Evaluation of Fractured Shale Formations as Aquifers: A Case Study of the Albian–Cenomanian Asu River Group, Southern Benue Trough, Nigeria.

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ABSTRACT

Groundwater is stored within subsurface pores and fractures. Weathering and diagenesis play critical roles in either increasing or reducing rock porosity. In this context, argillaceous rocks (typically regarded as impermeable) can develop fracture porosity, which enhances permeability and allows substantial water storage through interconnected matrix pathways. Alex Ekwueme University Ndufu-Alike and Gregory University Uturu are expanding institutions facing challenges in securing adequate groundwater for domestic and other uses. The study began with preliminary geophysical investigations using electrical resistivity methods across various locations within both campuses. Based on the findings, five drilling points were recommended: three at Ndufu-Alike and two at Uturu. Drilling results indicated that boreholes equipped with small motorized pumps were feasible at Ndufu-Alike, whereas higher-capacity pumps could be utilized at Gregory University if boreholes were sited at Marist Brothers Uturu, approximately one kilometer east of the campus. Very low resistivity values obtained from the survey confirmed that the lithology is predominantly shale with moderate to high plasticity. Pumping tests were conducted following the Cooper–Jacob (1946) method. Transmissivity (T) at Ndufu-Alike ranged from 18.23 m^2/day to 37.44 m^2/day, while at Uturu it ranged from 22.85 m^2/day to 23.04 m^2/day. Storativity (S) values ranged between 0.22 and 0.32, indicating an intermediate class associated with confined aquifers. The researchers observed that at Uturu, sandy shales occur within the borehole depth range, resulting in uniform transmissivity. At Ndufu-Alike, however, fractured shales appear sandwiched between two impermeable layers, creating a confined condition. The pumping tests were closely monitored to establish sustainable pumping rates. The study demonstrates that fractured shale aquifers hold promise for domestic water supply and that shales can be considered viable groundwater sources when developed following careful, site-specific geophysical investigations.

Keywords: Groundwater, fractured shale, aquifer, weathering, Asu River Group

INTRODUCTION

Water is essential for life, ranking second only to air. In many areas, surface water is scarce, prompting communities to rely on groundwater. Groundwater occurs beneath the Earth's surface, often at depths not easily accessible to the general population. It has become increasingly important for meeting water supply needs in both urban and rural settings across developed and developing nations, leading to intensified exploration and extraction using a variety of methods and technologies.

The study area is underlain by shales of the Asu River Group. These shales are generally hard and brittle; however, successful groundwater exploitation in the area is attributed to deep fracturing and faulting characteristic of the Asu River Group. When fractured, shales develop secondary porosity, and their permeability is enhanced sufficiently to host economically viable quantities of groundwater.

This study focuses on the potential of fractured shales to act as aquifers within the Asu River Group, using well data from Alex Ekwueme University Ndufu-Alike in Ebonyi State and Gregory University Uturu in Abia

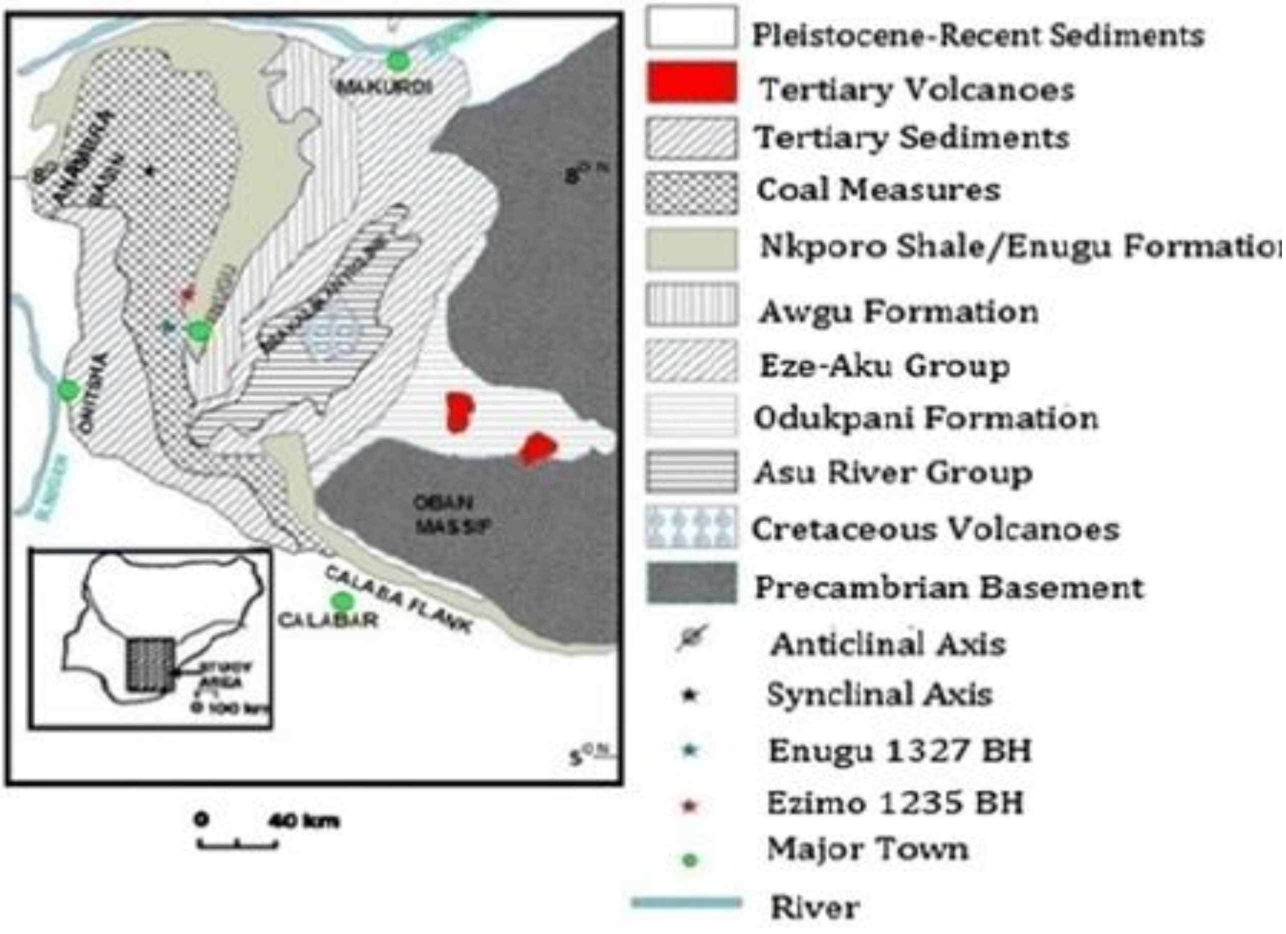
State. Following detailed geological and geophysical investigations, groundwater was exploited through borehole drilling. Three boreholes were drilled at different locations within each university using rotary and percussion methods. Pumping tests were subsequently performed to determine hydraulic conductivity, storativity, borehole yield, and transmissivity.

