PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (4) 1237-1243 April 2025

Simulation of Transient Nitrate Contaminant Transportation in Open Municipal Dumpsite into Shallow Terrace Alluvium Aquifer of the Ogwashi-Asaba Formation, Niger Delta, Nigeria

[1*]AWETO, KE; [2]ATOMA, OE; [2]OYEM, MN

[2]*Department of Geology, Delta State University of Science and Technology, Ozoro, Delta State, Nigeria*
[1]*Department of Geology, Delta State University, Abraka, Delta State, Nigeria*

**Corresponding Author Email: keaweto@delsu.edu.ng*
**ORCID: https://orcid.org/0009-0008-7996-5345*
**Tel: +234 803 615 1364*

Co-Authors Email: atomaobokparo@gmail.com; me14oyem@gmail.com

ABSTRACT: Contaminant transport in groundwater poses significant risks to human health and ecosystems. Hence, the objective of this paper is to utilize the three-dimensional multi-species solute transport model (MT3DMS) computer programme to simulate nitrate contaminant transportation in open municipal dumpsite into shallow terrace alluvium aquifer of the Ogwashi-Asaba Formation, Niger Delta, Nigeria. Results show a spread of plume with depth and distance after 3650 days with concentrations of nitrate observed to have increased with distance from the source over time. The highest concentrations of each soil type beneath the dumpsite were observed at the following distances from the plume: laterite: 88.8 mg/l at 0 - 2.5 m; fine sand: 18.5 mg/l at 40.6 m; coarse sand: 0.85 mg/l at 274.9 m and clayey sand: 0.70 mg/l at 330 m. This is adduced to the laterites underneath the dumpsite acting as a secondary source of contamination as it slowly releases contaminants into the aquifer beneath and gives rise to contaminant plumes that lingers for long term. This research provides a reliable numeric model for spatial and temporal contaminant transport and ultimately crucial for monitoring, managing and evaluation of risk to this resource.

DOI: https://dx.doi.org/10.4314/jasem.v29i4.27

Cite this Article as: AWETO, K. E; ATOMA, O. E; OYEM, M. N (2025) Simulation of Transient Nitrate Contaminant Transportation from an Open Municipal Dumpsite into Shallow Terrace Alluvium Aquifer of the Ogwashi-Asaba Formation, Niger Delta, Nigeria. *J. Appl. Sci. Environ. Manage.* 29 (4) 1237-1243

Dates: Received: 28 February 2025; Revised: 29 March 2025; Accepted: 11 April 2025; Published: 30 April 2025

Keywords: contaminant transport; numeric simulation; nitrate concentration; open municipal dumpsite; diffusion

Dumping of municipal wastes in open dumpsites is a common practice in developing countries; these dumpsites are point source of groundwater contamination as a result of infiltration of potential contaminants (Ameloko, 2018). This causes significant environmental and health risks due to the potential for contaminant to be transported into groundwater thus putting the inhabitants that utilizes the groundwater resources under risk. Leachate from a dumpsite can migrate through soils and underlying aquifers, threatening drinking water sources and ecosystems as it intermix with groundwater and create a plume that advances in the direction of groundwater flow. When groundwater is contaminated, it may take several years for natural processes to remove contaminants from an aquifer even after the source of contaminants has been eradicated. One of the primary problems in field

**Corresponding Author Email: keaweto@delsu.edu.ng*
**ORCID: https://orcid.org/0009-0008-7996-5345*
**Tel: +234 803 615 1364*

investigations of groundwater pollution is locating the contaminant plume. Groundwater modeling can be used to overcome this challenge because they are essential tools for managing and protecting groundwater resources. Predicting contaminant transport in groundwater zones is crucial for mitigating these risks associated with contamination and ensuring sustainable waste management practices. A groundwater model refers to a mathematical representation of behavior and movement of groundwater in an aquifer. It is a veritable tool used to simulate and predict flow patterns and transport of contaminants as groundwater interacts with its surrounding (Dilip *et al*., 2011; Ghoraba *et al*., 2013; Lakshmi and Narayanan, 2015). Numerical simulation which is a type of groundwater model offers a powerful tool for understanding and predicting contaminant transport from dumpsites into groundwater zones. By incorporating hydrological, geological properties such as permeability, porosity; aquifer geometry and boundary; recharge, discharge rates; water levels and chemical processes, simulation models can predict contaminant migration pathways, concentrations, and arrival times. This enables evaluation of remediation strategies and improved decision-making for waste management policies.

