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Estimating Geophysical and Hydrogeological Parameters through Well Logging and Hydrogeological Data in El-Sadat City Extension, West Nile Delta, Egypt

Ahmed G. Abuzaid [1*], Hassan S. Sabet [2] and Ayman M.M.AL-Temamy [3]

[1] *B.Sc. of Geology, Al-Azhar University*

[2] *Professor of Hydrogeophysics, Geology Department, Faculty of Science, Al-Azhar University, Cairo, Egypt*

[3] *Professor of Applied Geophysics, Head of Geophysical Exploration, Desert Research Center, Cairo, Egypt*

EL SADAT has several industrial projects that rely on water resources. Groundwater is one of the most important resources for these initiatives. The Quaternary aquifer is the principal aquifer in the research area. The research area includes a 9000-acre zone for a groundwater station in the process of being completed, as well as its environs. The current study examines the geophysical and hydrogeological properties of the Quaternary aquifer in the El Sadat City expansion. Twelve well logs were collected in the research region. We analyzed well-log data to determine shale volume content (V_{sh}), true resistivity (R_t), aquifer salinity at various depths, and depth to the water table in the research area. Thick sections of graded sand and gravel, each with clay lenses, comprise the subsurface strata in the examined area, according to the well logging data. Well logging results show that V_{sh} ranges from 16.6 to 5.3% of the average value of 10%, R_t ranges from 148.5 to 101 Ω.m of the average value of 124 Ω.m, salinity ranges from 695 to 270 ppm of the average value of 399 ppm, and static water level averages 27 M.G.L. Seven pumping tests were conducted in the study area. The pumping tests for wells show that their efficiency ranges from 66 to 97%, with an average of 84%. The aquifer's transmissivity ranges from 4133 to 14708 m^2/d, with an average value of 8474 m^2/d, indicating a high potential aquifer. The quaternary aquifer's hydraulic conductivity values range from 20.7 m/day to 133.6 m/day, with an average of 61.5 m/day, indicating that it is made up of coarse sand.

Keywords: Groundwater, Well logging, Pumping test, El Sadat city, West Nile Delta.

1. Introduction

The Western Desert of Egypt encompasses a significant portion of the vast territory that makes up Egypt. It accounts for approximately 68% of the entire land area of Egypt. Over the course of the past half-century, the West Nile Delta region has carried out a significant number of land reclamation projects. For the purposes of these activities, both surface water and groundwater were utilized (Hiscock, 2005). A 9000-acre zone that is now being constructed as a groundwater station is included in the study area, which is located to the north of Wadi El-Natrun El-Boraigat Road. Additionally, the study area comprises the lands neighboring the station. Latitudes 30° 27′ and 30° 32′ North and longitudes 30° 26′ and 30° 32′ East are the boundaries that define the study region (Fig. 1). The primary objective of this study is to evaluate the geophysical and hydrogeological properties of the Quaternary aquifer in the El Sadat City expansion, which is critical for supporting the numerous industrial projects in the region. Specifically, the research aims to analyze well-log data to determine shale volume content (V_{sh}), true resistivity (R_t), aquifer salinity at various depths, and the depth to the water table. Additionally, the study seeks to assess the subsurface strata composition and the efficiency of wells through pumping tests. By investigating the transmissivity and hydraulic conductivity of the aquifer, the study aims to determine its potential and capacity to sustain the water demands of ongoing and future industrial activities.

*Corresponding author e-mail: aabuzaid055@gmail.com

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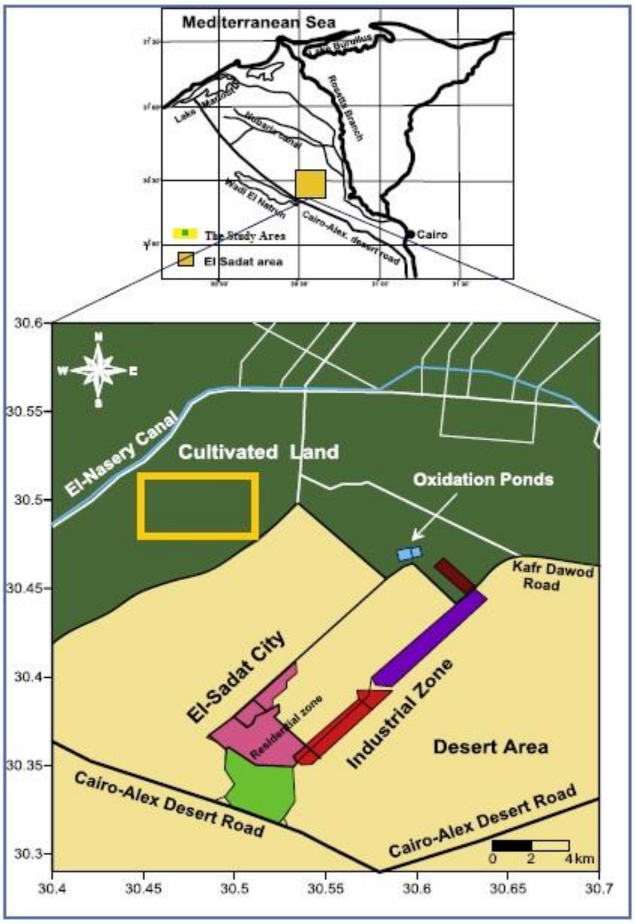

Fig. 1. Location Map of the Study Area.

