Assiut Univ. J. of Geology
46(1), p-p1- 18(2017)

HYDROGEOLOGICAL SETTING OF ARGEEN AND ADINDAN AREAS, ON BOTH SIDES OF LAKE NASSER, SOUTH EGYPT.

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Received: 26/2/2017 **Accepted:** 17/5/2017

The present work aims to elucidate for the first time the hydrogeological conditions in the Argeen (west Lake Nasser) and Adindan (east of the Lake Nasser) areas on both sides of Lake Nasser. The Abu Simbil sandstone rocks ocuupy most of the western and eastern shorelines of Lake Nasser. The groundwater is exploited from Abu Simbil sandstone aquifer and exists under unconfined conditions. The depths to basement rocks are recorded at depths west of Lake Nasser(313 m) while they are recorded shallower (212 m) at east. The saturated thickness of Abu Simbil sandstone aquifer ranges between 30m (Adindan area) and 312m (Argeen area). The main result of the present study shows that the seepage water from Lake Nasser attains 15 million m^3/year. This huge recharge from the Lake Nasser increases the groundwater head in the Nubia aquifer.

The groundwater potential in the west of the Lake Nasser (Argeen area) is high than in the eastern part (Adindan area). The rise of water table from 1965 to 2015 ranges between 29.61m and 51.86m reflect the impact of Lake Nasser on the groundwater in the study area. The calculated transmissivity for two productive wells attains 409m^2/day (Argeen area) and 305m^2/day (Adindan area) indicating moderate potential of Abu Simbil sandstone aquifer. The groundwater salinity ranges from 229ppm to 782ppm. The groundwater salinity reveals an increase of groundwater salinity towards the west direction in Argeen area (west of the Lake Nasser) and the east direction in Adindan area (east of the Lake Nasser) confirming the groundwater flow from Lake Nasser to abu simbil sandstone aquifer.

Keywords: Hydrogeological setting, Argeen and Adindan areas, Lake Nasser, South Egypt.

INTRODUCTION

The investigated area lies on the both sides of Lake Nasser in south Egypt (Fig. 1), they occupy about 2,000km^2. They are located at the Egyptian-Sudanease borders and playes an important role in the trade between the two countries. They are bounded by longitudes 31° 10´ and 31° 40´E and latitudes 22° 00` and 22° 20` N. This area is characterized by an extremely arid climate and high air temperature as well as a relatively short day rainless winter. It has wide diurnal variations with almost no precipitation.

Very few works were published on the study area dealing with its stratigraphy, whereas several studies were conducted on Tushka and north of the study area.

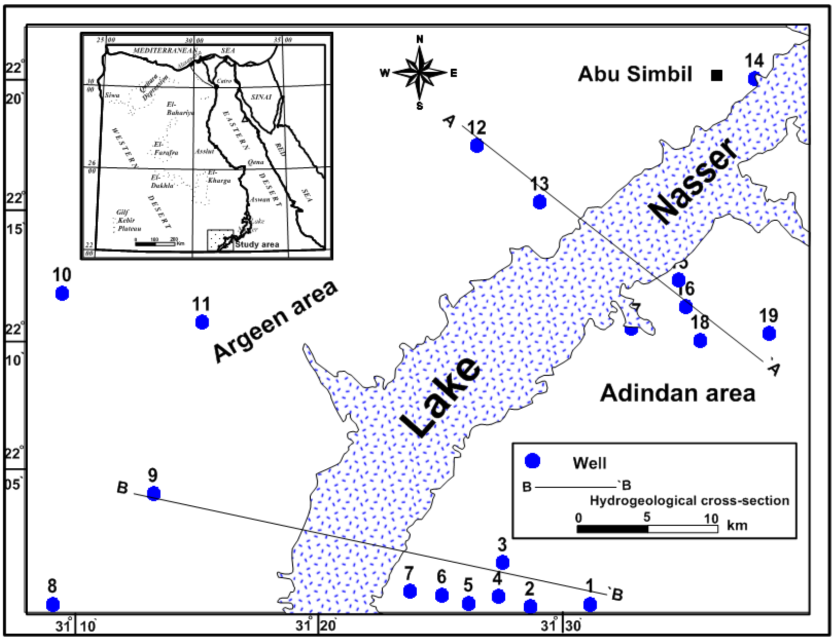

Fig. 1. Location & wells location map of the study area.

The study area lies within the most promising development zone in the Southern Western Desert, due to its renewable groundwater resource from Lake Nasser (1). In this promising area, the Nubia sandstone aquifer is represented by Abu Simbil Formation. This groundwater is used for the irrigation and drinking purposes.

The present work aims to elucidate the hydrogeological characteristics of Nubia sandstone aquifer (Abu Simbil sandstone Formation). It depends on the obtainted hydrogeological and hydrological information of 19 deep drilled wells (7 wells in Argeen and 12 wells in Adindan) as well as the hydrochemical analyses of representative groundwater samples.

