KASU ENVIRONMENTAL SCIENCE JOURNAL (KESJ)
KASU Environmental Science Journal (KESJ) ISSN: 2734-2751
Volume 5, Issue 1, August 2025

ASSESSMENT OF GROUNDWATER POTENTIAL ZONES USING GIS AND AHP TECHNIQUES IN OSOGBO, OSUN STATE, NIGERIA

Oluwafunmilola M. SAJUYIGBE[1], Yekeen I. BALOGUN[2], and Ezekiel S. OLUWABUNMI[3],
[1,2,3]Department of Geography, Kwara State College of Education, Oro,
Kwara State, Nigeria.
Corresponding author email: oyelowofunmilola12@gmail.com

ABSTRACT

Purpose: *Globally, groundwater is a crucial resource for human survival. Supporting diverse anthropogenic activities such as agriculture, domestic use, industrial use, and recreational use. for a sustainable groundwater supply, there is a need to identify areas with high and low groundwater prospects.*

Design/methodology/approach: *This study utilized the combination of Remote Sensing (RS), Geographic Information System (GIS), and Analytic Hierarchy Process (AHP) techniques to delineate groundwater potential zones (GWPZ) in Osogbo, Osun State, Nigeria. Thematic maps for groundwater influencing factors were generated using Remote Sensing and GIS techniques. Weight was assigned to each groundwater influencing factors in accordance to their importance using AHP approach. The combined thematic maps in ArcGIS generated a groundwater potential zones map.*

Findings: *The results showed that most high and moderate groundwater potential areas were found in the central and eastern parts of the study area and are the most viable for groundwater exploitation in the study area. The map showed the needed information and the zones were classified into five categories: very low GWPZ is 4.7km^2 (3.3%), low GWPZ is 28.2km^2 (19.8%), moderate GWPZ is 74.9km^2 (52.5%), High GWPZ is 34.8km^2 (24.4%), and very high GWPZ is 0.1km^2 (0.1%).*

Research limitations/Implications: *This study relied on secondary datasets which may not fully capture real-time variations in groundwater dynamic. And extensive validation of the groundwater potential zones could not be carried out due to limited boreholes yield records.*

Practical Implications*: It is recommended that delineation of groundwater potential zones should be adopted to provide scientific basis for stakeholders, agencies and policy makers to ensure Osogbo Metropolis secure reliable freshwater reserves and minimized unnecessary drilling in low-yield areas and reducing financial losses associated with failed boreholes.*

Originality/value: *This study revealed efficient and effective techniques for delineating and mapping groundwater potential zones for planning, decision-making for optimal utilization of groundwater and water resources management in Osogbo Metropolis.*

KEYWORDS: Groundwater Potential Zone, Geographic Information System (GIS), Analytical Hierarchy Process (AHP), Remote Sensing, Osogbo

[1] Email: kesj@kasu.edu.ng

1.0 INTRODUCTION

Water is a crucial resource in sustaining life on earth and a means of livelihood for man for various anthropogenic activities (Garcia,2024). Ground water is a natural resource hidden beneath the Earth's surface, and it is an important part of the hydrological cycle, recharged and replenished through precipitation, and abstracted through wells and boreholes (Brands et al., 2017; Diriba et al., 2024). Groundwater is an essential resource for freshwater supply that is safe and reliable for anthropogenic activities (Mukherjee et al., 2024). Several factors influence the occurrence and distribution of groundwater in an area, which are drainage density, slope, soil characteristics, geology, lineament, rainfall, landuse/landcover (Zewdie et al., 2024).

Uneven spatial distribution of groundwater poses a significant problem affecting water usage by man, and this is attributed to different environmental factors influencing its distribution. An exponential rise in human population exerted more demand for clean and safe water for various anthropogenic activities such as industrial use, domestic use, and agricultural activities (Vikova, 2022; Murray, 2023). Many wells and borewells have been drilled without a detailed hydrogeological investigation of areas for good and poor groundwater potential. Ray et al., (2022) opined that to ensure sustainable groundwater management, identifying groundwater potential zones is essential for optimal water resources utilization and prevention of over-extraction of groundwater, which can exacerbate the water scarcity problem. It is of vital importance to map out groundwater potential zones for proper planning and exploitation of groundwater to prevent wastage from overexploitation and sudden dryness of wells and borewells (Abshishank et al., 2020).

Mapping of groundwater potential zone enhance the prediction of potential groundwater areas. Remote sensing, Geographic Information System, and Analytical Hierarchy Process (AHP) method have been utilized by several researchers, hydrologists, and hydrogeologist to achieve sustainable and effective groundwater management (Abdulmutallib et al., 2024). This study utilizes a combination of Geographic Information System (GIS), Remote Sensing (RS) and Analytical Hierarchy Process (AHP) techniques proposed by Saaty (1980) utilizing data from these parameters (geological data, precipitation data, climatic data, landuse data, topographic data etc.) to generate thematic maps which are combined to produce groundwater potential zones map. This spurred this study to investigate and map out groundwater potentiality zones in Osogbo, Osun State, Nigeria, using GIS and Remote Sensing Techniques

i. to generate thematic maps of groundwater influencing factors
ii. weighing each of the thematic map of groundwater influencing factors using analytical hierarchy process (AHP); and as well as to
iii. identify and map zones of groundwater potential in the study area

2.0 LITERATURE REVIEW

The integration of GIS and AHP techniques has become a robust methodology in assessment of groundwater potential zone. It effectively combines spatial data and expert-driven weightings to produce insightful maps for sustainable water management. GIS handles the spatial processing of multiple thematic layers, while AHP provides a structured decision-making framework via pairwise comparisons and prioritization of factors (Yacob et al., 2025). Several major thematic layers such as geology, slope, drainage density, landuse/landcover, lineament density, soil type, rainfall, topographic wetness index, and topographic roughness index have been utilized in studies to understand their influence in groundwater occurrence and recharge (Rajesh et al., 2021; Opoku et al., 2024). These layers are reclassified and assigned weights based on their relative importance, typically established via Saaty's scale in AHP (Arumugam et al., 2023).

