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ASSESSING GROUNDWATER POTENTIALS USING GEOELECTRIC DATA: A CASE STUDY OF PARTS OF SOUTHERN BIDA BASIN, NORTH CENTRAL, NIGERIA

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ABSTRACT

Evaluation of groundwater potentials can provide a lucid understanding of viable areas for sustainable groundwater exploitation especially in water scarce regions. This research, therefore, aims to assess groundwater potentials in parts of Southern Bida Basin, North central Nigeria by utilizing vertical electrical sounding data. The method employed involved a geophysical survey using Vertical Electrical Sounding (VES) conducted in 20 locations across the study area. Dar-zarouk parameters was then utilized to derive the aquifer hydraulic parameters and the groundwater potentials estimated accordingly. The results reveals that the range of aquifer thickness, longitudinal conductance, transverse resistivity, hydraulicconductivity and transmissivity are 1.89-45.70 m (mean-18 m), 0.2-5.80 mhom (mean-0.84 mhom), 24.3-11026 Ωm^2 (mean-2970 Ωm^2), 1-74 m/day (mean-20 m/day), and 13-2543 m^2/day (mean-382 m^2/day), respectively. The classified groundwater potentials presented with a map, reveals three (3) classes namely: very high, high, and intermediate potentials covering 4%, 15%, and 81% of the study area, respectively. The value of the aquifer parameters computed indicate that the high values of parameters such as transmissivity and hydraulic conductivity reside within the southeastern, central and Northeastern part of the study area, with notable towns like KotonKarfe, Lokoja and Abaji, respectively. The groundwater potentials, therefore indicates predominance of intermediate potentials in the study area, which conforms with the aquifer hydraulic parametervalues obtained. It is therefore recommended that surface water sources should be deployed to complement water supply in areas with low groundwater potentials to meet large scale water need.

Keywords: Groundwater potentials; VES; Transmissivity; Aquifer parameters; Hydraulic conductivity

INTRODUCTION

Freshwater sources like river systems, springs, wells, and various water bodies are essential for human consumption, industrial processes, household use, and agricultural activities (Akudo *et al.*, 2021; Akudo & Otaru, 2023) Among these sources, groundwater stands out for its availability, protection from contamination, and potability. Groundwater is vital for both drinking water supply and agricultural irrigation, particularly in arid and semi-arid regions where surface water is limited. The primary source of drinking water in the study area is groundwater, with numerous wells drilled in recent years.

However, many of these wells were constructed without considering the area's hydrogeological conditions, leading to a high rate of borehole failures. Understanding the potential and distribution of groundwater resources is essential for effective water management and sustainable development. One of the most valuable methods for assessing groundwater potential is Vertical Electrical Sounding (VES), a geophysical technique that provides insights into subsurface conditions by measuring electrical resistivity.

Vertical Electrical Sounding is based on the principle that the resistivity of the subsurface materials varies with their composition, saturation, and the depth of investigation (Loke, 1996). With the application of an electrical current to the ground and attaining the resulting potential differences, VES can delineate different geological layers and estimate their thicknesses and resistivities. This information is critical for identifying aquifers, understanding their depth and extent, and evaluating their potential for water extraction (Telford *et al.,*1990).

In recent years, VES has been successfully applied in various hydrogeological settings to determine groundwater potential, including in crystalline rocks (Akpah *et al.*, 2023; Musa *et al.*, 2023, Chandra *et al.*, 2919), sedimentary basins (Ige *et al.*, 2018), and fractured aquifers (Obasi *et al.,*2021).

VES has been widely used in hydrogeological studies due to its effectiveness in providing detailed vertical profiles of subsurface resistivity. This method has proven particularly useful in areas with complex geological formations, where traditional drilling methods may be impractical or costly. For example, in regions with variable soil types and rock formations, VES can help distinguish between different types of aquifer materials and their water-bearing capacities (Khaki *et al.*, 2016)

In recent years, advances in VES technology and data interpretation techniques have enhanced the accuracy and reliability of groundwater assessments. Modern equipment and software have allowed for more precise measurements and more detailed analysis of the resistivity data, leading to better delineation of groundwater resources and improved resource management strategies (Ahmed II & Pradhan, 2019).

This research aims to explore the applicability of Vertical Electrical Sounding in determining groundwater potential, highlighting recent developments in technology and methodology. It will also, review key studies that demonstrate the effectiveness of VES in various geological settings and discuss best practices for integrating VES data with other hydrogeological information to make informed decisions about groundwater resource management.

It is sufficiently established that several scholars have used geoelectric data to determine aquifer parameters and assess the groundwater potential in the area of study. Ejiogu*et al.* (2019) used the geoelectric data to determine aquifer vulnerability in Imo State and environs. the research revealed that areas within the Benin Formation have high groundwater potential, while Nsukka and Ajali Formations have moderate water-bearing capacity. On the other hand, Imo and Ogwashi Formations have poor water-bearing potential. Building on this, Anomohanran et al. (2020) conducted a comprehensive study in Agbor, Delta State, Nigeria, using a combination of methods like VES, well-logging, and pumping tests to assess the aquifer's hydraulic characteristics and groundwater potential. Their findings showed that the aquifer can supply sufficient water for domestic and other uses, benefiting the local inhabitants.

This current study takes a similar approach, applying VES to determine groundwater potential in the Southern Bida Basin. By integrating VES data with information on hydrogeology from existing literatures in the

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study area discussed in the hydrogeology section of this paper, we aim to evaluate aquifer hydraulic parameters and determine groundwater potential, and contribute to the development of effective groundwater management strategies in the study area, ensuring sustainable use of this vital resource.

GEOLOGY AND HYDROGEOLOGY

The geologic sequence of Bida Basin is unified under the Northern and Southern Bida Formation (Adeleye, 1973) (Fig. 1). The stratigraphic sequence of the Southern Bida Basin shows an unconformable relation with the Basement complex and the LokojaFormation that overlays it, followed by conformable successions of the Patti and Agbaja Formations (Obaje, 2009).

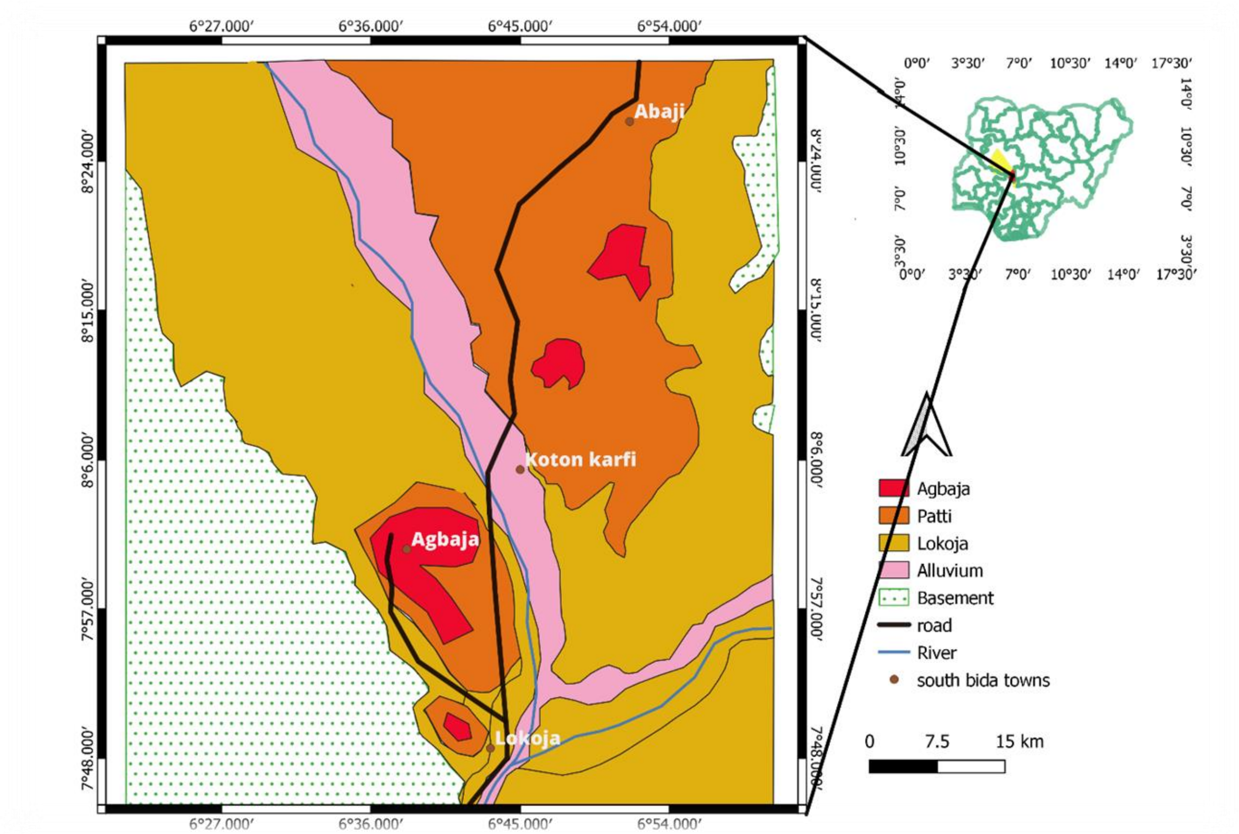

Figure 1: Geological map of the study area (modified after Ojo&Akande, 2009)

The Lokoja Sandstone

The LokojaFormation which are of Campanian - Maastrichtian were deposited and overlies unconformably on an eroded and older Precambrian Basement Rocks (Adeleye&Dessauvagie, 1972). The Formations' basal section consists of conglomerate with quartz and feldspar clasts ranging from sub-rounded to well-rounded, embedded with whitish clay matrix typified with an upward fining trend interbedded with siltstones and claystone. (Akande*et al.*,2005).

Patti Formation

The Patti Formationsits directly on top of the Lokoja formation (Adeleye&Dessauvagie, 1972). It is made up of a mix of fine to medium-grained sandstones, grey and white in color, along with clays, silts, and shales that contain carbon. Ironstone can also be found with a distinctive oolitic texture and thin seams of coal that aren't entirely pure. Argillaceous rocks - that's shale, siltstone, and claystone - are well exposed in Koton-karfi and Abaji, which falls in the study area.(Obaje, 2009).

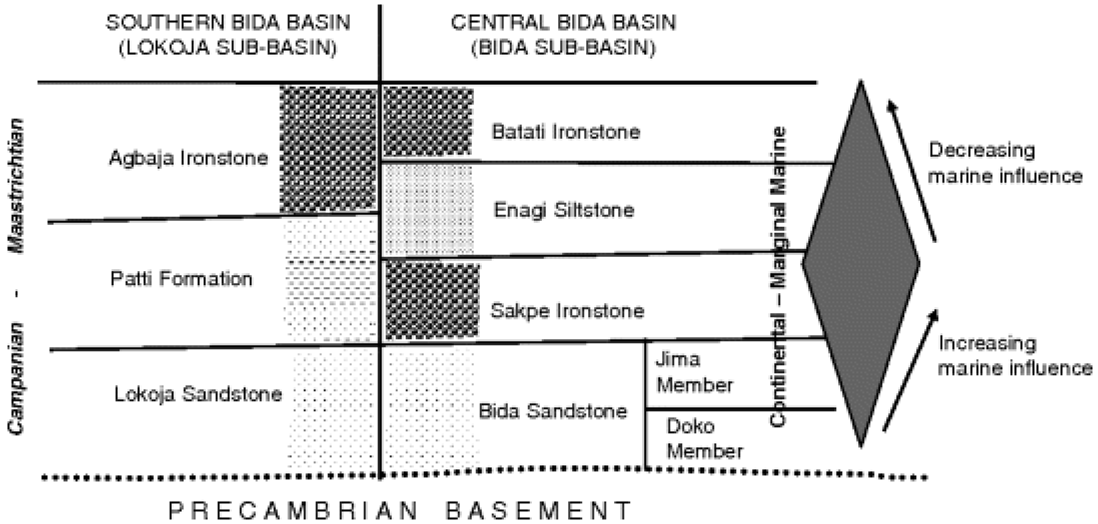

Figure 2: Stratigraphic succession in the Bida Basin (After Obaje, 2009)

The Patti Formation siltstones often display neat parallel layers and occasional wavy ripples - a testament to the region's turbulent past. These rocks are fossilized, preserving the tracks of ancient creatures like *Thalasinoides*. The claystonesinterbeddedwith the siltstones are characteristically thick and rich in kaolinite. While the formation's thickness varies, it can reach an impressive 70 meters, with ironstones adding an extra 7 to 16 meters. The Formation is well exposed in Lokoja Town, where the sandstone shows more maturity and distinct from other parts of the Basin where they are exposed (Akande*et al.*, 2005).

The Agbaja Ironstone

The Agbaja Ironstone, first called by Adeleye and Dessauvagie in 1972, is a stratified deposit consisting of sandstones, claystones, and ironstone layers. These deposits are believed to have formed from ancient river channels and banks that were subsequently altered by marine activity, leading to the distinct ironstone formations observed today (Ladipo*et al.,*1994). Marine forces also impacted the surrounding Lokoja Sandstone and Patti Formation, indicating a blend of continental and marine environments. (Braide, 1992; Olaniyan&Olobaniyi, 1996). The ongoing marine influence during the formation of the AgbajaIronstones suggests a complex geological history. (Ladipo*et al.,*1994).

MATERIALS AND METHOD

Location and Sampling Points

Southern Bida basins spans approximately 2742 km^2 (Ige*et al.,* 2018) between latitudes 07^{0}45’-08^{0}30’ N and longitudes 006^{0}40’-E006^{0}55’ E and falls within FCT and Kogi State (Fig. 1). This research was conducted in four localities within the Southern Bida Basin. These localities are: the Agbaja, KotonKarfe, Lokoja and Abaji, respectively.

Geophysical Survey

A geophysical survey using Vertical Electrical Sounding (VES) was conducted at 20 locations across the study area (Fig. 3), employing a Schlumberger array configuration and a DDR3 resistivity meter. The electrode spacing was varied, with current electrodes (AB/2) ranging from 1 to 200 meters and potential electrodes ranging from 0.5 to 15 meters. This incremental increase in electrode spacing allows for greater depth penetration and subsurface exploration.