GEOLOGICAL SETTING

The lithostratigraphic successions of the investigated area are represented by Precambrian basement and sedimentary rocks ranging in age from Cretaceous to Quaternary. Figure 2 shows the distribution of the main geologic units exposed in the studied area. The basement rocks are exposed on the surface in the northwest of the study area due to the Nakhlai-Aswan

Uplift which separates the Dakhla Basin (Kharga and Dakhla Oases) from Lake Nasser Basin (study area).

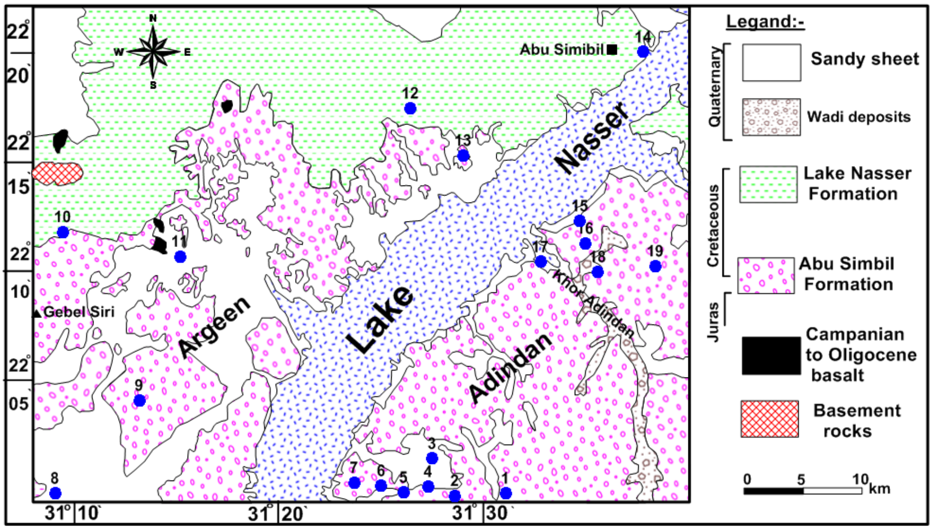

Fig. 2. Geological and well location map of the study area (modified after (6))

The sedimentary succession in the area belongs to the Nubia Formation (refer to many authors, among them, (2); (3); (4) and (5)). The sedimentary cover is relatively thin due southeastern part of the study area (Adindan) as compared with the southwestern part (Argeen).

The basement relief map is compiled as based on the data of the drilled wells (Fig. 3). It indicates that the level of the basement surface varies between -20 m at southeast (well no. 2, east Lake Nasser) to – 143.42 m at west Argeen (well no. 12). The map indicates that the depth to basement is deeper in the West of Lake Nasser than in the East. Accordingly, the thickness of the sedimentary cover increases towards the northwest.

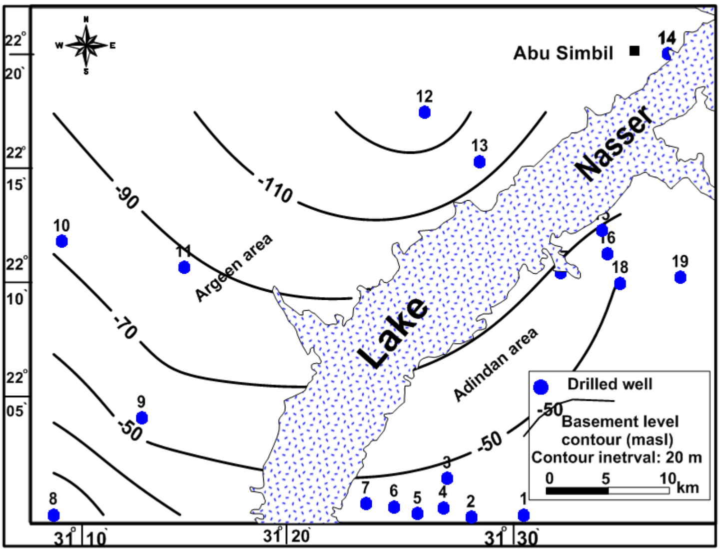

Fig. 3. The basement level contour map of the study area

The sedimentary rocks in Lake Nasser Basin are dominated by sandstone interfingering with siltstone and claystone. These rocks are represented by Nubia sandstone which is differentiated into Abu Simbil sandstone and Lake Nasser claystone Formations and some basaltic outcrops. This basin is dissected by E-W, NE-SW and NW-SE fault systems. The NNE-SSW and E-W faults are predominant. These fault systems play a very important role for recharging the aquifer from Lake Nasser. The Nubia Formation belongs to Late Jurassic-Early Cretaceous time. This sedimentary succession is subdivided into the following two rock units; from base to top as the follows:

