

Assessment Of Groundwater Potentials Of The Crystalline Aquifers Using Hydraulic Propertiesfor Gidanwaya Town And Its Environs, Southern Parts Of Kaduna State, North Western Nigeria

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Abstract

Pumping test data for 25 boreholes were used to evaluate the hydraulic properties of the aquifers derived from the crystalline Basement rocks of Gidan Waya in southern part of Kaduna State Sheet 188 Jema'a NE and NW North Western Nigeria using the Cooper – Jacobs's non equilibrium graphical procedures. The transmissivity values for the 25 boreholes in the area have a range of between 1.16×10^{-1} and 9.76×10^{-3}.The hydraulic conductivity values are between 1.12×10^{-2}m/s and 9.24×10^{-3}m/s. The specific capacity values in the studied area ranges between 1.00×10^{-1} and 9.95×10^{-2}. The maximum drawdown recorded for the boreholes is between 4.24 to 22.9 m while the drawdown per log cycle ranges from 0.28 to 4.40 m. The above range of aquifer properties has revealed the area to be of high to very high groundwater potentials. Lithological borehole logs revealed the aquifers in the area to comprise of clay, silt, sand, gravels and fractured basement rocks aquifer materials. This is further supported by the values of hydraulic conductivity obtained. Generally the result of the pumping test analysis shows that the boreholes on the average have high groundwater potentials with capacity to sustain withdrawals for regional importance in most cases and in fewer situations the supply can only be local and limited.

Keywords: Basement Complex, Aquifers, Groundwater potentials, Hydraulic Properties.

1. INTRODUCTION

The increasing demand for potable water supply has led to the widespread exploration and exploitation of the groundwater resources of the countries of the world of which Nigeria is not an exception. The Basement Complex terrain which was neglected and considered un-important in terms of water resources have in the past two or three decades received a lot of attention by researchers, government agencies like the Directorate of Food Road and Rural Infrastructure (DFFRI), Kaduna State Agricultural Development Project(KADP), Petroleum Trust Fund (PTF), Fadama programs, Ministries, States, Local Governments, Non-Governmental Organizations and internationally by the World Bank, United Nations Children Emergency Fund (UNICEF), Japanese International Cooperation Agency (JICA), United Nation Development Project (UNDP), Water Aid and a lot of Charity Organizations and donor agencies. Nearly 50% (461, 884.5km^2) of the surface area of Nigeria is occupied by the basement rocks. Du Preeze and Barber (1965) described the basement complex in other region as a poor groundwater region with recorded average yield of just 3960 1/hr (880 gph). Despite its poor hydrogeological characteristics, the crystalline basement is very important in groundwater development and Offodile (2002) shows that 50% of the water needed by the rural populace in Nigeria is provided by the Basement Complex rocks.

Kaduna State has a population of six million, sixty six thousand, two hundred and ninety (6,066,290) out of 50% of the population in the area, three million, thirty one thousand, one hundred and eight (3,031,108) belong to rural, Nine hundred and eighty four thousand, seven hundred and twenty seven (984,727) representing 16% of the semi urban, while the population of the urban area stood at two million fifty thousand and forty five (2, 050, 045) representing 34%. It is important to note that the first two categories of population rely solely on boreholes and dug wells for their potable water supply (KDS WASH REPORT, 2010). This is because pipe -borne water has not yet been extended to most of the rural and semi-urban areas. The daily standard water requirements for the rural, semi urban, and urban areas for Kaduna State are 30, 60, 120 (lcd)respectively (KSWB 2009). As people migrate from rural to urban centres the water demand will increase. Also as the population increases there will also be greater demand for more water. The total daily water demand for consumption in Kaduna State for the year 2009 was 432.80 million cubic litres of water per day. According to Kaduna State Water Board (2009) a total of 9 water plants exist in the State with a total capacity of 376.66 (mld). This is not adequate to meet the total daily water demand of the State.

It is very important to harness the groundwater resources of the crystalline terrain in the area under investigation apart from its being the readily alternative source of water for the rural population in the sub-tropical and tropical climatic region (Wright, 1992). It also has the advantage of its being found almost everywhere. However the

Millennium Development Goals (MDGs) which is jointly sponsored by the State and Federal Governments have been embarking on the drilling of boreholes, as well as the supply of hand pumps, solar powered semi urban water schemes across the State. It is very important to properly investigate the groundwater potential of the area so as to have good reliable information on the groundwater resources to be able to plan properly for the fast growing population future water demand.

2. PHYSICAL CHARACTERISTICS OF THE STUDY AREA

The area under investigation is located at the southern part of Kaduna State, Nigeria and lies between latitude 9 ·15 - 9 ·30 N and between longitude 8.00 - 8.30 E, Fig. 1. It falls within the Guinea Savannah climatic belt of West Africa with two distinct seasons, namely the wet and the dry season. The wet season lasts for 7 months starting from March/April. The rainfall is greater in the eastern part of the area than in the other parts due to its close proximity to the Jos Plateau region. The average annual rainfall is about 1575 mm while the average annual temperature is about 27^{o}C. The dry season is characterised by the north – west trade wind known as the harmattan. This is dusty and dry with low humidity. The area is accessible from the north east direction through the Jos – Nimbia – Gidan waya (Old Jema'a) road, from the north west, by the Kafanchan – Fadan Kagoma – Kwoi road; andfrom the south – west, through the Gitata - Barde road. A railway track also passes through the area, and connects the northern part with the southern part of Nigeria. Easy accessibility is equally provided by a network of footpaths as well as rural feeder roads which are not tarred.

