

Gis–Ahp Groundwater Potential Mapping and Sensitivity Analysis for Public Borehole Planning in Ikorodu, Lagos State, Nigeria

Oluwayemisi OGUNLEYE

ogunleye.yemisi@eksu.edu.ng

Ekiti State University

Ademola ADEYEMI

Lead City University

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GIS-AHP GROUNDWATER POTENTIAL MAPPING AND SENSITIVITY ANALYSIS FOR PUBLIC BOREHOLE PLANNING IN IKORODU, LAGOS STATE, NIGERIA

Highlights

- A GIS-AHP model delineates five groundwater potential zones across Ikorodu, Lagos State.
- Lineament density (30%) is the dominant factor in the AHP weighting scheme.
- A 26-scenario sensitivity test confirms the AHP weighting is robust ($CR < 0.10$ throughout).
- The LULC input layer achieves 89.3% classification accuracy ($Kappa = 0.86$).
- The map is translated into a four-tier public-borehole planning framework.

Abstract

Groundwater is a critical domestic water source in rapidly urbanizing coastal areas, yet borehole siting in Ikorodu, Lagos State, is frequently undertaken without adequate hydrogeological guidance, resulting in low-yield or failed boreholes and considerable financial loss to households and communities. This study delineates groundwater potential zones across Ikorodu Local Government Area using an integrated Geographic Information Systems (GIS), Remote Sensing (RS), and Multi-Criteria Decision Analysis (MCDA) approach, and translates the resulting map into a tiered decision-support framework for public and community borehole planning. Six groundwater-controlling factors elevation, slope, rainfall, drainage density, lineament density, and land use/land cover (LULC) were derived from SRTM, ERA5, and Landsat 8 datasets and standardized within a GIS environment. Relative factor weights were assigned using the Analytical Hierarchy Process (AHP, Saaty scale, eigenvector method), yielding a highly consistent judgment matrix ($\lambda_{max} = 6.014$, $CI = 0.0028$, $CR = 0.0022$) in which lineament density (0.33), rainfall (0.19), and slope (0.19) dominated the weighting scheme. To address a key limitation of comparable studies in the area, the robustness of this weighting scheme was tested through a systematic one-at-a-time sensitivity analysis of the pairwise comparison matrix (26 perturbation scenarios): lineament density remained the top-ranked factor and the Consistency Ratio remained below the 0.10 acceptability threshold in every scenario, supporting the stability of the adopted weights. The weighted layers were combined through weighted overlay to generate a five-class groundwater potential map (Very Low to Very High). The land use/land cover layer underlying the model achieved an overall classification accuracy of 89.3% and a Kappa coefficient of 0.86. Model verification was performed qualitatively by overlaying the predicted potential zones with previously published Vertical Electrical Sounding (VES) locations; most reference points fell within Moderate-to-High potential classes, offering supporting — though not independent quantitative — evidence for the map's screening value. Very High and High potential zones are concentrated in the southern, southeastern, and parts of the central study area, while Low and Very Low zones dominate the north and northwest. Although Ikorodu has previously been mapped using GIS-based multi-criteria analysis (Epuh et al., 2020), this study extends that work by testing the robustness of the AHP weights, formally assessing LULC classification accuracy, and translating the map into an operational planning tool. The map is translated into a four-tier public-borehole prioritization framework intended to guide, not replace, site-specific geophysical and hydrogeological investigation. The principal contribution of this study relative to earlier Ikorodu groundwater-mapping work is methodological transparency: a documented, reproducible sensitivity test of the AHP weighting scheme, a formally accuracy-assessed LULC layer, and an explicit, honestly-scoped protocol for the independent quantitative validation that this and comparable regional screening studies still require.

Keywords

Groundwater potential mapping; GIS; Analytical Hierarchy Process; sensitivity analysis; borehole planning;

1. Introduction

1.1 Background

Groundwater is a vital component of freshwater resources and plays a major role in domestic, agricultural, and industrial water supply, particularly in rapidly urbanizing regions where surface-water resources are increasingly stressed. Its occurrence and availability are controlled by the interaction of environmental factors including geology, topography, rainfall, drainage characteristics, and land use/land cover; terrain characteristics such as elevation and slope influence

water retention and infiltration, with low-relief landscapes generally favouring groundwater recharge and steeper terrain promoting rapid runoff (Condon et al., 2015; Rukundo et al., 2019; Zhang et al., 2022; Gnann et al., 2025).

Land use and land cover further modify groundwater systems by influencing infiltration and recharge. Natural vegetation, wetlands, and agricultural land generally facilitate replenishment through enhanced infiltration, whereas urban development introduces impervious surfaces that reduce recharge and increase surface runoff (Wei et al., 2022; Glanville et al., 2023). These interactions are particularly significant in rapidly urbanizing coastal environments such as Lagos State, where extensive land-cover transformation, coupled with increasing groundwater abstraction, has altered the natural hydrological balance and heightened concerns over groundwater sustainability; excessive withdrawal in coastal aquifers may also induce saltwater intrusion, compromising both availability and quality (Kretschmer et al., 2025).

Groundwater has become an important domestic water source for many Lagos State households because of the increasing inadequacy of centralized water supply. Rapid population growth, urbanization, and industrial development have intensified abstraction and encouraged widespread borehole development, but many boreholes are constructed without adequate hydrogeological investigation, resulting in low-yield or failed boreholes, financial loss, and inefficient resource use (Dangar et al., 2021). Traditional exploration methods — field reconnaissance and geophysical investigation — are comparatively expensive, time-consuming, and spatially limited, and advances in GIS and remote sensing have transformed groundwater exploration by enabling the integration of diverse spatial datasets describing terrain, hydrology, geology, and land cover within a single analytical framework (Arabameri et al., 2019; Zhu et al., 2021).

To improve decision-making, GIS-based groundwater potential mapping is frequently combined with Multi-Criteria Decision Analysis, particularly the Analytical Hierarchy Process, which allows multiple groundwater-controlling factors to be evaluated according to their relative importance. This integrated approach has been adopted widely because it provides a systematic and transparent framework for delineating groundwater potential zones (Ifediegwu, 2022; Ogunbade et al., 2021; Abdullateef et al., 2021), and its effectiveness has been demonstrated across diverse hydrogeological settings in Nigeria and elsewhere (Badamasi et al., 2016; Adiat et al., 2012; Singh et al., 2018; Etuk et al., 2022; Ajayi et al., 2022).

1.2 Previous studies in Ikorodu

Ikorodu has already received direct research attention from a groundwater-mapping perspective. Epuh et al. (2020) produced a multi-criteria groundwater potential map for Ikorodu integrating hydrogeophysical (VES) evidence with GIS-based thematic layers, and their identified favourable drilling locations form the principal external reference dataset used for verification in the present study. At a finer, site-investigation scale, geoelectrical and geotechnical work in the adjoining Ijede–Ikorodu corridor has characterized subsurface structure and its engineering implications within the Dahomey Basin using Vertical Electrical Sounding (Amos-Uhegbu et al.; Amos-Uhegbu & Akoma, 2023), while regional hydrogeological syntheses of the wider Lagos coastal aquifer system — aquifer horizon thickness, transmissivity, and storage characteristics — were established by Longe et al. (1987) and later refined through geophysical and isotopic characterization of saline intrusion by Yusuf (2020) and Oyeyemi et al. (2023). Elsewhere in southwestern Nigeria, Ejepu et al. (2022), Osinowo et al. (2020), and Oludayo et al. (2021) have applied comparable GIS-MCDA and triangulation approaches to coastal and basement terrains.

Collectively, this body of work establishes that (a) the GIS-MCDA/AHP overlay technique is well proven in this hydrogeological setting, and (b) Ikorodu itself has already been the subject of a dedicated groundwater potential mapping study using essentially the same six-factor logic adopted here. Any new contribution from the present study must therefore be justified on grounds other than the mere repetition of the mapping technique in the same location.

Accordingly, the present study is positioned not as a replacement for Epuh et al. (2020) but as a methodological and applied extension that tests the robustness of the AHP weighting, quantifies LULC accuracy, and operationalizes the map for public borehole planning

1.3 Research gap

Notwithstanding the existing Ikorodu-specific work, four gaps remain in the published record for this area:

- No published AHP-based groundwater potential study for Ikorodu reports a documented sensitivity analysis of the pairwise comparison matrix itself; expert-derived weights are conventionally reported and used without any test of how robust the resulting factor ranking is to plausible disagreement among expert judges.
- The land use/land cover layer used as an MCDA input in earlier Ikorodu groundwater mapping has not been accompanied by a formal classification accuracy assessment (confusion matrix, Kappa statistic), leaving the reliability of this particular input layer unquantified.
- Existing groundwater potential maps for Ikorodu have been presented primarily as hydrogeological products rather than as an operational decision-support tool with explicit prioritization tiers, response actions, and investigation requirements for public-sector borehole planners.
- Model verification in the area to date, including in the present study, has relied on comparison with previously published VES-derived reference points rather than on independently collected borehole-yield, pumping-test, or groundwater-level data; the practical requirements and limits of this qualitative approach have not been made explicit.

1.4 Scientific novelty

Consistent with the gaps above, this study does not claim to introduce a new spatial-analysis technique; the underlying GIS-MCDA/AHP weighted-overlay method is well established and shares its factor set with Epuh et al. (2020). The study therefore builds directly on the earlier Ikorodu groundwater-potential map of Epuh et al. (2020), using a similar factor set and study area, but adds a structured sensitivity analysis of the AHP weights, a formal accuracy assessment of the LULC input, and an explicit tiered planning framework for public borehole siting. The contribution is instead methodological and applied, and consists of four elements:

- A documented, reproducible sensitivity analysis of the study's own AHP pairwise comparison matrix (26 one-at-a-time judgment perturbations), used to test whether the adopted factor weighting is a robust basis for the resulting map rather than an artefact of a single set of expert judgments.
- A formal accuracy assessment of the LULC input layer (confusion matrix, overall accuracy, Kappa coefficient), which quantifies the reliability of one of the six model inputs rather than treating it as a given.
- Translation of the resulting groundwater potential map into an explicit, tiered public-borehole prioritization framework linking each potential class to a defined planning and investigation action, rather than presenting the map as a hydrogeological end-product alone.
- A transparent, honestly-scoped treatment of validation: the qualitative VES-based verification is explicitly distinguished from independent quantitative validation, and a concrete data protocol is specified for the latter, so that the map's current evidentiary status is not overstated.