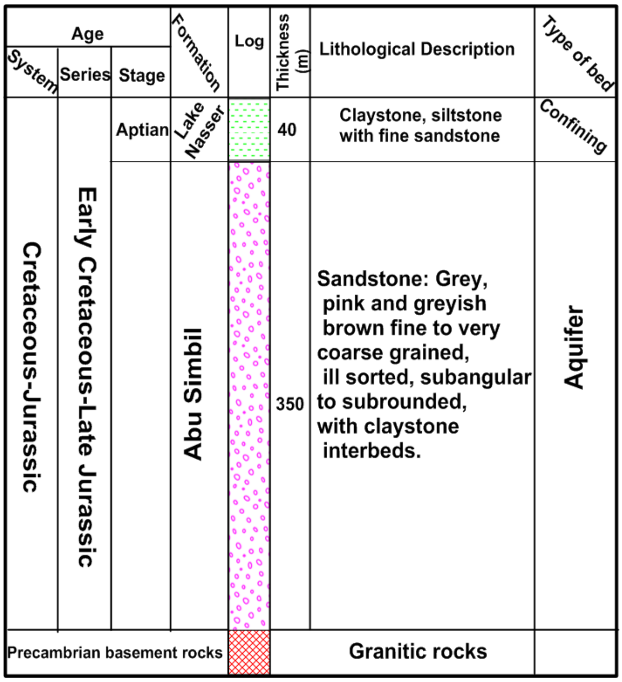

Fig. 4. Stratigraphic succession in the study area

1- Abu Simbil Formation (7)

It represents the oldest sedimentary rock unit in the study area. It overlies directly the Precambrian basement rocks and underlies the Lake Nasser Formation at north and the Quaternary deposits at the south of the study area (Fig. 2). It is assigned to Late Jurassic-Early Cretaceous time. This formation is equivalent to the Six Hills Formation in the Dakhla Basin. It represents the sole water-bearing formation in the study area. This formation covers vast parts of the study area on both sides of Lake Nasser (Fig. 2). The concerned formation was deposited under fluvial environmental conditions.

2-Lake Nasser Formation (7)

It overlies the Abu Simbil Formation and assigned to Aptian of Lower Cretaceous age (8). Lake Nasser Formation is equivalent to the Abu Ballas Formation in the Dakhla Basin. It is exposed on surface at the northern part of the study area and is composed of claystone, siltstone and fine sandstone. The average thickness of this formation attains 100m and represents a confining unit.

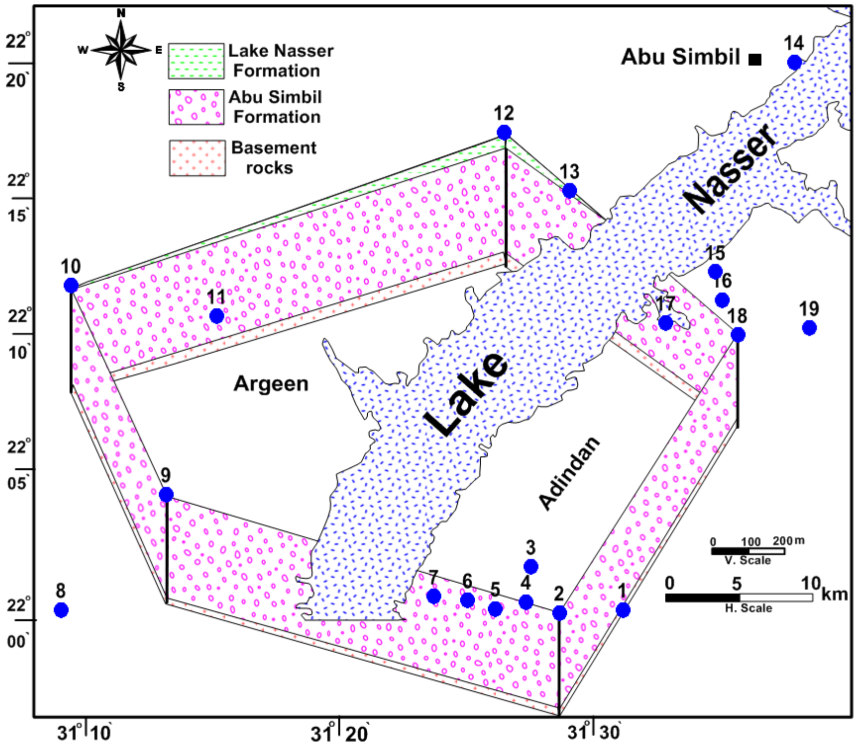

Fig. 5. Panel diagarm subsurface layers in the study area

The constructed panel diagram (Fig. 5) shows that the thickness of Abu Simbil Formation in the west of Lake Nasser is greater than that in the eastern part.

HYDROGEOLOGY

The present research deals with the hydrogeological characteristics in the Argeen and Adindan areas on both sides of Lake Nasser. It is attainted through the hydrogeological inventory of 19 pizemeter and productive wells and with depths vary from 66m (well no. 7) to 390m (well no. 12) (Table 1). The Nubia sandstone aquifer is built of one water- bearing formation namely Abu-Simbil and represents the sole aquifer in the study area. This aquifer is hydraulically connected with Lake Nasser (Fig. 4).