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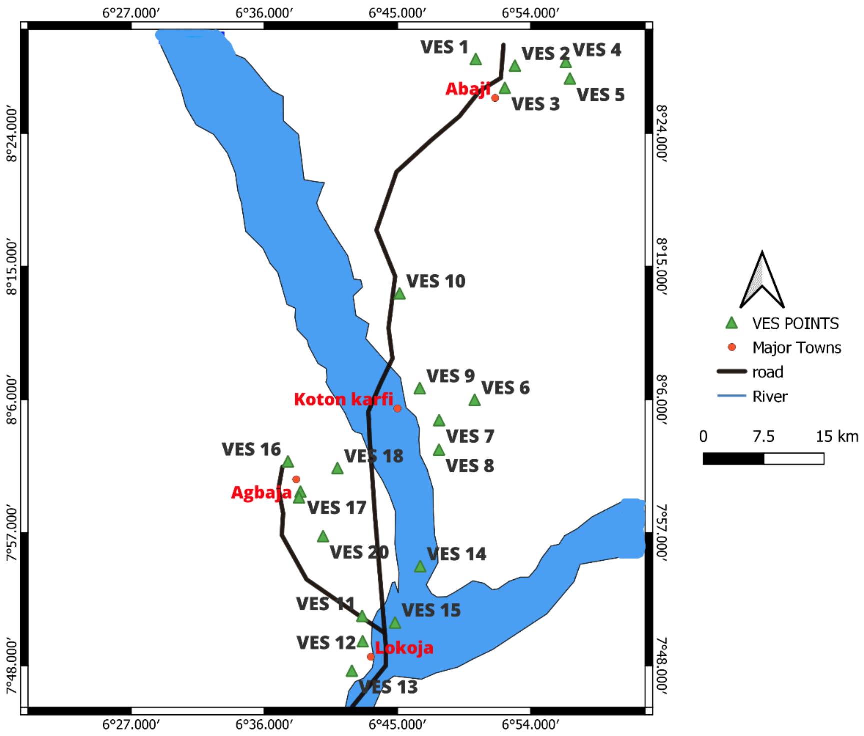

Figure 3: Location of VES points in the study area

The geometric factor (K) was calculated using equation 1 while apparent resistivity (ρ_a) was computed with equation 2, enabling the team to analyze the resistivity data and gain insights into the subsurface structure.

Computer analysis was carried out using IPI2WIN computer software, this helps to model the VES data from the manual plotting to give a smooth curve after a set of numbers of iteration processes. The final output resulted to VES curves/graphs and delineated different layers with their respective resistivity, depth and thickness.

$$K = \frac{\pi\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{4\left(\frac{MN}{2}\right)} \qquad 1$$

$$\rho_a = KR \qquad 2$$

Where; AB/2 represents the current electrode spacing, MN/2 the potential electrode spacing, π is constant, $\rho_a$for Apparent resistivity, K as the coefficient of geometric factor, and R is the resistance.

Table 1: Location of Vertical Electrical Sounding (VES) Points

VES No.	LOCATION	Formation	COORDINATE NORTHING	COORDINATE EASTING
1	Abaji: LGEA Primary School	Patti	008°29`09.22``	06°50`17.5``
2	Abaji: Back of NIPCO Filling Station	Patti	08°28`35.41``	06° 56`56.28``
3	Abaji: UBE Primary School	Patti	08°28`10.21``	06°55`45.4``

4	Abaji: Back of FRSC	Patti	08°28`50.14``	06°56`10.79``
5	Abaji: Back of Central Mosque	Patti	08°28`23.32``	06°56`39.38``
6	KotonKarfe: Government Science Secondary School	Patti	08°04`59.3``	06°48`13.0``
7	KotonKarfe: Kekere Primary Health Centre	Patti	08°05`36.9``	06°44`29.0``
8	KotonKarfe: Central Mosque	Patti	08°04`36.9``	06°48`48.4``
9	KotonKarfe: Central Primary School	Patti	08°05`27.0``	06°48`10.9``
10	KotonKarfe: Aquatic Fishery	Patti	08°06`29.5``	06°47`8.6``
11	Lokoja: Emmanuel Baptist Church Felele	Lokoja	07°52`07.40``	06°42’36.8``
12	Lokoja: Poly Village	Lokoja	07°51`24.80``	06°45`04.83``
13	Lokoja: Patti Road	Lokoja	07°48`31.90``	06°45`55.07``
14	Lokoja; Up Nataco	Lokoja	07°50`34.54``	06°44`54.6``
15	Lokoja: SarkiNoma	Lokoja	07°50`55.50``	06°44`50.29``
16	Agbaja: Community Secondary School	Agbaja	07°59`20.48``	06°38`31.79``
17	Agbaja: Beside MTN Mast	Agbaja	07°59`11.90``	06°38`26.60``
18	Agbaja: Behind Primary Health Care	Agbaja	07°59`21.18``	06°38`26.60``
19	Agbaja: LGEA Primary School	Agbaja	07°59’23`68``	06°38`31.64``
20	Agbaja Community Entrance	Agbaja	07°59`13.15``	06°38`35.19``

Dar Zarouk parameters

The Dar-Zarrouk parameters are crucial for interpreting and understanding the geological models, thatare derived from the combination of aquifer thickness and resistivity of the geoelectrical layer. (Zohdy*et al.*,1974). These parameters including aquifer transmissivity are essential in assessing aquifer potentials. They are calculated using the following equations:

Transverse unit resistance $T_R = h_p$ (Ωm^2)(3)

Longitudinal unit conductance (S) = h/ρ (mhom)$(S) = \frac{h}{\rho}$(mhom) (4)

The hydraulic conductivity (K) and Transmissivity (T) were determined mathematically using Eqs. (5) and (6) in line with procedures of Obiora *et al.*(2016), Raji and Abdulkadir (2020).

Hydraulic conductivity $(\text{K}) = 386.40\rho a - 0.93283\ (\text{m/d})$ (5)

Transmissivity = $(\text{T}) = \sigma \text{T R} = \text{KS}/\sigma = \text{Kh}\ (\text{m2/d})$ (6)

RESULTS AND DISCUSSION

The Vertical Electrical Sounding (VES) surveys revealed a complex subsurface structure in the Lokoja, Patti Formation, and Agbaja areas, with 4-5 geo-electrical layers. The top layer's resistivity and thickness values indicated variable composition from 330 ohm and 0.2-6.1m, while the second layer showed a wide range of resistivity values ranging from 12.9-20464ohm and thickness varying

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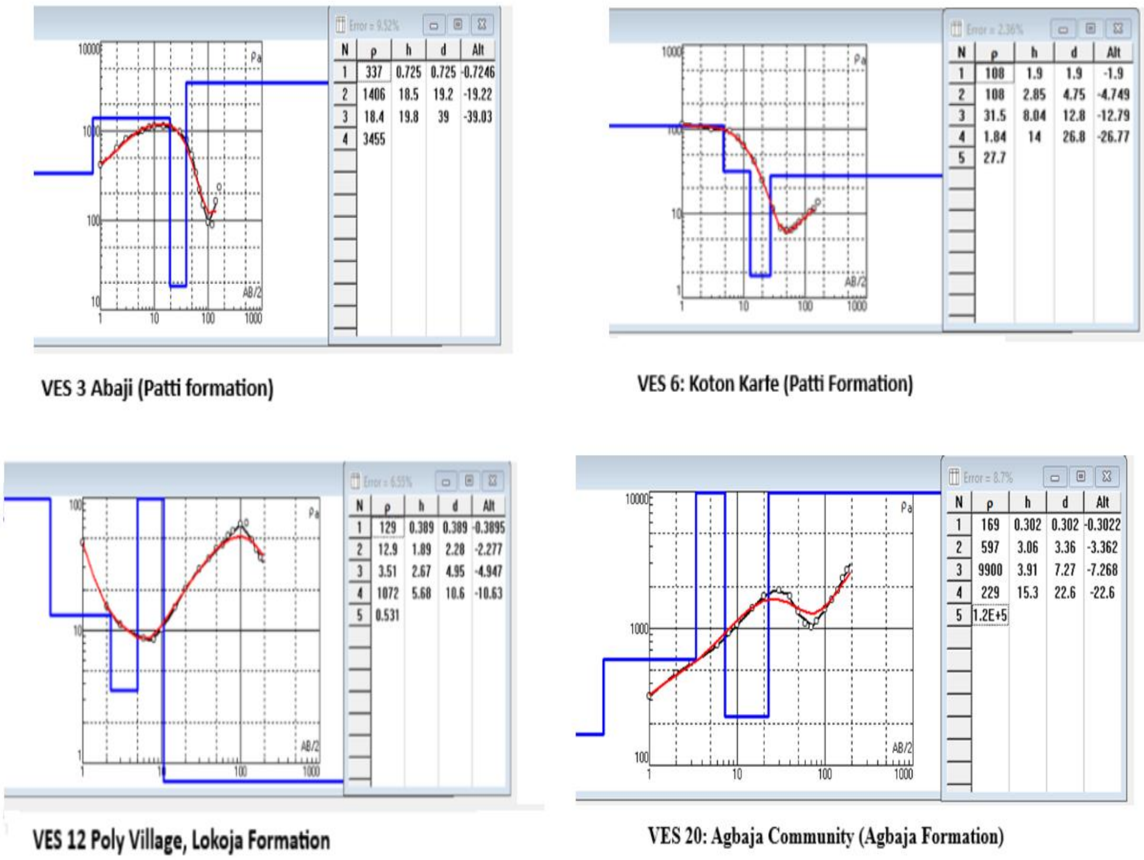
from 0.9-18.5 m, The third layer with 2.5-14130ohm resistivity and 3.91-43m thickness, and the fourth layer potentially hosting significant aquifers with values of resistivity and thickness ranging from 10.5-258.14 ohm-m and 8.19-32.3 m, respectively (Fig. 4). The pie chart (Fig.5) revealed that the VES sounding comprises of HK (20%), KH (20%), and HA (60%) curves respectively, indicating the dominance of the HA-curve type in the study area.

The low resistivity values in the area were linked to the presence of lateritic clay and clayey-sandstone (Abdulbariu*et al.*, 2023). The fourth layer's aquifers showed promise for groundwater potential evaluation. The sedimentological characteristics of the rocks in the basin support this interpretation.

Transmissivity and hydraulic conductivity values ranged from 13.85-2543 m^2/day and 0.96-74 m/day, (Table 2), respectively, indicating low to moderate values. These findings align with previous studies.

The bi-log plots and geoelectric sections revealed varying resistivity curve types; The VES 1,2,3 and 4 has KH curve type, VES 16, 17,18, 19, 20 has HK and VES 5,6,7,8,9,10,11,12,13,14,15 has the HA type. These inconsistency in resistivity curve type throughout the area of study is characteristic of areas with groundwater-bearing fractures.

The study area comprises three formations: Lokoja, Patti, and Agbaja Ironstone. VES points near the Patti-Agbaja boundary showed low resistivity, suggesting potential for hand-dug wells. Points near the Patti-Lokoja boundary had very low resistivity and appreciable depth, making them suitable for borehole drilling.



VES 3 Abaji (Patti formation)

VES 6: Koton Karfe (Patti Formation)

VES 12 Poly Village, Lokoja Formation

VES 20: Agbaja Community (Agbaja Formation)

Figure 4:VES graphs of selectedresistivity layers and interpretations.

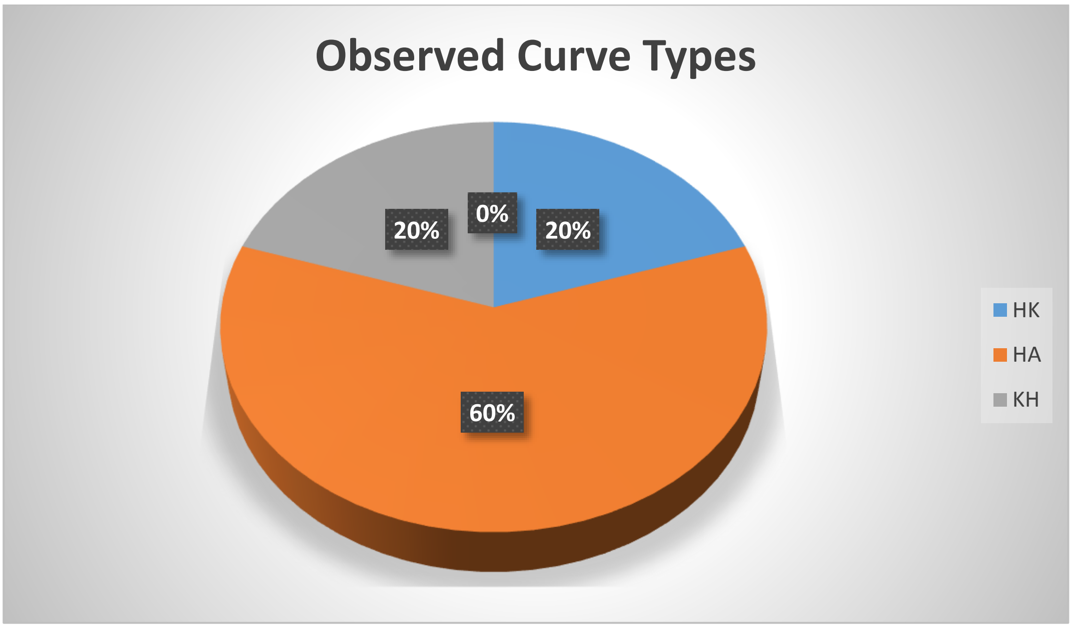


Figure 5: Observed curve type distribution in the study area

Table 2: Overview of computed aquifer characteristics and Dar-Zarrouk parameters

VES NO	ρa (Ωm)	d(m)	h (m)	TR (Ωm^2)	S (mhom)	K (m^2/day)	T (m^2/day)
1	616	29	17.9	11026.4	0.029	0.9657	17.28564434
2	457	28.5	17.6	8043.2	0.039	1.2758	22.45433288
3	18.4	39	19.8	364.32	1.076	25.5374	505.6410193
4	5.74	39	20	114.8	3.484	74.7010	1514.019026
5	10.7	15.7	14.6	156.22	1.364	42.3445	618.2297559
6	31.5	12.8	8	252	0.254	15.4656	123.7251733
7	7.85	64.5	45.7	358.745	5.822	56.5296	2543.402383
8	60.3	16	9.55	575.865	0.158	8.4392	80.59481283
9	14.4	15.7	8.93	128.592	0.620	32.0983	286.6376886
10	10.5	8.8	6.2	65.1	0.590	43.0964	267.1977479
11	612	10.5	9.21	5700.99	0.015	0.9613	8.853682827
12	12.9	10.6	1.89	24.381	0.147	35.5669	67.22139525
13	43.5	15.7	13.7	595.95	0.315	11.4447	156.7926684
14	35.3	10.6	9.67	341.351	0.274	13.9068	134.4785177
15	19.7	54.5	42.9	845.13	2.178	23.9618	1027.962993
16	308	43.9	31.8	9794.4	0.103	1.8435	58.62319349
17	290	43.3	30.2	8758	0.104	1.9500	58.89051284
18	115	36.5	24.7	2840.5	0.215	4.6212	114.144057
19	482	19.2	12.3	5928.6	0.026	1.2140	14.93191333
20	229	22.6	15.3	3503.7	0.067	2.4306	37.18803368

From the Table:6 above ρa= Aquifer resistivity; *h* = Aquifer thickness; *d* = Depth to aquifer; *S* = Longitudinal conductance; *T R* = Transverse unit resistance; *K* = Hydraulic conductivity; *T* = Transmissivity.

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The water-bearing formation possess sufficient potential to supply groundwater for individual and small-scale community needs, and potentially even larger regional requirements. However, further comprehensive investigations are necessary to fully ascertain and harness this resource in a sustainable manner.

