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GIS-BASED SPATIAL ASSESSMENT AND WATER QUALITY INDEX MAPPING OF GROUNDWATER CONTAMINATION NEAR OPEN WASTE DUMP SITES IN NNEWI, ANAMBRA STATE, NIGERIA

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Abstract

Open waste dump sites threaten groundwater quality in rapidly urbanising Nigerian cities where shallow aquifers supply domestic water. This study aimed to assess groundwater quality near four open dump sites and an upstream control in Nnewi, Anambra State, and to map the spatial variation of a composite Groundwater Quality Index (GWQI). Monthly samples were collected for twelve months from 25 stations (15 hand-dug wells, 10 boreholes). Physico-chemical, heavy metal and microbiological parameters were compared with WHO and NESREA limits; GWQI was computed per site by the weighted arithmetic method and interpolated by inverse distance weighting (IDW). Groundwater pH (4.9–5.5) and BOD5 (up to 24.3 mg/L) breached guideline values at all dump sites. Lead reached 0.078 mg/L (7.8× the WHO limit) and cadmium 0.011 mg/L (3.7×) at DS-2. All dump sites were unsuitable for drinking (GWQI 216–444) against 12.5 (excellent) at the control. GWQI showed no significant relationship with distance from the control ($r = -0.06$, $p = 0.94$), indicating that waste composition and operational age, not proximity, drive contamination severity. We recommend site-specific protection zones, restriction of drinking-water use near dump sites, groundwater monitoring wells, enforcement of NESREA waste regulations, and replacement of open dumps with engineered sanitary landfills.

Keywords: GIS, Groundwater Contamination, Heavy Metals, Nnewi, Waste Dump Sites, Water Quality Index.

1.0 Introduction

The management of municipal solid waste (MSW) in Nigerian cities has become a major environmental governance challenge. Rapid urbanisation, expanding commercial activity and inadequate waste management infrastructure have led to a proliferation of uncontrolled open dump sites, which threaten the quality of groundwater used by millions of urban households [3]; [6]. Nnewi, located in Nnewi-North Local Government Area (LGA) of Anambra State, is one of Nigeria's most commercially significant cities, renowned for its automobile spare parts trade and light manufacturing industries. Waste from automobile workshops and small industries, including used batteries, solvents and lubricants, is often dumped together with household refuse at open sites that have no liners or leachate control [4].

Groundwater from shallow aquifers, typically accessed through hand-dug wells and shallow boreholes at depths of 10–30 m, serves as the primary domestic water source for a substantial proportion of Nnewi households, particularly in communities adjacent to dump sites where piped water provision is unreliable. This creates a direct pathway for leachate-derived contaminants - including heavy metals, nitrates, organic loading and pathogens to reach the drinking water of large numbers of residents without treatment or prior warning [5]; [10].

While the impacts of landfill leachate on groundwater quality are well documented internationally [3]; [8], to the best of the authors' knowledge no peer-reviewed study has quantified these impacts in Nnewi, where automotive and industrial waste is co-disposed with domestic waste and may produce more toxic leachate than purely residential dump sites. This study addresses that gap.

The objectives of this study were to: (i) characterise the physico-chemical and heavy metal quality of groundwater at four Nnewi dump sites relative to an upstream control; (ii) compare results against World Health Organization (WHO) [14] and NESREA permissible limits; (iii) assess the degree of deviation from acceptable water quality standards using ANOVA; (iv) evaluate public health implications for communities reliant on groundwater within 100 m of dump sites; and (v) map the spatial variation of groundwater quality using a composite Groundwater Quality Index (GWQI) and IDW interpolation.

2.0 Materials and Methods

2.1 Study Area and Sampling Stations

The study was conducted within Nnewi-North Local Government Area, Anambra State, Nigeria (approximately 6°01'N, 6°54'E), an area characterised by humid tropical climate, annual rainfall of 1,700–2,100 mm and shallow sandy-loamy aquifer systems at 10–30 m depth. Four dump sites and an upstream control site were selected (Table 1; Figure 1).