Hydrogeological characteristics

Abu Simbil Formation is exposed on the surface in the study area at both sides of Lake Nasser, (with exception at the northern part of the study area), it is overlained by Lake Nasser claystone Formation (Fig. 4). It represents the oldest sedimentary rock unit in the investigated area. It overlies directly the Precambrian Basement rocks. It belongs to Late Jurassic-Aptian age (7). Abu

Simbil Formation is mainly composed of fine to very coarse grained and granules sands and sandstone with few claystone interbeds at the west of the Lake Nasser, while due East it is highly intercalated with clay beds. The concerned aquifer exists under unconfined conditions in the majority of the studied area. To the North the aquifer exists under semi-confined conditions, where it is overlained by thin Lake Nasser claystone layer (Fig. 6).

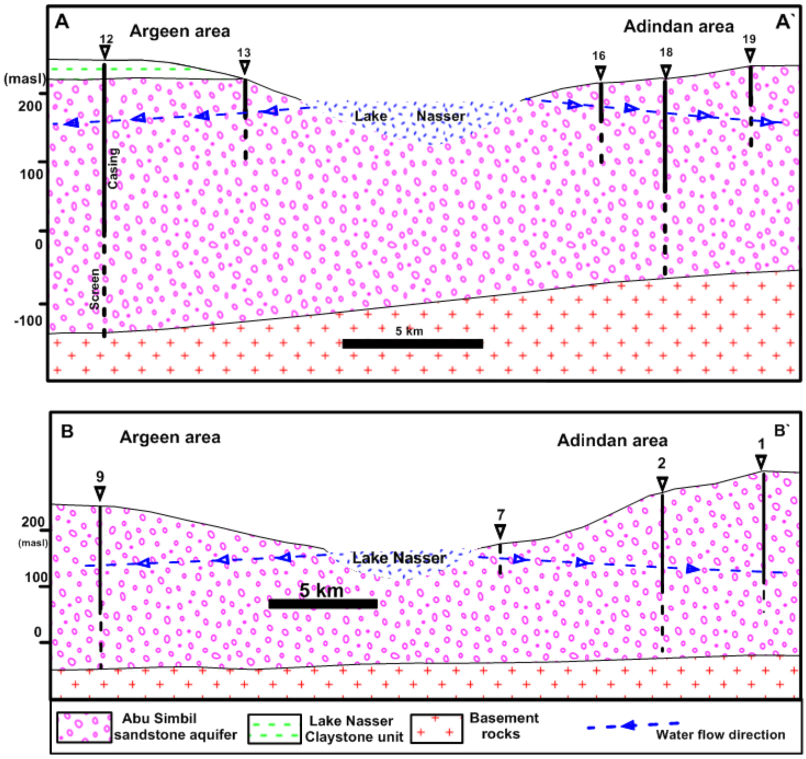

Fig. 6. Hydrogeological cross-sections (A-A` and B-B`) in the study area.

Table 1. Hydrogeological inventory data, Argeen and Adindan areas.

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Well Name	Well No.	Total Depth (m	Depth to water (m)	Water level (masl)	Screen interval (m)		Saturated thickness (r	Salinity (ppm)
					From	To		
East El-Salam	1	230	200	113	210	230	30	-
East Argeen 5	2	288	130	151	200	280	150	-
PW-4	3	141	90.01	156.5	130	141	+51	-
East Argeen 4	4	165	100	150	120	160	+65	-
PE-3	5	145	92	152	100	160	+73	-
East Argeen 2	6	105	43	157	50	100	+62	-
East Argeen 1	7	66	30	161	40	60	+33	-
West El-Salam	8	160	105	151	130	160	+55	782
West Argeen 1	9	300	100	185	200	300	200	-
Obs. 16	10	306	81	149	209	221	225	-
Obs. 16`	11	313	58.03	154	160	175	255	285
West Adindan 1	12	390	77.58	169	290	370	312	-
PW-3	13	115	28	172	105	115	+87	-
Abu Simbil	14	112	23	172	80	100	+89	229
Qasdon1	15	100	16.14	173.86	60	100	+84	-
PE-4	16	108	46.86	160.7	70	100	+61	-
Adindan1	17	120	14.14	159.8	60	120	106	1166
East deep Adindan1	18	274	61.93	154	225	170	212	-
Qasdon El-Magzar	19	126	75	153	100	125	+51	612

The following hydrogeological conditions are defined as following:

1. Variation of the saturated thickness

The saturated thickness of the Abu Simbil sandstone aquifer is equal to the difference between the level of the free water table and that of the basement rock (Fig. 6). It ranges between 30m (well no. 1, south Adindan area) in the eastern part of the Lake Nasser and 312m (well no. 12, Argeen area) in the west of the Lake Nasser (Table 1). It is noticed that the saturated thickness of the investigated aquifer in the Argeen area (West) is more than in the Adindan (East). It is attributed to the increase of thickness of sedimentary cover in the west and the head difference between West and East.

The constructed saturated thickness map for the concerned aquifer reveals an increase towards the west (Fig. 7).

