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Numerical Prediction of Ammoniacal Nitrogen Concentrations Profile in Soil within the Vicinity of Soluos Dumpsite in Lagos State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author LS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AAS managed the analyses of the study. Author OK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The presence of pollutants in soil is a threat not only to human life but also to surface and groundwater integrity as well as the vegetations in the area. This work was carried out to predict the ammonia nitrogen concentrations in soil within the vicinity of Soluos dumpsite in Lagos state of Nigeria. A one – dimensional transport model of David and Peter was used in this work. The model was solved using explicit finite difference method implemented in Matlab 7.9 with the aid of model parameters obtained through screening method of sensitivity analysis of model parameters of Bhamnani and Singh. The predicted results revealed a regular trend of decreasing ammonia nitrogen concentrations as the depth increases downward in the soil which was in line with the experimental data used for the validation of the predicted results. The experimental data validated the predicted results to a 99 percent confidence level. This indicated that the model parameters used in this work are suitable for Soluos dumpsite and the one – dimensional transport model employed is useful in the prediction of ammonia nitrogen concentrations in the soil.

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1. INTRODUCTION

Areas near landfills have a greater possibility of soil contamination because of leachate sources originating from the nearby site [1]. Leachates produced as a result of precipitation falling on the waste on the open dump infiltrate through the soil towards the groundwater and the soil filters the leachates on its way down to groundwater. Ammoniacal nitrogen (NH_3-N) is a measure of the amount of ammonia, a toxic pollutant found in landfill leachates [2] and other liquid organic waste product [3]. The ammonium nitrogen value is used in the context of properly designed landfill systems, where the leachate is being pumped to the surface and treated before it infiltrates to groundwater via soil. The ammoniacal nitrogen levels can be lowered using a sequencing batch reactor. The sorption of contaminants in leachates such ammoniacal nitrogen by soil is beneficial to groundwater in short term, it removes pollutants from seepage leachate which reduce toxic effects significantly by reducing the contaminants availability for groundwater [4]. Leachate contains large concentration of ammonium which contaminate soil and groundwater integrity [5]. The sorption of contaminants from leachates by soil increases the level of soil pollution.

Some researchers have worked on the effect of leachates from landfill sites on soil within the vicinity of the landfill sites [6–17]. The effect of leachates on soil within the vicinity of a dumpsite can be assessed either by experimental determination of the level of contamination or estimation through mathematical modeling [18-20]. Wanpeng et al. [21] studied the adsorption characteristics of ammonium ion in saturated silty and sandy loam by means of dynamics soil column experiments. The migration of ammonium ion in soil was also modeled with a combined equilibrium and kinetics adsorption model. The studies revealed that the adsorptive capacity of sandy loam is far larger than that of silty sand. Roelle and Aneja [22] researched on modeling of ammonia emission from soil. The research indicated that the developed model predicted the measured values up to eighty four percent confidence level. Marinov and Diminescu [23] worked on experiment research and mathematical modeling of soil and groundwater contamination with nitrogen compounds. The studies showed a relatively good agreement between the predicted and the experimental values. Eugeniusz et al. [5] focused on determining the influence of an old municipal landfill leachate on pollution of soil and groundwater by ammonium. The studies indicated that discharge of leachate contained large concentrations of ammonium and organic substances which contaminate soil and groundwater integrity.

It is obvious from the available literature that numerical prediction of ammoniacal nitrogen concentrations profile in soil within the vicinity of Soluos dumpsite in Igando area of Lagos State has not been carried out. Therefore, the aim and objective of this work is to predict numerically the ammoniacal nitrogen concentrations profile in soil within the vicinity of Soluos dumpsite in Igando area of Lagos State. The predictive model uses the data generated during the joint study on surface and groundwater contamination near municipal dumpsites carried out by Lagos State Ministry of Environment and Lagos State University for validation. If the concentrations of ammoniacal nitrogen profile in soil within the vicinity dumpsites can be predicted, it will helps to put in place remediation measures and proper waste management which justifies this work. The prediction of ammoniacal nitrogen concentrations profile in soil within the vicinity of Soluos dumpsite in Lagos State therefore serves as a tool to sanitise our environment and improve the quality of human life which justifies this work.