Study Location and Regional Geology

The study area lies within the Albian Asu River Group sedimentary formations in the Lower Benue Trough, around Abakaliki and extending eastward to Uturu in Abia State. Researchers generally agree that the origin of the Benue Trough is closely linked to the breakup of Gondwana during the separation of the African and South American plates and the opening of the South Atlantic (Wight, 1968, 1976; Burke et al., 1971). Consequently, the region exhibits structural features that favor fluid movement, including groundwater flow.

The Cretaceous southern Benue Trough, which underlies much of southeastern Nigeria, contains a stratigraphic record represented by sediments from the Albian–Cenomanian, Turonian–Santonian, and Campanian–Maastrichtian cycles (Reyment, 1965; Ofoegbu, 1985; Ofoegbu and Amajor, 1987). The Asu River Group consists predominantly of shales, with localized occurrences of sandstone, siltstone, and limestone facies (Ofoegbu and Amajor, 1987). The group rests unconformably on the Precambrian basement (Benkhelil et al., 1989). The presence of igneous intrusive rocks within the Asu River Group has been reported by several authors (Reyment, 1965; Murat, 1972; Nwachukwu, 1972; Tijani et al., 1989).

The Abakaliki shale has an average thickness of approximately 500 m. It is predominantly dark gray, blocky, and non-micaceous in most locations. The formation is calcareous and deeply weathered to brownish clay over much of its extent (Okogbue and Aghamelu, 2010a). Intense folding, faulting, and fracturing in this shale resulted from a series of tectonic events (Ezeh and Anike, 2009). These structural features enable the shale to host economically viable groundwater in some areas, while in other locations where fracturing is less developed, the shale continues to act as an aquiclude.



1. Location map of the study area showing main rock formations.

MATERIALS AND METHODS

Groundwater occurrence is not uniform across regions (Idu, 2015) and varies considerably on a global scale. Groundwater exploration generally relies on surface or subsurface techniques. In this study, both surface geological investigation—specifically the Electrical Resistivity Method (ERM)—and subsurface geophysical exploration were employed. Geophysical surveys detect variations in physical properties within the Earth's crust, including density, radioactivity, magnetism, elasticity, and electrical resistivity. The Electrical Resistivity Method, which involves surface measurements to characterize subsurface resistivity distribution, was the primary technique used (Asry et al., 2012).

This method is used to image subsurface resistivity structures, which are then interpreted to infer geological features and physical properties of earth materials. Resistivity, measured in ohm-meters, depends on porosity, permeability, water saturation, and the concentration of dissolved solids in pore fluids (Telford, 1996; Amah et al., 2025).

The objective of direct current (DC) resistivity surveys is to determine the subsurface resistivity distribution, which can be related to lithology, porosity, water saturation, and the presence of voids. Resistivity is the fundamental parameter measured. This method is particularly effective in groundwater exploration because rock resistivity is highly sensitive to water content, and water resistivity is strongly influenced by ionic concentration. It can differentiate stratigraphic units provided there is sufficient resistivity contrast, which often reflects variations in porosity and water saturation.

Resistivity represents a material's opposition to electric current flow (SEG.org, 2021) and is derived from Ohm's law, where resistance R=V/I$R=V/I$. Measurements can be made using lateral profiling, depth sounding, vertical electrical sounding (VES), or electrical imaging. In this research, the VES technique was adopted, employing the Schlumberger array due to its greater depth of penetration compared to the Wenner configuration (Telford, 1990).