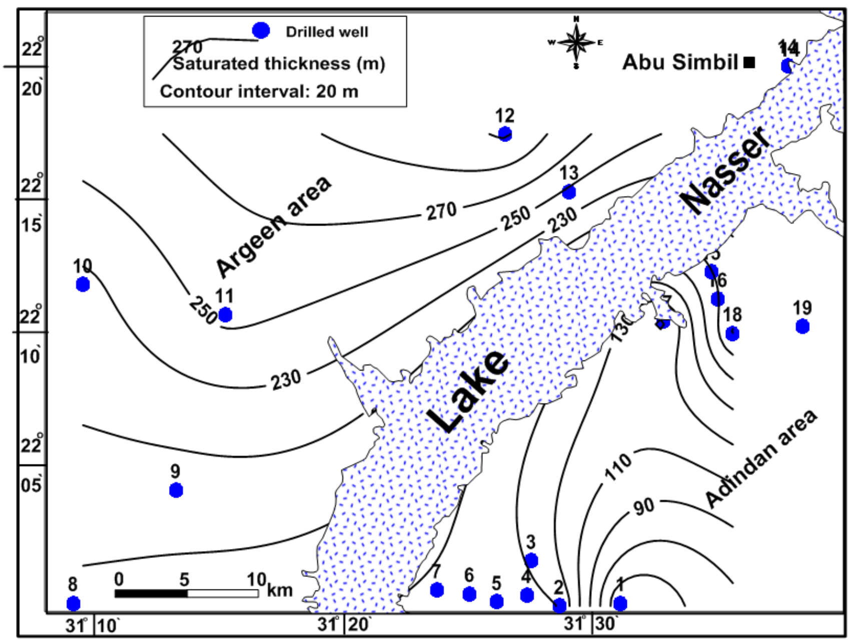

Fig. 7. Saturated thickness of the Abu Simbil sandstone aquifer in the study area

2. Variation of the groundwater depth

In the present work, the depth to water was measured in Janurary 2015 for some productive wells and piezometers. The measured depth to water ranges between 14.14m below ground surface (well no. 17) and 200m (well no. 1) (Table 2 and Figure 8). These wells are located in Adindan area at the east of Lake Nasser. The high depth to water in well no. 1 is attributed to its presence away from Lake Nasser (about 15 km) and its high ground elevation (+313masl). On the other hand, the low depth to the groundwater in well no. 17 is due to it's nearness Lake Nasser.

Table 2. A comparison of the depth to the water in some wells (2015 and 1965).

Well No	Well Name	Depth to water (m) in years		The differences in depth to water (m)
		1965 (9)	2015 (present work)	
3	PW-4	125.57	90.01	35.56
12	West Adindan	123.44	77.58	45.86
16	PE-4	83.98	46.86	37.12
17	Adindan1	66	14.14	51.86
18	East deep Adindan1	91.54	61.93	29.61

A comparison to the present depth to water (2015) measured by the author and depth to water measured in 1965 during the construction of Aswan High Dam (9) for the same wells, shows that the depth to water decreases upward with time as shown in Table 2 and Figure 8. The decrease of the depth to water ranges between 29. 61 m (well no. 18) and 51.86 m (well no. 17). The lowest depth to water is well no. 17 due to its nearness drom the Lake Nasser and the impact of Lake Nasser on the groundwater.

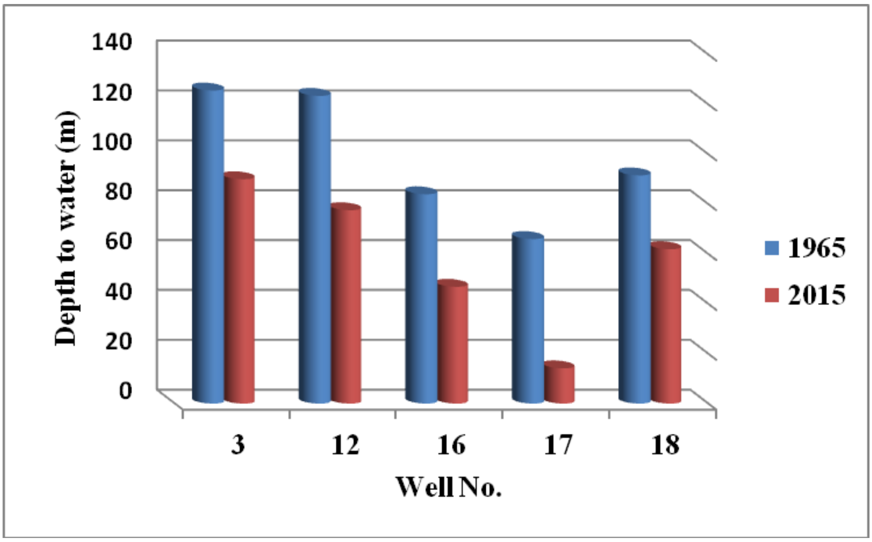

Fig. 8. Bar diagrams showing the level of water in wells from the years 1965 to 2015

3. Variation in the water table and flow direction

The groundwater level ranges between 113masl in well no. 1 at Adindan area east Lake Nasser and 173.86masl in well no. 15 beside the Lake Nasser. The water table contour map is constructed to determine the groundwater flow directions in the Abu Simbil sandstone aquifer (Fig. 9). In Argeen area, the groundwater flows from Lake Nasser to the west and the average calcaluted hydraulic gradient is 0.0008m/m.

