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Research Paper

Modelling of Chemical Contaminant Transport of Open Dumpsite Leachate on Groundwater using MATLAB Program

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ABSTRACT: *The research models and simulates the chemical contaminants transport of open dumpsite leachate on groundwater quality surrounding the study area ofOyigbo Local Government Area in Rivers State, Nigeria. Chemical analysis assessmentswere conducted on the groundwater samples collected from three (3) boreholes. The chemical parameters tested include the Nitrates (NO_3^{2-}), Chlorides (Cl^-) and Sulphates (SO_4^{2-}) ionswhich inadvertently contaminate the groundwater quality through the formation of leachates from the dumpsite. This environmental impact on the groundwater quality of leachate contamination of the dumpsite at Oyigbo Local Government Area was simulated. The MATLAB programming language was deployed in modelling the transport of the chemical contaminants in the groundwater. The simulated model demystify that the contaminants diffuses profusely through the porous media and the model elucidates that the concentration of the chemical contaminants diminishes as they travel and spread out downstream of the landfill to an insignificant concentration level at about 50 metres from the source point of the plume.*
KEYWORDS: *Leachate, Groundwater Contaminant Transport, MATLAB Program*

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I. INTRODUCTION

The devastation of waste disposal in municipal communities has become uncontrollably alarming. Solid wastes are disposed on the land surface causing potential sources ofgroundwater contamination [1]. The objective in this paper is to develop mathematical modelthat describes the transport in the subsurface of contaminants dissolvedin the groundwater that occupies the void space, or part of it.

The impact of leachates on groundwater and other water sources has become a global predicament due to its overwhelming environmental significance. Leachate transport from waste dumpsites or landfill areas and the release of pollutants from sediment poses a high risk to groundwater if not effectively and properly managed [1].

Leachates are liquids produced that when water has been dissolved and percolated or infiltrated through the solid wastes as well as by the squeezing of the waste due to self-weight. Water that penetrates into landfill picks up the soluble constituents from the wastes and may enter either the ground water or the surface water and thus act as a vehicle carrying potentially toxic matter from the landfill to the water sources. The important factors that influence leachate quality are waste composition, elapsed time, temperature, moisture and available oxygen. In general, leachate quality of the same waste type may be different in landfills located in different climatic regions.

The physicochemical concentration was tested from the collected groundwater samples. The effect of depth and distance of landfill from groundwater were studied and remedial measures were suggested to avoid future contamination by leachate percolation[2].

One prevailing crisis faced in the urban and industrial areas predominantly in the developing countries is the solid waste disposal and management which deteriorates the environmental ecosystems. Enormous amount of solid waste are generated on daily basis and its management becomes a huge task. Solid waste generation has stimulated an increasing trend parallel to the development of industrialization, urbanization and rapid growth of population. The solid waste management encompasses from the collection, transportation and disposal of waste. In recent times, the management of solid waste necessitates transporting the waste from founded areas to distant places for dumping without any measure of dealing away with the waste, leaving nature to take its course. However, today, the increasing land value, inadequate space, limited capacity of nature to handle unwanted emissions and residues pose long-term environmental and human health problems. Uncontrolled open dumping is commonly prevalent in mostdeveloping countries as it is the simplest and most cost-effective method of waste disposal. This practice is alsoadopted in the developed countries to some extent. Therefore, it desperately needs immediate action to be takento minimize the associated harmful impact. Due to urbanization, the generation of solid waste is increased andalso affect the groundwater quality [2].

As the natural environmentcan no longer digest the produced wastes, thedevelopment of solid waste management has contributedto their automated collection, treatment and disposal.One of the most common waste disposal methods islandfilling, a controlled method of disposing solidwastes on land with the dual purpose of eliminatingpublic health and environmental hazards and minimizing nuisances without contaminating surface or subsurfacewater resources.

