

Remote Sensing and GIS-Based Groundwater Potential-Zone Mapping in Imo State, Southeastern Nigeria

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ABSTRACT

Groundwater is an important source of water for domestic, agricultural and economic activities, yet its spatial occurrence is controlled by interacting geological, hydrological, terrain, soil and land-use factors. This study delineated groundwater potential zones in Imo State, southeastern Nigeria, using an integrated remote sensing and Geographic Information System (GIS) approach. Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS), Shuttle Radar Topography Mission (SRTM) digital elevation data, rainfall, soil, geological, drainage-density and lineament datasets were integrated to characterize factors controlling groundwater occurrence. The thematic layers were reclassified according to their relative groundwater potential, weighted using the Analytical Hierarchy Process (AHP), and integrated through GIS-based weighted-overlay analysis. Overlay analysis was also used to examine relationships between groundwater potential, soil characteristics and terrain slope, while logistic regression was applied to investigate the association between land-use/land-cover (LULC) and groundwater occurrence. The resulting groundwater-potential map classified the study area into very-low, low, moderate, high and very-high potential zones. The moderate-potential class constituted the largest reported proportion of the study area (59.6%), followed by low (20.2%) and high (18.6%) potential zones. The reported validation produced an overall mapping accuracy of 97.4%, with class-specific accuracies ranging from 91.7% to 99.3%. Sandy-loam soils and areas with relatively gentle slopes were associated with greater groundwater potential, whereas steeper terrain was generally associated with lower potential. The LULC analysis indicated greater groundwater occurrence in vegetated areas than in built-up areas. The study demonstrates the usefulness of integrating remote sensing, GIS and statistical techniques for regional groundwater-potential assessment and provides a spatial basis for groundwater planning and management in Imo State.

Keywords: groundwater potential; remote sensing; GIS; weighted overlay; land-use/land-cover

1.0 INTRODUCTION

Groundwater is a major freshwater resource and an important alternative to surface water for domestic, agricultural and economic activities. Groundwater recharge occurs when precipitation infiltrates the soil and reaches aquifer systems or when surface water contributes to aquifer replenishment. Earlier studies by scientist revealed that groundwater is the second most important reservoir for freshwater and the best alternative for human and economic activities compared to surface water [1-3].

The occurrence and movement of groundwater are controlled by the interaction of geological, geomorphological, hydrological and environmental conditions. Important controlling factors include lithology, geological

structures, soil characteristics, slope, drainage density, lineament distribution, rainfall, distance from river and land-use/land-cover (LULC) conditions [4-7].

The increasing demand for water associated with population growth, agricultural activities, industrialization and environmental change has increased the need for reliable groundwater assessment and management. In Nigeria, groundwater is particularly important in areas where surface-water resources are insufficient, seasonally variable or vulnerable to contamination. Imo State in southeastern Nigeria faces increasing pressure on water resources arising from population growth, urban development and changing land-use practices. Improved knowledge of the spatial distribution of groundwater potential is therefore important for water-resource planning and sustainable development.

Conventional groundwater exploration techniques include geological and hydrogeological investigations, drilling, geophysical surveys and geo-electrical methods. Although these approaches provide valuable information, regional application may require considerable time, field measurements and financial resources. Remote sensing (RS) and Geographic Information Systems (GIS) provide complementary approaches for integrating spatial datasets covering large areas. GIS allows the storage, processing, analysis and visualization of spatial information, while satellite remote sensing provides information on land-surface characteristics over extensive and sometimes inaccessible areas.

Previous studies have demonstrated the usefulness of GIS-based weighted-overlay and multi-criteria decision-analysis approaches for groundwater-potential mapping. Studies in Nigeria and elsewhere have integrated geology, soil, rainfall, slope, land use and related parameters to delineate groundwater-potential zones. The GIS-based groundwater exploration framework described by [8], for example, integrates several spatial datasets through weighted overlay to produce a groundwater-potential map. Other studies have similarly demonstrated the importance of combining geological, topographic, soil and land-use information.

The present study sought to integrate remote sensing and GIS with geological, soil, climatic and terrain information while also examining LULC effects statistically. The study therefore aimed to delineate groundwater-potential zones in Imo State and to examine the relationships between groundwater occurrence and selected environmental factors. Furthermore, the research aimed to integrate remote sensing and GIS techniques for identifying groundwater-potential zones in Imo State; examine the relationship between geological/soil characteristics, terrain parameters and groundwater occurrence; investigate the effects of land-use/land-cover on groundwater occurrence using regression analysis; and to evaluate the accuracy of the RS-GIS-derived groundwater-potential zones and compare the result with reported conventional groundwater-assessment approaches.