The area is drained by a network of rivers and streams which are mostly perennial. The north eastern part has three major rivers namely, Assob, Gimi and Sanga. These have their sources from the western escarpment of the Jos Plateau. They join southward to form the River Mada. All these rivers have tributaries, like the Dangwa, Masoyi, Jema'a and river Ojib. The north western part of the area has the Kogum and KanockRivers as the major rivers. These have their sources at the Kagoro and Samban hills, respectively and their tributaries include the Garti, Chori, Nok, Pyneba, Pynecho rivers. All the rivers in the area flow southward and drain into the Mada River which belongs to the Benue system. The tributaries are controlled either by master-joint pattern or the schistosity of the basement rock. The resulting drainage pattern is largely trellised and less dendritic.Kaduna State Water Board (1989) has subdivided the drainage system into seven sub catchments/river basins and the area under investigation falls into two of the catchments namely the Mada and Gurara.

3. GEOLOGY

The geology of the area is made up of four distinct rock units namely; porphyritic granites, migmatites, gneisses, and volcanic/basaltic units (McCurry, 1976; Okezie, 1970; Jacobson and Webb, 1946; and Nahikhare, 1971), (Fig. 2).Varieties of granites include biotite granite and porphyritic granites. Their textures vary from course–, medium–, to fine-grained. The migmatite shows alternating and discontinuous dark and light coloured bandings and, the gneisses occur as ortho- and paragneisses, with former type characterized by layered structures while the latter has bands of light and dark alignment of minerals mostly of biotite and quartz. The basaltic rock occurs as boulders which are either vesicular or amygdaloidal. The boulders occur at the subsurface within the regolith at depths between 5–10 metres and sometimes as flow at the surface. Joints, pegmatite and aplite dykes, quartz veins and minor folds constitute some of the structural elements in the area.

4. Materials and Method

Data on 25 boreholes in the area of study were used for the determination of the aquifer properties. The boreholes were tested for periods of 50, 60,120, 150, 180, 240, 360 minutes depending on the time at which equilibrium position was reached for individual well being pumped. The non-equilibrium solution was chosen and used for this analysis because it has the following advantages.

1. The equation permits the determination of the aquifer constants coefficient of storage (S) and transmissivity (T)
2. A shorter period of pumping is required and no assumption of steady flow state condition is required.
3. It required one or no observation well.

The Cooper- Jacob method was used for assessing the aquifer properties. At least two important modifications of the non-equilibrium equation can be traced to a very simple observation made by Cooper and Jacob (1946)

$$s = \frac{Q}{4\pi T}\int_{U}^{\infty}\frac{e^{-u}\,du}{u} \quad \ldots\ldots\ldots\ldots \quad (1)$$

Where s = drawdown Q= constant well discharge
u = well function T=Transmissivity

r= radius of well

It was noted that for small values of radius of well (r) and large value of time (t), u is small, so that the series terms in the equation below become negligible after the first two terms

By rewriting and changing to decimal logarithm the equation reduces to

$$s = \frac{2.30Q}{4\pi T}\log\frac{2.25Tt}{r^2 S} \qquad (2)$$

And the storage coefficient (S) is giving by

$$S = \frac{2.25Tt_o}{r^2} \qquad (3)$$

T can be obtained by noting that if t t/t_o = 10 then log t/t_o = 1

Replacing s by Δs where Δs is the drawdown difference per log cycle of t

This is given by

$$T = \frac{2.30Q}{4\pi\Delta s} \qquad (4)$$

Where

Q = Constant pumping rate l/s
T = Transmissivity in m²/s
s = Drawdown
t = Time since pumping started.
r = radius of the well

This is known as the modified non-equilibrium equation. This equation can be applied to the time drawdown observation made in a single observation well.

Krusman and Ridder (1991) show that the hydraulic conductivity K is calculated from the equation K = T/b where b= aquifer thickness. (Total length of aquifer penetrated by screen)

Todd (1980) shows that the specific capacity is obtained from the relation

Specific capacity = $\frac{Q}{s}$ where s = Total or maximum drawdown.

Pumping test data obtained from literature and those obtained from the field were used to determine the aquifer characteristics. No observation well was used; measurements were taken from the tested boreholes. Hence the wells were pumped until stability was reached, then the drawdown in the boreholes was recorded and the recovery phases were observed and recorded. The rest water levels and the pumping water levels were measured using a dip meter. The length of screen was taken to be the thickness of the aquifer.

5. Result and Discussions

The transmissivity values for the 25 boreholes in the area have a range of between 1.16×10^{-1} and 9.76×10^{-3}. Table 2 give the aquifer properties while Table 8 the summary of these properties for the area of study. Using the classification range in table 3 the transmissivity values of the aquifers in the area of study are predominantly within the > 500 m^2/day class with high potentials. Using the classification by Krasny (1993) in Table 4 the transmissivity values of the aquifers shows very high potentials for groundwater withdrawals. This is also of great regional importance, having a range well greater than 1000 m^2 /day (Table 2).

The hydraulic conductivity values are between 1.12×10^{-2}m/s and 9.24×10^{-3}m/s. In Table 2 the interpretation and classification of aquifer hydraulic conductivity is based on the material composition of the aquifer. The hydraulic conductivity values shows aquifer materials are derived from deep weathering and fracturing of the basement rocks or deposited in the subsurface within the area of study. Borehole logs and well cuttings reveal composition of the aquifer materials to vary from clay, sandy clay and gravel to pebbles.

The specific capacity values in the studied area ranges between 1.00×10^{-1} and 9.95×10^{-2}. Table 8 gives a summary of the aquifer properties in the area of study. Comparing the values of hydraulic conductivity by (Domenico and Schwartz, 1990) for crystalline rocks and unconsolidated sedimentary materials with result given in table 2 the values obtained for the area is within the range given in tables 6 and 7.

