Contaminant Attenuation of Some Potential Toxic Metals and Antibiotic Residues in Aquifers Due to Unlined Aquaculture Discharge in Kokori Niger Delta

Etaga Onovwede Daniel and O. Ohwoghere-Asuma
Department of Geology, Delta State University, Abraka, Nigeria
Corresponding author: oetagadan@gmail.com
November, 2026
https://doi.org/10.56201/ijgem.vol.12.no11.2026.pg192.206

Abstract
Aquaculture effluent can introduce dissolved nutrients, metals and veterinary pharmaceuticals to shallow groundwater where ponds and waste-disposal structures are hydraulically connected to permeable sediments. This study evaluated the spatial occurrence of selected heavy metals and antibiotic residues in groundwater associated with unlined fish ponds in Kokori, western Niger Delta, Nigeria. Seventeen groundwater sampling locations associated with eight fish-farming areas yielded 25 water samples comprising eight borehole samples and 17 hand-dug-well samples. Ten subsurface soil samples were collected by hand auger to a maximum depth of 4 m and characterized by sieve analysis. Field measurements included pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO) and biochemical oxygen demand (BOD); cadmium (Cd), lead (Pb), chromium (Cr) and manganese (Mn) were determined by atomic absorption spectrophotometry, while tetracycline, chloramphenicol and formalin were analyzed using procedures based on HPLC and Nash methods respectively. Groundwater was acidic, with mean pH values of 5.58–5.77. Mean Cd concentrations were 0.0041 mg/L in boreholes and 0.0048 mg/L in hand-dug wells close to ponds, compared with 0.0020 mg/L in hand-dug wells located farther from the farms; the first two means exceed the 0.003 mg/L value. The Mean Pb and Cr concentrations remained below the corresponding drinking-water values. Mean Mn increased from 0.14 mg/L in wells near ponds to 0.17 mg/L in the farther well group. Mean tetracycline declined from 0.26 to 0.006 µg/L between the near-pond and farther well groups, corresponding to approximately 97.7% spatial attenuation, whereas chloramphenicol declined from 0.011 to 0.005 µg/L (approximately 54.5%). The patterns are consistent with attenuation during subsurface transport. The findings demonstrate localized deterioration of shallow groundwater quality near aquaculture facilities and support improved effluent management, appropriate siting of water-supply wells, and routine monitoring of aquaculture-impacted groundwater.

Keywords: *aquaculture effluent; groundwater quality; toxic metals; antibiotic residues; attenuation; Benin Formation; Niger Delta1.*

Introduction

Aquaculture is an increasingly important component of food production and livelihood systems, including in Nigeria. The expansion of fish farming has increased the volume of water used in

pond-based production and, consequently, the volume of wastewater requiring management. Aquaculture wastewater may contain suspended solids, nutrients, organic matter, disinfectants, metals associated with feeds and farm infrastructure, and residues of veterinary pharmaceuticals. Where wastewater is discharged directly to soil or unlined waste pits, infiltration can provide a pathway to shallow groundwater. The hydrogeological setting is particularly important in the Niger Delta, where unconsolidated sands and interbedded sandy and clayey materials can form shallow aquifer systems. The permeability of sandy intervals can facilitate rapid movement of dissolved contaminants, whereas clay-rich layers and mineral surfaces may retard transport through sorption, ion exchange and filtration. The net behaviour of a contaminant therefore depends on the interaction among groundwater chemistry, sediment properties, contaminant speciation and travel distance (Appelo & Postma, 2005). Heavy metals are of concern because they are not destroyed by natural attenuation and may persist in sediments or groundwater. Cadmium and lead are particularly relevant to drinking-water protection, while manganese can be mobilized under acidic and reducing conditions. Chromium behaviour depends strongly on oxidation state and mineral surface interactions (Fendorf, 1995). Veterinary antibiotics are also environmentally relevant because their mobility is controlled by sorption, pH, organic matter and mineralogy, and their occurrence in the environment can contribute to selection pressure on microbial communities (Sarmah et al., 2006; Tolls, 2001). Previous studies have documented groundwater and sediment impacts associated with anthropogenic waste and aquaculture activities in southern Nigeria. Moses et al. (2013), for example, reported heavy-metal contamination associated with catfish ponds in Delta State, while Iwegbue et al. (2008) investigated metals in fish-pond sediments in the Warri area. Studies outside Nigeria have also demonstrated the occurrence and transport of antibiotic residues in groundwater associated with aquaculture systems (Mkwate et al., 2017). These studies indicate the need to examine contaminant behaviour in the specific hydrogeological conditions of the western Niger Delta. The present study focuses on Kokori, Delta State, where fish ponds, soak pits and shallow domestic water sources occur within a permeable Quaternary aquifer setting. The study evaluates (i) the physicochemical quality of groundwater around aquaculture facilities, (ii) the concentrations of Cd, Pb, Cr and Mn, (iii) the occurrence of tetracycline, chloramphenicol and formalin, and (iv) spatial changes in concentrations with distance from fish-farming areas. Particular attention is given to whether the observed concentration gradients are consistent with attenuation during subsurface transport.

2. Study Area

Kokori is located in Agbon Kingdom, Ethiope East Local Government Area of Delta State, within the western Niger Delta of Nigeria. The study area is described as a relatively flat, tropical environment occupied largely by farming and fishing communities. The land area is approximately 196 km² and a population of approximately 30,000 inhabitants. The climate is characterized by a long-wet season extending broadly from March to October and a comparatively drier period from approximately October to February. The area is underlain by the Benin Formation and associated Quaternary sediments. The observations indicate near-surface sandy to silty-clayey materials and a shallow multi-aquifer setting. The juxtaposition of permeable sands with finer-grained horizons is important because it provides both potential preferential flow pathways and mineral surfaces capable of retarding dissolved contaminants. The groundwater sources investigated in this study were hand-dug wells and boreholes used for domestic water supply.

