

Spatial Modelling of Groundwater Potential Zones Using GIS-Based Machine Learning Techniques: A Case Study of Abuja, Nigeria

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1. Introduction

Groundwater is an important global freshwater resource that supports domestic, agricultural, and industrial water needs, especially in developing countries. Groundwater potential refers to the likelihood of groundwater occurrence within a given hydrogeological setting. Increasing population growth, large-scale agricultural activities, urbanisation and industrialisation have intensified groundwater exploitation beyond natural recharge rates, threatening its sustainability (Sachdeva & Kumar, 2020). Groundwater occurrence is controlled by several hydrogeological and environmental factors, including lithology, slope, fractures, rainfall, drainage characteristics and land use/land cover (Sankar et al., 2023).

Conventional groundwater exploration techniques, although reliable, are often expensive, labour-intensive and unsuitable for large-scale applications in data-scarce regions (Ajay Kumar et al., 2020). Consequently, GIS and Remote Sensing (RS) techniques are increasingly applied in groundwater potential zone (GWPZ) mapping due to their efficiency in spatial analysis (Akter et al., 2020). Recent advances in machine learning (ML), particularly Random Forest (RF), XGBoost and Support Vector Machine (SVM), have improved groundwater modelling accuracy and reduced subjectivity compared to conventional multi-criteria decision-making (MCDM) approaches (Prasad et al., 2020).

This study aims to integrate geophysical data, GIS, RS, and ML techniques to delineate groundwater potential zones (GWPZ) in Abuja, Nigeria. The research will also evaluate the influence of groundwater conditioning factors and assess model predictive performance to support sustainable groundwater management.

2. Significance and Contribution

This research demonstrates the effectiveness of integrating GIS, RS and ML techniques for groundwater potential mapping in Abuja, Nigeria. The application of Random Forest (RF), XGBoost, and Support Vector Machine (SVM) models in this research improves mapping accuracy and reduces the subjectivity often associated with conventional methods. The generated GWPZ maps will support sustainable groundwater exploration, water resource management and long-term water security planning in the study area.

3. Study area

Abuja is situated between latitudes 8°21' – 9°18' N and longitudes 6°45' – 7°39' E and covers an area of approximately 8,000 km² with an average elevation of 476 m above sea level. The region is in a tropical climate with distinct wet and dry seasons. Geologically, around 85% of Abuja is underlain by the Precambrian basement complex rocks, while the remaining 15% consists of Cretaceous sedimentary rocks from the Bida Basin. Major lithological units include Migmatite-Gneiss, Schist, Amphibolites, Older Granites, and Sedimentary Deposits. Groundwater occurs mainly within weathered regolith and fractured basement aquifers, with its occurrence and movement controlled by lithology, soil properties, overburden thickness and fracture connectivity.

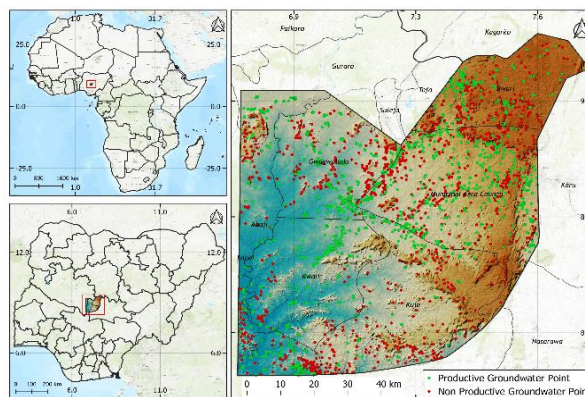


Figure 1: Location of the study area

4. Data and Methods

This study developed a groundwater database for Abuja, Nigeria, using borehole data obtained from FCT-RUWASSA, the FCTA's SDGs office, and private drilling companies. Productive boreholes represented groundwater presence points while abortive boreholes and rock outcrops represented absence points. A total of 2410 georeferenced points were divided into 80% training and 20% testing datasets. Groundwater potential mapping was conducted using nine conditioning factors: geology, depth to bedrock, aquifer thickness, slope, lineament density, drainage density, distance from rivers, rainfall, and land use/land cover (LULC).

Depth to bedrock and aquifer thickness were derived from Vertical Electrical Sounding (VES) data collected at 823 locations, while other thematic layers were generated from DEM, Landsat-8 imagery, CHIRPS rainfall data, and geological datasets within a GIS environment. RF, XGBoost and SVM models were developed and validated using ROC-AUC, confusion matrix metrics, stratified 10-fold cross-validation, and hold-out validation to ensure predictive accuracy and model reliability.

