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Groundwater hydrology and characteristics of the tertiary aquifers, Northwest Cairo, Egypt

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ABSTRACT

The study area lies to the northwest of Cairo at Km.34 (Cairo – Alexandria Desert Highway) between latitudes 30° 00' 00" N & 30° 10' 00" N and longitudes 30° 50' 00" E & 31° 10' 35" E. It attains an area of about 590 Km^2. The main objective of the present work is to focus on the configuration and assessment of groundwater potentials of the Tertiary aquifers including the Lower Miocene (Moghra Formation), Oligocene and Eocene limestone. These aquifers are considered as moderately productive where their transmissivity values are (197.5 &1352), 92.9 and 150 m^2/day and their specific capacity are (5.9 & 12.7), 7.6 and 5.2 m^3/h/m, for the Miocene, Oligocene and Eocene aquifers, respectively. The general flow direction of the groundwater is from east to west and from southeast to northwest with some local changes which may be attributed to the over-exploitation at these locations. The ranges of the water salinities of these aquifers are 288-3776, 2000-3100 and 2715-13120 mg/l for the Miocene, Oligocene and Eocene aquifers, respectively. The inferred faults play an important role in the direct hydraulic connection between the three aquifers.

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Groundwater; hydrology; oligocene; transmissivity; specific capacity

1. Introduction

Northwest Cairo area is considered as a part of the West Nile Delta of Egypt, where it is one of the most important areas in Egypt for agricultural investments due to its high groundwater potentials, accessibility and official facilities provided by the government. The area in the western Nile Delta fringes is subjected to intensive land reclamation activities using groundwater as a source of water supply in the study area. The concerned area is characterised by a long hot summer and a short warm winter. The average minimum air temperature is recorded during January and it varies from 7°C to 9°C, while the maximum air temperature is recorded in July ranging between 34.1°C and 34.9°C. Also, the total annual rainfall ranges between 18.4 mm/year and 26.25 mm/year (Embaby 2003).

In the last decade West Nile Delta of Egypt suffered from water deteriorations in its quantity and quality which made a problem for the investors in the cultivation.

The main objectives of the present study are to study the characteristics of the dominated aquifers and to highlight on the groundwater potentialities at the Northwest of Cairo area aiming to realise the sustainable development of such area. In the study area, the groundwater resources are represented by the Quaternary aquifer and the Tertiary aquifers (Lower Miocene, Oligocene and Eocene aquifers). Several factors play a significant role in the occurrence and sustainability of groundwater such as sedimentary succession, geologic structure and lateral facies change. In the present study the lithological sequence, the total drilled depth, water level, water salinity, depth to basaltic sheet were collected for the investigated wells to delineate the followings:

- The sedimentary succession and its vertical and lateral facies changes.
- The extension of water-bearing formations
- The hydrological characteristics of the existing aquifers.
- The impact of geological structures on the groundwater occurrences as well as the hydraulic connection between the existed aquifers.
- The distribution of the basaltic sheet and its impact on the groundwater occurrences.
- The hydraulic parameters of the existed aquifers.

The area of study has been subjected to many studies, aiming to delineate the geomorphological, geological and hydrological setting. Some of these works that are Shata (1961) & Shata (1962), Said (1962 & 1990), Shata and El Fayoumy (1967), Sanad (1973), Omara and Sanad (1975), El Ghazawi (1982), Abd El Baki (1983), CONOCO (1987), Gomaa (1995); Abd El Rahman (1996), Ahmed (2002), El Abd (2005), Ibrahim (2005) and Elsheikh and Ahmed (2014).