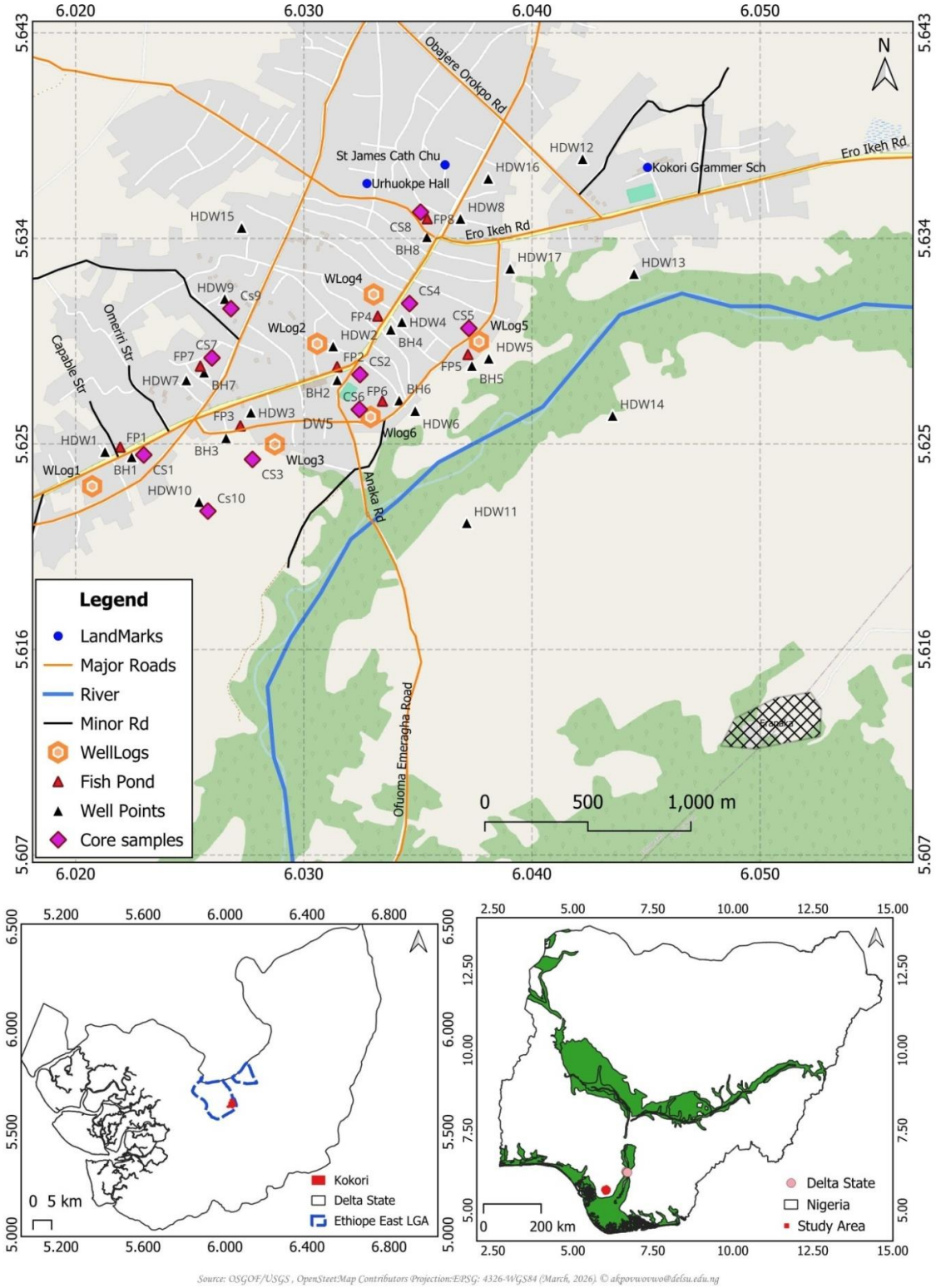

Figure 1. Location of the study area and sampling locations in Kokori, western Niger Delta, Nigeria.

3. Materials and Methods

3.1 Study design and sampling

The investigation targeted groundwater sources and wastewater-disposal features associated with selected fish farms. Seventeen sampling locations representing eight fish-pond areas were investigated. A total of 25 groundwater samples were collected, comprising eight borehole-water samples and 17 hand-dug-well samples. Water sources were classified according to their position relative to the fish-farming areas, and the distance between the water source and the associated fish farm was recorded. Pond water and water from associated soak pits were also sampled to characterize the source environment. Static water levels were measured with a dip meter before sampling; the reported groundwater static levels ranged from 3.78 to 4.25 m, while soak-pit depths ranged from 1.8 to 3.0 m.

3.2 Soil sampling and grain-size analysis

Ten representative subsurface soil samples were collected from selected fish-farm locations using a 150-mm-diameter stainless-steel hand auger to a maximum depth of 4.0 m. Approximately 2 kg of material was collected at each selected interval after removal of the outer exposed material to reduce the likelihood of surface contamination. Samples were sealed, labelled and transported to the laboratory for grain-size analysis. Sieve analysis followed standard procedures, and grain-size distributions were plotted as cumulative percentage finer against particle diameter on semi-logarithmic coordinates. The resulting distributions were used qualitatively to assess the relative abundance of fine- and coarse-grained materials and their implications for infiltration and contaminant retardation.

3.3 Field measurements and water-quality analysis

pH, EC and TDS were measured in the field using calibrated portable meters. Dissolved oxygen was determined using the Winkler iodometric method, and BOD was determined from the change in dissolved oxygen following incubation under the specified analytical conditions. Nitrate, phosphate, ammonia, chloride and sodium were also determined. Appropriate blanks and calibration procedures were used during field and laboratory measurements.

3.4 Heavy-metal analysis

Cadmium, lead, chromium and manganese were determined by atomic absorption spectrophotometry. Manganese was analyzed by flame atomic absorption spectrophotometry, whereas Cd, Cr and Pb were analyzed by graphite furnace atomic absorption spectrophotometry. Calibration standards, blanks and quality-control procedures were applied, and concentrations were calculated from calibration curves. Results were taken in mg/L.

3.5 Antibiotic analysis

Tetracycline and chloramphenicol were analysed using HPLC methods. For sample preparation, 500 mL of water was passed through a 0.45-µm glass-fibre membrane, the sample was adjusted to pH 2, and a mixed surrogate solution and Na_2EDTA were added before extraction with an ASE 350 pressurized liquid-extraction system. Analytical blanks and quality-control procedures were used. Concentrations were reported in µg/L.

3.6 Formalin Analysis

Nash Method was used to determined formalin. 5ml of filtered groundwater sample was poured into a test tube, 5 ml of acetylacetone was added as reagent. It was heated at 60 degrees for 10 mins to develop yellow colour and it was cooled and measured. Concentration were measured in ug/L

3.6 Data analysis

Descriptive statistics (mean, median, standard deviation, minimum and maximum) were calculated for the sampling groups. Spatial attenuation was calculated from the difference between the mean concentration near the fish farms and the mean concentration in the farther hand-dug-well group as: attenuation (%) = [(Cnear − Cfar)/Cnear] × 100. This calculation represents a spatial concentration decrease rather than a measured first-order decay constant or a mass-balance estimate.

