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GROUNDWATER QUALITY ASSESSMENT AND MAPPING IN UYO CAPITAL CITY, NIGERIA: A GIS-BASED APPROACH

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Abstract

Background: Groundwater from commercial boreholes is a major source of drinking water in urban areas, yet its quality is often compromised by poor siting and inadequate treatment. This study assessed the physicochemical and microbial quality of water from commercial boreholes in Uyo Capital City, Nigeria.

Methodology: Water samples were collected from seven commercial boreholes and analyzed for 17 parameters including pH, conductivity, turbidity, TSS, TDS, chloride, bicarbonate, total hardness, calcium, magnesium, sulphate, total iron, nitrate, sodium, lead, total coliforms, and faecal contamination. Results were compared with WHO and Federal Ministry of Environment standards. Inverse Distance Weighting (IDW) spatial interpolation in ArcGIS 10.7 was applied to generate continuous surface maps of key contaminants.

Results: The findings revealed widespread non-compliance with drinking water standards. pH ranged from 4.5 to 6.61, with most samples below the acceptable limit of 6.5-8.5. Total coliform counts (30-40 CFU/100ml) exceeded the 20 CFU/100ml standard, and faecal contamination (20-40 CFU/100ml) was detected at all sites, violating the required 0 CFU/100ml. Other parameters such as conductivity, TDS, chloride, and sulphate fell within acceptable ranges. IDW interpolation successfully visualized contamination hotspots, particularly for microbial parameters and pH, indicating influence from proximate septic tanks and soakaways.

Conclusion: Commercial boreholes in Uyo do not fully comply with drinking water standards and pose potential health risks. GIS-based IDW interpolation proved to be a valuable tool for groundwater quality monitoring and public health protection.

Recommendations: The study recommends enhanced regulatory enforcement, regular monitoring programmes, improved borehole siting regulations with adequate separation distances from contamination sources, appropriate water treatment such as disinfection and pH adjustment, and public awareness campaigns on the health risks of consuming untreated borehole water. ‘

Keywords: Groundwater quality, IDW, GIS, physicochemical parameters, microbial contamination, Uyo

INTRODUCTION

Water is fundamentally essential for human survival and development, serving as a critical factor in the growth and well-being of communities worldwide (Mshelia & Mbaya, 2024). The availability of safe and clean water directly influences public health, economic productivity, and overall quality of life. However, the degree of water contamination is increasingly influenced by prevailing human activities, making water quality assessment an urgent priority for

environmental management and public health protection (Mshelia & Mbaya, 2024). The issue of water impurity and associated health risks stems from multiple interconnected factors, including rapid population growth, particularly in urban centres of developing nations, which has placed unprecedented pressure on water resources and sanitation infrastructure (Chidiac *et al.,* 2023).

Poor waste management practices, inadequate sanitation systems, absence of wastewater collection networks and functional treatment plants, deteriorating soakaways and septic tanks, and unsanitary conditions surrounding wells and boreholes collectively contribute to deteriorating water quality (Chen *et al.,* 2020; Choi & Choi, 2021). Of particular concern is the dangerous proximity of water sources to contamination sources such as soakaways, pit toilets, and wastewater channels in metropolitan areas (Samandra *et al*., 2022; Mshelia *et al.,* 2023). Industrial and domestic wastewater further exacerbates contamination through infiltration into groundwater at various locations across urban centres globally (Gamvroula & Alexakis, 2022; Makubura *et al.*, 2022; Mshelia *et al.*, 2020; Mshelia *et al*., 2022).

Groundwater, stored in aquifers beneath the Earth's surface, constitutes the world's largest distributed store of freshwater, accessed primarily through boreholes, and serves as a critical resource for human consumption, agricultural irrigation, and industrial development across all continents (Raimi *et al.,* 2019). In urban areas, households typically face two primary options for water supply: private boreholes or commercial borehole-connected systems. The quality and safety of water from these sources have been subjects of extensive research, with important implications for public health policy and urban planning (Omorogieva *et al*., 2024). Private boreholes theoretically offer homeowners a degree of control over water quality through personal monitoring and maintenance. Conversely, commercial borehole systems, which require effective treatment protocols, systematic monitoring, and regular maintenance, theoretically provide safer service delivery to water users (Omorogieva *et al.,* 2024).

Literature suggests that commercial borehole-connected systems tend to provide more consistently high-quality water, potentially reducing health risks for urban households when properly regulated and maintained (Okhuebor & Izevbuwa, 2020). Commercial boreholes serve as essential components of water supply systems, typically established and maintained by governmental bodies, water supply agencies, private companies, and sometimes households operating water vending businesses (Raimi *et al*., 2019). Unlike private boreholes, commercial ones ideally operate under regulatory oversight and are subject to monitoring to ensure compliance with water quality standards. The World Health Organisation (WHO) has established comprehensive guidelines for safe drinking water quality, encompassing parameters such as pH levels, turbidity, microbial contamination, and chemical composition (Oyerinde & Jacobs, 2022; WHO, 2022). These guidelines serve as benchmarks for borehole

operators and regulatory authorities in safeguarding public health.

Despite the theoretical advantages of regulated commercial boreholes, limited spatial understanding exists regarding whether commercial boreholes in urban centres actually comply with established standards (Mshelia *et al*., 2024). Traditional point-based assessment methods fail to capture continuous spatial variation in groundwater quality, which is essential for identifying pollution hotspots and evaluating compliance with regulatory standards (Gamvroula & Alexakis, 2022). Spatial interpolation techniques, particularly Inverse Distance Weighting (IDW), bridge this gap by estimating values at unsampled locations based on known measurements from surrounding points (Chen *et al*., 2020). This study therefore aimed to: (i) assess the physicochemical and microbial quality of water from seven commercial boreholes across Uyo Capital City; (ii) compare measured parameters against WHO and Ministry of Environment standards; and (iii) apply Inverse Distance Weighting (IDW) interpolation within GIS (ArcMap 10.7) to generate continuous surface maps of water quality parameters across the study area.

