Policy Implications and Public Health Risks of Contaminated Groundwater in Urban Nigeria: A GIS-Based Case Study of Uyo, Akwa Ibom State

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ABSTRACT

Groundwater remains a primary source of drinking water in many Nigerian cities, yet its quality is increasingly compromised by anthropogenic activities. This study examines the public health risks and policy implications of groundwater contamination in Uyo, Akwa Ibom State, using a GIS-based multi-criteria assessment framework. Forty borehole samples were collected from urban and rural locations and analysed for key bio-physicochemical parameters including pH, total coliform, cadmium, nickel, nitrate, and iron. Results reveal widespread contamination, with over 90% of urban samples exhibiting pH levels below WHO standards, detectable total coliform in all samples, and cadmium and nickel concentrations exceeding permissible limits. GIS mapping identified clear spatial patterns: urban core areas were classified as “very unsuitable” for drinking, while peripheral rural areas were largely “suitable.” These findings underscore significant public health vulnerabilities, with an estimated 148,922 residents exposed to substandard groundwater. The study highlights the urgent need for integrated policy measures, including mandatory borehole testing, centralised water treatment, improved waste management, and public awareness campaigns. This research demonstrates how geospatial tools can inform evidence-based policy and regulatory interventions to safeguard groundwater quality and public health.

Keywords: Groundwater contamination, public health policy, GIS mapping, water quality standards, Nigeria.

INTRODUCTION

Groundwater is a vital resource for drinking, agriculture, and industry, especially in regions with limited access to treated surface water. In Nigeria, rapid urbanisation, industrial expansion, and inadequate waste management have intensified groundwater pollution, posing severe public health risks. Contaminants such as heavy metals, pathogens, and nitrates are linked to diseases including cholera, kidney disorders, methemoglobinemia, and cancer. Despite existing guidelines from the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ), regulatory enforcement remains weak, and monitoring systems are underdeveloped.

Geographic Information Systems (GIS) have emerged as powerful tools for visualizing and analysing spatial patterns of environmental contamination. In Uyo, Akwa Ibom State, groundwater is extensively used for domestic purposes, yet systematic studies on its quality and health implications are limited. This study leverages GIS to assess groundwater suitability and delineate high-risk zones, providing a scientific basis for public health advisories and policy formulation.

MATERIALS AND METHODS

The study was conducted in Uyo Capital City, located between latitudes 4°58'N and 5°04'N and longitudes 7°51'E and 8°01'E as shown in Figure 1. The study area is one of the fastest growing city in Nigeria since it assumed the status a state capital as a result of the creation of Akwa Ibom State in 1987. The Uyo Capital City extends by a radius of 10 km from the city centre with an area coverage of about 214.31 km^2 (Ekpenyong et al., 2019). The area encompassed about 99 settlements with the population of 148,922 people.