4. Results

4.1 Hydrogeological and grain-size characteristics

The grain-size for the representative soil sample indicates a predominance of fine-grained material at the upper end of the distribution and progressively coarser material toward the lower phi values. The sieve data show 96.0% passing at 1.5 phi, 80.0% at 2.24 phi, 74.5% at 2.5 phi, 54.5% at 3.0 phi, 42.0% at 3.5 phi, 31.0% at 4.24 phi and 6.0% at 10 phi. The associated cumulative curve is relatively steep over part of the distribution, indicating a substantial sand fraction in the sampled material. Only one complete sieve table is presented because of space, these observations should be interpreted as representative rather than as a statistical characterization of all ten soil cores.

Sieve size (phi)	Mass retained (g)	Cumulative mass (g)	Retained (%)	Passing (%)
0.5	0.00	0.00	0.00	100.00
1.5	8.00	8.00	4.00	96.00
2.24	32.00	40.00	20.00	80.00
2.5	11.00	51.00	25.50	74.50
3.0	40.00	91.00	45.50	54.50
3.5	25.00	116.00	58.00	42.00
4.24	22.00	138.00	69.00	31.00
10.0	50.00	188.00	94.00	6.00
Pan	12.00	200.00	100.00	—

Table 1. Grain-size distribution for the representative soil sample (initial dry mass = 200 g).

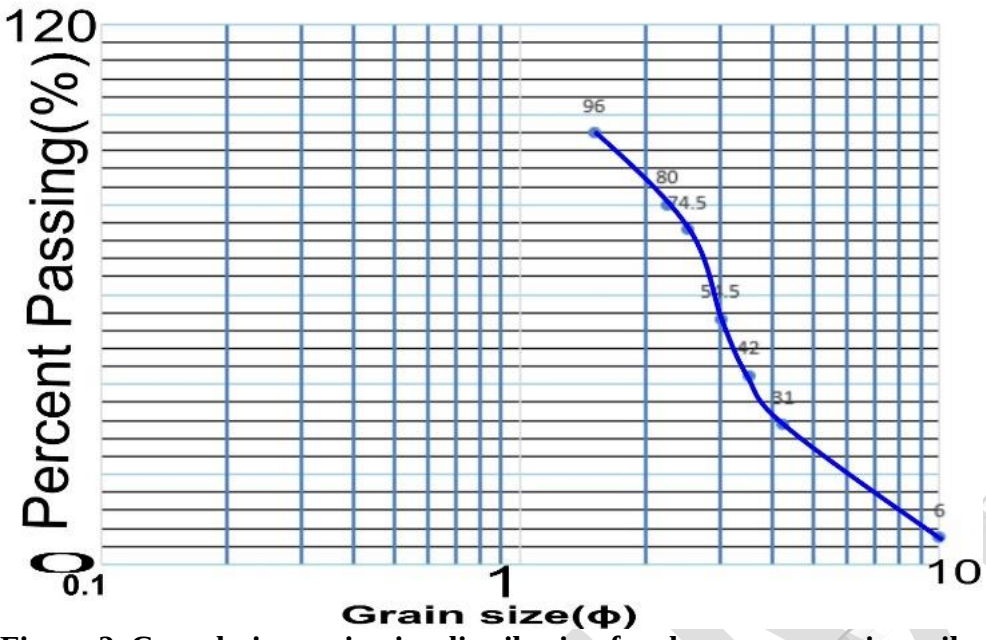

Figure 2. Cumulative grain-size distribution for the representative soil sample.

4.2 Groundwater physicochemical characteristics

Groundwater in the sampling groups was acidic. Mean pH values were 5.70 for boreholes, 5.58 for hand-dug wells at less than 50 m in sites 1–8 near the fish-farming areas, and 5.77 for hand-dug wells at sites 9–17 at 50 m farther from farms. The corresponding ranges were 5.25–6.15, 4.95–6.10 and 4.45–7.40. Mean EC values were 194.8, 302.5 and 129 (as indicated in Table 2 EC values), respectively, while mean TDS values were 97.13, 150.9 and 63.78 in the three groups. Table 2 therefore indicates higher dissolved-solids loading in the near-pond hand-dug wells than in the farther well group. Mean nitrate concentrations were 10.8, 12.2 and 7.85 mg/L, respectively, and were below the 50 mg/L comparison value in Table2. Phosphate concentrations were substantially higher in the hand-dug wells near the ponds (mean 93.1 mg/L) than in boreholes (11.9 mg/L) or the farther hand-dug-well group (18.0 mg/L). Mean BOD ranged from 101 to 115 mg/L, with all group means above the 30–100 mg/L comparison range listed in Table 2. These results indicate a stronger organic and nutrient signal in groundwater close to the fish-farming areas.

Parameter	Group	Mean	SD	Range
pH	BH	5.70	0.347	5.25–6.15
pH	HDW 1–8	5.58	0.431	4.95–6.10
pH	HDW 9–17	5.77	0.876	4.45–7.40
EC	BH	194.8	34.12	106–218
EC	HDW 1–8	302.5	101.2	198–500
EC	HDW 9–17	129	16.45	106–156
TDS	BH	97.13	18.26	53–109
TDS	HDW 1–8	150.9	50.99	96–250
TDS	HDW 9–17	63.78	8.16	53–78
Nitrate	BH	10.8	5.24	4.88–19.8
Nitrate	HDW 1–8	12.2	4.83	5.42–18.4
Nitrate	HDW 9–17	7.85	2.54	4.70–11.9
Phosphate	BH	11.9	8.58	<LOQ–28.3
Phosphate	HDW 1–8	93.1	84.1	13.3–232
Phosphate	HDW 9–17	18.0	15.1	3.25–54.5
BOD	BH	115	42.1	72–162
BOD	HDW 1–8	107	52.0	36–162
BOD	HDW 9–17	101	55.6	36–210

Table 2. Descriptive statistics for selected groundwater physicochemical parameters.