2. Geologic Setting

Geologically, the Miocene, Pliocene, and Quaternary periods are the most outcropping sediments in the examined area and surroundings (Fig. 2). The sedimentary strata in the subsurface are approximately 4500 m thick and sit on basement rocks (El Ghazawi, 1982). After drilling a borehole, geophysical logging methods offer crucial information for pinpointing groundwater-containing layers in the subsurface. Many writers (e.g., Shata and El Fayomy 1967, Sanad 1973, El Ghazawi 1982, Abdel Baki 1983, Askalany and Eid 1998, El Abd 2005) have conducted studies on various aspects of the west Nile Delta region, including topography and geomorphology, geology, geophysics, and hydrochemistry. Usama Massoud et al. (2014) report that the shallow Pleistocene aquifer comprises sand and gravel saturated with fresh water, with a thickness exceeding 200 meters. In the El-Nubariya-Wadi El-Natrun neighborhood. Given its unrestricted nature in the El Sadat location, the Pleistocene aquifer may experience intrusion. Figure 3 illustrates the composition of the Quaternary aquifer, which consists of thick sections of successive layers of graded sand and gravel with clay lenses. The Quaternary aquifer was bounded by Wadi El Natrun NW-SE faults from the west and by El Khattab E-W fault in the south. The downthrown sides of these faults are into the east and north directions, respectively. So Quaternary aquifer comprises a subsidence area. Moreover, these structures have a great impact on the aquifer parameters (El Abd, 2005).

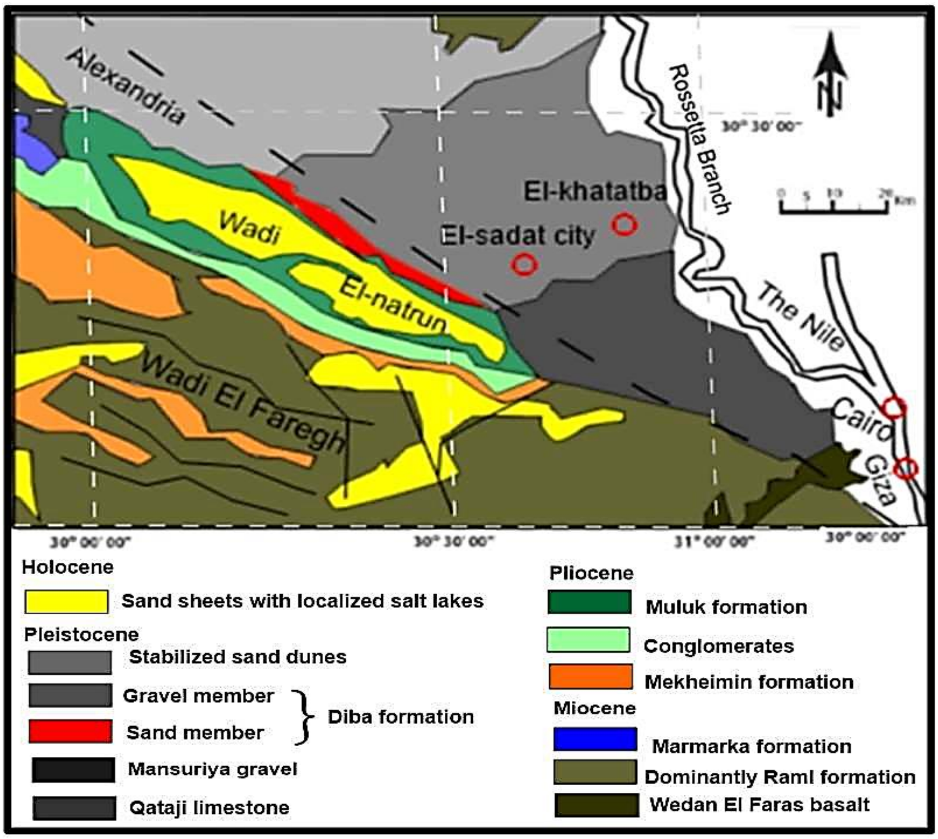

Fig. 2. Geological Map of the West Nile Delta Area modified from Abu Zeid, 1984.

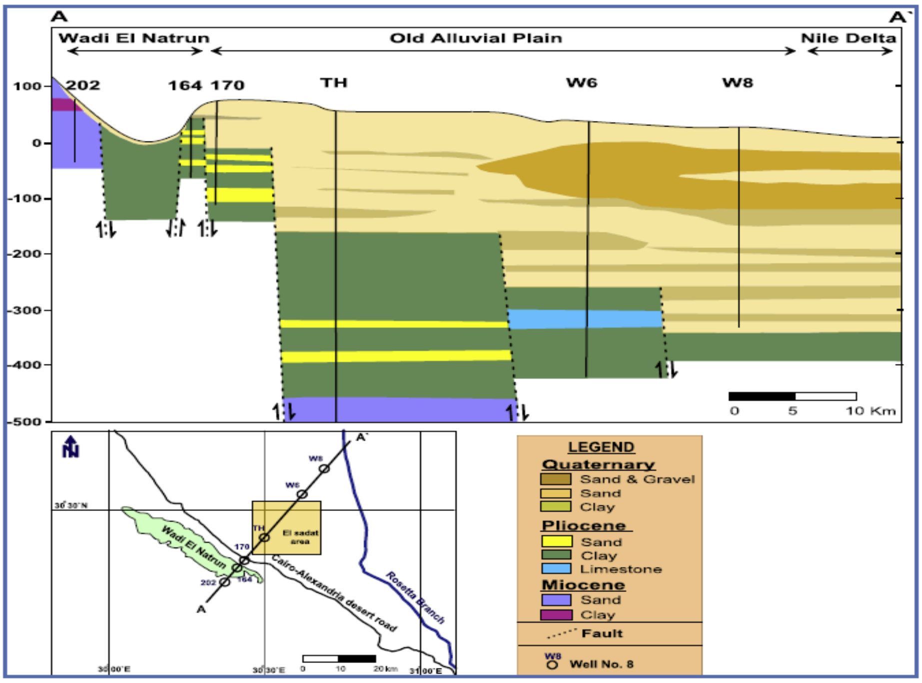

Fig. 3. Geological/hydrogeological cross-section of the shallow aquifers between Rosetta branch and Wadi El Natrun (El-Abd, 2005).