Geology and drainage: Nnewi lies within the Anambra Basin of south-eastern Nigeria. The Ogwashi-Asaba Formation underlies the Nnewi North and South LGAs and contains multiple aquifers [9]. Surface water and groundwater in this part of southern Anambra State generally flow westward, from the higher ground on the Nanka Formation towards the lower ground underlain by the Ogwashi-Asaba and Benin formations [2]. The area is drained by the Idemili, Ubuh Ekulo, Obolo and Eze rivers and the Mmili Eze tributary, together with smaller streams and the Nnewichi Main Gully (Figure 1). Figure 1 also shows the position of each sampling location relative to these drainage lines, the road network and the terrain.

Table 1: Description of Sampling Stations, Nnewi Groundwater Study (June 2014–May 2015)

Station	Community	Coordinates	Area (ha)	In Operation Since	Primary Waste Type
Control	Otolo Forest Reserve	6°02'52"N, 6°53'48"E	—	—	No waste — upstream reference
DS-1	Otolo	6°02'18.4"N, 6°54'43.2"E	1.8	~1995	Domestic, market & workshop waste
DS-2	Uruagu	6°01'55.1"N, 6°55'08.7"E	2.3	~1989	Domestic & auto-workshop waste
DS-3	Umudim	6°01'12.5"N, 6°54'22.9"E	1.2	~2001	Industrial, commercial & domestic
DS-4	Nnewichi	6°00'38.2"N, 6°54'02.6"E	0.8	~2007	Residential domestic waste

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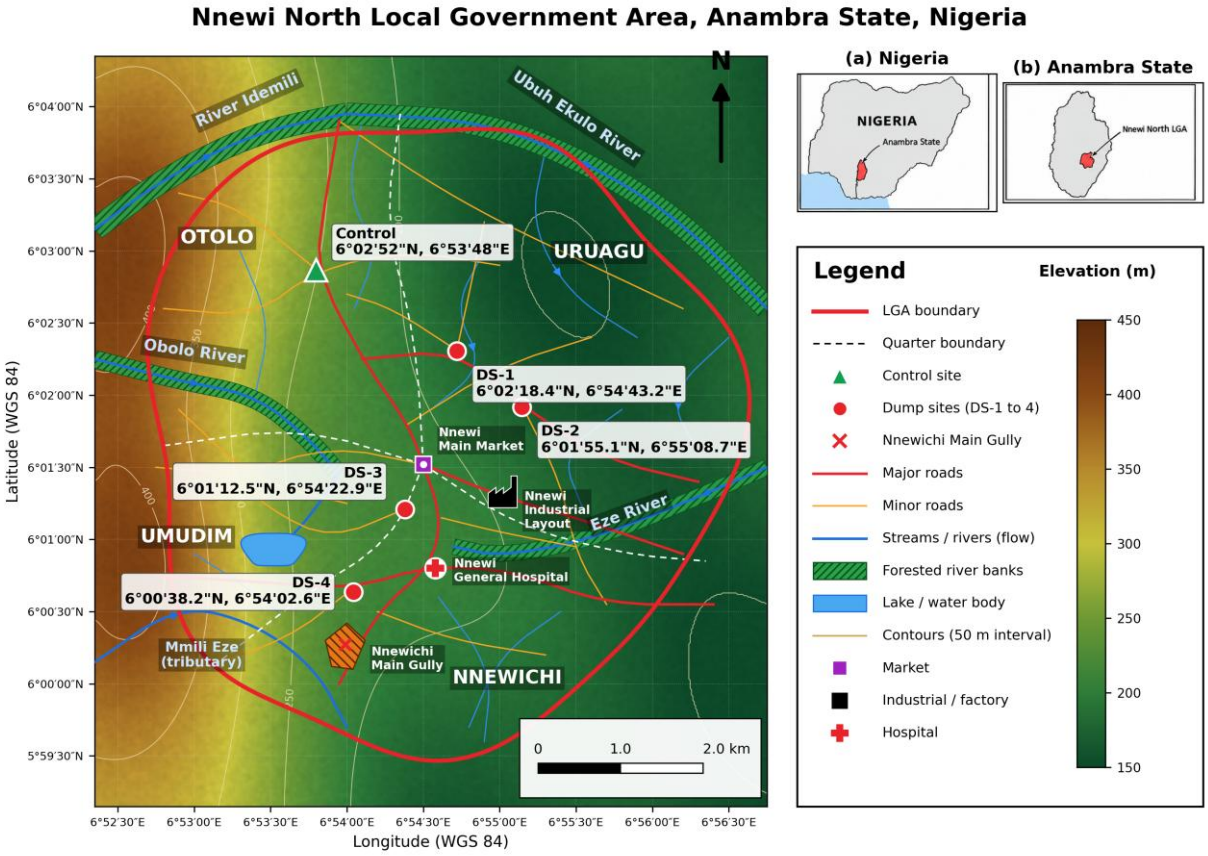

