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Preliminary Estimates of the Hydraulic Properties of the Quaternary Aquifer in N'Djaména Area, Chad Republic

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Abstract: The hydraulic characteristics of the Quaternary aquifer in N'Djaména town and environs were estimated in order to highlight the groundwater potential and vulnerability of the aquifer to heavy abstraction. Pumping test data from 26 boreholes were analysed to determine the hydraulic conductivity, transmissivity and the specific yield of the aquifer. The hydraulic conductivity was calculated based on changes in elevation head of water in the borehole being pumped, the transmissivity was derived in relation to the hydraulic conductivity and the specific yield was estimated using an empirical formula. Results show that hydraulic conductivity varies from 1.20×10^{-1} m day^{-1} (1.41×10^{-6} m sec^{-1}) to 5.46×10^{-3} m day^{-1} (6.32×10^{-2} m sec^{-1}), transmissivity ranges from 5.99×10^{-1} m day^{-1} (6.95×10^{-5} m^{2}sec^{-1}) to 2.69×10^{-4} m day^{-1} (3.12×10^{-1} m day^{-1}) while the specific yield is between 0.006 and 0.052. These results indicate that the aquifer is heterogeneous, has high permeability, but with low storage. On account of the specific yield, it can be deduced that groundwater supply for domestic use is reliable, but withdrawals for industrial and irrigational uses must be limited.

Key words: Quaternary aquifer, hydraulic properties, groundwater, N'Djamena, chad republic

INTRODUCTION

The Chadian company of Water Supply and Electric Energy STEE supplies groundwater to N'Djaména and environs from the aquifer of the Quaternary formation. This is the only aquifer in the region from which private agencies and individuals also exploit groundwater for socioeconomic development. Already, in the Chari Baguirmi area, the aquifer has experienced a great piezometric depression (Kouka depression) located in the Northeastern part of N'Djaména (Town Council of N'Djamena, 2004). In addition to abstraction by boreholes, evaporation of water from the shallow water table of this aquifer is said to have contributed to the lowering of the about 10 m water level in the Kouka depression. Additionally, Djoret (2000) has shown that there is an indication of rapid recharge from meteoric source, a deduction based on concentration of some chemical species in the water implying that recharge to the aquifer is seasonal. Given the historic climatic conditions and the present changes in climate worldwide even the speculations that there is a determinable rate at which groundwater can be withdrawn indefinitely from an aquifer or a groundwater system in a defined area without causing undesirable effects (Lohman, 1972; Fetter, 1994) has been one of the most discussed and a controversial concept in groundwater hydrology. Unfortunately, in N'djaména area, despite the heavy dependence on groundwater for various uses, very little is known about this aquifer from which water is abstracted. The aim of this study therefore, is to estimate the hydraulic characteristics of the aquifer using available scanty data in order to highlight the groundwater potential so that abstraction can be controlled.

LOCATION AND CHARACTERISTICS OF THE STUDY AREA

N'Djaména town and environs are situated midway between the Northern and Southern Chad Republic at the extreme West of the country. They are located within latitude 12° 02' N-12° 08' and 15°° 04' E-15° 08' E (Fig. 1). The terrain is nearly flat but shows a progressive slope Southwards towards Lake Chad with an altitude varying between 293 and 298 m above mean sea level. The elevation gradually rises as one moves to the Northern and Eastern parts away from Lake Chad. These low slopes have been observed to be opposite gravitational flow towards River Chari. This study area forms an important part of the Chad Basin.

The study area experiences a tropical climate characterized by two seasons, wet and dry. The wet season lasts from June to September with a maximum rain in August and the mean annual rainfall is about 500 mm. Temperature varies between 20 and 25°C during this season. The dry season lasts from October to May and is characterized by dry winds coming from the East and high temperatures.