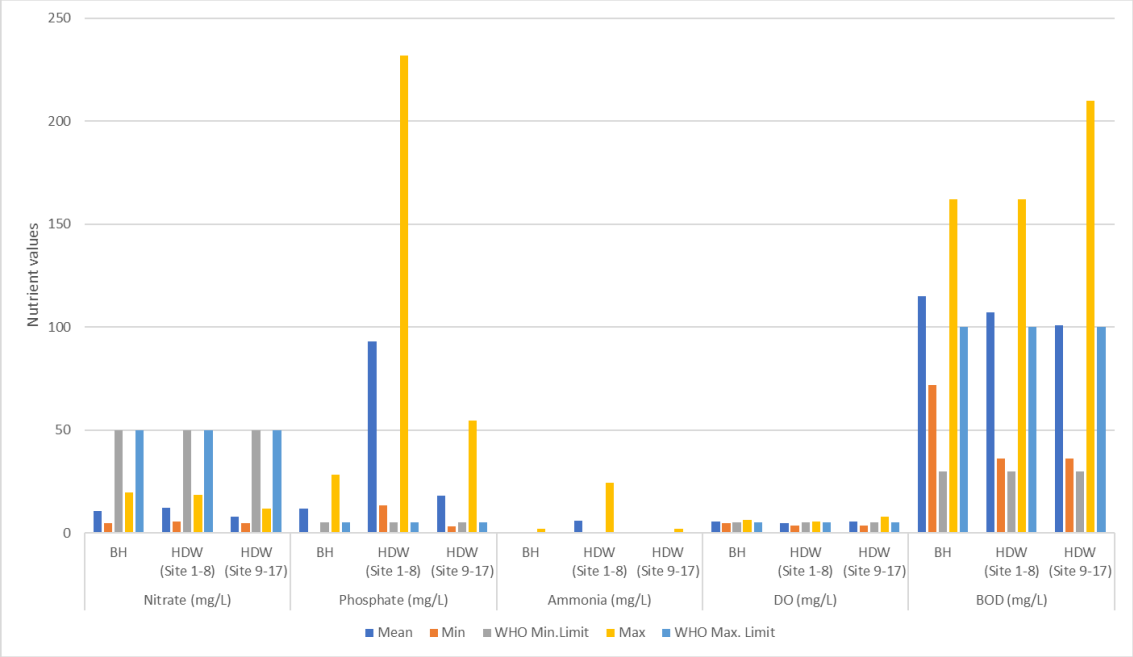

Figure 3. Distribution of selected groundwater physicochemical parameters and contaminants across sampling locations.

4.3 Heavy metals

Metal (mg/L)	Group	Mean	SD	Range
Mn	BH	0.120	0.0489	0.066–0.181
Mn	HDW 1–8	0.140	0.0468	0.087–0.223
Mn	HDW 9–17	0.170	0.0688	0.077–0.288
Pb	BH	0.0049	0.00767	<LOQ–0.018
Pb	HDW 1–8	0.0064	0.00868	<LOQ–0.019
Pb	HDW 9–17	0.0030	0.00691	<LOQ–0.019
Cd	BH	0.0041	0.00342	<LOQ–0.008
Cd	HDW 1–8	0.0048	0.00515	<LOQ–0.011
Cd	HDW 9–17	0.0020	0.00409	<LOQ–0.011
Cr	BH	0.011	0.00963	<LOQ–0.022
Cr	HDW 1–8	0.012	0.0136	<LOQ–0.030
Cr	HDW 9–17	0.006	0.0136	<LOQ–0.038

Table 3. Descriptive statistics for heavy metals in groundwater.

Mean Cd concentrations in boreholes (0.0041 mg/L) and near-pond hand-dug wells (0.0048 mg/L) exceeded the 0.003 mg/L comparison value, whereas the farther hand-dug-well group had a lower mean of 0.0020 mg/L. Mean Pb concentrations decreased from 0.0064 mg/L in near-pond hand-dug wells to 0.0030 mg/L in the farther group. Mean Cr concentrations decreased from 0.012 to 0.006 mg/L. In contrast, Mn increased from 0.14 to 0.17 mg/L between these two hand-dug-well groups. The spatial decrease corresponds to approximately 58.3% attenuation for Cd, 53.1% for Pb and 50.0% for Cr. The increase in Mn should not be interpreted as evidence of attenuation; it indicates that additional geochemical processes or non-pond sources may influence Mn distribution.

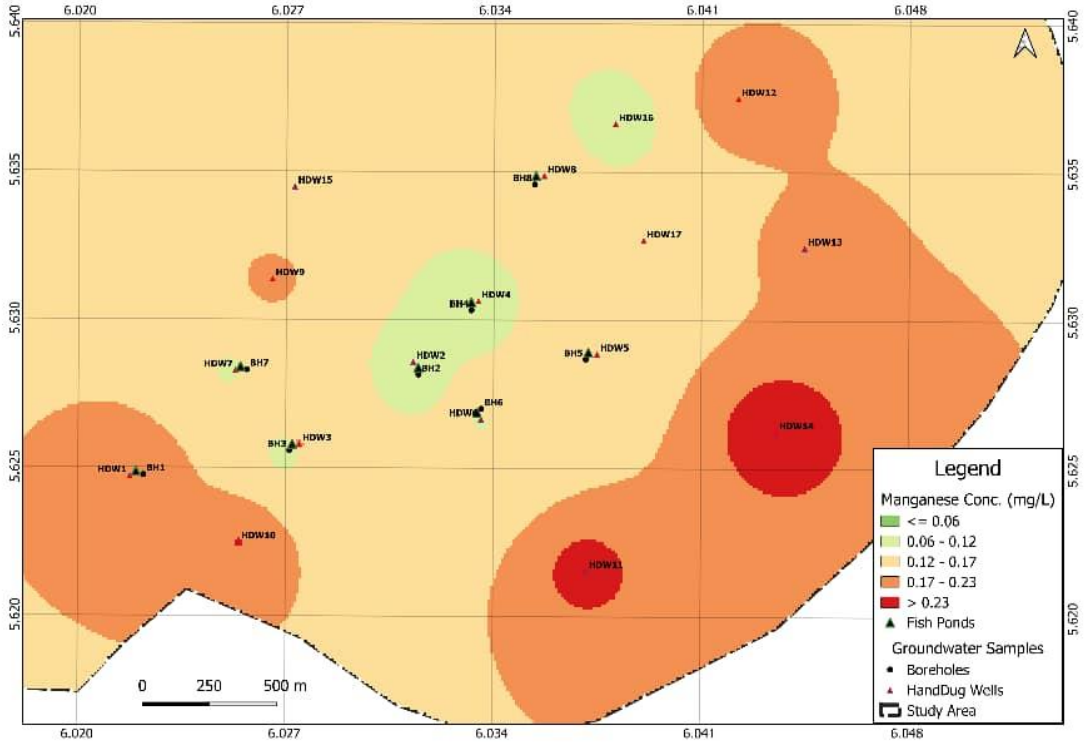

Figure 4. Spatial distribution of manganese (Mn) in groundwater.