2.0 MATERIALS AND METHODS

2.1 Study Area

Imo State is located in southeastern Nigeria, with Owerri as its capital. The state lies approximately between latitudes 4°45'N and 7°15'N and longitudes 6°50'E and 7°25'E and covers approximately 5,100 km² according to the study-area information reported in this study. The state is bordered by Anambra State to the north and Rivers State to the south and west. It has a tropical rainforest climate characterized by rainy and dry seasons. The rainy season generally extends from March to October, while the dry season occurs from November to February. The study reports substantial annual rainfall across the state, with 2023 rainfall data ranging spatially from approximately 3,389 to 5,150 mm and an average of about 4,169 mm [9]. The relief of Imo State is generally low-lying, although upland and highland areas occur. The study describes lowland plains, upland areas and highlands as major physiographic units. Major drainage systems include the Imo, Orashi and Njaba rivers.

Land use in the state includes agriculture, forest and other vegetation, built-up areas, grassland and water bodies. Agricultural activities include subsistence production of cassava, yam and maize as well as commercial production of crops such as oil palm and rubber. Urbanization and associated vegetation clearance have altered the natural land-cover characteristics of several parts of the state.

Geologically, Imo State is predominantly underlain by sedimentary formations ranging from Cretaceous to Recent age. The geological setting includes the Benin Formation and Agbada Formation, together with sandstone, shale, claystone and other lithological units. Geological structures including faults, fractures and joints are relevant to groundwater movement and storage.

2.2 Data Sources

The study employed an integrated set of remotely sensed, terrain, climatic, geological and soil datasets. Landsat 8 OLI/TIRS imagery was used for LULC classification. SRTM digital elevation data with 30-m spatial resolution were used to derive terrain-related parameters, including slope, drainage density and lineament information. Rainfall data were obtained from the Nigerian Meteorological Agency (NIMET), while soil and geological information were obtained from mapped datasets.

The major datasets reported in the thesis included Landsat 8 OLI/TIRS imagery, 2023 rainfall data, soil data, geological data, drainage-density data, elevation data and lineament data.

2.3 Land-Use/Land-Cover Classification

Landsat 8 OLI/TIRS imagery was used to characterize the surface land-use/land-cover conditions of Imo State. Bands 2, 3, 4 and 5 were identified in the study as relevant to the LULC analysis. These multispectral bands provide information useful for vegetation, soil and surface characterization. The resulting LULC information was incorporated into the groundwater-potential analysis.

2.4 Groundwater-Potential Conditioning Factors

Seven thematic parameters were considered in the groundwater-potential analysis: soil, LULC, lineament density, drainage density, geology, slope and rainfall. Rainfall was treated as an important source of groundwater recharge. Soil characteristics were used to represent infiltration and water-storage conditions. Geological formations were used to represent lithological controls on groundwater storage and movement. Drainage density, slope and lineament density were used to characterize runoff, infiltration and structural pathways, while LULC was used to represent surface conditions affecting recharge.

The study classified sandy-loam soils as relatively favourable for groundwater recharge, loamy sandy soils as moderate, and sandy clay loamy soils as lower potential. Slope was classified into five potential classes: 0–0.99° (very high), 0.99–2.24° (high), 2.24–4.06° (moderate), 4.06–7.04° (low), and 7.04–21.2° (very low).

2.5 Analytical Hierarchy Process and Weighted Overlay

The Analytical Hierarchy Process (AHP) was used to determine the relative importance of the groundwater-conditioning parameters. The study recorded the following principal parameter weights: soil 15%, LULC 15%, lineaments 5%, drainage density 10%, geology 20%, slope 15%, and rainfall 20%.

The reclassified thematic layers were converted to raster format and integrated using GIS weighted-overlay procedures. The resulting composite surface was classified into very-low, low, moderate, high and very-high groundwater-potential zones.

2.6 Statistical Analysis

Regression analysis was used to investigate the relationship between LULC and groundwater occurrence. The thesis states that logistic regression was used to model groundwater occurrence, while linear regression was considered for groundwater-level relationships. The analysis was performed using SPSS at a 0.05 significance level.

2.7 Accuracy Assessment

The groundwater-potential map was evaluated by comparing mapped potential zones with reference information representing the actual/reference extent of the corresponding potential classes. Class-specific accuracy was calculated, and an overall accuracy was subsequently derived from the correctly mapped extent relative to the reference extent.