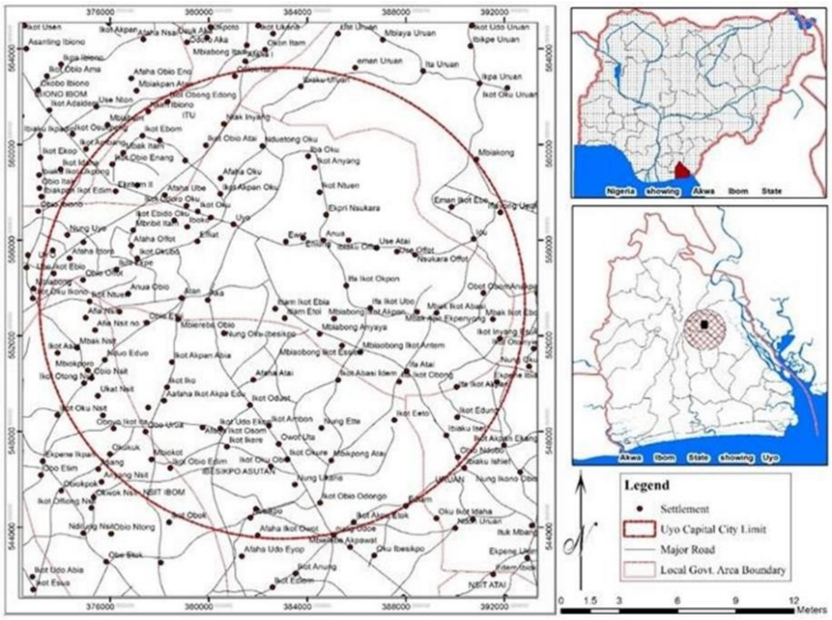

Figure 1: Location of Uyo Capital City (the study area) on the map of Akwa Ibom State

Forty borehole water samples as indicated in Figure 2 were purposively collected from urban (domestic, commercial, industrial) and rural (control) areas. The In-situ measurements of pH, electrical conductivity (EC), and total dissolved solids (TDS) were performed using a digital meter. Laboratory analyses were conducted for total coliform, nitrate, iron, cadmium, and nickel using standard methods (APHA, 2017). The geospatial data such as based maps were processed and the water parameters modelled using ArcGIS and Erdas Imagine software. Each water quality parameter was rasterized, classified based on WHO/NSDWQ standards, and assigned a weight according to its health significance. A suitability map was generated using weighted overlay analysis, categorising areas as “suitable,” “slightly unsuitable,” or “unsuitable” for drinking.

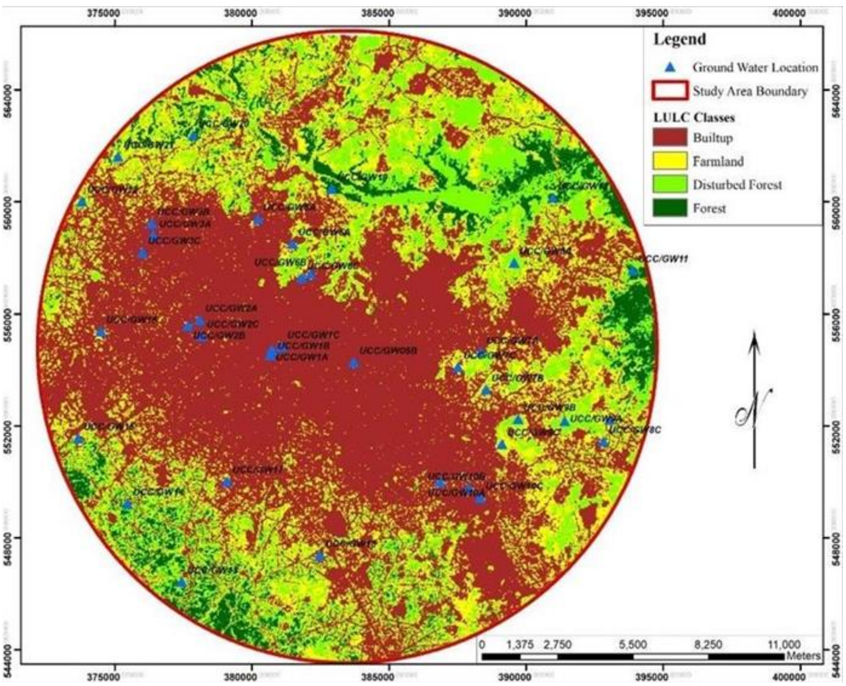

Figure 2: The Location of Ground Water Sampled Points on Image Map of the Study Area

Source: Researcher’s filed work, 2025

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RESULTS AND DISCUSSION

Groundwater Quality Status: Findings from the water samples, as shown in Table 1 and Figures 3–7, revealed systemic contamination that poses significant public health risks. A comparison with World Health Organisation (WHO) guidelines for drinking-water quality highlights multiple, concurrent exceedances, indicating a water security crisis (WHO, 2017).