6. Discussions on the Hydraulic Properties

From the above section it is clear that the aquifers in the area have very high to high groundwater potentials except for a few boreholes. This is seen from the average values of both transmissivity and hydraulic conductivity for the area which are 4.73×10^{-2} m^2/sand 4.03×10^{-3} m/s respectively. Generally the result of the pumping test analysis shows that the boreholes on the average have high groundwater potentials with capacity to sustain withdrawals for regional importance in most cases and in fewer situations the supply can only be local and limited.

7. Conclusion

The area has two types of aquifers, the fractured basement aquifer and the weathered overburden aquifers with high to very high groundwater potentials to sustain water supply from boreholes connected to hand pump or submersible pump which can meet the water demand of the rural and semi urban population in the area investigated.

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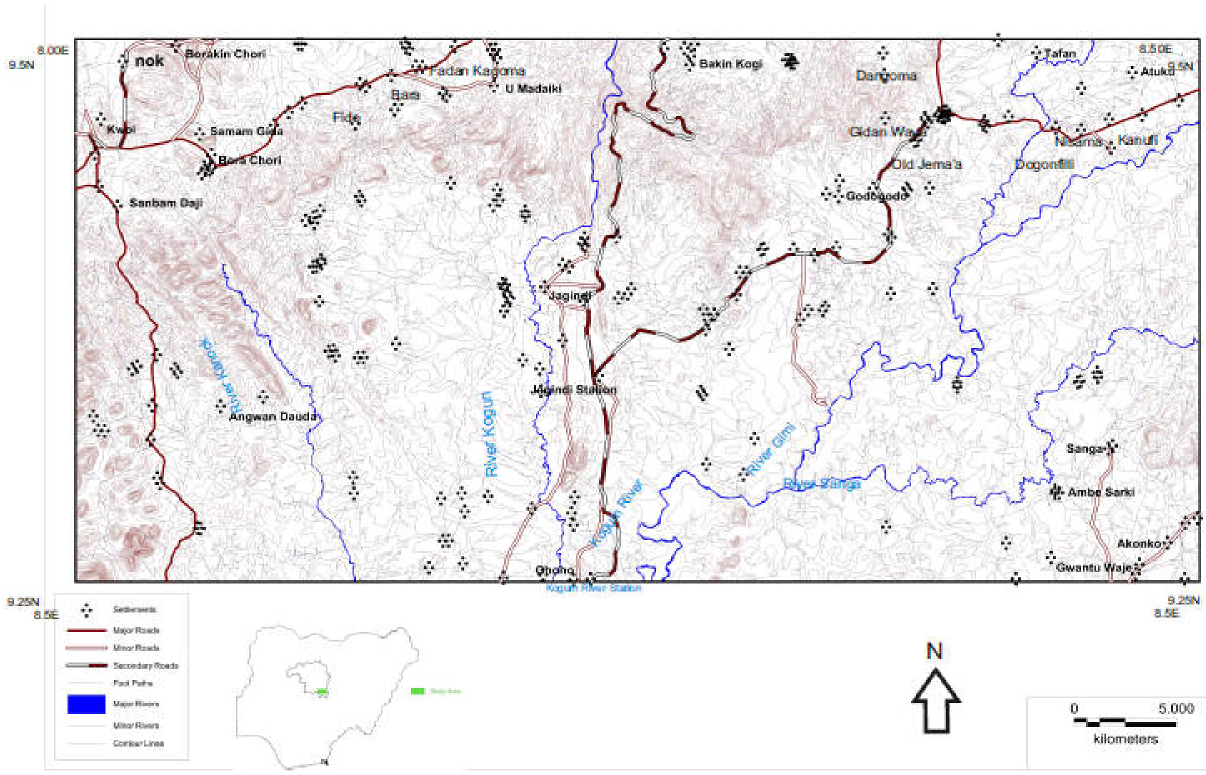

