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Research Article

Delineation of Groundwater Potential Zones in Oyo State, Nigeria using Multi Criteria (MIF and AHP) and Hydro Geophysics

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ABSTRACT

This study was carried out to delineate groundwater potential zones in Oyo state, southwestern Nigeria using an integrated approach of remote sensing, Geographical Information System (GIS) and Hydrogeophysics. Seven (7) thematic layers of land cover, drainage density, lineament density, soil, geology, slope, and rainfall were processed and prepared using satellite imageries and geographical information system techniques. Two different multi-criteria analysis techniques: Multi Influencing Factor (MIF) and Analytic Hierarchy Process (AHP) were employed in assigning weights to each thematic layer and internal features. The Integration of the layers was done using the weighted overlay analysis tool in ArcGIS software to develop groundwater potential zones. In the Hydrogeophysics, the Groundwater Potential Conducting Factors (GPCFs) were evaluated using the Vertical Electrical Sound (VES) data. The results of the MIF and AHP were further integrated into one map to obtain a ptimum result. Five classes were obtaining with the percentage distribution as: very high (1%), high (29%), moderate (62%), low (8%) and very low (0.01%). The longitudinal conductance values ranges from 0.04 Ω^{-1} to 0.12 Ω^{-1} (low conductance) and in the region with higher longitudinal conductance its values range from 0.12 Ω^{-1} to 0.24 Ω^{-1} Most of the values of the reflection coefficient of the study area are low (<0.8) signifying a good aquiferous zone. The ROC validation technique reveals that the AHP method has (AUC: 0.65) while the MIF and the integrated groundwater potentiality maps have (AUC: 0.60). This shows that the three approaches are significantly reliable for groundwater prediction.

Keywords: Groundwater potential; Multi Influencing Factor (MIF); Analytical Hierarchical Process (AHP); Remote sensing; Geographical Information System (GIS); Hydrogeophysics

INTRODUCTION

Among the various sources of water, groundwater is known to be more appropriate and often meets the criteria of quality of water, the most widely used as sources of water in most African countries, Nigeria inclusive [1]. Groundwater is water that lies under ground and it is the best quality fresh water which the world depends on its availability source. It is the water held in the sub-surface within the saturated zone under hydrostatic pressure below water table. The groundwater can be in the sedimentary terrain where it is less difficult to exploit or in the basement complex terrain in which it can be a bit difficult to locate especially in areas underlined by crystalline rocks [2].

Oyo state is situated within the basement complex of southwestern Nigeria. The area is dominated by Precambrian undifferentiated basement rocks. Basement rocks are characterized by low porosity and permeability. Where the Basement Complex rocks are fractured and/or weathered, it is possible for the rocks to be porous and permeable. Groundwater occurs in pockets restricted by fractures and weathered zones in Basement Complex rocks [3].

The occurrence, appropriation and stream of groundwater is spasmodic and it is controlled by the dynamic connections of different natural factors such as geotectonic structures, lithology, overburden thickness, weathering grade, geomorphology, fracture extent, drainage pattern, land use/cover and climate, secondary

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porosity, vegetation, overburden thickness, and permeability of topsoil [4]. Test drilling and stratigraphy analysis are some reliable ways in determining the location of an aquifer and its characteristics. However, these methods are costly and time-consuming and as such, these methods are rarely used. Nowadays, the use of geophysical techniques such as Vertical Electrical Sounding (VES) for groundwater exploration and water quality evaluations is also very common due to the simplicity of the technique and rapid advances in computer software and other numerical modeling techniques. This technique for exploring groundwater resources overcomes the above limitations (to a certain extent) and makes use of evaluation of electrical resistivity. Paine and Collins applied the use of airborne electromagnetic induction in groundwater salinization and resource studies [5]. Other methods for groundwater investigation include the use of the electromagnetic waves reflected from the water table and groundwater penetrating radar for groundwater exploration which has carried out at various locations [6].