Table 1: Result of Sampled Water Parameters

SN	Location Type	Location	pH	Elec. Cond.	Total Dissolved Solid	Total Coliform (CFU/100 ml)	Total Hetero-trophic Bacteria (CFU/ml)	Nitrate mg/l)	Iron (mg/l)	Cadmium (mg/l)	Nickel (mg/l)
1	Urban	UCC/GW1A	5.52	104.2	72.8	10	18	1.25	0.65	0.055	<0.001
2	Urban	UCC/GW1B	4.98	476	33.5	8	21	2.03	0.48	0.051	<0.001
3	Urban	UCC/GW1C	5.37	26.5	18.7	14	25	1.33	0.39	0.032	<0.001
4	Urban	UCC/GW2A	4.46	132.9	93.5	14	22	2.45	0.42	0.216	0.032
5	Urban	UCC/GW2B	3.77	657	463	16	27	2.36	0.37	0.122	0.059
6	Urban	UCC/GW2C	4.5	97.6	69.5	15	24	2.74	0.55	0.101	0.004
7	Urban	UCC/GW3A	4.45	55.7	39.7	17	30	1.32	0.5	0.005	<0.001
8	Urban	UCC/GW3B	4.25	86.9	61.6	15	28	1.55	0.58	0.002	<0.001
9	Urban	UCC/GW3C	4.89	38.5	27.1	10	22	1.42	0.63	0.003	<0.001
10	Urban	UCC/GW4A	4.66	43.2	30.8	6	18	1.6	0.38	<0.001	<0.001
11	Urban	UCC/GW4B	4.75	31.1	22.1	3	11	1.72	0.36	<0.001	<0.001
12	Urban	UCC/GW5A	4.36	38.1	27.1	15	23	2.02	0.8	0.108	0.012
13	Urban	UCC/GW6A	5.23	60.3	43.1	8	16	2.31	0.75	0.2	0.005
14	Urban	UCC/GW6B	4.22	292	206	13	18	1.65	0.33	0.013	<0.001
15	Urban	UCC/GW6C	4.16	476	339	2	16	1.38	0.74	<0.001	<0.001
16	Urban	UCC/GW5B	4.52	149.5	105	4	13	1.23	0.49	<0.001	<0.001
17	Urban	UCC/GW7A	6.58	20.5	15	2	7	1.04	0.41	<0.001	<0.001
18	Urban	UCC/GW7B	5.39	30.7	21.9	5	10	1.15	0.52	<0.001	<0.001
19	Urban	UCC/GW7C	5.73	26.9	19	2	8	1.21	0.63	<0.001	<0.001
20	Urban	UCC/GW8A	5.59	29.2	29	3	11	0.78	1.43	<0.001	<0.001
21	Urban	UCC/GW8B	5.99	40.6	28.7	7	14	0.54	1.55	0.005	<0.001
22	Urban	UCC/GW8C	6.26	36.1	25.6	4	9	0.68	1.28	<0.001	<0.001
23	Rural	UCC/GW9A	6.05	27.7	19.5	9	13	1.08	1.14	0.004	<0.001
24	Rural	UCC/GW9B	5.65	24.7	23.1	6	15	0.84	1.18	0.008	<0.001
25	Rural	UCC/GW9C	5.16	36.3	25.7	3	10	1.01	1.22	0.003	<0.001
26	Rural	UCC/GW10A	4.36	106.7	75.4	10	16	0.71	0.53	<0.001	<0.001
27	Rural	UCC/GW10B	5.72	30.3	21.5	6	12	0.55	0.57	<0.001	<0.001