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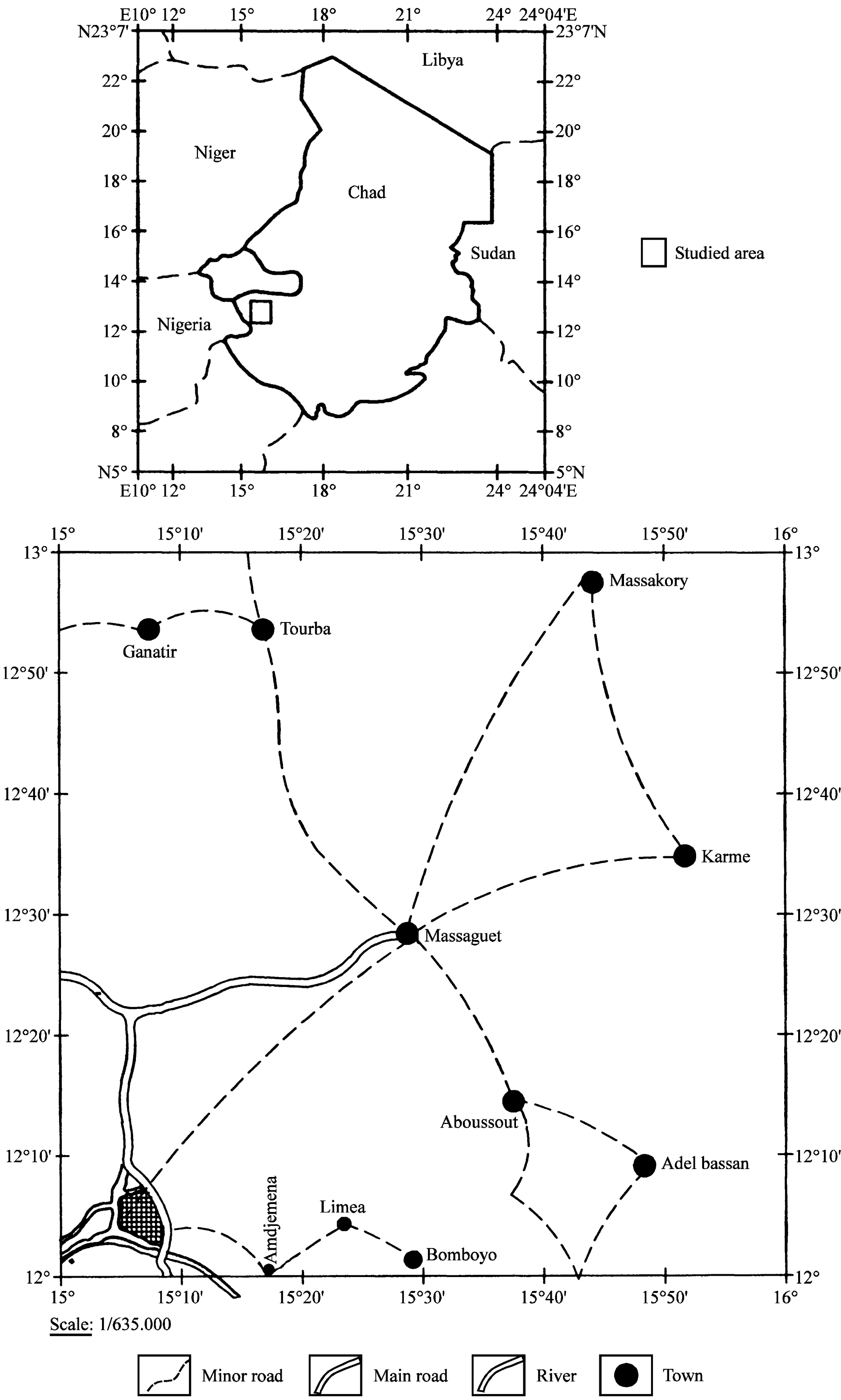

Fig. 1: Location of the study area

Sedimentary rocks form the Tertiary and Quaternary terrains in N'Djaména (Gerard, 1958). The sediments accumulated from detrital materials of variable grain size carried by rivers and streams coming from massif of

Adamaoua (granite) in the South, Tibesti (eruptive rocks and granite) in the North and Guéra-Mongo-Abou Deia (granite) in the centre. The sediments themselves have been eroded, transported and deposited to produce alluvium and primary sandstone of Borkou-Tibesti-Ennedi and Ouaddaï. Eolian sedimentation also contributed to deposition wherein winds have changed fluvial sandy formations to a sandy landscape. The thickness of sediments is variable, being shallow in the vicinity of massifs and increases progressively to about 400 m away from it. Bardeau (1956) represented a succession of sedimentation observed above the granitic basement in the East of the region and Northeast of N'Djaména as a series dominated by clay of about 10 m thick in contact with the basement, a series dominated by sand of about 50 m, a series dominated by clay of 150 to 200 m and a series dominated by sand of 50 to 60 m. Sediments from the Continental Terminal overlie the Basement Complex and underlie the Pliocene formation and the Quaternary formations.