A municipal solid waste (MSW) landfill is not abenign repository of discarded material; it is a biochemicallyactive unit where toxic substances are leached orcreated from combinations of non-toxic precursors andgradually released into the surrounding environmentover a period of decades. Biological, chemical and physicalprocesses within the landfill promote the degradationof wastes and result in the production of leachateand gases. Leachate is defined as the polluted liquidemanating from the base of the landfill. The downwardtransfer of leachate contaminates groundwater resources,whereas the outward flow causes leachate springs atthe periphery of the landfill thatmay affect surface waterbodies. Hence, leachate seepage is a long-term phenomenonthat must be prevented in order to protect naturalwater resources.In this paper, the potential contamination risk, due toleachate leakage, of the aquifer beneath aMSWlandfillis examined. The Municipal Landfill of the City of Patras(MLP) inGreece was selected for the field application asa potential contamination of the aquifer beneath thelandfill may have a significant impact on public healthand the local economy. The main objectives of this paper are the characterization of the leachate produced at the MLP and the hydrogeological characterization of thearea of study, which includes the underlying aquifer and extends from the MLP to the sea. A groundwater flow and leachate mass transport model of the hydrogeological region beneath the municipal landfill was developed in order to examine the impact of leachate seepage from the MLP into the groundwater. Furthermore, a risk assessment model (RAM) was applied in order todetermine the magnitude of the potential groundwater contamination plume due to the landfill leachate seepage [1].

Dumpsite operational practices also influence the leachate quality. Significant quantity of leachate is produced from the active phases of a landfill under operation during the monsoon season. Leachates which emerge out of the dumpsite percolate down to the aquifer. Characterization of the leachate is necessary in the assessment of ground water contamination near disposal sites. The following principal groups are contained in leachate. Inorganic macro components: calcium, magnesium, sodium, potassium, ammonium, iron, manganese, chloride, sulphate and bicarbonate. Dissolved organic matter expressed as COD, Total organic carbon and including methane and volatile fatty acids [3].

The wastes at Oyigbo dumpsite composed of both degradable (paper wastes, food and agricultural wastes, sewage etc.) and non-biodegradable wastes (plastics, nylon, aluminium and other metal containing substances). The composition of solid wastes found in other cities includes papers and cartons, food remnants, glass and bottles, plastic and polythene, tin and metals, ashes and dust, textile and rags, aluminium and other minerals [4].

II. MATERIALS AND METHODS

2.1 Study Area Description

The study area was a dumpsite within the Oyigbo town in Rivers State, Nigeria. The environmental area covered was over 248 km^2 with a population density of 710.1/km^2. The Oyigbo landfill is located within latitudes 4° 52′ 41.268″ and 4° 52′ 30.39″, and Longitudes 7° 07′ 26.695″ and 7° 07′ 45″ along the Aba-Port Harcourt Expressway in the Oyigbo Local Government Area [4].

The area is characterized by tropical monsoon climate with lengthy and heavy wet seasons and very short dry seasons. December and January are basically the dry season months. The Harmattan period which climatically influences many cities in West Africa, is less pronounced in the area. The peak precipitation (rainfall) happens within September with an average precipitation of 367 mm. December as a month holds the least precipitation at an average rainfall of 20 mm. The atmospheric temperature within the covered area of study ranges typically between 25 ºC - 28 ºC [4].

2.2 Sampling and Data Collection

The data for chemical parameters of groundwater samples were obtained from the work carried out around the dumpsite situated in Oyigbo by direct field method, within the Oyigbo Local Government Area, Rivers State, Nigeria [4]. The results obtained were compared with World Health Organization [5] and Nigerian Standard for Drinking Water Quality[6].

2.3Modelling of Chemical Contaminant Transport

The chemical contaminant concentration transport has been used to assess the pollution of groundwater by leachate from the landfill. Mathematical models have the advantage of being able to predict different scenarios without involving tedious and time-consuming experimentation.

However, these models and their predictions have to be tested and verified withfield studies. In this study, field investigations, which involved the collection and analyses of samples, was used to establish the groundwater quality data for the Oyigbo dumpsite as the case study with severe potential contamination problems.

The one-dimensional Advection–Dispersion reaction equation model was used, quantifying contaminant transport from the source point and spreading out through the groundwater movement based on mass balance. Advection refers to the transport of contaminants at the same speed as the average linear velocity of groundwater (v) given by the Darcy's law [7].

$$v = \frac{K}{\mu}\frac{dh}{dx} \qquad (1)$$

Where **K** is hydraulic conductivity, **I**(or$\frac{dh}{dx}$) is the head gradient, and **μ** is the effective porosity. $\boldsymbol{v}$ is the average pore velocity.

Dispersion is the spreading out of the contaminant plume from the areas of high concentration to low concentration.