Numerous investigations have established the usefulness of modeling as a tool in the detection of and its movement (Dilip *et al*., 2011; Ghoraba *et al*., 2013; Lakshi and Narayanan, 2015). However, groundwater modeling studies in the Niger Delta is limited. Okocha and Atakpo (2013); Aweto *et al*. (2023); Atoma and Aweto (2024) simulated groundwater flow and contaminant transport in the Niger Delta using MODFLOW and Groundwater Modeling System (GMS). Results of these studies showed significant flow systems, contaminant transport and a conceptual understanding of the subsurface in the area. The study area was previously studied by Atoma and Aweto (2024), who investigated the geochemical constituents and water quality around the vicinity of an open dumpsite in Asaba. Building on this research, the objective of this paper is to utilize the three-dimensional multi-species solute transport model (MT3DMS) computer programme to simulate nitrate contaminant transportation from an open municipal dumpsite into shallow terrace alluvium aquifer of the Ogwashi-Asaba Formation, Niger Delta, Nigeria.

MATERIALS AND METHODS

Study Area: The study area (fig 1) is an open dumpsite in Asaba which is surrounded by residential areas. Geologically, the area of study lies within the Niger Delta Basin; it is underlain by alluvial deposits, Coastal Plain Sands and the Benin Formation. Groundwater is typically shallow and stored in the alluvial deposits and Coastal Plain Sands; the groundwater is recharged by rainfall.

Flow Simulation and Calibration: A conceptual model of the groundwater flow system and the contaminant spread from the dumpsite within the study area was developed (Fig 2). This was done using the (MODFLOW-2005 and MT3DMS package. The MODFLOW model is premised on the finite difference groundwater equation given by Harbaugh & U. S. Geological Survey (2005).

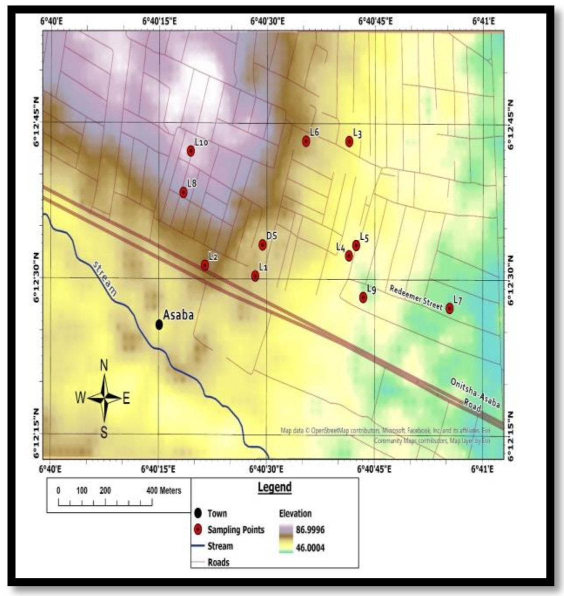

Fig. 1: Map of study area (Atoma and Aweto, 2024)

MODFLOW-2005 utilized for the groundwater flow model involved the implementation of the following parameters: well logs, digital elevation model (DEM), hydraulic conductivity, hydraulic heads, rainfall, and evapotranspiration. While for the MT3D, initial concentration of nitrate from leachate dumpsite, longitudinal dispersity, and diffusion coefficient were parameters used. The MT3DMS package is used for groundwater modeling which helps in tracking transport of contaminants in saturated groundwater flow systems. This package solves the transport of contaminants in a groundwater flow system under generalized hydrogeologic conditions using the method of Bedekar *et al.* (2016). A regression analysis was used to calibrate the model by a plot of the observed heads in the field against the modelled heads (Fig 4) which shows a strong correlation (0.965) with goodness of fit (R^2 = 0.931). This implies that the model can therefore be used for analysis on groundwater management in the region.

