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Article

Assessing the Potentiality of fractured shale deposits as an aquifer in the Asu-River Group, Southeast Nigeria

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Abstract

Groundwater beneath earth's surface is stored in pores and rock fractures.Weathering and diagenesis plays vital roles in the enhancement or decrease of rock porosity. To that extent, argillaceous rocks ordinarily considered impervious could earn fracture porosity,enhancing the permeability and substantial storage of water through interconnected matrix channels. Alex Ekwueme University Ndufu-Alike and Gregory University, Uturu are growing universities faced with challenges of good groundwater for domestic uses. Preliminary geophysical studies were carried out within the campuses using electrical resistivity method. Thereafter, the group recommended drilling at five points ,three at Ndufu-Alike and two at Uturu. The very low resistivity data obtained from the survey confirmed that the lithology of the area is predominantly shale of moderate to high plasticity. The pumping test of drilled boreholes were carried out according to the Cooper-Jacob's(1946) method. Test results showed that Transmissivity (T) varied from 18.23m^2/day to 37.44m^2/day at Ndufu-Alike and from 22,85m^2/day to 23.04m^2/day at Uturu. Storativity (S) was determined to range from 0.22 to 0.32. These values suggest intermediate class associated with confined aquifers. The study shows that fractured shale aquifers hold a promise for domestic water supply and that the shales can be counted as groundwater prospects to be harnessed after careful site-specific geophysical studies.

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Keywords
Groundwater; shale; aquifer; weathering; Asu-River Group

Introduction

Water is very important for the sustainance of life,second only to the air we breathe.On the earth surface,water is either non available in some places or people resort to ground water for their daily living.Ground water occurs beneath the surface of the earth,often at depths generally inaccessible to ordinary citizens.Groundwater has become immensely important for the different water supply needs in urban and rural areas of both developed and developing nations and this has led to increased exploration and exploitation of water resources using different methods and tools. The study area is underlain by the shales of the Asu River Group. These shales are hard and brittle but the success of the groundwater exploitation is attributed to deep fracturing and faulting peculiar to the Asu River Group. When fractured,shales acquire secondary porosity,the permeability is enhanced to host groundwater at economic quantities. This study focuses on the potentiality of fractured shale as aquifer within the Asu

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River Group as represented by well data from in Alex Ekwueme university Ndufu-Alike in Ebonyi State and that of Gregory university Uturu, Abia State. After the necessary geological and geophysical investigations, the water was exploited through borehole drilling process. About three boreholes were drilled at different points in each of the universities using both rotary and percussion drilling. Pumping tests were done to determine the borehole parameters such as hydraulic conductivity, storativity, and borehole yield and transmissivity.

Study Location and Regional Geology

The study area is located on the Albian Asu River Group sedimentary Formations in the Lower Benue Trough around Abakaliki and extending east to Uturu in Abia State. There is some consensus among researchers that the origin of the Benue trough is closely related to the breakup of Gondwana land during the separation of the African and a South American plates and opening up of the south Atlantic (Wight, 1968, 1976; Burke et al., 1971).Thus, there are associated structural features that favour fluid migration like groundwater flow.

The cretaceous southern Benue Trough, which underlies most parts of southeastern southeastern parts of Nigeria, has a stratigraphic record of deposits represented by sediments of Albian- Cenomanian, Turonian – Santonian, and Campanian- Maastrichtian cycles (Reyment, 1965; Ofoegbu, 1985; Ofoegbu and Amajor, 1987). Greater parts of the Asu River Group sediments are shales with localized occurrences of sandstones, siltstones and limestone facies (Ofoegbu and Amajor, 1987). The group rests unconformably on the Precambrian Basement (Benkhelil et al., 1989). Reyment, 1965; Murat, 1972; Nwachukwu, 1972 and Tijani et al 1989 all reported the existence of intrusive igneous rock within the Asu River Group. The Abakaliki shale has an average thickness of about 500m. The Abakaliki Formation is dominantly shale, dark grey in colour, blocky and non-micaceous in most locations. It is calcareous and deeply weathered to brownish clay in the greater part of the formation (Okogbue and Aghamelu, 2010a). The deep folding, faulting and fracturing in this shale is as a result of series of tectonic activities which has acted on the rocks (Ezeh and Anike, 2009). This has given the shales the ability to house groundwater in economic quantities in some areas while its nature as aquiclude still exists in other parts where fracturing is not pronounced.