A review of literature of several research studies on groundwater potential using integration of remote sensing and GIS with AHP techniques in delineation of groundwater potential zones and proffer valuable insights into effective water resources management. These researches include; assessment of groundwater potential zones in Lafia, Nasarawa State (Ifediegwu, 2022); Groundwater potential zones mapping using remote sensing and GIS in Zaria, Kaduna State (Sani et al., 2016); Delineation of groundwater potential zones in Obudu basement terrain of Cross River (Ebong et al., 2023); Groundwater mapping in Ado Ekiti, Ekiti State (Okoli et al., 2019); Assessment of groundwater potential zones in Oke Ero, Kwara State (Agboola, 2021); Delineation of groundwater potential zones using an integrated GIS and remote sensing approach in Minna, Niger State (Fagoroyo et al., 2018); Delineation of groundwater potential zones in the crystalline basement terrain (Fashae et al., 2014); A combined GIS, remote sensing and geophysical methods for GWPZ (Ogungbade et al., 2021) and others. Ahmed et al., (2022) integrated Geographic Information System, Remote Sensing, and Analytical Hierarchy Approach to study the influence of geology, slope gradient, drainage density, lineament density, rainfall distribution, land use and landcover, geomorphology, and soil type on groundwater potential zone in Enugu Metropolis, Nigeria. Ajayi et al. (2022) also integrated geospatial techniques and the analytical hierarchy process to delineate groundwater potential zones in Bosso, Niger State, Nigeria.

Lack of in-depth details investigation of hydrogeological characteristics of an area before digging wells and drilling boreholes can lead to wells and boreholes drying up within a short period or give low yield of water supply. Thus, waste of time and resources in digging or drilling wells and boreholes.

3.0 AREA OF THE STUDY

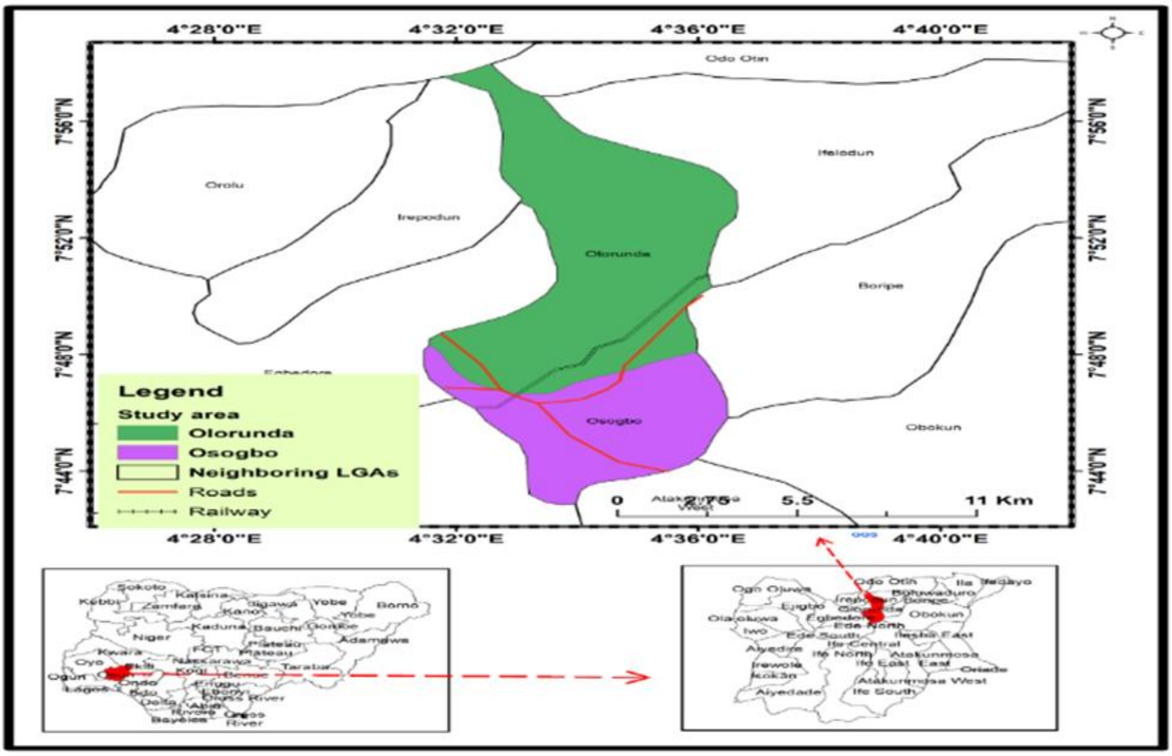

Figure 1: The study area

The study area (figure 1), Osogbo is the capital of Osun State in the Southwestern region of Nigeria. This area lies within latitude $7^0$46” N and $7^0$48” N and between longitude $4^0$31” E and

$4^0 35$" E. The geology is a Precambrian basement complex, and the dominant basement rocks in the study area are schist and migmatites (Tijani and Onodera, 2009). The landscape is over 500m above sea level and is drained by the major river in the area Osun River and its tributaries (Olaniran, 2000). Osogbo climate by Koppen's Aw classification is within the tropical climate of two distinctive seasons dry and wet seasons. The study area experiences an average annual temperature of 26.1^0C with average annual rainfall of 1241mm with the wet season, starts in March and ends in October. The dry season begins in the month of November till February (Olajire et al., 2018). The prominent commercial activities carried out in the study area are buying and selling, while farming is the main traditional occupation of the inhabitants due to the favorable tropical climate (Gasu et al., 2020).