M. Gad et al. (2016) concluded that the increase of human activities in the West of the Nile Delta area resulted in more exhaustion of groundwater from the

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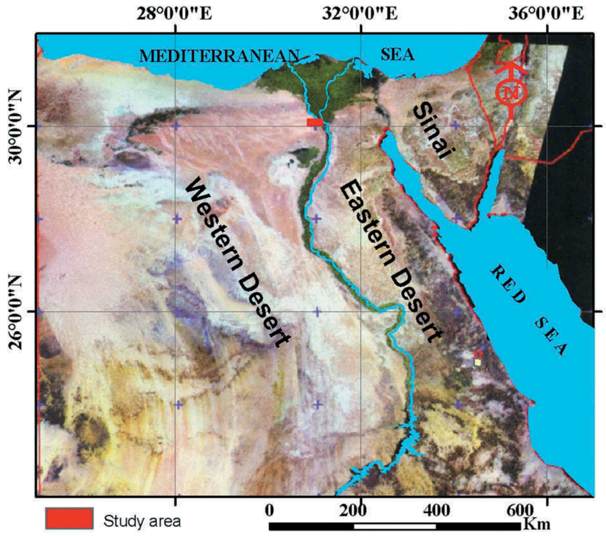

Figure 1. Location map of the study area.

Miocene aquifer which is accelerated also by the poverty of groundwater recharge.

A.M.A. Youssef et al. (2017) revealed that the water depletion in the West of the Nile Delta area was approximately between 1.3 m/year and 1.7 m/year in 2003 and 2015, respectively. Also, they conducted that the water salinity of the Miocene aquifer varies from 234 mg/L to 2458 mg/L which attributed to interaction with the Oligocene aquifer which has higher water salinity.

Mohamed M. Sobeih et al. (2017) concluded that about 28,101,041 m^3/day of surface water is infiltrated to groundwater dominantly from canals and excess irrigation water and about the same quantity 28,101,052 m^3/day is discharged from groundwater through productive wells, open drains and through reaches of canals.

2. Location of the study area

The study area (Figure 1) is bounded by latitudes 30° 00′ 00” N to 30° 10′ 00” N and longitudes 30° 50′ 00” E to 31° 10′ 35” E. It lies to the northwest of Cairo at Km. 34 (Cairo – Alexandria Desert Highway) with an area of about 590 km^2.

3. Geomorphological, geological and hydrological setting

3.1. Geomorphological setting

The area west of the Nile Delta constitutes a portion of the great arid belt covering Egypt and is divided into four geomorphological units (Shata and El Fayoumy 1967) namely the alluvial plains, the structural plains, the tablelands and the drifting sand. The alluvial plains are differentiated into two main units, namely; young alluvial plains (Recent flood plains) and old alluvial plains (gravelly terraces).

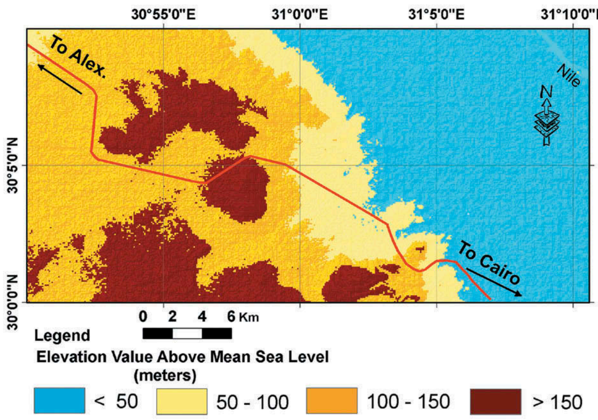

Figure 2. Digital Elevation Model (DEM) of the study area.

The investigated area is a part of the old alluvial plain, the young alluvial plain and the structural plains. The area is characterised by a slightly undulating land surface, where the ground elevation varies from less than 50 m at the east to more than 150 m at the west. Generally, the slope is from the west to the east towards the Nile Delta as shown in the Digital Elevation Model (Figure 2).

3.2. Geological setting

The study area is occupied by sediments and sedimentary rocks ranging in age from the Late Cretaceous to Quaternary. However, the surface deposits dominating the area are studied through the geological map scale 1:500000 issued by CONOCO (1987) which shown in Figure 3.

The Late Cretaceous rocks are the oldest exposed sedimentary rocks formed of limestone and chalk and have a local occurrence at Abu Roash area.

The Eocene and Oligocene deposits are of limited distribution whereas the Miocene, Pliocene and Pleistocene deposits are the most outcropping sediments in the study area and, the Mid-Tertiary basaltic sheets are the only exposed volcanic rocks in the south part of the study area.