MATERIALS AND METHODS

Study Area: The study area (Uyo Capital City) is the capital of Akwa Ibom State, Nigeria. As shown in Figure 1, it is in Latitudes $4^0 58^{II}$ - $5^0 4^{II}$ North and Longitudes $7^0 52^{II}$ - $8^0 00^{II}$ South. The study area represents a typical growing urban landscape in the Niger Delta region, where groundwater serves as the primary source of drinking water for most households (Raimi *et al.*, 2019).

Sampling Techniques: Water samples were collected from seven commercial boreholes located along the roads in Uyo Capital City: Oron Road, Nwaniba Road, Aka Road by Udo Udoma, Ikpa Road by CCC, Abak Road, Mbieriebe Junction, and Ikot Ambang. Samples were collected and stored in accordance with standard groundwater quality detection protocols (DZ/T 0064.2-1993) and tested within 5 days to ensure sample integrity (Mshelia *et al*., 2020).

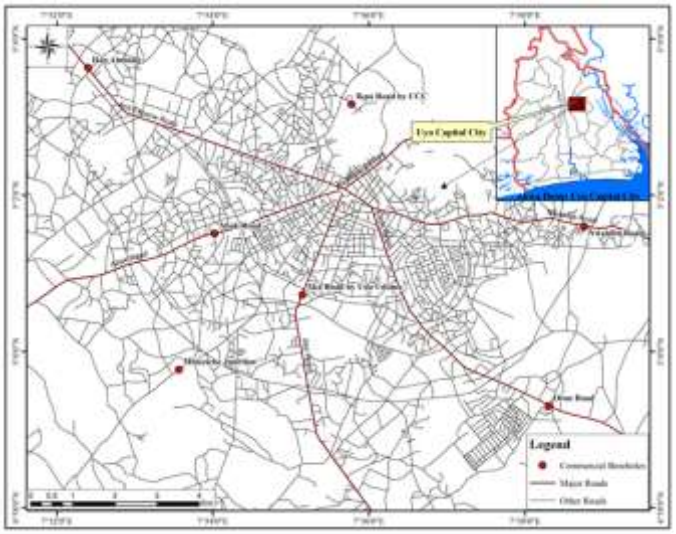

Figure 1: Uyo Capital City showing Sampled Commercial Boreholes

Parameters and Laboratory Analysis: Physical and chemical parameters analysed included copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), chromium (Cr), nickel (Ni), mercury (Hg), arsenic (As), pH, total dissolved solids (TDS), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulphate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-), nitrate (NO_3^-), fluoride (F^-), total coliforms, faecal contamination, conductivity, turbidity, total suspended solids (TSS), total hardness, total iron, and sodium. These parameters were selected based on their documented significance in groundwater quality assessment and human health risk evaluation (Chen *et al*., 2020; Choi & Choi, 2021; Gamvroula & Alexakis, 2022).

In situ measurements of pH and TDS were conducted using a portable measuring instrument (HI98195, HANNA), following standard procedures described by Mshelia *et al.* (2023). Microbial parameters were determined using membrane filtration methods for total coliforms and a multiple-tube fermentation test for faecal contamination, as recommended by Sherchan *et al.* (2022) for faecal source tracking in water systems. Chemical parameters such as calcium, magnesium, sodium, potassium, sulphate, chloride, bicarbonate, nitrate, and fluoride were analysed using ion chromatography and atomic absorption spectrometry (AAS) where appropriate (Omorogieva *et al*., 2024).

GIS and IDW Interpolation: Water quality sample locations, recorded with geographic coordinates (latitude and longitude) alongside the corresponding parameter values, were first organised in an Excel spreadsheet. Each coordinate field was formatted as a numeric column, with a separate column assigned to each water quality parameter of interest (e.g., pH, dissolved oxygen, total dissolved solids, nitrate). This spreadsheet was imported into ArcGIS 10.7 using the Display XY Data function (File → Add Data → Add XY Data), with the Longitude and Latitude columns specified as the X and Y fields, respectively, and the geographic coordinate system set to match the datum of the original data (e.g., GCS_WGS_1984). This process generated a temporary XY event layer, which was subsequently exported to a permanent shapefile or geodatabase feature class to allow it to be used in further geoprocessing operations.

Prior to interpolation, the geoprocessing environment was configured so that the processing extent matched the boundary of the study area, ensuring that the output raster surfaces remained spatially confined and relevant to the region under investigation. An appropriate output cell size was also specified at this stage to balance raster resolution with processing efficiency.

Spatial interpolation was then performed for each water quality parameter using the Inverse Distance Weighting (IDW) tool, accessed via Spatial Analyst Tools → Interpolation → IDW. The exported point feature class served as the input, with each parameter in turn designated as the Z-value field. A power value of 2 was applied, a widely adopted empirical setting that determines the rate at which the influence of a

sampled point decreases with distance from the location being estimated; a search radius (variable, using the default of 12 nearest points) was used to control which surrounding points contributed to each estimate. This procedure produced a continuous raster surface for each parameter, representing its predicted spatial distribution across the study area. Where necessary, the resulting rasters were further refined using the Extract by Mask tool to trim the output precisely to the boundary of the study area. Finally, the interpolated rasters were symbolised in ArcMap using a classified standard deviation scheme, with break values expressed in fractions of a standard deviation from the mean and displayed using colour ramps appropriate to each parameter to enhance visual interpretation of spatial trends. Sample point locations and the study area boundary were overlaid on each map for spatial context, and standard cartographic elements (legend, scale bar, north arrow, and title) were added in Layout View before exporting the final maps for presentation and analysis.