4.0 METHODOLOGY

This study utilized geospatial technologies (Remote Sensing, Geographic Information Systems) and the Analytical Hierarchy approach to investigate and map Groundwater Potential Zones (GWPZ). Thematic maps of geology, rainfall, slope, lineament, land use and land cover change, drainage density, and topographic wetness index were produced. They were incorporated into ArcGIS 10.8 and superimposed using weighted overlay analysis to create groundwater potential zones.

4.1. DATA ACQUISITION

Table 1: Data types and sources

S/N	Data types	Source	Resolution	Purpose
1	Landsat 9 satellite image of 2021	USGS (https://earthexplorer.usgs.gov/)	Path=190 Row =055	Land Use/Land Cover
2	SRTM DEM	USGS (https://earthexplorer.usgs.gov/)	30 m	Slope, Elevation, Lineament TRI, TPI, TWI and Drainage
3	Geology Map	Nigerian Geological Survey Agency	1:50,000	Geology thematic layer
4	Rainfall data	Nigeria Metrological Agency, Osogbo		Rainfall/Precipitation
5	Soil	World digital soil map		Soil map

Source: Author's compilation, 2024

4.2 THEMATIC MAPS PREPARATION

In this study, supervised classification was used to classify the land use characteristics of Osogbo Metropolis into water body, forest, grassland/shrubs, built-up areas, and bare land. This was done on a Landsat 9 satellite image of 2023 in ArcMap 10.8. The supervised classification is the essential tool used for extracting quantitative information from remotely sensed image data. Using this method, the analyst has sufficient known pixels to generate representative parameters for each class of interest. The first step after the preprocessing of the image is to select the training site. The trained site was saved as a signature. Once trained, the classifier is then used to attach labels to all the image pixels according to the trained parameters.

The quality of a supervised classification depends on the quality of the training sites. The most commonly used supervised classification is maximum likelihood classification which was adopted in this study. Digital Elevation Model (DEM) of Osogbo Metropolis from Shuttle Radar Topography Mission (SRTM) acquired from USGS was imported into ArcGIS 10.8 to produce the slope map using the spatial analyst tool's function. The slope map produced was reclassified according to the criteria evaluation for slope, as it affects groundwater.

The conventional geological map of Osogbo Metropolis was scanned, imported into ArcGIS, and geo-referenced. On-screen manual digitization was carried out on the paper geology map imported into ArcGIS to produce the geological map of Osogbo Metropolis. The lineament map for this study was extracted from the Digital Elevation Model (DEM) of the area by producing the hill shade of the area to enhance the feature extraction at various Azimuth and Altitude ratios (315:45, 200:50, 150:65 and 100:60) in ArcGIS 10.8. According to Adaviruku and Oyatayo (2023), this approach enhances the satellite image for lineament extraction. This was followed by manual digitization of the lineaments. The line density function of the spatial analyst tools was then used to produce the lineament density map from the lineament. Rainfall is directly proportional to groundwater potentiality.

The groundwater potential of a place is high if the rainfall is high and it is low if the rainfall is low (Mahalingam, 2014). For this study, the rainfall data for 23 years (2000-2023) was obtained in comma-separated value format, which was imported into the ArcGIS environment to produce the rainfall map using the interpolation method through the Ordinary Kriging technique. The Ordinary Kriging technique assumes that the expected value of the interpolation is an unknown constant. In areas where fossil groundwater is available, rainfall may not indicate groundwater potential, but it will indicate the sustainability of groundwater exploitation and can be used to estimate optimum water extraction levels (Castilloetet al., 2022). The drainage map of Osogbo Metropolis was extracted from the Digital Elevation Model (DEM) of the area by filling the DEM, followed by flow direction determination and flow accumulation. The resulting flow accumulation was used to extract the drainages using the expression "value>500", which implied any drainage greater than 500m in length should be extracted. The extracted drainages were converted to a polyline, which was later converted to line density as the drainage density of the study area within the ArcGIS environment. The soil map of the area was acquired from the World Digital Soil Map. Topographic Wetness Index (TWI), Topographic Position Index (TPI), and Topographic Roughness Index (TRI). The TWI, TPI and TRI we created using Focal Statistics in the ArcGIS environment.

4.3 DETERMINATION OF THE GROUNDWATER POTENTIAL ZONES IN THE STUDY AREA

This was achieved by integrating the thematic maps of individual criteria. The different factors influencing groundwater occurrence were weighted using the Analytical Hierarchy Process (AHP). The AHP uses pairwise comparison to calculate weight based on the influence each criterion has on the occurrence of groundwater. The weighting was done by assessing the relative weight of criteria on a scale of 1 to 9, 1 means equal importance and 9 means extremely important. This is done to make decisions of their impact on groundwater occurrence, the criteria with the highest weight value have very high influence while the criteria with the lowest weight value have low influence (Saaty, 1980; Saaty, 1988). The thematic map of individual criteria was reclassified using the weight values calculated using the AHP pairwise comparison, and the reclassification was done with ArcGIS software.

The reclassified maps of each factor were overlaid using the weighted overlay in the ArcGIS environment to produce the Groundwater Potential Zone (GWPZ) of Osogbo Metropolis using equation 1. The thematic maps to be integrated were weighted. The Ground Water Potential Zones produced were categorized into 3 zones which are regions of low, moderate and high groundwater availability.

5.0 PRESENTATION AND DISCUSSION OF RESULTS

5.1 FACTORS INFLUENCING GROUNDWATER POTENTIAL

5.1.1 Geology of Osogbo Metropolis

The study area is underlain by the Basement Complex. The geologic units that covered the study area include Schist, Banded Gneiss, Undifferentiated schist amphibolite, Undifferentiated older granite, and Pegmatite. The Schist covers a spatial extent of 48.5 km^2 representing 34% of the total study area. Banded Gneiss covers 22.9 km^2 (16%), Undifferentiated schist amphibolite (5.3%), undifferentiated older granite and Pegmatite (12.3%), and pegmatite (32.3%) respectively (Table 2). Fashae et al. (2014) pointed out that usually, massive unfractured lithologic units in the Basement Complex setting have little influence on groundwater availability except in cases with secondary porosity through the development of weathered overburden and fractured bedrock units, which form potential groundwater zones.