The aquifer type in the research location ranges from semi confined to confined aquifers (Idris-Nda, 2013) which is typified by low groundwater recharge compared to the unconfined to semi confined aquifer of the Northern and Central Bida Basin. This study will be a good guide for groundwater prospecting which can be used for the planning and management of groundwater resources.

Aquifer Resistivity

The resistivity values obtained from the survey showed a wide range of variation, indicating differing subsurface conditions. Areas with low resistivity values, such as KotonKarfe, are likely to have higher groundwater potential due to the presence of more conductive materials. In contrast, areas with high resistivity values, like Agbaja, may have lower groundwater potential due to the presence of less conductive materials as shown in Figure 6. The mean aquifer resistivity value of 169.34 Ωm provides a baseline for understanding the overall groundwater potential in the study area.

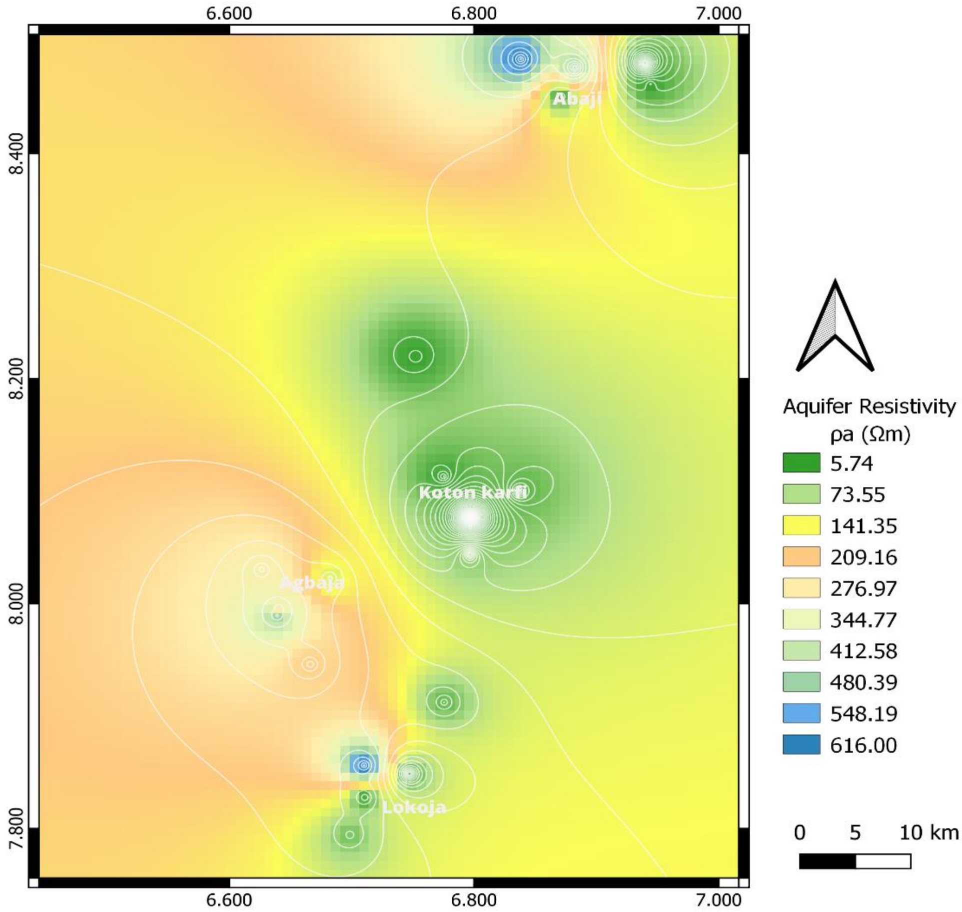

Figure 6: Spatial distribution of the aquifer resistivity of the study area

Aquifer Thickness

The assessment of aquifer thickness in the study area ranges from 1.89 m to 45.70 m(Figure 7)with the mean value as 18m. This variability has important implications for groundwater resource management. The areas characterized by appreciably thicker aquifers, presents opportunities for sustainable groundwater exploitation, although aquifer thickness alone does not guarantee groundwater potential. Transmissivity and permeability also play critical roles in determining aquifer productivity. It is also it is essential to recognize that local-scale variations can significantly impact groundwater availability and sustainability.

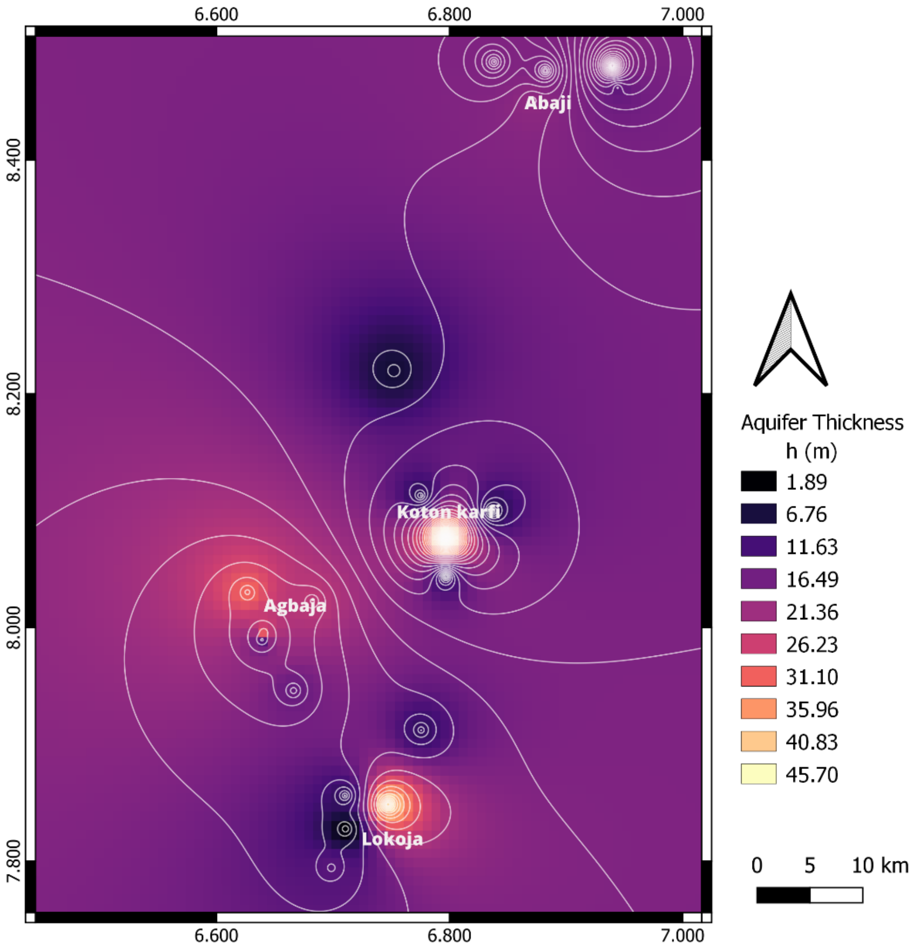

Figure 7: Spatial distribution maps of aquifer thickness

Aquifer Depth

The study reveals significant variations in aquifer depth across the formation, ranging from 8.80 m to 64.50 m (Figure 8) with a mean depth of 26.82 m. These findings have important implications for groundwater resource management. Shallow aquifers (e.g., 8.80 m) may be more vulnerable to contamination and over-extraction, while deeper aquifers (e.g., 64.50 m) may require more extensive infrastructure for exploitation. The spatial distribution of aquifer depth suggests areas with deeper aquifers may have greater groundwater storage capacity.

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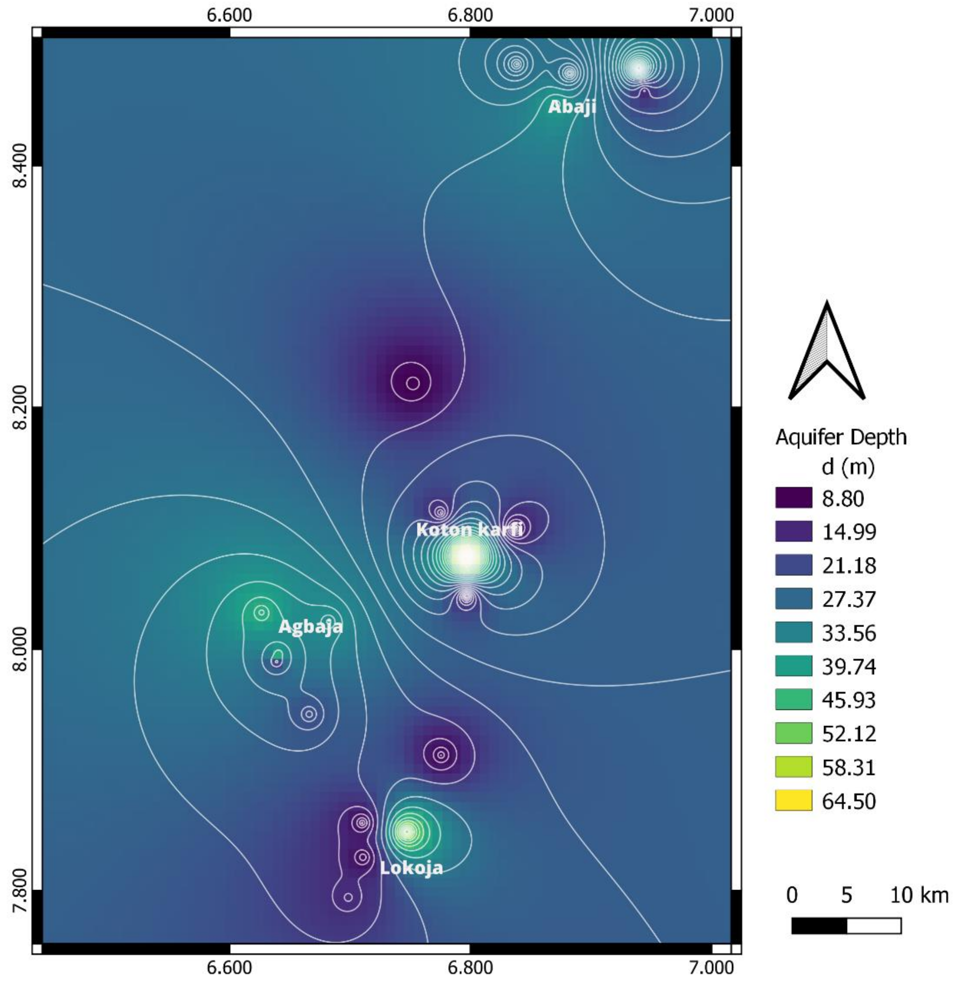

Figure 8: Spatial distribution maps ofaquifer depth of the study area.

Longitudinal Conductance

Significant range in aquifer longitudinal conductance across the formation was revealed, spanning from 0.20 mhom to 5.80 mhom (Figure 9) with a mean value of 0.84 mhom. High conductance areas may experience enhanced groundwater flow, while low conductance areas may exhibit restricted flow.

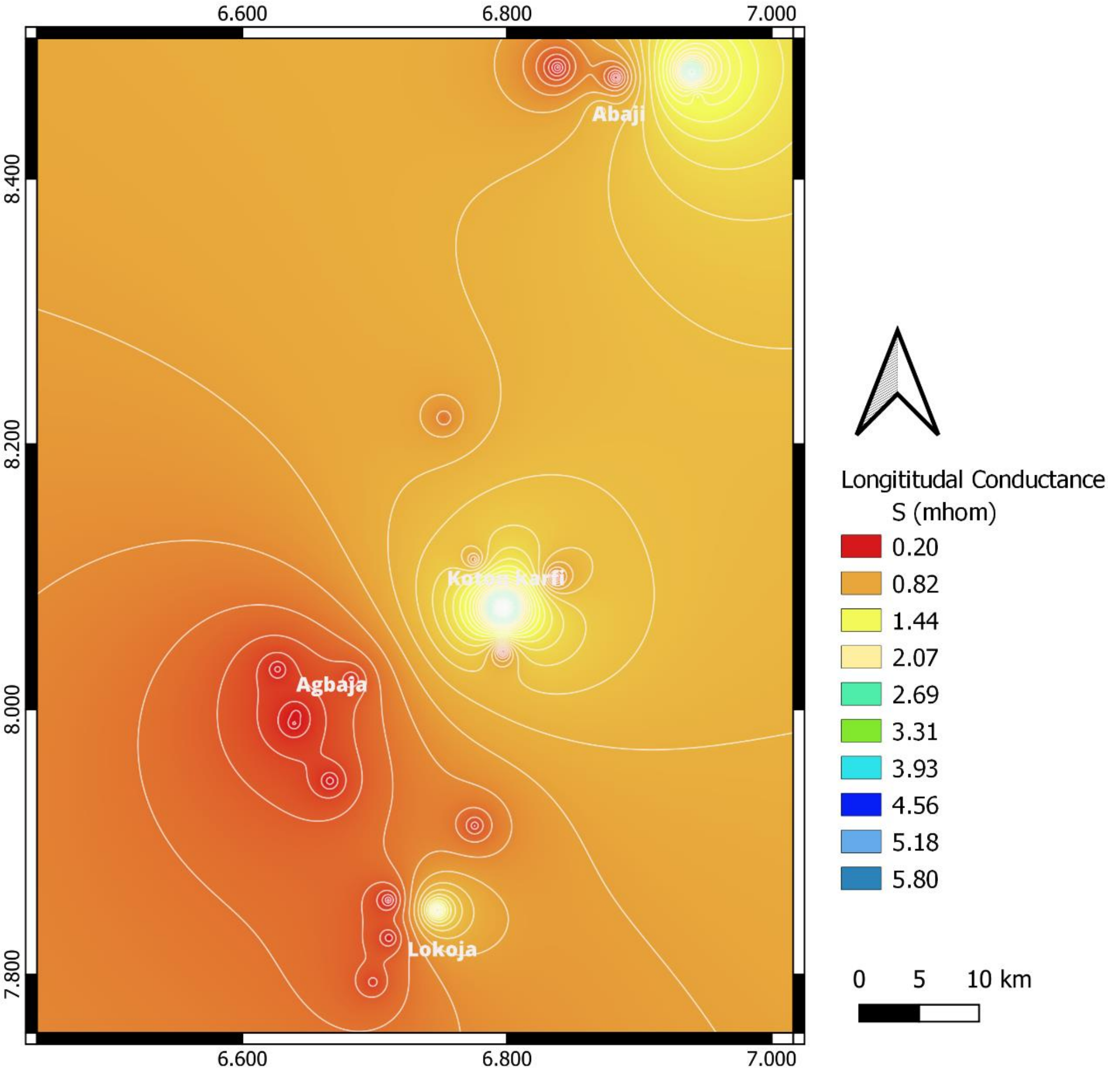

Figure 9: Spatial distribution maps of longitudinal conductance

Transverse Resistivity

The aquifer's transverse resistance, a key indicator of its ability to impede groundwater flow, ranges from 24.3 Ωm² to 11026 Ωm² (Figure 10) with a mean value of 2970 Ωm². This variability suggests that the aquifer's heterogeneity and anisotropy may significantly impact groundwater flow patterns. Areas with high transverse resistance may experience reduced groundwater flow, while areas with low transverse resistance may facilitate greater flow.