Data Acquisition and Analysis

Data were obtained from boreholes drilled at the study locations (Fig. 1). Geophysical surveys were conducted to assess aquifer presence, parameters, and exploitability. The electrical resistivity method was applied using an ABEM Terrameter SAS instrument following standard procedures. Inferred lithology guided the drilling, which was carried out using rotary rigs with mud circulation. Drilling logs were carefully recorded, with rock samples documented alongside penetration depths. These samples informed well completion decisions and screen placement. Subsequently, pumping tests were performed on the completed boreholes following the Cooper–Jacob (1946) method.

Pumping Test Results

Aquifer parameter estimation through pumping tests ideally involves observation wells to monitor drawdown. However, this approach is costly and has been largely superseded by more practical alternatives, such as the single-well constant-rate test developed by Cooper and Jacob (1946). The Cooper–Jacob method simplifies the Theis (1935) equation by noting that for sufficiently large time values tt and small radial distances rr (where u≤0.01$u\leq0.01$), the series expansion terms beyond the first two become negligible. Under these conditions, the Theis drawdown equation reduces to a linear form that allows straightforward determination of transmissivity and storativity from drawdown versus time data on a semi-logarithmic plot.

Theis (1935) drawdown equation:

$$s = \frac{Q}{4\pi T}\left[-0.5772 - \ln u + u - \frac{u}{2.2!} + \frac{u}{3.3!} - \cdots\right]$$

Where: $u = \frac{r2s}{4Tt}$

According to Jacob's(1946) assumptions,the drawdown equation simplifies to:

$$s=\frac{Q}{4\pi T}[-0.5772-\ln u]$$

Then rearranging the equation and changing -0.5772 to ln 1.78:

$$s=\frac{Q}{4\pi T}\left[-\ln 1.78-\ln\frac{r2s}{4Tt}\right]$$

$$s=\frac{Q}{4\pi T}\left[-(\ln 1.78+\ln\frac{r2s}{4Tt})\right] \quad (5)$$

$$s=\frac{Q}{4\pi T}ln\left[-\ln\frac{1.78r2s}{4Tt}\right]$$

Using the rules of natural logarithm,the terms are inverted to become:

$$s=\frac{Q}{4\pi T}\left[\ln\frac{4Tt}{1.78r2s}\right]$$

For a small value of r,theeq.(7) is the equation of a straight line plotted between drawdown(s) and log of time (t) on semilog paper and rewriting the equation in a standard logarithmic format becomes:

$$s=\frac{2.3Q}{4\pi T}\mathrm{Log}\left[\frac{2.25Tt}{r2s}\right]$$

Thus,thestraight line equation is:

$$s=\frac{2.3Q}{4\pi T}\mathrm{Log}\left[\frac{2.25T}{r2s}\right]+\frac{2.3Q}{4\pi T} \qquad \log t$$

Y = B(intercept) + A(slope) x.

Results of the aquifer parameters, borehole particulars and hydraulic analyses determined from the study are presented in Tables 1 - 4

Table 1 Classification of Transmissivity.

Coefficient of Transmissivity (m^2/day)	**class of Transmissivity magnitude**	**Designation of Transmissivity magnitude**
>1000	I	veryhigh
100 to1000	II	High
10to100	III	Intermediate
1to10	V	Low
0.1to1	IV	Verylow
<0.1	VI	Imperceptible

The geological map of the area is shown in Fig.1 while borehole logs recorded from drilling are presented in Figs 2 and 3. The lithology is mainly composed of shales. East of the study towards the escarpment of southeast Nigeria where elevations are higher in comparison to the synclinorum that characterize the Asu River Group,layers of sandstone are locally prominent around Uturu.(Fig 2). However, at Ikwo and Abakaliki areas,these sandstone layers are rarely encountred and the aquifer zones are usually fractured shales.

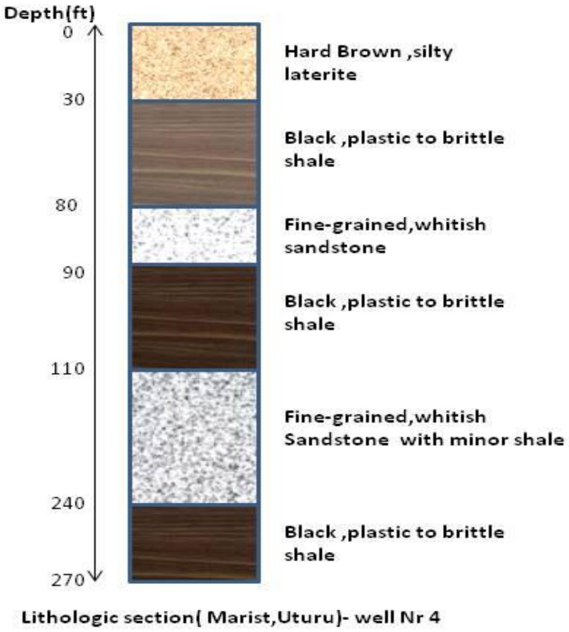


Fig 2. Typical well lithologic log at Uturu(Well Nr 4).