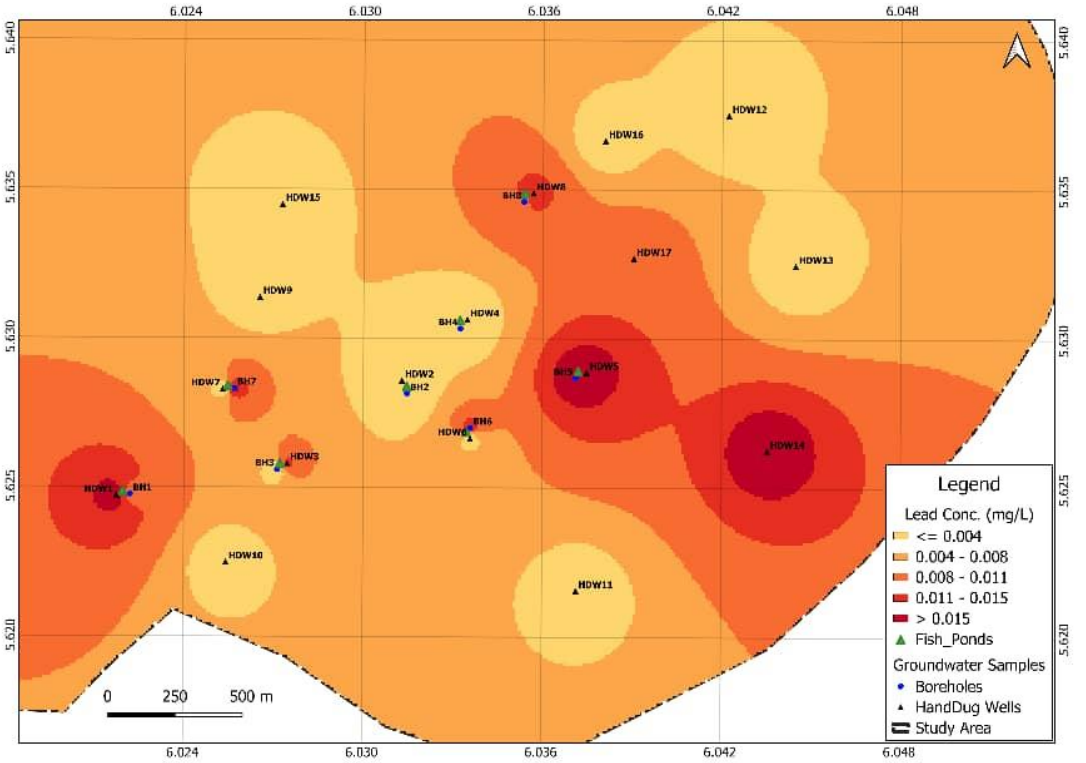

Figure 5. Spatial distribution of lead (Pb) in groundwater.

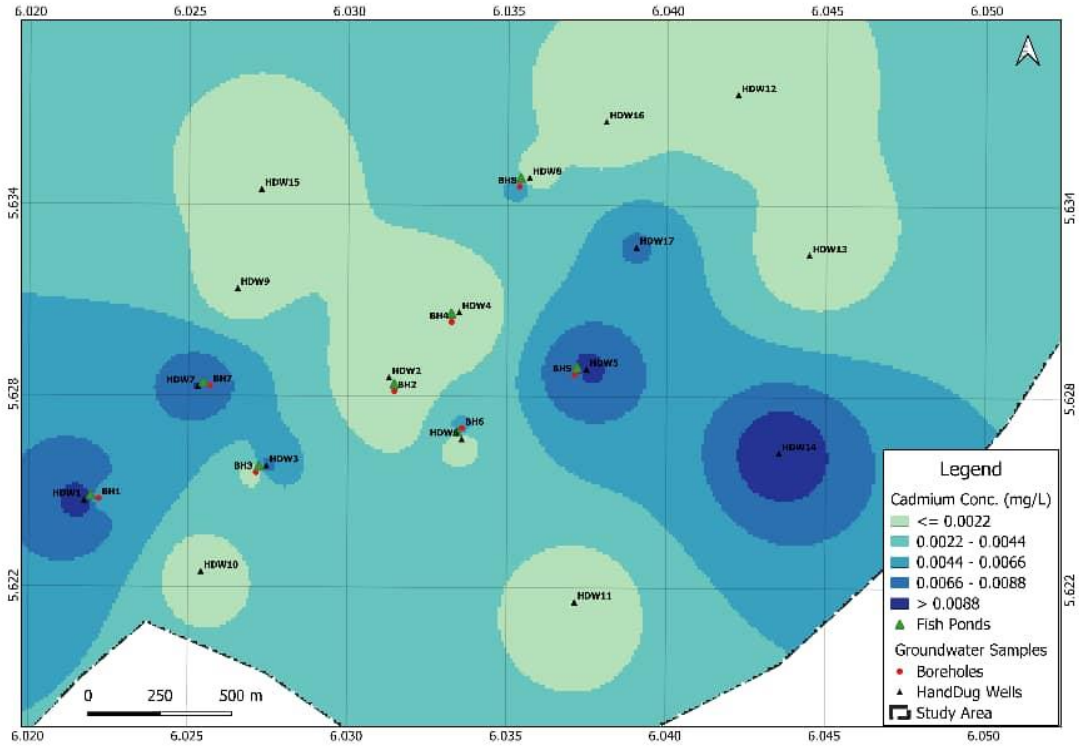

Figure 6. Spatial distribution of cadmium (Cd) in groundwater.