1.5 Aim and objectives

Aim: To apply GIS, remote sensing, and MCDA techniques to delineate groundwater potential zones, test the robustness of the underlying AHP weighting scheme, and develop a spatial decision-support framework for public and community borehole planning in Ikorodu Local Government Area, Lagos State, Nigeria.

Objectives:

- Examine the influence of topographic and hydrological factors on groundwater occurrence in Ikorodu.
- Evaluate the influence of structural and land-surface characteristics, particularly lineament density and land use/land cover, on groundwater potential, including formal accuracy assessment of the LULC layer.
- Integrate the six groundwater-controlling factors using a GIS-based AHP-MCDA framework to delineate groundwater potential zones.
- Test the sensitivity and robustness of the AHP-derived factor weights through systematic perturbation of the pairwise comparison matrix.
- Translate the groundwater potential map into a tiered decision-support framework for public and community borehole planning, and specify the data requirements for its future independent quantitative validation.

2. Study Area

2.1 Geographic setting

Ikorodu Local Government Area is situated in the northeastern part of Lagos State, southwestern Nigeria. It is bounded by Ibeju-Lekki LGA to the south, Epe LGA to the east, Ogun State to the north, and the Lagos Lagoon to the west (Figure 2.1), and lies approximately between latitudes 6°31'N and 6°41'N and longitudes 3°29'E and 3°42'E, covering an estimated land area of about 664 km² (Osayomi et al., 2022).

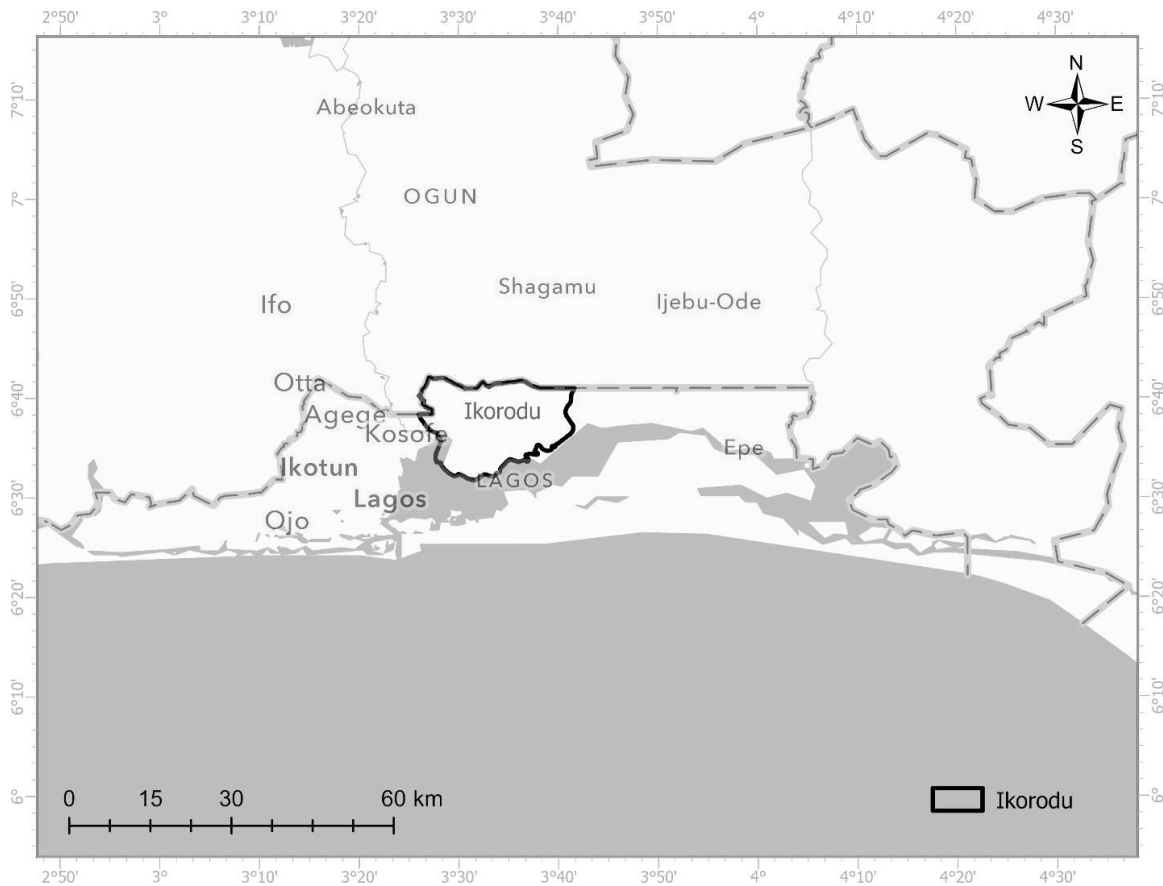


Figure 2.1: Location map of Ikorodu Local Government Area, Lagos State, Nigeria (adapted from Osayomi et al., 2022).

2.2 Climate and hydrology

The study area has a humid tropical climate with two distinct seasons: a wet season from April to October and a dry season from November to March. Annual rainfall ranges between approximately 1,500 and 1,800 mm, and average temperatures vary from 25–32°C. These climatic conditions provide favourable opportunities for groundwater recharge, particularly during the prolonged rainy season (Balogun et al., 2019). Ikorodu's surface hydrology is dominated by its lagoon frontage to the west and a network of creeks and minor streams that drain the low-lying coastal plain; the combination of gentle relief, extensive wetlands, and proximity to the Lagos Lagoon means that surface water and shallow groundwater are closely interconnected across much of the study area.

2.3 Geological setting

Ikorodu forms part of the Dahomey (Benin) Basin, a passive-margin sedimentary basin extending along the West African coast. The basin's stratigraphic sequence, established through earlier regional work (Adegoke, 1977; Oli, 2019), comprises Cretaceous-to-Tertiary formations at depth (Ise, Afowo, and Araromi Formations of the Abeokuta Group) overlain by the Paleocene Ewekoro Formation and younger Akinbo, Oshosun, and Ilaro Formations; the near-surface sequence across most of Ikorodu, however, is dominated by the unconsolidated Coastal Plain Sands (Benin Formation equivalent) and Quaternary alluvial deposits — sands, silts, and clays — that host the shallow aquifer system exploited by most domestic and community boreholes in the area (Amos-Uhegbu & Akoma, 2023). These near-surface formations exhibit variable hydraulic properties, and the predominance of sandy deposits generally favours groundwater occurrence,

although availability varies spatially due to lithological heterogeneity and structural controls associated with basin-margin faulting.

2.4 Hydrogeological framework

The Lagos coastal aquifer system, of which the Ikorodu shallow aquifer forms part, has been characterized regionally through borehole-log, well-production, and geophysical studies. Longe et al. (1987) delineated three principal aquifer horizons beneath Lagos metropolis from an alternating sequence of sand and clay: a shallow, unconfined water-table aquifer of average thickness ~8 m, exploited mainly through hand-dug wells, and two deeper confined-to-semi-confined aquifers of approximately 10–25 m and 10–35 m thickness respectively, which are the horizons typically tapped by boreholes and by the Lagos State mini water-works programme. Reported transmissivity and storage-coefficient values for these deeper horizons (of the order of 10^{-3} – 10^{-2} m² s⁻¹ and 10^{-4} , respectively) indicate considerable inter-horizon heterogeneity, consistent with the lithological variability of the Coastal Plain Sands. Table 2.1 summarizes this regional aquifer framework, which provides the hydrogeological context within which the six groundwater-controlling factors used in this study are interpreted.

Aquifer horizon	Approximate depth / thickness	Typical development mode	Notes
Water-table (unconfined) aquifer	~8 m average thickness, near-surface	Hand-dug wells; shallow hand-pump boreholes	Most directly influenced by DEM, slope, drainage density, and LULC-controlled infiltration
First confined/semi-confined aquifer	~10–25 m thickness	Community and private motorized boreholes	Tapped by most domestic boreholes referenced in this study's verification dataset
Second (deeper) confined aquifer	~10–35 m thickness	Public mini-waterworks-scale boreholes	Higher transmissivity reported regionally; more vulnerable to saline intrusion near the lagoon margin

Because Ikorodu fronts the Lagos Lagoon along its western margin, the deeper aquifer horizons in the western and coastal parts of the study area carry an elevated risk of saline intrusion under conditions of over-abstraction, as documented for other parts of the Lagos coastal basin (Yusuf, 2020; Oyeyemi et al., 2023). This risk is not directly represented among the six mapped factors in the present study and is noted here as a hydrogeological caveat relevant to borehole depth selection in the coastal southern and southwestern parts of the study area, even where the GWPI classification indicates favourable shallow-aquifer conditions.

2.5 Groundwater occurrence and development

Groundwater occurrence in Ikorodu is controlled primarily by the thickness and lateral continuity of the sandy horizons within the Coastal Plain Sands and Alluvium, by the degree of hydraulic connection between the shallow and deeper aquifers, and by structural discontinuities that can locally enhance secondary porosity. Development has historically proceeded informally: households and communities have progressively shifted from hand-dug wells toward motorized boreholes tapping the first confined aquifer as centralized piped-water coverage has failed to keep pace with population growth, generally without prior geophysical siting.

2.6 Urbanization and groundwater-management context

Land use within Ikorodu has changed considerably in recent decades owing to rapid urbanization; residential, commercial, and industrial development has expanded at the expense of natural vegetation and agricultural land (Section 4.2.6 quantifies this at 82.7% built-up cover). This expansion of impervious surface area is occurring without a correspondingly developed regulatory framework for borehole siting, permitting, or groundwater abstraction monitoring in the study area, which increases both the ecological pressure on recharge and the financial risk borne by individual households and community groups who drill without hydrogeological guidance. This management gap is the practical entry point for the decision-support framework developed in Section 3.14.

3. Materials and Methods

3.1 Research design

This study followed a sequential GIS-MCDA research design comprising data acquisition, thematic-layer preparation, AHP weighting with consistency and sensitivity analysis, weighted-overlay modelling, classification, qualitative verification, and translation of the resulting map into a public-borehole planning framework. The full workflow is summarized in Figure 3.1.