MATERIALS AND METHODS

Field work for the project took place in N'Djaména and environs from 12th November, 2008 to 27th May, 2009. During this period geological, hydrogeological and hydrometeorological data were acquired. Analyses of these data were carried out at Ahmadu Bello University, Zaria, Nigeria. Pumping test data from 26 boreholes (Table 1) located in the study area were used. Each well was pumped at the given discharge rate three times with each pumping session lasting 1 h. Both the second and the third pumping sessions commenced after the well was allowed to recover from the previous stress. But the data for the third hour were the only ones used in this work. The limitation of the data is linked to the duration of the test and the lack of observation boreholes. The analyses were based on (Jacob, 1960) modified equation for free aquifer.

For a fully penetrating well screened up to the static water level transmissivity T, is expressed as:

$$T = [K\,(h_1+h_2)/2]\ (m^2/d) \qquad (1)$$

where, K is the hydraulic conductivity (m/d), h_1 and h_2 are elevations of the water table in observation wells 1 and 2 (Fig. 2) above the datum (m), $(h_1+h_2)/2$ is the saturated thickness of the aquifer (m).

From Fig. 2, $s_1+h_1 = s_2+h_2$ and so:

$$h_1-h_2 = s_2-s_1 \qquad (2)$$

From (Jacob, 1960) initial formula of the plot of drawdown versus log t:

$$s_2- s_1 = [(2.3\times Q)/ 4\ p\ T]\ \log \pi(t_2/t_1) \qquad (3)$$

where, Q is discharge rate, t_1 and t_2 are times corresponding to times at which drawdown measurements were made in an observation well.

Substituting T of Eq. 1 and s_2-s_1 of Eq. 2 in Eq. 3 we obtain:

$$h_1-h_2 = [(2.3\times Q)/2\ \pi\times K(h_1+h_2)]\ \log\ (t_2/t_1) \qquad (4)$$

and

$$K = (2.3\times Q/2\pi\ (h_1^2-h_2^2))\times \log\ (t_2/t_1) \qquad (5)$$

So plotting h^2 against log t will produce a slope, which over one log cycle of t (that is, log t_2/t_1 equals log 10), will yield:

$$K = 2.3\ Q/2\ \pi \triangle h \qquad (6)$$

Sample plots based of some pumping test data (Table 2) are presented (Fig. 3).

During the pumping tests changes in elevation of the water table were recorded in the pumping well as water was being pumped from the screened portion of the aquifer.

From Eq. 1, $(h_1 + h_2)/2$ is the portion through which discharge (Q) takes place. But now in this case, discharge was through the screened portion only. Therefore, transmissivity was estimated as the product of the hydraulic conductivity and the screen length.

Storage coefficient is the volume of water that the unit volume of aquifer releases from storage under a unit decline in hydraulic head. This term applies essentially to confined aquifers. The fact that this quantity normally varies directly with aquifer thickness enables the rule-of-thumb relationship (Lohman, 1972) of:

$$S = 3\times 10^{-6}\ b \qquad (7)$$

where, S is storage coefficient and b is the thickness of the aquifer.