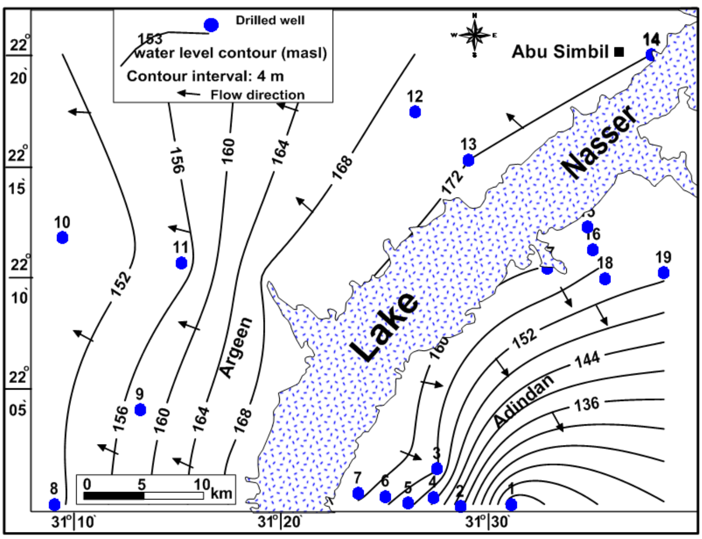

Fig. 9. Water table map of the Abu Simbil sandstone aquifer (Jan. 2015).

In Adindan area, the groundwater flows from Lake Nasser to the southeast and the average calcaluted hydraulic gradient is 0.0016m/m.

4. Transmissivity variation

Transmissivity of the Abu Simbil sandstone aquifer in the study area is calculated by substitution of drawdown (h_o-h) and discharge (Q). The transmissivity is obtained using the following equation (10):

$$\mathbf{T = 15.3\ (Q/\ h_o\text{-}h)^{0.67}}$$

Table 3. The transmissivity values of two wells tapping Abu Simbil aquifer

Well No.	Discharge (m^3/day)	Drawdown (m)	Transmissivity (m^2/day)
14	2160	16	409
17	960	11	305

Where T is the transmissivity in m^2/day, Q is the discharge in m^3/day and the drawdown (h_o-h) in m. The calculated transmissivity attains 409m^2/day (well no. 14, in the western part) and 305m^2/day (well no. 19, in the eastern part) as shown in Table 3. The transmissivity values of the concerned Abu Simbil sandstone aquifer indicate its moderate potential (50-500m^2/day) according to Gheorhge classification (11).

5. Recharge measures from from Lake Nasser

Lake Nasser is hydraulically connected with the Abu Simbil sandstone aquifer in the study area. The water table contour map shows that the groundwater in the study area is recharged from Lake Nasser. By applying Darcy law (12) the amount of recharge from Lake Nasser are calculated in both sides into Abu Simbil sandstone aquifer from water table map (Fig. 9).

$$Q = T*I*L$$

where Q is the amount of recharge to the aquifer in m^3/day, T is the average ternsmissivity of the aquifer in m^2/day (409 in Argeen and 305m^2/day in Adindan), I is the average hydraulic gradient in m/m (0.0008 in Argeen and 0.0016 in Adindan), and L is the length of the shoreline of Lake Nasser (52,000m). Thus, the estimated recharge from Lake Nasser in both sides (Argeen and Adindan areas) of Lake Nasser attains about 42,000m^3/day. The annual recharge amounts to 15 million m^3/year. This huge recharge from Lake Nasser increases the groundwater head in the Nubia aquifer.

The estimated seepage value of the surface water (Lake Nasser) to the adjacent Abu Simbil sandstone aquifer in Argeen area (west the Lake Nasser) attains $0.61x10^6$ m^3/year (13). While the amount of recharge from Lake Nasser to the Nubia sandstone aquifer (Sabaya and Abu Simbil sandstone aquifers) in Tushka area attains 24 x 10^6m^3/year (1). It is notacied that the amount of recharge from Lake Nasser to the adjacent Nubia sandstone aquifer decreases towards the south direction. This may be related to the decrease in thickness of Nubia sandstone aquifer due south.

HYDROCHEMISTRY

Groundwater samples for chemical analysis were obtained from 5 productive wells and one surface sample from Lake Nasser in Abu Simbil City. Each well was pumped at least 12 hour before sampling. These groundwater samples represent the Abu Simbil sandstone aquifer in the study area. Sampling was carried out in May 2014. The major cations Na^+,K^+, Ca^{++} and Mg^{++} , and the major anions Cl^-, $SO_4^{--}$and HCO_3^-, were measured in the Laboratory of the Desert Research Center (Table 4). The hydrochemical characteristics of the investigated groundwater are discussed in the following paragraphs and include groundwater salinity and hydrochemical facies.