From the structural point of view, a major fault trending NW-SE and runs approximately parallel to Rosetta branch is found to separate the Delta Basin from the area to the West (El Shazly et al. 1975). Moreover, the area west of the Nile Delta is characterised by many minor faults that contributed to the groundwater occurrences. In the study area different faults related to the Syrian arc and Clysmic systems, have been presented by El Ghazawy and Attwa (1994).

3.3. Hydrogeologically

In the study area, the sedimentary succession comprises several water-bearing formations belonging to different ages such as Pleistocene, Lower Miocene

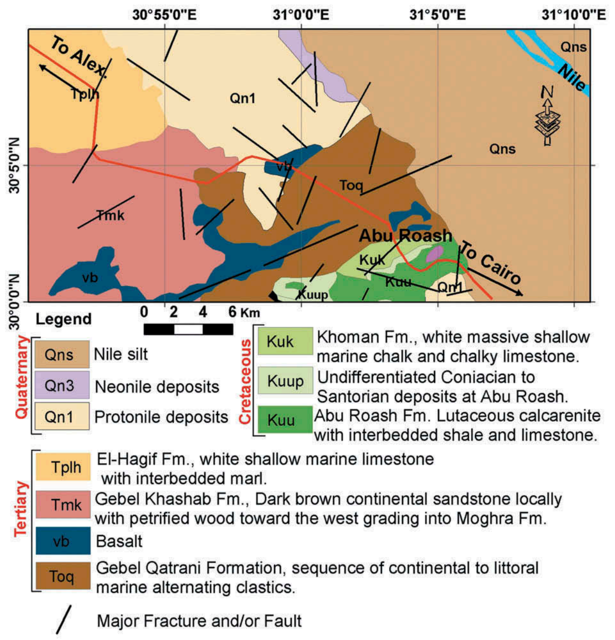

Figure 3. Geological map of the study area (Modified after CONOCO 1987).

(Moghra Formation), Oligocene and Eocene aquifers which are particularly influenced by the structural features.

4. Materials and methods

In the present work, both field and lab works were carried out through the investigation of 119 wells (Figure 4) tapping the Pleistocene, Lower Miocene (Moghra), Oligocene and Eocene aquifers. Through the field investigations the data of the drilled wells were measured including depth to water, long duration and step discharge pumping tests and water sampling. Also, through the personal contact with the farm's owners, all available data of these wells were collected including drilling date, total drilled depth, lithological logs, depth to water and water salinity. Such investigations have revealed that the dominated aquifers in the study area fall into two broad categories: unconsolidated aquifers (granular) including the Pleistocene, Lower Miocene (Moghra) and Oligocene aquifers and consolidated fractured aquifer represented by the Eocene fractured limestone aquifer of secondary porosity.

The analysis of the pumping tests was achieved by the application of the GWW software.

One of the primary goals of groundwater resource evaluation must be the prediction of hydraulic head drawdown in aquifers under proposed pumping schemes. The theoretical response of idealised aquifers to pumping should be examined.

4.1. Time-drawdown and recovery tests

In the present study, four time-drawdown and recovery tests were carried out, where two wells tapping the Miocene, one well tapping the Oligocene and one well tapping the Eocene fractured limestone. Jacob (1950) equations were applied for analysing the pumping tests for the porous media aquifers (Miocene and Oligocene). For the Eocene fractured aquifer, the transmissivity can be approximated from specific capacity by the following simple linear equation (Verbovsek 2008).

$$T = C\ (Q/s)$$

where

T is the transmissivity m^2/day, Q/s is the specific capacity m^3/day/m

C is constant value and is found to vary from 0.9 to 1.5 with an average of 1.2 (Jalludin and Razack 2004) or 1.22 (Misstear 2001)