RESULTS AND FINDINGS

Water Quality Assessment: Laboratory results revealed significant variations across the seven boreholes. pH values presented in Table 1 and Figure 2 ranged from 4.5 (BH3) to 6.61 (BH6), with five locations falling below the WHO acceptable range of 6.5–8.5, indicating acidic conditions that may affect taste, corrosivity, and potential for heavy metal mobilisation (WHO, 2022; Mshelia *et al*., 2024). This finding is consistent with previous studies in Nigerian urban centres that have reported acidic groundwater conditions near sanitation infrastructure (Raimi *et al.,* 2019; Oyerinde & Jacobs, 2022). The Total coliform counts indicated in Figure 3 ranged from 30 to 40 CFU, exceeding the WHO-permitted standard of 20 at all sites (WHO, 2022). Faecal contamination was detected in all samples, with values between 20 & 40, violating the mandatory standard of 0. These microbial contamination levels are comparable to those reported by Mshelia *et al.* (2023) in Kano metropolis and by Sherchan *et al.* (2022) in stormwater runoff studies, suggesting widespread faecal pollution of groundwater sources in urban Nigeria.

Table 1: Results from the sample collection in the commercial borehole sites.

Parameters	**BH1** Oron Road	**BH2** Nwaniba Road	**BH3** Aka Road by Udo Udoma	**BH4** Ikpa Road By CCC	**BH5** Abak Road	**BH6** Mbieriebe Junction	**BH7** Ikot Ambang
Ph	5.3	6.3	4.5	5.9	5.1	6.61	5.7
Total Coliforms	40	35	30	40	35	40	30
Faecal Contamination	30	40	20	30	20	35	20
Conductivity (µScm-1)	53.60	118.20	95.80	73.50	74.50	91.00	83.10
Turbidity (NTU)	4.15	4.23	4.66	5.50	5.64	4.21	4.27
Total Suspended Solids (TSS)	11.00	6.67	13.41	13.15	5.12	6.29	6.39
Total Dissolved Solids (TDS)	23.22	13.91	27.16	13.15	33.95	21.56	4.51
Chloride (Cl-) (mgl-1)	24.29	26.21	13.93	15.34	19.91	41.71	25.44
Bicarbonate (HCO3-) (mgl-1)	3.40	-0.10	1.20	0.50	0.40	0.50	1.54

Total Hardness (mgl-1CaCO3)	51.40	31.60	34.60	37.60	39.60	50.60	61.60
Calcium ($Ca2^{+}$) (mgl-1)	25.40	23.50	28.71	26.52	24.60	23.53	26.90
Magnesium ($Mg2^{+}$) (mgl-1)	8.22	9.83	10.41	8.38	8.80	8.41	8.83
Sulphate (SO4 2-) (mgl-1)	0.49	0.03	0.05	0.06	0.03	0.07	0.04
Total Iron (Fe) (mgl-1)	0.47	0.11	1.65	10.40	0.11	0.56	-0.05
Nitrate (NO3-) (mgl-1)	0.07	0.70	0.50	0.06	0.03	0.04	0.51
Sodium (Na+) (mgl-1)	100.40	101.50	110.50	102.50	92.50	112.50	95.50
Lead (Pb) (mgl-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Source: Ministry of Science and Technology, Lab. Analysis Result (2026)