Figure 1: Map of Nnewi North Local Government Area, Anambra State, Nigeria, showing the four quarters (Otolo, Uruagu, Umudim and Nnewichi), sampling locations (Control and DS-1 to DS-4), major roads, rivers and streams, key landmarks, forested river banks, the Nnewichi Main Gully and terrain elevation (DEM/contours).

2.2 Sample Collection and Laboratory Analysis

Groundwater samples were collected monthly from June 2014 to May 2015 from 25 designated sampling stations (3 hand-dug wells and 2 boreholes per site). Before collection, each well was purged of three well volumes and boreholes were pumped for 10 minutes. Samples were collected in acid-washed HDPE bottles (physicochemical and heavy metal analysis) and sterilised glass bottles (microbiological analysis) following Baird and Bridgewater [1] Standard Methods. Field measurements of pH, temperature, dissolved oxygen (DO), total dissolved solids (TDS) and electrical conductivity (EC) were made in situ using calibrated multi-parameter meters. Heavy metal samples were acidified to pH<2 with concentrated HNO_3 and analysed by Atomic Absorption Spectrophotometry (AAS). All analyses were conducted at Imo State University Central Research Laboratory and cross-validated at Michael Okpara University of Agriculture, Umudike.

2.3 Household Survey

A structured questionnaire was administered to approximately 200 households living near the dump sites. Households were selected by random sampling from both low-income and high-income residential areas. Respondents were grouped into three distance classes from the nearest dump site (<100 m, 100–200 m and >200 m). The questionnaire recorded the household's water source and reported health complaints, including respiratory symptoms and skin irritation. Informed consent was obtained from all respondents before the questionnaire was administered.

2.4 Statistical Analysis

Data were expressed as Mean ± Standard Deviation (SD). One-way ANOVA tested for significant differences between dump sites and the control, with Tukey's post-hoc test applied where significant. Results were compared against WHO [14] Guidelines for Drinking-Water Quality and NESREA standards. The association between distance class and reported health complaints in the household survey was tested with the chi-square test of independence. Statistical analyses used SPSS Version 20.0 (significance level $p<0.05$).

2.5 Geospatial and Water Quality Index (GWQI) Analysis

Geographic coordinates for each of the five study sites (four dump sites and the control; Table 1) were converted from degrees-minutes-seconds to decimal degrees and used to compute pairwise inter-site distances via the haversine formula. A composite Groundwater Quality Index (GWQI) was calculated for each site using the weighted arithmetic water quality index method [13]. The index incorporated all fourteen measured parameters that have a numerical guideline value in WHO [14] or NESREA standards: pH, TDS, DO, BOD5, nitrate, sulphate, turbidity and the seven heavy metals in Table 3 (Pb, Cd, Cr, Fe, Mn, Ni and Zn). Temperature, electrical conductivity and COD were excluded as non-specific indicators, and faecal coliforms were excluded because their guideline value of zero leaves the unit weight undefined. Unit weights were assigned as $Wi = K/Si$, where Si is the guideline value for each parameter and K is a proportionality constant ($K = 1/\Sigma(1/Si)$). Sub-indices (Qi) were calculated relative to Si and an ideal value (Videal), and the overall GWQI for each site was obtained as $\Sigma(Wi \cdot Qi)/\Sigma Wi$. Sites were classified as excellent (GWQI ≤ 25), good (26–50), poor (51–75), very poor (76–100) or unsuitable for drinking (>100). Variation in GWQI was examined in relation to Euclidean distance from the upstream control site using linear regression, to test for a distance-