3. Materials and Methods

This study relies on the analysis and interpretation of well logging and pumping test data. Twelve well logs were measured in the study area (Fig. 4). The well logging data includes self-potential, resistivity, and gamma ray logs. The analysis of the well log data was utilized to determine shale volume content (V_{sh}), true resistivity (R_t), salinity of the aquifer at different depths, and depth to the water table in the study area (Fig. 5). The well logging results indicate that V_{sh} ranges from 16.6 to 5.3%, with an average of 10%. R_t ranges from 101 to 148.5 Ω.m, averaging 124 Ω.m. Salinity ranges from 270 to 695 ppm, with an average of 399 ppm. The static water level in all wells averages 27 MGL. The well logging data were used to construct two geologic cross-sections, indicating that the subsurface layers consist of thick sections of successive layers of graded sandstone with clay intercalations.

Seven pumping tests (step, constant, and recovery tests) were conducted in the study area. Step discharge tests are useful for evaluating a well's safe yield and the depth at which to position the pump. Constant pumping tests are effective to calculate the aquifer’s hydraulic parameters. Various hydraulic parameters were determined, including formation loss (B), well loss (C), efficiency (E), transmissivity (T), and hydraulic conductivity (K). Results from the pumping tests indicate a formation loss value of 8.7×10^{-4} and a well loss value of 1.4×10^{-7}. Well efficiency ranges from 66% to 97%, with an average of 84%. The aquifer's transmissivity ranges from 4133 to 14708 m²/d, averaging 8474 m²/d, indicating a highly potential aquifer. The hydraulic conductivity values of the Quaternary aquifer vary from 20.7 m/day to 133.6 m/day, averaging 61.5 m/day, suggesting the aquifer material is primarily coarse sand.

4. Results and Discussion

The well logging and pumping tests were very helpful in understanding the Quaternary aquifer's geophysical and hydrogeological features in the El Sadat City expansion area. The results reveal significant variations in shale volume content, true resistivity, salinity, and static water levels, which have implications for groundwater resource management and utilization. We will briefly discuss the results below.

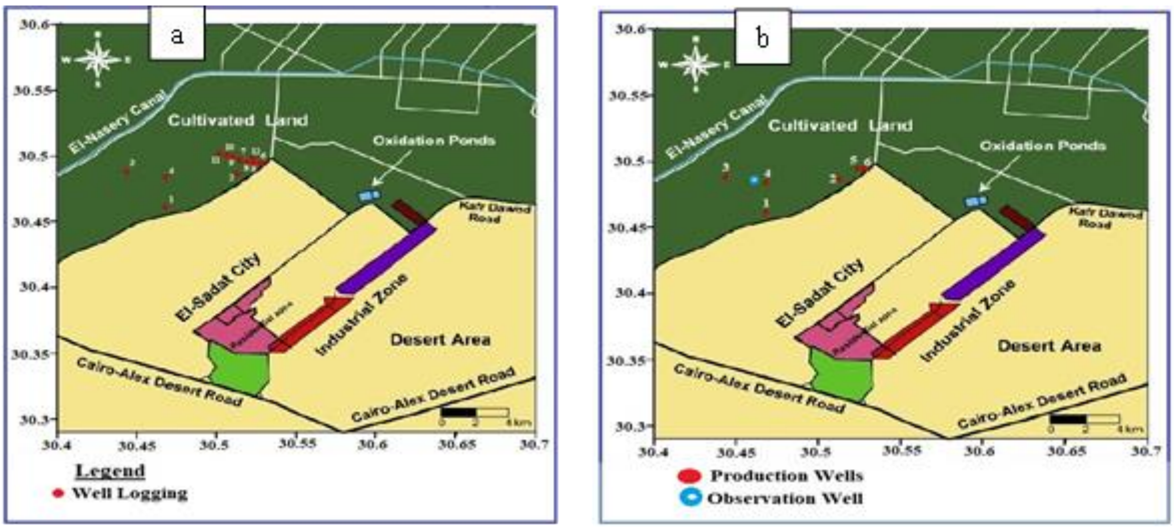

Fig. 4. a) Well Logging Sites Map, b) Pumping Test Sites Map.

4.1 Geophysical well logging

The evaluation of water-bearing layers in the study area relies heavily on well-log analysis (Fig. 5). The figure illustrates the composite log analysis of Well No. 1. The interpreter can obtain more information by comparing one log with another of the same or different type. Two correlation profiles, 1 and 2, were established using the information inferred from available logs, especially gamma-ray and resistivity logs. Figures (6 and 7) represent two correlation profiles. The geologic cross-sections reveal three geological layers composing the subsurface section; the initial layer is the uppermost layer, composed of dry sandstone with an average thickness of 27 meters. The second layer corresponds to the primary aquifer in the research region, referred to as the quaternary aquifer. It is composed of sandstone and claystone layers, with an average thickness of 200 m. The third geologic layer consists of claystone, which has an average thickness of 20 meters. The geologic sections indicate that the static water level is at 27 meters below ground level (M.G.L.).

