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Multi-Criteria Evaluation of Groundwater Potential Zones in Abuja (FCT) Using Analytical Hierarchy Process: A Pathway to Sustainable Water Management

Danlami IBRAHIM, Tatsuya NEMOTO and Venkatesh RAGHAVAN

Department of Geosciences, Graduate School of Science, Osaka Metropolitan University,
3-3-138 Sugimoto Sumiyoshi-ku, Osaka, 558-8585, Japan E-mail: sp23519y@st.omu.ac.jp

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1. Introduction

The global demand for freshwater is increasing due to climate change and anthropogenic activities (Döell et al., 2012). A significant portion of global water needs for domestic, agricultural and industrial use, is met using groundwater, which makes it essential, especially in Sub-Saharan Africa. While Africa holds vast groundwater reserves, rising population growth and rapid urban development, particularly in Nigeria, are putting considerable stress on this crucial resource. Abuja, the Federal Capital Territory (FCT), has seen its population grow by over 400% in the past twenty years, leading to an increased reliance on groundwater, especially in rural communities where surface water is scarce (UN DESA, 2022).Previous assessments of groundwater in the FCT have mainly utilised Vertical Electrical Sounding (VES) methods without incorporating comprehensive hydrogeological and climatic datasets, which restrict their spatial accuracy and reliability when considered on a large scale. This study presents an improved methodological framework by integrating eight essential factors, such as rainfall, depth to bedrock, geology, elevation, landuse/landcover (LULC), distance from river, drainage density, and lineament density, using Geographic Information system (GIS) technology and the Analytical Hierarchy Process (Saaty, 1980).

An important innovation in this study is the validation of the groundwater potential zone (GWPZ) map by utilising actual borehole yield data, thereby enhancing its empirical reliability. Remote sensing and GIS facilitate effective spatial analysis across complex terrains at a minimal cost.

The main objective of this research is to:

1. Integrate geophysical, climatic and geospatial datasets for groundwater potential zone mapping
2. Use AHP for multi-criteria decision-making analysis.
3. Validate the GWPZ findings through empirical borehole yield data.

2. Significance and Contribution

This research presents a validated method for identifying groundwater potential zones (GWPZ) in Abuja, Nigeria, by integrating geophysical data, geological information, and environmental factors using GIS and the Analytical Hierarchy Process (AHP). A significant element is the empirical validation of the GWPZ map through borehole yield data using the SRC Curve and ROC curve analysis, which enhances model reliability.

The study addresses gaps in previous methodologies, particularly in areas of subsurface integration and validation. It offers a scalable, cost-effective framework for other complex and data-limited regions.

By aiding groundwater exploration and management, this research directly supports the achievement of Sustainable Development Goal (SDG) 6 (Clean Water and Sanitation) by providing a valuable tool for decision-makers in managing water security in rapidly urbanising settings.

3. Study area

Abuja, which serves as the Federal Capital Territory (FCT) of Nigeria, is situated between latitudes 8°21' - 9°18' N and longitudes 6°45' - 7°39' E, covering an area of approximately 8,000 km² and featuring an average elevation of 476 m above sea level. The region is part of the savannah ecological zone and experiences a tropical climate characterised by a dry season from November to March and a wet season from April to October, with temperatures ranging between 30°C and 37°C during the dry months.

Geologically, around 85% of Abuja is underlain by the Precambrian Basement Complex, while the remaining 15% consists of Cretaceous sedimentary rocks from the Bida Basin. Key lithological units present include the Migmatite-Gneiss Complex, metasedimentary belts (such as schists and amphibolites), Older Granites, and the sedimentary deposits of the Bida Basin. The study area features a dual-aquifer system comprising weathered regolith and fractured basement rocks. The distribution and movement of groundwater are affected by lithology, soil characteristics, the thickness of overburden, and the connectivity of fractures.