Fig 1: Location Map of the Study Area

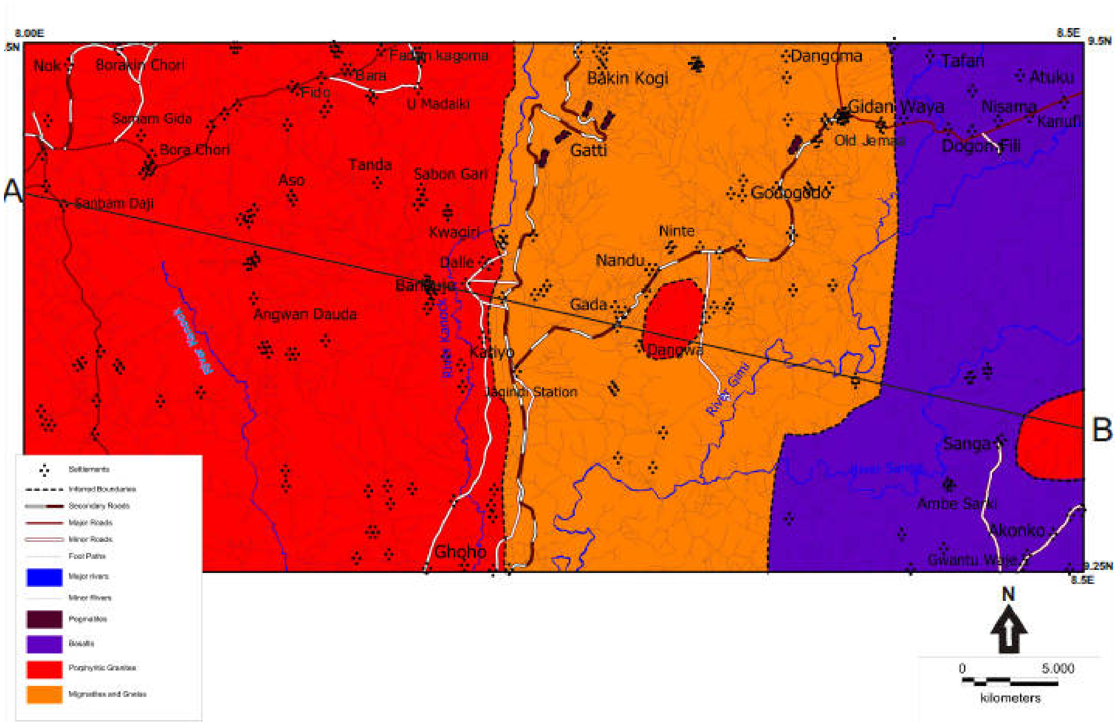

Fig 2: Geologic Map of the Study Area

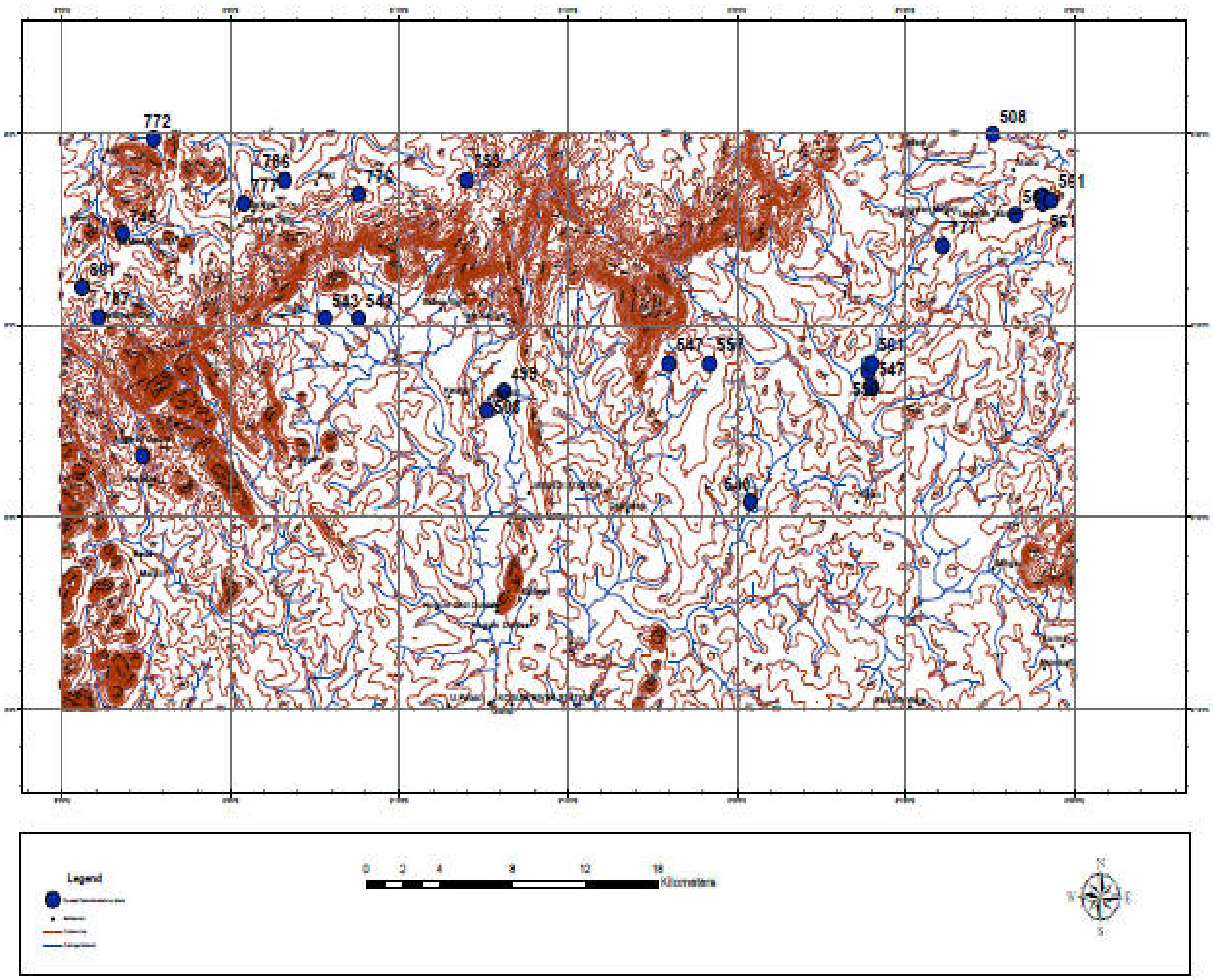

Fig 3: Pumped Tested Boreholes Locations