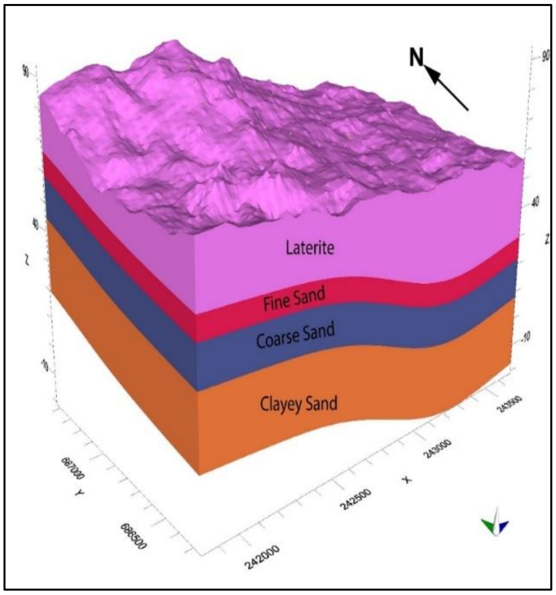

Fig. 2: Study area model domain

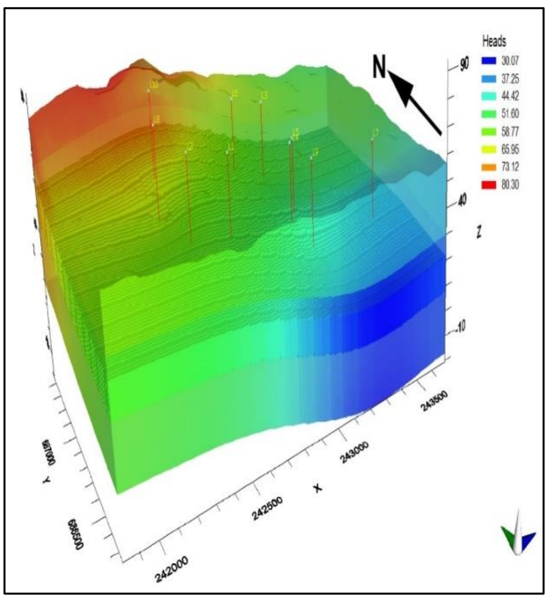

Fig. 3: Oblique view of groundwater flow in the region.

Another calibration was done using water budget, a veritable tool used to quantify the amount of water flowing into and out of an aquifer system. The volumetric budget of the model (Table 1) shows that the stream which was simulated as it flows does not influence groundwater flow in the region.

Recharge from precipitation plays a significant role in volumetric input of water while the constant head which can be attributed to the water from the surrounding aquifer flowing through the model domain contributes a major part of the volumetric groundwater in the model. Groundwater discharge is majorly through the constant heads, groundwater withdrawal through wells with evapotranspiration having some impact on the loss of groundwater.

The model shows a good discrepancy of 0.18 between the input and output of groundwater in the model.

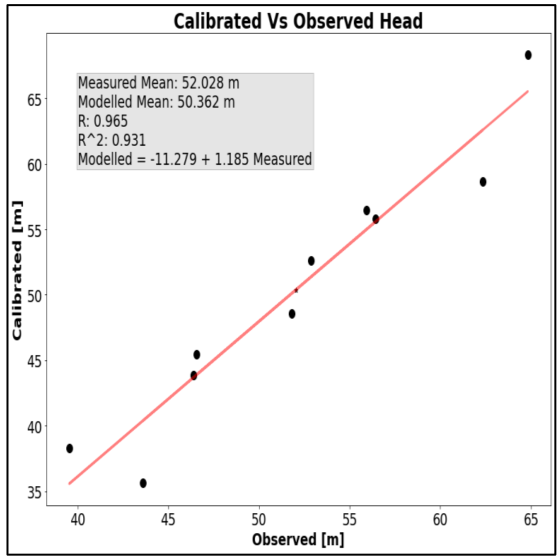

Fig. 4: Correlation of modelled and observed hydraulic heads.

Table 1: Volumetric budget for the model

Parameter	In	Out
Storage	0.0000	0.0000
Constant Head	23376.7246	28384.8398
Wells	0.0000	2616.0161
Drains	0.0000	0.0000
Evapotranspiration	0.0000	260.8311
Recharge	7941.3833	0.0000
Total	31318.1074	31261.6875
Difference	56.4199	
Percent Discrepancy	0.18	

The volumetric budget was also used to account for water in the vadose (unsaturated) and saturated (aquifer) zone; layers 1 and 2 were classified as the vadose zone and the volumetric rate in these zones are shown in Fig. 5 and 6.