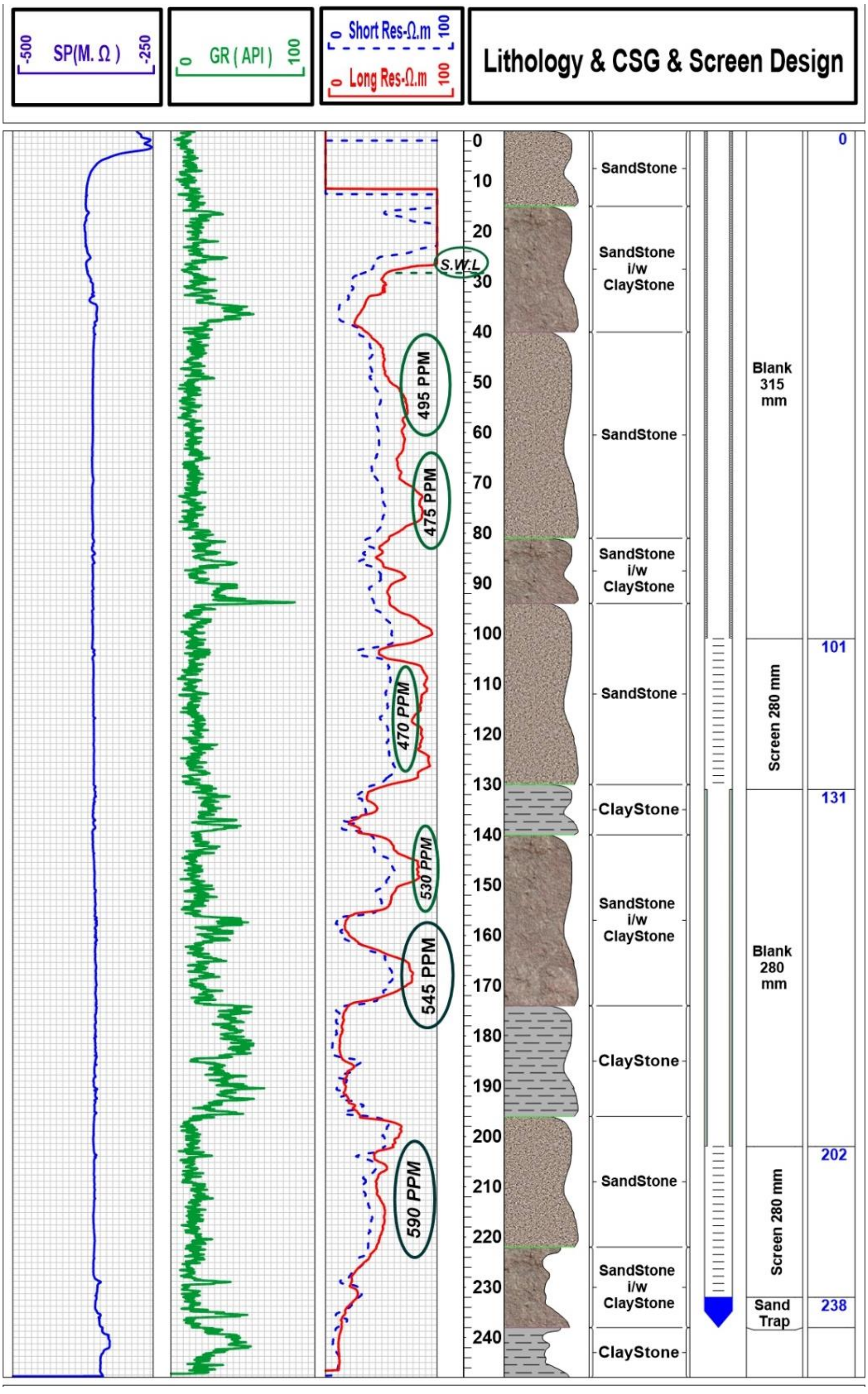

Fig. 5. Log analysis of Well 1.

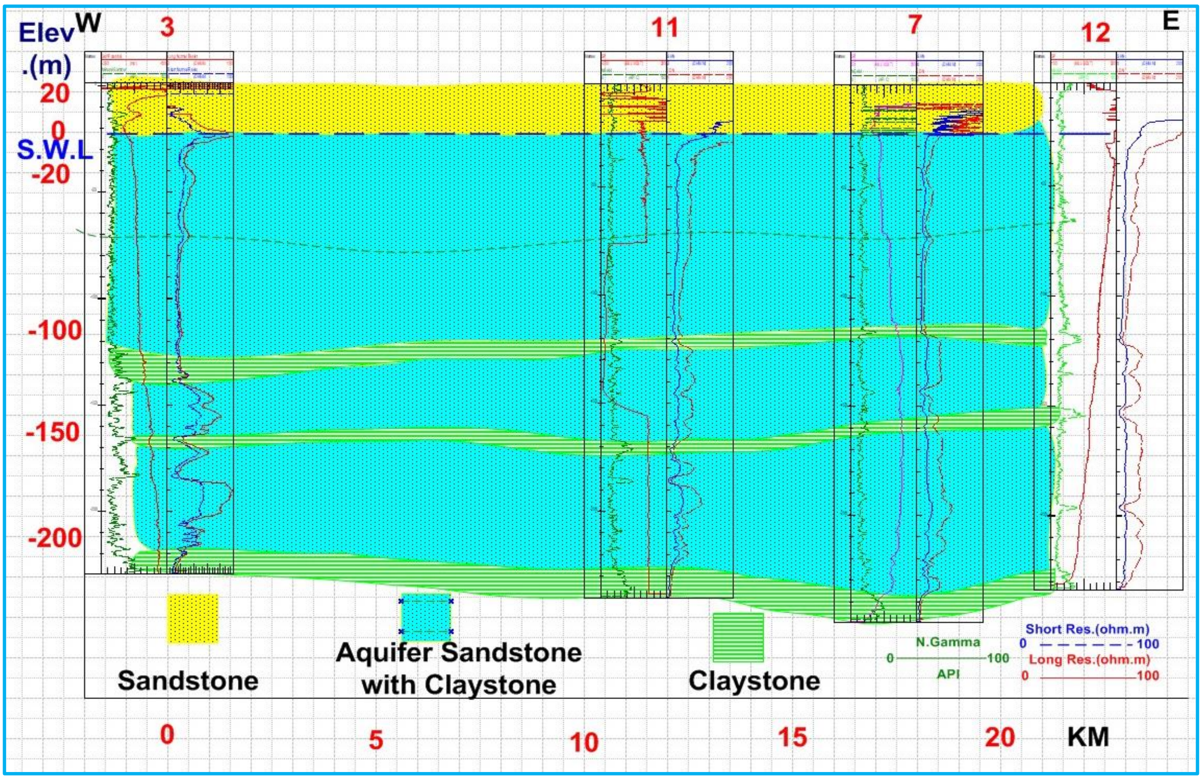

Fig. 6. Lithostratigraphic correlation using natural gamma ray and resistivity logs at profile 1.