Data presentation

Table 2 and Figs 4-5 show the results of the analysis of pumping test data and a summary of the aquifer parameters in the study area. Pumping rates of the boreholes with recorded drawdown per minute are the key inputs required for the computation of the required aquifer parameters.

The well diameter is uniform throughout the study

Table 2 Classification of Well Parameters within the Asu River Group.

Well	**Q (m^3/min)**	**r_w(m)**	**Δs (m)**	**t_o (min)**	**T (m^2/day)**	**T (m^2/day)**	**classtype**	**S**	**(S)range**
FUNAI 1	0.075	0.15	9.97	0.2	18.23	10to100	Intermediate	0.254	0.1-0.3
FUNAI 2	0.075	0.15	1.1	0.1	37.44	10to100	Intermediate	0.264	0.1-0.3
FUNAI 3	0.075	0.15	1.13	0.1	33	10to100	Intermediate	0.22	0.1-0.3
UTR1	0.18	0.15	2.1	0.2	23.04	10to100	Intermediate	0.32	0.1-0.3
UTR2	0.18	0.15	1.51	0.15	22.85	10 TO 100	Intermediate	0.30	0.1-0.3

Table 3: Pumping test records of FUNAI boreholes.

FUNAI 1		FUNAI 2		FUNAI 3	
Time(min)	Waterlevel(m)	Time(min)	Waterlevel(m)	Time(min)	Waterlevel(m)
1	16.78	1	18.10	1	15.0
10	17.53	2	18.21	2	15.20
20	17.91	3	18.34	3	15.28
30	18.57	4	18.37	4	15.35
40	20.13	5	18.40	5	15.40
50	22.04	6	18.45	6	15.45

60	23.07	7	18.46	7	15.48
70	23.70	8	18.49	8	15.52
80	24.08	10	18.55	10	15.58
90	24.40	12	18.56	12	15.62
100	24.22	14	18.61	14	15.64
110	24.22	16	18.65	16	15.67
120	24.25	18	18.68	18	15.70
110	24.22	20	18.70	20	15.72
120	24.25	25	18.77	25	15.77
		30	18.82	30	15.80
		35	18.86	35	15.85
		40	18.91	40	15.87
		45	18.95	45	15.90
		50	18.93	50	15.92
		55	19.00	55	15.95
		60	19.03	60	15.97
		90	19.20	90	16.05
		100	19.25	100	16.09
				110	16.09
				120	16.10