The major input (91%) is from the rainfall recharge with 9 % from zone 2. Discharge is through evapotranspiration (3 %) and flow to saturated zone (97 %). In the saturated zone, inflow is driven by vadose zone supply and constant head, while out flow is through wells and saturated-vadose zone flow, thus validating that the model is sufficiently calibrated. The groundwater flow was simulated in a steady state while the contaminant model was simulated for a stress period of (3650 days) 10 years.

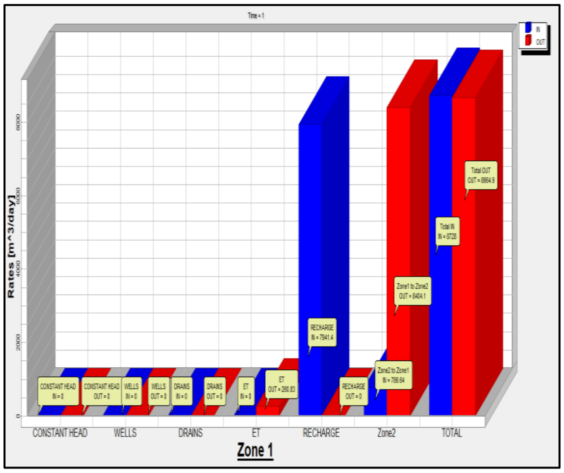

Fig. 5: Vadose zone budget:

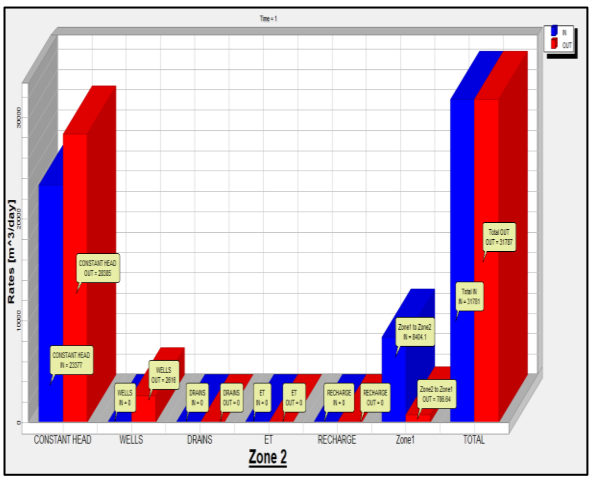

Fig. 6: Saturated zone budget.

RESULTS AND DISCUSSION

Hydraulic head range from 30.07 - 80.30 m (Fig 3) and groundwater is observed to flow from northwest-southeastern part of the model. The groundwater flow conforms to the elevation of the area. Groundwater thus flows towards the River Niger in the eastern part, implying that the base flow of the groundwater in the region is towards River Niger; suggesting that River Niger is recharged by groundwater.

The mean concentration of nitrate (16.7 mg/l) in leachate was used to simulate contaminant transport; nitrate concentration was used because of its conservative nature in leachates and a major source of contamination (Aweto *et al.*, 2023) The region around the plume was observed to be the most affected and decreasing concentrations in horizontal and vertical directions (Fig 7). It was observed that transport of nitrate is influenced by dispersion, sorption, gravity, advection, topography, time and distance in the study area. As nitrate moves in each layer, the rate of spread varies, which is a function of the hydrogeologic properties of the material. As observed in Fig 7, the dispersion also correlates with the source. Dispersion of the plume decreases with distance from source and the properties of the material (a higher hydraulic conductivity and effective porosity would have a higher longitudinal dispersivity and will increase the spread of nitrate).