2. THEORY AND NUMERICAL SIMULATION

The pollutant one – dimensional transport model equation (1) of David and Peter [4] was used in this study which was solved using explicit finite difference method (FDM) implemented in Matlab 7.9 and was validated by the field data shown in Table 1.

$$\frac{dC_w}{dt} = \frac{-\lambda}{(1+\frac{\ell}{\theta}K_d)}C_w - \frac{U_z}{(1+\frac{\ell}{\theta}K_d)}\frac{\partial C_w}{\partial z} \quad (1)$$

Where C_w = pollutant concentration in soil pore water

λ = first order rate constant

ℓ = dry bulk density in soil

θ = volumetric water content

K_d = distribution coefficient

U_z = soil pore water flow velocity in the z – direction

t = time

Z =vertical distance from the soil surface towards the groundwater table

The transport model of equation (1) assumed that the aqueous concentration of contaminant is the limiting factor for degradation and local equilibrium conditions between soil and aqueous concentrations of contaminant characterized by a distribution coefficient. A transport model involving first order rate constant was used, the first order rate constant is proportional to soil pore water flow velocity and has a relationship with flow resistance and time. According to David and Peter [4], the term $(1+\frac{\ell}{\theta}K_d)$ slows down the organic pollutant biodegradation and advective pollutant transport. Jhamnani and Singh [24] indicated that the term $(1+\frac{\ell}{\theta}K_d)$ is the retardation factor (R_f). Substitution of retardation factor within the equation, it becomes:

$$\frac{dC_w}{dt} = \frac{-\lambda}{R_f}C_w - \frac{U_z}{R_f}\frac{\partial C_w}{\partial z} \quad (2)$$

The initial and the boundary conditions:

$$C(z,0) = 0; z \geq 0$$

$$C(0,t) = C_0; t \succ 0$$

$$t \geq 0;\ \ z = z_0 \text{ and } \frac{\partial C}{\partial z} = 0$$

Equation (2) in finite difference can be written as:

$$\frac{C_i^{m+1} - C_i^m}{\Delta t} = \frac{-\lambda}{R_f}C_i^m - \frac{U_z}{R_f}\frac{C_{i+1}^m - C_i^m}{\Delta z} \quad (3)$$

Multiplying through by Δt , equation (3) gives:

$$C_i^{m+1} = C_i^m + \frac{-\lambda\Delta t}{R_f}C_i^m - \frac{U_z\Delta t}{R_f}\left(C_{i+1}^m - C_i^m\right) \quad (4)$$

$$\text{Let A} = \frac{-\lambda\Delta t}{R_f} \quad (5)$$

and

$$\text{B} = \frac{U_z\Delta t}{R_f} \quad (6)$$

Substituting equations (5) and (6) in equation (4), we have:

$$C_i^{m+1} = C_i^m + AC_i^m - BC_{i+1}^m + BC_i^m \quad (7)$$

Factorizing equation (7), it yields:

$$C_i^{m+1} = (1 + A + B)C_i^m - BC_{i+1}^m \quad (8)$$

From the boundary condition,

$$\frac{\partial C}{\partial z} = 0 \quad (9)$$

Applying centre difference to the boundary condition of equation (9), it gives:

$$\frac{C_{i+1}^m - C_{i-1}^m}{2\Delta z} = 0 \quad (10)$$

$$\therefore\ C_{i+1}^m - C_{i-1}^m = 0 \quad (11)$$

Substituting equation (11) in equation (8), it yields:

$$C_i^{m+1} = (1 + A + B)C_i^m - BC_{i-1}^m \quad (12)$$

Equation (12) is the final model equation in the explicit finite difference mode for the solution of the partial differential equation characterizing the inorganic pollutant transport equation that was used in the simulation and predictive part of this work. Table 1 showed the concentrations of ammoniacal nitrogen in soil samples from boreholes dug within the vicinity of Soluos dumpsite in Igando area of Lagos State. The model parameters showed in Table 2 were generated through the screen method of sensitivity analysis of the model parameters of Jhamnani and Singh [25]. Screening method of sensitivity analysis is used to identify which input variables are contributing significantly to the output of a model. Screening tends to have a relatively low computational cost when compared to other approaches such as local methods, scattered plots and regression analysis method and can be used to weed out uninfluential variables in a system [26,27]. The generated model parameters were used for the implementation of the final model equation (12) in Matlab 7.9. Fig. 1 presented the flowchart for the implementation of the final model equation.