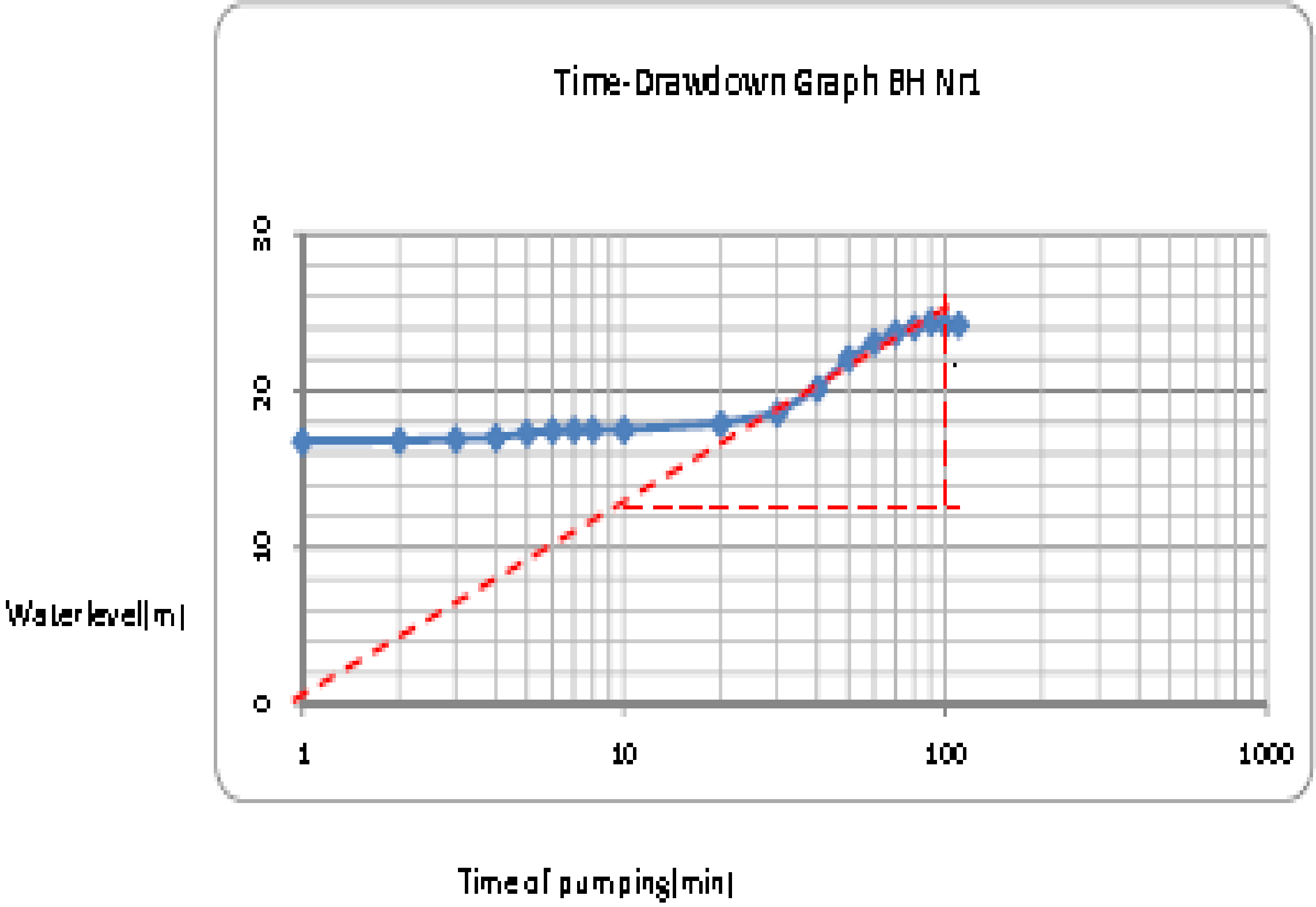
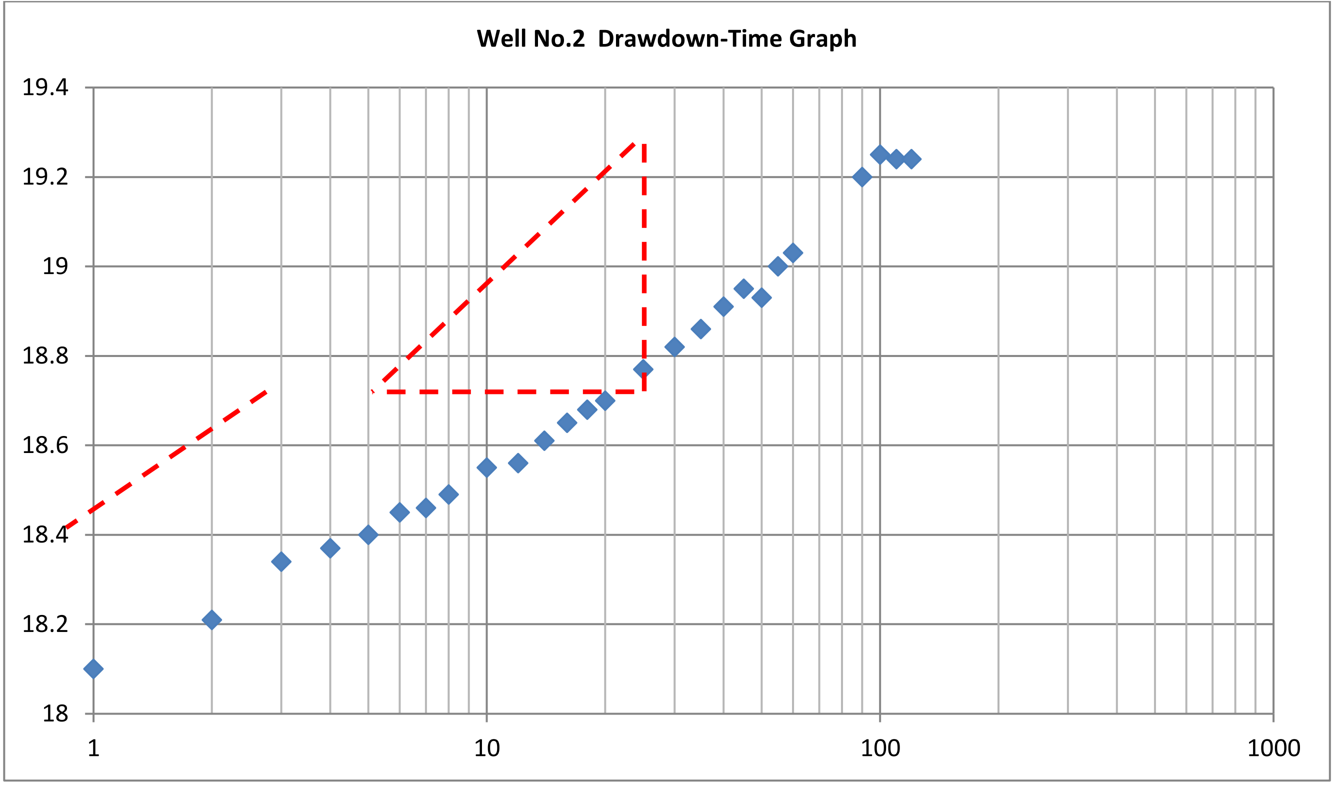


Fig 4(a) Time-drawdown graph of FUNAI BH 1



Time of pumping (min)