3.0 Results and Discussion

The integrated RS-GIS analysis delineated the study area into five groundwater-potential classes: very low, low, moderate, high and very high. The moderate groundwater-potential class was the dominant reported class, accounting for 59.6% of the study area. Low-potential areas accounted for 20.2%, while high-potential areas accounted for 18.6%. Very-low and very-high potential classes represented comparatively small proportions. The study indicates a significant relationship between LULC and groundwater occurrence. Vegetated areas were associated with greater groundwater occurrence, whereas built-up areas were associated with reduced potential. The predominance of the moderate groundwater-potential class suggests that groundwater occurrence across Imo State is controlled by a combination of favourable and unfavourable environmental conditions rather than by a single dominant factor. The integrated approach allows geology, rainfall, soil, terrain, drainage, lineaments and LULC to be considered simultaneously. The regression results support this spatial pattern, with a positive vegetation coefficient and a negative built-up coefficient.

Table 1: Effect of LULC on Groundwater occurrence

Potential zone	Reported area (km ²)	Percentage
Very low	550	0.6
Low	1,053	20.2
Moderate	2,382	59.6
High	954	18.6
Very high	390	0.36
Total	5,329	100

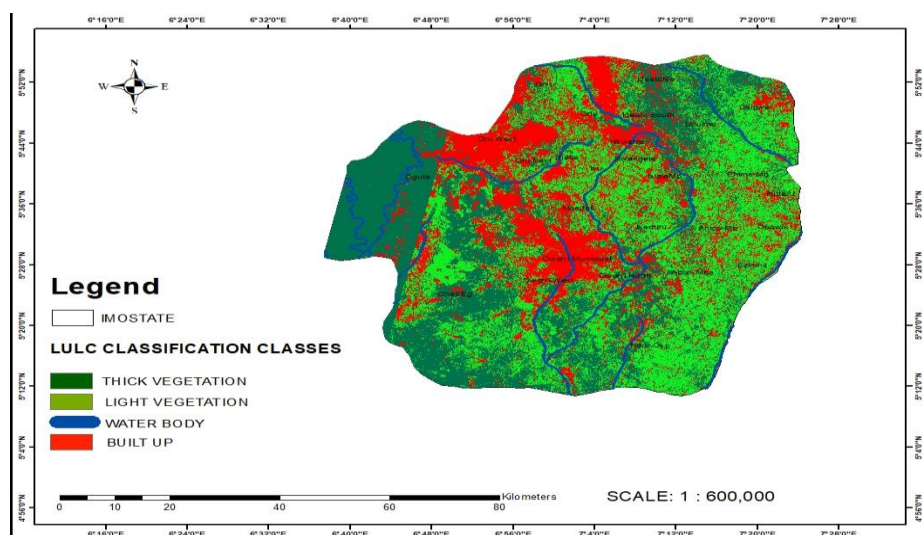


Figure1: Land use/ land cover classification map of Imo State for the year 2024

The LULC analysis identified thick vegetation, light vegetation, built-up areas and water bodies. The thesis reports thick and light vegetation and water bodies as relatively favourable groundwater-recharge conditions, whereas built-up areas were associated with moderate to low groundwater potential. This pattern is consistent with the influence of vegetation and impervious surfaces on infiltration.

3.2 Accuracy Assessment

The reported class-specific accuracies were 91.7% for the very-high class, 96.3% for the high class, 99.3% for the moderate class, 95.7% for the low class and 94.8% for the very-low class. The study recorded an overall accuracy of 97.4%. The reported overall accuracy of 97.4% demonstrates the potential value of integrating RS and GIS for regional groundwater-potential assessment. The approach integrates multiple spatial factors and provides broad spatial coverage. Nevertheless, the accuracy should not be interpreted as evidence that the model can replace site-specific hydrogeological and geophysical investigation.

Table 2: Comparison of underground water mapping with reference data

Zone	Mapped extent (km ²)	Reference extent (km ²)	Error (km ²)	Accuracy (%)
Very high	390	360	30	91.7
High	954	920	34	96.3
Moderate	2,382	2,400	18	99.3
Low	1,053	1,100	47	95.7
Very low	550	580	30	94.8