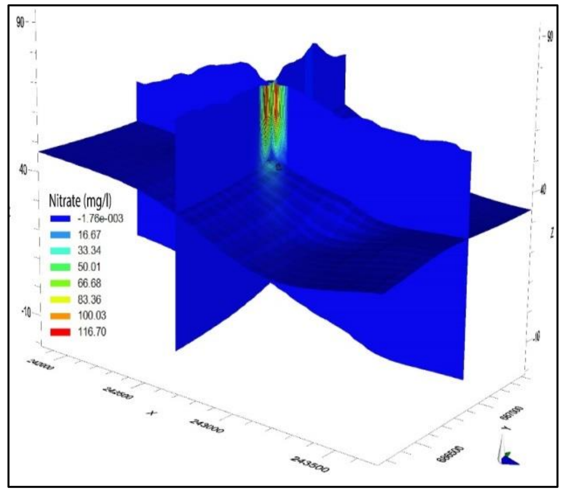

Fig. 7: Nitrate spread from the plume.

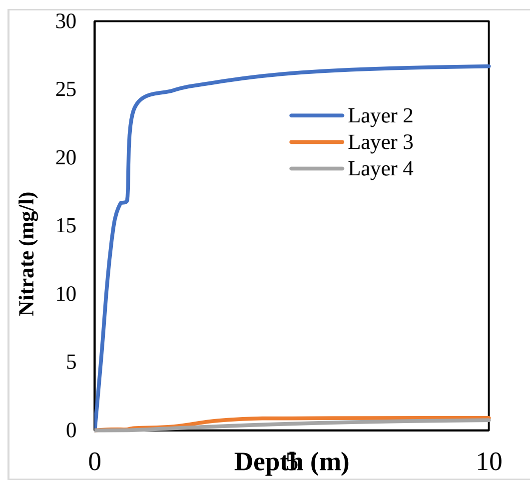

Fig. 8: Vertical spread of the plume in the layers.

The decreasing concentration (C) of nitrate in the plume from the source is also influenced by the adsorption of the material. The graph of the vertical spread at the end of the stress period (Fig 8) depicts the decreasing C in the layers, as the plume moves through the layers. Decreasing concentration is due to adsorption of constituents of nitrate in the various layers. The sediments in contact with the leachate have its surface contaminated with it and thus concentration decreases with depths. The vertical spread of the plume from the source other than horizontal is a function of gravity; the movement of water in the vadose zone is driven by gravity, which is mostly downward, therefore the spread is mostly downward. A previous study by Atoma and Aweto (2024) showed significant percolation of leachate up to depths greater than 20 m.

The horizontal spread of the contaminant is shown in Fig 8; the spread is influenced by time, distance, and topography. As time increases, the C increases in the layers, although the spread in the first layer is almost same with minor variation. In the second and last layers, the spread of the contaminant increases with time, but decrease in C from the top to last layer was observed in all the time series. This implies an increase in C with time and a decrease with depth (also observed in Fig 8). A general decrease in C was observed with distance (Fig 9), the concentration begins diminishing with farther distance from the plume in all the layers, and this may be influenced by dispersion and adsorption of the materials. However, an increase in C with time was observed in all the layers as shown in Fig 9a – d. The concentration of leachate from a contaminant plume can increase over time if the source of the contaminant is still active as more contaminants are released.

A study by Aweto (2023) in the Niger Delta also reported a contaminant plume that grew with time. The distance in which the highest C value was observed varies; this is because of the topography of the study area. A total distance of 730 m with origin at the plume was analyzed with respect to groundwater flow in all the layers. It was observed after 3650 days (T3650 = 10 years) that laterite has its highest C value of 88.8 mg/l at distances between 0 - 2.5 m from the plume, fine sand had highest C value of 18.5 mg/l at 40.6 m, coarse sand had highest C of 0.85 mg/l at 274.9m, while clayey sand had highest C value of 0.70 mg/l at 330 m. Concentrations of nitrate was observed to have increased with distance over time. Contaminants diffuse into the laterites are stored, leading to increasing concentration in the laterites; a process known as forward diffusion (Lipson *et al*, 2005; Suresh Kumar, 2008).

By contrast, contaminants can be disseminated from the laterites as a consequence of the concentration gradient reversal at the boundary between the laterite and aquifer. This mechanism known as back diffusion influences contaminant transport, can facilitate the prolonged presence of contaminant in the environment (Chapam and Barker, 2005; Suresh Kumar, 2008; Seyedabbasi *et al*, 2012; Masoner and Cozzarelli, 2015; Yang *et al*, 2015; Yang *et al*, 2017a). Consequently, the contaminated laterites function as a secondary source zones characterized by a slow release of contaminants into neighbouring aquifers; forming long-lasting contaminant plumes (Yang *et al*, 2017a; Yang *et al*, 2017b; Ding and Feng, 2022, Ding and Feng, 2023). The region is sloping to the southeastern (Fig 3), advection which describes the spread of the contaminant with the groundwater flow plays a major role in the spread of contaminants. The direction of the spread of nitrate is along the groundwater flow direction that is towards the southeastern direction (Fig 10). Groundwater dissolves, carries the leachates and migrates away from the point-source location in a direction controlled by the hydraulic gradient in the aquifer.