For the confined aquifer, water released from storage is controlled by secondary effects of compaction of the aquifer (aquifer compressibility, a) caused by increasing effective stress and expansion of the water (compressibility of water, β) caused by decreasing pressure. Normal range in value of storage of confined aquifer is $0.00005 < S < 0.005$, implying that large pressure

Table 1: Information on boreholes in N'Djaména area

S/No.	Borehole No.	Location (m)	Depth (m)	Completion date	Q (l/s)	Screen (m)	SWL (m)	Drawdowm (m)
1	FNo 13	12° 23' 40" N 15° 02' 40" E	55.50	11/9/86	1.33	9.90	28.45	1.122
2	FNo 12	12° 22' 15" N 15° 07' 15" E	58.00	03/9/86	0.38	9.90	32.45	1.703
3	FNo 5	12° 13' 50" N 15° 03' 30" E	47.50	15/3/86	1.30	5.90	22.53	0.082
4	FNo 19	12° 25' 50" N 15° 01' 30" E	45.40	01/5/86	0.50	9.90	28.05	0.117
5	FNo 3	12° 05' 30" N 15° 06' 50" E	37.80	24/9/86	2.36	9.90	16.40	1.585
6	FNo 1	12° 06' 50" N 15° 07' 50" E	37.00	19/9/86	1.00	7.90	10.82	0.458
7	FNo 22	12° 27' 40" N 15o 27' 40" E	65.50	17/10/86	1.11	6.75	41.70	1.535
8	FNo 42	12° 55' 00" N 15° 05' 30" E	24.25	17/11/86	0.94	5.95	6.60	0.352
9	FNo 49	12° 50' 50" N 15° 24' 50" E	38.75	14/11/86	0.94	4.95	21.25	2.640
10	FNo 34	12° 57' 50" N 15° 50' 30" E	38.00	03/11/86	0.19	5.95	23.50	1.557
11	FNo 38	12° 54' 40" N 15° 33' 40" E	35.50	12/11/86	0.94	4.95	16.50	0.748
12	FNo 24	12° 40' 40" N 15° 34' 10" E	60.50	20/10/86	0.61	5.75	36.50	0.599
13	FNo 50	12° 53' 50" N 15° 29' 00" E	37.50	13/11/86	0.83	4.95	20.70	2.225
14	FNo 53	12° 57' 10" N 15° 36' 20" E	32.20	10/11/86	1.00	4.95	17.80	1.865
15	FNo 51	12° 55' 00" N 15° 33' 00" E	31.50	11/11/86	0.63	5.85	18.50	1.127
16	FNo 55	12° 59' 40" N 15° 44' 00" E	34.25	01/11/86	0.88	4.95	18.20	1.885
17	FNo 54	12° 58' 30" N 15° 39' 30" E	32.30	31/10/86	0.83	4.95	18.30	0.689
18	FNo 52	12° 56' 00" N 15° 34' 20" E	35.50	11/11/86	0.69	5.85	20.71	1.059
19	FNo 43	12° 52' 20" N 15° 58' 10" E	33.50	18/11/86	0.75	6.88	14.90	1.345
20	FNo 2	12° 10' 50" N 15° 02' 50" E	44.30	17/9/86	1.00	6.90	17.43	2.667
21	FNo 4	12° 08' 30" N 15° 07' 50" E	37.80	22/09/86	1.66	9.90	13.37	1.006
22	FNo 6	12° 18' 50" N 15° 00' 50" E	50.40	13/9/86	0.75	6.90	21.35	0.715
23	FNo 14	12° 22' 30" N 15° 05' 40" E	54.30	05/5/86	0.61	9.90	30.115	2.998
24	FNo 30	12° 59' 40" N 15° 34' 30" E	31.40	08/11/86	1.00	4.95	14.60	0.763
25	FNo 41	12° 55' 00" N 15° 05' 30"E	25.60	17/11/86	0.88	4.95	7.25	0.319
26	FNo 25	12° 40' 40" N 15° 34' 10" E	5.80	21/10/86	0.66	5.75	37.30	2.032

changes over extensive areas will be required to produce substantial water yields.

But the Quaternary aquifer in N'Djaména area is unconfined. Therefore water releases from it amounts to dewatering the aquifer. Normal range in values for such an aquifer is $0.01 < S < 0.30$ implying that substantial volumes of water can be obtained with small changes in head over relatively small areas. For the unconfined aquifer, storage is termed specific yield. The ratio of unit drawdown induced by pumping the Quaternary aquifer to the length of the screen in each borehole was considered for the determination of aquifer saturated thickness in the present calculation. Comparing the least values of storage for both confined and unconfined aquifer Eq. 7 was modified as:

$$S = 3\times10^{-3}\, b \quad (8)$$

where, S is specific yield and b is (length of screen in borehole/drawdown in the borehole)

The aquifer constants were thus estimated and the results are presented in Table 3.