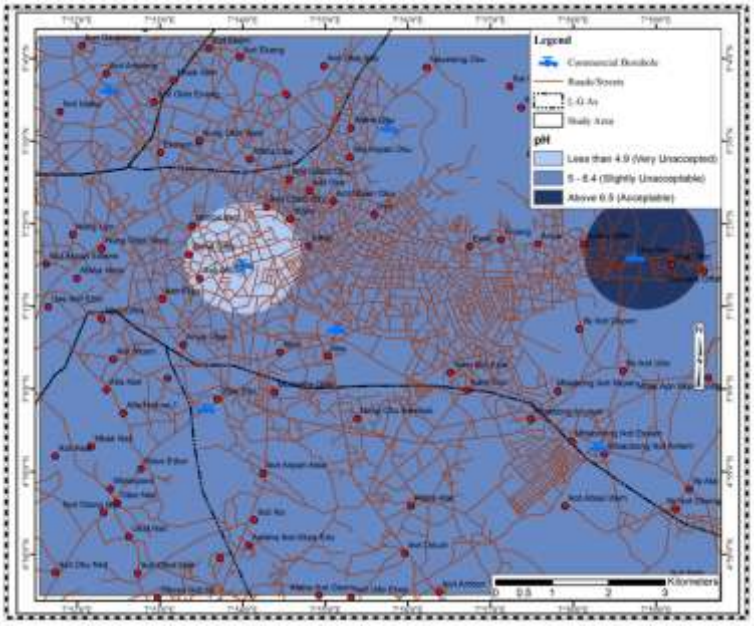

Fig. 2: pH distribution in the study area

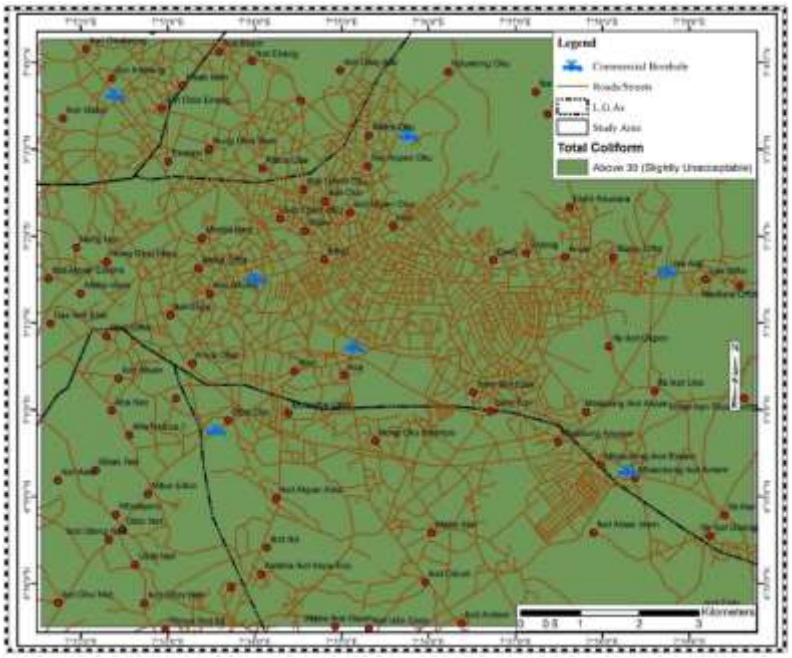

Fig. 3: Distribution of Total Coliform Concentration

Conductivity in Figure 4, which ranged from 53.60 to 118.20 µScm⁻¹, is well within the WHO limit of <843 µScm⁻¹, indicating that dissolved ion concentrations were generally acceptable (WHO, 2022) . In Figure 5,

Turbidity ranged from 4.15 to 5.64 NTU, with BH4 and BH5 exceeding the 5 NTU standard, suggesting the presence of suspended particles that may harbour pathogens (Oyerinde & Jacobs, 2022). Total suspended solids in Figure 6 ranged from 5.12 to 13.41 mg/L, exceeding the 5 mg/L standard at most locations, which is consistent with findings from industrial areas reported by Mshelia *et al*. (2020). Total dissolved solids (4.51–33.95 mg/L) shown in Figure 7 were within the 500 mg/L limit, indicating that dissolved mineral content did not pose a health risk (WHO, 2022).