28	Rural	UCC/GW10C	5.55	23	16.4	7	16	0.64	0.6	<0.001	<0.001
29	Rural	UCC/GW11	6.67	105.6	78.2	2	10	0.77	0.45	<0.001	<0.001
30	Rural	UCC/GW12	5.37	140.9	100	5	13	0.56	0.38	<0.001	<0.001
31	Rural	UCC/GW13	5.32	39.4	27.9	7	16	0.75	0.5	<0.001	<0.001
32	Rural	UCC/GW14	6.05	43.8	30.9	5	14	0.67	0.51	<0.001	<0.001
33	Rural	UCC/GW15	6.3	14.4	10.2	3	12	0.66	0.44	<0.001	<0.001
34	Rural	UCC/GW16	4.73	333	236	6	13	0.72	0.49	<0.001	<0.001
35	Rural	UCC/GW17	6.33	49.6	35.1	4	11	0.82	0.42	<0.001	<0.001
36	Rural	UCC/GW18	6.13	32	22.3	7	15	0.65	0.5	<0.001	<0.001
37	Rural	UCC/GW19	5.88	40.7	31.8	3	10	0.55	0.43	<0.001	<0.001
38	Rural	UCC/GW20	5.01	41.3	36.9	5	12	0.48	0.47	<0.001	<0.001
39	Rural	UCC/GW21	6.09	17.5	12.3	2	9	0.7	0.46	<0.001	<0.001
40	Rural	UCC/GW22	6.13	18.5	13.6	6	01:03	0.57	0.54	<0.001	<0.001

Source: Researcher’s Field/Laboratory Analysis, 2025

The pH ranged from 3.77 to 6.67, with 90% of samples below WHO’s acceptable range (6.5–8.5). The groundwater in Uyo is predominantly acidic, with urban samples showing severe acidity (as low as 3.77 at GW2B). Only two samples (GW7A at 6.58 and GW11 at 6.67) approach the lower limit. Chronic consumption of acidic water can corrode distribution pipes, leaching metals like iron and cadmium into the water, and may cause gastrointestinal irritation (Akpan & Udosen, 2019).

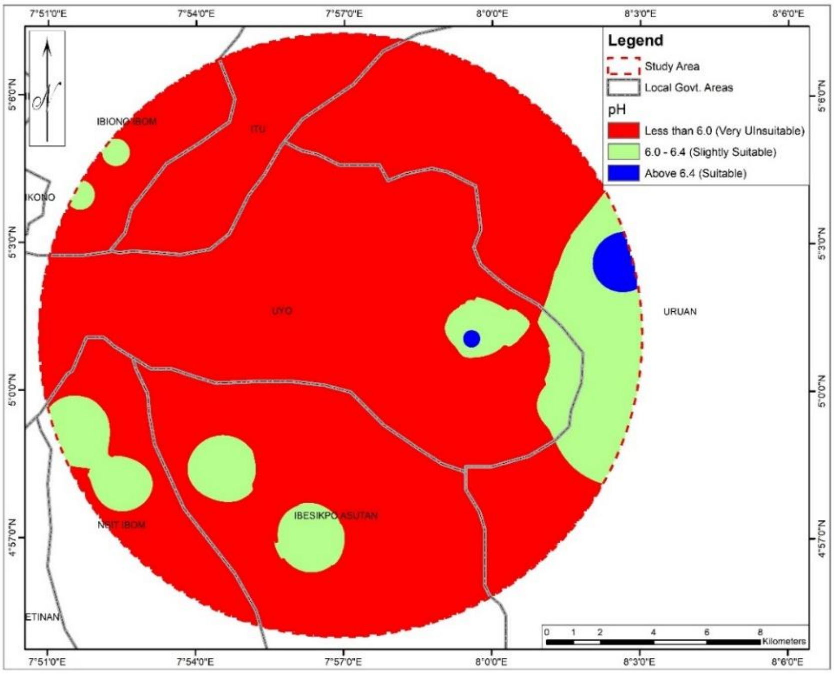

Figure 3. Distribution of pH based on WHO (2017) suitability limit.