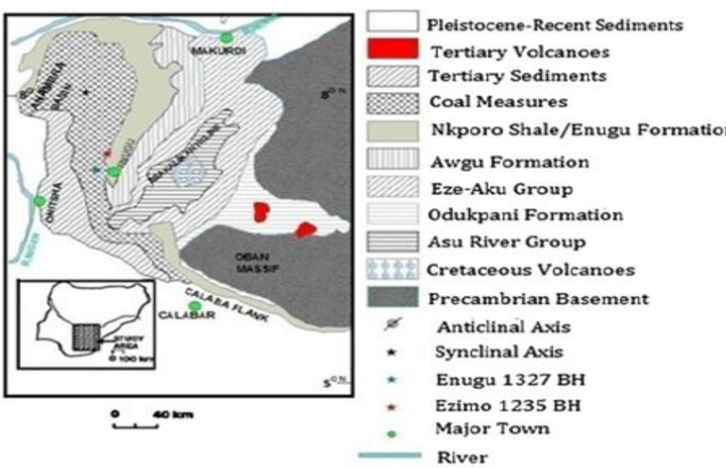

Figure 1. Location map of the study area showing main rock formations

Method

Groundwater is not uniformly distributed everywhere (Idu,J.2015).The occurrence of groundwater varies spatially on the global domain. Generally, groundwater is explored using surface or sub-surface methods. Surface geological investigation (Electrical Resistivity Method, ERM) and subsurface geophysical exploration methods were used in the current study. Geophysical investigations are conducted on the surface of the earth to detect the differences or anomalies of physical properties within the earth crust such as density, radioactivity, magmatism, elasticity and electrical resistivity. Electrical Resistivity Method which is mainly employed, involves ground measurements made on the surface to determine the subsurface resistivity distribution (Asry et al., 2012).

The electrical resistivity method is used to map the subsurface electrical resistivity structure, which is interpreted by the geophysicist to determine geologic structure and/or physical properties of the geologic materials. The electrical resistivity of a geologic unit or target is measured in ohmmeters, and is a function of porosity, permeability, water saturation and the concentration of dissolved solids in pore fluids within the subsurface.(Telford,1996).

The purpose of a DC electrical survey is to determine the subsurface resistivity distribution of the ground, which can then be related to physical conditions of interest such as lithology, porosity, the degree of water saturation, and the presence or absence of voids in the rock. The basic parameter of a DC electrical measurement is resistivity. The electrical resistivity method is one of the most useful techniques in groundwater hydrology exploration because the resistivity of a rock is very sensitive to its water content. In turn, the resistivity of water is very sensitive to its ionic content. In general, it is able to map different stratigraphic units in a geologic section as long as the units have a resistivity contrast. Often this is connected to rock porosity and fraction of water saturation of the pore spaces.

Resistivity is the value of resisting power of a certain material to the flow of a moving current (SEG.org, 2021) and is fundamentally related to ohms law measuring resistance. Resistance is defined as voltage divided by current ($R= V/I$) and the value of a materials resistance depends on the resistivity of that material (SEG.org, 2021). Resistivity measurements are either taken in the form of lateral profiling, depth sounding or vertical Electrical Sounding or electrical imaging. Vertical Electrical Sounding (VES) technique was adopted in this research. The Schlumberger array method was used in this study because it has a greater penetration than the Wenner method.(Telford,1990)

Data Acquisition and Analysis

The study was carried out using data from boreholes drilled at the locations(Fig.1). Geophysical studies were carried out at the locations to estimate the presence of aquifer, parameters, and exploitability. The electric resistivity methods were employed for the purpose of the exploration exercise using ABEM Terrameter SAS geophysical instrument with accessories according to standard practice. The inferred lithology was used as guidance for the drilling exercise carried out with rotary rigs with mud. The drilling logs were carefully taken with rock samples recorded along with depths of penetration of the hole. The rock samples provided the needed guide on well completion processes and areas for screen placement. Thereafter, pumping tests exercises were carried out on the drilled borehole according to Cooper-Jacob (1946) method.

Pumping Test Results

Pumping test exercises to estimate the aquifer parameters are ideally conducted using observation wells to observe drawdown of water levels in the new boreholes.This method is very costly and outdated as very viable alternatives emerged.That is the case of the single well constant rate test credited to Cooper and Jacob(1946). The Cooper-Jacob's (1946) method which simplified the Theis (1935) equations was used in this study. Cooper and Jacob(1946) simplified Theis (1935) equation and noted that for large values of time t, and small value of r,(u ≤ 0.01) the series expansion of the Theis (1935) equation after the first two terms became negligible, so that

Theis (1935) drawdown equation:

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

(1).