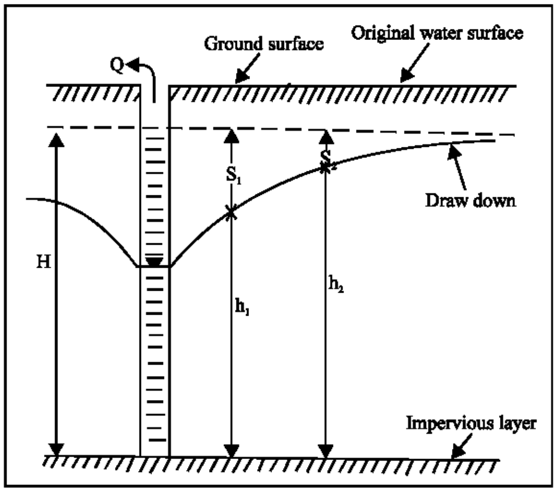

Fig. 2: Schematic section showing radial variation in water level around a well in an unconfined aquifer

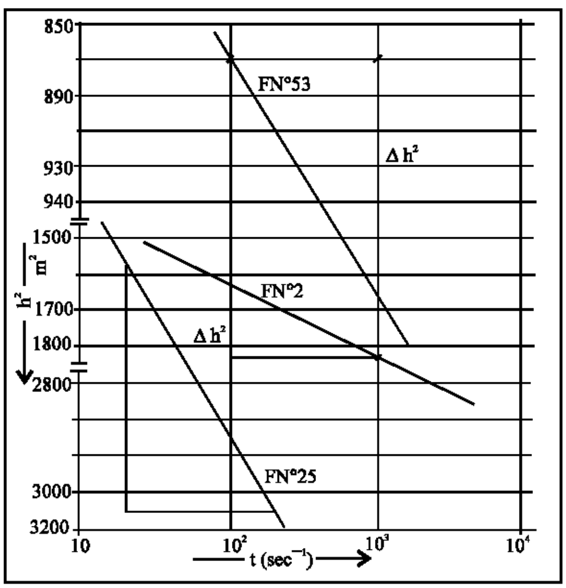

Fig. 3: Time-Water level above stratum curves for boreholes FN° 2, FN° 25 and FN° 53

RESULTS AND DISCUSSION

Table 3 presents the results of analyses. The least value of transmissivity (5.8×10^{-1} m day^{-2}) was recorded in borehole FN° 22 and the highest (2.69×10^{-4} m day^{-2}), was recorded in borehole FN° 41. Very low values of transmissivity (below 1000 m day^{-2}) were recorded in boreholes numbers FN° 14, FN° 12, FN° 25, FN° 51, FN° 34, FN° 6 and FN° 22 while very high values (above 18, 000 m^{-2} day) were obtained for boreholes numbers FN° 5, FN° 42, FN° 41, FN° 4, FN° 1 and FN° 30. But the remainder of the boreholes have 2, 592.34 m day^{-2} as the mean value of aquifer transmissivity. The range of values compares with those of (Town Council of N'Djamena, (2004) elsewhere in the basin, accommodates those of Cotei (1967) - 3.2×10^{-3} m sec^{-1}-6.6×10^{-3} m sec^{-1}-using six boreholes within N'Djaména township and Schneider and Wolf, 1992-3.0×10^{-4} m sec^{-1} < T < 7.0×10^{-3} m sec^{-1} and 1.7×10^{-3} m sec^{-1} < T < 2.5×10^{-2} m sec^{-1} for Northern and Southern N'Djaména, respectively. The mean hydrodynamic parameters of Chari Baguirmi, according to Artis and Garin (2007), BRGM (1987) and Schneider (1967) are 3.0×10^{-4} m sec^{-1} < T < 7.0×10^{-3} m sec^{-1} and 2.8×10^{-8} m sec^{-1} < T < 2.0×10^{-2} m sec^{-1}, respectively and compare with the present results.