Microbiological Contamination (Total Coliform & Heterotrophic Bacteria): The WHO stipulates that E. coli or thermotolerant coliform bacteria, key indicators of faecal contamination, must not be detectable in any 100 ml sample. The presence of Total Coliform (2–17 CFU/100ml) and high Heterotrophic Bacterial counts (7–30 CFU/ml) in nearly all samples, particularly in urban centres, indicates widespread faecal pollution from inadequate sanitation, septic tank leakage, or surface water ingress. This represents the most immediate public health threat, signalling a high risk of waterborne diseases such as typhoid, cholera, and dysentery.

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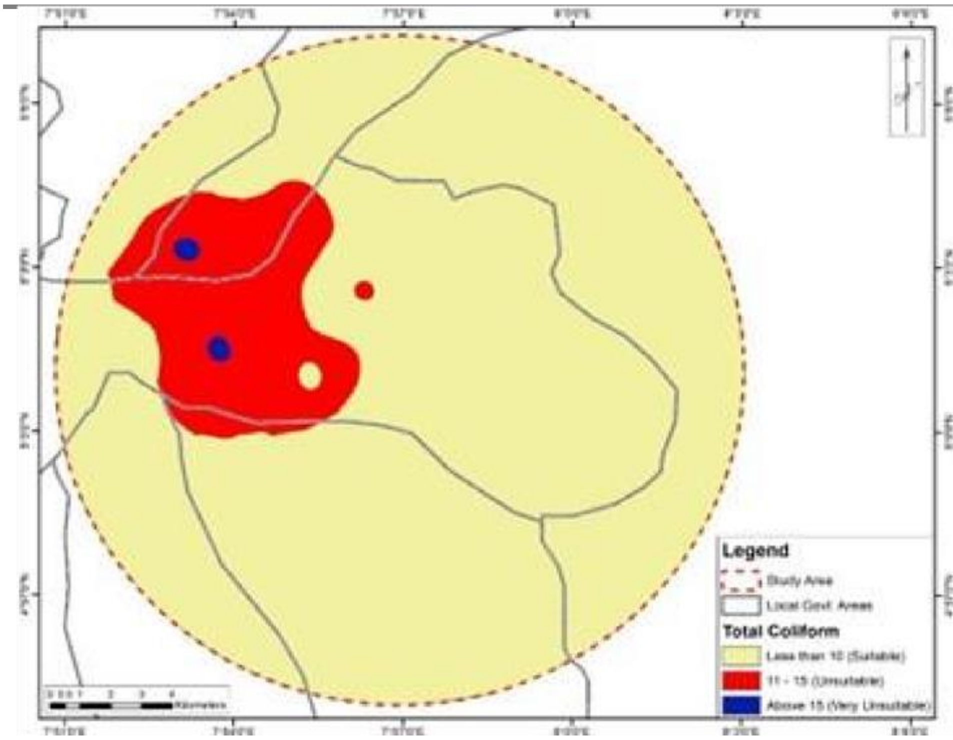

Figure 4: Distribution of Total Coliform based on WHO (2017) suitability limit

Heavy Metals like Cadmium was alarmingly as many urban samples showed extreme exceedances of the WHO permissible limit is 0.003 mg/L. With values like 0.216 mg/L (GW2A) and 0.2 mg/L (GW6A) exceeding the limit by over 70 times. Cadmium is a potent cumulative toxicant, causing kidney damage, bone demineralization, and is classified as a human carcinogen (IARC, 2012). The source is likely anthropogenic, linked to improper industrial waste disposal, electronic waste (e-waste) dumping, or corrosion of galvanised pipes in the acidic environment. Iron wasn't as toxic as cadmium, iron concentrations (0.33–1.55 mg/L) exceed the WHO aesthetic guideline of 0.3 mg/L in most samples. This causes unpleasant taste, odour, and staining, which can drive communities to seek alternative, potentially unsafe water sources. High iron can also promote bacterial growth in distribution systems.