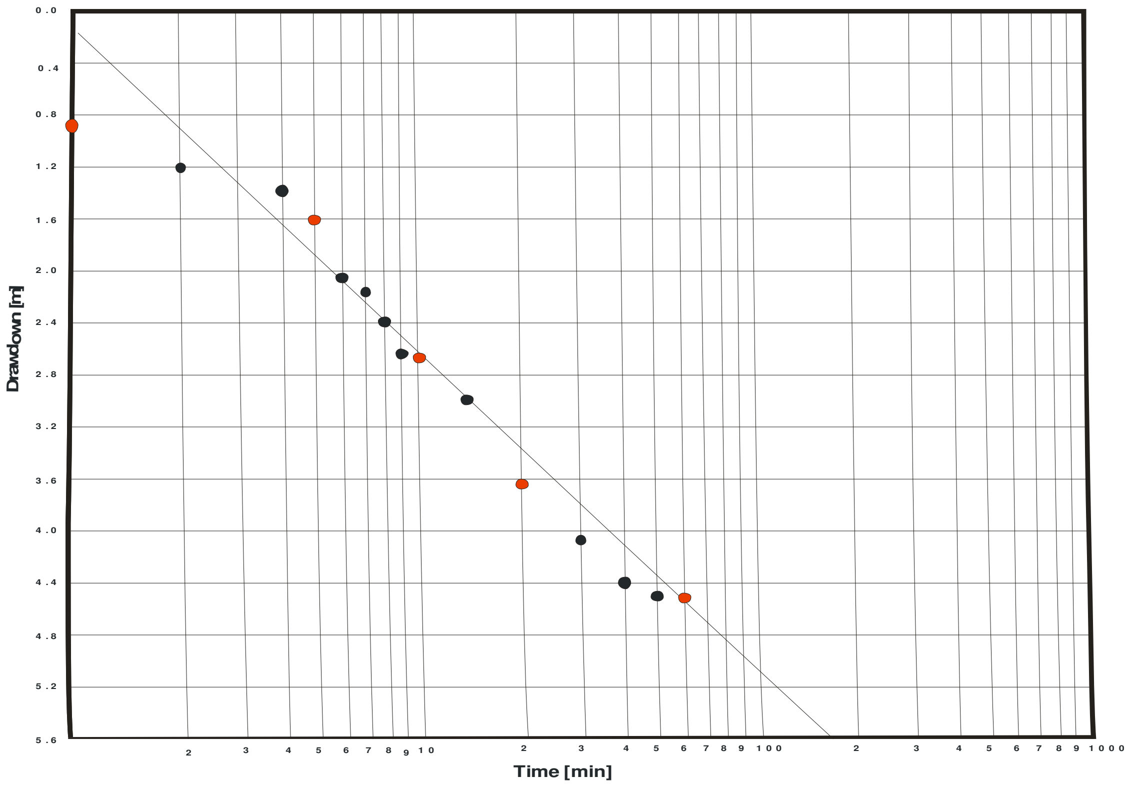

Fig 4: Time-draw down curve for a borehole at L.G.E.A. Atuku Kasa

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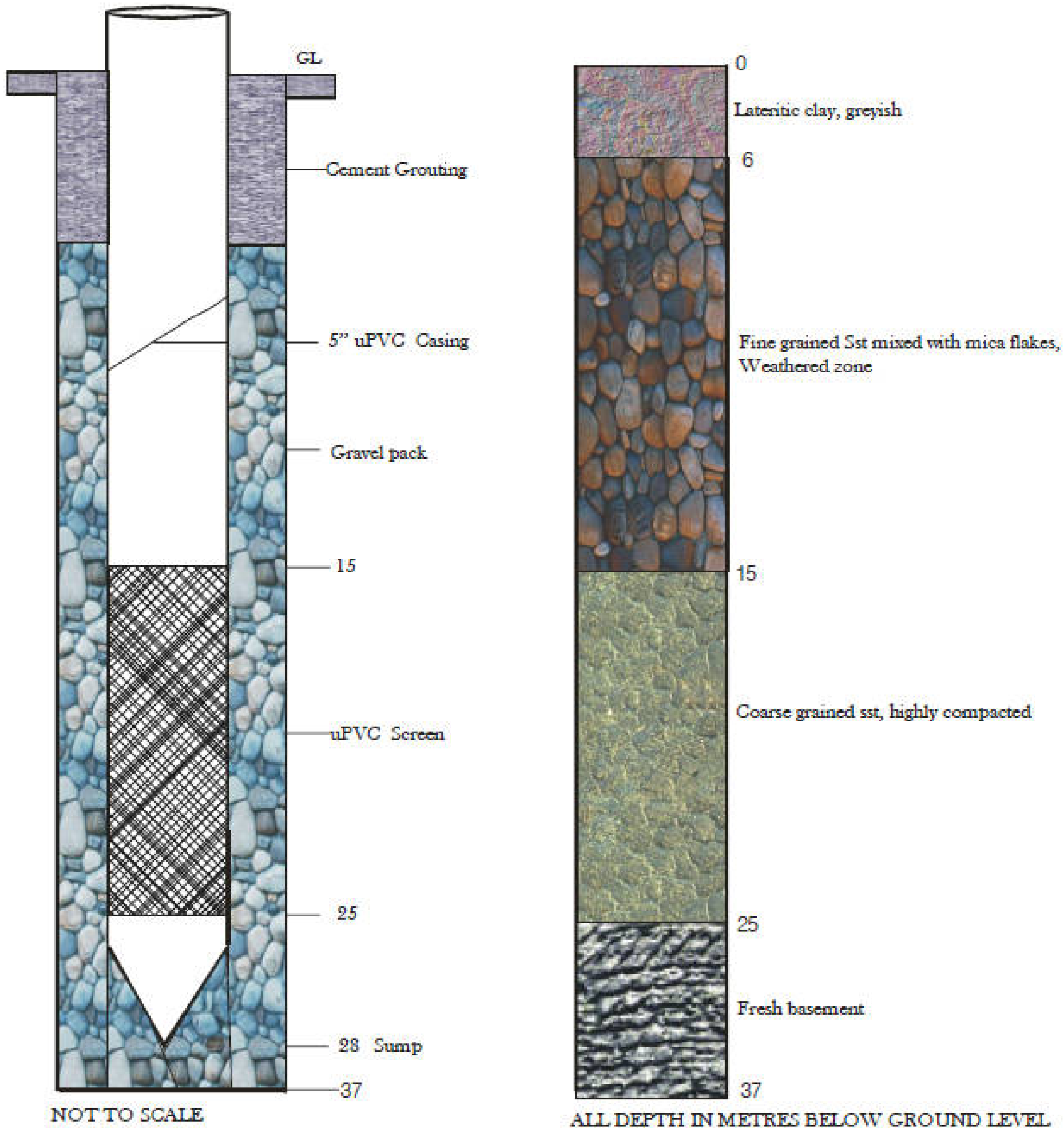