Figure 3.1 Methodological workflow of the GIS-MCDA groundwater potential assessment (sensitivity-analysis step highlighted in red)

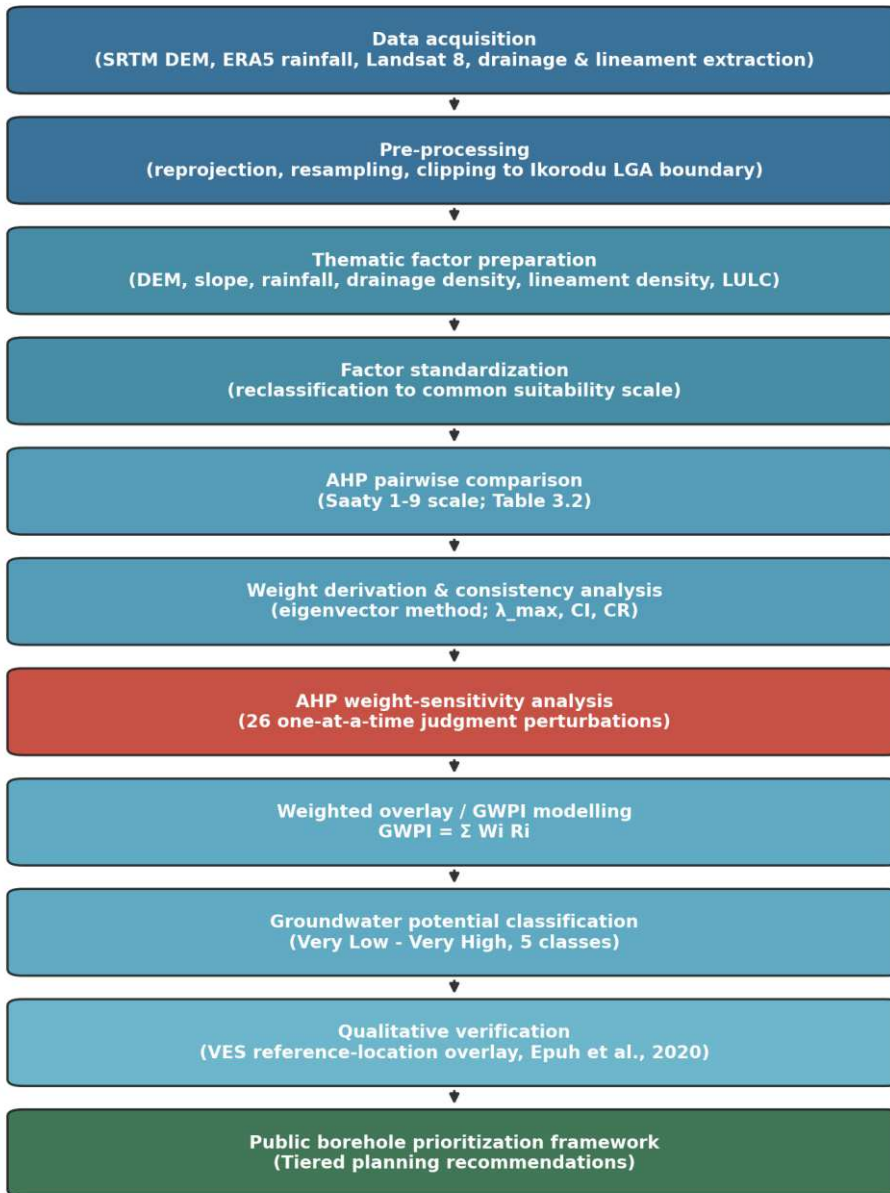


Figure 3.1: Methodological workflow of the GIS-MCDA groundwater potential assessment (the sensitivity-analysis step added in this study is highlighted).

3.2 Data sources

Secondary geospatial datasets were obtained from reputable national and international sources (Table 3.1). Six groundwater-controlling factors were considered: elevation (DEM), slope, rainfall, drainage density, lineament density, and land use/land cover.

Dataset	Purpose	Source
Digital Elevation Model (30 m)	Elevation and slope generation	SRTM (NASA/USGS)
Rainfall data (2019–2025)	Rainfall distribution	ERA5 Reanalysis
Landsat 8 imagery	LULC classification; lineament interpretation	USGS
Drainage network	Drainage density analysis	Derived from SRTM DEM
Lineament data	Lineament density analysis	Satellite imagery and DEM interpretation
VES reference locations	Qualitative model verification	Epuh et al. (2020)

All datasets were reprojected to a common coordinate reference system, resampled to a uniform spatial resolution, and clipped to the Ikorodu LGA boundary prior to analysis; limited field verification using GPS was conducted to check selected spatial features.

3.3 Hydrogeological conceptualization

Each of the six mapped factors is interpreted here against the aquifer framework described in Section 2.4. Elevation and slope govern the surface residence time of rainfall and therefore the opportunity for infiltration into the shallow water-table aquifer; drainage density is an inverse proxy for the same infiltration opportunity, since a denser channel network evacuates surface water more rapidly. Rainfall is the primary recharge input common to all aquifer horizons. Lineament density is treated as a proxy for structural discontinuities that can locally enhance secondary porosity and provide preferential vertical pathways between the shallow and first confined aquifer, consistent with structural controls reported elsewhere in the Dahomey Basin (Akinluyi et al., 2018; Amos-Uhegbu & Akoma, 2023). Land use/land cover controls the partitioning of incident rainfall between infiltration and runoff at the land surface, with built-up cover suppressing recharge to the water-table aquifer most directly. This conceptual linkage — factor to hydrogeological process to aquifer horizon — is what the AHP weighting scheme in Section 3.6 attempts to formalize numerically.

3.4 Preparation of thematic factors

The DEM was used to derive elevation and slope; hydrological analysis tools were used to extract the drainage network and compute drainage density; rainfall data were spatially interpolated to a continuous surface; lineaments were interpreted from satellite imagery and terrain data and converted to a lineament density map; and LULC classification was performed by supervised classification of Landsat 8 imagery into four classes (built-up, vegetation, water bodies, bare land).

3.5 Factor standardization

Each of the six thematic layers was reclassified onto a common ordinal suitability scale reflecting its relative favourability for groundwater occurrence and recharge, following the spatial patterns described for each factor in Section 4.2 (for example, lower elevation, gentler slope, and lower drainage density were assigned higher suitability scores, consistent with the hydrogeological reasoning in Section 3.3). The standardized layers constituted the input variables for the weighted-overlay model.

3.6 AHP pairwise comparison

Relative weights were assigned to the six factors using the Analytical Hierarchy Process (Saaty, 2001). Factors were ranked according to their perceived influence on groundwater occurrence and recharge, with lineament density considered most influential, followed by rainfall and slope, and then drainage density, LULC, and DEM. A pairwise comparison matrix was constructed using the standard 1–9 Saaty scale (Table 3.2).

Factor	Lineament density	Rainfall	Slope	Drainage density	LULC	DEM
Lineament density	1	2	2	3	3	3
Rainfall	1/2	1	1	2	2	2

Factor	Lineament density	Rainfall	Slope	Drainage density	LULC	DEM
Slope	1/2	1	1	2	2	2
Drainage density	1/3	1/2	1/2	1	1	1
LULC	1/3	1/2	1/2	1	1	1
DEM	1/3	1/2	1/2	1	1	1

Notes: values represent the relative importance of the row factor compared with the column factor on the Saaty 1–9 scale.

3.7 Weight derivation

The normalized principal eigenvector of the pairwise comparison matrix was computed to derive factor weights: lineament density = 0.33, rainfall = 0.19, slope = 0.19, drainage density = 0.10, LULC = 0.10, and DEM = 0.10 (reported in the text as 30%, 20%, 20%, 10%, 10%, and 10% respectively). These values were independently recomputed for this study directly from the Table 3.2 matrix using the eigenvector method and confirmed to $\lambda_{\max} = 6.014$.

3.8 Consistency analysis

The consistency of the pairwise judgments was evaluated using the Consistency Index ($CI = (\lambda_{\max} - n)/(n - 1)$) and Consistency Ratio ($CR = CI/RI$, with a Random Index of 1.25 for $n = 6$). The base matrix yielded $CI = 0.0028$ and $CR = 0.0022$, well below the commonly accepted $CR \leq 0.10$ threshold, indicating acceptably consistent judgments (Saaty, 2001).

3.9 Weighted-overlay / GWPI modelling

The weighted thematic layers were integrated using GIS-based weighted overlay to generate the groundwater potential map. The groundwater potential index (GWPI) was computed as:

$$GWPI = \sum (Wi \times Ri), \quad i = 1 \dots n$$

where Wi is the AHP weight assigned to the i -th factor, Ri is the standardized rating of the i -th factor, and n is the total number of factors ($n = 6$). The resulting index was classified into five groundwater potential zones — Very High, High, Moderate, Low, and Very Low — using natural-breaks classification within the GIS environment.

3.10 Sensitivity analysis

To test whether the AHP weighting scheme is a robust basis for the groundwater potential map, rather than an artefact of one particular set of expert judgments, a systematic one-at-a-time sensitivity analysis was performed directly on the Table 3.2 pairwise comparison matrix. Each of the 15 pairwise judgments was independently perturbed by ± 1 unit on the Saaty scale (bounded within the valid 1/9–9 range), the corresponding reciprocal entry was updated, and the principal eigenvector, $\lambda_{\max}$, CI , and CR were recomputed for each of the resulting 26 valid perturbation scenarios. This procedure evaluates the structural robustness of the factor weighting itself — i.e., whether small, plausible disagreements in expert judgment would change the ranking of factors or push the matrix outside acceptable consistency. It does not, and is not intended to, test the sensitivity of the final spatial GWPI raster to weight changes, which would additionally require re-running the weighted overlay on the source raster layers; this spatial (“map-removal”) sensitivity test is identified as a specific item for future work in Section 5.8, since it requires access to the underlying GIS layers rather than the map images available for the present revision.

3.11 Independent validation

Qualitative model verification was performed by overlaying the groundwater potential map with reference VES locations identified by Epuh et al. (2020) as suitable for drilling. These locations were used as independent spatial references — independent in the sense that they derive from a separate prior study rather than from the present model — to examine whether previously identified favourable sites fall within the Moderate, High, or Very High potential classes. Because these reference points were themselves derived from a prior interpretive study rather than from directly measured borehole-yield, pumping-test, or groundwater-level data, this comparison is explicitly treated as qualitative, screening-level verification, not as independent quantitative validation.