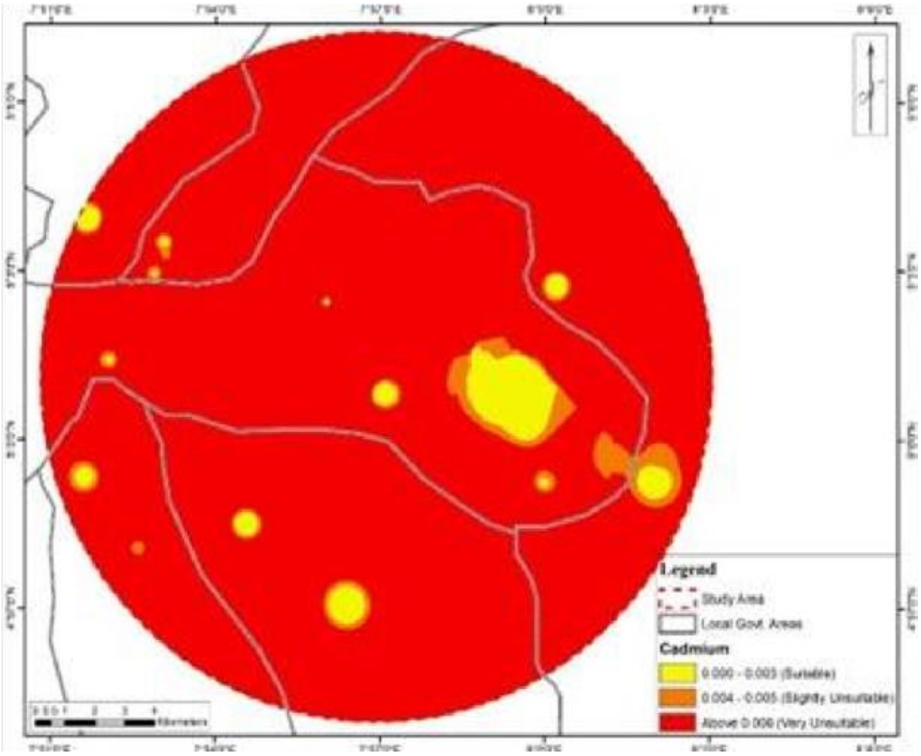

Figure 5: Distribution of Cadmium based on WHO (2017) suitability limit

Nitrate and Other Parameters: Nitrate levels (0.48–2.74 mg/L) are currently within the WHO limit of 50 mg/L, indicating minimal immediate threat from agricultural runoff. Nickel levels are mostly below detection, and Total Dissolved Solids (TDS) and Electrical Conductivity are generally low, suggesting overall low salinity.