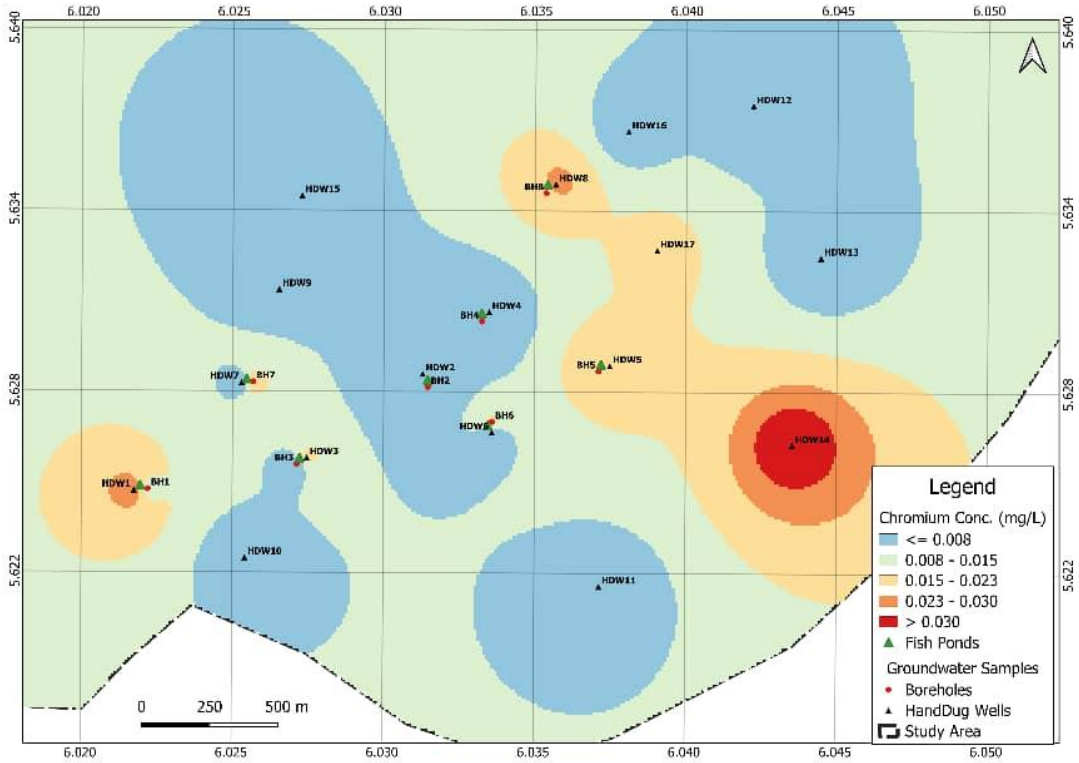

Figure 7. Spatial distribution of chromium (Cr) in groundwater.

4.4 Antibiotic residues

Analyte (µg/L)	Group	Mean	SD	Range
Tetracycline	BH	0.140	0.0469	<LOQ–0.220
Tetracycline	HDW 1–8	0.260	0.124	<LOQ–0.520
Tetracycline	HDW 9–17	0.006	0.0360	LOQ–0.020
Chloramphenicol	BH	0.007	0.0438	<LOQ–0.050
Chloramphenicol	HDW 1–8	0.011	0.0160	<LOQ–0.050
Chloramphenicol	HDW 9–17	0.005	0.0000	<LOQ–0.010
Formalin	BH	<LOQ	—	<LOQ
Formalin	HDW 1–8	<LOQ	—	<LOQ
Formalin	HDW 9–17	<LOQ	—	<LOQ

Table 4. Antibiotic and formalin results.

Tetracycline showed the strongest spatial decline. The mean concentration decreased from 0.26 µg/L in near-pond hand-dug wells to 0.006 µg/L in the farther group, corresponding to approximately 97.7% attenuation. The borehole mean was 0.14 µg/L. Chloramphenicol decreased from 0.011 to 0.005 µg/L, corresponding to approximately 54.5% attenuation. Formalin was below the limit of quantification in all groups as shown in Table 4.

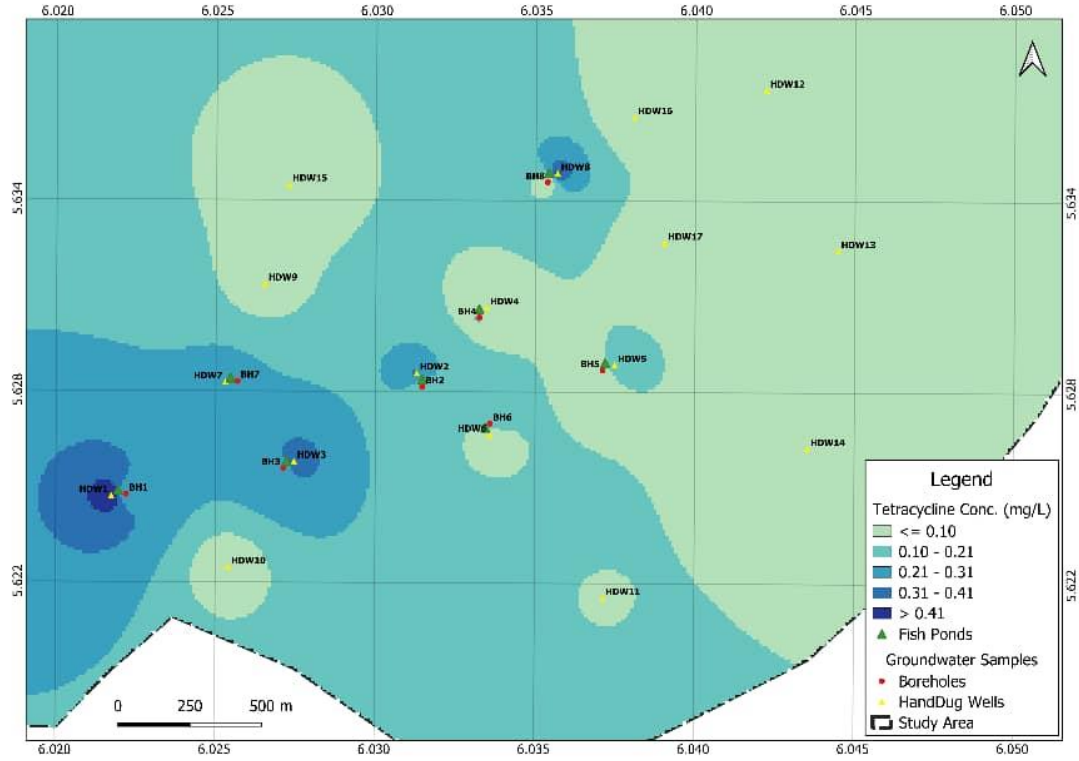

Figure 8. Spatial distribution of tetracycline in groundwater.