3.12 Statistical validation

Formal statistical validation of a GIS-MCDA groundwater potential model typically requires an independent set of measured points not used in model construction, against which standard metrics — Receiver Operating Characteristic (ROC) curve and Area Under the Curve (AUC), the Frequency Ratio (FR) of known productive points across potential classes, or agreement statistics against measured static water level or specific-capacity data — can be computed. No independent quantitative dataset of this kind (borehole yield, pumping-test, or groundwater-level records not already used by Epuh et al., 2020) was available for the present study. This step is therefore reported here as the validation protocol to be executed once such a dataset is assembled (Section 3.14 and Recommendations), rather than as a completed analysis, so that the current absence of quantitative validation is not concealed by the presence of the qualitative VES comparison in Section 3.11.

3.13 Uncertainty analysis

In the absence of the source raster layers needed for formal Monte Carlo error propagation through the weighted-overlay model, uncertainty in the present study is characterized qualitatively using the outcome of the AHP weight-sensitivity analysis (Section 3.10) as a proxy: zones whose classification depends on the convergence of several factors that are individually robust to weight perturbation (Section 4.4) are interpreted as comparatively lower-uncertainty classifications, while zones lying close to a class boundary on a single dominant factor are interpreted as comparatively higher-uncertainty and better candidates for confirmatory site investigation before drilling. A quantitative, raster-based uncertainty (stability) map — for example via Monte Carlo perturbation of the standardized input layers — is recommended as a direct extension of this work once the source GIS layers are available.

3.14 Public borehole planning framework

The five GWPI classes were translated into a four-tier public-borehole planning framework (Table 3.3), linking each class to a defined planning and investigation action, so that the map functions as an operational screening tool for local water-supply authorities rather than a purely descriptive hydrogeological product.

Priority tier	GWPI class(es)	Recommended planning action
Tier 1 — Priority	Very High	Recommended as first candidates for detailed geophysical (VES) survey and pilot drilling
Tier 2 — Conditional priority	High	Recommended for phased investigation following Tier 1; standard site-specific VES prior to drilling
Tier 3 — Requires justification	Moderate	Considered only after desk study and site-specific VES; treated as transitional / uncertain zone
Tier 4 — Deprioritized	Low / Very Low	Not recommended without a detailed, independently justified hydrogeological investigation prior to any drilling approval

4. Results

4.1 Hydrogeological characterization

Synthesizing Section 2.4 with the six mapped factors, the Ikorodu shallow aquifer system is best characterized as an unconfined water-table horizon (~8 m average thickness) hosted in the Coastal Plain Sands and Alluvium, directly overlying and hydraulically linked to a first confined aquifer (~10–25 m thickness) that is the horizon most commonly tapped by community and private boreholes in the area. The six mapped factors act principally on the water-table horizon (via infiltration/runoff partitioning) and, through lineament-controlled secondary porosity, on vertical connectivity to the underlying confined aquifer. This characterization does not replace direct lithological logging at candidate sites but provides the physical basis for interpreting the GWPI classification in Sections 4.2–4.5.

4.2 Thematic factors

4.2.1 Elevation (DEM)

Elevation across Ikorodu ranges from approximately –12 m to 70 m above mean sea level (Figure 4.1). The northern and northeastern parts are characterized by higher elevations, the southern and southwestern parts are low-lying, and the central portion forms a transitional zone. Lower-elevation zones generally serve as areas of water accumulation and infiltration, favouring recharge to the water-table aquifer; accordingly, the central, southern, and southwestern portions of Ikorodu are expected to have more favourable conditions for groundwater storage than the higher-elevation northern and northeastern parts.

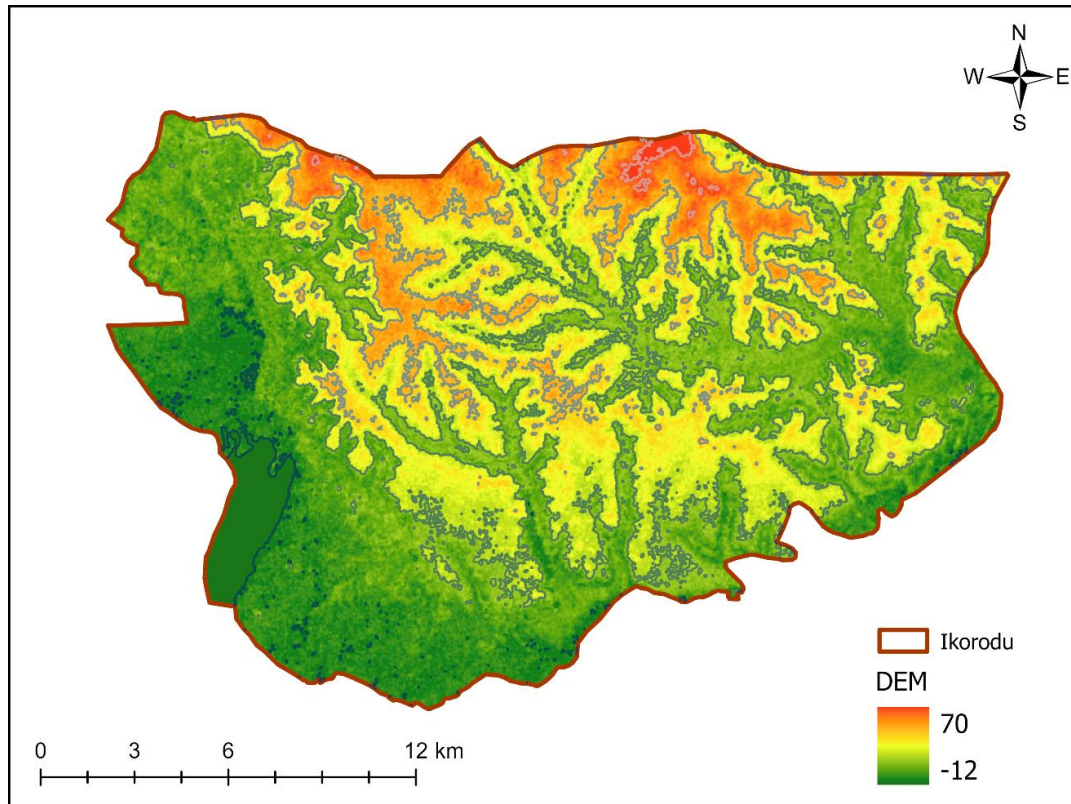


Figure 4.1: Digital Elevation Map of Ikorodu, Lagos State.

4.2.2 Slope

Slope values range from approximately 0.01° to 20.23° (Figure 4.2). Ikorodu is predominantly a region of gentle slopes (0.01 – 5.06°), with moderate slopes occurring as narrow, elongated bands corresponding to drainage channels and terrain breaks, and steeper slopes (15.19 – 20.23°) sparsely distributed in isolated locations. Gentle slopes favour groundwater accumulation by extending the surface residence time of rainfall, and the extensive low-slope regions across much of Ikorodu are therefore likely to promote recharge and enhance borehole productivity.

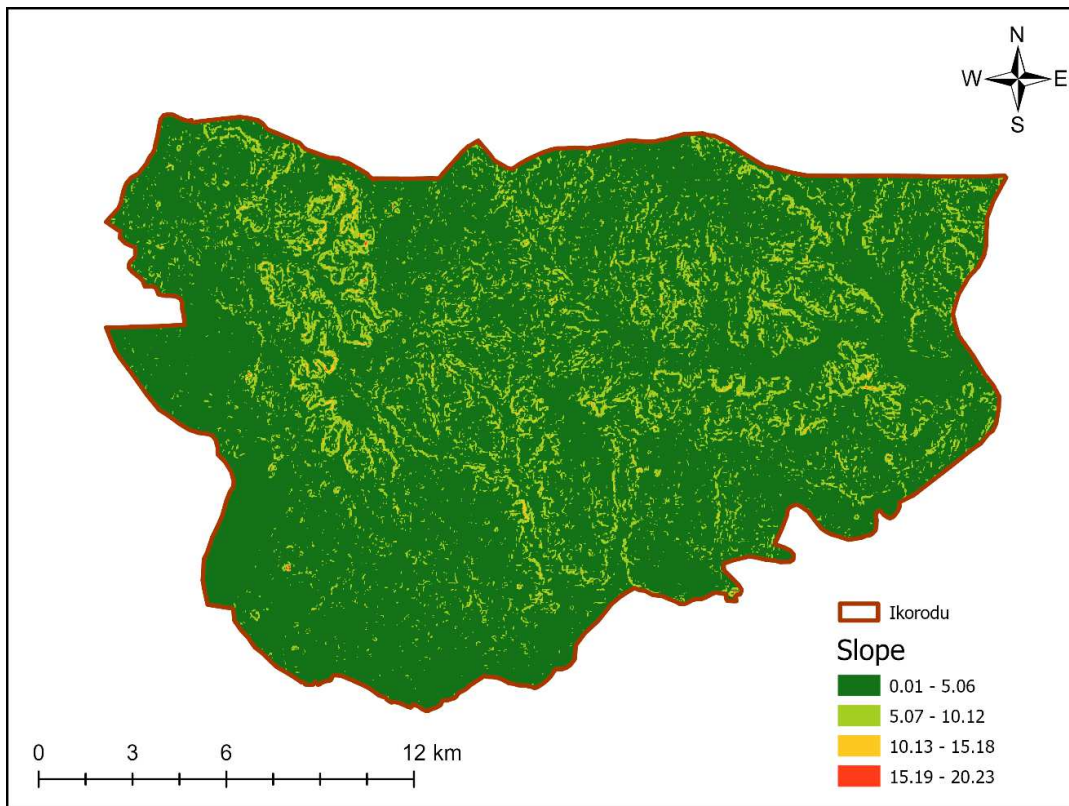


Figure 4.2: Slope Map of Ikorodu, Lagos State.

4.2.3 Rainfall

Figure 4.3 shows the spatial distribution of mean annual rainfall for 2019–2025 on the standardized scale used in the analysis (4.23–5.13), indicating a relatively uniform pattern with slightly higher values in the northern, northwestern, and central portions and comparatively lower values in the south and southeast. Given this overall uniformity, rainfall's influence on the final GWPI is expected to be moderate relative to structural and topographic factors when the six layers are combined.