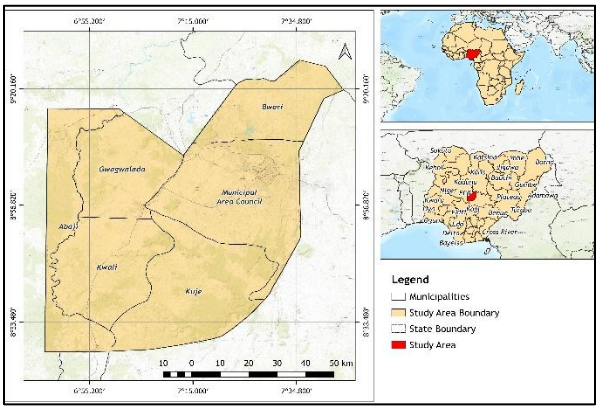

Figure 1: Study area

2.1 Data and Methods

This study utilized various datasets to identify groundwater potential zones in Abuja, Nigeria. Thematic layers were created from multiple sources: depth to bedrock from geophysical surveys, elevation and drainage density from the SRTM Digital Elevation Model (DEM), geological data from the Geological Survey of Nigeria, lineament density from Landsat imagery, and rainfall data from NIMET and CHIRPS datasets. Additionally, land use and land cover (LULC) information was sourced from Sentinel-2 imagery via Google Earth Engine (GEE). Eight groundwater-controlling factors were selected and ranked based on literature, expert input and field relevance. Their impacts were assessed using the Analytic Hierarchy Process (AHP) via pairwise comparisons. The weighted layers were integrated using overlay analysis in GRASS GIS and classified into five groundwater potential zones using the Natural Breaks (Jenks, 1967) Method. Model accuracy was validated with borehole data from 722 locations, confirming its effectiveness for groundwater resource planning and management.

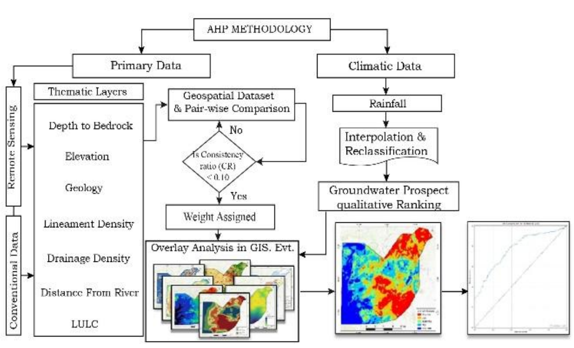

Figure 2: Methodology Flow Diagram

3. Results

The Groundwater Potential Zone (GPZ) map was created using the Analytic Hierarchy Process (AHP) by integrating essential hydrogeological factors. The study area was classified into five levels of groundwater potential: Very Low, Low, Moderate, High, and Very High. The resulting spatial distribution reveals a varied landscape, with high and very high potential zones primarily located in the central and southeastern regions. This pattern is likely due to favourable geological and structural characteristics in these areas. In contrast, the low potential zones are mostly found in the eastern and southwestern regions, indicating less permeable conditions. The distribution of area across the different categories is relatively balanced, suggesting that the model's output is fair and unbiased. This AHP-based mapping approach provides a valuable spatial tool for groundwater exploration, resource management, and sustainable development planning in regions with basement terrain.

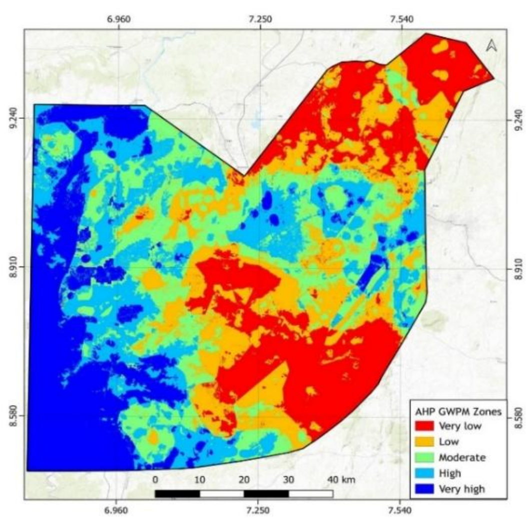

Figure 3: Groundwater Potential Zone Map

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