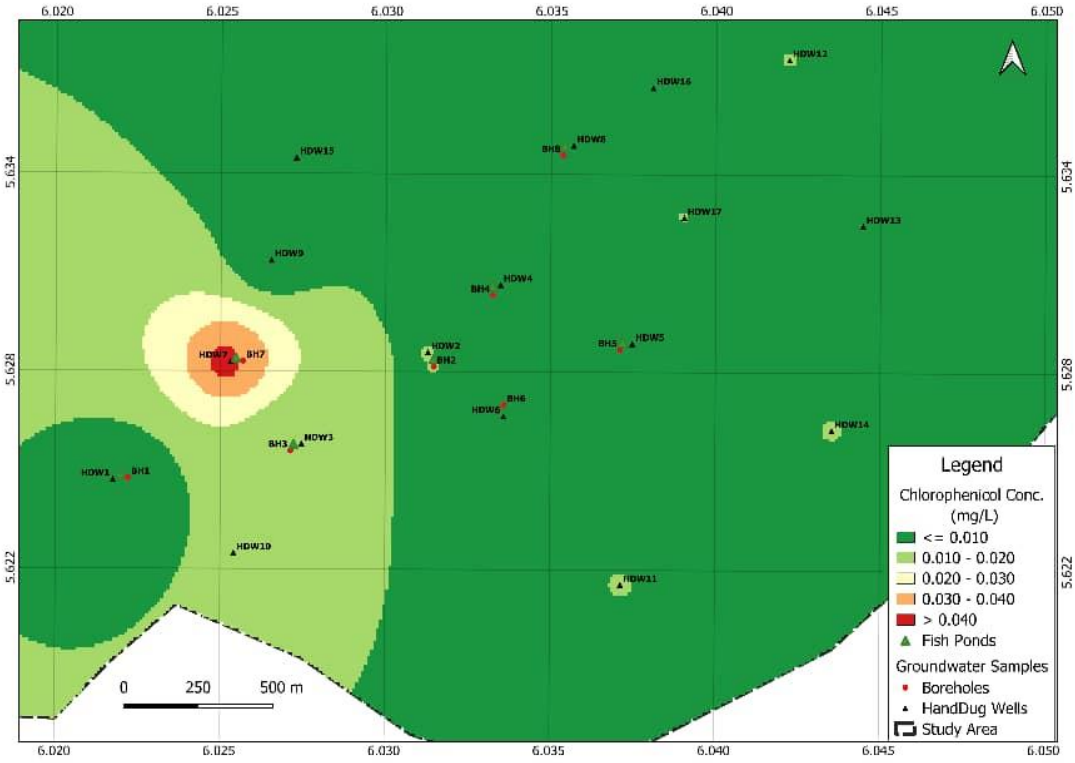

Figure 9. Spatial distribution of chloramphenicol in groundwater.

5. Discussion

5.1 Hydrochemistry and contaminant mobility

The acidic groundwater conditions observed in Kokori are important for interpreting the mobility of dissolved constituents. Mean pH values below the 6.5–8.5 range for drinking water, this indicate that the aquifer water is naturally or anthropogenically acidic. In sandy aquifer systems, pH affects mineral dissolution, surface charge and the speciation of dissolved metals and pharmaceuticals (Appelo & Postma, 2005). The observed spatial variation in EC and TDS, together with elevated phosphate and BOD in near-pond hand-dug wells, is consistent with a stronger wastewater influence in shallow groundwater close to the fish-farming areas.

The grain-size results suggest that the subsurface contains both fine-grained and sandy materials. Fine-grained minerals can provide reactive surfaces for sorption, whereas sandier intervals can facilitate advective transport. The presence of soak pits 1.8–3.0 m deep is therefore potentially important because such structures can bypass part of the shallow soil profile and concentrate wastewater infiltration.

5.2 Heavy-metal behaviour

Cadmium displayed a clear decrease in mean concentration with increasing distance from the fish-farm areas: 0.0048 mg/L in near-pond hand-dug wells versus 0.0020 mg/L in the farther group. The difference is consistent with attenuation during subsurface transport, potentially through sorption and dilution. The persistence of Cd in the farther group indicates that attenuation was incomplete. Lead and chromium showed similar spatial decreases. Mean Pb decreased from 0.0064 to 0.0030 mg/L, while Cr decreased from 0.012 to 0.006 mg/L. These patterns are

compatible with retardation by mineral surfaces and dilution during transport. Chromium behaviour is particularly dependent on oxidation state, and the study measured total Cr rather than Cr(III) and Cr(VI) separately; therefore, statements about chromium speciation or reduction should be treated as hypotheses requiring targeted analysis (Fendorf, 1995).

Manganese behaved differently, increasing from 0.14 mg/L in near-pond hand-dug wells to 0.17 mg/L in the farther group. This pattern indicates that Mn distribution is not governed simply by dilution from a single pond-derived source. Acidic groundwater can enhance mineral dissolution and Mn mobility, while redox conditions and interactions with mineral surfaces may modify its concentration (Appelo & Postma, 2005). The recorded values therefore support a geochemical interpretation but do not establish that aquaculture activities are the primary source of Mn.

5.3 Antibiotic attenuation

Tetracycline showed a much larger spatial decline than chloramphenicol. Tetracyclines are known to interact strongly with mineral surfaces and can form complexes with dissolved and surface-associated species; consequently, sorption can be an important control on their mobility in soil and groundwater (Tolls, 2001; Sarmah et al., 2006). The approximately 97.7% spatial decrease observed in this study is consistent with substantial retardation or attenuation along the sampled flow path. Chloramphenicol declined by approximately 54.5%, indicating weaker spatial attenuation than tetracycline. The observed concentration gradient reflects the combined effects of sorption, dilution, biodegradation and possible differences in source loading.

5.4 Implications for groundwater protection

The occurrence of Cd above the comparison value used in near-pound groundwater, together with elevated phosphate, BOD and antibiotic residues, indicates that shallow domestic water sources located close to unlined aquaculture wastewater-disposal areas warrant monitoring. The findings are consistent with earlier observations of aquaculture-related groundwater and sediment contamination in the Niger Delta (Moses et al., 2013; Iwegbue et al., 2008) and with reports of antibiotic residues associated with aquaculture environments (Mkwate et al., 2017).