3.3 Relationship between Soil, Terrain and Groundwater Occurrence

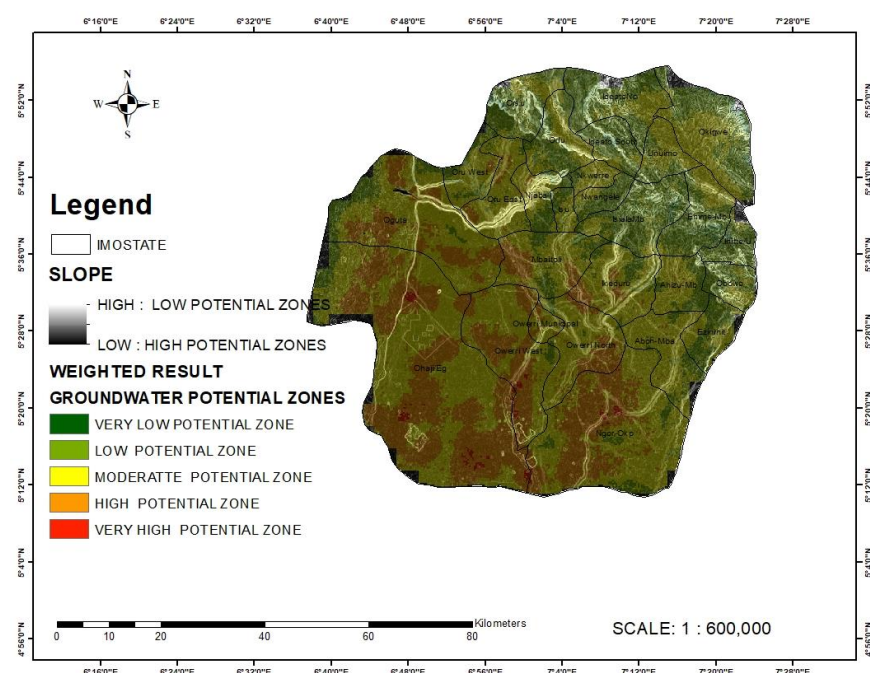


Fig. 1: Underground water potential zone mapping

The overlay analysis demonstrated a relationship between terrain characteristics and groundwater occurrence. Areas characterized by relatively low slopes were associated with higher groundwater-potential classes, whereas areas with steeper slopes tended to exhibit low to very-low groundwater potential. Sandy-loam soils were

considered more favourable for groundwater recharge because of their relatively high permeability and infiltration capacity. Loamy sandy soils were associated with moderate conditions, while sandy clay loamy soils were assigned lower potential. The relationship between soil characteristics and groundwater occurrence identified by the study is consistent with the role of soil permeability in controlling infiltration. Sandy-loam soils generally permit more rapid movement of water through the soil profile than soils with higher clay content. Terrain slope also affects groundwater recharge through its influence on runoff and residence time. Gentle slopes provide greater opportunity for infiltration, whereas steep slopes encourage rapid surface runoff.

3.5 Logistic Regression Results

The reported logistic-regression coefficients were 0.02 for vegetation ($p = 0.005$; odds ratio = 2.5), -0.03 for built-up land ($p = 0.010$; odds ratio = 0.4), and -1.5 for the constant ($p = 0.010$; odds ratio = 0.2). Both LULC variables were statistically significant at the 0.05 level. The positive vegetation coefficient indicates a positive association with groundwater occurrence, whereas the negative built-up coefficient indicates an inverse association.

3.6 Comparison with Conventional Methods

The study recorded an overall RS-GIS accuracy of 97.4% and compares this with conventional investigations reported at 75% and 81% accuracy. The comparison suggests strong performance of the integrated RS-GIS approach within the reported validation framework.

5.0 CONCLUSION

This study integrated remote sensing, GIS, AHP-based weighting and statistical analysis to delineate groundwater-potential zones in Imo State, southeastern Nigeria. The resulting map classified the state into very-low, low, moderate, high and very-high potential zones, with the moderate class constituting the largest reported proportion at 59.6%. The analysis showed that soil characteristics and terrain conditions influence groundwater occurrence. Sandy-loam soils were identified as relatively favourable for infiltration and recharge, while areas with gentle slopes generally exhibited greater groundwater potential than steeper areas. The LULC analysis indicated that vegetation was associated with greater groundwater occurrence, whereas built-up areas were associated with reduced groundwater potential. The reported validation produced an overall accuracy of 97.4%. The integrated RS-GIS approach therefore provides a useful regional screening tool for groundwater-resource planning, while site-specific hydrogeological and geophysical investigations remain necessary before groundwater development. For sustainable groundwater management, groundwater development should be guided by spatial information on potential zones, while land-use planning should protect vegetated recharge areas and reduce the hydrological impacts of uncontrolled urban expansion. Future studies should incorporate more extensive groundwater-level, borehole-yield, geophysical and field-validation datasets.

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