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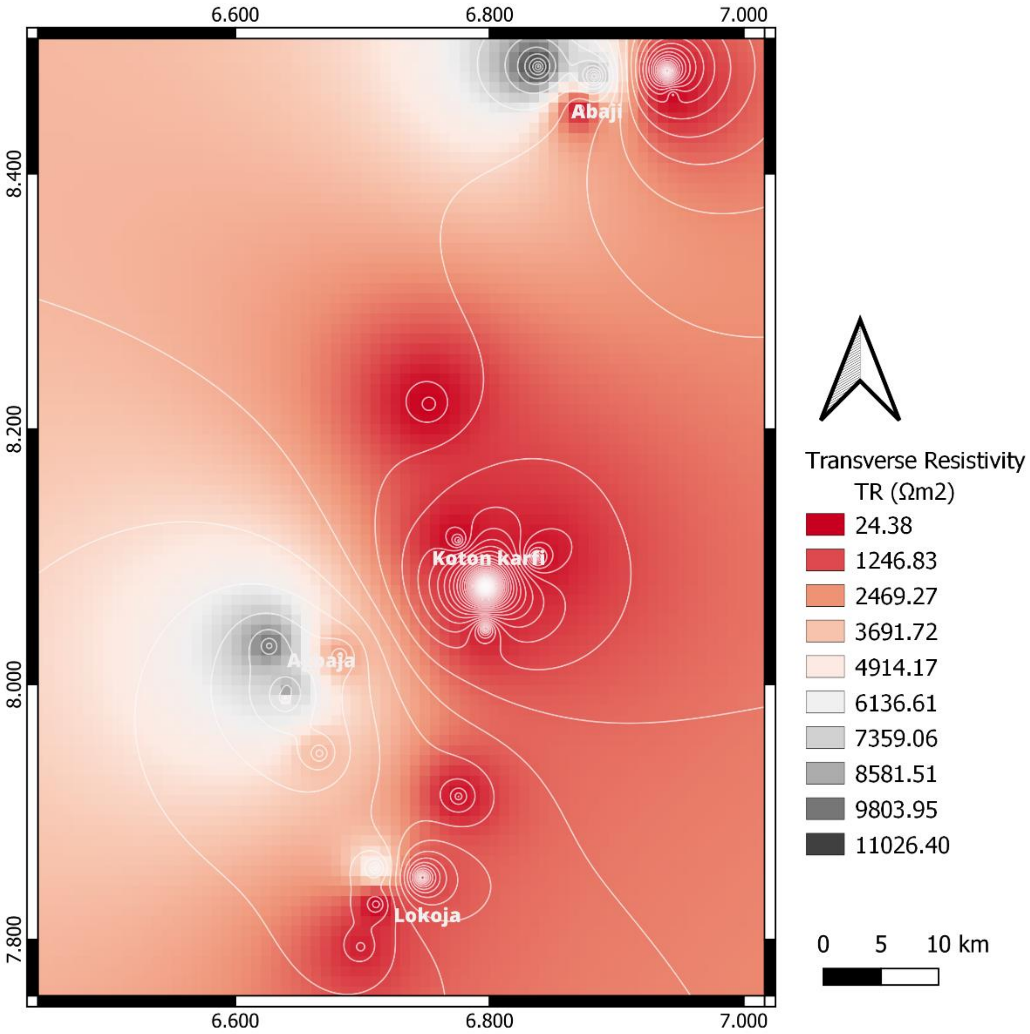

Figure 10: Spatial distribution maps oftransverse unit resistance of the study area.

Hydraulic Conductivity

The aquifer's hydraulic conductivity, a key indicator of its water-transmitting capacity, varies significantly across the formation, ranging from 1 m/day to 74 m/day (Figure 11) with a mean value of 20 m/day. This variability suggests that the aquifer's permeability and water transmissivity differ substantially across the study area. High hydraulic conductivity zones indicates enhanced groundwater flow and capacity to allow flow of groundwater, while low hydraulic conductivity zones may have reduced flow.

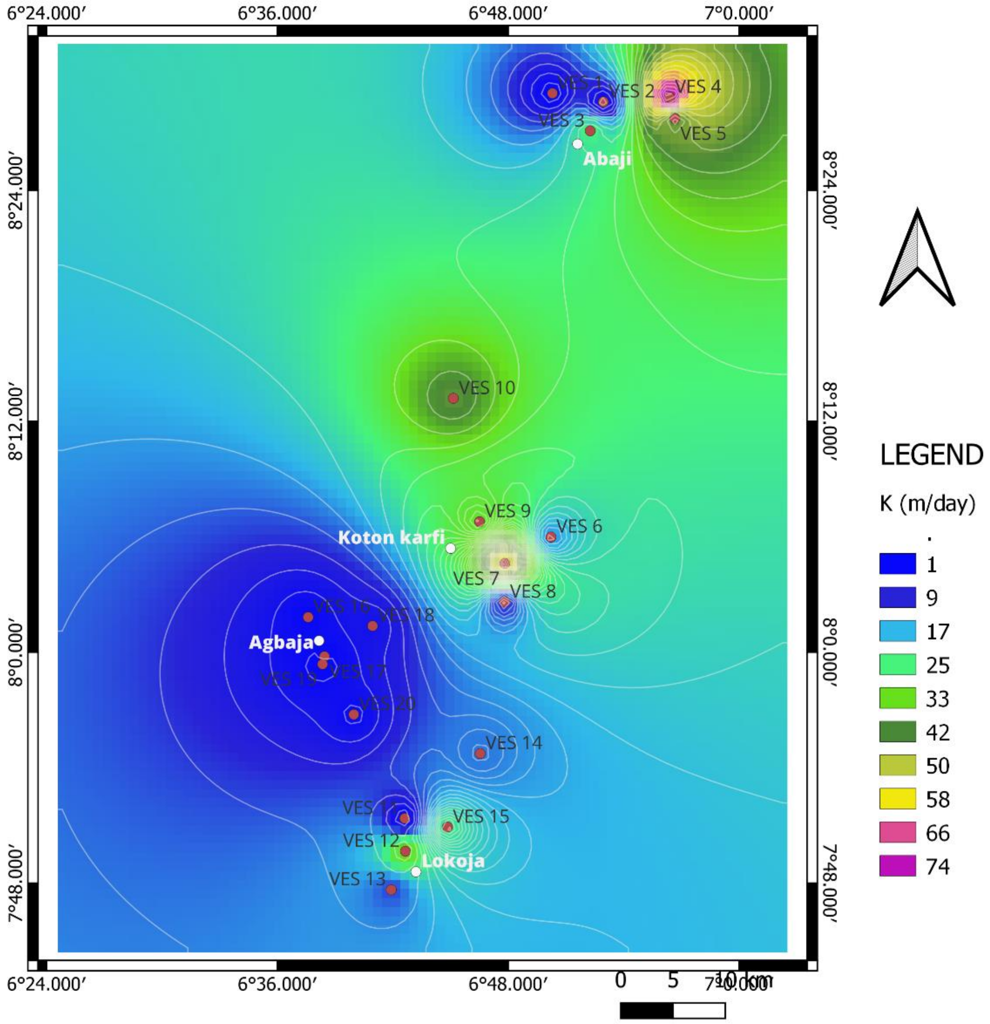

Figure 11: Spatial distribution maps of hydraulic conductivity

Transmissivity

The transmissivity of the aquifer, is a measure of its capacity to transmit water through its entire thickness. It ranges from 13 m²/day to 2543 m²/day (Figure 12) with a mean value of 382 m²/day. The wide range of transmissivity values indicates varying levels of aquifer productivity and water-yielding capacity. Areas with high transmissivitysuggests the availability of more groundwater quantity which can survive appreciable groundwater extraction, while areas with low transmissivityimplies limited water-yielding capacity of the groundwater aquifers.

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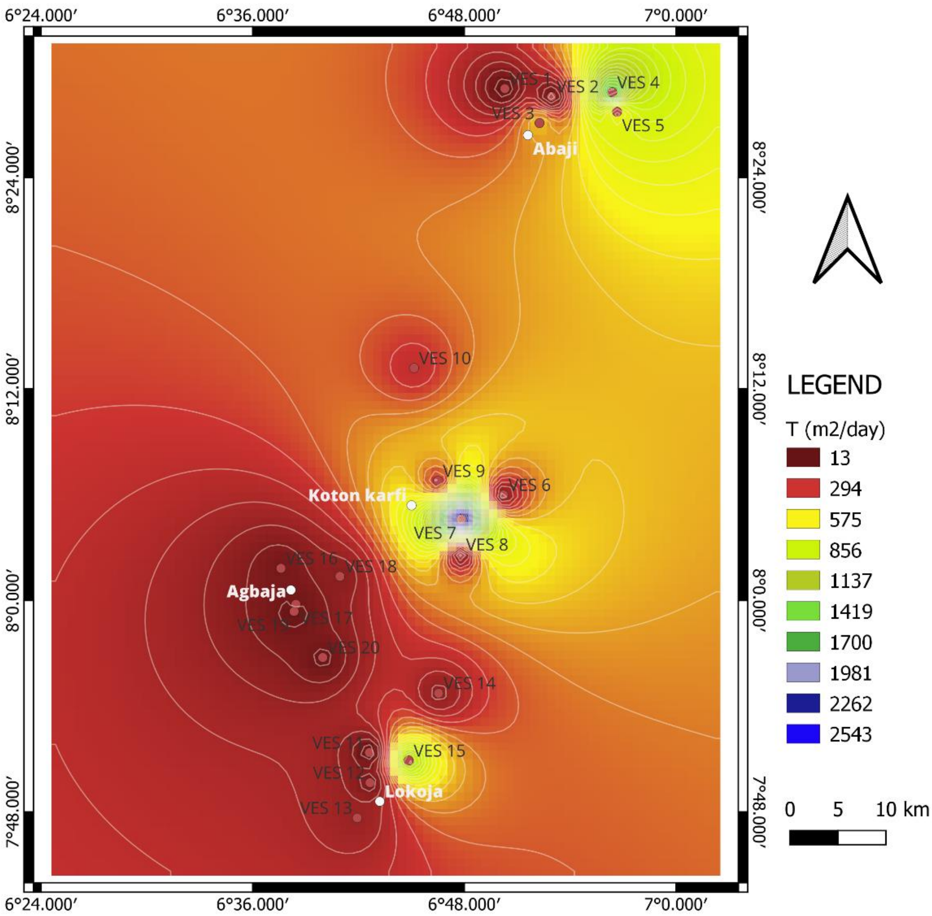

Figure 12: Spatial distribution maps oftransmissivity of the study area.

Groundwater Potential

The overall capacity of an area's aquifers to accumulate water for extended period of time is regarded as groundwater potential (Ahmed II *et al.*, 2022; Akudo*et al.*, 2024). It's mainly controlled by how porous the rocks are and how much space is available within the rock layers to hold water. This is a parameter that is considered when planning for groundwater exploitation that will guarantee the sustainability of the limited resource.

To evaluate the groundwater potential of the study area, Krasny (1993) classification technique wasfollowed. This approach aggregatesthe transmissivity data from across the study area to group areas according to their ability to store and supply groundwater (Table 3).

Table 3: Classification of transmissivity magnitude (after Krasny,1993)

The Magnitude of Transmissivity (m2/day)	Designation	Groundwater Supply Potential
> 1000	Very high	Regional importance
100–1000	High	Lesser regional importance

10–100	Intermediate	Local water supply
1—10	Low	Low Private consumption
0.1–1	Very low	Limited consumption
< 0.1	Imperceptible	Very difficult to utilize for local water supply

This classification provides a vivid scenario of the groundwater potential, distinguishing areas with abundant groundwater from those with limited groundwater resources. The outcome reveals a variation in groundwater potential, spanning from very high to moderate levels, respectively (Figure 13).

The map reveals that a small portion of the area, about 4%, has very high groundwater potential, marked in blue. These areas are capable of providing substantial groundwater resources that can serve regional needs. However, around 15% of the area was assigned to high potential zones, shown in yellow, which can meet significant local groundwater demands and potentially support regional supply. The majority of the area, approximately 81%, falls into the intermediate potential zones, indicated by brown, andsuggests moderate groundwater potential adequateto provide for local water needs. The outcome of this research is supported by earlierstudies by Ige et al. (2018), in the study area, which also identified moderate to high groundwater potential zones in the Southern Bida basin.

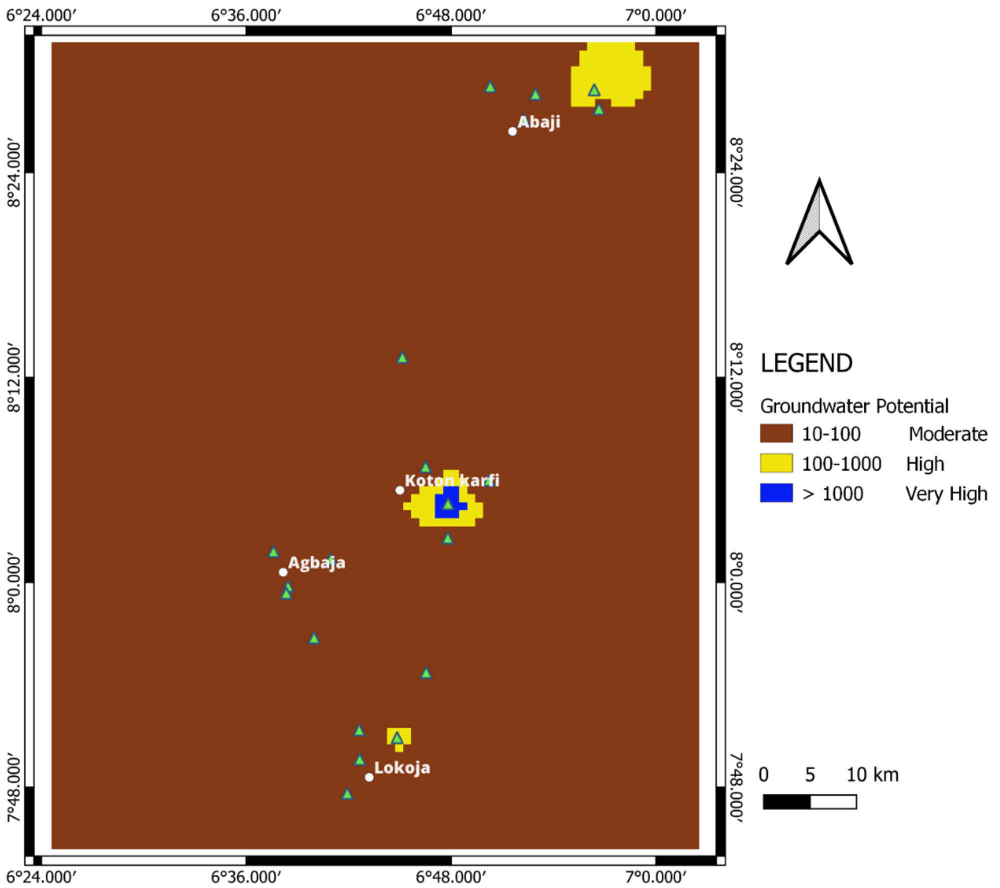

Figure 13: Groundwater potential map of the study area

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Research by Ibrahim et al. (2018) in the Karaworo area found that the Patti and LokojaFormations have higher transmissivity values, indicating greater groundwater potential compared to the AgbajaFormation, which supports our study's findings. Similarly, Ali et al. (2022) studied groundwater potential in arid regions and obtained comparable results, classifying zones based on transmissivity and porosity, which validates the Krasny classification method. Akhter and Hassan (2016) investigated aquifer host rocks and discovered that clay/shale presents low hydraulic conductivity and transmissivity values, whereas sand/gravel materials act as good aquifers with high hydraulic parameter values. This corresponds with this current study's results, which show high groundwater potential zones correlated with high transmissivity values, indicating permeable materials.