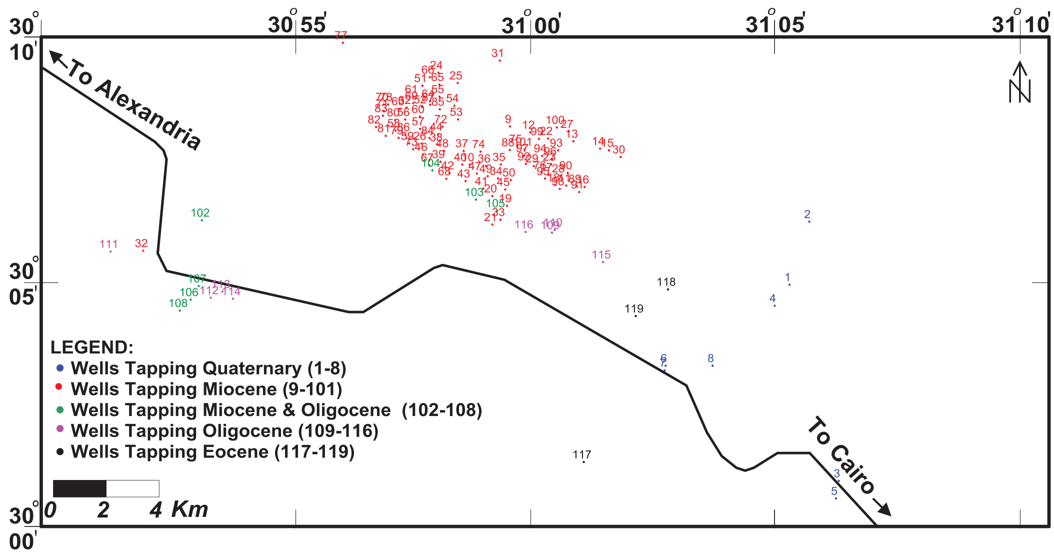

Figure 4. Location map of investigated wells in the study area.

4.2. Step pumping tests

For the step pumping tests, the total drawdown (s_t) in a pumping well can be expressed in the form of the following equation:

$$s_t = s_a + s_b$$

where s_a is the drawdown in the aquifer at the effective radius of the pumping well, s_b is well loss.

5. Results and discussions

5.1. Aquifer systems

In the granular aquifers, the water is stored and transmitted through pore spaces between individual sediment granules but in fractured rock aquifers store and transmit water are taking place through crevices, joints and fractures which are invariably unevenly distributed within the rock formation. Due to their nature, they present unique problems in their investigation, evaluation and management, largely because of their heterogeneous nature, and the dependence of aquifer properties on fracture distribution, connectivity, width and extent.

5.1.1. Pleistocene aquifer

This aquifer occupies the eastern part of the study area and is represented by the well Nos. 1–8. It is composed of sand, gravel and clay intercalations. The depth to water of the wells tapping this aquifer ranges between 18.2 m at well No. 2 and 29 m at well No. 8. The salinity of this aquifer ranges between 700 ppm (Well No.4) and 5000 ppm (Well No.7). The high salinity may be attributed to the effect of the drainage water in Abu Roash area.

5.1.2. Lower miocene (Moghra) aquifer

This aquifer is considered as the main water resource in the study area where the most investigated wells are tapping this aquifer (Well Nos. 9–101). It is composed of sand and gravels with clay intercalations. The depth to water of the wells tapping this aquifer ranges between 34.2 m (Well 15) and 180.8 m (Well 102). The salinity of this aquifer ranges between 288 ppm (Well No.58) and 3776 ppm (Well No.28). The high salinities are attributed to the over pumping at well No.28 which resulted in discharge of more saline water from Oligocene aquifer through existing faults.

5.1.3. Oligocene aquifer

This aquifer is underlying the basaltic sheet and is represented by eight wells (Nos. 109–116). It consists of calcareous sand and clay. The depth to water ranges between 89 m at well No. 109 to 155.4 m at well No. 115. According to Freeze and Cherry (1979), the water of this aquifer is classified as brackish water, where it varies from 2000 ppm at well No. 113 to 3100 ppm at well No. 110.

5.1.4. Middle eocene limestone aquifer

This aquifer is not outcropping in the study area but it exists in the subsurface as fractured system. This aquifer is represented by three wells (117, 118 & 119). It consists of limestone and shale. The depth to water ranges between 45 m at well No. 118 to 80.2 m at well No. 117. On the other hand, its water salinity varies from 2715 ppm (Well No.118) to 13,120 ppm (Well No.117). This indicates that the water salinity of this aquifer is brackish to saline water. The high salinity of well No.17 may be attributed to the presence of argillaceous limestone.