Management should prioritize containment and treatment of pond wastewater, reduction of direct discharge to unlined soak pits, improved control of chemical and veterinary-product use, and hydrogeologically informed siting of domestic water points. Where groundwater is used for drinking, periodic testing for pH, EC, nutrients, metals and relevant pharmaceutical residues is advisable. The present study provides a baseline spatial assessment; future work should incorporate sediment mineralogy, contaminant speciation and time-series sampling to distinguish source effects from natural geochemical variability.

7. Conclusions

Groundwater associated with unlined aquaculture facilities in Kokori, Delta State, shows measurable spatial variation in physicochemical parameters, heavy metals and antibiotic residues. The near-pond groundwater groups which are less than 50 m from farms were characterized by acidic pH and elevated EC, TDS, phosphate and BOD relative to the farther hand-dug-well group greater than 50 m from farms. Mean Cd concentrations in boreholes and near-pond hand-dug wells exceeded the 0.003 mg/L , whereas Pb and Cr remained below their corresponding comparison values. Mn increased with distance in the hand-dug-well groups, indicating that its distribution is influenced by processes beyond simple pond-derived attenuation.

The strongest attenuation was observed for tetracycline, with a mean decrease of approximately 97.7% from near-pond wells to the farther well group. Chloramphenicol decreased by approximately 54.5%, while Cd, Pb and Cr decreased by approximately 58.3%, 53.1% and 50.0%, respectively. These decreases indicate concentration attenuation along the sampled gradient.
The study supports improved wastewater containment at fish farms, avoidance of unlined discharge structures where they are hydraulically connected to shallow aquifers, and routine monitoring of groundwater used for domestic purposes.

8. Practical Recommendations

- Provide lined or otherwise engineered wastewater-retention and treatment structures at aquaculture facilities where site conditions permit.
- Minimize direct disposal of pond wastewater into unlined soak pits or shallow subsurface zones hydraulically connected to domestic wells.
- Apply hydrogeological criteria when siting new boreholes and hand-dug wells around aquaculture facilities.
- Implement routine monitoring of pH, EC, TDS, nutrients, Cd, Pb, Cr, Mn and relevant veterinary pharmaceuticals in groundwater surrounding intensive fish farms.
- Maintain records of veterinary medicines, feed additives and other chemical inputs to improve source identification during future investigations.
- Future studies should include sediment mineralogy, replicate seasonal sampling and contaminant-specific fate experiments.

References

Adeyemi, A. A., & Ojekunle, Z. O. (2021). Concentrations and health risk assessment of industrial heavy metals pollution in groundwater in Ogun State, Nigeria. Scientific African, 11, e00666. https://doi.org/10.1016/j.sciaf.2020.e00666

Akpoborie, I. A., Ehbor, M. A., & Ogbamikhumi, A. (2003). Hydrochemical characteristics of groundwater in the Benin Formation, Warri, Nigeria. Journal of Mining and Geology, 39(2), 87–94.

American Public Health Association, American Water Works Association, & Water Environment Federation. (2005). Standard methods for the examination of water and wastewater (21st ed.). APHA.

Appelo, C. A. J., & Postma, D. (2005). Geochemistry, groundwater and pollution (2nd ed.). A.A. Balkema.

Boyd, C. E. (2005). Aquaculture and water pollution. American Water Resources Association Specialty Conference, Snowbird, Utah, pp. 231–234.

FAO. (2022). The state of world fisheries and aquaculture 2022: Towards blue transformation. Food and Agriculture Organization of the United Nations.

Fendorf, S. E. (1995). Surface reactions of chromium in soils and waters. Geoderma, 67(1–2), 55–71.

Iwegbue, C. M. A., Nwajei, G. E., & Ogala, J. E. (2008). Metal concentrations in fish pond sediments from Warri, Niger Delta, Nigeria. Journal of Applied Sciences, 8(5), 878–883.

Mkwate, O., Chidya, R. C. G., & Wanda, E. M. M. (2017). Assessment of antibiotics residues in groundwater near aquaculture farms in Malawi. Physics and Chemistry of the Earth, 100, 288–295.

Moses, E. A., Akpoveta, O. V., & Osakwe, S. A. (2013). Heavy metal pollution of groundwater from catfish ponds in Delta State, Nigeria. Archives of Applied Science Research, 5(4), 1–6.

NSDWQ. (2007). Nigerian standard for drinking water quality. Standards Organisation of Nigeria.

Ojo, A. O., Olurin, O. T., Ganiyu, S. A., Badmus, B. S., & Idowu, O. A. (2020). Hydro-geochemical assessment of an open dumpsite in a basement complex of Abeokuta, Ogun State, Southwestern Nigeria. Arabian Journal of Geosciences, 13, 620.

Ohwoghere-Asuma, O., Chinyem, F. I., Atiti, P., & Ophori, D. (2024). Contaminant transport modelling of the vulnerability of aquifer to cyanide from cassava processing mill in the western Niger Delta. HydroResearch, 7, 154–163.

Sarmah, A. K., Meyer, M. T., & Boxall, A. B. A. (2006). A global perspective on the use, sales, exposure pathways, occurrence, fate and effects of veterinary antibiotics (VAs) in the environment. Chemosphere, 65(5), 725–759. https://doi.org/10.1016/j.chemosphere.2006.03.026

Tolls, J. (2001). Sorption of veterinary pharmaceuticals in soils: A review. Environmental Science & Technology, 35(17), 3397–3406. https://doi.org/10.1021/es0003021

WHO. (2011). Guidelines for drinking-water quality (4th ed.). World Health Organization. Editorial quality-control notes before submission

- The manuscript has been rewritten from the supplied document without inventing missing measurements or inferential statistics.
- Scopus is an indexing database rather than a single manuscript-format standard. Final formatting, word count, reference style, graphical abstract requirements and reporting checklists must be adapted to the specific target journal.
- The original manuscript contains several reference/attribution issues and some unit/benchmark inconsistencies. In this revision, unsupported antibiotic 'WHO limit' comparisons were removed from the scientific interpretation, and chromium speciation and mechanism-specific attenuation claims were qualified.
- The laboratory method section should be completed with detection limits, recoveries, calibration information, sample preservation conditions, analytical instrument models, QA/QC acceptance criteria and exact EPA/APHA method numbers from the laboratory records.
- Before submission, the authors should verify every bibliographic record and DOI against the journal/publisher database and supply the complete raw dataset or supplementary table if required.

IJGEM