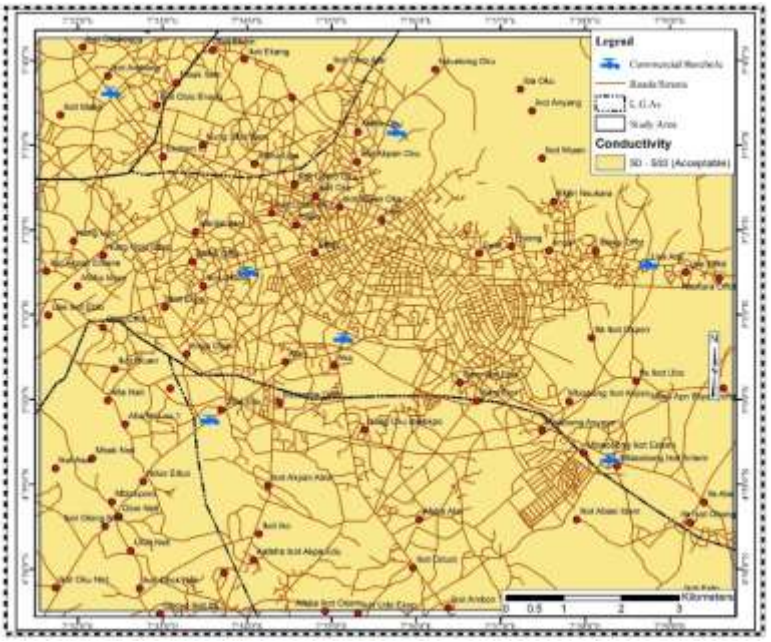

Fig. 4: Distribution of Conductivity Concentration

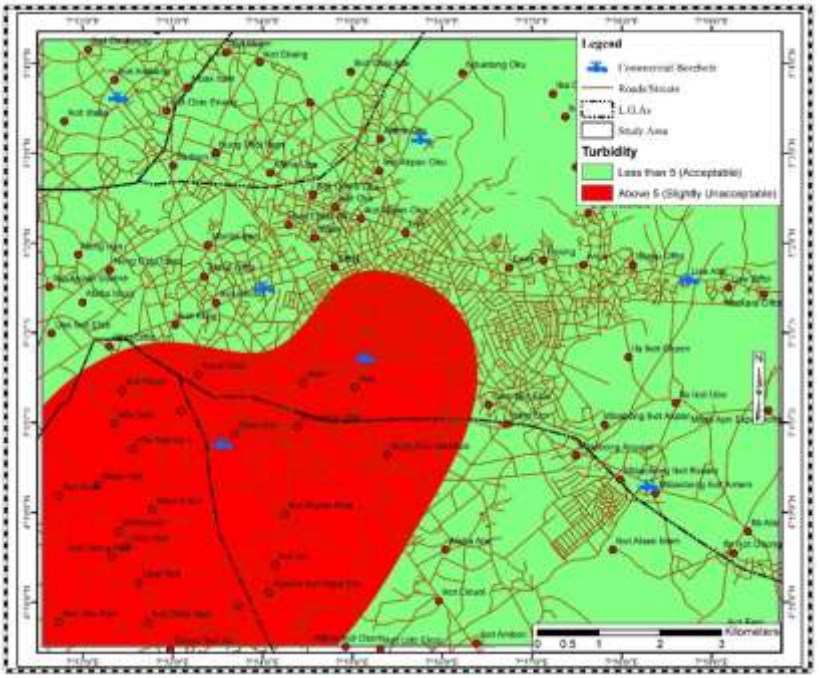

Fig. 5: Distribution of Turbidity

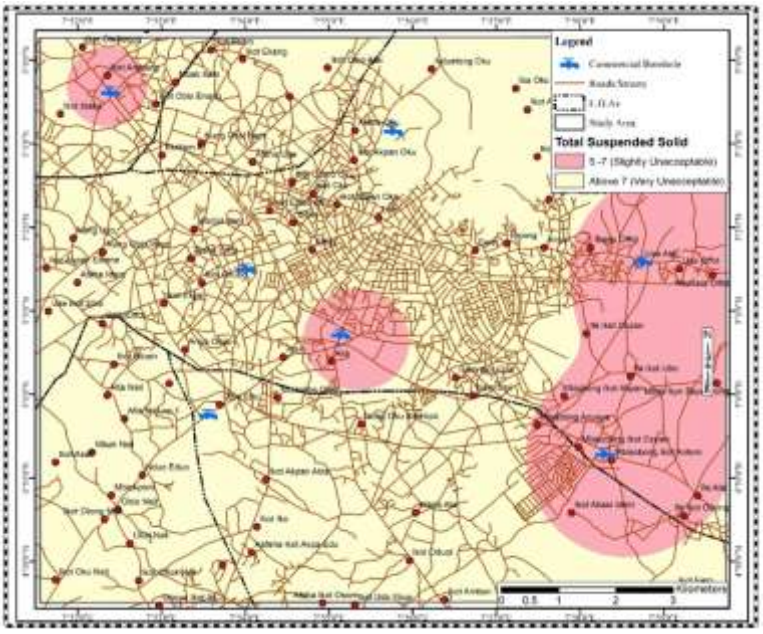

Fig. 6: Distribution of Total Suspended Solids

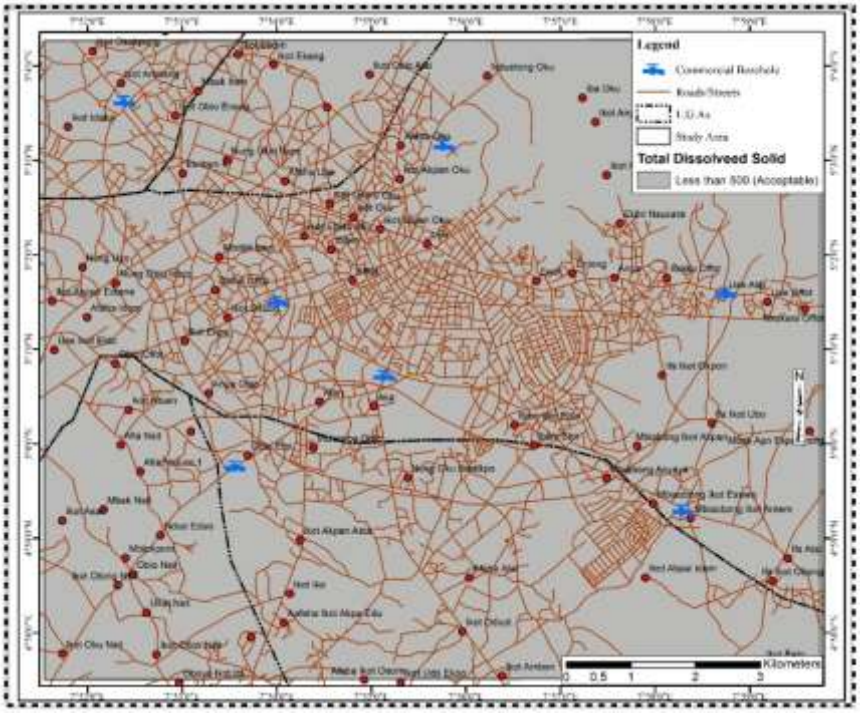

Fig. 7: Distribution of Total Dissolved Solids

Chloride (13.93–41.71 mg/L) and bicarbonate (-0.10–3.40 mg/L) in Figures 8 and 9, respectively, were within acceptable ranges, suggesting minimal influence from saline intrusion or industrial effluents (Chen *et al*., 2020). Total hardness (31.60–61.60 mg/L) in Figure 10 was classified