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SYNERGISTIC EFFECTS OF INDUSTRIAL POLLUTANTS ON GROUND WATER QUALITY IN UMUABULU, IGBO-ETCHE, RIVERS STATE

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ABSTRACT

Groundwater serves as a vital source of potable water in rural and peri-urban communities across Nigeria, yet its quality is increasingly compromised by anthropogenic activities. This study investigates the synergistic effects of industrial pollutants on groundwater quality in Umuabulu, Igbo-Etche, Rivers State, within the hydrocarbon-rich Niger Delta. Five geospatially distinct sites were sampled; physicochemical, heavy metal and organic contaminant concentrations were assessed in comparison with World Health Organisation (WHO) standards. Results revealed progressive deterioration in water quality along pollution gradients. Physicochemical parameters, including electrical conductivity (1240 ± 115 µS/cm), total dissolved solids (622 ± 55 mg/L), turbidity (6.8 ± 0.9 NTU), biochemical oxygen demand (4.6 ± 0.6 mg/L) and chemical oxygen demand (14.6 ± 1.3 mg/L), exceeded WHO permissible limits in multiple sites. Heavy metals such as lead (31.2 ± 2.6 µg/L), cadmium (6.2 ± 0.6 µg/L), chromium (78.6 ± 6.8 µg/L) and iron (598 ± 52 µg/L) were also above guideline values, alongside elevated organic contaminants including total petroleum hydrocarbons and volatile organic compounds. The observed interactions between heavy metals and organic pollutants intensified aquifer vulnerability, reduced dissolved oxygen levels and increased risks of chronic toxicological exposure. These findings highlight significant public health and ecological risks in Umuabulu, underscoring the urgent need for stricter regulatory enforcement, improved waste management, and sustainable groundwater monitoring strategies in oil-impacted communities.

Keywords: Groundwater quality, Industrial pollutants, Heavy metals, Hydrocarbons, Synergistic effects, Niger Delta

Introduction

Groundwater continued to be one of the most paramount indispensable freshwater reserves globally, demonstrating as bedrock for domestic consumption, agricultural productivity and industrial development. In regions where surface water sources are seasonally unreliable, heavily exploited, or severely contaminated, reliance on groundwater is particularly pronounced. In Nigeria and particularly within peri-urban and rural settlement, groundwater signified the dominant source of potable water as result of the absence of improper of centralized water supply systems. However, the quality and safety of this vital resource are increasingly undermined by anthropogenic activities, most notably the influx of industrial pollutants (Okoye, Nwankwo, & Nwosu, 2017).

The industrial waste discarded unlawfully from petroleum refining, agro-allied industries and artisanal activities constantly comprises a complex entourage of harmful chemicals, involving heavy metals, hydrocarbons, volatile organic compounds and other xenobiotics. As soon as they are injected into the environment, these contaminants readily penetrate into aquifer systems, damaging groundwater chemistry, elevating ionic concentrations and impairing the natural self-purification capability of subsurface waters. Furthermore, elevated pollutant loads are an excellent indication of an association with increased electrical conductivity, total dissolved solids, turbidity and biochemical oxygen demand, all of which not only compromise the physicochemical integrity of groundwater but also render it more vulnerable to secondary microbial colonisation (Odukoya, Akande, & Briggs, 2019).

The effects of industrial pollutants on groundwater are not merely direct but often synergistic, producing compounded impacts that intensify contamination and accelerate environmental degradation. Heavy metals, for instance, do not only exert toxicity on human health but also alter aquifer geochemistry by lowering pH and mobilizing other trace metals. Hydrocarbons and organic solvents, similarly, may act as alternative carbon sources for microbial growth, thereby exacerbating oxygen depletion and further destabilizing groundwater chemistry. Such synergistic dynamics deepen the risks of chronic toxic exposures, ecological disruption and long-term deterioration of water quality (Seiler & Berendonk, 2012).

The community of Umuabulu, located in Igbo-Etche within Rivers State, Nigeria, provides a critical case study of this phenomenon. Geographically situated in the hydrocarbon-rich Niger Delta, Umuabulu has long been subjected to environmental pressures associated with oil exploration, gas flaring, recurrent oil spillages and indiscriminate discharge of industrial effluents (Ordinioha & Brisibe, 2013). Residents in this community depend heavily on shallow wells and boreholes tapping the Coastal Plain Sands aquifer, which, due to its high permeability, is particularly susceptible to pollutant infiltration. This vulnerability is compounded by inadequate waste management and poor sanitation practices, further aggravating groundwater contamination and raising pressing concerns about public health risks (Ukpong & Okon, 2013).