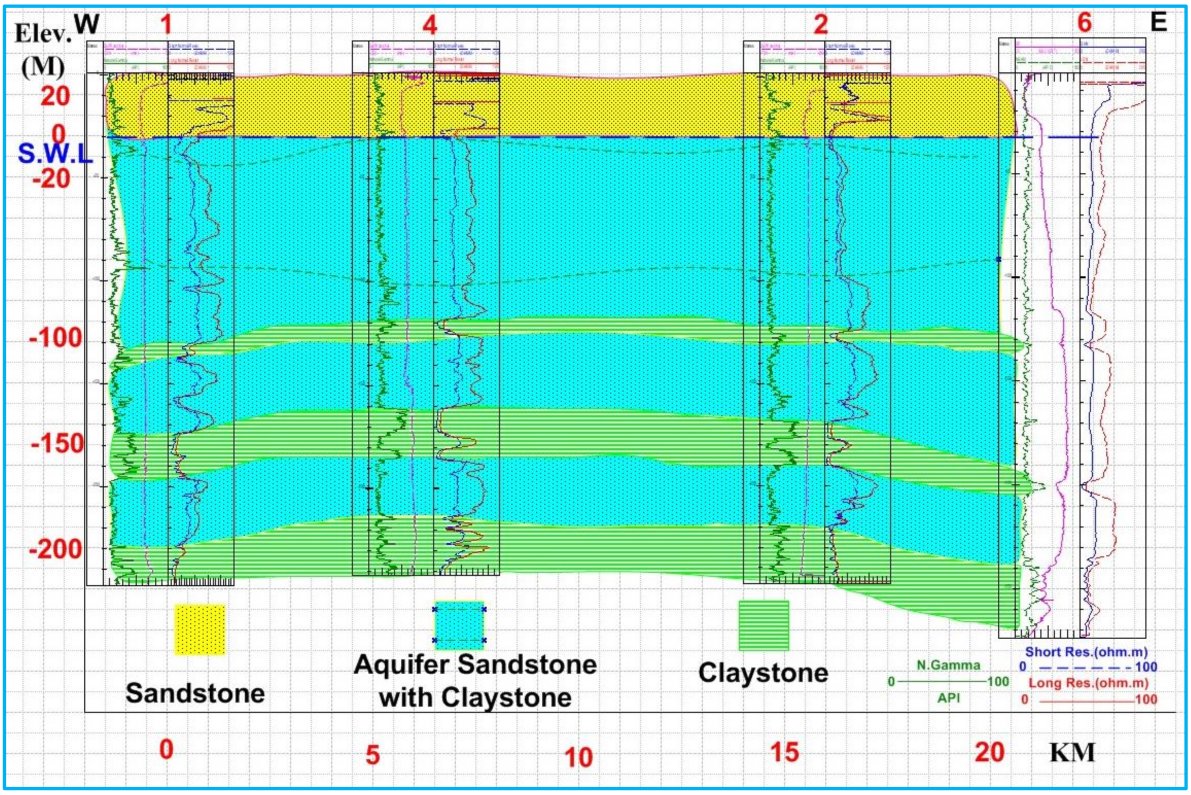

Fig. 7. Lithostratigraphic correlation using natural gamma ray and resistivity logs at profile 2.

4.1.1 Electric logs

The electric log serves as an excellent correlation tool, providing a clear indication of the general material composition of each bed. In addition, the formation's pore space volume, fluid quantity, and type can be determined.

a) True Resistivity (R_t).

We calculated the true resistivity using the Schlumberger (1972) formula based on the long normal resistivity (LLD) and short normal resistivity (LLS) curves.

If LLD > LLS, $R_t = 1.7\ LLD - 0.7\ LLS$ …..… (1)

If LLD < LLS, $R_t = 2.4\ LLD - 1.4\ LLS$ …..…. (2)

The maximum R_t of the water zone in the quaternary aquifer attains 148.5 Ω.m at well (6), and the minimum R_t reached 101 Ω.m at well (1) (Fig. 8a).

b) Salinity.

The concentration of ions in the solutions has an impact on the LLD and LLS values. The present study calculated the formation water resistivity (R_W) and determined the total dissolved solids (TDS) in parts per million (ppm) for the formation water in several well logs within the study area. The TDS values were obtained by applying the formulae supplied by Davis and Deweist (1966) to the conductivity data.

$C = 10000 / R_w$ …..… (3)

$TDS = 0.64 * C$ …..… (4)

C represents the conductivity in micromhos/cm.

The maximum TDS in the quaternary aquifer attains 695 ppm at well (7), and the minimum TDS reached 270 ppm at well (5) (Fig. 8b).

4.1.2 Gamma-ray logs

Gamma-ray logs are a crucial instrument for finding and quantifying the V_{sh} (Dresser, 1982). This is due to the normal concentration of radioactive minerals in clay and shale (Schlumberger, 1984).

a) Shale Volume (V_{sh}).

The current study involves the calculation of shale volume (V_{sh}%) for each zone of the various composite logs. This is done by employing the gamma-ray logs and applying the following equation (Schlumberger, 1984):

$V_{sh} = GR_{log} - GR_{min} / GR_{max} - GR_{min}$ …..… (5)

The single measured gamma-ray value is denoted as GRlog.