5.2. Aquifer distribution

The lateral and vertical distributions of the above-described aquifers as well as their inter-relationships are illustrated through the construction of three hydrogeological sections and spatial maps for the depth to water, water level, Moghra thickness and water salinity.

5.2.1. Hydrogeological cross-sections (Fig. 5a,b,c & d)

From the constructed three hydrogeological sections (A-A', and B-B' having W-E direction) and (C-C' having N-S direction), the following features are distinguished:

5.2.1.1. Hydrogeological cross-section A-A'. This cross-section has W-E direction with a length of about 14.4 km (Figure 5(b)). From this section, the following can be concluded:

(1) The water-bearing formations along this cross-section are represented by the Pleistocene aquifer that consists of sand, gravel and clay (Well No.2) and the Lower Miocene aquifer (Moghra) which consists of sand and clay intercalations (Well Nos. 73, 46, 48, 37, 74, 88, 75, 13, 14, 15 and 30).
(2) The depth to water varies from 18.2 m at well No. 2 at the east and increases westward to reach 179 m at well No. 73.
(3) The general groundwater flow along this cross-section is from the east to the west, where it varies from +35.4 m at well No. 2 at the east to −33.5 m at well No. 73 at the west.
(4) The sedimentary succession along this cross-section is affected by six normal faults (F1-F3, F8, F15 and F10). The faults F1, F2 and F3 are making stepping towards the