Fig 5: Borehole Geological log at Ngashang Kwoi

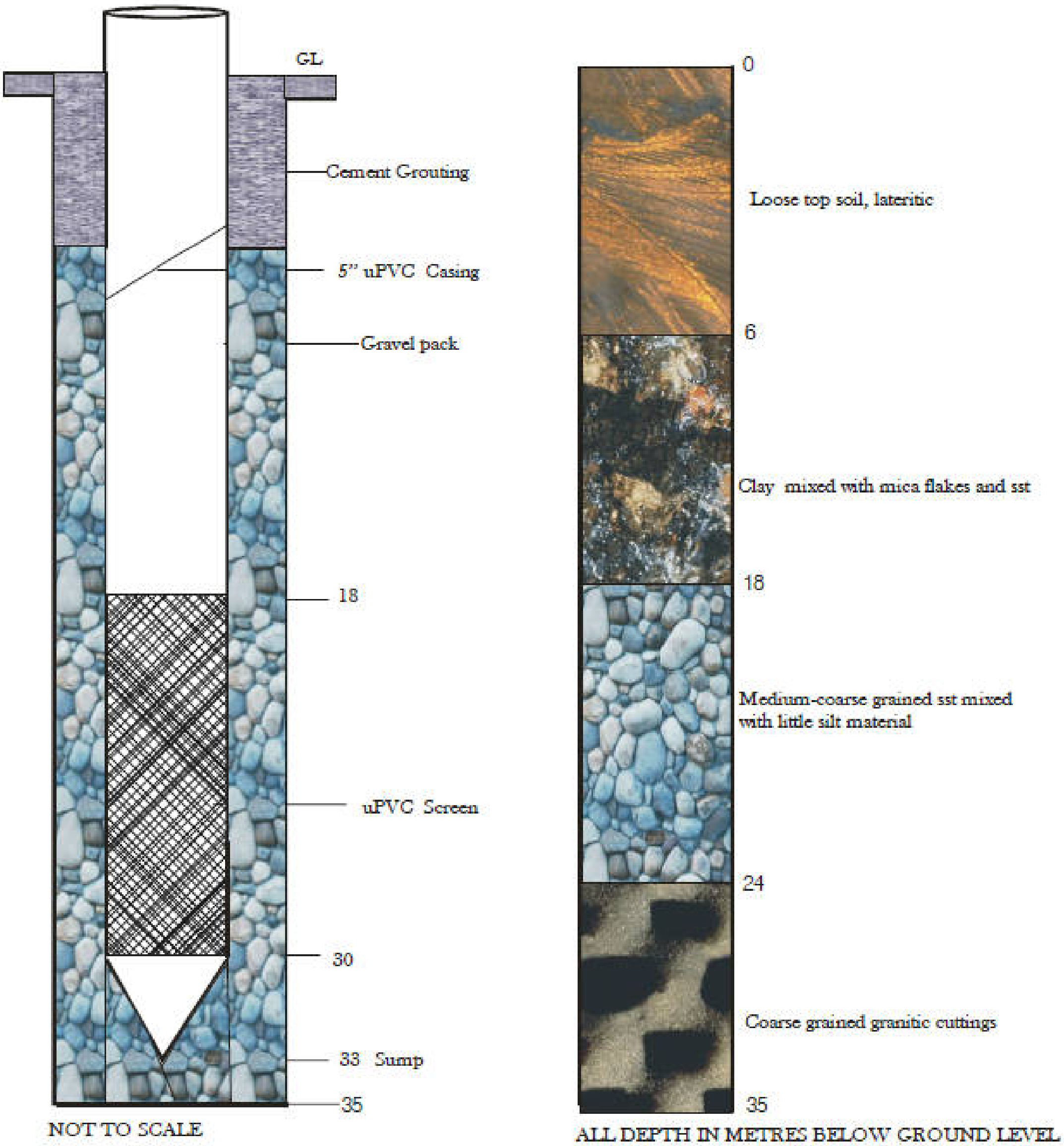

Fig. 6: Borehole Geologic log at Government Secondary School Nok

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Table 1: Summary of pumping test data for boreholes in the area of study