decay relationship. GWQI values at the five sites were interpolated by inverse distance weighting (IDW, distance power = 2) to produce a continuous GWQI surface, which was classified using the same GWQI categories. Because coordinates were recorded once per study site (n = 5) rather than for each of the 25 sampling stations, the interpolated surface is based on five points only; it indicates broad spatial trends rather than a precise surface, and station-level interpolation is identified as a direction for future work.

Results and Discussion

Physico-chemical Parameters of Groundwater

Mean physico-chemical parameter values across the monitoring period are presented in Table 2. All dump sites showed statistically significant deviation from the control across every parameter measured ($p<0.05$).

Table 2: Mean Physico-chemical Parameters of Groundwater at All Sites (June 2014–May 2015) ±SD; values in bold exceed WHO/NESREA limits

Parameter	Control	DS-1 Otolo	DS-2 Uruagu	DS-3 Umudim	DS-4 Nnewichi	WHO Limit	NESREA Limit
pH	6.8±0.2	5.2±0.4	4.9±0.5	5.5±0.3	5.1±0.4	6.5–8.5	6.5–8.5
Temperature (°C)	26.1±0.8	27.8±1.1	28.3±1.3	27.4±0.9	27.9±1.0	≤30	≤30
TDS (mg/L)	142±18	684±92	812±115	541±78	723±98	500	1000
EC (µS/cm)	218±24	1028±132	1245±178	879±105	1102±149	—	—
DO (mg/L)	7.4±0.6	2.1±0.5	1.3±0.4	2.8±0.6	1.7±0.5	≥5.0	≥5.0
BOD_5 (mg/L)	1.2±0.3	18.5±4.2	24.3±5.8	14.8±3.9	21.2±4.7	<10	≤10
COD (mg/L)	4.8±1.1	85.0±18.2	112.0±24.6	72.0±15.8	98.0±21.3	—	100
Nitrate (mg/L)	1.8±0.4	14.2±3.1	18.6±4.2	11.5±2.8	16.3±3.5	10	10
Sulphate (mg/L)	24±6	198±38	245±52	162±29	211±44	250	250
Turbidity (NTU)	1.2±0.3	18.4±5.1	24.7±6.2	14.2±4.0	20.1±5.5	5	5
Tukey ($p<0.05$)	—	Significant	Significant	Significant	Significant	—	—

Groundwater pH at all dump sites (4.9-5.5) fell significantly below the WHO minimum of 6.5, with the lowest value recorded at DS-2 (Uruagu). This strong acidification reflects the production of humic and fulvic acids during organic waste decomposition and dissolution of acid components from automotive waste, particularly battery acid from lead-acid batteries disposed at this site [5]. ANOVA confirmed highly significant differences in pH between all dump sites and the control ($F=28.4$, $p<0.001$).

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TDS exceeded the WHO guideline of 500 mg/L at DS-1, DS-2, DS-3 and DS-4, indicating high ionic loading from dissolved leachate constituents. DS-2 recorded the highest TDS (812 mg/L), consistent with its longer operational history (since ~1989) and the greater dissolved solids contribution from automotive waste decomposition. Dissolved oxygen was critically depleted at all dump sites (1.3–2.8 mg/L), far below the 5.0 mg/L minimum, confirming intense aerobic microbial decomposition of organic matter consuming available oxygen from groundwater - a finding consistent with similar studies at Nigerian dump sites [10].