GRmax represents the maximum gamma-ray value.

GRmin represents the minimum gamma-ray value.

We can divide the rock zones into three categories based on the percentage of shale in each zone: Clean rock: where $V_{sh} < 10\%$.

Shaly rock: where $10\% < V_{sh} < 33\%$.

Shale rock: where $V_{sh} > 33\%$.

This study's effective zones are the clean rock zones and the shaly rock zones, which are the most intriguing of them. The maximum V_{sh} in the quaternary aquifer attains 16.6% at well (6), and the minimum V_{sh} reached 5.3% at well (8) (Fig. 8c).

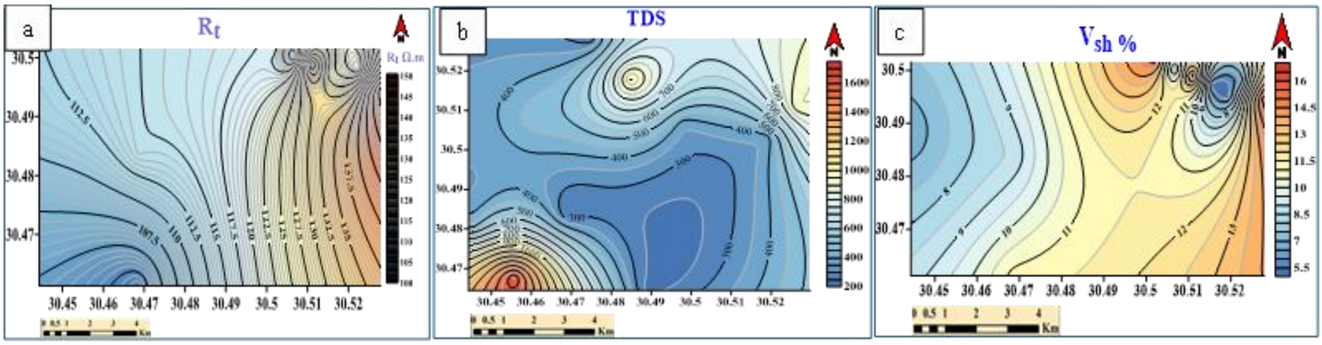

Fig. 8. a) The True Resistivity Contour Map, b) The TDS Contour Map, c) The V_{sh} Contour Map.

4.2 Hydrogeology

Pumping experiments are utilized to determine the hydraulic properties of the aquifer. The pumping test is based on measuring the discharge and the subsequent drawdown at a given time. These readings can be utilized to compute the aquifer's hydraulic properties. For example, the pumping test data for well 2 in the study region (Table 1) includes step drawdown, continuous discharge, and recovery tests. (Figure 9).

4.2.1 Step discharge tests

Step drawdown test data provide information on well design, efficiency, safe yield, and pump setting depth by calculating the aquifer loss coefficient (B) and the well loss constant (C).

The step-drawdown test data were utilized to provide information regarding the well design and efficiency as well as to establish the required safe yield and setting pump depth by computing the aquifer loss coefficient (B) and well loss constant (C). These two parameters (B and C) were calculated using the findings of the step drawdown test (Jacob,1947). Jacob (1947) proposed the following equation for calculating the total drawdown (S):

$S = BQ + CQ^2$ …..… (6)

By plotting S/Q against Q (the discharge) and drawing a straight line across the data points, the slope of the line can be used to calculate the well loss coefficient (C). Additionally, the point where the line intersects the S/Q axis at Q = 0 can be used to derive the formation loss coefficient (B) (Todd, 1980). Jacob (1964) gives an approximate estimate of the entire decline using the following equation:

$S = BQ + CQ^2$. (6)

Where S represents the total drawdown in meters, Q represents the discharge rate in m3/day, C represents the well loss in d^2/m^5, and B represents the formation loss constant in d/m^2. Based on the graph, the B = 8.3 × 10-4 d/m^2 and the C = 1.1 × 10−7 d2/m5 (Fig. 9a). Then we may apply this equation to calculate well efficiency.

$E = (BQ/(BQ+CQ^2)) \times 100$ …..… (7)

The ratio of aquifer loss to total drawdown in the well expresses the efficiency of a pumping well (Kruseman and de Ridder 1970). Table 2 shows that well 2 in the study region has a 95% efficiency.

4.2.2 Constant discharge tests

This test is one of the most successful methods to determine the aquifer’s hydraulic properties. To achieve satisfactory results, it is crucial to study the optimal design and pumping well construction (Driscoll, 1986). The test results for well 2 (Fig. 9b) show a linear relationship between the observed drawdown (s) and time (t), with a slope of s (Jacob 1964).

$T = 0.183 \times Q/s$ …..… (8)

The variables used in this context are as follows: T represents transmissivity, measured in square meters per day (m^2/d); Q represents discharge, measured in cubic meters per day (m^3/d); s represents the slope of the line, measured in meters per log cycle; and Tp indicates a transmissivity value of 14493 m^2/d, indicating a high potential aquifer (see to Figure 9b). The value of T_r is 13176 square meters per day, as shown in Figure 9c. T_p and T_r represent the parameters that measure the ability to transmit and recover throughout continual testing and recovery tests. Table 3 displays the categorization of aquifer potentiality according to transmissivity values, as outlined by Gheorhg in 1979. Table 4 displays the range of recommended safe yield for the wells, measured in cubic meters per hour (m^3/h), which varies from 124 m^3/h to 172 m^3/h. Additionally, the table indicates the range of maximum drawdown, measured in meters (m), which ranges from 0.53 m to 7.88 m. In addition, the transmissivity for the constant test (T_p) ranges from 4133 m2/d to 14708 m^2/d, while the transmissivity for the recovery test (T_r) ranges from 3346 m^2/d to 13176 m^2/d. Out of the wells that were checked, 84% of them were found to be functional. The hydraulic conductivity of the continuous test ranges from 25.6 (m/d) to 133.6 (m/d), whereas the hydraulic conductivity of the recovery test ranges from 20.7 (m/d) to 121.5 (m/d). This indicates that the aquifer material is coarse sand, as stated by Schoeller in 1962 (Table 5).