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

(2)

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

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

(3)

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

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

(4)

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

(5)

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

(6)

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

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

(7)

For a small value of r,the eq.(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:

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

(8)

Thus,the straight line equation is:

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

(9)

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 (m²/day)	class of Transmissivity magnitude	Designation of Transmissivity magnitude
>1000	I	Very high
100 to1000	II	High
10 to 100	III	Intermediate
1 to10	V	Low
0.1 to 1	IV	Very low
<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.

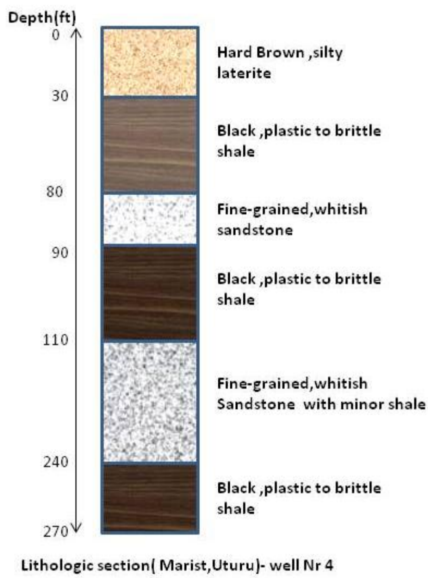

Figure 2. Typical well lithologic log at Uturu(Well Nr 4).

Pumping Test Results

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)	class type	S	(S) range
FUNAI 1	0.075	0.15	9.97	0.2	18.23	10 to 100	Intermediate	0.254	0.1-0.3
FUNAI 2	0.075	0.15	1.1	0.1	37.44	10 to 100	Intermediate	0.264	0.1-0.3
FUNAI 3	0.075	0.15	1.13	0.1	33	10 to 100	Intermediate	0.22	0.1-0.3
UTR1	0.18	0.15	2.1	0.2	23.04	10 to 100	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

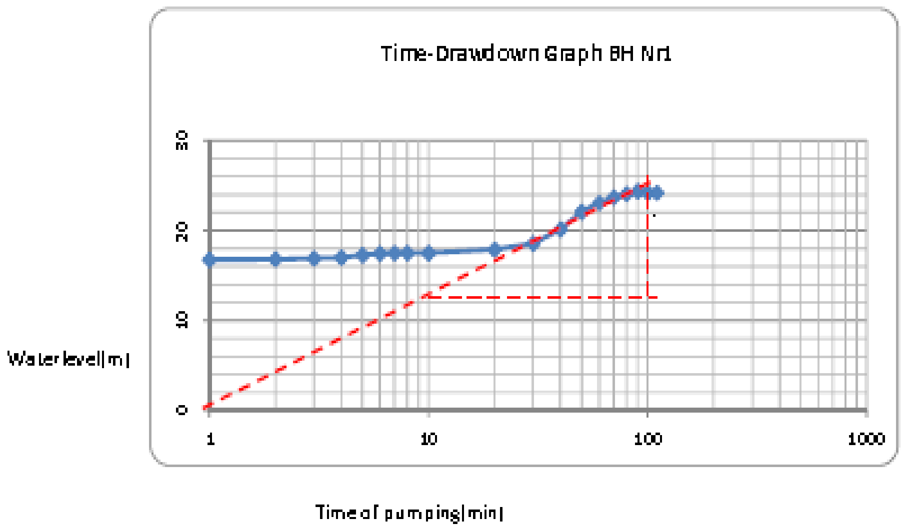

Figure 3. Typical well lithologic log at Uturu(Well Nr 4)