The advection – dispersion reaction equation is derived by combining a mass-balance equation with an expression for the gradient of the mass flux for which the Fick's law is applicable as shown in Equations 2 and 3 [8].

$$\frac{C_f}{C_o} = \frac{1}{2}\left[erf_c\left(\frac{x - vt/R}{2\sqrt{Dt/R}}\right) + exp\left(\frac{vx}{D}\right).erf_c\left(\frac{x + vt/R}{2\sqrt{Dt/R}}\right)\right] \qquad (2)$$

Where,

$$erf_c(p) = 1 - \frac{2}{\sqrt{\pi}}\int_o^p e^{-t^2}dt \qquad (3)$$

Values of $erf_c(p)$is called the complementary error function for various p values.

$\mathbf{C_o}$ is the initial mass chemical contaminant concentration. $\mathbf{C_f}$ is the final mass chemical contaminant concentration**.** $\boldsymbol{x}$ is contaminant travelled distance. **D** is the coefficient of hydrodynamic dispersion.$\boldsymbol{v}$ is the average pore velocity. $\boldsymbol{t}$ is the time length of contaminant transport. **R** is the retardation factor.

Matlab programming language was employed in modelling the groundwater chemical contaminant transport of the plume from the source point and its distribution through the travelled length.

2.3.1MATLAB Program for Contaminant Transport Model

```
clear all;
clc;
T=100;
X=50;
C_nitrate0=20;
C_chloride0=11564;
C_sulphate0=181;
D=11;
R=10;
v=1.1;
C_nitrate=zeros(X,1);
C_chloride=zeros(X,1);
C_sulphate=zeros(X,1);
C_nitrate(1)=C_nitrate0;
C_chloride(1)=C_chloride0;
C_sulphate(1)=C_sulphate0;
x=zeros(X,1);
t=x;
for i=2:1:X+1
   x(i)=i-1;
   t(i)=2*x(i);
```

```
    C_nitrate(i)=0.5*C_nitrate0*(erfc((x(i)-v*t(i)/R)/(2*sqrt(D*t(i)/R)))...
      +exp(v*x(i)/D)*erfc((x(i)+v*t(i)/R)/(2*sqrt(D*t(i)/R))));
    C_chloride(i)=0.5*C_chloride0*(erfc((x(i)-v*t(i)/R)/(2*sqrt(D*t(i)/R)))...
      +exp(v*x(i)/D)*erfc((x(i)+v*t(i)/R)/(2*sqrt(D*t(i)/R))));
    C_sulphate(i)=0.5*C_sulphate0*(erfc((x(i)-v*t(i)/R)/(2*sqrt(D*t(i)/R)))...
      +exp(v*x(i)/D)*erfc((x(i)+v*t(i)/R)/(2*sqrt(D*t(i)/R))));
end
d=length(x)-1;
i=[0:1:d]';
disp('2.3.1: MODELLING OF CHEMICAL CONTAMINANT CONCENTRATION TRANSPORT OF
OYIGBO GROUNDWATER FROM THE OPEN DUMPSITE LEACHATE')
disp(' ')
disp('Table 2: Tabulated Result of Nitrate Concentration Distribution:')
table(i,t,x,C_nitrate)
disp('Table 3: Tabulated Result of Chloride Concentration Distribution:')
table(i,t,x,C_chloride)
disp('Table 4: Tabulated Result of Sulphate Concentration Distribution:')
table(i,t,x,C_sulphate)
display('3.2: GRAPHICAL CONCENTRATION TRANSPORT PROFILE:')
subplot(3,1,1);
plot(x,C_nitrate,'m')
grid on;
xlabel('Travel Distance, X (m)')
ylabel('ConcentratioN, C (mg/l)')
legend('Nitrate Profile')
text(-3,-5,'Figure 1: Nitrate Transport Profile')
subplot(3,1,2);
plot(x,C_chloride,'b')
grid on;
xlabel('Travel Distance, X (m)')
ylabel('ConcentratioN, C (mg/l)')
legend('Chloride Profile')
text(-3,-3000,'Figure 2: Chloride Transport Profile')
subplot(3,1,3);
plot(x,C_sulphate,'r')
grid on;
xlabel('Travel Distance, X (m)')
ylabel('ConcentratioN, C (mg/l)')
legend('Sulphate Profile')
text(-3,-50,'Figure 3: Sulphate Transport Profile'):
```

III. RESULTS AND DISCUSSION

The chemical parameters of the selected boreholes meet the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) standards for drinking water as shown in Table 1 below.

Table 1: Chemical Parameters of Groundwater Samples

Chemical Parameters	W1	W2	W3	WHO Standard	NSDWQ (Maximum permitted levels)
Nitrate (mg/l)	0.10	0.09	0.04	50	50
Chloride (mg/l)	100	100	50	250	250
Sulphate (mg/l)	1.03	0.01	1.54	250	100

Source: Arimieari&Olanyika, (2020).