as soft to moderately hard, well below the 500 mg/L standard, and comparable to values reported by Gamvroula and Alexakis (2022) in Greek aquifers. The Figures 11 and 12, Calcium (23.50–28.71 mg/L) and magnesium (8.22–10.41 mg/L) concentrations were within WHO standards and similar to those reported by Omorogieva *et al*. (2024) in Benin City, Nigeria. Sulphate (0.03–0.49 mg/L), shown in Figure 13, fell within WHO acceptable ranges, indicating no

significant influence from industrial sources or atmospheric deposition (Choi & Choi, 2021).

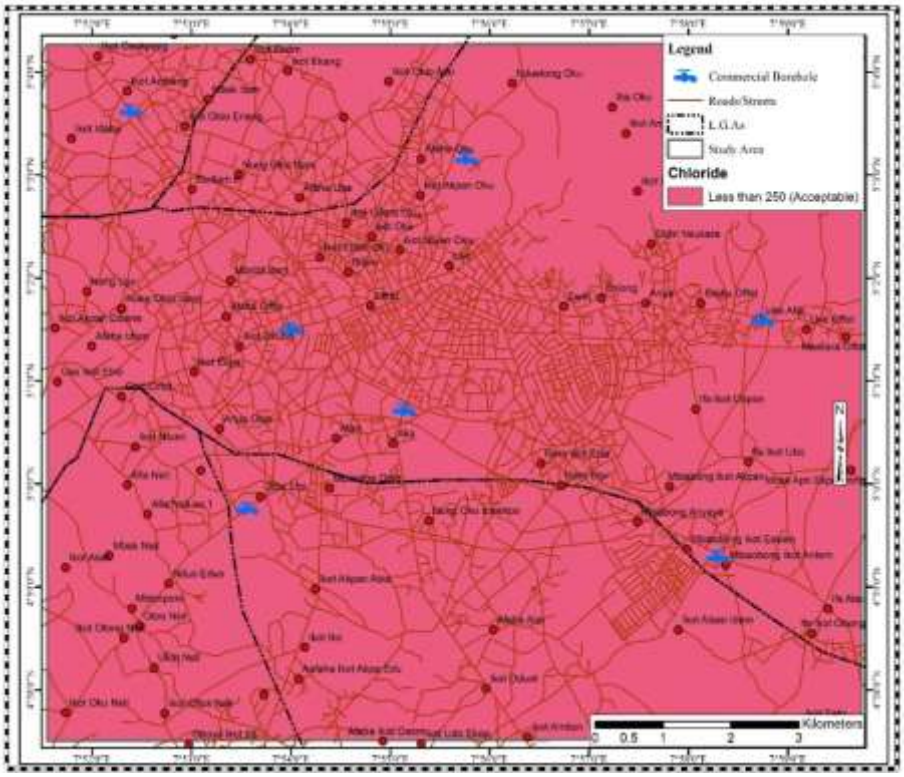

Fig. 8: Distribution of Chloride (Cl-mgl-1)