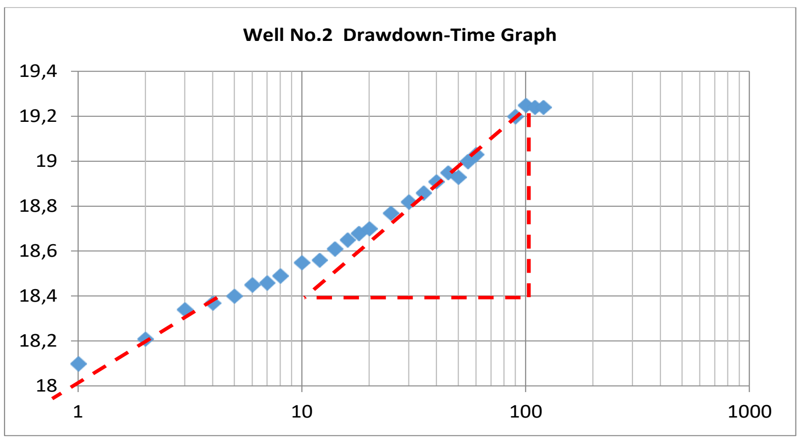

Figure 4. Time-drawdown graph of FUNAI BH 1

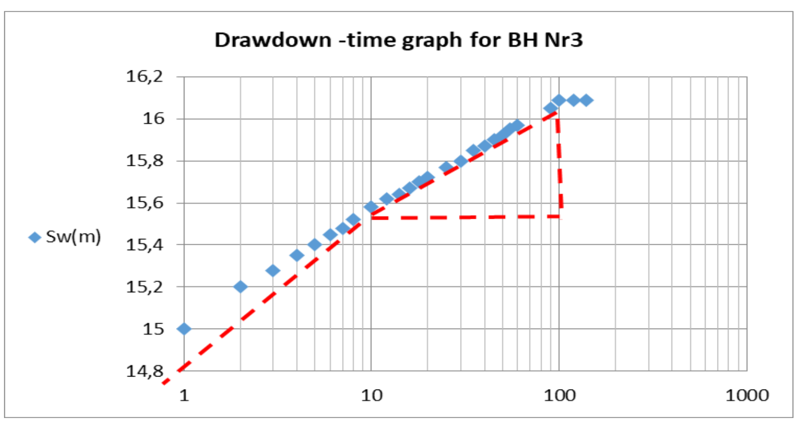

Figure 5. Time-drawdown graph of FUNAI BH 3

Table 4. Pumping test data of Boreholes 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

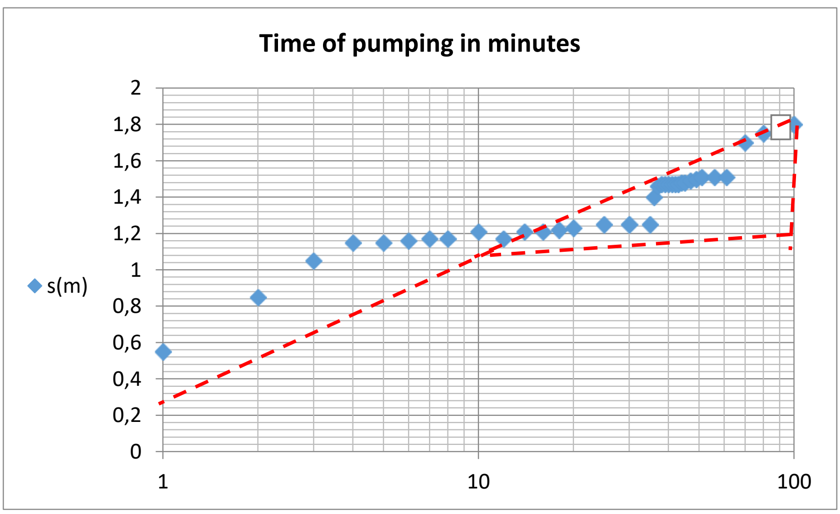

Figure 6. Drawdown – time graph of Marist Borehole Uturu (UTR1)

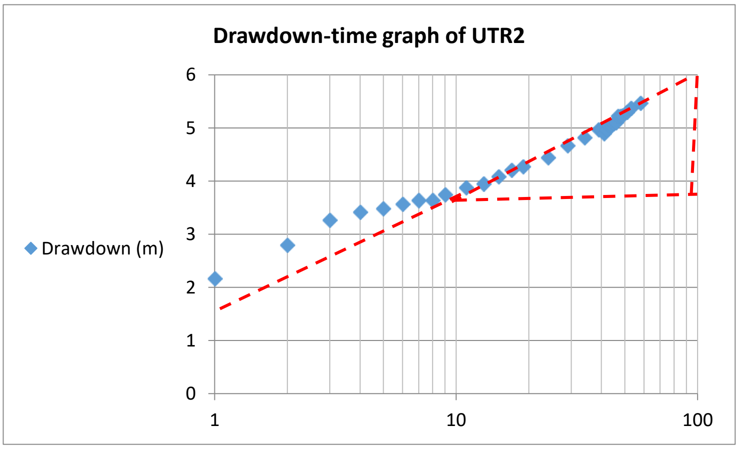

Figure 7. Drawdown – time graph of Marist Borehole Uturu (UTR2)