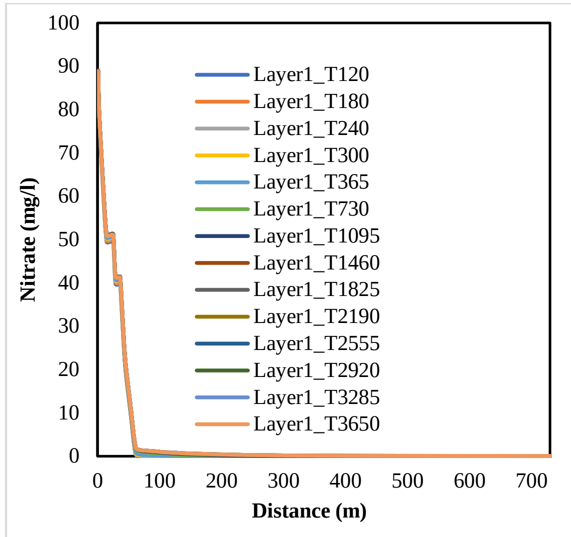

Fig. 9a: Plume spread with time and distance in layer 1.

The lines labelled Layer1_T120 signify spread in layer 1 in 120 days.

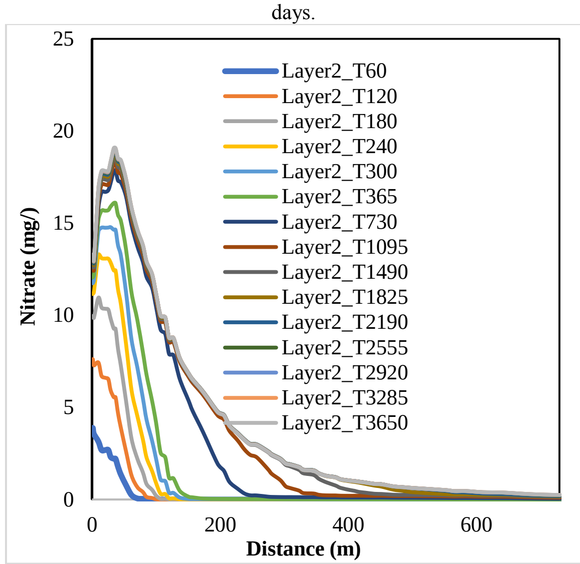

Fig. 9b: Plume concentration spread with time and distance in layer 2.

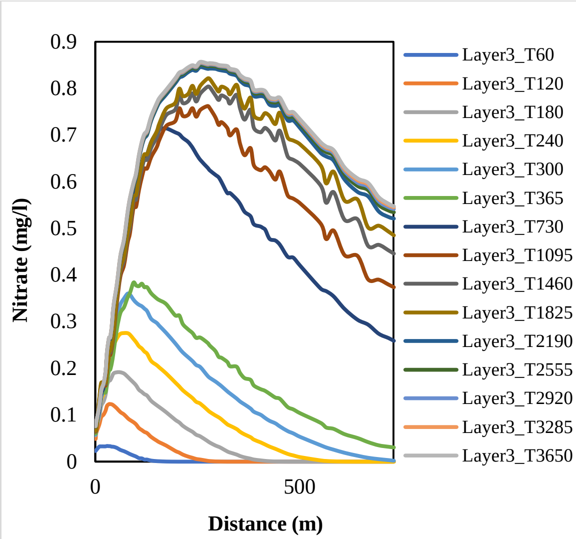

Fig. 9c: Plume concentration spread with time and distance in layer 3.