Table 2: Geology Statistics

S/N	Name	Area	%
1	Schist	48.5	34.0
2	Banded Gneiss	22.9	16.0
3	Undifferentiated schist amphibolite, metavolcanics with pegmatites complex	7.6	5.3
4	Undifferentiated older granite, mainly porphyritic granite with some migmatite	17.6	12.3
5	Pegmatite	46.1	32.3
	Total	142.7	100.0

5.1.2 Drainage density of Osogbo Metropolis

The drainage pattern of Osogbo Metropolis is dendritic. Adendritic drainage pattern is the most common form and looks like the branching pattern of tree roots. It develops in regions underlain by homogeneous material. That is, the subsurface geology has a similar resistance to weathering so there is no apparent control over the direction the tributaries take. Tributaries of dendritic drainages merge with larger streams at an acute angle (Pidwirny, 2006). According to Fashae*et al.* (2014), closer proximity to the drainage network means that the probability of finding groundwater is high, moving away from the drainage causes the groundwater potential to decrease. According to Shamuyarira (2017), groundwater movement is very slow, and as a result, at an imaginary threshold proximity to drainage, the influence of the drainage becomes insignificant. Moreover, the drainage pattern reflects the characteristics of surface as well as subsurface formation (Coblentz *et al.,* 2014). The drainage density of the area was found to range between 0-5.3km^2.

5.1.3 Lineament and lineament density of Osogbo Metropolis

In a basement complex like Osogbo Metropolis, the presence of lineaments and their density is a major determinant of groundwater recharge and occurrence. Lineaments are linear features that occur on the earth's surface, distinct from the surrounding features, and reflect what the unseen subsurface can be (O'Leary *et al***.,** 1976). The result of lineament analysis in Osogbo Metropolis showed the lineament density ranges between 0 km/km^2 to 2.3 km/km^2. This implies that for every km^2 coverage, there is about 0 km to 2.3 km of lineament present. The denser lineament in the central region down south of Osogbo Metropolis signifies the intensity of rock fracturing, which is a prerequisite for the development of conduits for groundwater in the basement complex. The northern part of Osogbo Metropolis has less lineament density implying that groundwater has less potential in the area than in other areas.

5.1.4 Land use and land cover of Osogbo Metropolis

The Land use and Land Cover (LULC) of Osogbo Metropolis was classified into five classes namely; Water body occupying 6.62 km^2 representing 4.64% of the study are, vegetation 57.74 km^2 (40.47%), farmlands 2.1km^2 (1.47%), Built up 76.21 km^2 (53.42%) of the study area and Bare surface 0.00 km (0.00%). According to Siddik*et al.* (2022), the long-term temporal and seasonal changes in LULC have a substantial influence on groundwater flow dynamics. Each of the classes of LULC in this study has an influence on groundwater recharge and occurrence in an area. For instance, the quantity of water that seeps into the soil to form groundwater depends on the vegetation cover, as vegetation impacts the speed of water that will move across a surface (Sun *et al.,* 2017). Similarly, in built-up areas, man-made features, like pavement, usually inhibit infiltration.

5.1.5 Rainfall map of Osogbo Metropolis

Rainfall in Osogbo Metropolis ranges between 1,711.6 mm to 1,734.2 mm. Rainfall is the major source of groundwater recharge; thus, it has a great influence on groundwater occurrence, especially in a crystalline terrain like Osogbo Metropolis. Places of high rainfall have high groundwater prospects compared to places of little or no rainfall (Mahalingam, 2014).

5.1.6 Slope map of Osogbo Metropolis

The slope in Osogbo Metropolis ranges between 0° to 24.4°. This aligns with the findings of Malavika (2021), who found that the slope in Patratu ranges between 0° and 20°. Slope has an inverse relationship with groundwater potential; high slope causes less penetration due to fast surface runoff while level and mild slope areas encourage minimum runoff, accordingly, allowing additional time to infiltrate rainwater and helping large groundwater rejuvenate (Balakrishnan, 2019). The slope of this study, however, in contrast to the findings of Adaviruku et al. (2023), who discovered that the highest slope in Okene Local Government Area, Nigeria, was 66.79 degree and the lowest was zero degree.

5.1.7 Soil map of Osogbo Metropolis

Soil plays a crucial role in determining the potential of groundwater resources. The composition, permeability, and structure of soil influence the rate of water infiltration, storage, and movement underground (Kresic, 2009). Soils with higher porosity and permeability allow for better groundwater recharge, while clay-rich soils impede groundwater flow (Fetter, 2018). Understanding the soil-groundwater relationship is essential for sustainable water management and resource conservation. Osogbo Metropolis is made up of two soil types, namely Sandy_Clay_Loam and Clay_Loam. The Sandy_Clay_Loam soil covered an area of about 14 km^2 which represents 9.8% of the total area found in the northern part of Osogbo Metropolis, while Clay_Loam occupies 128.6 km^2 (90.2%), as shown in Table 3.

Table 3: Soil statistics

Soil	**Area**	**%**

Sandy_Clay_Loam	14.0	9.8
Clay_Loam	128.6	90.2
Total	142.7	100

5.1.8 Topographic Position Index of Osogbo Metropolis

The Topographic Position Index (TPI) is a useful metric for evaluating groundwater potential. TPI describes the relative elevation of a given location compared to its surrounding areas, providing insights into landscape features that influence groundwater flow and recharge. According to Elmahdy and Mohamed (2021) areas with low TPI values (valleys and depressions) had higher groundwater potential.