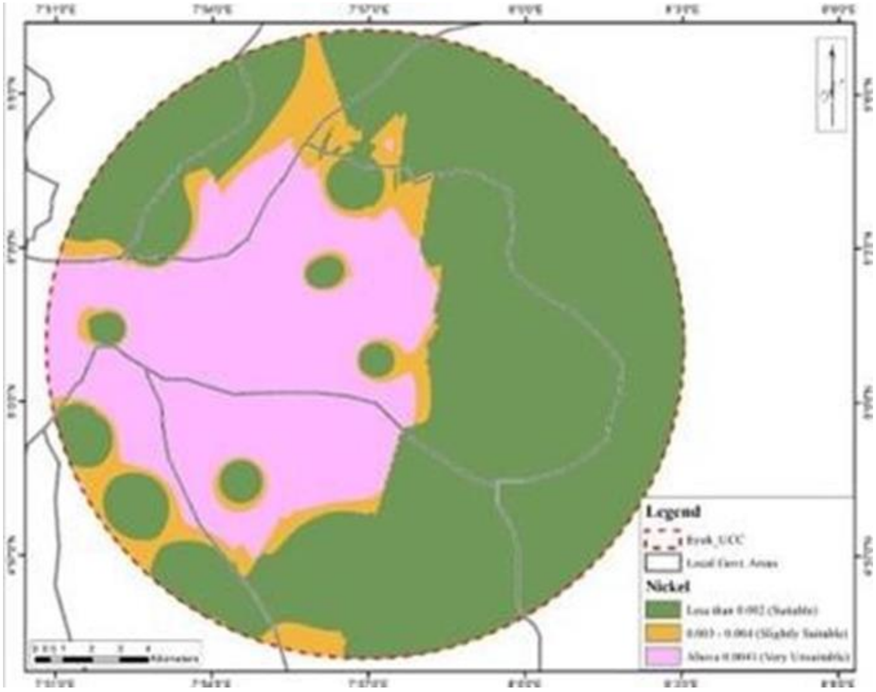

Figure 6: Distribution of Nickel based on WHO (2017) and NSDWQ (2008) suitability limit.

Spatial Distribution: The GIS mapping shown in Figures 3 to 6 revealed a clear urban-rural divide. Urban core areas including Uyo Village, Effiat, Anua Obio, and Idoro were classified as "very unsuitable" for almost all the parameters. Peripheral rural areas such as Ikot Otong Nsit and Nung Ette were "suitable." Transitional zones showed "slightly unsuitable" quality.

The contamination patterns aligned with anthropogenic activities: low pH correlates with industrial emissions and organic decay; elevated coliform indicates sewage infiltration; cadmium and nickel point to industrial and waste disposal sources. These pollutants pose documented health risks, cadmium is nephrotoxic, coliform indicates pathogenic risk, and low pH exacerbates heavy metal leaching and corrosion. (55.8% of the study area's population) are exposed to unsuitable groundwater, primarily in urban zones.

The absence of a regulatory framework for private borehole testing exacerbates public health risks. Current policies do not mandate pre-commissioning water quality checks, leaving users vulnerable. GIS-based suitability maps offer actionable intelligence for targeted intervention, such as installing treatment systems in high-risk areas and prioritizing sanitation infrastructure upgrades.

Assessment of Institutional framework for water in Akwa Ibom State.

Fragmentation & Overlap: Multiple agencies share responsibility for water quality, but coordination is poor. For example, borehole licensing is under the Ministry of Lands and Water Resources, while pollution control falls under the Ministry of Environment. Ansa, *et al* (2025), Uzoma, (2022)

Weak Enforcement: Regulations exist but are rarely enforced. Many private boreholes operate without proper water quality testing. (Ansa, *et al* 2025)

Capacity Gaps: Institutions lack adequate laboratories, trained personnel, and monitoring equipment. (Uzoma, 2022)

Urban vs. Rural Divide: Urban areas benefit from AKSWC, though inconsistently, while rural communities rely heavily on unregulated boreholes and wells. (Ansa, *et al* 2025)

Policy Disconnect: Federal water quality standards are not fully localized or enforced at the state level. (Uzoma, 2022)

CONCLUSION

Groundwater contamination in Uyo capital city represents a significant public health threat, disproportionately affecting urban populations. GIS-based assessment provides a transparent, spatial framework for identifying risk hotspots and guiding policy action. Without urgent regulatory and infrastructural interventions, waterborne diseases and chronic health conditions will continue to rise. This study advocates for a proactive, data-driven approach to groundwater management, aligning with Sustainable Development Goal 6 (clean water and sanitation).

RECOMMENDATIONS

- Mandatory Borehole Testing: Enact laws requiring water quality testing before borehole commissioning and annual re-testing.
- Centralized Water Treatment: Revamp and expand public water treatment facilities to reduce dependence on untreated groundwater.
- Waste Management Reform: Implement stricter controls on industrial discharge, landfill management, and sewage treatment.
- Public Health Campaigns: Use media to educate communities on groundwater risks and safe water practices.
- GIS Monitoring System: Develop a state-wide groundwater quality database with real-time monitoring and public access to maps and reports.
- Interagency Collaboration: Strengthen coordination between environmental, health, and urban planning agencies for integrated water governance.

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