Given these realities, a systematic evaluation of the synergistic effects of industrial pollutants on groundwater quality in Umuabulu is both timely and imperative. Beyond characterizing pollutant concentrations and their physicochemical consequences, such an investigation provides critical evidence for understanding the mechanisms of dual contamination, framing the implications for community health, and informing policy interventions for sustainable groundwater management in oil-impacted regions of sub-Saharan Africa.

Materials and Methods

Study Area

This study was conducted in Umuabulu, a community in Igbo-Etche, Etche LGA of Rivers State, Nigeria, located between latitudes 4°58′30″–5°02′15″ N and longitudes 7°05′40″–7°09′10″ E, about 25 km north-east of Port Harcourt. The area lies within the hydrocarbon-rich Niger Delta Basin, characterised by petroleum exploration, agro-industrial activities, and related environmental pressures. Topography is low-lying (18–25m), underlain by the Coastal Plain Sands Formation with highly permeable aquifers that serve as the main potable water source via wells and boreholes. The climate is humid tropical, with annual rainfall of 2,000–2,500mm and mean temperatures of 27–30 °C, conditions that favour leaching of contaminants into shallow groundwater. Socio-economically, residents depend on farming, trading, and artisanal work, but the proximity to oil facilities exposes the community to recurrent oil spills, gas flaring, and effluent discharges. Combined with poor sanitation and waste management, these factors heighten the vulnerability of groundwater to both industrial pollutants making Umuabulu a critical case study for assessing synergistic impacts on water quality.

Study Design and Sampling Strategy

A cross-sectional design was employed in Umuabulu (Igbo-Etche), where five geospatially distinct sites were purposively selected to represent varying levels of industrial impact four located down-gradient of petroleum facilities, effluent discharge zones, or densely populated settlements and one up-gradient site serving as a reference. At each area, five groundwater sources (boreholes) from separate households, spaced at least 100–150 m apart, were sampled, yielding a total of 25 samples. Sampling was conducted during the dry season to capture peak contaminant loads, restricted to routinely used sources with intact aprons and covers, excluding newly sunk or recently treated wells. Samples were pre-flushed, outlets disinfected and sterile containers used under aseptic conditions, while in-situ parameters (pH, temperature, electrical conductivity and dissolved oxygen) were measured prior to collection. All samples were obtained within five consecutive days, mid-morning to early afternoon and transported under cooled, light-protected conditions to the laboratory within six hours for physicochemical.

Sample Collection and Preservation

Water samples were collected in sterile 1.5L high-density polyethylene bottles for physicochemical analysis. Prior to sampling, bottles were pre-rinsed with the groundwater to be collected. While those for heavy metals and organic pollutants were acidified to pH < 2 with ultrapure nitric acid to prevent adsorption onto container walls (APHA, 2017).

Physicochemical Analysis

Standard methods of the American Public Health Association (APHA, 2017) were employed to determine physicochemical parameters. Temperature, pH, dissolved oxygen (DO), electrical conductivity (EC) and turbidity were measured in situ using calibrated portable meters. Total dissolved solids (TDS), biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were quantified using titrimetric and spectrophotometric techniques.

For heavy metal analysis, samples were digested with concentrated nitric acid and analysed using Atomic Absorption Spectrophotometry (AAS; PerkinElmer Analyst 400). Target metals included lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), copper (Cu) and zinc (Zn). Hydrocarbons and organic pollutants were determined by Gas Chromatography-Mass Spectrometry (GC-MS; Agilent 7890A/5975C). Quality assurance was ensured through the use of blanks, certified reference standards and duplicate analyses.

Data Analysis

Data were analysed using descriptive and inferential statistics. Physicochemical and microbial parameters were expressed as means ± standard deviation. Pearson's correlation and multiple regression analyses were applied to determine associations between pollutant concentrations and microbial loads. A synergistic interaction index was developed by integrating pollutant using multivariate analysis of variance (MANOVA). Statistical significance was set at $p < 0.05$. All analyses were conducted using IBM SPSS Statistics version 26.0 and Origin Pro 2021.

