcinogen and can cause cancer of the skin, lungs, liver and bladder. Lower level exposure can cause nausea and vomiting.

Table 4. Simulated results of Lead contaminant at various locations.



Distance (km)	Concentration (mg/L)		
	After 5years	After 10years	After 20years
0	0.1	0.1	0.1
0.2	0.0797	0.0995	0.1
0.4	0.0301	0.0951	0.1
0.6	0.0166	0.0776	0.1
0.8	0.0031	0.0444	0.1
1.0	0.00028	0.0149	0.0992
1.2	0.000012	0.00026	0.0938
1.4	0.00000025	0.00023	0.0731
1.6	0.000000002	0.0000095	0.0389
1.8	0.0000000000012	0.0000002	0.0118
2.0	0.00000000000002	0.000000002	0.00186
2.2	0.0000000000000002	0.000000000006	0.000413

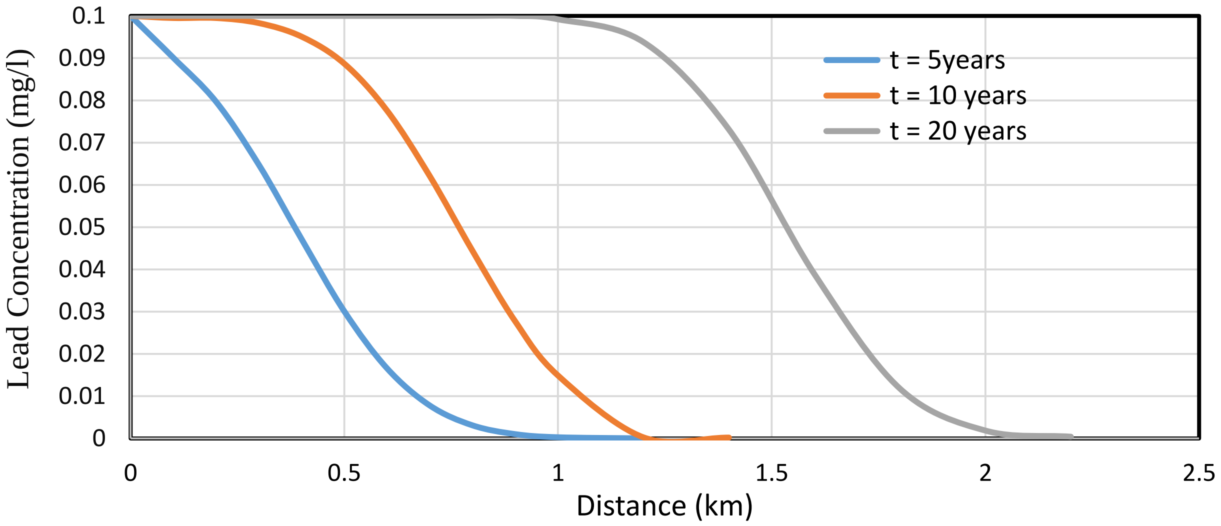
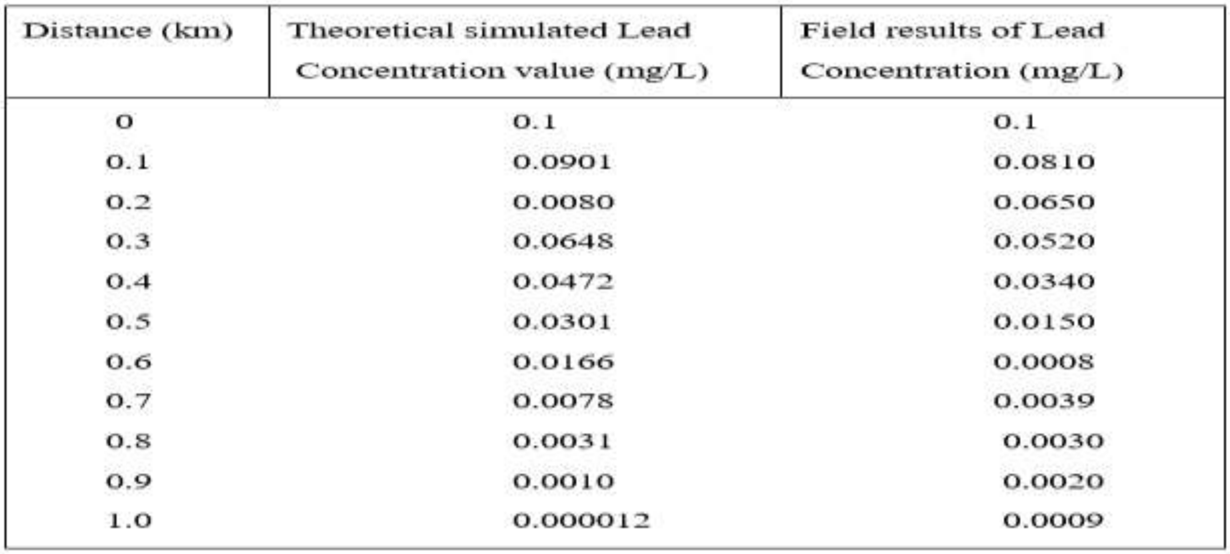


Fig. 2 Results of simulated Lead concentration at various location with time

Table 5. Comparison of the theoretical simulated values of Lead concentration with the field results.