In the study area, the TPI was found to range from -12.9 to 21.9. The northern part of Osogbo Metropolis shows low TPI, indicating the likelihood of more groundwater availability in the area, all other factors being equal. Integrating TPI with other hydrogeological data can help identify prime areas for groundwater exploration and recharge, supporting the development of effective strategies for groundwater utilization and conservation (Ahmed et al., 2019)

5.1.9 Topographic Roughness Index of Osogbo Metropolis

The Topographic Roughness Index (TRI) quantifies the variability in elevation within a defined area, providing insights into the landscape features that can influence groundwater flow and recharge. It is used for assessing the impact of terrain complexity on groundwater potential. Jasrotia et al. (2021) found that areas with lower TRI values (smoother terrain) had higher groundwater potential.

In Osogbo Metropolis, the Topographic Roughness Index was found to be between 0.1 to 0.9. The values of TRI varied spatially across the study area, implying that on the basis of TRI, the whole study area has a chance of groundwater occurrence. Incorporating TRI into groundwater assessments can help optimize the identification of high-potential groundwater areas, leading to more efficient and responsible utilization of these valuable resources.

5.1.10 Topographic Wetness Index of Osogbo Metropolis

The Topographic Wetness Index (TWI) is a powerful tool for evaluating the influence of terrain on groundwater potential. TWI describes the tendency of a location to accumulate moisture, providing insights into areas with higher soil moisture and potential groundwater recharge. Recent studies by Elmahdy and Mohamed (2021) found that areas with high TWI values (indicating greater soil moisture accumulation) had higher groundwater potential.

In Osogbo, the study area, the Topographic Wetness Index ranges from-5 to 20.1. The northerly side of Osogbo Metropolis is characterized by higher TWI, indicating that the northern areas are more likely to favor groundwater occurrence than other areas. Incorporating TWI into groundwater studies can help identify prime areas for targeted exploration and sustainable management of this vital resource. By understanding the relationship between terrain characteristics and groundwater potential, water resource planners can make more informed decisions to ensure the long-term availability and quality of groundwater supplies.

5.2 DETERMINATION OF GROUNDWATERBEARINGZONES IN OSOGBO METROPOLIS

5.2.1 Pairwise comparison of groundwater potential influencing factors

The different factors influencing groundwater yield zones were weighted using the Analytical Hierarchy Process (AHP). The AHP utilizes pairwise comparison to quantify the weight value and the domination of each criterion on groundwater occurrence. The weighting was done using a scale of 1 to 9. 1 means equal importance, 3 means moderate importance, 5 means strong importance, 7 means very strong importance and 9 for extremely importance (Saaty, 1980; Saaty, 1988). The most dominant variable for groundwater yield will have the highest weight, and the lowest weight is the least important variable. The pairwise comparison result and weighting of Groundwater Controlling Factors in the study area are presented in Table 4. Rainfall ranked the highest with the weight of 27.3% meaning that in Osogbo Metropolis, rainfall is the most influential factor in the determination of groundwater occurrence in the area, followed by lineament, which ranked 9with the weight of 20.4%. The third most influential factor in the area is drainage density, which ranked 8 and was weighted 15.6%. A similar observation was reported by Adavirukuet *al.* (2023) who found that rainfall (39.94%) and lineament density (28.65%) were the major factors influencing groundwater potentiality in the Okene administrative area. The consistency ratio of 0.038implies that the pairwise comparison of the factors was consistent and acceptable.

Table 4: Pairwise comparison and weighting of Groundwater Controlling Factors

Factors	Rainfall	Lineament	Drainage density	Slope	LULC	Geology	Soil	TWI	TPI	TRI	**Weight**	**Rank**
Rainfall	1	2	3	3	4	5	5	7	8	8	27.3%	10
Lineament	½	1	2	3	3	4	5	6	7	6	20.4%	9
Drainage density	1/3	½	1	2	3	4	5	5	6	5	15.6%	8
Slope	1/3	1/3	½	1	3	4	4	5	4	4	12.3%	7
LULC	¼	1/3	1/3	1/3	1	2	3	4	3	3	7.5%	6
Geology	1/5	¼	¼	1/4	½	1	1	3	2	2	4.7%	5
Soil	1/5	1/5	1/5	1/4	1/3	1	1	3	2	2	4.4%	4
TWI	1/7	1/6	1/5	1/5	¼	1/3	1/3	1	2	2	2.9%	3
TPI	1/8	1/7	1/6	1/4	1/3	1/2	1/2	1/2	1	1	2.4%	1
TRI	1/8	1/6	1/5	1/4	1/3	1/2	1/2	1/2	1	1	2.5%	2

Consistency Ratio = 0.038 (3.8%)

5.2.2 Groundwater potential of Osogbo Metropolis

The thematic map of individual criteria was reclassified using the weight values calculated using the AHP pairwise comparison. Reclassification was conducted by utilizing the spatial analyst tool in ArcGIS. Each reclassified thematic layer was overlaid using the weighted overlay method in ArcGIS Spatial Analyst to delineate the Groundwater Potential Zone (GWPZ) of Osogbo Metropolis using equation 1. The identified ground water potential zones were grouped into five categories which are: Very low, low, moderate, high, and very high groundwater potential zones.

GWPZ = RFw + LDw + DDw +GLw + SLw + LULCw + SOw +TWIw +TRIw + TPIw…………………….…………….. (1)

Source: Modified after Kabeto, *et al.* (2022)

Where;

GWPZ = Groundwater Potential Zone RF = Rainfall
SO = Soil LD = Lineament Density
DD = Drainage Density GL = Geology
SL = Slope LULC =Land use/Land cover

TWI = Topographic Wetness Index　　　TPI = Topographic Position Index

TRI = Topographic Roughness Index　　　w = the normalized weight of each them

The groundwater potential map of Osogbo Metropolis (Figure 2) revealed areas characterized with very low to low groundwater potential are mostly found in the southern part of the study area. These are areas with high Topographic Position Index, high Topographic Roughness Index, and low Topographic Wetness Index. And areas characterized by high to very high groundwater potential zones are found in the northern part of Osogbo Metropolis through the central region. These are areas with low Topographic Position Index, low Topographic Roughness Index, and high Topographic Wetness Index. This finding agreed with the works of Elmahdy and Mohamed (2021) and Jasrotia et al. (2021) who found that areas with low Topographic Position Index and low Topographic Roughness Index had high groundwater potential.