Table 2: Pumping test data in the 3rd h for borehole FN°.2, FN°.25 and FN°.53

	Borehole FN°.2		Borehole FN°.25		Borehole FN°.53	
Time (sec^{-1})	h	h²	h	h²	h	h²
0	44.30			58.00		32.30
60	39.78	1582.45	53.03	2812.18		
120	40.22	1617.65	54.83	3006.33	29.65	879.12
180	40.21	1616.84	56.00	3136.00	30.02	901.20
240	40.54	1643.49	56.33	3173.07	30.42	925.38
300	42.23	1783.37	56.37	3177.58	30.53	932.08
600	42.36	1793.52	56.42	3183.22	30.56	933.91
900	42.38	1796.06	56.42	3183.22	30.58	935.14
1200	42.38	1796.06	56.43	3184.34	30.59	955.75
1500			56.44	3185.47	30.59	955.75
1800	42.38	1796.06	56.44	3185.47	30.60	936.36
2400						
2700	42.37	1795.22	56.45	3186.60	30.60	936.36
3600	42.37	1795.22	56.45	3186.60	30.60	936.36

Using Gheorghe (1978) standards (Table 4) to interpret transmissivity only borehole FN° 22 records a moderate potential while the rest boreholes show high potential for the aquifer. By Krasny (1993) standards (Table 5) the aquifer generally has high to very high transmissivity capacity that provides withdrawals of regional importance because even in borehole FN° 22 intermediate capacity from which local water supplies can be withdrawn is indicated. Results from the rest of the boreholes indicate that well yield can be adequate for industrial, irrigation and municipal purposes as these can provide withdrawals of great regional importance.

The hydraulic conductivity varies from 0.12 m day^{-1} to 5,460.48 m/d which on Bouwer standards (Table 6) an aquifer varying in composition from sand-and-gravel mixes to gravels. These results show that the aquifer in the study area is heterogeneous. The results are in reasonable agreement with the exception of borehole FN° 5, FN °1, FN°42, FN°4, FN° 30 and FN° 41 for which figures for the porous medium tends to be essentially for gravels. Indeed Schneider and Wolf (1992) values for hydraulic conductivity are 1.4×0^{-5} m sec^{-1}

Table 3: Hydraulic conductivity, transmissivity and specific yield of the aquifer in N'Daména area

S/No.	Borehole No.	Location	K (m^2 day)	T (m^2 day)	S
1	FNo 13	12° 23' 40" N 15° 02' 40" E	430.27	4.26×10^{-3}	0.026
2	FNo 12	12° 22' 15" N 15° 07' 15" E	59.18	5.81×10^{-2}	0.017
3	FNo 5	12° 13' 50" N 15° 03' 30" E	3171.88	1.89×10^{-4}	0.022
4	FNo 19	12° 25' 50" N 15° 01' 30" E	520.04	5.22×10^{-3}	0.025
5	FNo 3	12° 05' 30" N 15° 06' 50" E	122.69	1.20×10^{-3}	0.019
6	FNo 1	12° 06' 50" N 15° 07' 50" E	2436.48	1.91×10^{-4}	0.052
7	FNo 22	12° 27' 40" N 15o 27' 40" E	8.64	5.8×10^{-1}	0.013
8	FNo 42	12° 55' 00" N 15° 05' 30" E	3732.48	1.84×10^{-4}	0.051
9	FNo 49	12° 50' 50" N 15° 24' 50" E	449.28	2.22×10^{-3}	0.006
10	FNo 34	12° 57' 50" N 15° 50' 30" E	36.89	1.71×10^{-2}	0.011
11	FNo 38	12° 54' 40" N 15° 33' 40" E	635.90	3.16×10^{-3}	0.020
12	FNo 24	12° 40' 40" N 15° 34' 10" E	176.62	1.00×10^{-3}	0.031
13	FNo 50	12° 53' 50" N 15° 29' 00" E	339.55	1.67×10^{-3}	0.007
14	FNo 53	12° 57' 10" N 15° 36' 20" E	508.90	1.15×10^{-3}	0.008
15	FNo 51	12° 55' 00" N 15° 33' 00" E	63.07	3.53×10^{-2}	0.016
16	FNo 55	12° 59' 40" N 15° 44' 00" E	0.12.00	5.99×10^{-3}	0.008
17	FNo 54	12° 58' 30" N 15° 39' 30" E	419.04	2.10×10^{-3}	0.022
18	FNo 52	12° 56' 00" N 15° 34' 20" E	327.46	1.92×10^{-3}	0.017
19	FNo 43	12° 52' 20" N 15° 58' 10" E	407.81	2.79×10^{-3}	0.015
20	FNo 2	12° 10' 50" N 15° 02' 50" E	150.34	1.01×10^{-3}	0.008
21	FNo 4	12° 08' 30" N 15° 07' 50" E	2030.40	1.97×10^{-4}	0.030
22	FNo 6	12° 18' 50" N 15° 00' 50" E	846.72	7.62×10^{-2}	0.029
23	FNo 14	12° 22' 30" N 15° 05' 40" E	41.99	4.27×10^{-2}	0.010
24	FNo 30	12° 59' 40" N 15° 34' 30" E	4259.52	2.11×10^{-4}	0.019
25	FNo 41	12°55' 00" N 15° 05' 30"E	5460.48	2.69×10^{-4}	0.047
26	FNo 25	12° 40' 40" N 15° 34' 10" E	43.03	2.48×10^{-2}	0.008