Table 1. Concentrations of ammonia nitrogen in soil samples from borehole dug within the vicinity of Soluos dumpsite in Lagos State

Depth (m)	Concentration (mg/kg)
1	25.93
2	25.62
3	25.31
4	25.11
5	24.70
6	24.35
7	24.11
8	23.79
9	23.72
10	23.29

Source: Report of joint study on groundwater contamination near Soluos dumpsite in Igando of Lagos state (2014) [29]

Table 2. Model parameters for simulation

S/N	Parameters	Value	Unit
1	Retardation factor	10	
2	Rate constant	0.04	/s
3	Flow velocity in the z direction	0.095	m/s

3. RESULTS AND DISCUSSION

Table 3 presented the predicted and experimental concentrations of ammonia nitrogen at various depths as well as percentage difference between predicted and experimental values. Fig. 2 showed a graph of concentrations of ammonia nitrogen against depth and time while Fig. 3. is a graph showing the variation in experimental and simulated concentrations of ammonia nitrogen at different depth.

The experimental values showed a trend of decrease in concentrations of ammonia nitrogen as the depth increases downward which implies that the concentrations of ammonia nitrogen are inversely proportional to the depth. These experimental values were used to validate the predicted values. The trend of the predicted values was in line with the experimental values, that is, the experimental values of ammonia nitrogen decreased as the depth increased. The decrease in concentrations of ammonia nitrogen as the depth increased also followed the trend of the previous work carried out by Jhamnani and Singh [25]. The decrease in concentrations of contaminants as the depth increases downward in soil may be attributed to natural attenuation in the form of chemical transformation, dilution or sorption [28]. This is likely to be the case in this work where the concentrations of ammonia nitrogen decrease as the depth increases downward.