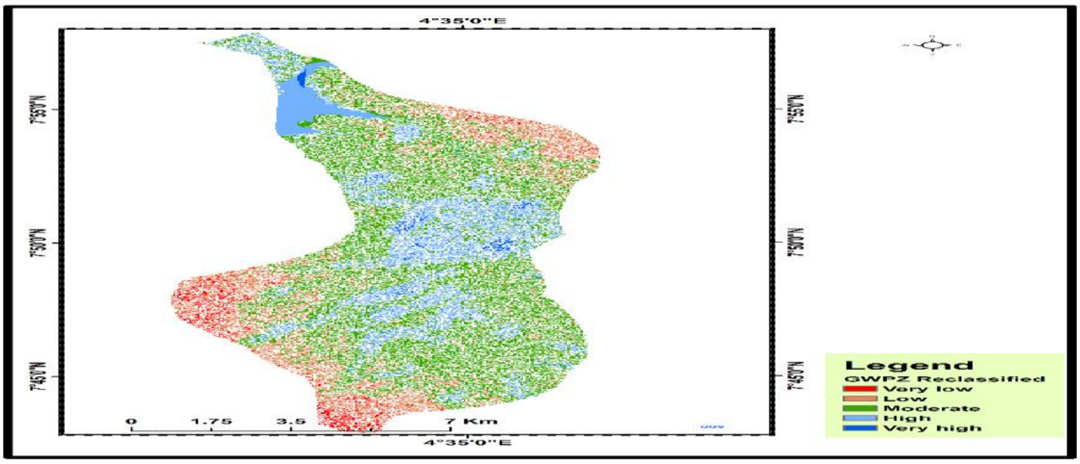

Figure 2: Groundwater Potential Zones Map of Osogbo Metropolis

5.2.3 Spatial Distribution of Groundwater Potential of Osogbo Metropolis

Reclassification of the groundwater potential map resulted in five categories: very low, low, moderate, high, and very high groundwater potential zones, and the field calculator in ArcGIS version 10.8 was employed in the calculation of the area coverage of each potential zone in square kilometers. The area extent covered by each groundwater potential zone is shown in Table 5.

Table 5: Area Coverage of Groundwater Potential Zones in Osogbo Metropolis

S/N	Groundwater Potential Zones	Area	%
1	Very low	4.7	3.3
2	Low	28.2	19.8
3	Moderate	74.9	52.5
4	High	34.8	24.4
5	Very high	0.1	0.1
	Total	142.7	100.

As presented in Table 5, very low potential zones cover an area of 4.7 km^2 which represent 3.3% of the total study area; low potential zones cover an area of 28.2 km^2 representing 19.8%, moderate potential zone covers an area of 74.9 km^2 representing 52.5%, the high potential regions cover an area of 34.8 km^2 (24.4%), while very high potential zone only accounted for 0.1% of the study area. This observation aligns with prior research of Ifediegwu *et al.* (2019)

it was observed that groundwater potential zones in Kogi Local Government Area, Kogi State were excellent (10.23%), good (51.35%), moderate (34.26%) and poor (4.16%). This finding is however contrary to that of Rilwanu (2014), who found out that moderate GWPZs constitute just about 6.2% in Kano State, Northern Nigeria. The finding also corroborates the work of Abdulkadir (2020), who reported that about 46.25% of Ilorin Metropolis fell under a moderate groundwater potential zone.

6.0 CONCLUSION AND RECOMMENDATIONS

Geospatial techniques provide a timely and cost-effective approach for investigating and mapping groundwater potential zones. A thematic map of groundwater influencing factors was generated using Remote Sensing (RS) and Geographic Information System (GIS) and the weights according to their relative importance in the occurrence of groundwater were determine using Analytic Hierarchy Process (AHP). High weighted value showed areas with high prospects for groundwater, and low weighted value showed areas with low prospects for groundwater. Findings on ground water prospects zones revealed Osogbo Metropolis, Osun State is segmented into five groundwater potential categories such as very low 4.7km^2 (3.3%), low 28.2km^2 (19.8%), moderate 74.9km^2 (52.5%), high 34.8km^2 (24.4%) and very high 0.1km^2 (0.1%) groundwater prospects areas and rainfall, lineament concentration and drainage intensity were the three most significant influencing factors for groundwater presence in Osogbo Metropolis. In conclusion, sustainable groundwater management has been ensured through the following: areas with potential groundwater resources are identified, which will aid decision making for groundwater development and management and also provide a framework for assessing climate impact and human activities on groundwater resources.
Based on the findings of this study, the following recommendations are made;

i. To avoid the incidence of borehole failure in Osogbo Metropolis, areas delineated as low classification potential zones should be exploited moderately to avoid the groundwater depletion problem while areas with high prospects for groundwater should be optimally utilized.
ii. The groundwater potential zones and thematic maps produced in this study are sources of vital information and database that can be updated from time to time by adding new information for development.
iii. Further studies of this nature should be conducted nationwide to help water development agencies and stakeholders, and the results should be made available in the public domain so that every citizen can have information about groundwater at their fingertips.
iv. It is also recommended that further studies should be conducted in Osogbo Metropolis to investigate the spatial variability among the existing borehole yields in the area and the groundwater resource potential of the area.