CONCLUSION

This study has shed new light on the subsurface hydrogeological characteristics of the area, by assessing the groundwater potentials using geoelectric data. The results have significant implications in managing and conserving groundwater resources sustainably. The findings showed only a small portion (4%) of the area has extremely high groundwater potential, while 15% has high potential. However, a substantial majority (81%) falls into the moderate category. This highlights the need for careful management and conservation strategies to ensure long-term sustainability.

Identifying areas with high and very high groundwater potential can guide targeted efforts for groundwater development, like constructing boreholes and wells. On the other hand, areas with moderate potential require more cautious approaches to prevent over-abstraction and depletion.

This study emphasizes the effectiveness of geoelectric data in assessing groundwater potentials, providing a valuable tool for water resource managers and policymakers. By incorporating these findings into decision-making, stakeholders can work towards sustainable groundwater use, mitigate over-exploitation risks, and protect this vital resource for future generations.

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STATUS OF SOILS COLLECTED UNDER SOME AGROFORESTRY TREES

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ABSTRACT

Soil the bed rock for natural provision of macro and micro nutrients for plant growth and development. A soil is considered unhealthy when it can longer supply required nutrients for plant growth due to over use or degradation. To mitigate soil low fertility, agroforestry method of raising trees and crops together makes nutrients available continuously for crop production, through dropping of its parts as litter which decays to add organic matter and nutrients to soil. Soils sampled with soil auger from seven agroforestry trees farm lands namely Gmelina arborea Roxb., Treculia africana Decne., Tectona grandis Linn. f., Pentaclethera macrophylla Benth., Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill., Mangifera indica Linn., Annona muricata Linn. and Fallow farmland as control were evaluated for macro and micro elements using standard laboratory methods and results presented with the highest and smallest values from each parameters evaluated: pH: 5.6, 4.5(Fa and Pm);%N,OC:0.21,0.10(Pm, Fl and Ma),3.40,1.30(Pm and Ig);EC (µS/cm):151.0,88.0(Fl and Tg), P, Mn, Fe, Cu, Zn (mg/Kg): 72.10, 19 .60 (Ta and Ma),111.02, 46.27 (Ta and Tg), 138.47,21.51(Pm and Am),1.53,0.80(Pm and Am), 8.08, 1.86(Ta and Mi); %Sand, Silt, Clay:88,70(Am, Ma and Tg), 16.50, 4.60(Ma and Tg, Am), 13.50,7.50 (Tg and Tg, Pm and Am); Ca, Mg, K, Na, Acidity, Al, ECEC(cmol/Kg)3.43, 0.59 (Ta and Tg),1.00, 0.24(Am and Mi), 0.15,0.07 (Pm, Ma, Ig and Am), 0.40,0.35(Tg, Ma, Ig and Am), 16.90,4.05(Tg and Am), 2.8,1.10(Tg and Am), 21.10,8.70(Tg and Am). We conclude by recommending agroforestry practice as way out of managing and sustaining soil health within the agroecosystems for continuous plant and food crop production as well sustaining the environment.

Keywords: Mineralization; Agroforestry trees; Mineral elements; Soil

INTRODUCTION

Farmers have this insight that the yield of arable crop depends on the status of the soil fertility and when average crop yield from farmland begins to decline, it is an indicationthat the soil can no longer support and supply the required soil nutrients for worthy crop harvest, therefore farmers sort and adopted several farming systems methods to ameliorate soil nutrients status (Hoffmann *et al.*2001; Stewart *et al.*2020) which included shifting cultivation, crop rotation, farm yard manure, inorganic fertilizer from plant residues and lately the application of agroforestry trees and crop combination (Hoffmann *et al.* 2001; Stewart *et al.*2020).

Nigeria is an agrarian nation, made up of different agroecological zones (Adenle *et al.* 2020), hence different farming systems methods were adopted to accommodate the diverse agroecosystems and coupled with different crop types. Agricultural practices adopted before now were shifting cultivation, crop rotation, mixed farming etc., which allowed a farmer to clear, and cultivate a piece of farmland for three to five years and with decline of crop yield, abandon land for a new place allowing the farmland to rest and recover from use and degradation (Fadairo *et al.*2020).

In Northern and Southern Nigeria, the methods of improving the soil status naturally are to some extent similar, however, both zones have some advantages and disadvantages over each other. Southern zone relies on its thick vegetation covers including shrubby and herbaceous plants with its numerous branches, leaves, twigs and dead parts which fall and decay to form organic matter (Mayer *et al.* 2020; Prescott and Vesterdal, 2021) and while in Northern zone, Savanna trees, shrubs and herbaceous plants and dropping from the cattle grazing contribute to organic status of the soil (Kgosikoma *et al.* 2013). Hence the moment the virgin land in each zone are opened up and used leads to soil erosion, degradation and loss of organic matter (AbdelRahman, 2023).

These were some methods put in place for upholding soil fertility owing to the availability of plenty uncultivated land in the forest and savanna zones of Nigeria which allows this long period of rest time before coming back to the farmland. However, population explosion and increase in demand for arable farmland for crop production to feed the teaming population and coupled with other land demanding projects like schools, hospitals, and industrial layouts etc. which require vast areas of land that abridged the time of wait (Akpan and Ebong, 2021; Döös,2002).

The world is experiencing a constant increase in human population, climate change which is impacting on the agroecosystems, high cost of mineral fertilizers, other farm inputs and world economy which has also impacted on every human economic and lives especially small scale farmers who constitute about 80% of labourin agricultural crop production (Chiaka *et al.* 2022; Babura *et al.* 2017; Mgbenka and Mbah, 2016).

Farmers' desire to increase crop yield and maximize soil nutrients, led to a number of improvement on the older methods for example shifting cultivation, crop rotation etc., which brought about some innovations of planting some desirable food crops and trees combinations to improve the soil texture, structure and keep the soil in a healthier condition for crop growth, development and yield; other agro allied activities and generally the environment which in turn benefit more from the practices without leaving the farmland to rest or fallow. The practice of combining trees or shrubs with crop production brought about the term agroforestry concept in the late 1970s (Atangana *et al.* 2014; Nair *et al.* 2021; Somarriba, 1992).

According to Kang and Gutteridge (1998) and Cooper *et al.* (1996) to cultivate the soil continuously for crop production with little or no fertilizer recommended the planting of leguminous trees and shrubs for example *Cajanus cajan* (Linn.) Mill sp., *Flemingia macrophylla* (Willd.) Merr., *Parkia biglobosa* (Jacq.) Benth., *Acacia auriculiformis* A. Cunn. ex Benth., *Albizia lebbeck* (L.) Benth. and *Leucaena leucocephala* (Lam.) de Wit.

There are some other agroforestry trees that serves dual purposes for example whose leaves are sometimes harvested and given to animals as feed, timber for construction, electricity and communication poles and the supply to other industrial uses for example *Gmelina arborea* Roxb. ex Sm *(Melina)* wood used for tables and doors, Tectona *grandis* L.f. (Teak) wood for boxes and platforms for export containers, *Ecalyptus* spp. log as poles, *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. fruit as food etc., whose leaves and other

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parts drops on the bear ground directly or indirectly and form manure over time or packed and heaped inside pit dugged into the ground for them to undergo decay and later unpacked and sprayed out on farmland as manure ploughed together along with soil.

At times some of these agroforestry trees by-products serve as food and income generation to farmer at maturity, fruits or seeds which are eaten directly, planted in nursery bags and later sold to other farmers. There are evidences that this system contributes to sustainable land management practices of improving quality and health status of soil according to Hombegowda *et al.* 2022, Ferdush *et al.* 2019 and Pinho *et al.* 2012).

This system enhances soil organic carbon; improve soil nutrient availability and soil fertility due to the presence of leaf liters in the agroecosystems (Pinho *et al.* 2012; Tsufac *et al.* 2019), soil microbial dynamics, with positive influence on soil health (Dollinger and Jose, 2018) and easy movement of water and air into the soil**.**

The objective of this present study is to appraise mineral content of soil samples collected under seven plant species used as agroforestry trees namely *Gmelina arborea* Roxb.; *Treculia africana* Decne., *Tectona grandis* Linn. f., *Pentaclethera macrophylla* Benth., *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill., *Mangifera indica* Linn., *Annona muricata* Linn. and Fallow farm land as control in University of Port Harcourt, Choba, Rivers State, Nigeria.

MATERIALS AND METHODS

Study site

The study was carried out at University of Port Harcourt, Choba in Obio/Akpor Local Government Area Council, Rivers State-Nigeria. Coordinates: latitude 4°8729'N and 4°55'N Longitudes 7°0011 in the Niger Delta wetland of Southern Nigeria. Climatic weather condition categorized by a tropical monsoon climate, mean annual temperature of 25 to 28°C and annual rainfall of over 3000 mm. Humidity is very high with an annual mean of 85% while the soil is sandy or sandy loam.

Soil samples collection

Soil samples were collected at random under individual agroforestry trees across the various arable farm lands at the depth of 0-15cm. Soil samples collected were air dried in the laboratory from which composite samples were taken for laboratory analysis. Eight soil samples sent out for analysis were as follows: fallow farm land as control; *G. arborea*, *T. africana*, *T. grandis*, *P. macrophylla*, *I. gabonensis*, *M. indica* and *A. muricata*.

Soil analysis

Composite soil samples prepared into coarse and fine soil which were sent to ANALAB Laboratory Services Limited in Ibadan, Oyo State Nigeria for complete physical and chemical analysis employing standard methods for soil analysis. Soils pH 1:1 soil-water ratio method, measured with EQUIP-TRONICS digital pH meter model EQ-610. Nitrogen estimated by titration of distillation after Kjeldahl, Phosphorus in the soil was measured with the perchloric corrosive albimilation strategy technique. Available Potassium was analyzed by using molybdenum blue colorimetry. Soil organic matter was measured with the potassium dichromate oxidation external heating method. Soil particle size was carried out using hydrometer method and measured with a standard hydrometer, ASTM No.1. 152H-type with Bouyoucos scale in g L-1. Exchangeable cations were extracted from the soil using an extracting solution (1 N NH4OAc) at pH 7.0, and analyzed with AA (Atomic absorption) for the soil cations. Contents in 1/20 dilution (sample/distilled water) soil digests were measured by reading their absorbance on a UNICAM 969 Atomic Absorption Spectrophotometer at 766.5, 422.7 and 285.2 nm respectively. Sodium content in 1/20 diluted sample determined by reading the absorbance at 248.3 nm. The exchangeable acidity (H++ Al3+) in the soil was extracted with 1M KCl. Solution of the extract was titrated with 0.05M NaOH to a permanent pink end point using phenolphthalein as indicator. Amount of base (NaOH) used is equivalent to the total amount of exchangeable acidity (H++Al3+) in the aliquot taken. The total sum of exchangeable bases (Ca2+ + Mg2++ K+ +Na+) and total exchangeable acidity (H+ + Al3+) gave the effective cation exchangeable capacity (ECEC).

RESULTS

Table 1, revealed various values obtained from the soil parameters evaluated on the soil samples collected from the seven agroforestry trees planted and fallow farm land serving as control, means to improve soil texture, structure and soil nutrients through dropping of leaves, twigs and fruits which decay and accumulate overtime; which provide continuous flow of nutrients into the soil and in turn used by plants, other soil organisms within the agroecosystems. Table 1, also revealed individual proportion of these elements and compared across different soil sources of agroforestry trees under investigation.

Table 1: Results of soil parameters evaluated from different soilsources

	Fl	Ma	Ta	Tg	Pm	Ig	Mi	Am
pH(1:1)	5.60	4.70	5.40	4.60	4.50	4.50	4.50	4.80
%N	0.10	0.10	0.14	0.13	0.21	0.13	0.08	0.12
%OC	1.70	1.60	2.40	2.30	3.40	1.30	1.40	2.20
EC (µS/cm)	151.0	91.0	146.0	88.0	141.0	99.0	89.0	133.0
P (mg/kg)	38.40	19.60	72.10	32.90	72.50	61.10	31.70	20.0
Mn (mg/Kg)	87.71	52.54	111.02	46.27	81.01	90.22	46.78	82.59
Fe (mg/Kg)	40.51	97.52	65.45	67.32	138.47	42.46	68.63	21.51
Cu (mg/Kg)	1.31	1.25	0.82	1.14	1.53	1.24	1.41	0.80
Zn (mg/Kg)	2.82	5.93	8.08	2.44	2.55	2.54	1.86	5.73
%Sand	78.0	70.0	80.0	70.0	82.0	76.0	82.0	88.0
%Silt	12.50	16.50	10.50	16.50	10.50	12.50	8.50	4.50
%Clay	9.50	13.50	9.50	13.50	7.50	11.50	9.50	7.50
Ca (cmol/Kg	0.88	0.74	3.43	0.59	1.75	0.90	0.68	2.14
Mg (cmol/Kg)	0.32	0.32	0.70	0.27	0.82	0.48	0.24	1.00
K (cmol/Kg)	0.10	0.07	0.14	0.09	0.15	0.07	0.08	0.07
Na (cmol/Kg)	0.38	0.35	0.37	0.40	0.38	0.35	0.36	0.35
Acidity (cmol/Kg)	9.40	12.55	5.15	16.90	14.65	13.70	11.35	4.05
Al (cmol/Kg)	1.50	2.00	1.60	2.80	1.60	2.35	1.60	1.10
ECEC (cmol/Kg)	12.57	16.03	11.39	21.10	19.36	17.84	14.31	8.70

Legend: Fl (*Fallow* land), Ma (*M. arborea*), Ta (*T. africana*), Tg (*T. grandis*), Pm (*P. macrophylla*), Ig (*I. gabonensis*), Mi (*M. indica*) and Am (*A. muricata*)

Soil samples pH

The pH values across the evaluated soils revealed the highest value 5.6 in fallow land and the smallest 4.5 from *P. macrophylla, I. gabonensis* and *M. indica*.