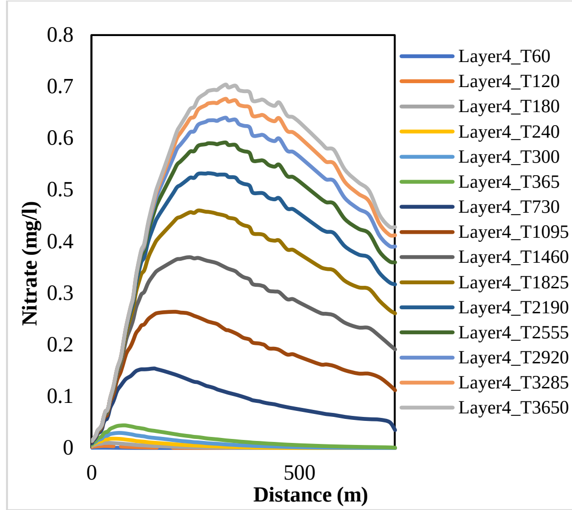

Fig. 9d: Plume concentration spread with time and distance in layer 4.

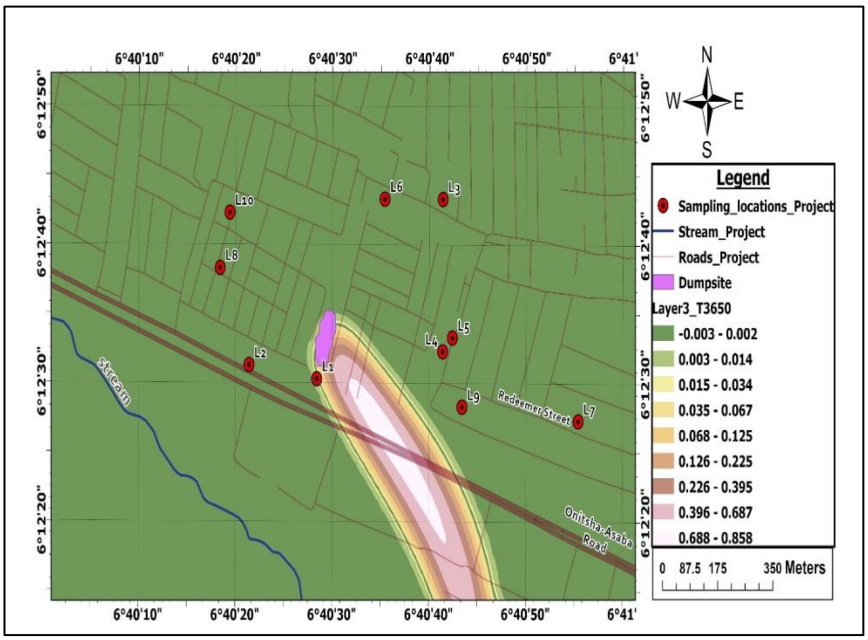

Fig. 10: Advection role in plume spread in aquifer (coarse sand – 3rd layer).

Conclusion: Unlined dumpsites are capable of creating contaminant plumes in groundwater that may last decades or centuries. This study reveals that simulation of transient nitrate concentration at a dumpsite created a detection of increasing nitrate concentration pattern in groundwater beneath the dumpsite. The increase in plume area with depth and distance from the source indicate that the laterite beneath the dumpsite did not provide a geologic barrier to restrict plume migration into the more permeable layers below. The spread of the plume is affected by, adsorption - sorption factor, dispersion rate, gravity, topography, advection, time and distance from the plume. The direction of the spread of contaminants is along the groundwater flow direction that is towards the southeastern direction. Understanding of spatial and temporal migration of leachate in groundwater is essential for monitoring, managing and evaluation of risk to this resource.

Declarations:

Declaration of Conflict of Interest: The authors declare no potential conflict of interest.

Data Availability Statement: Data are upon request from the first author or corresponding author.

REFERENCES

Ameloko, AA; Ayolabi, EA; Enaworu, E; Bolujo, E (2018). Assessment of leachate contamination of groundwater around the Igbenre Ekotedo dumpsite, Ota, Southwestern Nigeria. *Petrol. Coal*. 60(5): 890 – 902

Atoma, E; Aweto, KE (2024). Geochemical and GMS – modeling approach in characterization of anticipated environmental threats of leachate from an open dumpsite, Niger Delta, Nigeria. *Nig. J. Pure Appl. Sci.* 37(2): 5103 – 5110

Aweto, KE (2023). Application of geophysical and geochemical approach to environmental impact assessment around Cassava mill in Western Niger Delta, Nigeria. *Nig. J. Pure Appl. Sci.* 36(1):4573 – 4581.