7.0 LIMITATION OF THE STUDY

This study relied on secondary datasets which may not fully capture real-time variations in groundwater dynamic. And extensive validation of the groundwater potential zones could not be carried out due to limited boreholes yield records. Important hydrogeological parameters such as aquifer depth and groundwater recharge rate could not be integrated due to insufficient data. To address these limitations the results could be improved for future studies. In spite of these limitations, this study provides a scientific basis for guiding borehole siting, groundwater exploration, and sustainable water resource management.

REFRENCES

Abdulkadir, G. (2020). Delineation of groundwater potential zones in Ilorin metropolis, Kwara State, Nigeria. *International Journal of Environmental Design and Construction Management, 18*(4), 116–133.

Abshishank, N., Awasthi, M. K., & Bunkar, N. (2020). Assessment of groundwater potential zones of Tons Basin using spatial data. *International Journal of Agriculture, Environment and Biotechnology, 13*(3), 261–268.

Adaviruku, P. E., &Oyatayo, K. T. (2023). Extraction, mapping, and analysis of structural lineaments using geospatial azimuth-altitude ratio technique on a DEM of a sub-catchment of the Upper Benue River Basin, Nigeria. *European Journal of Theoretical and Applied Sciences, 1*(6), 939–946.

Adaviruku, P. E., Akpu, B., & Zubairu, S. M. (2023). Geospatial analysis of groundwater potential zones in Okene Local Government Area, Kogi State, Nigeria. *Paper presented at the Association of Nigerian Geographers Conference, Caliphate 2023.*

Ahmed, K., Shahid, S., Harun, S. B., & Wang, X. J. (2019). Characterization of groundwater dynamics in coastal regions using water quality and multivariate statistical techniques. *Environmental Monitoring and Assessment, 191*(1), 1–17.

Ahmed, S., Ifeakor, A. R., Zayyan, A. S., & Dadan-Garba, A. (2022). Groundwater potential zone mapping using analytical hierarchy process, remote sensing, and geographic information system for Enugu Metropolis, Nigeria. *Academic Journal of Science and Engineering, 16*(1), 28–48.

Ajayi, O. G., Nwadialor, I. J., &Odumosu, J. O. (2022). Assessment and delineation of groundwater potential zones using integrated geospatial techniques and analytic hierarchy process. *Applied Water Science, 12*(6), 1–22.

Alimi, A. S., Ige, O. O., & Okeke, C. (2022). Assessing groundwater potential of Kaduna State, Northern Nigeria using geographic information system and remote sensing techniques. *Arabian Journal of Geosciences, 15*(23), 1741.

Arumugam, M., Kulandaisamy, P., Karthikeyan, S., Thangaraj, K., Senapathi, V., Chung, S. Y., Muthuramalingam, S., Rajendran, M., Sugumaran, S., &Manimuthu, S. (2023). An assessment of geospatial analysis combined with AHP techniques to identify groundwater potential zones in Pudukkottai District, Tamil Nadu, India. *Water, 15*(6), 1101. https://doi.org/10.3390/w15061101

Badmus, G. O., Fagbohun, B. J., Ogungbemi, O. S., Akinyemi, O. D., Gbadebo, A. M., & Oyedepo, J. A. (2024). Delineation of potential zones for groundwater recharge using integrated GIS-based AHP and CSI techniques in Ogun Waterside, Southern Nigeria. *Water Supply, 24*(10), 3326–3342.

Balakrishnan, M. (2019). Groundwater potential zone mapping using geospatial techniques in Walayar watershed. *International Journal of Engineering and Advanced Technology, 9*(1), 1157–1161.

Brands, E., Rajagopal, R., Eleswarapu, U., & Li, P. (2017). Groundwater. In *The international encyclopedia of geography*. John Wiley & Sons Ltd.

Coblentz, D., Pabian, F., & Prasad, L. (2014). Quantitative geomorphometry for terrain characterization. *International Journal of Geosciences, 5*(3), 247–266.

Diriba, D., Karuppannan, S., Takele, T., & Husein, M. (2024). Delineation of groundwater potential zonation using geoinformatics and AHP techniques with remote sensing data. *Heliyon, 10,* e25532. https://doi.org/10.1016/j.heliyon.2024.e25532

Ebong, D. E., Chimezie, N. E., Qualid, M., Rose, I. U., Anthony, E. I., & Jamal, A. (2023). Delineation of groundwater potential zones using electrical resistivity techniques in Obudu basement terrain of Cross River State, Nigeria. *Journal of Water Practice and Technology, 18*(1), 2884–2900.

Ejepu, S. J., Jimoh, M. O., Abdullahi, S., & Mba, M. A. (2022). Groundwater exploration using criteria decision analysis and analytic hierarchy process in Federal Capital Territory, Abuja, Central Nigeria. *International Journal of Geosciences, 13*(1), 33–53.

Elmahdy, S. I., & Mohamed, M. M. (2021). Groundwater potential zone mapping using an integrated GIS-based analytic hierarchy process and multivariate statistical techniques. *Groundwater for Sustainable Development, 13*, 100568.

Fagoroyo, H. A., Mamodu, A., &Ejepu, J. S. (2018). Delineation of groundwater potential zones of Minna and its environment, North Central Nigeria: An integrated GIS and remote sensing approach. *Minna Journal of Geosciences, 2*(1), 95–111.

Fashae, O. A., Tijani, M. N., Talabi, A. O., & Adedeji, O. I. (2014). Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: An integrated GIS and remote sensing approach. *Applied Water Science, 4*(1), 19–38.

Fetter, C. W. (2018). *Applied hydrogeology* (4th ed.). Waveland Press. ISBN 9781478637441

García, E. (2024). The essential role of water: A crucial resource for life and sustainability. *Journal of Aquatic Pollution and Toxicology, 8*(3), 27.

Gasu, M. B., Ibrahim, R. B., & Yakubu, D. A. (2020). An appraisal of informal commercial activities in Osogbo, Osun State, Nigeria. *UNIOSUN Journal of Engineering and Environmental Sciences, 2*(1), 53–65.