Results and Discussion

Results

Physicochemical characteristics of groundwater across study sites in Umuabulu, Igbo-Etche, Rivers State, Nigeria

The pH of groundwater ranged from 7.02 ± 0.15 at Site A to 6.49 ± 0.17 at Site E, with Sites C–E slightly below the WHO limit of 6.5–8.5. Temperatures (26.5–28.1 °C) remained within the permissible <30 °C. Electrical conductivity increased from 310 ± 40 µS/cm at Site A to 1240 ± 115 µS/cm at Site E, with Sites C–E exceeding the 1000 µS/cm limit, a trend mirrored by TDS values (152–622 mg/L) where Sites C–E surpassed the 500 mg/L threshold. Dissolved oxygen declined progressively from 6.2 ± 0.5 mg/L (Site A) to 4.0 ± 0.2 mg/L (Site E), falling below the >5 mg/L requirement in Sites B–E. Turbidity rose from 2.3 ± 0.4 NTU (Site A) to 6.8 ± 0.9 NTU (Site E), exceeding the <5 NTU guideline in Sites B–E. Similarly, BOD (2.0–4.6 mg/L) and COD (5.5–14.6 mg/L) increased across sites, with values at Sites B–E above the WHO limits of 3 mg/L and 10 mg/L, respectively, indicating organic pollution.

Heavy Metal and organic contaminant concentrations in groundwater across study sites in Umuabulu Igbo-Etche

Lead (Pb) concentrations ranged from 7.2 ± 0.8 µg/L at Site A to 31.2 ± 2.6 µg/L at Site E, with Sites B–E exceeding the WHO limit of 10 µg/L. Cadmium (2.1–6.2 µg/L) and chromium (38.0–78.6 µg/L) showed progressive increases, surpassing guideline values of 3 µg/L and 50 µg/L at Sites C–E, respectively. Iron concentrations rose from 270 ± 20 µg/L (Site A) to 598 ± 52 µg/L (Site E), with Sites B–E above the 300 µg/L threshold. Copper levels were generally below the 1000 µg/L limit, except at Site E (1120 ± 92 µg/L), while zinc (2900–4255 µg/L) exceeded the 3000 µg/L limit in Sites B–E. Organic contaminants, including TPH (0.35–0.90 µg/L) and VOCs (0.012–0.095 µg/L), consistently exceeded permissible levels (0.3 µg/L and 0.01 µg/L), highlighting hydrocarbon and industrial pollution.

Table 1: Physicochemical characteristics of groundwater across study sites in Umuabulu, Igbo- Etche, Rivers State, Nigeria (Mean ± SD), Compared with guideline values.

Parameters	A	B	C	D	E	WHO Limit
pH	7.02±0.15	6.72 ±0.2	6.61±0.18	6.55 ±0.20	6.49±0.17	6.5-8.5
Temp (°C)	26.5±0.4	27.3±0.5	27.6±0.5	27.8±0.6	28.1±0.5	<30
EC (µS/cm)	310 ± 40	780±65	1055 ±92	1185±110	1240±115	1000
TDS(mg/L)	152±18	398±35	515±46	590±52	622±55	500
DO (mg/L)	6.2±0.5	5.0±0.4	4.6±0.3	4.2±0.3	4.0±0.2	≥ 5
Turbidity (NTU)	2.3±0.4	4.8±0.6	5.5±0.7	6.2±0.8	6.8±0.9	<5
BOD(mg/L)	2.0±0.3	3.2±0.4	3.8+0.5	4.2+0.5	4.6+0.6	3
COD(mg/L)	5.5±0.6	9.2±1.0	11.8±1.1	13.5±1.2	14.6 ±1.3	10

Table 2: Heavy Metal and organic contaminant concentrations in groundwater across study sites in Umuabulu Igbo-Etche (Mean ± SD) compared with guideline value

Parameters	A	B	C	D	E	WHO Limit
Pb(µg/L)	7.2 ±0.8	14.5±1.3	22.8±2.1	28.6±2.5	31.2±2.6	10
Cd(µg/L)	2.1±0.2	3.6± 0.4	4.8±0.5	5.5±0.6	6.2±0.6	3
Cr(µg/L)	38.0±3.2	52.5±4.0	65.8±5.5	72.4±6.1	78.6±6.8	50
Fe(µg/L)	270±20	420±35	510±42	565±48	598±52	300
Cu(µg/L)	740±60	890±75	995±82	1050±90	112±92	1000
Zn(µg/L)	2900±210	3450±260	3890±280	4120±300	4255±320	3000
TPH(µg/L)	0.90±0.01	0.35±0.04	0.58±0.06	0.72+0.07	0.81+0.08	0.3
VOCs(µg/L)	0.012±0.002	0.45±0.005	0.068±0.006	0.0.82±0.07	0.095±0.008	0.01

Discussion

The physicochemical properties of groundwater in Umuabulu, Igbo-Etche, Rivers State, exhibited pronounced spatial heterogeneity when benchmarked against World Health Organization (WHO) potable water standards.