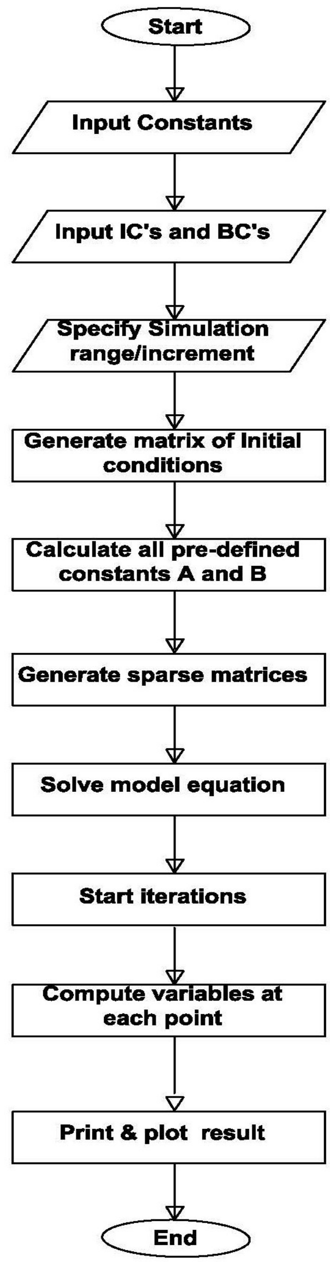

Fig. 1. Flowchart for the implementation of the model

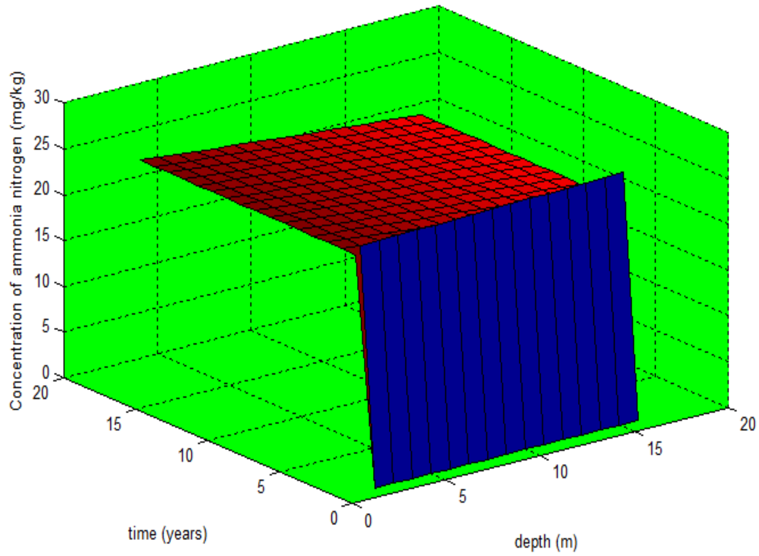

Fig. 2. A graph of concentration of ammonia nitrogen against depth and time

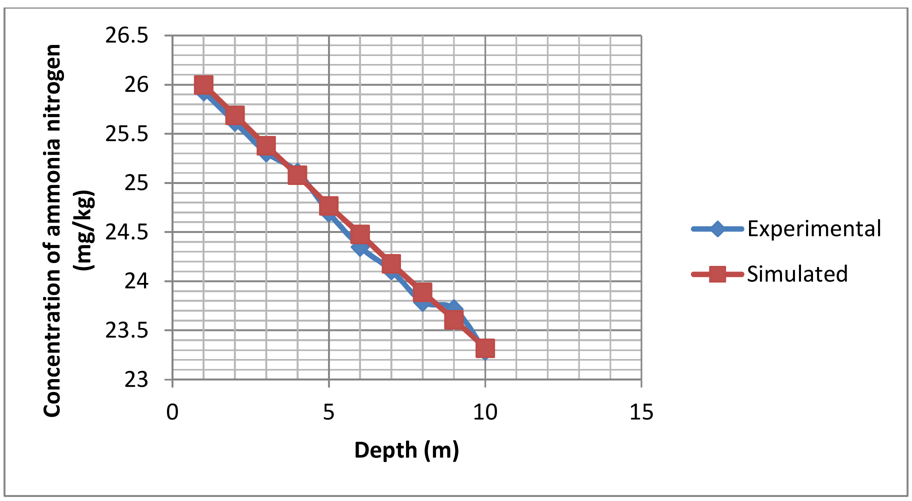

Fig. 3. A graph of variation in experimental and simulated concentrations of ammonia nitrogen at different depths

Table 3. Predicted and experimental concentrations of ammonia nitrogen at various soil depths as well as percentage difference between predicted and experimental values

Depth (m)	Experimental value (mg/kg) at 10 years	Predicted value (mg/kg) at 10 years	Percentage difference
1	25.93	26.00	0.26
2	25.62	25.69	0.27
3	25.31	25.38	0.28
4	25.11	25.08	0.12
5	24.70	24.77	0.28
6	24.35	24.48	0.53
7	24.11	24.18	0.29
8	23.79	23.89	0.43
9	23.72	23.61	0.46
10	23.29	23.32	0.13

The percentage difference between the experimental and predicted values in this work ranged between 0.12 and 0.53 percent. This revealed clearly that the experimental values validated the predicted values and the model presented in equation (1) predicted the concentrations profile of ammonia nitrogen to a 99 percent confidence level in the soil of Soluos dumpsite in Igando area of Lagos State, Nigeria. This is an indication that the explicit finite difference numerical method applied in the work is capable of solving the model presented in equation (1). It also reveals that the model parameters used in the work are suitable for Soluos dumpsite.

4. CONCLUSION

The experimental concentrations of ammonia nitrogen decreased as the soil depth increased downward and this was attributed to the natural attenuation in the subsoil. The predicted results were in line with the trend of the experimental values. The experimental values validated the predicted results to a 99 percentage confidence level. This is a clear revelation that the model parameters used in this work, which were generated through screening method of sensitivity analysis of model parameters of Bhamnani and Singh are suitable for Soluos dumpsite in Igando area of Lagos State. The one dimensional model used in this work which was solved numerically by employing explicit finite difference technique implemented in Matlab 7.9. The validation of the predicted values by experimental values shows that the model applied is suitable for Soluos dumpsite in Igando area of Lagos State. It also shows the accuracy numerical method applied to the model.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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