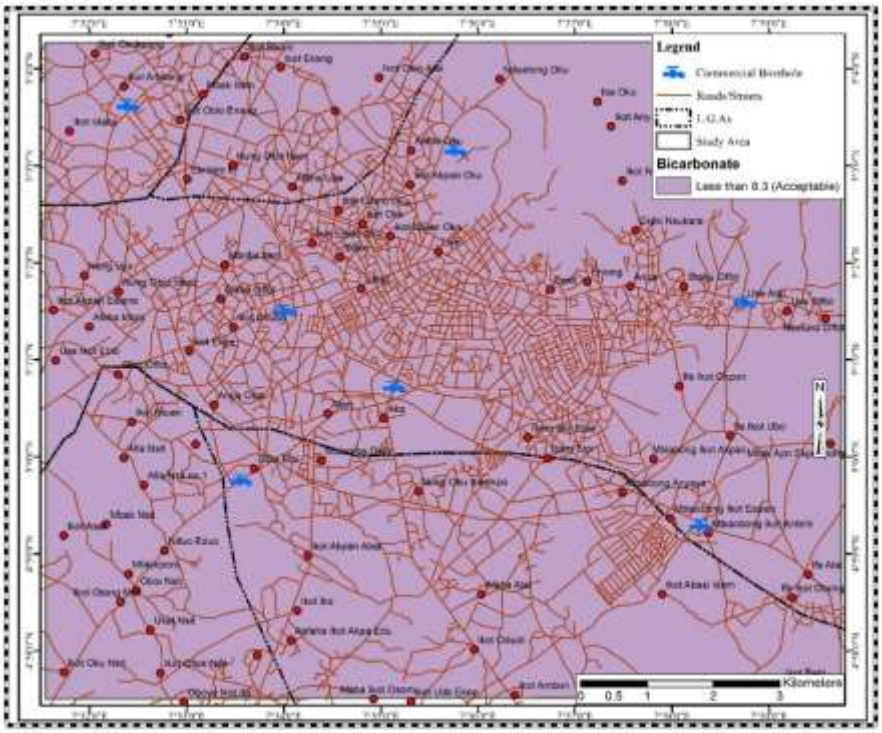

Fig 9: Distribution of Bicarbonate

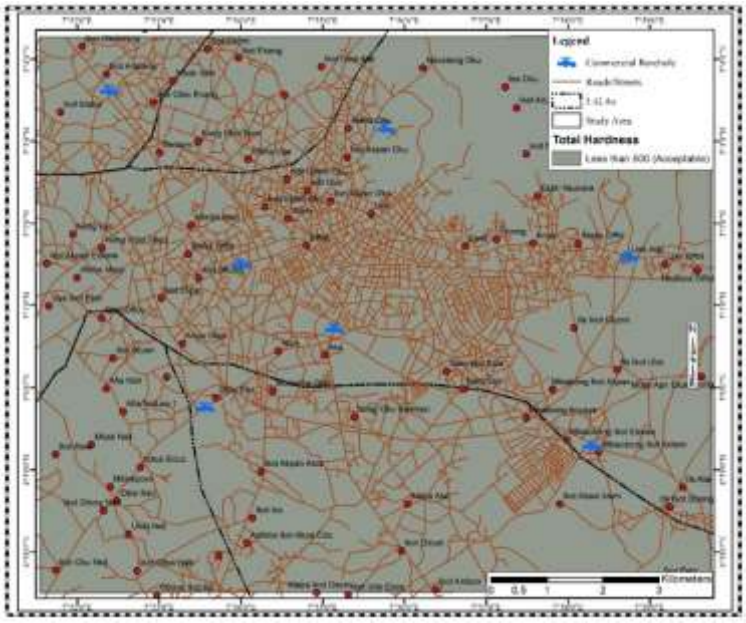

Fig. 10: Distribution of Total Hardness

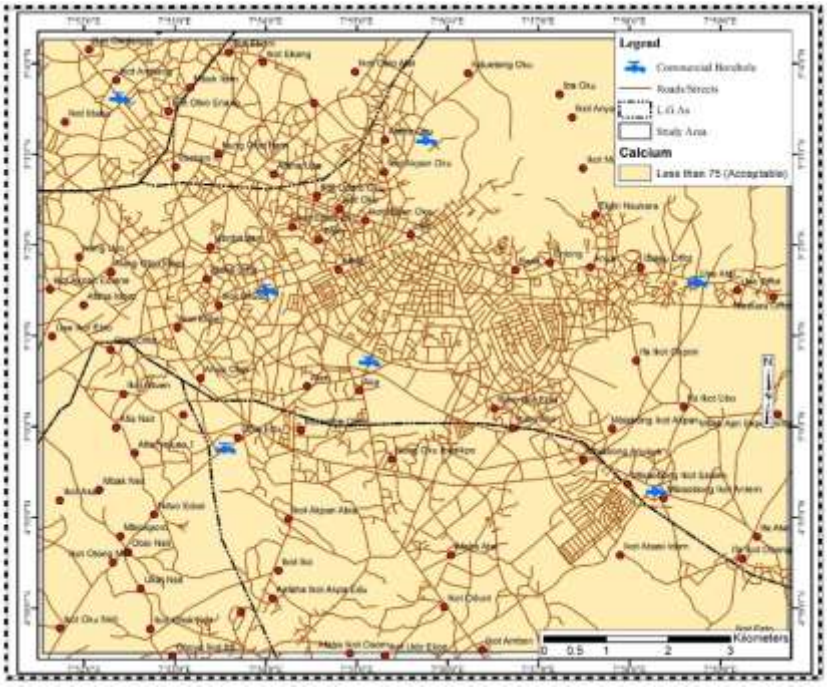

Fig. 11: Distribution of Calcium concentration

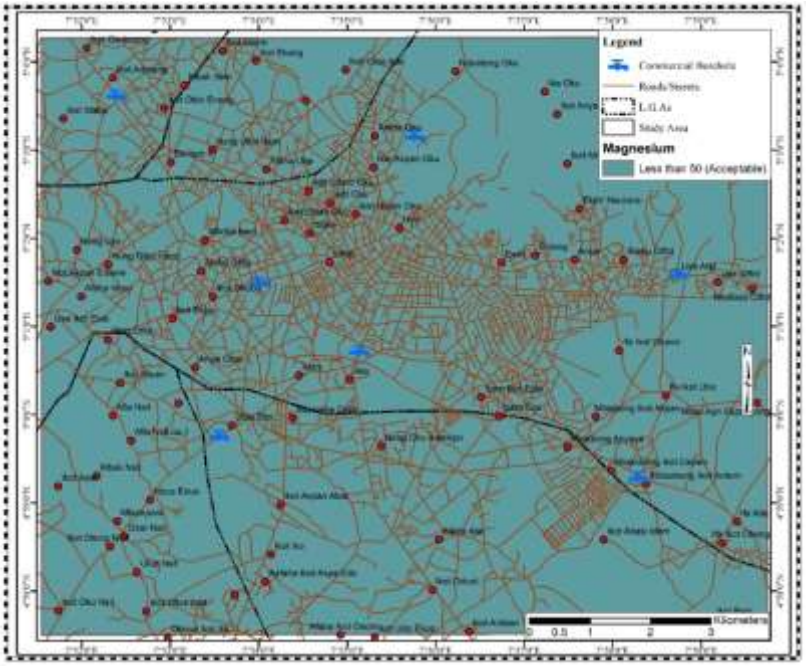

Fig. 12: Distribution of Magnesium

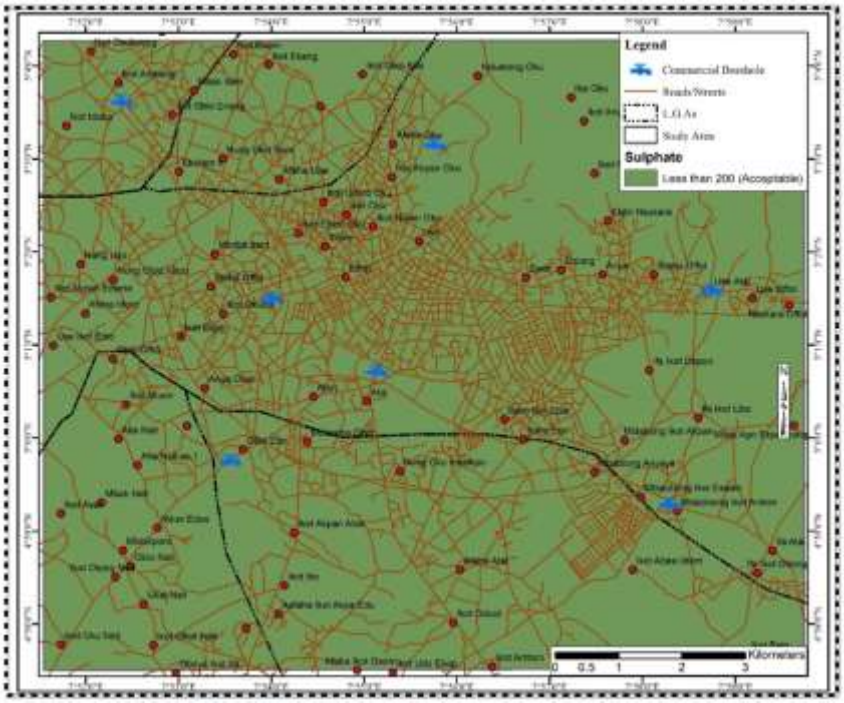

Fig. 13: Distribution of Sulphate Concentration

Total iron presented in Figure 14 ranged from -0.05 to 10.40 mg/L, with BH4 showing elevated levels (10.40 mg/L) exceeding the 0.3–0.5 mg/L standard. This finding is consistent with Mshelia et al. (2022), who reported elevated iron concentrations in borehole water near industrial activities. Nitrate (0.03–0.70 mg/L) and sodium (92.50–112.50 mg/L) were within acceptable ranges, suggesting that agricultural runoff and sewage infiltration were not major contributors at the time of sampling (Chen *et al*., 2020). Lead was below the detection limit (<0.001 mg/L) at all sites, which is reassuring given the documented health risks of lead exposure (WHO, 2022; Makubura *et al*., 2022).