Table 4. Chemical analyses of groundwater samples (May 2014)

Well No.	E.C μmhos/cm	TDS (ppm)	Units	Cations				Total Cations (epm)	Anions			Total Anions (epm)
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}		HCO_3^{-}	SO_4^{--}	Cl^{-}	
Lake Nasser	258	167	ppm	36.07	4.86	12	8	2.92	100.2	33	22.82	2.97
			epm	1.80	0.4	0.52	0.2		1.64	0.69	0.64	
			epm %	61.64	13.70	17.81	6.85		55.22	23.23	21.55	
8	1250	782	ppm	56.9	9.6	200	6	12.48	122	266	182.4	12.68
			epm	2.84	0.79	8.7	0.15		2.0	5.54	5.14	
			epm %	22.76	6.33	69.71	1.20		15.77	43.69	40.54	
11	500	285	ppm	68.14	4.86	26	4	5.03	122	50	70.92	5.03
			epm	3.4	0.4	1.13	0.10		2.0	1.04	1.99	
			epm %	67.59	7.95	22.46	2.0		39.76	20.67	39.57	
14	337	229	ppm	54.11	10.94	13	7	4.34	195.2	30.1	15.96	4.28
			epm	2.7	0.9	0.56	0.18		3.2	0.63	0.45	
			epm %	62.21	20.74	12.90	4.15		74.77	14.72	10.51	
17	800	467	ppm	98.5	13.85	40	10	8.04	250	140	40	8.14
			epm	4.91	1.14	1.74	0.25		4.1	2.91	1.13	
			epm %	61.07	14.18	21.64	3.11		50.37	35.75	13.88	
19	1000	612	ppm	76.35	32.59	69.92	27.04	10.22	342.89	62.44	117.02	10.22
			epm	3.81	2.68	3.04	0.69		5.62	1.30	3.30	
			epm %	37.28	26.22	29.74	6.76		54.99	12.71	32.30	

1. *Groundwater salinity*

The groundwater samples of Abu Simbil sandstone aquifer in the study area belong to freshwater type (<1000 ppm) according to (14). The salinity value ranges from 229ppm at the south (well no. 14) at Abu Simbil City to 782ppm (well no. 8). The low groundwater salinity of well no. 14 is its nearness from Lake Nasser; while the high salinity of the groundwater (well no. 8) is attributed to its location far away from Lake Nasser (about 15 km).

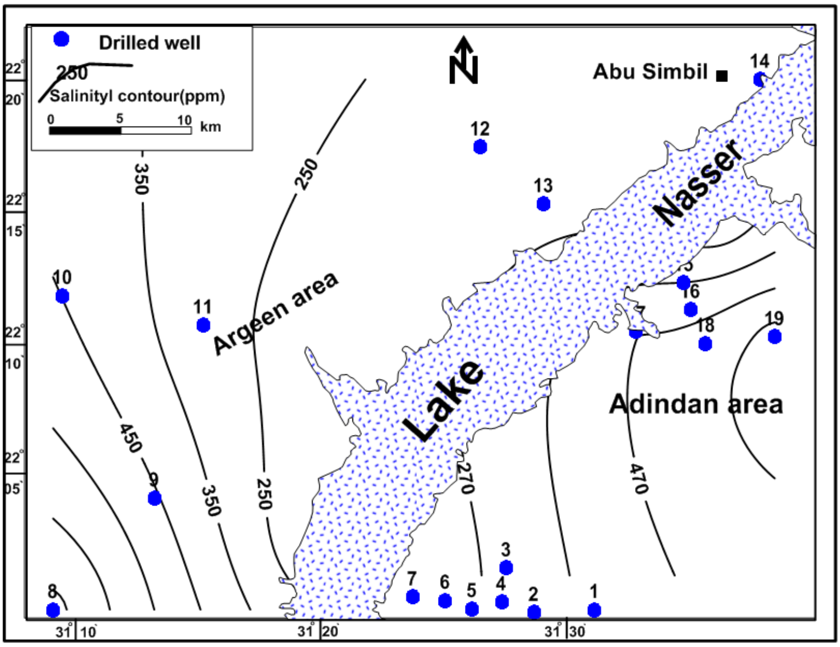

Fig. 10. Groundwater salinity of the study area (May, 2014).

The groundwater salinity map in May 2014 (Fig. 10) reveals an increase of groundwater salinity towards the west direction in Argeen area (west of Lake Nasser) and east direction in adindan area (east of Lake Nasser) conciding with the groundwater flow from Lake Nasser to abu Simbil sandstone aquifer.

2. Hydrochemical facies

Durov's diagram (15) and expanded of this diagram introduced by (16) and (17) give more information on the hydrochemical facies and the evolution of groundwater quality when compared with other graphical methods (18). It helps in identifying the hydrochemical facies or water types, groundwater flow direction and indicating the mixing of different water types and ion-exchang and reverse ion-exchange processes.

Durov's diagram (Fig. 11) was used to help in classifying the groundwater types. These types in the study area have four hydrochemical facies according to their order of importance. These types are 1, 2,4and 6. Type 1 is characterized by bicarbonate and calcium ions being dominant and type 4 has sulphate and calcium ions as dominant. These types indicate recharging area (Lake Nasser area). The two types (1 and 4) are recorded in wells nos. 11, 14 and 17. Type 2 (sample no. 19) is dominated by Ca and HCO_3 ions. Association with basement rocks rich in Mg if Mg is significant. Type 6 has sulphate and sodium ions as dominant and this indicates the probable mixing influence of types 3 and 5. This type is represented in well no. 8.