Fig 4(b)Time-drawdown graph of FUNAI BH 2

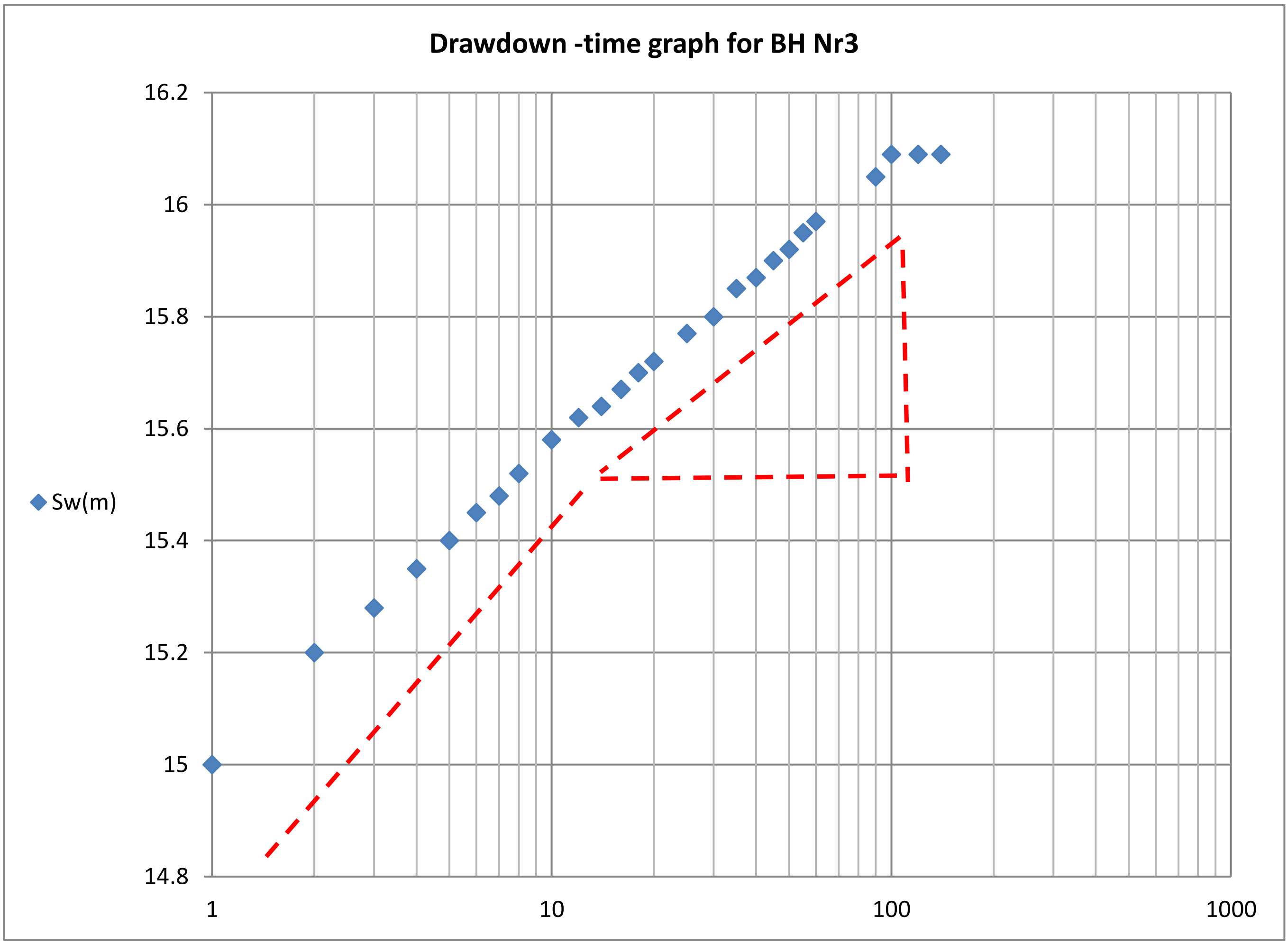
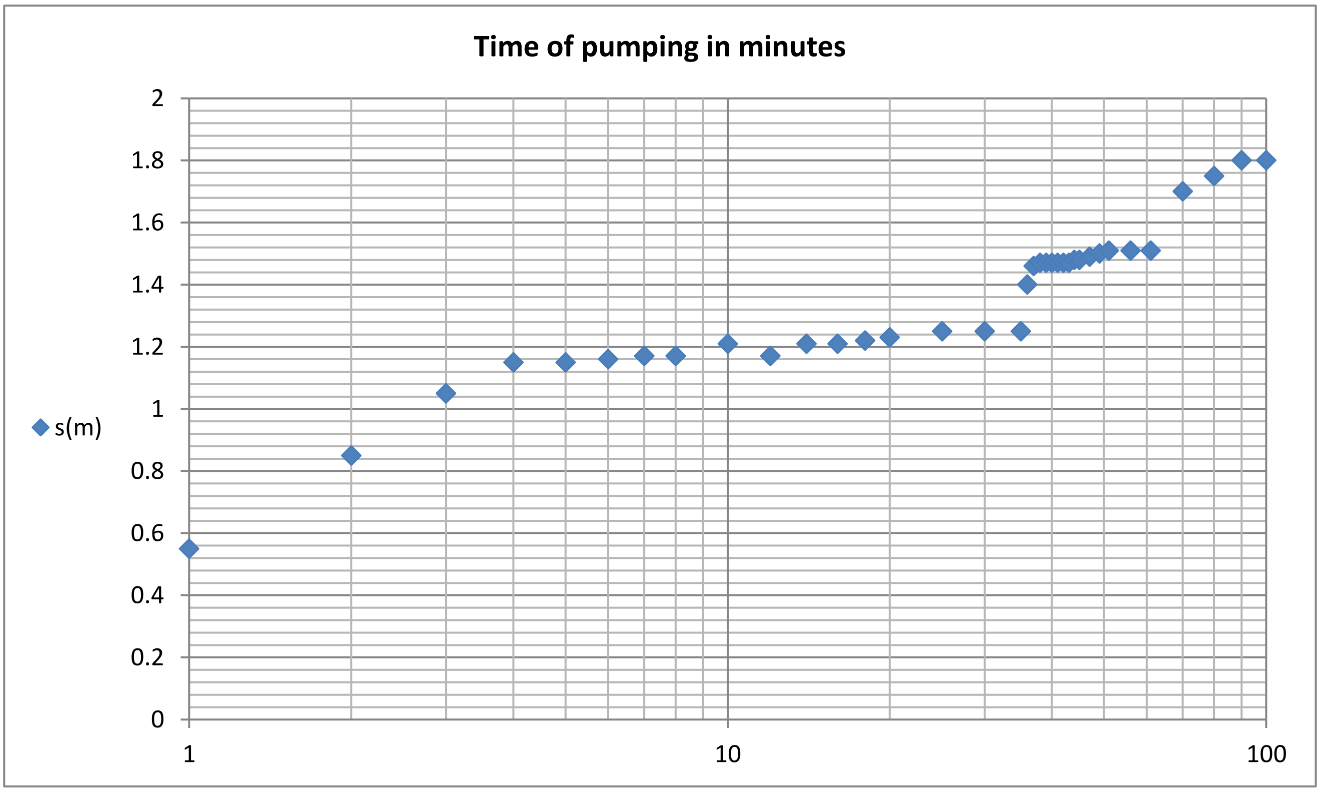