BOD_5 values at dump sites (14.8–24.3 mg/L) exceeded the 10 mg/L NESREA standard across all sites, with DS-2 recording the highest value - 20 times the control. The BOD/COD ratio of approximately 0.22 at DS-2 indicates a complex mixture of readily biodegradable and recalcitrant organic compounds in the leachate. Nitrate concentrations exceeded the WHO limit of 10 mg/L at all dump sites throughout the monitoring period, with wet-season peaks of 22.8 mg/L at DS-2 (August). Chronic nitrate exceedance at these levels poses a significant risk of methemoglobinaemia (blue baby syndrome) in infants and contributes to eutrophication of adjacent surface water bodies.

Heavy Metal Concentrations in Groundwater

Mean heavy metal concentrations are presented in Table 3.

Table 3: Mean Heavy Metal Concentrations in Groundwater (mg/L) — *denotes exceedance of WHO [14] guideline value

Metal	Control	DS-1 Otolo	DS-2 Uruagu	DS-3 Umudim	DS-4 Nnewichi	WHO Limit	Exceedance at DS-2
Lead (Pb)	0.002	0.065*	0.078*	0.041*	0.058*	0.010	×7.8
Cadmium (Cd)	0.0003	0.008*	0.011*	0.005*	0.009*	0.003	×3.7
Chromium (Cr)	0.010	0.120*	0.150*	0.090*	0.130*	0.050	×3.0
Zinc (Zn)	0.050	0.850	1.020	0.670	0.920	3.000	Within limit
Iron (Fe)	0.08	1.82*	2.45*	1.42*	2.01*	0.300	×8.2
Manganese (Mn)	0.01	0.38	0.51*	0.29	0.44*	0.400	Borderline
Nickel (Ni)	0.005	0.048	0.061	0.032	0.054	0.070	Within limit

Lead concentrations exceeded the WHO guideline of 0.010 mg/L at all dump sites, reaching 0.078 mg/L at DS-2 — 7.8 times the permissible limit. The elevated lead levels at DS-2 are directly attributable to the disposal of used lead-acid automotive batteries, a common waste

type given the proximity of auto-parts workshops [11]. Lead is a potent neurotoxin with no known safe level of exposure, causing irreversible neurodevelopmental damage in children at even low concentrations [7]. Cadmium a Group 1 IARC carcinogen specifically toxic to renal tubules - exceeded its WHO guideline of 0.003 mg/L at all dump sites, with DS-2 recording 0.011 mg/L (3.7 times the limit). Chromium exceeded 0.050 mg/L at all sites. Iron showed the largest exceedance relative to its guideline value, reaching 2.45 mg/L at DS-2 (8.2 times the WHO aesthetic limit of 0.300 mg/L). Similar iron-related discolouration of well water was reported by 67% of surveyed residents near the Igando dumpsite in Lagos [15], which suggests that residents near the Nnewi sites may notice the same problem.

Spatial Distribution and Water Quality Index Mapping

Table 4 presents the composite GWQI for each site. The control site returned a GWQI of 12.5 (excellent), while all four dump sites exceeded a GWQI of 100 and were classified as unsuitable for drinking, with DS-2 (Uruagu) recording the highest value (444.0), followed by DS-4 (Nnewichi, 351.9), DS-1 (Otolo, 341.6) and DS-3 (Umudim, 216.4). The IDW-interpolated GWQI surface (Figure 2) shows GWQI rising sharply away from the control, with the highest values around DS-2 (Uruagu); only the immediate vicinity of the control falls below the GWQI = 100 threshold. Because the surface is interpolated from five points, values between sites should be read as indicative only.