S/NO	BOREHOLE LOCATION	LATITUDE	LONGITUDE	DISCH. Q(l/s)	B.H. Depth	SWL	SCREEN LENGTH	TOTAL DRAW DOWN
1	C.O.E GIDAN WAYA	N09°23`48.8``	E008°23`53.8``	0.68	30	7.40	12.00	21.46
2	C.O.E GIDAN WAYA	N09°23`41.4``	E008°23`52.5``	0.68	34	7.50	9.00	19.45
3	SABONGARIN KWOI CLINIC	N09°26`00.2``	E008°01`35.7``	0.60	18	6.20	9.00	17.90
4	NOK CLINIC	N09°14`21.0``	E008°01`38.2``	0.70	30	6.20	12.00	12.00
5	SANBAN DAJICLINIC	N09°25`13.2``	E008°01`40.0``	0.75	31	7.30	15.00	17.90
6	CHORI BARIKI CLINIC	N09°29`52.8``	E008°02`43.1``	0.80	21	6.90	9.00	13.40
7	L.G.E.A.MAUDE KWOI	N09°27`04.4``	E008°01`46.6``	0.80	23	7.00	12.00	6.20
8	FORI CLINIC	N09°28`31.7``	E008°06`20.1``	0.70	21	6.50	9.00	4.58
9	ATUKU CLINIC	N09°28`54.9``	E008°27`48.9``	0.40	20	8.84	9.00	16.20
10	L.G.E.A ATUKU KASA	N09°29`07.6``	E008°28`53.5``	0.35	21	8.40	12.00	4.58
11	CHORI UNG DADI	N09 28'26.3	E008 05'22.7	1.00	30	3.50	12.00	13.80
12	JAGINDI GARICLINIC	N09°22`49.7``	E008°12`41.0``	0.40	21	13.60	9.00	4.02
13	ZANKAN KWANO	N09 23.406	E008 0.17'809	1.00	32	7.00	21.00	6.29
14	NISAMA	N09 27'914	E008 28'22.9	1.00	30	13.50	21.00	6.52
15	L.G.E.A WAZO	N09°25`144.3``	E008°07`39.0``	0.40	21	9.25	12.00	14.70
16	L.G.E.A DOGON AWO	N09°17`11.1``	E008°13`59.1``	1.10	24	5.20	12.00	16.70
17	L.G.E.A KWARABE	N09°21`18.5``	E008°02`04.4``	0.65	27	6.10	9.00	20.70
18	L.G.E.A GIGIRA	N09°23`21.7``	E008°06`21.1``	0.70	24	6.20	9.00	20.70
19	L.G.E.A RAMINDOPE	N09°19`43.6``	E008°02`06.8``	0.75	23	7.05	12.00	16.20
20	UNG/LOGKO JABA	N09 27 54.1	E008 28 16.4	1.33	30	2.83	15.00	11.00
21	L.G.E.A KANUFI	N09°28`24.0``	E008°29`40.5``	0.44	24	9.30	9.00	7.13
22	MANTE ZANKAN	N09°24`06.0``	E008°19`01.3``	1.00	28	7.30	16.00	22.20
23	KANUFITOWN	N09°28`16.9``	E008°29`19.7``	0.19	26.5	10.20	9.00	2.95
24	L.G.E.A UNG WAKILI	N09°29`49.8``	E008°27`38.6``	0.6	24	8.05	14.00	6.00
25	GIGIRATOWN	N09 08'26.8	E008 05'22.0	0.6	29.5	10.5	22.20	22.29

TABLE 2: AQUIFER PROPERTIES FOR SOME BOREHOLES IN THE AREA OF STUDY

S/No	Borehole No			Discharge Q (l/s)	Transmissivity		Hydraulic Conductivity		Specific Capacity ($m^3/s/$)	Draw down per log cycle (Δs)
		Lat. N	Long. E		(m^2/s)	T (m^2/day)	K (m/s)	K (m/day)		
1	H_{14}	09°25’13.2”	008°01’40”	0.75	$6.00x10^{-2}$	5184	$6.30x10^{-2}$	5443.2	$6.82\ x10^{-2}$	2.50
2	H_{33}	09°23’21.7”	008°06’21.1”	0.70	$3.35x10^{-2}$	2894.4	$3.73\ x10^{-3}$	3222.72	$5.00x10^{-2}$	3.00
3	H_{10}	09°14’21.0”	008°01’38.2”	0.70	$5.12x10^{-2}$	4423.68	$4.30\ x10^{-3}$	3715.2	$3.91\ x10^{-2}$	2.50
4	H_{20}	09°21’18.5”	008°02’04.4”	0.65	$3.03x10^{-2}$	2617.92	$3.37x\ x10^{-5}$	2911.68	$3.51\ x10^{-2}$	3.92
5	H_{38}	09°22’49.7”	008°12’41.0”	0.40	$8.32x10^{-2}$	7188.48	$9.24\ x10^{-3}$	7983.36	$9.95\ x10^{-2}$	0.88
6	H_{40}	09°29’49.8”	008°27’38.6”	0.60	$5.40x10^{-2}$	4665.6	$4.00\ x10^{-3}$	3456	$1.00\ x10^{-1}$	2.04
7	H_{39}	09°28’31.7”	008°06’20.1”	0.70	$2.30x10^{-1}$	1987.2	$2.54\ x10^{-2}$	2194.56	$1.53\ x10^{-1}$	0.56
8	H_{44}	09°17’11.1”	008°13’59.1”	1.10	$1.35x10^{-1}$	1166.4	$1.12x10^{-2}$	24192	$6.59\ x10^{-2}$	1.50
9	H_{7}	09°26’00.2”	008°01’35.7”	0.60	$1.74x10^{-1}$	1503.36	$1.50x10^{-2}$	1296	$4.63\ x10^{-2}$	0.8
10	H_{18}	09°29’07.6”	008°28’53.5”	0.35	$3.20x10^{-2}$	2764.8	$3.00\ x10^{-3}$	2592	$2.70\ x10^{-4}$	2.00
11	H_{9}	09°28’24.0”	008°29’40.5”	0.44	$3.00\ x10^{-1}$	2592	$3.20\ x10^{-2}$	2764.8	$6.17\ x10^{-2}$	0.28
12	H_{17}	09°27’04.7”	008°01’46.6”	0.80	$9.76x10^{-3}$	8432.64	$8.13\ x10^{-3}$	7024.32	$4.94\ x10^{-2}$	1.50
13	H_{15}	09°23’41.4”	008°23’52.5”	0.67	$4.90x10^{-2}$	4233.6	$3.00\ x10^{-3}$	2592	$3.17\ x10^{-2}$	2.50
14	H_{1}	09°29’52.8”	008°02’43.1”	0.80	$7.00x10^{-2}$	6048	$7.74\ x10^{-3}$	6687.36	$5.97\ x10^{-2}$	2.10
15	H_{12}	09°19’43.6”	008°02’06.8”	0.70	$3.22\ x10^{-2}$	2782.08	$3.57\ x10^{-3}$	3084.46	$4.63\ x10^{-4}$	4.00
16	H_{3}	09°23’48.8”	008°23’53.8”	0.68	$6.22\ x10^{-2}$	5374.08	$6.91x10^{-3}$	5970.24	$3.50\ x10^{-2}$	2.00
17	H_{23}	09°25’14.3”	008°71’39.0”	0.40	$5.72x10^{-2}$	4942.08	$5.00\ x10^{-3}$	4320	$8.73\ x10^{-2}$	1.28
18	H_{2}	09°24’06.0”	008°19’01.3”	1.00	$6.78\ x10^{-2}$	5857.92	$4.24\ x10^{-3}$	3663.36	$7.19\ x10^{-2}$	2.70
19	H_{6}	09°28’16.9”	008°29’19.7”	0.19	$1.16\ x10^{-1}$	1002.24	$1.30\ x10^{-2}$	1123.2	$6.44\ x10^{-2}$	0.30
20	H_{13}	09°27’54.1”	008°28’16.4”	1.00	$2.61\ x10^{-1}$	2255.04	$1.24\ x10^{-2}$	1071.36	$9.90\ x10^{-2}$	0.70
21	H_{25}	09°23’23.7”	008°17’51.1”	1.00	$9.10\ x10^{-2}$	7862.4	$4.40\ x10^{-3}$	3801.6	$5.08\ x10^{-2}$	2.00
22	H_{27}	09°28 58.7”	008°01’11.0	0.30	$4.00\ x10^{-1}$	3456	$3.00x10^{-2}$	2592	$1.93\ x10^{-2}$	0.60
23	H_{37}	09°28’26.3”	008°05’22.7”	1.00	$7.62\ x10^{-2}$	6583.68	$6.40\ x10^{-3}$	5529.6	$4.73\ x10^{-2}$	2.40
24	H_{47}	09°28’26.8”	008°05’22.8”	0.60	$4.99\ x10^{-2}$	4311.36	$2.30\ x10^{-3}$	1987.2	$2.69\ x10^{-2}$	2.20
25	H_{46}	09°23’0.41”	008°20’08.6”	1.00	$4.20x10^{-2}$	3628.8	$2.21\ x10^{-3}$	1909.44	$8.81\ x10^{-2}$	4.40