Distance (km)	Theoretical simulated Lead Concentration value (mg/L)	Field results of Lead Concentration (mg/L)
0	0.1	0.1
0.1	0.0901	0.0810
0.2	0.0080	0.0650
0.3	0.0648	0.0520
0.4	0.0472	0.0340
0.5	0.0301	0.0150
0.6	0.0166	0.0008
0.7	0.0078	0.0039
0.8	0.0031	0.0030
0.9	0.0010	0.0020
1.0	0.000012	0.0009

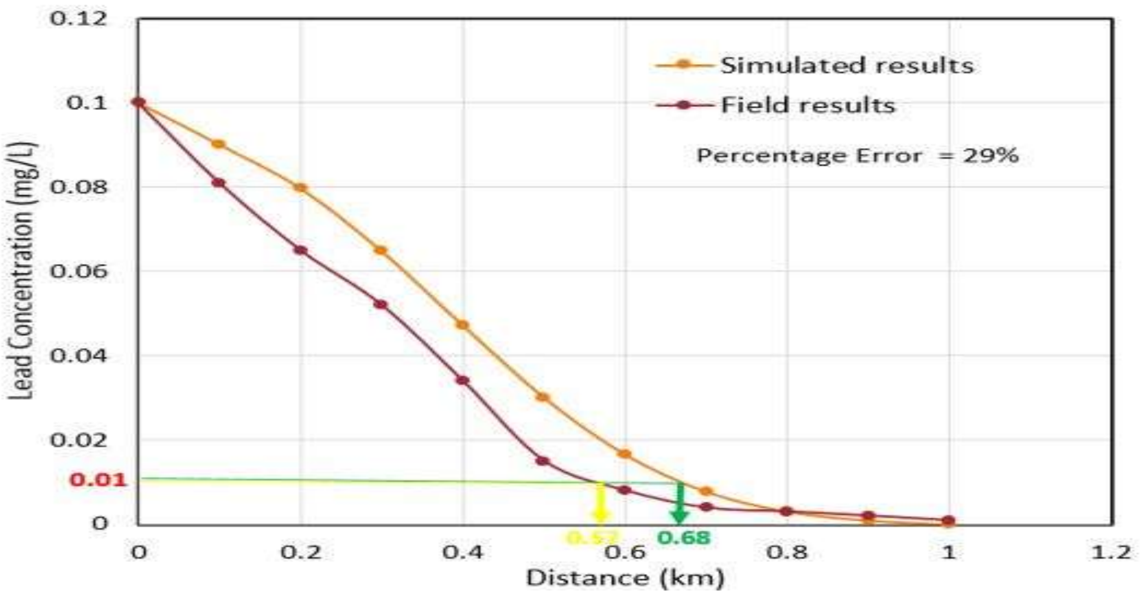


Fig. 3 Comparison of field results with the simulated results.

Distances of selected boreholes from the dumpsite and the concentration of Lead in those boreholes were recorded as shown in table 5. The obtained values were used to model Lead concentration in groundwater in the study area. It was assumed that the dumpsite had an initial Lead concentration of 0.1mg/L. The results of the simulation are shown in figure 3, which shows a good fit of the field results with 29% error. The theoretical model simulation shows that the distance at which the Lead concentration in ground water is less than 0.01mg/L (safe distance) is 680m. Based on this observation, groundwater at distances beyond 680m away from the dumpsite is safe for drinking. Furthermore, the field results shows that the safe distance at which the lead concentration is less than 0.01mg/L is 570m as shown in yellow colour in figure 3 above. Therefore, water from boreholes situated at distances greater than 570m away from the dumpsite is safe for drinking base on both NAFDAC and WHO standards. Figure 2 shows that the groundwater contaminant concentrations drop with increase in distance away from the solid waste dumpsites. The concentration of the contaminant is higher close to the dumpsite. Therefore, boreholes sited close to the dumpsite are at a higher risk of contamination. The modelling results also shows that at a greater distance away from the dumpsite the concentration of the contaminant reduces to zero.

CONCLUSION

Base on the findings of this study, it is evident that the water from hand dug wells and boreholes located within the contaminated zones could be responsible for high prevalence of water related diseases in the study area. The average depth of hand dug wells in the study area is 20m (Agada et al., 2020) and some of the boreholes were sited within the first aquifer which is not confined (Agada et al., 2020), and this situation makes them vulnerable to pollution by leachate from the dumpsite. The modelling results showed that the concentration of the contaminants drops fast as the distance from the dumpsite increases, but the longitudinal, transverse advection and dispersion of the contaminants will increase with time. This implies that if the groundwater pollution problem is not solved, the rate of its pollution will increase with time.

RECOMMENDATION

The following are therefore recommended.

i. Government should enforced environmental protection laws that will prohibit indiscriminate disposal of solid waste material from domestic and industries.

ii. The consumption of water from hand dug wells and shallow boreholes should be discouraged in the study area. Boreholes closed to the dumpsites should be closed and new ones should be sited at distances far from the dumpsites to avoid pollution.

iii. Sensitization workshops and public awareness programmes on dangers of consumption of contaminated water should be carried out in the study area.

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