Table 4: Composite Groundwater Quality Index (GWQI) by Site

Site	GWQI	Classification
Control (Otolo Forest Reserve)	12.5	Excellent
DS-3 (Umudim)	216.4	Unsuitable for drinking
DS-1 (Otolo)	341.6	Unsuitable for drinking
DS-4 (Nnewichi)	351.9	Unsuitable for drinking
DS-2 (Uruagu)	444.0	Unsuitable for drinking

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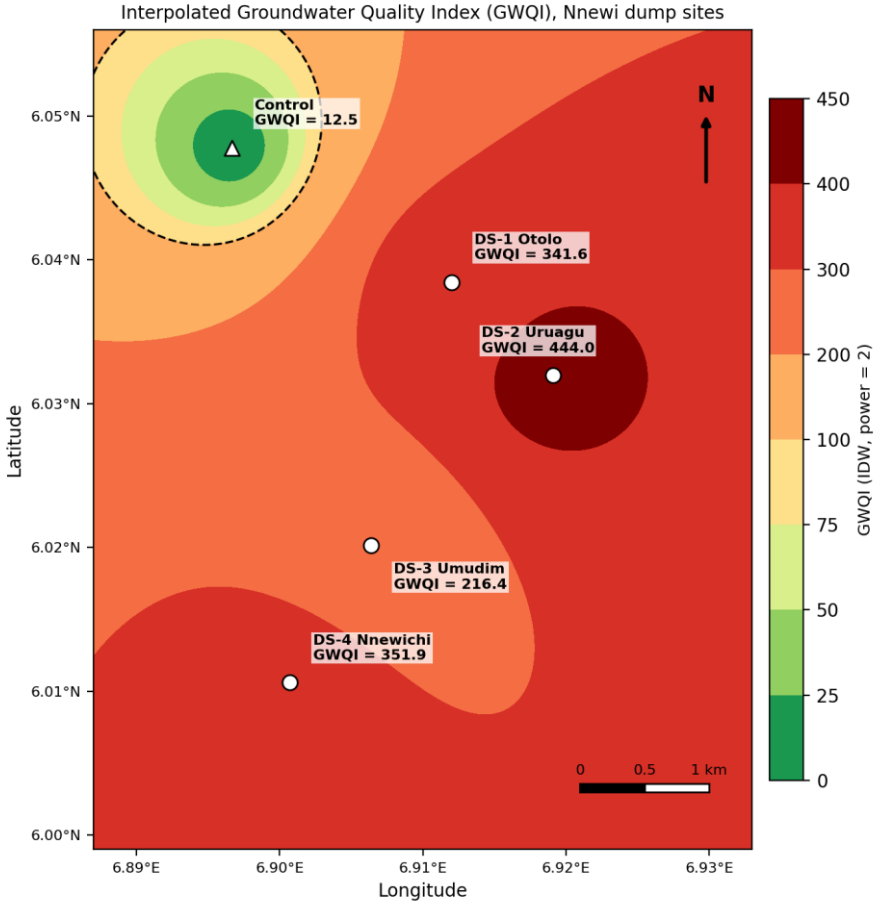

Figure 2: Groundwater Quality Index (GWQI) surface interpolated by inverse distance weighting (power = 2) from the five study sites. The dashed line marks GWQI = 100, above which water is unsuitable for drinking.

Linear regression between GWQI and Euclidean distance from the upstream control site (Figure 3) showed no statistically significant relationship ($r = -0.06$, $r^2 = 0.003$, $p = 0.94$, $n = 4$), indicating that spatial proximity to the control point does not predict contamination severity among the four dump sites. This result suggests that site-specific factors particularly operational age and the composition of the waste stream are stronger determinants of groundwater degradation than distance alone. DS-2, the oldest site (operational since ~1989) receiving mixed domestic and automotive workshop waste including lead-acid batteries, recorded the highest GWQI despite being neither the nearest nor the farthest site from the control. This has a practical implication for regulatory practice: a uniform distance-based buffer zone (e.g., a single 200 m exclusion radius) may not adequately protect groundwater users, since contamination severity is governed more by waste-stream composition and site age than by geographic distance alone. Site-specific risk assessment, informed by waste characterisation and operational history, is recommended over blanket distance criteria.