3.1: Results of MATLAB Program Model

Table 2: Tabulated Result of Nitrate Concentration Distribution:

i	t	x	C_ Nitrate
0	0	0	20
1	2	1	13.298
2	4	2	11.007
3	6	3	9.4305
4	8	4	8.2216
5	10	5	7.246
6	12	6	6.4345
7	14	7	5.7461
8	16	8	5.1538
9	18	9	4.6387
10	20	10	4.1873
11	22	11	3.7889
12	24	12	3.4355
13	26	13	3.1207
14	28	14	2.8392
15	30	15	2.5866
16	32	16	2.3594
17	34	17	2.1546
18	36	18	1.9695
19	38	19	1.8019
20	40	20	1.6499
21	42	21	1.5119
22	44	22	1.3864
23	46	23	1.2722
24	48	24	1.168
25	50	25	1.073
26	52	26	0.98617
27	54	27	0.90683
28	56	28	0.83424
29	58	29	0.76779
30	60	30	0.70692
31	62	31	0.65111
32	64	32	0.59992
33	66	33	0.55294
34	68	34	0.5098
35	70	35	0.47017
36	72	36	0.43374
37	74	37	0.40024
38	76	38	0.36942
39	78	39	0.34107
40	80	40	0.31496
41	82	41	0.29091
42	84	42	0.26876
43	86	43	0.24835
44	88	44	0.22953
45	90	45	0.21218
46	92	46	0.19618
47	94	47	0.18141
48	96	48	0.16779
49	98	49	0.15521
50	100	50	0.1436

Table 3: Tabulated Result of Chloride Concentration Distribution:

i	t	x	C_ Chloride

0	0	0	11564
1	2	1	7689
2	4	2	6364.3
3	6	3	5452.7
4	8	4	4753.8
5	10	5	4189.6
6	12	6	3720.4
7	14	7	3322.4
8	16	8	2979.9
9	18	9	2682.1
10	20	10	2421.1
11	22	11	2190.7
12	24	12	1986.4
13	26	13	1804.4
14	28	14	1641.6
15	30	15	1495.6
16	32	16	1364.2
17	34	17	1245.8
18	36	18	1138.7
19	38	19	1041.9
20	40	20	953.99
21	42	21	874.19
22	44	22	801.63
23	46	23	735.56
24	48	24	675.34
25	50	25	620.39
26	52	26	570.2
27	54	27	524.33
28	56	28	482.36
29	58	29	443.94
30	60	30	408.74
31	62	31	376.47
32	64	32	346.87
33	66	33	319.71
34	68	34	294.77
35	70	35	271.85
36	72	36	250.79
37	74	37	231.42
38	76	38	213.6
39	78	39	197.2
40	80	40	182.11
41	82	41	168.21
42	84	42	155.4
43	86	43	143.6
44	88	44	132.72
45	90	45	122.68
46	92	46	113.43
47	94	47	104.89
48	96	48	97.015
49	98	49	89.743
50	100	50	83.029

Table 4: Tabulated Result of Sulphate Concentration Distribution:

i	t	x	C_Sulphate
0	0	0	181
1	2	1	120.35
2	4	2	99.613
3	6	3	85.346

4	8	4	74.406
5	10	5	65.576
6	12	6	58.233
7	14	7	52.002
8	16	8	46.642
9	18	9	41.981
10	20	10	37.895
11	22	11	34.289
12	24	12	31.091
13	26	13	28.242
14	28	14	25.695
15	30	15	23.409
16	32	16	21.353
17	34	17	19.499
18	36	18	17.824
19	38	19	16.307
20	40	20	14.932
21	42	21	13.683
22	44	22	12.547
23	46	23	11.513
24	48	24	10.57
25	50	25	9.7103
26	52	26	8.9248
27	54	27	8.2068
28	56	28	7.5499
29	58	29	6.9485
30	60	30	6.3976
31	62	31	5.8925
32	64	32	5.4293
33	66	33	5.0041
34	68	34	4.6137
35	70	35	4.255
36	72	36	3.9253
37	74	37	3.6222
38	76	38	3.3433
39	78	39	3.0866
40	80	40	2.8504
41	82	41	2.6328
42	84	42	2.4323
43	86	43	2.2476
44	88	44	2.0773
45	90	45	1.9202
46	92	46	1.7754
47	94	47	1.6418
48	96	48	1.5185
49	98	49	1.4047
50	100	50	1.2996