In Oyo state groundwater investigation, several authors have worked on various locations within the state using the Vertical Electrical Sounding (VES). Olajundoye and Jekanyinfa worked on and improved Schlumberger area (Hummel–Schlumberger array) to obtain an improved result using Ibadan metropolis as a case study. The author opined that the Hamel-Schlumberger technique for exploring groundwater resources overcomes the limitations of using the conventional Schlumberger array and makes use of evaluation of electrical resistivity. Oladejo carried out a groundwater exploration study in Ogbomosho using Very Low Frequency (VLF) method. None of these approaches; integrated the use of satellite remote sensing data, Geographic Information System (GIS) and Hydrogeophysics data. Olajundoye and Jekanyinfa, Shakespeare opined that a high degree of accuracy to pinpoint the prospective drilling sites for groundwater is being obtained through the integration of two or more methods. This will help to limit the vulnerability of errors linked with the use of a single method [7].

The integration of remote sensing data and the Geographical Information System (GIS) for the exploration of groundwater resources has become a breakthrough in the field of groundwater research, and also assists in assessing, monitoring, and conserving groundwater resources have all demonstrated the technique of integration of remote sensing data and GIS tool to be extremely useful for groundwater studies. For effective groundwater exploration and exploitation, it is important to study the different parameters in a combined approach [9]. The integration of multiple data sets, with various indications of groundwater availability, can decrease the uncertainty and lead to safer decisions [10]. None of groundwater studies in Oyo state has incorporated the use of Multi-Influencing Factor (MIF) and Analytical Hierarchical Process of multi-criteria decision-making analysis for groundwater mapping in the study area. Besides, each of them was localized to their immediate study area. None has been comprehensive to give the perspective of the distribution of groundwater potential zones within Oyo state. However, very few studies have considered the TR and S factors in spatial modeling of groundwater potentiality and groundwater vulnerability assessment With respect to the study area which lies within a basement complex region, a comprehensive groundwater development scheme should include a good knowledge of the groundwater potential zones determined from satellite observations and the hydrogeophysical parameter of the subsurface layers, overlying the crystalline bedrock structures/relief determined using electrical methods [11]. The aim of this research is to determine the groundwater potential of Oyo state using an integrated approach of remote sensing, Geographical Information Studies (GIS) and Hydrogeophysics. Seven thematic layers of land cover, drainage density, soil, geology, slope, and rainfall and lineament density maps were processed and prepared using satellite imageries and geographical information system techniques [12].

Two different multi-criteria analysis techniques: Multi Influencing Factor (MIF) and Analytic Hierarchy Process (AHP) were employed in assigning weights to each thematic layer and internal features [13]. The results from the two techniques were integrated to obtain the optimum groundwater potential zone map of the study area. The hydrogephysics data acquisition and interpretation provided the subsurface aquifer characteristics and lithology definition for the determination of the drilling sites for groundwater exploration [14,15].

MATERIALS AND METHODS

In this study, the datasets used include Landsat 8 Operational Land Imager (OLI) image and Advanced Land Observation Satellite Digital Elevation Model (ALOS DEM), rainfall data, existing geological and soil data of Oyo State as well as the Vertical Electrical Sounding (VES) data of an area in Laniba, Oyo State.

Table 1 shows the final weights and rank of the layers utilized in the development of groundwater potential using the Pair Wise concept.

Table 1: Final weights and rank of the layers

Theme	Weight (%)
Geology	22
Lineament Density	20
Slope	17
Soil Texture	15
Drainage	11
Land Cover	9
Rainfall	6

RESULTS

Land cover and land use map are major factors that influence the occurrence of groundwater in any region. Their effect on availability of ground water in any area varies based on the land cover type dominant in the area. Different types of land use act differently in the run-off and infiltration capacities. Areas covered with forests tend to cover infiltration rate while regions that are highly urbanized can impede ground water availability as a result of more surface run off. Lands dominated by agriculture are also good sites for ground water because of loose top soil on the surface. The study area, Oyo state has more of vegetation and cultivated areas than it has built up areas, bare land and water bodies.