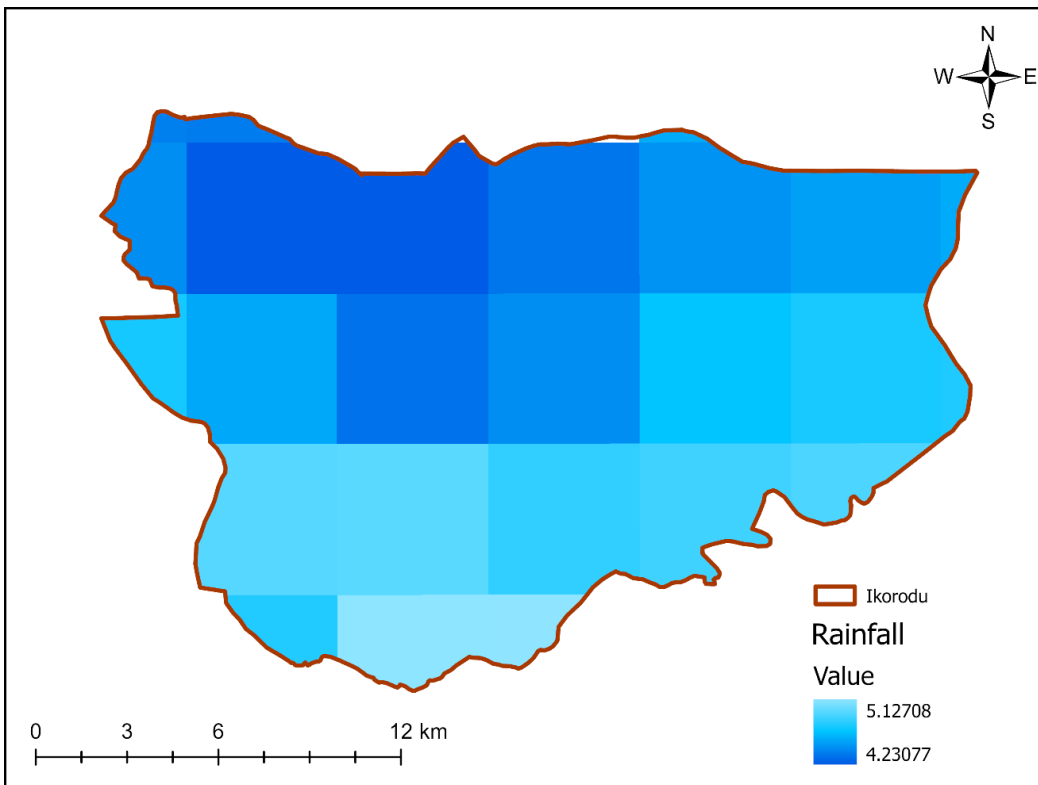


Figure 4.3: Mean Annual Rainfall Map of Ikorodu, Lagos State (2019–2025).

4.2.4 Drainage density

Drainage density values range from approximately 0.01 to 0.13 (Figure 4.4). High drainage density (0.09–0.13) is concentrated in the western and southwestern portions, moderate values occur along major drainage corridors, and extensive low-density areas (0.01–0.05) dominate the central and northern sections. Lower drainage density generally indicates greater infiltration capacity and reduced runoff, so the central portions of Ikorodu are, on this factor alone, more likely to possess favourable groundwater conditions.

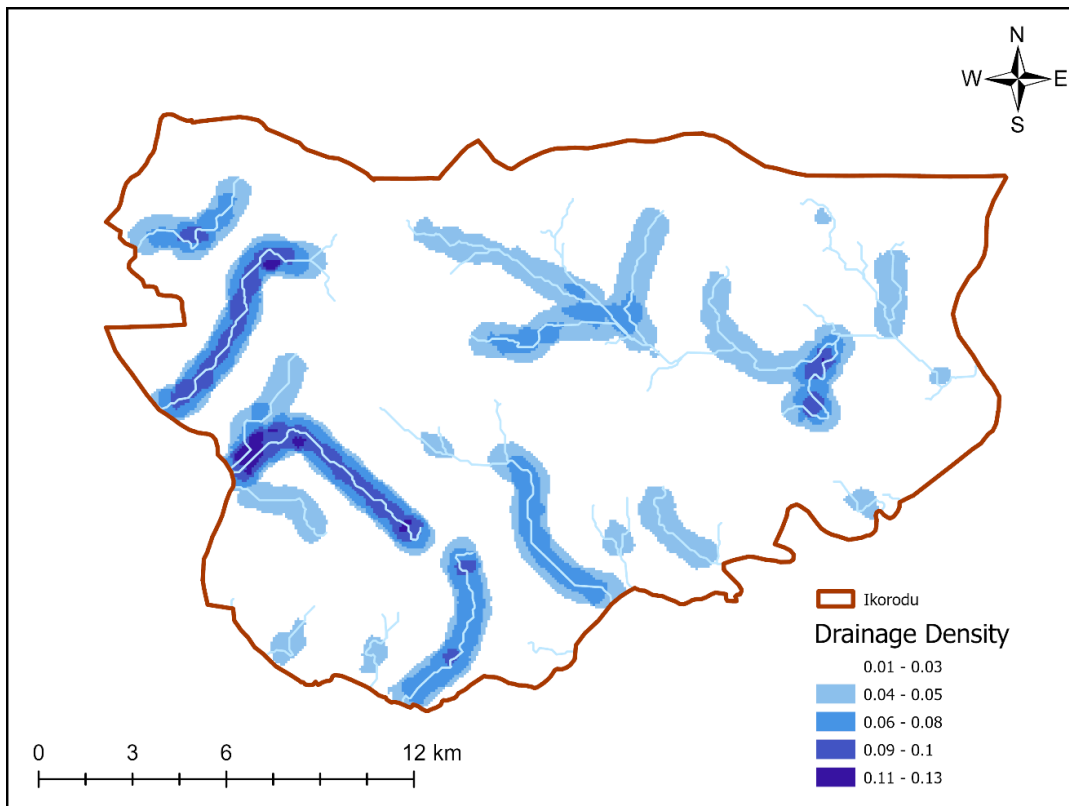


Figure 4.4: Drainage Density Map of Ikorodu, Lagos State.

4.2.5 Lineament density

Lineament density ranges from approximately 0.01 to 2.80 (Figure 4.5), with moderate-to-high concentrations in the northwestern, northern, central, and eastern portions of the study area, reflecting clustered structural features rather than a uniform distribution. As the highest-weighted factor in the AHP scheme, this structural pattern exerts the strongest single influence on the final GWPI classification (Sections 4.3–4.4).

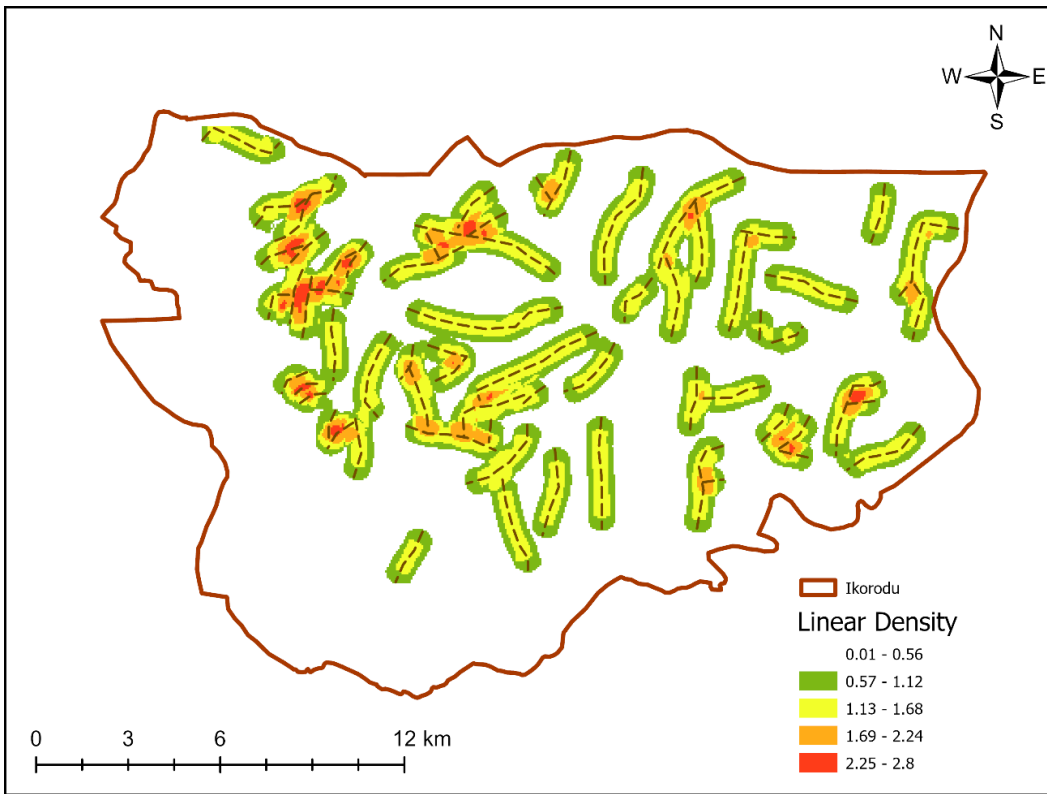


Figure 4.5: Lineament Density Map of Ikorodu, Lagos State.

4.2.6 Land use/land cover (LULC)

The LULC classification (Figure 4.6a) categorizes Ikorodu into four classes: water bodies, built-up areas, bare land, and vegetation. Built-up areas dominate the central, northern, and southeastern sections, reflecting rapid urbanization; vegetation is distributed along drainage corridors and peripheral areas; water bodies concentrate in the western, southwestern, and eastern portions; and bare land occurs as small, scattered patches. Quantitatively, 82.7% of the study area is built-up, 10.8% vegetation, 6.3% water, and 0.3% bare land (Figure 4.6b).