Fig 4(c)Time-drawdown graph of FUNAI BH 3

Table 4a. Pumping test data of Borehole at Marist Brothers Uturu

UTR 1		UTR 2	
Pumping time(t) in minutes	Drawdown(s) in metres	Pumping time(t) in minutes	Drawdown(s) in metres
1	0.55	1	2.17
2	0.85	2	2.8
3	1.05	3	3.27
4	1.15	4	3.42
5	1.15	5	3.49
6	1.16	6	3.57
7	1.17	7	3.64
8	1.17	8	3.64
10	1.21	9	3.75
12	1.17	11	3.88
14	1.21	13	3.95
16	1.21	15	4.09
18	1.22	17	4.21
20	1.23	19	4.28
25	1.25	24	4.45
30	1.25	29	4.67
35	1.25	34	4.82
36	1.4	39	4.97
37	1.46	40	4.97
38	1.47	41	4.9
39	1.47	42	4.97
40	1.47	43	5.05



Step-drawdown test of Marist P.S Borehole,Uturu(UTR 1)

Fig 5(a)Drawdown – time graph of Marist Borehole Uturu(UTR1)

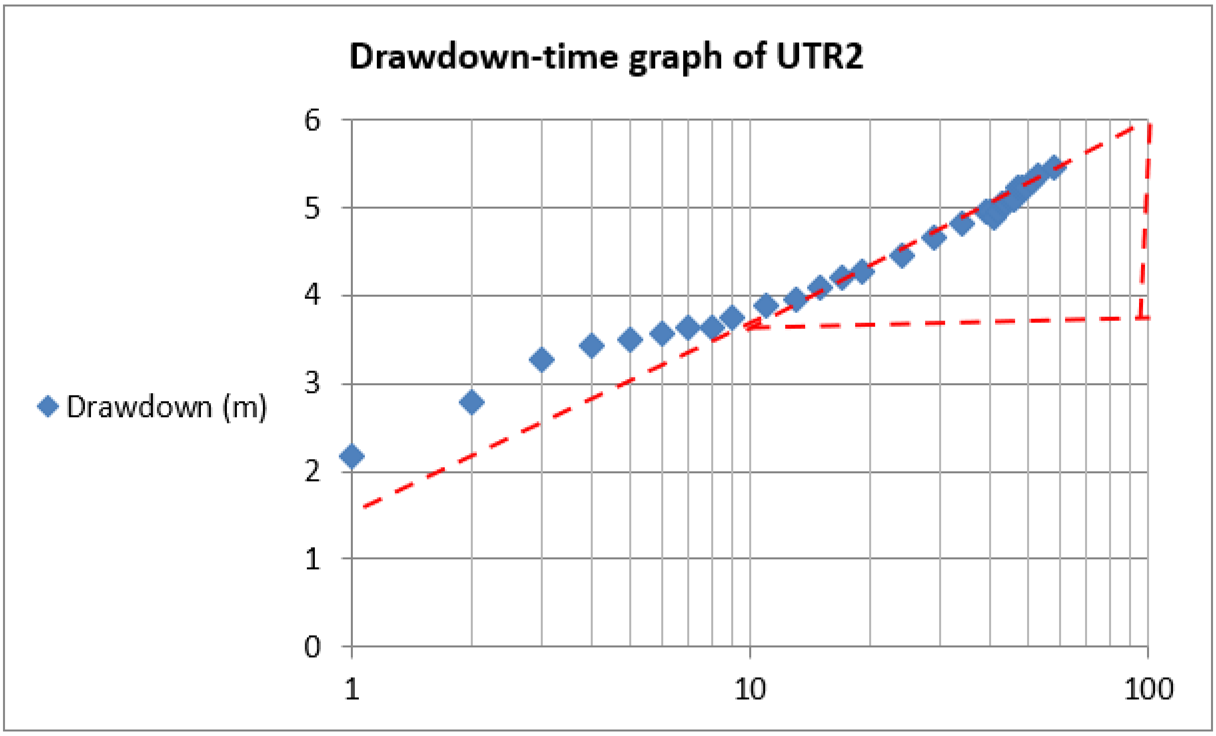


Fig 5(b)Drawdown – time graph of Marist Borehole Uturu (UTR2)