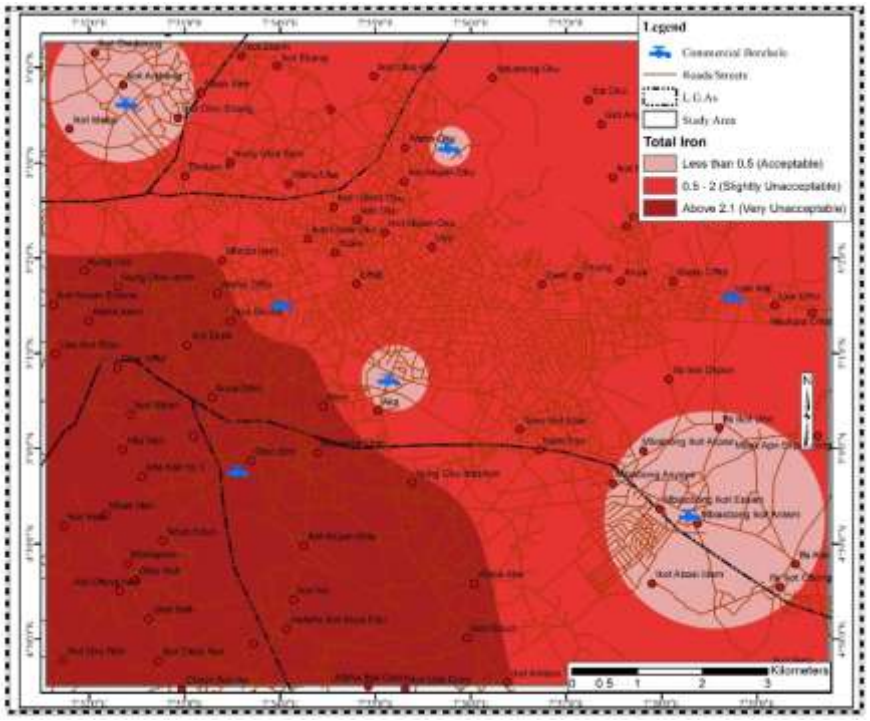

Fig. 14: Distribution of Total Iron concentration

GIS-Based Spatial Distribution: The IDW interpolation generated continuous surface maps for all 14 parameters. The pH distribution map showed widespread unsuitability across most of the study area, with acidic conditions concentrated near locations with high densities of septic tanks and soakaways. This spatial pattern aligns with the findings of Mshelia *et al*. (2024), who demonstrated that proximity to sanitation infrastructure significantly influences groundwater pH.

Total coliform and faecal contamination maps revealed that microbial contamination was the most serious concern, with spatial patterns suggesting strong influence from nearby septic tanks, soakaways, and wastewater channels. These findings corroborate Samandra *et al*. (2022), who documented similar spatial relationships between faecal contamination sources and groundwater quality in metropolitan areas. The IDW surfaces effectively highlighted contamination hotspots that would not have been identifiable using traditional point-based assessment methods alone.

Conductivity, TDS, chloride, bicarbonate, total hardness, calcium, magnesium, and sulphate maps demonstrated general compliance with WHO standards across the study area, with relatively uniform spatial distributions suggesting natural geological controls rather than anthropogenic influences. Total iron distribution showed localised contamination hotspots, particularly in areas coloured red and maroon, which may be associated with localised corrosion of borehole casings or natural geological enrichment. Turbidity and TSS maps indicated unacceptable levels in several locations, with spatial patterns suggesting contributions from surface runoff and poor wellhead protection.

SUMMARY

This study investigated the quality of water from seven commercial boreholes in Uyo Capital City using laboratory analysis and GIS-based IDW interpolation. Key findings showed that microbial contamination (total coliforms and faecal coliforms) and acidic pH were the most critical violations of WHO and Ministry of Environment standards, present at nearly all sampling locations. These results are consistent with a growing body of literature documenting groundwater contamination in Nigerian urban centres (Raimi *et al.,* 2019; Mshelia *et al*., 2020; Mshelia *et al*., 2023; Oyerinde & Jacobs, 2022; Omorogieva *et al*., 2024). Parameters such as conductivity, TDS, chloride, total hardness, calcium, magnesium, and sulphate were generally within acceptable limits, suggesting that natural geological conditions in the study area are favourable for these parameters. The IDW interpolation technique successfully transformed discrete point measurements into continuous surface maps, revealing spatial contamination patterns linked to proximity of sanitation infrastructure, consistent with the findings of Samandra *et al*. (2022) and Mshelia *et al*. (2024). The study confirms that commercial borehole water quality in Uyo does not fully comply with safety standards, posing potential health risks to consumers, and demonstrates that GIS-based spatial interpolation is a valuable tool for groundwater quality monitoring and public health protection.

CONCLUSION

This study concludes that commercial boreholes in Uyo Capital City indicate significant compliance failures, particularly regarding microbial water quality and pH levels, with all seven sampling locations exhibiting unacceptable levels of total coliforms and faecal contamination. These findings highlight a critical gap between the theoretical safety assurances of regulated commercial borehole systems and actual water quality delivered to consumers, a problem that had previously been documented across multiple Nigerian urban centres (Raimi *et al*., 2019; Mshelia *et al.,* 2024). The spatial patterns revealed through GIS-based IDW interpolation strongly suggest that groundwater contamination is influenced by the proximity of boreholes to sanitation infrastructure, including septic tanks, soakaways, and wastewater channels, confirming the problems identified in previous studies (Samandra *et al*., 2022; Mshelia *et al*., 2023; Chidiac *et al*., 2023). The study confirms that commercial borehole water in Uyo Capital City does not fully comply with WHO and Ministry of Environment standards and therefore poses potential health risks to the urban population relying on these water sources.

RECOMMENDATIONS

The successful application of GIS and IDW interpolation demonstrates the value of integrating spatial analysis into routine water quality monitoring for identifying contamination hotspots and vulnerable areas. Urgent interventions are required, including enhanced regulatory enforcement, regular monitoring programmes, improved borehole siting regulations requiring adequate separation distances from contamination sources, appropriate water treatment

(disinfection and pH adjustment), and public awareness campaigns about the health risks associated with consuming untreated borehole water.

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