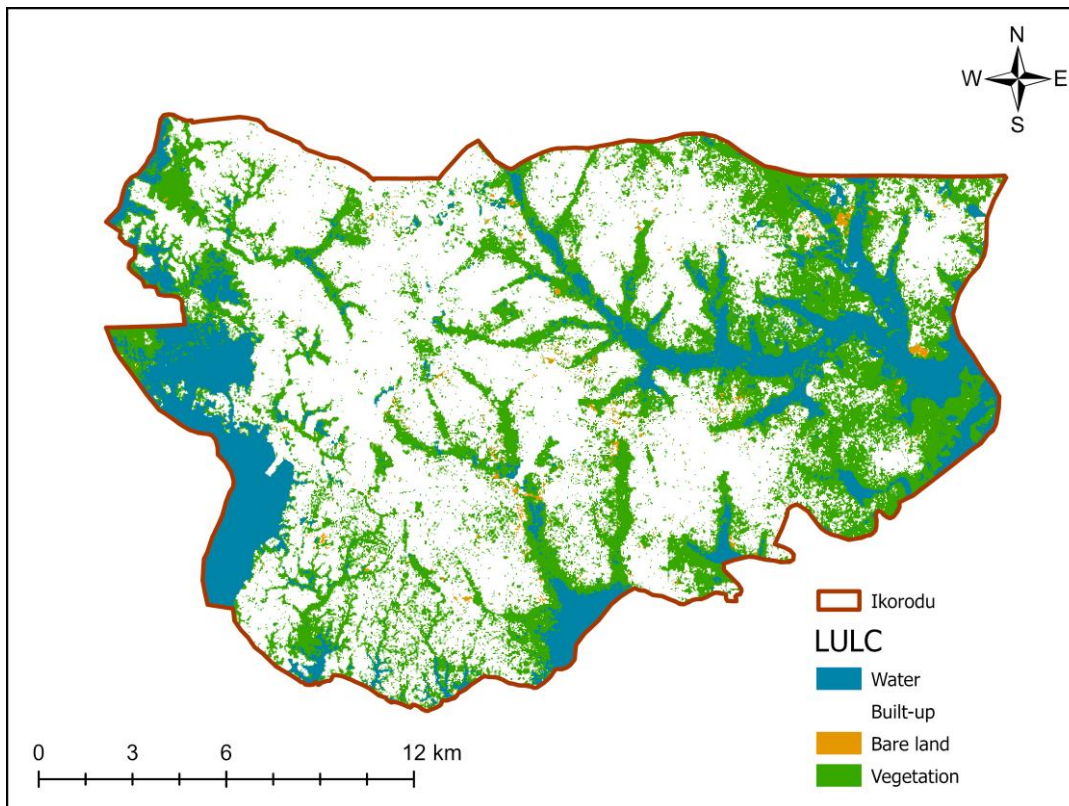


Figure 4.6a: LULC Map of Ikorodu, Lagos State.

Figure 4.6 Land use / land cover composition of Ikorodu LGA, 2025

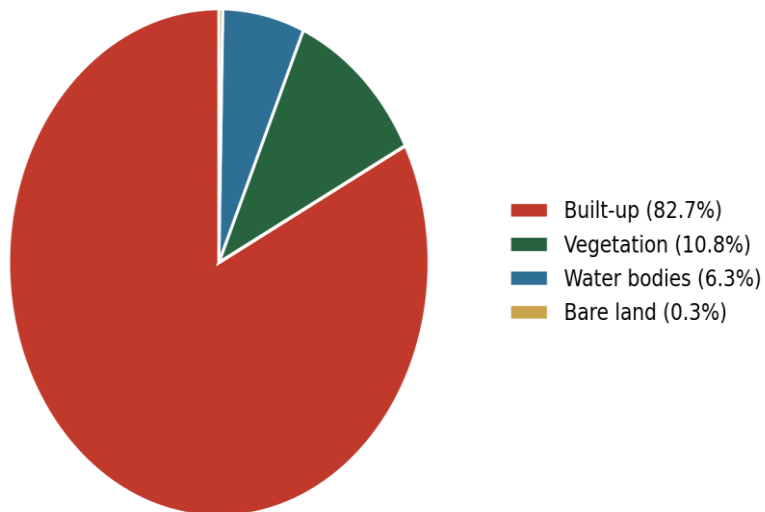


Figure 4.6b: Land use / land cover composition of Ikorodu LGA.

A confusion matrix was constructed against 150 independent reference points to assess classification reliability (Table 4.1).

Reference data	Water	Built-up	Bare land	Vegetation	Row total	Producer's accuracy (%)
Water	34	1	0	1	36	94.44
Built-up	2	42	2	2	48	87.50
Bare land	0	2	16	2	20	80.00
Vegetation	1	2	1	42	46	91.30
Column total	37	47	19	47	150	
User's accuracy (%)	91.89	89.36	84.21	89.36		

Overall Accuracy = 89.33%; Kappa Coefficient = 0.86, indicating strong agreement between the classified map and reference data beyond chance. Bare land recorded the lowest class accuracy, reflecting spectral overlap with built-up and vegetated surfaces typical of heterogeneous urban–rural transition zones.

4.3 AHP weights and consistency

Lineament density received the highest weight (30%), reflecting the importance of structural discontinuities in facilitating groundwater movement and storage; rainfall and slope were each weighted 20%; and drainage density, LULC, and DEM were each weighted 10% (Table 4.2, Figure 4.7). The matrix achieved $\lambda_{\max} = 6.014$, $CI = 0.0028$, and $CR = 0.0022$ — well within Saaty's (2001) acceptability threshold of $CR \leq 0.10$.

Criterion	Thematic group	Weight (%)	Normalized weight
Lineament density	Structural / Geological	30	0.30
Rainfall	Hydrological	20	0.20
Slope	Topographic	20	0.20
Drainage density	Hydrological	10	0.10
LULC	Land surface	10	0.10
DEM	Topographic	10	0.10

Figure 4.9 AHP-derived factor weights with single-judgment sensitivity envelope ($\pm$ range from perturbation analysis)

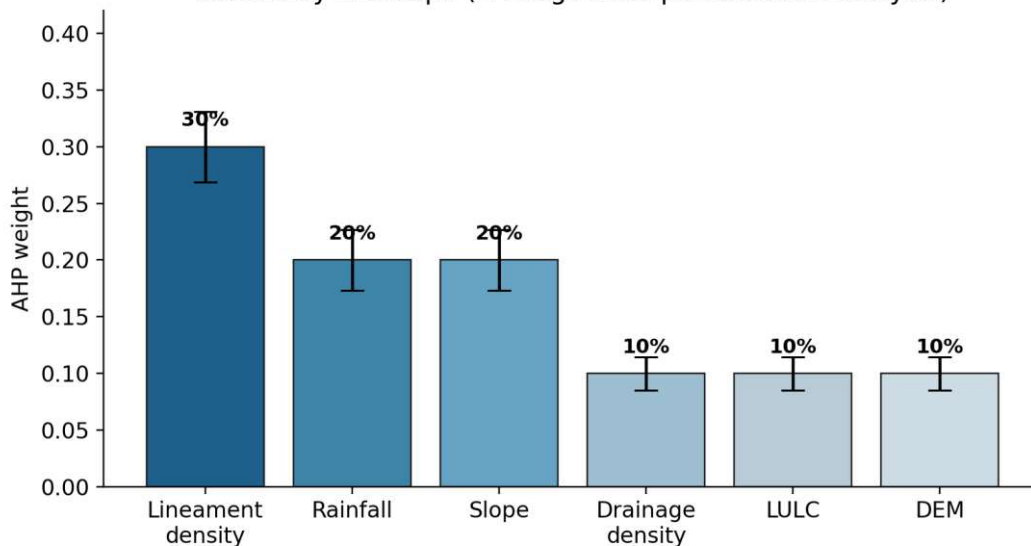


Figure 4.7: AHP-derived factor weights with the sensitivity envelope from Section 4.4.

4.4 Sensitivity analysis

The 26 one-at-a-time perturbation scenarios (Section 3.10) produced the following results (Table 4.3, Figures 4.8–4.9): lineament density remained the top-ranked factor in 26 of 26 scenarios (100%), and the drainage density / LULC / DEM group remained the lowest-weighted tier in all 26 scenarios. The Consistency Ratio ranged from 0.0022 to 0.0110 across all scenarios — an order of magnitude below the 0.10 acceptability threshold in every case — and the maximum observed shift in any single factor's weight was ± 0.031 (for lineament density itself). These results indicate that the adopted AHP weighting scheme is structurally robust to plausible one-step disagreements in expert judgment: no single, individually-plausible change to the pairwise matrix reverses the factor ranking or renders the matrix inconsistent.

Pairwise comparison perturbed	Range of resulting judgment value	CR range across scenario(s)	Top-ranked factor
Lineament density vs. Rainfall	1.0 – 3.0	0.0055 – 0.0084	Lineament density (stable)
Lineament density vs. Slope	1.0 – 3.0	0.0055 – 0.0084	Lineament density (stable)
Lineament density vs. {Drainage, LULC, DEM}	2.0 – 4.0	0.0022 – 0.0073	Lineament density (stable)
Rainfall vs. Slope	2.0	0.0110	Lineament density (stable)
Rainfall / Slope vs. {Drainage, LULC, DEM}	1.0 – 3.0	0.0062 – 0.0091	Lineament density (stable)
{Drainage, LULC, DEM} mutual comparisons	2.0	0.0109	Lineament density (stable)

Figure 4.10 Consistency Ratio across 26 one-at-a-time AHP weight-perturbation scenarios

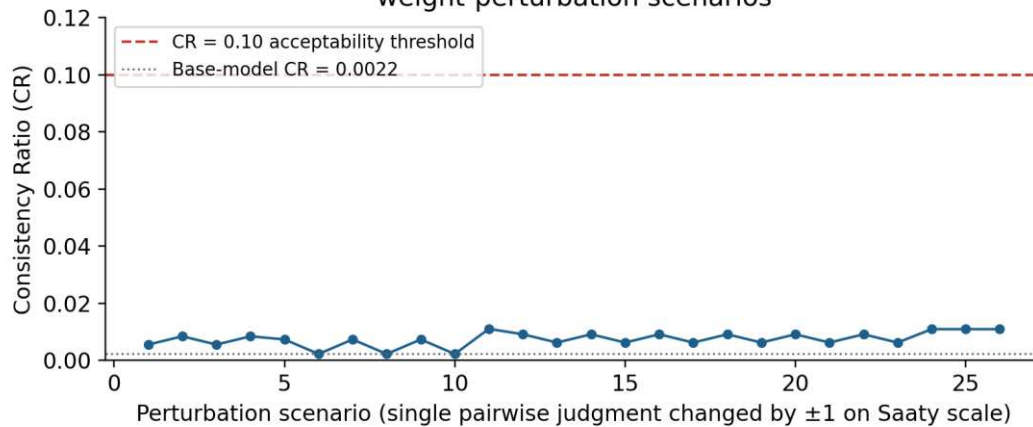


Figure 4.8: Consistency Ratio across all 26 one-at-a-time AHP weight-perturbation scenarios, remaining well below the CR = 0.10 threshold throughout.