Aweto, KE; Ohwoghere-Asuma, O; Omeru, T (2023). A comparative aquifer vulnerability study of the Quaternary Sombreiro-Warri Deltaic Plain Deposits, Western Niger Delta, Nigeria. *Ife J. Sci.* 25(1): 069 – 085.

Aweto, KE; Ohwohere-Asuma, O; Ovwamuedo, G; Atiti, PC (2023). Hydro-geochemical characterization and Groundwater modelling of the subsurface around Ughelli West Engineered Dumpsite in the Western Niger Delta, Nigeria. *Nig. J. Technol. Develop.* 20 (2): 62 – 72

Bear, J (1972) Dynamics of Fluids in Porous Media, Chapter 10: Hydrodynamic dispersion. American Elsevier Publishing Company. NY. Pp. 579-757

Bedekar, V; Morway, ED; Langevin, CD; Tonkin, MJ (2016). MT3D-USGS version 1: A U.S. Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with *MODFLOW* [Report](6-A53). (Techniques and Methods, Issue. U. S. G. Survey. https://pubs.usgs.gov/publication/tm6A53

Dilip, KJ; Atul, K; Naveen, K; Mritunjay, KS (2011). Solute transport along temporally and spatially dependent flows through horizontal semi-finite media: dispersion proportional to square of velocity. *J. Hydrol. Eng.* 16(3): 228 - 238.

Ghoraba, SM; Zyedan, BA; Rashwan, IMH (2013). Solute transport modeling of groundwater for Quaternary aquifer quality management in Middle Delta, Egypt. *Alex. Eng. J.* 52(2): 197 - 207.

Harbaugh, AW; Geological Survey (U.S.). (2005). *MODFLOW-2005* : the U.S. Geological Survey modular ground-water model--the ground-water flow process. U.S. Geological Survey. http://pubs.water.usgs.gov/tm6A16/

Lakshmi, P; Narayanan, RM (2015). Study on groundwater modeling of aquifer using visual modflow. *Inter. J. Eng. Technol.* 2(3): 23 - 26

Okocha, FO; Atakpo, EA (2013). Groundwater Flow Modeling at the Source of River Ethiope, Delta State Nigeria. *Pac. J. Sci. Technol.* 14 (2): 594-600

Chapman, SW; Parker, BL (2005). Plume persistence due to aquitard back diffusion following dense nonaqueous phase liquid source removal or isolation. *Wat. Resour. Res.* 1 -16. DOI: https://doi.org/10.1029/2005WR004224

Lipson, DS; Kueper, BH; Gefell, MJ (2005). Matrix diffusion-derived plume attenuation in fractured bedrock. *Groundwater.* 43: 30 – 39. DOI:

Massoner, JR; Cozzarelli, IM (2015). Spatial and temporal migration of a landfill leachate plume in alluvium. *Water Air Soil Pollut.* 226:18.

Suresh Kumar, G (2008). Effect of sorption intensities on dispertivity and macro-dispersion coefficient in a single fracture with matrix diffusion. *Hydrogeol. J.* 235 – 249.

Seyedabbasi, MA; Newell, CJ; Adamson, DT; Sale, TC (2012). Relative contribution of DNAPL dissolution and matrix diffusion to long-term persistence of chlorinated solvent source zones. *J. Cont. Hydrol.* 134-135: 69 – 81. DOI:

Yang, M; Annable, MD; Jawitz, JW (2017a). Forward and back diffusion through argillaceous formations. *Wat. Resour. Res.* 53: 4514 – 4523.

Yang, M; Annable, MD; Jawitz, JW (2017b). Field-scale forward and back diffusion through low permeable zones, *J. Cont. Hydrol.* 202: 47 – 50.

Ding, X; Feng, S (2022). Forward and back diffusion of reactive contaminants through multi-layer low permeability sediments. *Wat. Res.* 222: 15. DOI:

Ding, X; Feng, S (2023). Contaminant back-diffusion from layered aquitards subjected to barrier-controlled source zones. *Wat Res.* 238: 30.