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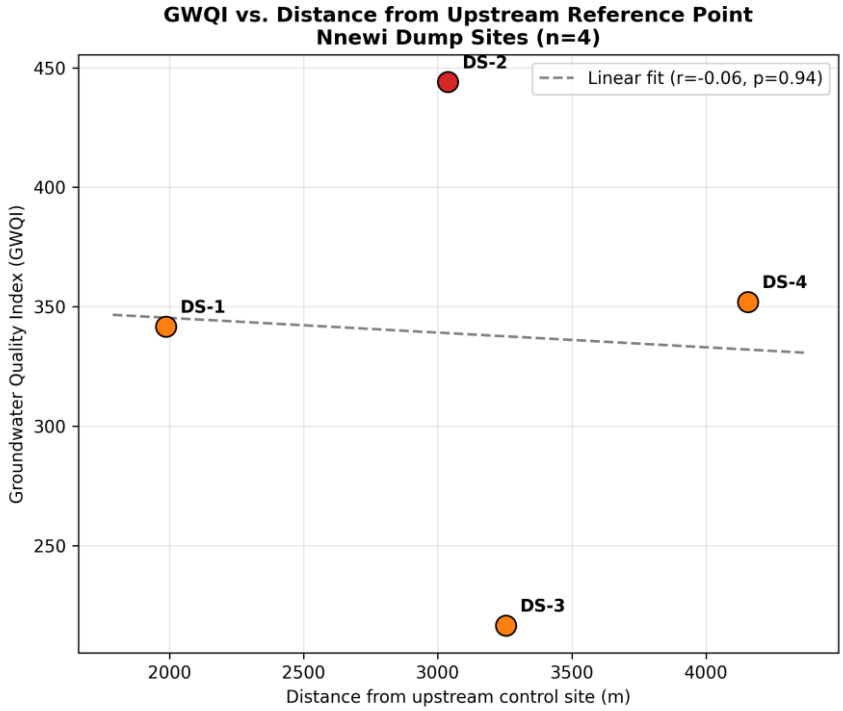

Figure 3: Groundwater Quality Index (GWQI) versus distance from the upstream control site, showing the absence of a significant distance-decay relationship (r = -0.06, p = 0.94, n = 4).

Public Health Implications

Faecal coliform counts at all dump sites exceeded the WHO guideline value of zero per 100 mL for drinking water, with DS-2 recording the highest count of 248 MPN/100 mL. The simultaneous presence of faecal coliforms, elevated nitrate, lead, cadmium and chromium in groundwater used for drinking without treatment exposes residents to microbial and chemical hazards at the same time: faecal contamination can cause acute gastrointestinal illness, while prolonged exposure to heavy metals is linked to cancer, neurological damage and renal failure [12]. In the household survey ($n \approx 200$), chi-square analysis confirmed significant associations between distance class (proximity to dump sites) and reported respiratory symptoms ($\chi^2=12.4$, df=2, p=0.002) and skin irritation ($\chi^2=8.7$, df=2, p=0.013).

Conclusion

This study provides the first comprehensive, multi-parameter, multi-seasonal groundwater quality assessment at open waste dump sites in Nnewi, Anambra State. Results demonstrate severe contamination across all physico-chemical, heavy metal and microbiological parameters at all four dump sites, with DS-2 (Uruagu) posing the greatest risk due to its long operational

history, auto-workshop waste inputs and its location in a community that relies on groundwater. Lead (×7.8 WHO limit), iron (×8.2), cadmium (×3.7) and chromium (×3.0) exceedances are serious public health concerns that call for prompt regulatory action. The installation of groundwater monitoring wells, immediate restriction of drinking-water use from wells close to all dump sites, with the restriction distance set for each site from its waste composition and operational history, and enforcement of NESREA (Sanitation and Wastes Control) Regulations are recommended as immediate priority actions. Long-term remediation requires the development of an engineered sanitary landfill with composite liner and leachate collection systems to replace all existing open dump sites in Nnewi. GIS-based spatial analysis and composite water quality indexing further indicate that contamination severity is governed principally by site-specific waste characteristics and operational history rather than spatial distance from a common reference point, underscoring the need for site-specific rather than uniform distance-based groundwater protection buffer zones.

Conflict of Interest

The authors declare no conflict of interest.

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