Results

The Asu River Group as captured in the Geology of Nigeria is basically an aquitard. Areas of its outcrop rely mainly on surface water comprising streams and rain water harvesting structures.Attempts to reclassify the geologic units in the Benue trough started in the mid 90s, although with undocumented individual experience of geoscientists. This research attempts to document the findings of a University study group on the matter. Data from five boreholes were selected for the study based on available drilling information. It is to be noted that the area is currently being exploited through borehole drilling by various developers but data from these campaigns are largely unavailable. At Ikwo, the host community of the Federal University, the elevations of the three boreholes that form part of the study range from 57m to 67m while the elevation ranges of the Uturu boreholes at Marist Brothers' Juniorate vary from 82.3m to 83m. This suggests preponderance of sandstone horizons upslope of the basin.

The lithology of the boreholes at FUNAI is mainly fractured shale while the lithology of the Uturu boreholes have intercalations of sandstone sandwiched between shales, making them to be classified as confined aquifers (Fig 2). The researchers carried out step-drawdown tests and selected suitable submersible pumps at the end of the tests. For the FUNAI boreholes, depth of installation is within the range of 35m-40m while the Uturu borehole were installed at greater depths of between 55m-70m.The results show that the boreholes at FUNAI record higher drawdown (Difference between the static and initial water levels).This drawdown could be spurious when the screen is placed where a locally prominent clay layer exists. The effects of clay lenses on borehole performance was witnessed at FUNAI1 site where the drawdown value reached 9.97m as against other boreholes with drawdown of 1.1m-1.15m to attain steady state.

The aquifer storativity (S) values recorded ranged from 0.22 – 0.32, the Uturu flank recording higher values due to the greater sand content. The researchers note that the boreholes at Uturu generally yield more water than the ones at Ikwo(FUNAI),underscoring the effects of porous sandstone lenses.Uturu boreholes can therefore support higher capacity pumping regimes. the fractured shale aquifers can be classified as intermediate especially when layers of sand and silt are locally prominent as the study shows. The average transmissivity of the studied boreholes is 26.9m²/day .The average yields of the boreholes is 0.15m³/day. The aquifer storativity (S) is within a range of 0.1- 0.3 which is considered intermediate and within the range of confined aquifers. The test shows that higher capacity pump of 3HP could be installed to increase the yield of the wells at Uturu while FUNAI and similar areas in Ikwo and environs are constrained to use 1.5Hp unless dictated by specific site records.

Conclusion and Implications

The potentiality of weathered shale deposits as aquifers has been a topic for debate amongst hydrogeologists in recent times. Shales in their very nature are aquitards.This designation has made shale deposits unattractive for ground water exploration. In recent times, particularly within the outcrop areas of shales in the Southern Benue Trough, exploitation of ground water through hand dug wells and shallow wells has brought about intense arguments amongst engineers and geologists.Thus, the status of shales as an aquitard has to be further examined in terms of their structural configurations The following conclusions can be drawn from this study:

(a) Weathering and diagenesis are important geological processes that alter rock structures and matrix.Shales benefit from this process and end up with microfractures and weakened lattices.This results in fracture porosity,also known as secondary porosity. This is what gives rise to a network of interconnected channels, enhance permeability and fluid storage.This is why fractured shale(FSh) should be considered as marginal aquifers.

(b) In an environment composed mainly of shale deposits, geophysics is key to the identification of water bearing zones. In most areas, the weathered zone in a sedimentary sequence extends from 0-300ft below ground surface. Weathered horizons with extremely low resistivity are usually plastic shale or clay that are impermeable.

(c) In most shale deposits, the sequence is usually heterogeneous with intercalations of sand and silt. These lenses of sand and silt are locally prominent aquifers that must be carefully harnessed. Where the rock samples are obscured by mud, cheap electric logs are helpful in the well completion process.

(d) Within the study area,shallow motorized boreholes are feasible. Depth ranges of 200ft are common in FUNAI while boreholes at Marist,Uturu can be put down to 300ft.At FUNAI and most of Abakaliki,small submersible pumps of 1HP -1.5HP are used while boreholes at Uturu can sustain 3HP submersible pumps.

(e) This study shows that Fractured Shale deposits are aquiferous and should be designated as such.The transmissivity (T) falls within the range of 10 to 100m²/day and classified as intermediate aquifers.

Declarations

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