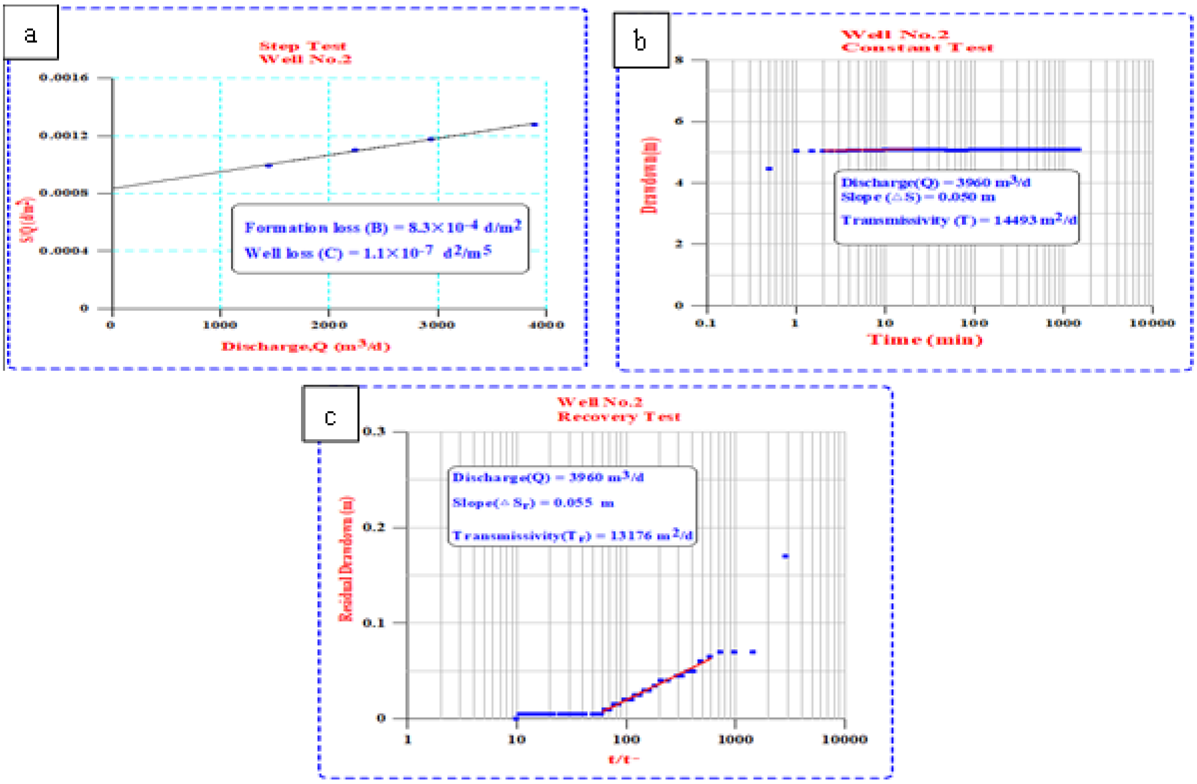

Fig. 9. a) Step-drawdown pumping test for well 2, b) Constant test for well 2. c) Recovery test for well 2.

Table 1. Step drawdown test results for well 2.

Step NO.	Discharge (Q)m^3/h	Discharge (Q)m^3/d	Drawdown (s) meters	s/Q (d/m^2)
1	60	1440	1.43	9.99×10^{-4}
2	93	2232	2.46	1.10×10^{-3}
3	122	2928	3.45	1.18×10^{-3}
4	165	3960	4.98	1.28×10^{-3}

Table 2. Well efficiency results for well 2.

Step NO.	Discharge (Q)m^3/d	BQ	CQ2	Efficiency %
1	1440	1.19	0.22	84
2	2232	1.85	0.54	77
3	2928	2.43	0.94	72
4	3960	3.28	1.72	65

Table 3. Classification of the aquifer potentiality according to transmissivity values (Gheorhg, 1979).

Potentiality of the aquifer	Transmissivity (m^2/day)	Potentiality of the aquifer	Transmissivity (m^2/day)
Highly potential	> 500	Very low potential	5 – 0.5
Moderate potential	500 – 50	Negligible potential	< 0.5
Low potential	50 – 5		

Table 4. Results of pumping test in the study area.

Well No. / Results	1	2	3	4	5	6	Observation well
Total Depth (m)	248	248	232	242	242	273	160
Water Table (m)	28.37	24.59	30.93	29.91	29.91	26	8.65
Formation loss (B)(d/m^2)	$1.09 * 10^{-3}$	$8.3 * 10^{-4}$	$1.6 * 10^{-3}$	$1.1 * 10^{-3}$	$8.7 * 10^{-4}$	$7.8 * 10^{-4}$	$1.3 * 10^{-4}$
Well loss (C) (d^2/m^5)	$4.02 * 10^{-8}$	$1.16 * 10^{-7}$	$7.7 * 10^{-8}$	$9.7 * 10^{-8}$	$1.4 * 10^{-7}$	$1.3 * 10^{-7}$	$2.9 * 10^{-9}$
Efficiency (%)	87	74	84.5	82.5	68	66	93
Discharge (Q) (m^3/h)	١72	165	160	144	124	128	144
Max drawdown (s) (m)	5.56	5.09	7.88	5.44	3.84	3.64	0.53
Transmissivity (T_p) (m^2/d)	12184	14493	4133	14708	--	--	5270
Transmissivity (T_r) (m^2/d)	5395	13176	3346	6588	--	--	5452
K (m/d) (Constant test)	70.17	133.6	25.6	88	--	--	42.1
K (m/d) (Recovery test)	31	121.5	20.7	39.4	--	--	43.6

Table 5. Magnitude of the hydraulic conductivity of different types of materials (Schoeller, 1962).