Percentage Sand, Silt and Clay

The percentage sand varied from 70 % in the soil collected from *M. arborea* and *T. grandis* to 88% in the soil collected from *A. muricata*. Silt revealed its highest value 16.5% from *M. arborea* and *T. grandis*, while smallest value of 4.5% from *A. muricata*. Clay soil highest values of 13.50% were from *M. arborea and T. grandis*, while smallest values of 7.50% were from *P. macrophylla and A. muricata.*

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Percentage Nitrogen (N) and Organic carbon (OC)

The percentage nitrogen in soil samples collected under *P. macrophylla* 0.21% was the highest while the least was from *M. indica* 0.08%. Organic carbon content of the soil samples 3.4% collected from soil under *P. macrophylla* was the highest, and the least was from *I. gabonensis* 1.30%.

Phosphorus (P) and Potassium (K)

Phosphorus highest value of 72.50 (mg/Kg) was from *P. macrophylla* and least 20(mg/Kg) from *A. muricata*. Potassium highest 0.15(cmol/Kg) was from *P. macrophylla* while the least 0.07(cmol/Kg) were from *M. arborea*, *I. gabonensis* and *A. muricata* respectively.

Electrical conductivity (EC) and Effective cation exchange capacity (ECEC)

Electrical conductivity (EC) of these soils revealed 151.0(µS) cm as the highest from fallow farmland and the least was from *T. grandis* with 88.0(µS) cm respectively. Effective cation exchange capacity (ECEC) highest and least values of 21.10 and 8.70 (cmol/Kg) were for *T. grandis* and *A. muricata* respectively.

Manganese (Mn), Iron (Fe), Cupper (Cu) and Zinc (Zn) contents

Among these metals Manganese with 112.02 mg/Kg, recorded under *T. africana* as the highest and smallest concentrations of 46.27mg/Kg and 46.78 mg/Kg were recorded under *M. indica* and *T. grandis* respectively. Iron revealed highest as 138.47mg/Kg and 21.51 mg/Kg smallest value from *P. macrophylla* and *A. muricata* respectively. Copper highest was 1.53mg/Kg and smallest 0.80 mg/Kg from *P. macrophylla* and *A. muricata*. Zinc highest and least was 8.08mg/Kg and 1.86 mg/Kg from *T. africana* and *M. indica* respectively.

Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na) and Aluminum (Al) contents

Calcium highest and smallest values of 3.43 (cmol/kg) and 0.59 (cmol/kg) *T. africana* and *T. grandis* respectively. Magnesium highest and smallest values 1.00(cmol/Kg) and 0.24(cmol/Kg) *M. indica* and *A. muricata* respectively. Sodium highest of 0.40(cmol/Kg) and smallest value 0.35(cmol/Kg) were recorded from *T. grandis, M. arborea*, *I. gabonensis* and *A. muricata* respectively and followed by 0.38(cmol/Kg) from fallow farmland and *P. macrophylla* and closely followed by *T. africana* and *M. indica* with 0.37 and 0.36 (cmol/Kg) respectively.

However, acidity value of 16.90(cmol/Kg) being the highest *T. grandis* and smallest 4.05(cmol/Kg) *A. muricata* respectively. Aluminum (Al) highest value of 2.80(cmol/Kg) in *T. grandis* and smallest 1.10(cmol/kg) from *A. muricata*.

Soil nourishes and supports the growth and development of plant to maturity and for fruit and seed bearing, and at intervals it could be harvested at tender age while growing and developing. It supplies micro and macro elements that are required in different proportions for plant growth, development and bearing of fruit and seed. The accessibility or lacks of these elements are at times noticeable on the plant performance and productivity at the end of the growing season (Ahmed *et al.* 2024, Kumar*et al.* 2021).

DISCUSSION

Soil nutrient comes through two ways either from the parent rock materials or from the decay of plants, animals, insects and other materials within the agroecosystems. However, accessibility of these elements depends on the pH of the soil because pH is considered as master variable in the soil which affects lots of chemical and biological reactions influencing solubility, readiness and useable nature for the uptake of plant as required (Penn *et al.* 2019, Barrow and Hartemink, 2023).

pH

Soil samples pH results revealed that fallow land which has been under fallow for few years has the highest pH value of 5.6 followed by *T. africana* 5.4 and *A. muricata* 4.8, while others *M. arborea*, *T. grandis*, *I. gabonensis*, *P. macrophylla* and *M. indica* followed in this order of pH values 4.7, 4.6, 4.5, 4.5 and 4.5 respectively.

It also revealed that pH values of soils are strongly and moderately acidic, hence would support almost all crops as the pH values are within 4.5 and 5.6. Under these situations the soils would accommodate a good number of crops coupled with availability of other elements in the soil, thus when acidity is below 4.5, the soil becomes increasingly difficult to produce food crops according to Harter (2007). As soil pH declines, the supply of most plant nutrients decreases while aluminum and a few micronutrients become more soluble and toxic to plants (Harter, 2007). These problems are particularly acute in humid tropical regions that have been highly weathered or degraded (Harter, 2007).

Percentage Sand, Silt and Clay

Soil is made up of mineral particles, organic materials, air, water and living things and all interact with each other. Sand, silt and clay in different percentage proportions constitute various soil types, and in effect determine plant that can flourish on them. Sand content from the soils are between 70% and 88%, while that of silt is between 4.5% and 16.5% and clay is 7.5% and 13.5%. This revealed that the soils are of sandy loam in nature. This is in agreement with earlier findings of Ekeke and Okonwu (2013) and Ogazie *et al.* (2022) from the soils of University of Port Harcourt and environs. These soil types accommodate quite a number of plants and crops during the planting season as observed by Ogazie *et al.* (2022).

% N and %OC

Nitrogen a member of the three macronutrients required by plant in large quantity to grow, develop and also enables plant to produce fruit and seed. The need of nitrogen varies from plant to plant and it is available naturally or artificially added to the soil. Its presence or absence could be seen from the physical appearance of the plant that the supply of nitrogen is limited in the soil. *P. macrophylla* has the highest yield of nitrogen 0.21% more than fallow farmland 0.1% which has rested for a number of years before clearing.

It was closely followed by *T. africana* with % 0.14, *I. gabonensis* 0.13%, *T. grandis* 0.13%, *A. muricata* 0.12%, *M. arborea* 0.10% and the smallest *M. indica* 0.08%. *P. macrophylla* is a tree legume and fixes nitrogen, thus the small numerous leaves that falls from it form thick cover on the top soil which decay to release nitrogen in the leaves to the soil. Thus, could be responsible for the high value of Nitrogen in the soil (Zhao *et al.* 2022).

EC (µS) cm, ECEC (cmol/Kg)

EC measures the salinity and electrically charged nutrient ions in a solution (Bluelab, 2015). EC values are influenced by clay and mineral content, soluble salts, soil water content, bulk density, organic matter and temperature (Corwin and Lesch, 2005). It is an important parameter which reveals the extent of soil's ability to transmit water and nutrients. The result from the tested soils samples from the agroforestry trees and fallow land control revealed that fallow farm land has a value of 151.0 EC (µS/cm) as the highest while the smallest *T. grandis* 88.0 EC (µS/cm).

Others followed in this order as *T. africana* 146.0 EC (µS/cm), *P. macrophylla* 141.0 EC (µS/cm), *A. muricata* 133.0 EC (µS/cm), *I. gabonensis* 99.0 EC (µS/cm), *M. arborea* 91.0 EC (µS/cm), *M. indica* 89.0 EC (µS/cm). The values obtained are within the permissible limits as low EC values indicate a low concentration of soluble salts and good soil fertility, while high values suggest excessive

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salt accumulation or poor drainage which can negatively affect plant growth (Shahid *et al.* 2018).

Effective cation exchange capacity (ECEC), in the soil indicates soil fertility status and its ability to supply and hold on to exchangeable cations by electrical attraction which are positively charged for example the five most abundant are calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), sodium (Na^{+}) and aluminum (Al^{+++}), and the availability of all to plant depends on the soil pH. Nutrient to the plant roots involves the exchange of cations and anions of clay minerals, inorganic compounds, and organic matter influencing soil nutrients availability (Havlin, 2013).

Result of the soil analysis revealed that *T. grandis* with 21.1 (cmol/Kg), a tree with very large and tough leaves as the highest, followed by *P. macrophylla*a tree legume with numerous tiny leaves, pods and twigs which cover the top soil and decay rapidity releasing its nutrient content to the soil has the value of 19.4(cmol/Kg), *I. gabonensis* 17.8(cmol/Kg), *M. arborea* 16.0 (cmol/Kg), *M. indica* 14.3(cmol/Kg), fallow farmland 12.6(cmol/Kg), *T. africana* 11.4 (cmol/Kg) and smallest *A. muricata* 8.7 (cmol/Kg).

Mn, Fe, Cu and Zn (mg/Kg)

Microelements are required in trace amount in the soil as they play important roles in plant for normal growth, development and optimal processes (Kumar *et al.* 2021). Micronutrients which are needed only in trace amounts are Fe, Mn, B, Zn, Cu, Mo, Cl, Na, Ni, Si, Co and Se. Nevertheless, this work evaluated Mn, Fe, Cu and Zn from the agroforestry farms soil samples (Table 1). The highest value of Mn 111.02(mg/Kg) was from *T. africana*, followed by *I. gabonensis* with 90.22(mg/Kg). Others are fallow farmland 87.71(mg/Kg), *A. muricata* 82.59(mg/Kg), *P. macrophylla* 81.01(mg/Kg), *M. arborea* 52.54(mg/Kg), *M. indica* 46.78 (mg/Kg) and *T. grandis* 46.27 (mg/Kg) respectively.

Manganese (Mn) is required for activation of enzymes processes and supports the conversion of nitrates into a readily form for plant and perform a role in chlorophyll production (Mousavi *et al.* 2011). The amount of available manganese is influenced by soil pH, organic matter, moisture, and soil aeration (Schulte and Kelling, 1999). According to *Rashed et al.* (2019) most plant species require between 10-20mg/Kg^{-1}, these results were far above this requirement, indicating remarkable contribution of the agroforestry trees and fallow farmland used as control.

Iron (Fe) present in the agroforestry trees sampled soils revealed as follows *P. macrophylla* with the highest value of 138.5(mg/Kg), *M. arborea* 97.52(mg/Kg), *M. indica* 68.63 (mg/Kg), *T. grandis* 67.32 (mg/Kg), *T. africana* 65.45(mg/Kg), *I. gabonensis* 42.46 (mg/Kg), fallow farmland 40.51 (mg/Kg) and *A. muricata* 21.51 (mg/Kg) respectively. Iron (Fe) is involved in chlorophyll manufacturing processes, works in close collaboration with soil pH and its deficiency in chlorophyll synthesis causes chlorosis (Morrissey and Guerinot, 2009, Rout and Sahoo,2015). The values obtained were within the ranges of 21.51 to 138.47(mg/Kg) and comparable with what was obtained by Mallarino (2005).

Copper (Cu) is essential for numerous enzymatic activities in plants for example chlorophyll leading to photosynthesis, respiration, antioxidant system and seed production; while deficiency of copper would lead to increased susceptibility to diseases like ergot, which can cause significant yield loss in small grains (Yruela,2005). Thus values obtained from the soil analysis revealed *P. macrophylla* 1.53 (mg/Kg), *M. indica* 1.41(mg/Kg), fallow land 1.31(mg/Kg), *M. arborea* 1.25(mg/Kg), *I. gabonensis* 1.24(mg/Kg), *T. grandis* 1.14(mg/Kg), *T. africana* 0.82 and *A. muricata* respectively.These values are far below the amount between 6-10 mg/Kg of Cu required by plant according to Hasnine *et al.*(2017) and also far below the maximum permissible level of 36(mg/Kg)(Denneman and Robberse, 1990) and (WHO, 1996).As a result could be supported where there is evident in short supply to the reach of plant.

Zinc (Zn) is a driving force relative to enzymatic activities in plant leading to cell growth, differentiation and metabolism, while its deficiency reduces carbohydrate, protein and chlorophyll formation significantly (Saleem *et al.* 2022). The result from the soils analysis revealed that *T. africana* has the highest value of Zn 8.08(mg/Kg), followed by *M. arborea* 5.93(mg/Kg), *A. muricata* 5.73(mg/Kg), fallow farmland 2.82 (mg/Kg), *P. macrophylla* 2.55(mg/Kg), *I. gabonensis* 2.54(mg/Kg), *T grandis* 2.44(mg/Kg) and *M. indica* (mg/Kg) respectively.

These values when compared with the maximum value of 50(mg/Kg) from unpolluted soil as documented by Denneman and Robberse (1990), Netherlands ministry of Housing (1994) and WHO (1996) uncovered that values from the soils were very low and would not interfere with plant development processes while too little would lead to malnutrition and stunted growth (Sharma, 2013).

Ca, Mg, K, Na and Al contents

T. africana with 3.43 Ca (cmol/Kg) highest value amid the soil sources followed by *A. muricata* 2.14Ca (cmol/Kg), and *P. macrophylla* with 1.75 Ca (cmol/Kg). These three plants have the capacity to provide Calcium to the soil more than the other agroforestry plants and fallow farmland. These agroforestry tree roots have the capacity to dig deep down the subsoil for more nutrients (Sileshi, 2014, Vanlauwe *et al.* 2005) and also their leaves and twigs would have also contributed to the increase in values obtained. Others were *I. gabonensis*, fallow land, *M. arborea*, *M. indica* and *T. grandis* with 0.90, 0.88, 0.74, 0.68 and 0.59(cmol/Kg) respectively. The rest of agroforestry plants also contributed to Calcium based on their ability and in addition to other elements within the soil in the agroecosystems (Sileshi, 2014).

A. muricata a shrubby tree plant gave the highest value of Magnesium 1.00 Mg (cmol/Kg), closely followed by *P. macrophylla* 0.82 (cmol/Kg), a leguminous tree and followed by *T. africana* 0.70 (cmol/Kg) a tree which can form dense canopy of leaves with deep green coloration. Other trees were not too different from fallow farmland value of 0.32 Mg (cmol/Kg) which has rested for few years when compared with *M. arborea* 0.32 Mg (cmol/Kg), *T. grandis* 0.27 Mg (cmol.), *I. gabonensis* 0.48 Mg (cmol/Kg) and *M. indica* 0.24 Mg (cmol/Kg) respectively. Arable farmland not continuously cultivated yearly provides litters in the course of the resting period which ameliorate back the soil nutrients lost in the previous cropping season.

These minerals are essential and play very important roles in soil fertility sustainability because their presence in the soil foster plant growth, development and yield production, for example Magnesium (Mg) is chlorophyll initiator, transportation and utilization of photoassimulates, enzyme activation and protein synthesis (Ishfaq *et al.* 2022).

Potassium from the agroforestry trees and fallow farmland soils evaluated revealed that *P. macrophylla* has the highest value of 0.15 K (cmol/Kg), *T. africana* with 0.14 K (cmol/Kg), while fallow farmland gave 0.10 K (cmol/Kg), *T. grandis*, *M. indica*, *M. arborea* and *A. muricata* with 0.09, 0.08, 0.07 and 0.07 K (cmol/Kg) respectively.