Table 3: Gheorghe Standards for Transmissivity (T)

Transmissivity Range (m^2/day)	Transmissivity Potentials
>500	High potential
50-500	Moderate potential
5-50	Low potential
0.5-5	Very low potential
<0.5	Negligible potential

Table 4: Standard for transmissivity (T) Krasny (1993

T (m^2/day)	Designation of Transmissivity	Groundwater Supply Potential
1000	Very high	Withdrawal of great regional importance
100	High	Withdrawal of lesser regional importance.
10	Intermediate	Withdrawal for local water supply (small community’ plants etc).
1	Low	Small withdrawals for local water supply (Private consumption etc)
0.1	Very low	Withdrawals for local water supply with limited consumption.
	Impermeable	Sources for local water supply are difficult if possible to ensure.

Table 5 : Bouwers (1978) Standards for Hydraulic Conductivity (K)

Materials	K Ranges (m/day)
Clay Soils (surface)	0.01 – 0.2
Deep clay beds	10^{-8} to 10^{-2}
Loam soils (surface)	0.1 to 1
Fine Sand	1 to 5
Medium sand	5 to 20
Coarse Sand	20 to 100
Gravel	100 to 1000
Sand and gravel mixes	5 to 100
Clay, sand, and gravel mixes (till)	0.01 to 0.1

Table 6:Hydraulic Conductivity Crystalline rocks
Domenico and Schwartz(1990)

Crystalline Rocks	
Material	**Hydraulic Conductivity (m/Sec)**
Permeable Basalt	$4x10^{-7}$ to $2x10^{-2}$
Fractured igneous and metamorphic rock	$8x10^{-9}$to $3x10^{-4}$
Weathered granite	$3.3x10^{-6}$to $5.2x10^{-5}$
Weathered gabbro	$5.5x10^{-7}$to $3.8x10^{-6}$
Basalt	$2x10^{-11}$to $4.2x10^{-7}$
fractured igneous and metamorphic	$3x10^{-14}$ to $2x10^{-10}$

Table 7: Hydraulic Conductivity for Unconsolidated Materials
Domenico and Schwartz(1990)

Unconsolidated Sedimentary Materials	
Material	**Hydraulic Conductivity (m/Sec)**
Gravel	$3x10^{-4}$ to $3x10^{-2}$
Coarse sand	$9x10^{-7}$ to $6x10^{-3}$
Medium sand	$9x10^{-7}$ to $5x10^{-4}$
Fine sand	$2x10^{-7}$ to $2x10^{-4}$
Silt, loess	$1x10^{-9}$ to $2x10^{-5}$
Till	$1x10^{-12}$ to $2x10^{-6}$
Clay	$1x10^{-11}$ to $4.7x10^{-9}$
Unweathered Marine Clay	$8x10^{-13}$ to $2x10^{-9}$

Table 8: Summary of aquifer properties for the 25 boreholes in the area of study

Aquifer Property	Transmissivity T (m^2/s)	Hydraulic Conductivity k(m/s)	Specific capacity (m^3/s)
Minimum	$1.16x10^{-1}$	$1.12x10^{-2}$	$1.00x10^{-1}$
Maximum	$9.76x10^{-3}$	$9.24x10^{-3}$	$9.95x10^{-2}$