4.5 Groundwater-potential map

The integrated groundwater potential map (Figure 4.9) classifies Ikorodu into five categories. Very High and High potential zones are concentrated in the southern, southeastern, and parts of the central regions, including areas around Oreta, Ewu Ebi, Ofin, Ijede, Oke Eletu, and portions of Ason. Moderate zones are widely distributed and represent transition areas. Low and Very Low zones concentrate in the northern and northwestern sections, including parts of Magbon, Emuren, Imota, Agbajeune, Maya, and Igbaga. Areas of Very High and High potential correspond to zones where lower elevation, gentle slope, lower drainage density, favourable land cover, and higher lineament density coincide, consistent with the hydrogeological reasoning in Sections 2.4 and 3.3.

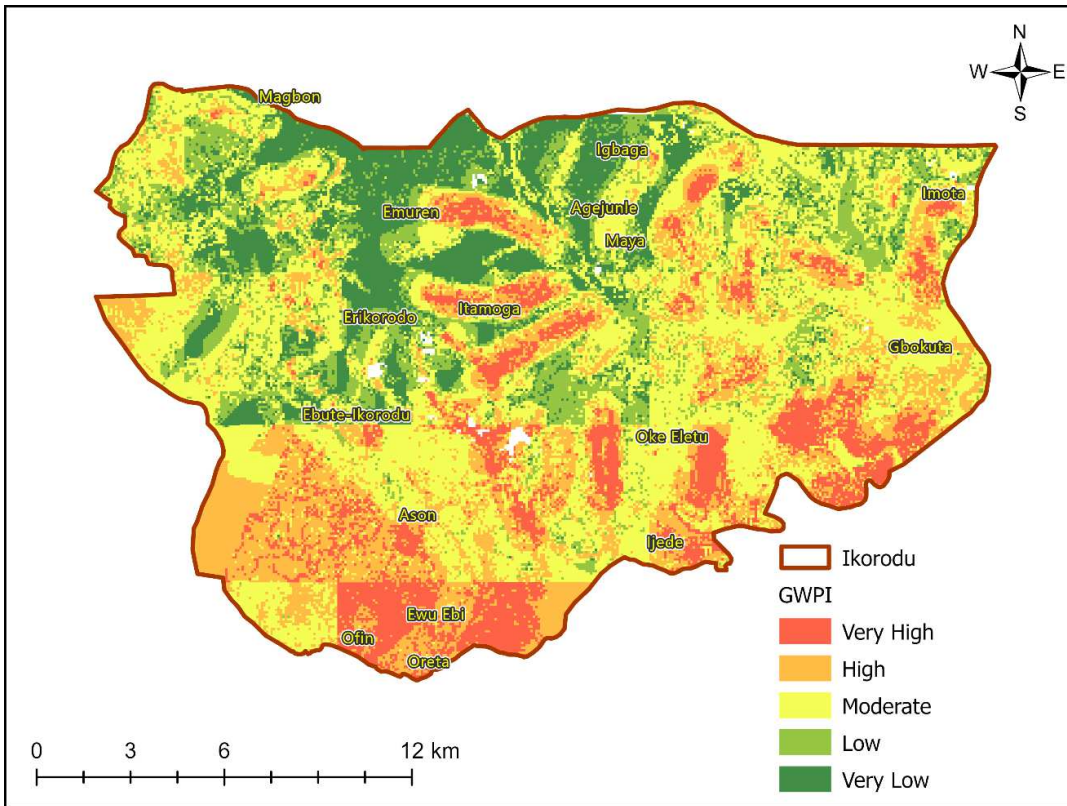


Figure 4.9: Groundwater Potential Map of Ikorodu, Lagos State.

4.6 Independent (qualitative) validation

Figure 4.10 overlays the groundwater potential map with reference VES locations reported by Epuh et al. (2020), clustered mainly around Itamoga, Maya, and Agbajeune. Most reference locations fall within Moderate-to-High potential zones, with only a few near Low-potential areas, indicating that the model is broadly consistent with previously identified favourable groundwater locations. As discussed in Section 3.11, this constitutes qualitative, screening-level verification and should not be read as independent quantitative validation.

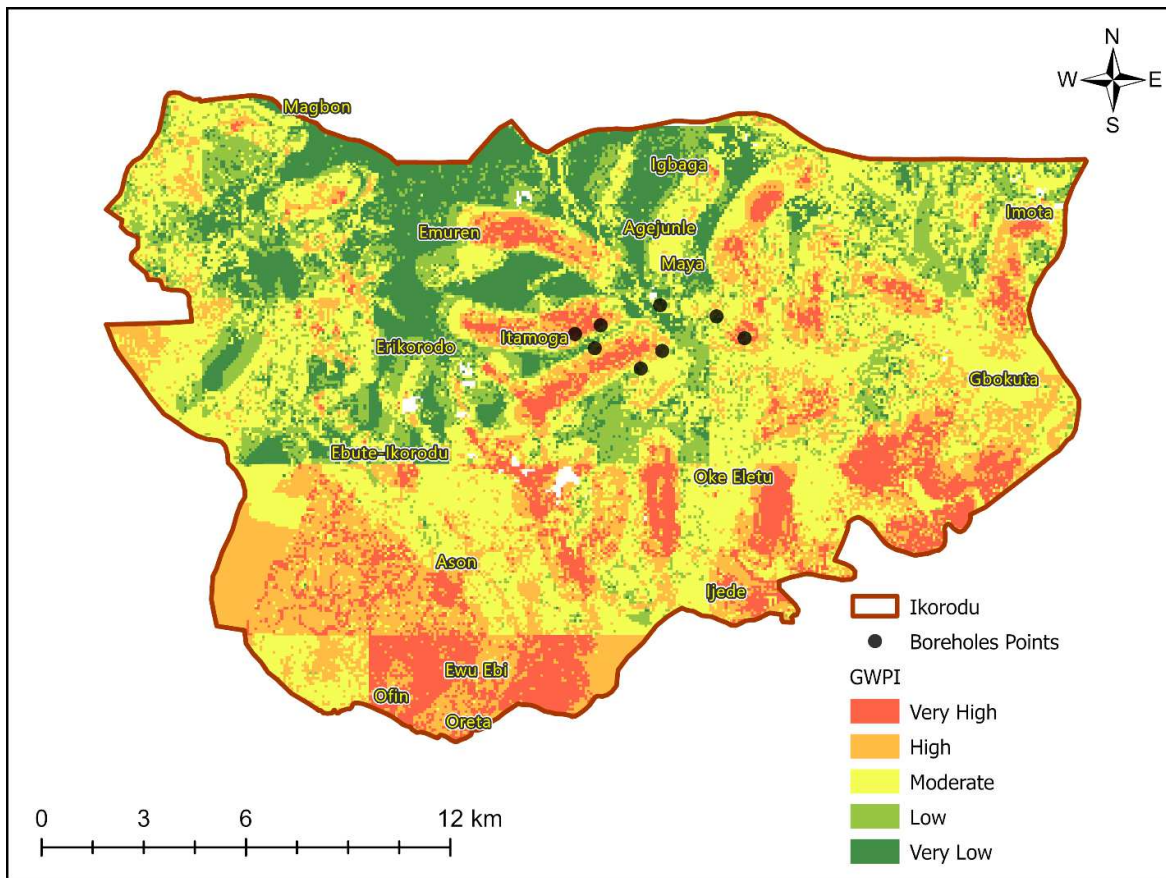


Figure 4.10: Groundwater Potential Map overlaid with reference VES locations (source of VES data: Epuh et al., 2020).

4.7 Quantitative validation statistics

No independent borehole-yield, pumping-test, or groundwater-level dataset was available for this study (Section 3.12), so no ROC-AUC, Frequency Ratio, or equivalent quantitative validation statistic is reported here. Table 4.4 specifies the protocol and minimum data requirements against which this step should be completed in follow-on work; presenting this as an open item, rather than substituting the qualitative VES comparison in its place, is intended to keep the model's current evidentiary status transparent to readers and to future investigators.

Metric	Minimum data required	Status in this study
ROC curve / AUC	≥ 15 –20 geolocated boreholes independently classified productive / non-productive (not used in model construction)	Not computed — data unavailable
Frequency Ratio (FR)	Independent inventory of known productive borehole locations across GWPI classes	Not computed — data unavailable
Agreement with measured yield / static water level	Borehole logs with yield and/or pumping-test records	Not computed — data unavailable

4.8 Uncertainty / stability synthesis

Applying the weight-sensitivity results (Section 4.4) qualitatively across the five GWPI classes (Table 4.5): Very High and High zones, which the base model attributes to the convergence of low elevation, gentle slope, low drainage density, and high lineament density, are interpreted as comparatively lower-uncertainty classifications because the top-ranked factor driving them (lineament density) was stable across all 26 perturbation scenarios. Moderate zones, being transitional and closer to class boundaries on more evenly-weighted factors (rainfall, slope), are interpreted as

comparatively more sensitive to weighting choices and are accordingly treated as Tier 3 (“requires justification”) rather than Tier 1/2 in the planning framework (Section 3.14). A quantitative raster-based stability map remains recommended future work (Section 3.13).

GWPI class	Dominant converging factors	Qualitative uncertainty (from Section 4.4 weight stability)
Very High	Low elevation, gentle slope, high lineament density	Lower — driven by the most weight-stable factor
High	Low–moderate elevation, gentle slope, low drainage density	Lower–moderate
Moderate	Mixed / transitional factor scores	Higher — more sensitive to relative weighting
Low	Higher elevation, steeper slope, sparse lineaments	Lower–moderate
Very Low	High elevation, unfavourable drainage / structure	Lower — consistently unfavourable across factors

4.9 Public borehole priority zones

Applying the Table 3.3 framework to the Section 4.5 classification yields the priority zoning summarized in Table 4.6.