The result from the analysis revealed further the nutritive contributions of the individual agroforestry trees of which *P. macrophylla* a tree legume whose leaves decay within a short time and release its mineral content to the soil contributed the highest value of potassium, however, *T. africana* followed closely, a tree with so much leaves and forms lots of leaf litters above ground with conducive and right conditions, other elements in the right proportion with right pH value will decay to release its nutrients to the soil (Couˆteaux *et al.* 1995).

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The outcome from the soil samples evaluation revealed that fallow farmland was 0.02 less than the highest value of 0.40 Na (cmol/Kg) from *T. arborea*. The other values also followed similar pattern in terms of Na values from *P. macrophylla* 0.38 Na (cmol/Kg), *T. africana* 0.37 Na (cmol/Kg), *M. indica* 0.36 Na (cmol/Kg), *M. arborea* and *A. muricata* 0.35 Na (cmol/Kg) respectively. Sodium is non-essential for most plants, sodium (Na+) can be beneficial to plants in many conditions, particularly when potassium (K+) is deficient (Frans, 2014). As such it can be regarded as a 'non-essential' or 'functional' nutrient to plant.

Al is one of those common metals found in the environment, which occurs natural and through anthropogenic activities. It is a metal that readily combines with the environment, with water at different pH levels especially at extremely strong acidic condition which makes it available for plant uptake. The acidity of the soluble water forms could make its presence to increase and these are evident in some plants like tea and coffee beans (Crisponi *et al*. 2013).

The values of aluminum obtained from the evaluation are quite small which could have gotten into the environment through anthropogenic activities and parents' soil. The fallow farmland revealed traces of aluminum at the value of 1.5(cmol/Kg). Yet, *T. grandis* has a value of 2.80 Al (cmol/Kg) as the highest followed by *I. gabonensis* 2.35 Al (cmol/Kg), *M. arborea* 2.0 Al (cmol/Kg), *P. macrophylla* 1.6 Al (cmol/Kg), *T. africana* 1.6 Al (cmol/Kg), *M. indica* 1.6 Al (cmol/Kg) and the smallest *A. muricata* 1.10 Al (cmol/Kg).

According to Ofoe *et al.* (2023), the presence of aluminum in the soil stimulate growth and mitigating biotic and abiotic pressures depending on the concentration, exposure time, plant species, developmental age and growing circumstances and sometimes it promotes root growth and development as found in some tea varieties (Sun *et al.* 2020) due the presence of Al^{3+} which in its absence does not encourage root growth and development. On the other hand, in a situation of reduced pH value below 4.5, its presence in the soil becomes poisonous to the plant preventing cell extension, cell division and transport (Mossor-Pietraszewska, 2001).

CONCLUSION

Effort to reduce impact on environment through clearing less of virgin forest, which led to soil degradation, because of cultivation and planting of crop to feed man. Long time use of arable farm land contributes to decline in yield of crop due to over use, poor soil health status and climate change. Hence older methods of crop rotation, shifting cultivation, application of farmyard manure etc., for sustaining soil fertility were improved upon with the addition and adoption of agroforestry trees and crop planting for continuous supply of nutrients to soil for plant uptake for greater crop harvest and thus reduce impact on the agroecosystems. This study was carried out on selected agroforestry trees to access their potentials to contribute macro and micro nutrients to the soil and make it available for plant use. The result revealed the level of macro and micro nutrients present in those soil samples evaluated which indicated the extent of minerals contributed by individual agroforestry tree to the soil for optimally plant growth and development. The outcome encourages agroforestry tree planting along with crop as it reduces use of inorganic fertilizer, pollution and safeguard the environment.

Conflict of Interest

The authors declare no conflict of interest.

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PALYNOLOGICAL AND PALEOENVIRONMENTAL ANALYSES OF THE MIOCENE SEDIMENTS OF GAP-1 WELL IN THE ONSHORE NIGER DELTA BASIN.

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ABSTRACT

A comprehensive palynological investigation has been carried out for Gap-1 well penetrating the Agbada Formation in the Niger Delta Basin. The identification of shaly-sandstone, shale, mudstone, and clayey-sandstone lithofacies units and the delineation of four (4) informal palynological biozones (GI, GII, GIII, and GIV), correlating with the P670, P680, and P720Niger Delta pollen zonations, suggested the Early to Middle Miocene age for the investigated Gap-1 well in the Agbada Formation. The interpretation for the common to the relatively abundant occurrence of land-derived palynomorphs such as Verrucatosporites sp., Laevigatosporites sp, Zonocostites ramonae, Sapotaceae, as well as the occurrence of dinoflagellate cysts, Pediastrum sp, amongst others, as a fluvial-dominated delta to shallow marine environment within a humid climate is confirmed.

INTRODUCTION

The Niger Delta, a prolific hydrocarbon region in West Africa, has been the subject of extensive geological research due to its complex sedimentary architecture and economic significance (Nton & Ogungbemi, 2011; Alege et al., 2020a; Alege, 2022; Odinaka et al., 2024). Palynostratigraphy has emerged as a vital tool in studying the stratigraphy and paleoenvironmental conditions of different world basins by offering insights into the age, depositional environments, and potential hydrocarbon reservoirs in sedimentary sequences. Numerous studies have investigated the palynostratigraphy and paleoenvironmental evolution of the Niger Delta, with works such as that of Evamy et al. (1978) and Jan du Chêne et al. (1978), laying the foundation for understanding the biostratigraphy and stratigraphic frameworks in the delta. These foundational studies established zonal schemes based on palynomorph assemblages, aiding in correlating sedimentary layers across the delta. Similarly, other researchers, such as Alege et al. (2020b) and Alege et al. (2023a), also conducted palynological analyses of the Campanian-MaastrichtianMamu Formation of the Anambra basin to identify its paleoenvironment during the Late Cretaceous period. Aigbadon et al. (2023) employed the palynological, petrological and geochemical attributes of sediments of the Southern Bida Basin to interpret its provenance and paleoenvironment of deposition.

Subsequent research expanded on these early works, with notable contributions by Petters (1995), who examined the paleoenvironmental changes in the Niger Delta using micropaleontological data, and Oloto (1989), who emphasized the role of palynology in dating sedimentary sequences and reconstructing past environments. Furthermore, Osokpor and Oboh-Ikuenobe (2008) provided detailed palynofloral analyses, contributing to understanding the delta's stratigraphic history. However, despite these advancements, gaps remain in the detailed palynostratigraphic zonation and paleoenvironmental interpretation of specific wells, particularly in underexplored onshore areas.

The GAP-1 well, located in the onshore Niger Delta, presented an opportunity to address these research gaps. Previous works have focused mainly on offshore or regional stratigraphic interpretations, leaving the palynostratigraphy of specific onshore wells, such as GAP-1, less understood. Detailed palynostratigraphic and paleoenvironmental analyses of sediments from the GAP-1 well could enhance the biostratigraphic resolution for this region and provide a more refined understanding of the depositional environments that characterised the onshore Niger Delta during different geological periods.

This study aimed at filling the gap by conducting a palynostratigraphic and paleoenvironmental analyses of sediments from the GAP-1 well with the objectives of analysing palynomorph assemblages and identifying age-diagnostic taxa. This research refined the biostratigraphic framework and reconstructed the paleoenvironmental conditions of deposition of these sediments. The findings contributed to a better understanding of the onshore Niger Delta's stratigraphic architecture and its implications for hydrocarbon exploration and environmental changes over geological time.

General Geology of the Area

The Niger Delta Basinis located on the continental margin of West Africa. It covers an area of approximately 75,000 square kilometres, extending from the Gulf of Guinea to onshore Nigeria (Weber & Daukoru, 1975). The delta developed during the Late Cretaceous to Tertiary periods as a result of the interplay between the tectonic activity associated with the opening of the South Atlantic Ocean and the enormous sediment supply from the Niger River system (Burke, 1972).

The geology of the basin is characterised by a thick sedimentary sequence exceeding 12,000 meters in some areas, consisting of three primary lithostratigraphic units: the Akata Formation, the Agbada Formation, and the Benin Formation (Short &Stauble, 1967). These units reflect a progressive transition from deep marine to coastal and fluvial environments (Figure 1)

The Akata Formation is the deepest unit, consisting of marine shales, silts, and clays. It was formed in deep marine environments and is the primary source of hydrocarbons in the Niger Delta. It ranges in age from Paleocene to Recent. Above the Akata Formation is the Agbada Formation, consisting of alternating sandstones and shales, representing deltaic environments. This formation contains the primary hydrocarbon reservoirs, with sandstone beds serving as reservoir rocks and shale units acting as seals (Stacher, 1995). The Agbada Formation developed during the Eocene to Recent. The Benin Formation is the shallowest and youngest, consisting of continental sands and gravels deposited in a fluvial environment. It is Miocene to Recent in age and is mainly non-hydrocarbon-bearing but is important for groundwater aquifers (Doust&Omatsola, 1990; Reijers, 2011).

The Niger Delta Basin is influenced tectonically by growth faulting and rollover anticlines, which are very significant as hydrocarbon traps (Doust & Omatsola, 1990; Alege, 2017b; Rotimi et al., 2022; Odinaka et al., 2024). The tectonic and sedimentary evolution of the delta, combined with the vast organic-rich sediments deposited in its deep marine environments, have made the basin one of the most prolific petroleum provinces in the world.

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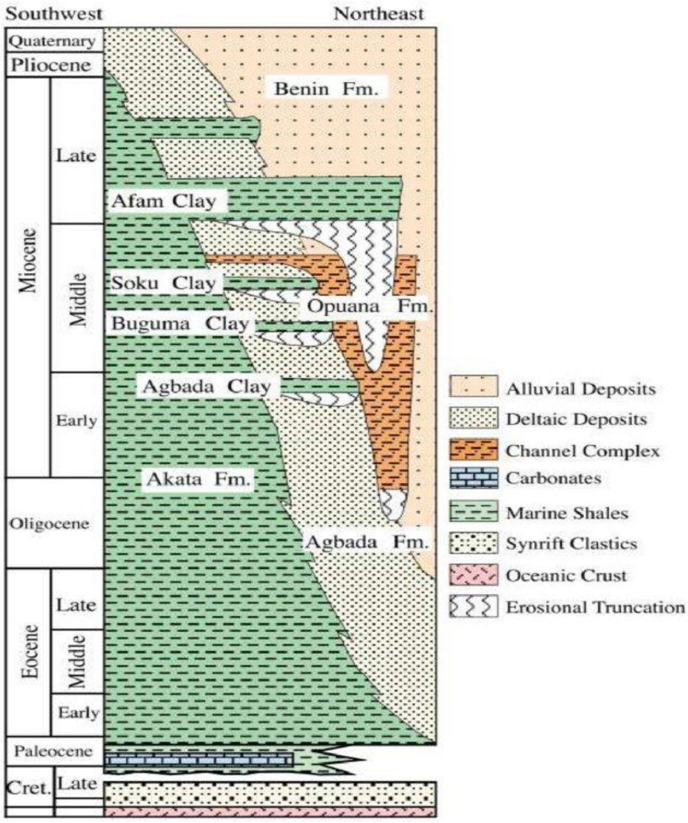

Figure 1. The stratigraphic column shows the three lithostratigraphic formations of the Niger Delta (Lawrence et al., 2002).

MATERIALS AND METHODS

Ninety (90) ditch-cutting samples of the GAP-1 well ranging from 3520 to 6190ft and composited at 30ft were processed and analysed for their palynomorphs contents.

Careful physical examination identified the dominant and minor lithologies, textures, colours, and other accessory mineral components, enabling a detailed lithologic description of the samples (Alege et al., 2015; Idakwo et al., 2013; Alege, 2022; Aigbadon et al., 2023).

A palynological processing method for the maceration of samples modified from Traverse (2007) was applied. This involved crushing samples into fragments, weighing 25 g of each of the samples and alternate usage of inorganic reagents such as dilute Hydrochloric acid (Hcl), concentrated Hydrofluoric acid (HF) and Nitric acid (HNO_3) to macerate the sediments. These reagents removed carbonate and silicate minerals and helped concentrate the palynomorphs. The acidic reaction was neutralised using potassium hydroxide (KOH) and distilled water. Subsequently, the palynomorph-rich residue was mounted on labelled glass slides using a Norland mounting medium for microscopic analysis. Photomicrographs of the palynomorphs were taken using a camera, and the Strataburg 2.0 software was used in the statistical analysis plot. The results were used to decipher the age and possible paleoenvironment of deposition of the well succession.

RESULTS AND DISCUSSION

Lithofacies

The lithofacies units of Gap-1 have been identified in the ditch-cutting samples by examining the physical and textural characteristics of the sediments (Billman, 1992; Alege, 2017b; Adamu et al., 2018a; Alege et al., 2020a; Oretade and Ali, 2021; Alege et al., 2024; Aigbadon et al., 2024). Four lithofacies units were identified in the study:

the shaly sandstone, shale, mudstone, and clayey sandstone units.

Shaly-sandstone facies

These facies represented about 60% of the constituent of the entire Gap-1 well. The facies comprise 85-90% sandstone and 10% shale constituent. The sandstones are mainly fine to medium-grained and sometimes coarse-grained, yellow to brown, and moderately sorted. The minor shale constituents were grey and less fissile. Thesefacies units were well represented at the following depths: 3520-3550 ft, 3760-3880 ft, 4030- 4150 ft, 4600-4630 ft, 5230- 5440 ft and 5860- 6190ft.

Shale facies

The Shale facies represent about 15% of the entire well-depth interval. They are dark grey, soft to moderately hard, and non-fissile. They occurred at depth intervals of 3910-4000ft, 4180-4330ft, 4480- 4950ft, and 4720- 4750ft.

Mudstone facies

The mudstone facies is represented in Gap-1 well by a mixture of shale (30%), clay (40%), and fine to medium-grained sandstone (30%) constituents at depth intervals of 3550 - 3760ft, 4330 - 4390ft, 4720 - 4750ft, 4950 - 5050ft, 5140 - 5230ft, and 5740- 5860ft. The colours range from brown to grey. This facies represents about 20% of the entire well.

Clayey-sandstone facies

The clayey sandstone facies consist of about 10 - 15% constituent of clay to 85 - 90% sandstone occurring at depth intervals of 5050 - 5140ft and 5440 - 5680ft. The sandstones are brownish, fine to medium-grained and well-sorted.

These facies suggest the fluvial-dominated deltaic facies to shallow marine facies of the transitional paralic sequence of the Agbada formation and are interpreted to be from the fluvial-dominated delta to shallow marine environment (Chukwu, 1991; Reijers, 2011; Nton&Ogungbemi, 2011; Alege, 2017a; Alege et al., 2020a; Alege, 2022).

Palynomorph distribution

Palynomorph analysis was carried out on ninety (90) ditch-cutting samples of the GAP-1 well, ranging from 3520 to 6190 feet. A total of sixty-eight (68) palynomorphs species consisting of forty-seven (47) species of pollens, twelve (12) species of spores, six (6) dinoflagellate spores, diatom frustules, fungal spores and *Pediastrum* were recovered from the well with the percentage proportions of 69.1% (pollens), 17.6% (spores), 8.82% (dinoflagellate cysts), 2.0% (diatom frustules), 2.0% (fungal spores) and 2.0% (freshwater algae, *Pediastrum* sp.) respectively.