Type of material	Hydraulic conductivity
Clay	10^{-5} to 10^{-7}
Silt	0.1
Fine Sand	0.1 to 1
Coarse Sand	1 to 100
Gravel	100 to 1000 (or more)

5. Conclusions

The detailed study of well logging and pumping tests in the area where El Sadat City is growing taught us a lot about the Quaternary aquifer's geophysical and hydrogeological features. The geophysical well logging results showed that the structure below the ground is made up of three layers of rock: a dry sandstone layer on top, a large Quaternary aquifer of sandstone mixed with claystone, and a claystone layer below that. Notably, the aquifer is characterized by interbedded clay lenses within the sand and gravel formations, with the static water level at 27 meters below ground level (M.G.L.).

The geophysical analysis indicated that the shale volume (V_{sh}) in the wells ranges from 5.3% to 16.6%, with an average of 10%. Salinity levels, as indicated by TDS, vary from 270 ppm to 695 ppm, with an average of 399 ppm. These variations in shale volume and salinity highlight the spatial heterogeneity of the aquifer and its water quality.

Pumping tests provided further characterization of the aquifer's hydraulic properties. Well efficiency ranges from 66% to 97%, with an average of 84%. The aquifer exhibits high transmissivity, ranging from 4,133 m²/day to 14,708 m²/day, with an average of 8,474 m²/day, indicating its significant potential for groundwater extraction. Hydraulic conductivity values range from 20.7 m/day to 133.6 m/day, with an average of 61 m/day, further confirming the high permeability and productivity of the quaternary aquifer.

Overall, the study underscores the importance of integrated geophysical and hydrogeological assessments for optimizing groundwater resource management. The identified variability in aquifer properties necessitates tailored strategies for water extraction and utilization, ensuring the long-term sustainability of groundwater resources in El Sadat City. Future work should focus on continuous monitoring and advanced modeling techniques to refine groundwater management practices and support the region's development needs.

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حساب المعاملات الجيوفيزيائية والهيدروجيولوجية من خلال تسجيل الآبار والبيانات الهيدروجيولوجية بامتداد مدينة السادات، غرب دلتا النيل، مصر

أحمد أبوزيد[١]، وحسن صالح[٢]، وأيمن التمامي[٣]

(١) بكالوريوس فى العلوم، قسم الجيولوجيا، كلية العلوم، جامعة الأزهر، أسيوط، مصر

(٢) أستاذ الهيدروجيوفيزياء، قسم الجيولوجيا، كلية العلوم، جامعة الأزهر، القاهرة، مصر

(٣) أستاذ الجيوفيزياء، قسم الجيوفيزياء، مركز بحوث الصحراء، المطرية، القاهرة، مصر

منطقة السادات تضم العديد من المشروعات الصناعية والتي تحتاج إلى وجود مصادر مائية، والمياه الجوفية هي واحدة من المصادر الرئيسة لهذه المشاريع والخزان الرباعي يمثل المتكون الرئيس الحامل للمياه في منطقة الدراسة. منطقة الدراسة تشمل نطاق ٩٠٠٠ فدان كمحطة مياه جوفية تحت الإنشاء ومحيطها، الدراسة الحالية تأخذ بعين الاعتبار المعاملات الجيوفيزيائية والهيدروجيولوجية للخزان الرباعي في امتداد مدينة السادات الواقعة شمال طريق وادي النطرون – البريجات. تم استخدام تسجيلات الآبار لعدد ١٢ بئر في منطقة الدراسة، تم تحليل بيانات الآبار المعطاة لحساب محتوى حجم الطين والمقاومة الحقيقية وملوحة الخزان عند أعماق مختلفة مثل نوع كلويد الصوديوم وقياس منسوب المياه الجوفية في منطقة الدراسة. تشير بيانات تسجيلات الآبار إلى أن الطبقة التحت سطحية للمنطقة التي تم فحصها تتكون من أقسام سميكة من طبقات متتالية من الرمل والحصى المتدرج مع عدسات طينية. تشير نتيجة تسجيلات الآبار إلى أن حجم طبقات الطين المتداخلة مع الخزان في الآبار تتراوح من ١٦,٦ إلى ٥,٣ % ومتوسط القيم ١٠%، والمقاومة الحقيقية تتراوح من ١٤٨,٥ إلى ١٠١ أوم *متر ومتوسط القيم ١٢٤ أوم *متر، ملوحة الآبار تتراوح من ٦٩٥ إلى ٢٧٠ جزء في المليون ومتوسط القيم ٣٩٩ جزء في المليون، ومتوسط مستوي الماء الاستاتيكي في جميع الآبار ٢٧ متر. تم إجراء ٧ إختبارات للضخ في منطقة الدراسة وتشير نتيجة اختبارات الضخ للآبار أن كفاءة الآبار تتراوح من ٦٦ إلى ٩٧ % بمتوسط ٨٤ %. التوصيلية (السماحية) تتراوح من ٤١٣٣ إلى ١٤٧٠٨ م٢/يوم ومتوسط القيم ٨٤٧٤ م٢/يوم والتي تمثل خزان واعد للغاية، وتتراوح القيم المتفاوتة للتوصيل الهيدروليكي للخزان الرباعي من ٢٠,٧ إلى ١٣٣,٦ م/يوم ومتوسط القيم ٦١,٥ م/يوم وهو ما يمثل خزان من الرمل الخشن.