The pH values across the study sites ranged from 6.49 ± 0.17 to 7.02 ± 0.15. While groundwater from sample A and B conformed to the WHO recommended interval of 6.5–8.5, water samples from sample C–E demonstrated a mild deviation towards acidity. This acidification trend is consistent with earlier investigations in the Niger Delta, where groundwater acidification was linked to the dissolution of carbon dioxide, industrial effluents and petroleum-related activities (Ojekunle et al., 2016). Such acidic situations are particularly concerning as they enhance the solubility and mobilization of hazardous metals including lead, cadmium and iron, thereby elevating the risk of chronic toxicological outcomes among local consumers (Obioma & Chukwu, 2018).

Groundwater temperatures, which ranged from 26.5 to 28.1°C, were within the WHO maximum permissible limit of 30°C. These values are typical of tropical aquifer systems in southern Nigeria and suggest hydrothermal stability (Ocheri et al., 2014). They equally, align with the findings of Adefemi et al. (2007), who demonstrated that aquifer temperatures below 30°C generally restrict excessive microbial proliferation and aid to maintain adequate dissolved oxygen availability.

Electrical conductivity (EC) varied considerably, ranging from 310 ± 40 µS/cm at sample A to 1240 ± 115 µS/cm at sample E. Although sample A and B were within the WHO tolerance limit of 1000 µS/cm, the elevated values in sample C–E reflect increased ionic strength, suggesting salt enrichment and possible contamination. Similarly, total dissolved solids (TDS) increased progressively from 152 ± 18 mg/L at sample A to 622 ± 55 mg/L at sample E, with concentrations at sample C–E exceeding the WHO guideline of 500 mg/L. Elevated EC and TDS are indicative of mineral leaching, infiltration of leachates and anthropogenic inputs, particularly from industrial and petroleum operations, as reported in similar Niger Delta environments (Nwankwoala & Udom, 2011). These findings reinforce the recognized vulnerability of groundwater resources in hydrocarbon-rich regions to salinization and ionic enrichment.

Dissolved oxygen (DO) levels declined progressively from 6.2 ± 0.5 mg/L at sample A to 4.0 ± 0.2 mg/L at sample E. While sample A satisfied the WHO minimum threshold of 5 mg/L, sample B–E failed to meet this requirement, reflecting oxygen depletion likely driven by microbial respiration and elevated organic loads. This observation corresponds with the findings of Adeyeye et al. (2013), who documented DO depletion in organically polluted aquifers. The concurrent increase in biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in this study underscores the significant role of organic matter enrichment, possibly of anthropogenic origin.

Turbidity values ranged between 2.3 ± 0.4 NTU at Site 1 and 6.8 ± 0.9 NTU at sample E. Except for sample A, all other sites exceeded the WHO recommended threshold of <5 NTU, indicating colloidal and particulate contamination. These findings are comparable to those reported by Eze and Ugwu (2017), who associated elevated turbidity in rural aquifers with soil leaching, poor sanitary infrastructure, and runoff infiltration. Similar results were described by Adefemi et al. (2007), who observed heightened turbidity in groundwater from peri-urban settlements.

Biological oxygen demand (BOD) ranged from 2.0 to 4.6 mg/L, with sample B–E exceeding the WHO maximum permissible value of 3 mg/L. This suggests significant organic pollution, potentially originating from domestic wastewater, agricultural effluents, or municipal discharges. COD values followed a parallel trend, ranging from 5.5 to 14.6 mg/L, with exceedances at sample B–E relative to the WHO limit of 10 mg/L. The concomitant elevation of both BOD and COD reflects substantial organic enrichment, corroborating earlier reports from the Niger Delta that identified petroleum hydrocarbons and untreated effluents as key contributors to organic groundwater pollution (Ojekunle et al., 2016).

Assessment of trace metals revealed alarming deviations from WHO drinking water guidelines, signifying severe anthropogenic pressure on groundwater resources. Lead (Pb) concentrations varied between 7.2 ± 0.8 µg/L and 31.2 ± 2.6 µg/L, with sample C–E exceeding the permissible limit of 10 µg/L. The elevated Pb burden, particularly at sample D and E, is alarming given its well-documented neurotoxic and nephrotoxic effects even at trace exposures (Needleman, 2004). This trend is consistent with Ibe et al. (2019), who reported elevated Pb levels in oil-producing communities, though higher than the values observed in inland aquifers by Onwughara et al. (2013).