The studied interval (3520 to 6190 ft) was characterized by poor to moderately abundant and diverse palynomorphs, which were dominated by terrestrial species such as *Laevigatosporites* sp., *Zonocostites ramonae, Acrostichum aureum, Psilatricolporit escrassus, Retitricolporites irregularis, Verrucatosporites sp., Sapotaceae* and *Striatricolporites catatumbus*. Low to common records of fungal spores and freshwater algae *Botryococcus braunii* also characterised the studied section. Sparse occurrence of dinoflagellate cysts such as *Lingulodinium machaerophorum, Spiniferites sp.* and *Operculodiniumc entrocarpum* were also identified (Figure 2).

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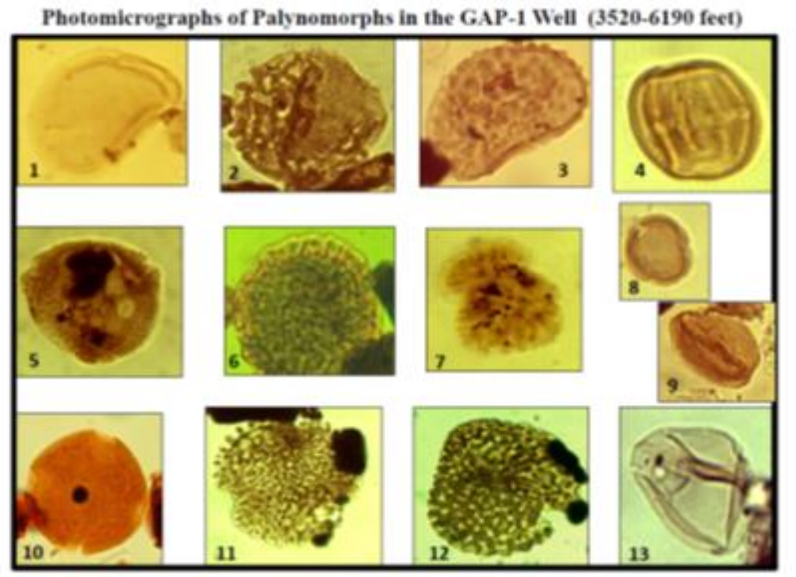

Figure 2: Photomicrographs of some palynomorph species from GAP-1 well.

(1).*Laevigatosporites* sp. (3520 ft) (2). *Peregrinipollisnigericus* (4480 ft) (3). *Verrucatosporites* sp. (4060 ft) (4). *Sapotaceae* (4450 ft) (5). *Retibrevitricolporitesobodoensis* (5020 ft) (6). *Spirosyncolpitesbrauni* (6070 ft) (7) *Botryococcusbraunii* (4510 ft) (8). *Zonocostitesramonae* (4030 ft) (9). *Striatricolporitescatatumbus* (4000 ft) (10). *Pachydermitesdiederixi* (6160 ft) (11). *Retitricolporitesirregularis* (3820 ft) (12). *Crassoretitriletesvanraadshoveni (*4030 ft) (13). *Monoporitesannulatus* (5350 ft) **(mag. X400)**

Palynostratigraphy

Stratigraphic significant species (marker species) and diagnostic palynoflora associations were identified and used to define the ages of the sedimentary successions penetrated by GAP-1. Figure 3 presents the stratigraphic chart of the palynomorphs.

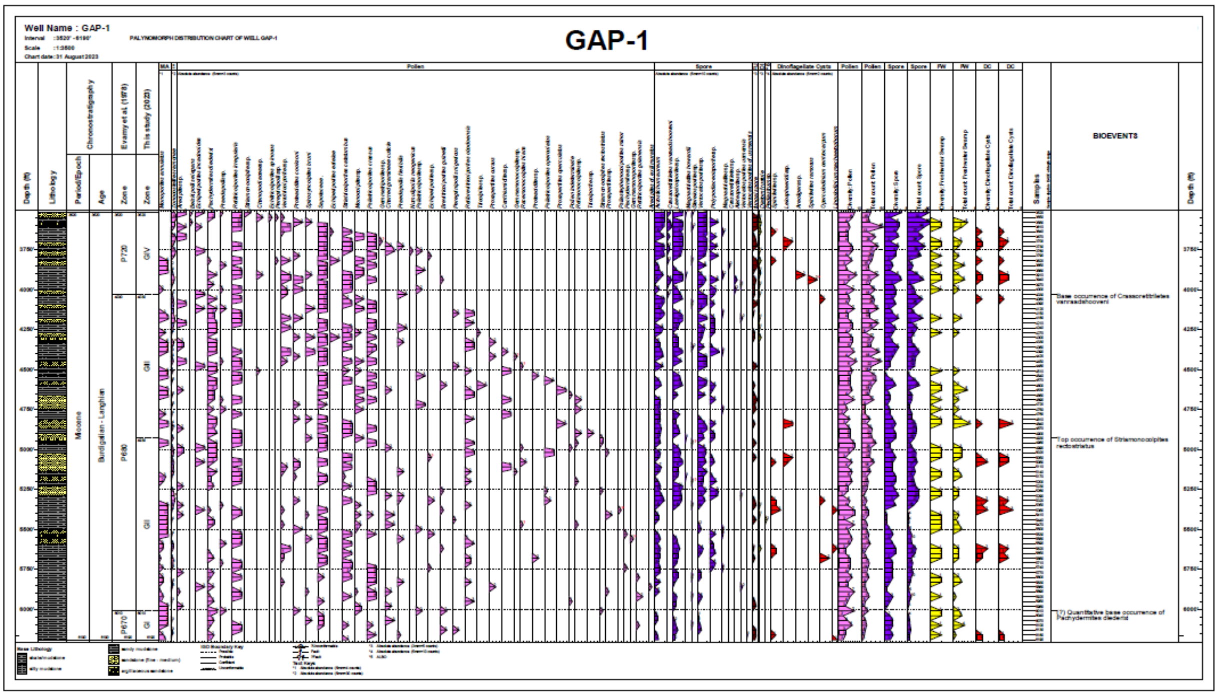

Figure 3. Stratigraphic distribution of palynomorphs in GAP-1 well

Palynostratigraphic zonation

Four (4) informal biozones, namely GI, GII, GIII, and GIV, were established based on the association of recovered marker species and palynomorphs (Figure 3). These zones correlate with the P670, P680, and P720 subzones of Evamy*etal*. (1978). Thus, the Early to Middle Miocene age is interpreted for the studied interval. Detailed results of the palynological zone are presented in Figure.

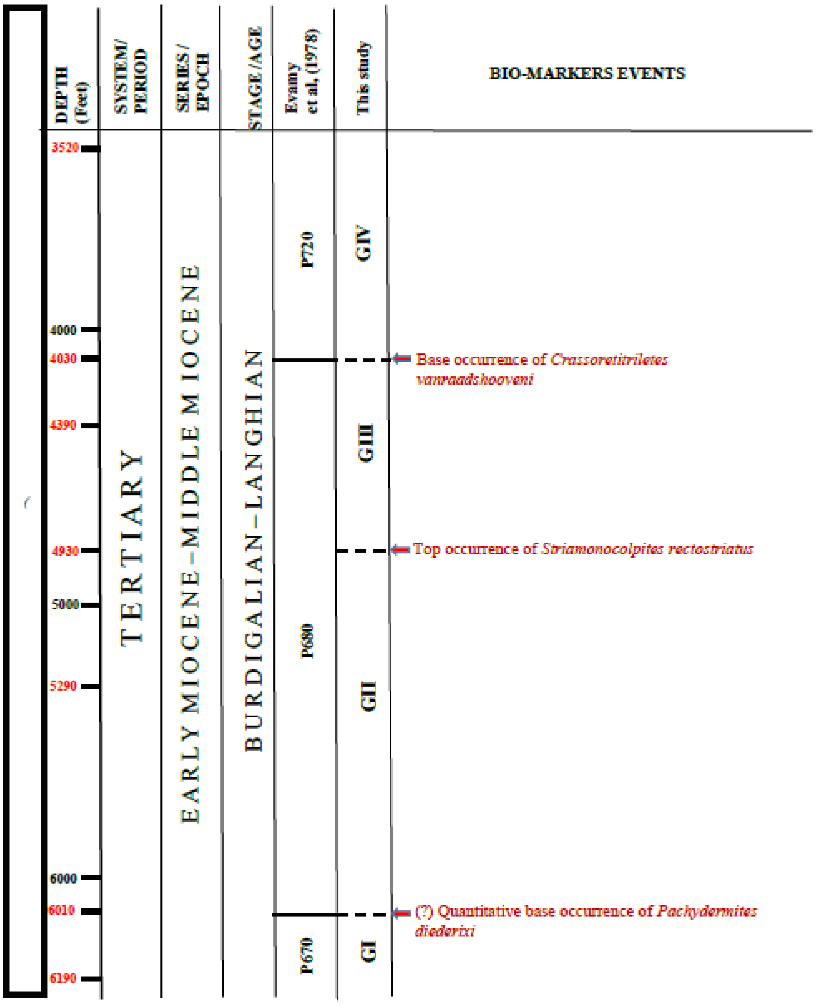

Figure 4. Summary of the palynological zones identified in the GAP-1 Well (3520-6190 feet)

Zone GIV

Depth: 3520 - 4030 feet

Age: Middle Miocene (Langhian)

The top of this zone coincides with the first sample analysed and, as such, is stratigraphically higher than the first sample at 3520 feet. The base is defined by the base occurrence of *Crassoretitriletes vanraadshoveni* at 4030 feet. This interval is further characterised by the common occurrence of *Proteacidites cooksonii*, *Magnastriatite showardi*, *Pachydermit esdiederixi*, the rare presence of *Belskipolliselegans* and abundant *Zonocostites ramonae* (Figure 4).

In addition, rare occurrences of dinoflagellate cysts such as *Spiniferites*sp. and *Operculodinium centrocarpum* were identified. This interval correlates with the P720 subzones of Evamy *et al*. (1978).

Zone GIII

Depth: 4030 – 4930 feet

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Age Middle Miocene (Langhian) – Early Miocene (Burdigalian)

The top occurrence of Striamonocolpites defines the base of this zone *rectostriatus* at 4930 feet. The top is defined by the base occurrence of *Crassoretitriletes vanraadshoveni* at 4030 feet. Additional palynoflora events characterising this interval include *Retibrevitricolporites obodoensis, Pachydermites diederixi, Retitricolporites irregularis* and *Sapotaceae*. A few fungal spores and diatom frustules were also identified (Figure 4&5). This interval correlates with the P680 subzone of Evamy et al. (1978).

Zone GII

Depth: 4930 - 6010 feet

Age: Early Miocene (Burdigalian) – Middle Miocene (Langhian)

The base of this zone is defined by the (?) quantitative base occurrence of *Pachydermites diederixi*at 6010 feet. In comparison, the top is defined by the top occurrence of *Striamonocolpites rectostriatus* at 4930 feet. The common occurrence of *Zonocostites ramonae*, *Pachydermites diederixi*, and *Acrostichum aureum* with low records of *Retibrevitricolporites obodoensis* also characterised this interval (Figures 4 and 5). Sparse *Lingulodinium machaerophorum, Leoisphaeridia* sp. And *Operculodinium centrocarpum* were also identified. This zone relates to the P680subzone of Evamy *et al*. (1978).

Zone GI

Depth: 6010 - 6019 feet

Age: Early Miocene (Burdigalian)

The base of this zone coincides with the last sample analysed, while the top is defined by the (?) quantitative base occurrence of *Pachydermites diederixi* at 6010 ft (Figures 4 and 5). Additional palynoflora events include common *Monoporites annulatus, Acrostichum aureum Verrucatosporites* sp., *Sapotaceae* and *Striatricolporites catatumbus*. This zone correlates with the P670 subzone of Evamy et al. (1978).

Paleoenvironment

The paleoenvironmental analysis was based on the different species of palynomorphs within the study (Figures 3 and 4). The relative abundance of land-derived palynomorphs such as *Verrucatosporites*sp., *Laevigatosporites*sp., *Acrostichumaureum, Zonocostitesramonae, Sapotaceae*, *Striatricolporites catatumbus* and *Pachydermites diederixi* amongst others, were interpreted to be predominantly fluvio-deltaic to brackish swamp water environment of deposition within a humid climate (Reijers et al., 1997; Idakwo et al., 2013; Ogbahon, 2019; Aigbadon et al., 2022; Alege et al., 2023).

The presence of dinoflagellate cysts: *Operculodinium centrocarpum* (4060ft, 5290ft and 5710ft) and *Spiniferites sp*. (3640ft, 3700ft) with moderate records of pollen, spores and *Botryococ cusbraunii* indicate a shallow marine environment with frequent freshwater incursions (Wrenn & Kokinos, 1986; Bolaji et al., 2020). Similarly, the lone occurrence of *Pediastrum*sp (5440ft) and freshwater algae suggests a progradational marginal marine environment (Tahoun et al., 2017; Aigbadon et al., 2023). Diatom frustules in the study also indicate a shallow marine deposition environment (Henchiri, 2007).

Thus, the occurrences of terrestrial palynomorphs and freshwater algae, along with dinoflagellate cysts and diatom frustules, give credence to a fluvial-dominated deltaic environment to a shallow marine environment of deposition within a wet to humid climate (Garzon et al., 2012; Adamu et al., 2018b; Ogbahon, 2019; Alege et al., 2020a).

CONCLUSION

The investigation of palynomorphs recovered from ninety (90) ditch cuttings obtained from Gap-1 well has aided in interpreting the palynostratigraphy and paleoenvironment in the onshore Niger Delta basin. Four lithofacies units were identified in the study: the shaly sandstone, shale, mudstone, and clayey sandstone units. These facies suggested the fluvial-dominated deltaic facies to shallow marine facies of the transitional paralic sequence of the Agbada formation. They were interpreted to be from the fluvial-dominated delta to shallow marine environment.

Four (4) informal biozones, namely GI, GII, GIII, and GIV, were established based on the association of recovered marker species and palynomorphs. These zones correlated with the P670, P680, and P720 subzones of Evamy*etal*. (1978). Thus, the Early to Middle Miocene age are interpreted for the studied interval. The paleoenvironmental analysis was based on the different species of palynomorphs within the study. The common occurrence of land-derived palynomorphs such as *Verrucatosporites* sp., *Laevigatosporites* sp, *Zonocostites ramonae, Sapotaceae, Striatricolporites catatumbus* and *Pachydermites diederixi* amongst others, are interpreted to be predominantly fluvial-deltaic to brackish swamp water environment of deposition within a humid climate.

Thus, the occurrences of terrestrial palynomorphs and freshwater algae (*Pediastrum* sp,) along with dinoflagellate cysts (*Operculodinium centrocarpum, Spiniferites* sp.*)* and diatom frustules, give credence to a fluvial-dominated deltaic environment to a shallow marine environment of deposition in a humid climate in the Agbada Formation of the Niger Delta.

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