3.2Graphical Concentration Transport Profile

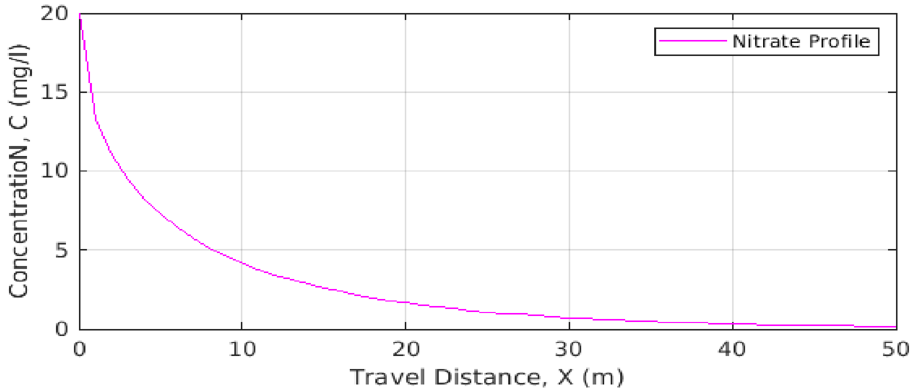

Figure 1: Nitrate Transport Profile

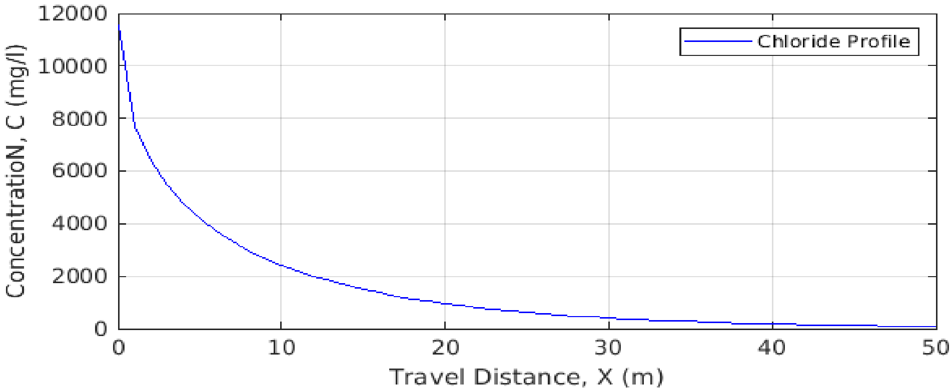

Figure 2: Chloride Transport Profile

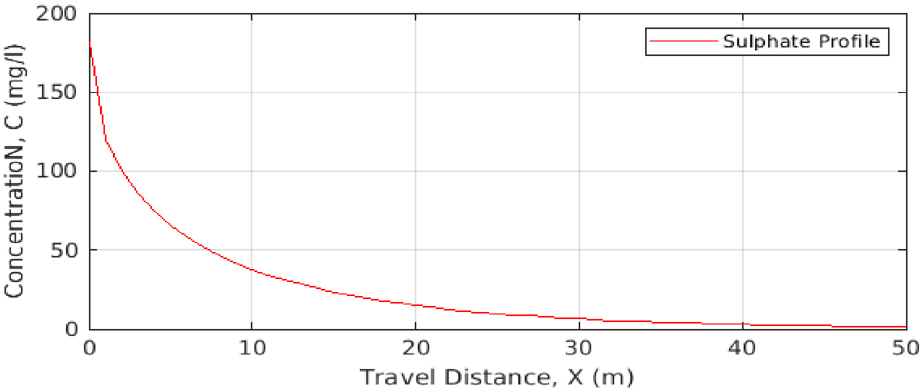

Figure 3: Sulphate Transport Profile

The simulated results show that the concentration of the chemical contaminants decreases as they travel and spread out downstream of the landfill to an infinitesimal concentration level about 50 metres from the source point of the plume.

IV. CONCLUSION

In this paper, the environmental impact on groundwater quality of leachate contamination of the dumpsite at OyigboLocal Government Area was simulated. The obtained results indicate that this impact is mostly dependent on the hydrogeology of the site, the water volume entering the aquifer and the concentration of the contaminant at the source. The contaminants spread rapidly downstream indicating that the porous media possesses high hydraulic conductivity.The simulated model depicts that the concentration of the chemical contaminants decreases as they travel and spread out downstream of the landfill to an infinitesimal concentration level about 50 metres from the source point of the plume.

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