Ifediegwu, S. I., Nnebedum, D. O., &Nwatarali, A. N. (2019). Identification of groundwater potential zones in the hard and soft rock terrains of Kogi State, North Central Nigeria: An integrated GIS and remote sensing techniques. *SN Applied Sciences, 1*(1151), 1–20.

Ifediegwu, S. I. (2022). Assessment of groundwater potential zones using GIS and AHP techniques: A case study of Lafia District, Nasarawa State, Nigeria. *Journal of Water Science, 12*(1), 1–15.

Jasrotia, A. S., Majhi, A., & Kumar, A. (2021). Delineation of groundwater potential zones in a mountainous terrain using geospatial techniques. *Environmental Earth Sciences, 80*(8), 1–17.

Kresic, N. (2009). *Groundwater resources: Sustainability, management, and restoration* (1st ed.). McGraw-Hill Education. ISBN 9780071492737

Mahalingam, S. (2014). Groundwater potential of a region. *Journal of Hydrology, 25*(3), 45–57.

Malavika, K. R. (2021). *Identification of groundwater potential zones in Patratu, Ramgarh District Jharkhand State* (Unpublished master's dissertation). Department of Geology and Environmental Science, Christ College, Irinjalakuda, Kerala.

Mukherjee, A., Jha, M. K., Kim, K. W., & Pacheco, F. A. (2024). Groundwater resources: Challenges and future opportunities. *Scientific Reports, 14*(1), 28540. https://doi.org/10.1038/s41598-024-28540

Murray, W. (2023). Importance, characteristics, and challenges of groundwater. *Environmental Risk Assessment and Remediation, 7*(3), 173–175.

Ogungbade, O., Ariyo, S. O., Alimi, S. A., Alepa, V. C., Aromoye, S. A., & Akinlabi, O. J. (2021). A combined GIS, remote sensing and geophysical methods for groundwater potential assessment of Ilora, Oyo Central, Nigeria. *Environmental Health Science, 81*(74), 1–12.

Okoli, F. U., Aigbedion, I. P., Marcellinus, L. M., Oludyi, S. M., & Idoko, I. A. (2019). Groundwater mapping in Ado Ekiti, Nigeria using GIS and remote sensing techniques. *International Journal of Advanced Research and Publication, 3*(3), 18–21.

Olajire, M. A., Matthew, O. J., Omotara, O. A., &Aderanti, A. (2018). Assessment of food crop production in relation to climate variation in Osun State, Southwestern Nigeria. *Journal of Agriculture and Ecology Research International, 14*(2), 1–4.

Olaniran, J. O. (2000). *Rainfall anomalies in Nigeria: The contemporary understanding* (55th Inaugural Lecture). University Press, Ilorin.

O'Leary, D., Friedman, J., &Pohn, H. (1976). Lineament, linear, lineation: Some proposed new standards for old terms. *Geological Society of America Bulletin, 87*(11), 1463–1469.

Opoku, P. A., Shu, L., & Amoako-Nimako, G. K. (2024). Assessment of groundwater potential zones by integrating hydrogeological data, geographic information systems, remote sensing, and analytical hierarchical process techniques in the Jinan karst spring basin of China. *Water, 16*(4), 566. https://doi.org/10.3390/w16040566

Pidwirny, M. (2006). *The drainage basin concept: Fundamentals of physical geography* (2nd ed.). Okanagan University College.

Rajesh, J., Pande, C. B., & Kadam, S. A. (2021). Exploration of groundwater potential zones using analytical hierarchical process approach in Godavari River Basin of Maharashtra in India. *Applied Water Science, 11*, 182. https://doi.org/10.1007/s13201-021-01462-9

Rilwanu, T. Y. (2014). *Assessment of groundwater potential for rural water supply in parts of Kano State, Northern Nigeria* (Unpublished doctoral dissertation). Department of Geography, Ahmadu Bello University, Zaria.

Saaty, L. T. (1988). *The analytical hierarchy process: Planning, priority setting, resource allocation*. RWS Publications.

Saaty, T. L. (1980). *The analytical hierarchical process*. McGraw-Hill.

Shamuyarira, K. K. (2017). *Determination of recharge and groundwater potential zones in Mhinga area, South Africa* (Unpublished master's dissertation). University of Venda.

Sani, B., Sawa, B. A., & Garba, M. L. (2016). Groundwater potential zones mapping using remote sensing and geographic information system techniques (GIS) in Zaria, Kaduna State, Nigeria. *American Scientific Research Journal for Engineering, Technology, and Sciences, 26*(1), 51–62.

Siddik, M. S., Tulip, S., Rahman, A., Islam, M., Torabi, H. A., & Mustafa, S. (2022). The impact of land use and land cover change on groundwater recharge in northwestern Bangladesh. *Journal of Environmental Management, 315*(1), 1–18.

Sun, L., Lizhe, Y., Lu, H., Di, F., Kailun, J., & Xiaolin, H. (2017). Hydrological effects of vegetation cover degradation and environmental implications in a semiarid temperate steppe, China. *Sustainability, 9*(2), 281–301. https://doi.org/10.3390/su9020281

Tijani, M. N., & Onodera, S. (2009). Hydrogeochemical assessment of metals contamination in an urban drainage system: A case study of Osogbo Township, South-West Nigeria. *Journal of Water Resources and Protection, 1*(3), 164–173. https://doi.org/10.4236/jwarp.2009.13020

Vikova, J. (2022). Groundwater: Importance and uses. *International Scholars Journals, 13*(2), 1–4.

Zewdie, M. M., Kasie, L. A., & Bogale, S. (2024). Groundwater potential zones delineation using GIS and AHP techniques in upper parts of Chemoga Watershed, Ethiopia. *Applied Water Science, 14*(85), 1–28.