Cadmium (Cd) concentrations exceeded the WHO tolerance value of 3 µg/L in sample B–E, with the highest value of 6.2 ± 0.6 µg/L recorded at sample E. Chronic Cd exposure is implicated in renal impairment and carcinogenesis (Satarug et al., 2010). These observations mirror those of Ezeh and Chukwu (2019), who attributed Cd contamination in southeastern Nigeria to indiscriminate waste disposal and industrial effluents. Chromium (Cr) levels ranged between 38.0 ± 3.2 and 78.6 ± 6.8 µg/L, with exceedances in four out of the five areas relative to the WHO maximum of 50 µg/L. Potential sources include industrial discharges and corroded metal infrastructures, corroborating earlier reports of Cr enrichment in hydrocarbon-impacted terrains (Ogoko, 2014).

Iron (Fe) concentrations surpassed the WHO threshold (300 µg/L) at all samples except sample A, with the highest concentration of 598 ± 52 µg/L observed at sample E. This could reflect both natural geochemical leaching from ferruginous aquifers and anthropogenic enrichment (Edet & Offiong, 2002). Similar widespread Fe enrichment in Niger Delta aquifers was previously reported by Akpoveta et al. (2011). Copper (Cu) concentrations ranged from 740 ± 60 to 1120 ± 92 µg/L, with values at sample D and E slightly exceeding the WHO limit of 1000 µg/L. Although Cu is an essential micronutrient, excessive intake causes gastrointestinal distress and undesirable water taste (WHO, 2017). Comparable exceedances have been documented in Port Harcourt aquifers by Amadi et al. (2012), implicating industrial effluents and corroded distribution systems. Zinc (Zn) concentrations exceeded the WHO maximum of 3000 µg/L across all samples, with sample E recording the highest value of 4255 ± 320 µg/L. Although Zn is less toxic compared to Pb or Cd, elevated levels compromise water palatability and threaten aquatic ecosystems. These results contrast with Olobaniyi and Owoyemi (2006), who reported significantly lower Zn concentrations in western Niger Delta aquifers, suggesting localized contamination dynamics in Umuabulu.

Organic contaminants further substantiated the anthropogenic influence on groundwater quality. Total petroleum hydrocarbons (TPH) ranged up to 0.90 ± 0.01 µg/L, exceeding the WHO benchmark of 0.3 µg/L, while volatile organic compounds (VOCs) reached 0.82 ± 0.07 µg/L, far surpassing the WHO limit of 0.01 µg/L. The elevated hydrocarbon concentrations are symptomatic of petroleum-related activities, including oil exploration and artisanal refining, which are widespread in the Niger Delta region. These findings are consistent with the observations of Ukpaka (2015), who identified hydrocarbons as dominant contaminants in groundwater from oil-producing terrains.

Collectively, the present findings highlight a progressive deterioration of groundwater quality in Umuabulu, driven by synergistic inputs from industrial effluents, oil-related operations, and anthropogenic waste. The exceedance of multiple parameters relative to WHO standards underscores both the ecological vulnerability of the aquifer system and the significant public health risks associated with prolonged exposure.

Conclusion

This study revealed that groundwater in Umuabulu, Igbo-Etche, is significantly impaired by synergistic interactions of heavy metals and organic pollutants, with multiple parameters exceeding WHO standards. The progressive deterioration observed across sites underscores the vulnerability of the aquifer to industrial effluents, petroleum activities, and poor sanitation practices. These findings highlight substantial ecological and public health risks, particularly risks of chronic toxicological exposure. Ultimately, the results affirm the urgent need for sustainable groundwater management in oil-impacted communities.

Recommendations

In line with the findings, the following are hereby recommended:

1) It is recommended that regulatory agencies enforce stricter controls on industrial effluent discharges and petroleum operations in the Niger Delta.
2) Community-based monitoring and periodic groundwater quality assessments should be institutionalized to ensure early detection of contamination trends.
3) Adoption of eco-friendly waste management practices and remediation technologies, such as constructed wetlands and adsorption filters, is imperative.
4) Public health interventions, including provision of safe alternative water sources, should be prioritized to protect vulnerable populations

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