Priority tier	Representative localities	Immediate planning implication
Tier 1 (Very High)	Parts of Oreta, Ewu Ebi, Ofin, Ijede	First candidates for VES survey and pilot public/community borehole drilling
Tier 2 (High)	Oke Eletu, portions of Ason and adjoining central-southern areas	Phased investigation following Tier 1 sites
Tier 3 (Moderate)	Widely distributed transition areas across the LGA	Desk study and site-specific VES required before consideration
Tier 4 (Low / Very Low)	Magbon, Emuren, Imota, Agbajeune, Maya, Igbaga	Deprioritized; detailed hydrogeological justification required before any drilling approval

5. Discussion

5.1 Hydrogeological controls

The results indicate that groundwater potential in Ikorodu is controlled by the combined influence of topographic, hydrological, structural, and land-surface factors acting principally on the shallow water-table aquifer and, through lineament-mediated connectivity, on the underlying first confined aquifer (Section 2.4). Very High and High zones concentrate where lower elevation, gentle slope, lower drainage density, and higher lineament density coincide, while Low and Very Low zones occur where higher elevation and less favourable structural and drainage conditions limit recharge. This spatial pattern underscores the value of integrating multiple environmental controls, anchored to an explicit aquifer framework, rather than relying on any single factor or a generic proxy-factor list.

5.2 Comparison with previous Ikorodu studies

The strong influence of topographic and hydrological conditions observed here is consistent with Epuh et al. (2020), who identified drainage characteristics and recharge conditions as key controls on groundwater potential in Ikorodu using hydrogeophysical and GIS evidence, and with Ejepu et al. (2022), who emphasized elevation and slope in governing infiltration and runoff in comparable coastal settings. In that sense, the present results confirm and extend the earlier Ikorodu mapping of Epuh et al. (2020) rather than replace it, by adding a documented sensitivity analysis of the AHP weights, a formally assessed LULC layer, and an operational planning framework. The present findings reinforce these conclusions and extend them in two specific respects: by explicitly testing the robustness of the relative factor weights (Section 4.4), which prior Ikorodu studies have not reported, and by grounding the six factors in a more detailed regional aquifer framework (Section 2.4) drawn from Longe et al. (1987), Yusuf (2020), and Amos-Uhegbu & Akoma (2023). The assignment of the highest weight to lineament density (30%) is consistent with the structural controls on groundwater occurrence reported for the Lagos region by these and other geoelectrical studies (Akinluyi et al., 2018; Osinowo et al., 2020).

5.3 Scientific novelty

As set out in Section 1.4, this study does not claim novelty in the GIS-MCDA/AHP technique itself, which is well established and was already applied to this same area by Epuh et al. (2020). The paper should therefore be read as a methodological and applied extension of the earlier Ikorodu groundwater-potential map, not as a claim to have produced the first such map for the area. Its contribution is the combination of (i) a documented sensitivity analysis of the AHP weighting scheme, (ii) a formally accuracy-assessed LULC input layer, (iii) an explicit tiered decision-support translation of the map for public-sector borehole planning, and (iv) a transparent, honestly-scoped account of what remains to be independently validated. Reviewers assessing incremental methodological contributions in an already-studied area may reasonably judge whether this combination meets a given journal's novelty bar; the intention here is that the paper's claims are calibrated to what has actually been demonstrated, rather than overstated.

5.4 AHP sensitivity and robustness

The sensitivity analysis (Section 4.4) shows that the factor ranking underlying the groundwater potential map — and in particular the primacy of lineament density — is stable under every individually plausible one-step change to the pairwise comparison matrix, and that the Consistency Ratio remains an order of magnitude below the acceptability threshold throughout. This supports confidence that the map's zonation is not an artefact of a single expert's judgment calls. The important caveat, stated plainly, is that this test evaluates the robustness of the weighting structure, not the robustness of the final spatial raster output; a full map-removal or Monte Carlo sensitivity test propagated through the source GIS layers is the logical next step and is identified as such in Sections 3.10 and 5.8.

5.5 Quantitative validation

The spatial correspondence between predicted potential zones and the VES-derived reference locations from Epuh et al. (2020) provides supporting, qualitative evidence for the model's usefulness as a regional screening tool. It does not constitute independent quantitative validation, because the reference points were themselves generated by a prior interpretive study rather than by direct field measurement, and because no accuracy statistic (AUC, FR, or equivalent) can be honestly computed from a handful of qualitatively-matched points. Table 4.4 sets out concretely what would be needed to close this gap. Until such data are assembled, the map should be used strictly as the first-stage screening instrument described in Section 3.14, not as a substitute for site-specific investigation.

5.6 Uncertainty

The qualitative uncertainty synthesis in Section 4.8 suggests that Very High, High, and Very Low zones — where classification is driven by factors that were stable across the sensitivity analysis — carry comparatively lower classification uncertainty than Moderate zones, which sit closer to class boundaries on more evenly-weighted factors. This distinction is reflected in the Tier 3 (“requires justification”) treatment of Moderate zones in the public-borehole planning framework (Section 3.14), and is offered as a reasoned interpretation rather than a measured statistic, pending the raster-based uncertainty mapping recommended in Section 3.13.

5.7 Borehole-planning implications

The groundwater potential map, translated through Table 3.3 into the four-tier framework, has practical implications for public and community borehole planning in Ikorodu. Very High and High zones — particularly around Oreta, Ewu Ebi, Ofin, Ijede, Oke Eletu, and portions of Ason — may be considered priority candidates for detailed geophysical and hydrogeological investigation. Low and Very Low zones, concentrated in Magbon, Emuren, Imota, Agbajeune, Maya, and Igbaga, should be treated as areas of higher drilling uncertainty requiring stronger technical justification before approval. The map's planning value lies in directing limited investigative resources toward comparatively favourable locations while flagging where additional evidence is required before commitment of funds; it should not be interpreted as a final borehole-siting map or as a guarantee that any individual location within a favourable class will yield a successful borehole.

5.8 Limitations and transferability

This study is subject to several specific limitations that should guide its use and any follow-on work:

- The six-factor set and their standardization follow the same general logic as Epuh et al. (2020); this study's contribution is methodological transparency (sensitivity testing, accuracy assessment, tiered planning translation) rather than a new factor set or spatial technique.
- The GIS map figures reproduced here (Figures 2.1, 4.1–4.6a, 4.9–4.10) are the study's original analytical outputs; no new raster processing was performed for this revision because the source GIS layers were not resupplied, so the spatial (“map-removal”) sensitivity and Monte Carlo uncertainty analyses recommended in Sections 3.10 and 3.13 remain items for follow-on work with access to those layers.
- Quantitative validation (Section 3.12/4.7) could not be completed for lack of an independent borehole-yield, pumping-test, or groundwater-level dataset; the qualitative VES comparison (Section 3.11) is a reasonable but explicitly weaker substitute.
- AHP weights remain expert-judgment-based; the sensitivity analysis in Section 4.4 tests robustness to plausible disagreement but cannot eliminate the underlying subjectivity of the initial pairwise comparisons.
- The elevated saline-intrusion risk noted for the western, lagoon-fronting part of the study area (Section 2.4) is not represented among the six mapped factors and should be considered separately in borehole depth selection near the coast.

The overall methodology remains transferable to other parts of Lagos State and comparable coastal sedimentary settings, provided local aquifer framework data, an independent validation dataset, and the source GIS layers are available to support the fuller sensitivity and validation protocol specified here.

6. Conclusion

This study assessed groundwater potential in Ikorodu, Lagos State, using a GIS-based AHP-MCDA framework integrating six factors — elevation, slope, rainfall, drainage density, lineament density, and land use/land cover — and, distinctively for this area, subjected the resulting AHP weighting scheme to a systematic sensitivity analysis. Lineament density received the highest weight (30%), followed by rainfall and slope (20% each); a 26-scenario one-at-a-time perturbation test showed this ranking to be stable in every case, with the Consistency Ratio remaining well below the 0.10 acceptability threshold throughout. The resulting map classified Ikorodu into five groundwater potential zones, with Very High and High potential concentrated in the southern, southeastern, and parts of the central areas, and Low and Very Low potential concentrated in the north and northwest. Qualitative comparison with VES-derived reference locations from Epuh et al. (2020) showed most reference points within Moderate-to-High potential areas, providing supporting but not independent quantitative evidence for the map's usefulness.

The principal contribution of this study is the translation of the groundwater potential map into an explicit, tiered decision-support framework for public and community borehole planning, combined with a transparent account — rather

than an overstated claim — of what has and has not yet been independently validated. The map should be used as a first-stage screening instrument, directing limited investigative resources toward comparatively favourable zones while flagging where site-specific geophysical and hydrogeological investigation is required, and not as a final approval basis for borehole construction.

Recommendations

- Public and community borehole planning should initially prioritize areas classified as Very High and High groundwater potential (Tier 1/2, Table 4.6), especially in the southern, southeastern, and central parts of Ikorodu, with each proposed site undergoing site-specific VES and hydrogeological investigation before drilling.
- Areas classified as Low and Very Low groundwater potential (Tier 4) should be treated as zones of greater drilling uncertainty, requiring stronger technical justification and detailed investigation before any approval.
- Vertical Electrical Sounding, borehole logging, lithological analysis, pumping tests, and groundwater-quality assessment should be conducted at all proposed public borehole sites to confirm aquifer depth, thickness, productivity, and suitability for domestic use, with particular attention to saline-intrusion risk in the western, lagoon-fronting part of the study area.
- Local authorities and water-supply agencies should adopt the groundwater potential map and the Table 3.3/4.6 prioritization framework as an initial screening layer within broader water-supply and urban-development planning, combined with population distribution, existing water-supply coverage, flood risk, and contamination-source data.
- Future research should prioritize assembling an independent quantitative validation dataset (≥ 15 –20 boreholes with yield, static water level, or pumping-test records not used in this study) to execute the ROC-AUC / Frequency Ratio protocol specified in Table 4.4, and should obtain the source GIS raster layers to perform the map-removal sensitivity and Monte Carlo uncertainty analyses identified in Sections 3.10 and 3.13 as direct extensions of the present sensitivity-analysis contribution.

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