DISCUSSION

The GWPZ distribution using the MIF and AHP approaches. The integrated GWPZ map and its pie chart show that (1%) comes under the very high GWPZ, (29%) comes under the high GWPZ with major towns like: Oyo west, Iseyin, Shaki west. 62% comes under the moderate GWPZ e.g: Akinyele, Itesiwaju, Ido and Ibarapa central. 8% comes under the low GWPZ (Ibadan south, Ibarapa east while (0.01%) comes under the very low GWPZ respectively. The lineament and drainage density are highest at the central Oyo where the AHP method has also defined as the region with the highest GWP distribution. These distributions all choose the AHP over the MIF technique.

The lineament density map shows a variation between 0-3.12 units. The Oyo west, Oyo east, Saki west and Iseyin are characterized by relatively high lineament density closures. The northwestern part and southeastern flanks have low lineaments densities. The high lineaments densities areas correspond to the area with undifferentiated basement complex within the study. This corroborates the opinion of that high lineament densities correlates to areas where basement rocks outcrop or are close to the source. A correlation between the Slope map and the lineament density map show that the basement rock outcrop areas with slope highs correlate with the zones of high lineament density whereas areas with low lineament frequencies coincide with the low (relatively) flat plains. The slope map shows that the groundwater flows into the various collecting converging centers. Kann et al., opined that the principal groundwater flow directions must have structural trends of the geology. The drainage density map shows that the major rivers and their tributaries will help to recharge the groundwater resource zones within the study area. Four geologic layers were delineated from the study area: topsoil, weathered layer, fractured layer and fresh basement. The regions with high longitudinal conductance and region with low longitudinal conductance were clearly demarcated. In the region with low longitudinal conductance, its values range from 0.04 Ω-1 to 0.12 Ω-1 and in the region with higher longitudinal conductance its values range from 0.12 Ω-1 to 0.24 Ω-1. The contour pattern and boundaries are unique clear and display overlapping features. Most the values of the reflection coefficient of the study area are low (<0.8) signifying a good aquiferous zone. The Area Under the Curve (AUC) value for MIF and the integrated map is 0.6 (60%) while AHP has AUC value of 0.65 (65%). It shows that the three approaches are significantly reliable for groundwater prediction.

The lineament map and the reflection coefficients map correlate in the definition of the high fractured zones within the study area. The topsoil which varies in composition from clay, sandy clay, clayey sand to sand and laterite has resistivity values from 36.1 to 185 ohm-meter with thickness ranges from 0.1 to 1.4 m. The weathered layer range in composition from clay to sand, clayey sand and sand. Its resistivity varies from 96.9 to 1129.6 ohm-meters. The weathered layer thicknesses range between 0.8 and 6.5 meters. The fractured layer resistivities lies between the range of 55.9 and 1408.9 ohm-meter, while its thicknesses generally vary from 2.6 m to 27.4 m the fresh basement is infinitely resistivity in most places but value of 435.8 ohm-meter in VES 1 location. Previous studies showed that the nature of the overlying weathered layer determines to a significant extent the yield of the borehole, irrespective of the thickness of the underlying fractured basement column. When the overlying layer is clayey, with low layer resistivity's (less than 100 ohm-meter), the yield of the borehole is low. A high correlation was established between the remote sensing integrated groundwater potential map and the VES data interpretation.

The study area lies within the tropics with a mean annual rainfall of between 110.20 mm and 169.50 mm. The high annual rainfall favors recharge of basement aquifers through surface precipitation. The discontinuities nature of basement aquifer reduces the influence of recharges through lateral groundwater flow. The Drainage map slope maps show that the rivers and their surface tributaries could be significantly recharged by groundwater flow from the basement aquifer.

CONCLUSION

The high and moderate ground water zones have more concentration in the Oyo west, Iseyin and Shaki west which has been characterized by more rainfall, high lineament and drainage density. The queries carried out on the geophysical survey points showed that all the points contained fractured layers at different depths. Overlay of the VES points on the integrated map also showed that the points fell on the moderate zone on the groundwater potential maps. This study needs to be replicated in the areas with significant need of water for irrigation and drinking purpose. This map should also be made available to serve as a base map which helps to guide allocation of lands for residential purposes and also a guide for future ground water exploration in the study area.

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