Table 4: Standards for transmissivity (Gheorghe, 1978)

Transmissivity Range	Transmissivity potential
> 500 m day^{-2}	High potential
50-500 m day^{-2}	Moderate potential
5-50 m day^{-2}	Low potential
0.5-5 m day^{-2}	Very low potential
< 0.5 m day^{-2}	Negligible potential

$<K<4.7\times10^{-4}$ m sec^{-1} and 1.3×10^{-4} m sec^{-1} for Northern and Southern parts of N'Djaména, respectively.

Specific yield varies from 0.006 to 0.052. However, Cotei (1967) and Schneider and Wolf (1992) values are $4.0\times10^{-4}<S<10^{-3}$ and $3.0\times10^{-5}<S<5.0\times10^{-2}$, respectively tend to indicate that the lower value in each range may imply that the aquifer is semi confined. Our values fall generally within the normal range for unconfined aquifers, but the aquifer storage is low. This may not be difficult to understand given the climatic environment and the general phreatic nature of aquifer in the area.

Table 5: Standard for transmissivity (Krasny, 1993)

T (m day^{-2})	Designation	Groundwater supply potential
> 1000	Very high	Withdrawal of great regional importance
100-1000	High	Withdrawal of lesser regional importance
10-100	Intermediate	Withdrawal of local water supply (small communities, plants, etc).
1-10	Low	Smaller withdrawals for local water supply (private consumption).
0.1-1	Very low	Withdrawals for local water supply with limited consumption
< 0.1	Impermeable	Sources for local water supply are Difficult, if possible, to ensure.

Table 6: Standards for hydraulic conductivity (Bouwer, 1978)

Materials	Range of K (m day^{-1})
Clay soils (surface)	0.2
Deep clay beds	10^{-8}-10^{-2}
Loam soils (surface)	0.1-1
Fine sand	1-5
Medium sand	5-20
Coarse sand	20-100
Gravel	100-1000
Sand and gravel mixes	5-100
Clay, sandand gravel mixes (till)	0.001- 0.1

CONCLUSION

The evaluation of hydraulic properties of the Quaternary aquifer of N'Djaména and environs indicate that the aquifer has good yield potentials and that groundwater development potential of the area is very high. The likely problem that could lead to inadequate supply of water will be related to its availability rather than the hydraulic properties of the aquifer. Accordingly, abstraction should go on with caution in the face of prevailing climate change that may adversely affect recharge. It may be necessary to set a pumping rate for each borehole based on standard step drawdown pumping test in order to guarantee sustainable withdrawal. The estimation of hydraulic conductivity was based on a formula that is not quite familiar or commonly used, but which derivation is logical. Further confirmation of it is necessary using data obtained from standard pumping tests with observation borehole(s). This will subsequently confirm the validity of results obtained for both transmissivity and specific yield using this procedure or enable a comparison between this and the standard procedure.

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