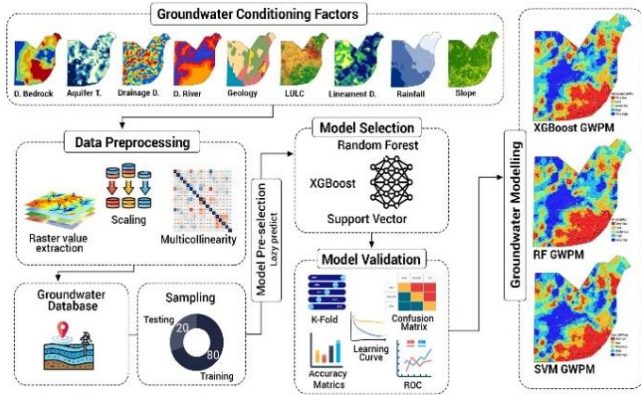


Figure 2: Methodology Flow Diagram

5. Results

The GWPZ maps generated using XGBoost, RF and SVM reflected the hydrogeological characteristics of Abuja. Very high to high GWPZ were mainly concentrated in the southwestern and western regions, where gentle slopes, thicker aquifer layers and favourable drainage conditions promote infiltration and groundwater storage. Conversely, the southeastern and northeastern areas exhibited low groundwater potential due to steep slopes, limited weathering and high runoff.

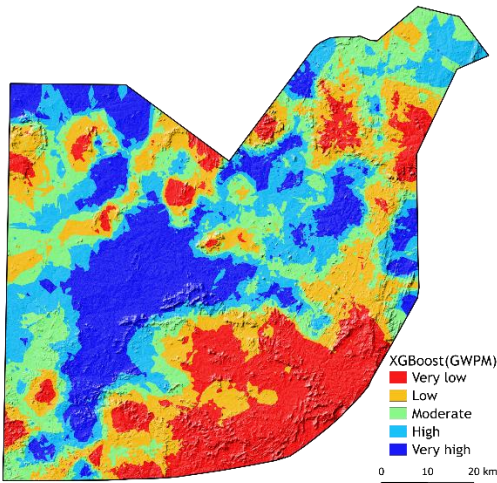


Figure 3: Groundwater Potential Zone Map

Feature importance analysis identified slope, land use/land cover, drainage density and proximity to rivers as the dominant groundwater controlling factors, while low pairwise correlations ($|r| < 0.5$) indicated minimal multicollinearity among predictors. The models demonstrated strong predictive performance with ROC-AUC values of 0.89 for XGBoost, 0.88 for RF, and 0.87 for SVM,

indicating good stability, reliability and generalisation capability for groundwater potential mapping.

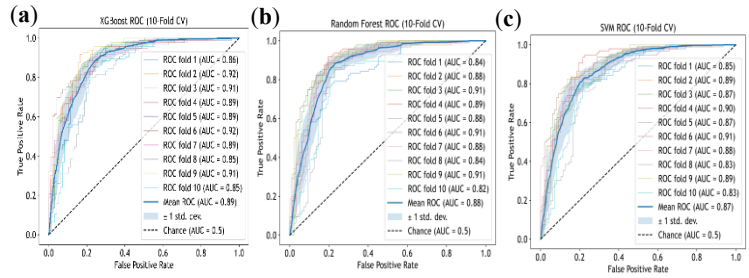


Figure 4: ROC-AUC curves of the ML models: (a) XGBoost model, (b) RF model, (c) SVM model.

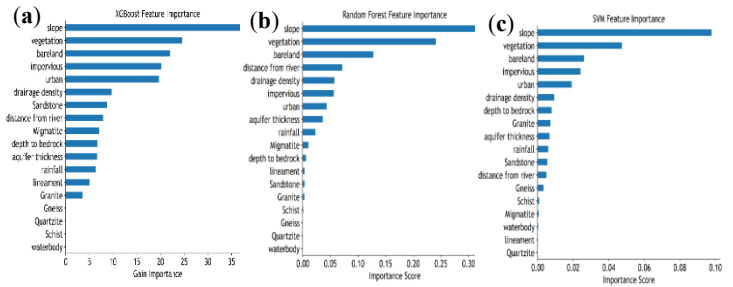


Figure 5: Variable importance of conditioning factors: (a) XGBoost; (b) Random Forest; (c) SVM.

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