DISCUSSION OF RESULTS

According to the Geology of Nigeria, the Asu River Group functions primarily as an aquitard. In areas where this group crops out, water supply depends largely on surface sources such as streams and rainwater harvesting structures. Efforts to revise the classification of geologic units within the Benue Trough began in the mid-1990s, although they were largely based on undocumented personal observations by geoscientists. This study aims to formally present the findings of a university research group on this issue. Data from five boreholes were selected based on the availability of reliable drilling records. Notably, while various developers currently drill boreholes in the region, campaign data remain largely inaccessible.

At Ikwo (host community of the Federal University), the three boreholes included in this study have elevations ranging from 57 m to 67 m. In contrast, the Uturu boreholes at Marist Brothers' Juniorate range from 82.3 m to 83 m in elevation. This difference suggests a predominance of sandstone horizons on the upslope side of the basin. The lithology at the FUNAI (Federal University Ndufu-Alike Ikwo) boreholes is predominantly fractured shale, whereas the Uturu boreholes show sandstone intercalations between shale layers, classifying them as confined aquifers (Fig. 2). Step-drawdown tests were conducted, and appropriate submersible pumps were selected based on the results. Installation depths at FUNAI ranged from 35 m to 40 m, while those at Uturu were deeper, between 55 m and 70 m.

The results indicate that the FUNAI boreholes exhibit higher drawdown (the difference between static and initial water levels). This drawdown can be misleading if the screen is placed opposite a locally prominent clay layer. The influence of clay lenses on borehole performance was observed at the FUNAI 1 site, where drawdown reached 9.97 m, compared to other boreholes that required only 1.1 m to 1.15 m of drawdown to reach steady state.

Aquifer storativity (S) values ranged from 0.22 to 0.32. Higher values were recorded on the Uturu side, attributed to a greater sand content. The researchers observed that the Uturu boreholes generally produce more water than those at Ikwo (FUNAI), highlighting the effect of porous sandstone lenses. Consequently, Uturu boreholes can support higher-capacity pumping regimes. Fractured shale aquifers can be classified as intermediate, especially where sand and silt layers are locally prominent, as shown in this study. The average transmissivity across the studied boreholes is 26.9 m^2/day, with an average yield of 0.15 m^3/day. Storativity falls within the 0.1–0.3 range, which is considered intermediate and consistent with confined aquifers. The tests indicate that a higher-capacity pump (3 HP) could be installed to increase yield at Uturu, whereas FUNAI and similar areas in Ikwo and surroundings are limited to 1.5 HP unless specific site data suggest otherwise.

CONCLUSIONS

The potential of weathered shale deposits to serve as aquifers has recently become a subject of debate among hydrogeologists. By their natural characteristics, shales are aquitards, a classification that has discouraged groundwater exploration in such formations. However, in recent times—particularly within shale outcrop areas of the Southern Benue Trough—groundwater extraction via hand-dug and shallow wells has generated considerable discussion among engineers and geologists. Therefore, the aquitard status of shales should be re-evaluated considering their structural configurations. The following conclusions are drawn from this study:

(a) Weathering and diagenesis are important geological processes that alter rock structure and matrix. Shales benefit from these processes, developing microfractures and weakened lattices, which result in fracture porosity (secondary porosity). This creates interconnected channel networks, enhancing permeability and fluid storage. Consequently, fractured shale (FSh) should be regarded as a marginal aquifer.

(b) In environments dominated by shale deposits, geophysics is essential for identifying water-bearing zones. In most areas, the weathered zone within sedimentary sequences extends from 0 to 300 ft below ground surface. Weathered horizons exhibiting extremely low resistivity typically correspond to plastic shale or clay, which are impermeable.

(c) Shale sequences are usually heterogeneous, with intercalations of sand and silt. These sandy or silty lenses act as locally prominent aquifers that must be carefully developed. Where rock samples are obscured by drilling mud, simple electric logs can aid well completion.

(d) Within the study area, shallow motorized boreholes are feasible. Depths of approximately 200 ft are common at FUNAI, while boreholes at Marist, Uturu, can be drilled to 300 ft. At FUNAI and most of Abakaliki, small submersible pumps of 1 HP to 1.5 HP are suitable, whereas Uturu boreholes can sustain 3 HP submersible pumps.

(e) This study demonstrates that fractured shale deposits are aquiferous and should be classified as such. Transmissivity (T) falls within the range of 10 to 100 m²/day, qualifying them as intermediate aquifers.

Declaration of conflict of interest

The authors declare that there is no conflict of interest associated with this research work.Thedata,ideas and resources embodied in this work belongs to the authors with no contributions from persons outside this group.

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