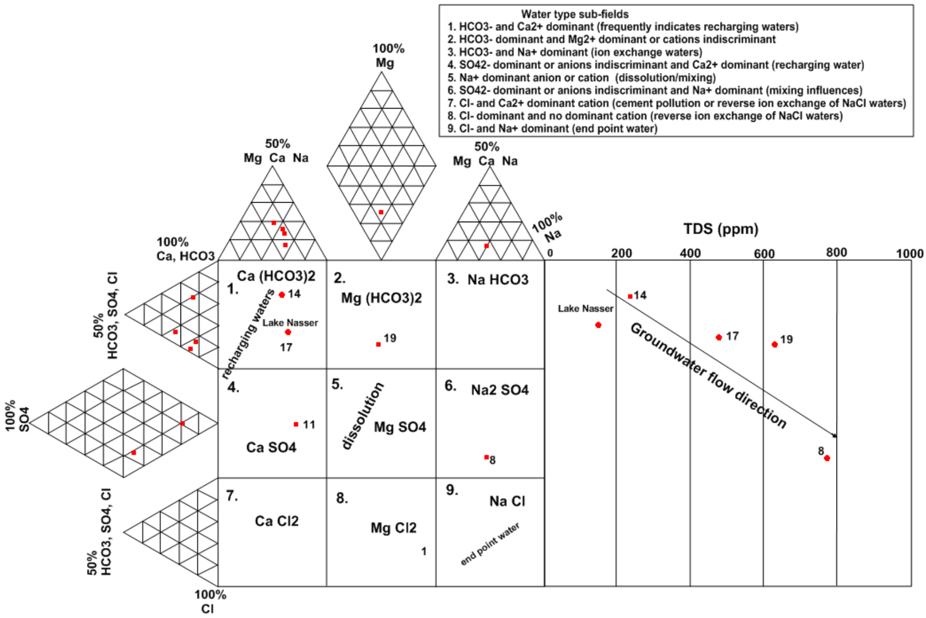

Fig. 11. Durov diagram (expanded) of the groundwater samples

It is noticed that the recharging area has low groundwater salinity, while the end point water has high groundwater salinity (Fig. 11). The groundwater salinity increases with the groundwater flow direction due to the dissolution and leaching of salts.

Conclusion

The study area is located in Lake Nasser Basin. The basement surface is deeper in Argeen area (west of the Lake Nasser) than the Adindan area in the east of Lake Nasser. The groundwater in the study area is avalible from Abu Simbil sandstone aquifer. The constructed water table map shows that the groundwater flows from Lake Nasser towards the Abu Simbil sandstone aquifer in Argeen and Adindan areas. The depth to water decreases upward in the same wells from (1965) to (2015) and ranges between 29.61m and 51.86m. This reflects the impact of Lake Nasser on the groundwater in the study area. The calculated transmissivity for two productive wells attains 409 m^2/day (Argeen area) and 305m^2/day (Adindan area) indicating moderate potential. The amount of recharge from Lake Nasser to adjacent Abu Simbil sandstone aquifer in the study area reaches 15 million m^3/year. The groundwater salinity of Abu Simbil sandstone aquifer ranges between 229ppm beside Lake Nasser and 782ppm away from the lake.

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الوضعية الهيدروجيولوجية لمنطقتى ارقين وادندان، على جانبى بحيرة ناصر، جنوب مصر

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يهدف العمل الحالى توضيح الظروف الهيدروجيولوجية لمنطقتى ارقين وادندان على جانبى بحيرة ناصر. يمثل مكون ابوسمبل الرملى خزان الحجر الرملى معظم سطح منطقة الدراسة. وتتوفر المياه الجوفية بمنطقة الدراسة من خزان ابوسمبل الرملى تحت الظروف الحرة ويتروواح العمق الى صخور القاعدة من 212 م بمنطقة ادندان بشرق البحيرة الى 313 م بمنطقة ارقين بغرب البحيرة. وايضا يتراوح السمك المشبع لخزان ابو سمبل من 30 م فى ادندان الى 300 م فى ارقين وتصل معدل التغذية من بحيرة ناصر لخزان ابو سمبل حوالى 15 مليون م^3/سنة وهذه التغذية ترفع منسوب المياه الجوفية. تتراوح الزيادة فى منسوب المياه الجوفية فيما قبل انشاء السد العالى لسنة (1965) وحتى تؤدى الى سنة (2015) خلال 50 سنة من 29.61م الى 51.86م وهذا يدل على تاثير بحيرة ناصر على المياه الجوفية. تم حساب معامل السريان حيث يصل الى 409م^2/يوم فى ارقين و305م^2/يوم فى ادندان وهذه القيم تدل على امكانية مياه جوفية متوسطة. تتراوح ملوحة المياه الجوفية لخزان ابو سمبل الرملى من 229 الى 782 جزء فى المليون وتزيد فى اتجاه حركة المياه الجوفية كلما بعدنا عن بحيرة ناصر.