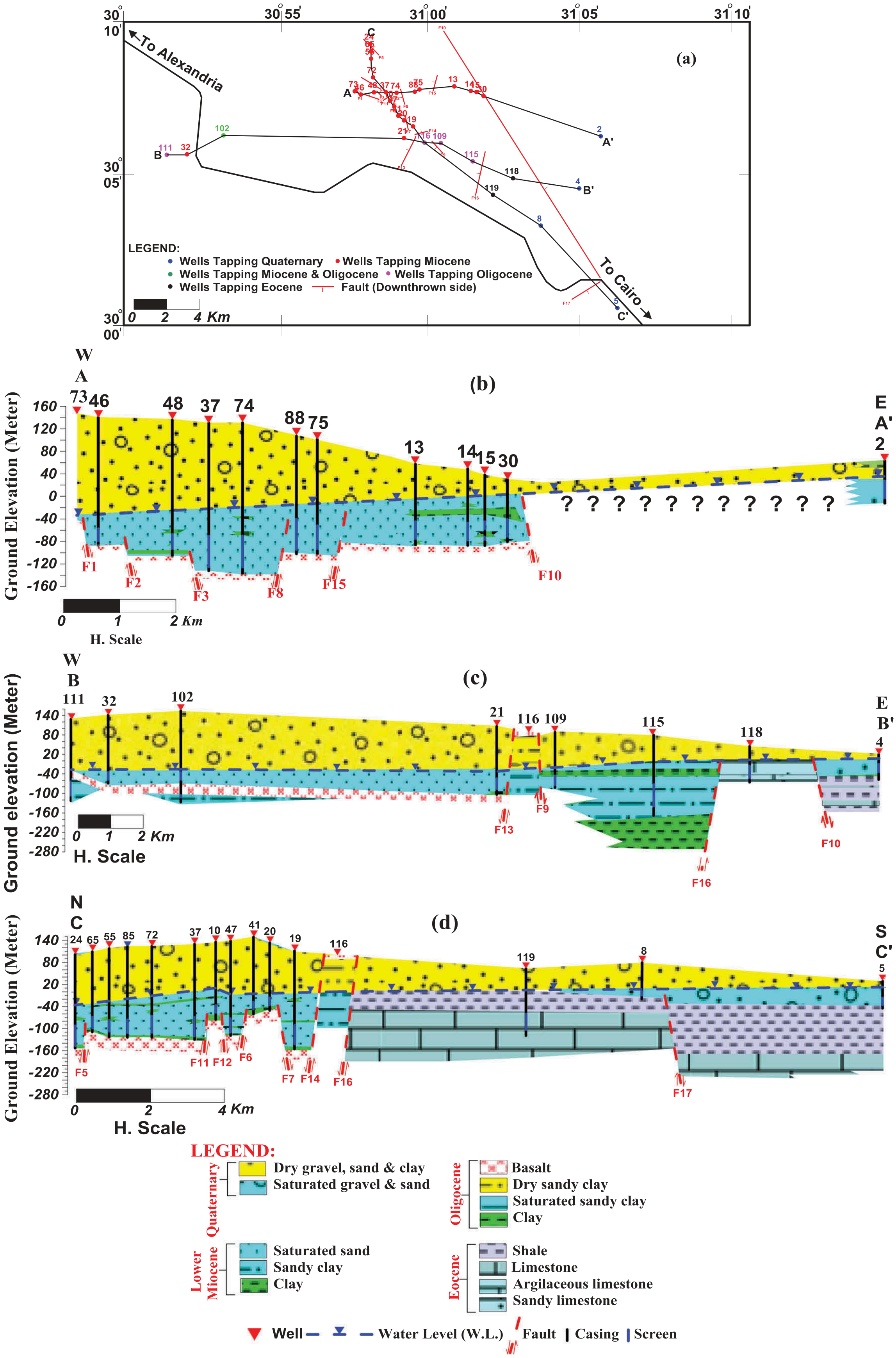

Figure 5. (a): Locations of hydrogeological cross-sections, (b): Hydrogeological cross-section A-A′, (c): Hydrogeological cross-section B-B′ and (d): Hydrogeological cross-section C-C′.

east while the faults F8 and F15 are making stepping towards the west. On the other hand, the faults F3 and F8 are making a graben at at wells 37 and 74, while the faults F15 and F10 are making an uplifting (horst) at wells 13, 14, 15 and 30.

5.2.1.2. Hydrogeological cross-section B-B'. This cross-section has W-E direction with a length of about 24.8 km (Figure 5(c)). From this cross-section some important features can be concluded as follows:

(1) The water-bearing formations along this cross-section are represented by Pleistocene aquifer that consists of sand, gravel and clay (Well No.4), Lower
(2) Miocene aquifer (Moghra) which consists of sand and clay intercalations (Wells Nos. 32, and 21), Oligocene aquifer which consists of sandy clay and clay (Wells Nos.111, 102, 116, 109 and 115) and Eocene aquifer which consists of limestone, argillaceous limestone and sandy limestone (Well No. 118).
(3) The depth to water ranges between 10.1 m at well No.4 at the east and increases westward to reach 182.4 m at well No. 102.
(4) The general groundwater flow along this cross-section is from the east to the west, where it varies from +8.87 m at well No. 4 at the east to −27.81 m at well No. 111 at the west.
(5) The sedimentary succession along this cross-section is affected by four normal faults (F13, F9, F16 and F10). The downthrown sides of faults F13and F16 are towards the west while the faults F9 and F10 have their downthrown sides towards the east. On the other hand, the faults F13 and F9 are making horst bringing the Oligocene basalt on the ground surface at well No.116 and the faults F16 and F10 are making another horst at well No.118, uplifting the Eocene succession in the front of the Pleistocene rocks at well No.4 at the east and in the front of the Oligocene rocks at well No.115 at the west.
(6) It can be concluded from this hydrogeological cross-section that the different aquifers in the study area are hydraulically connected through the existing faults.

5.2.1.3. Hydrogeological cross-section C-C'. This cross-section has N-S direction with a length of about 21.8 km (Figure 5(d)). From this cross-section the followings can be concluded:

(1) The water-bearing formations along this cross-section are represented by Pleistocene aquifer that consists of sand, gravel and clay (Well Nos. 5 and 8), Lower Miocene aquifer (Moghra) which consists of sand and clay intercalations (Well Nos. 24, 65, 55, 85, 72, 37, 10, 47, 41, 20, and 19), Oligocene aquifer which consists of sandy clay and clay (Well No. 116) and Eocene aquifer which consists of limestone, argillaceous limestone and sandy limestone (Well No. 119)
(2) The depth to water ranges between 13.9 m at well No.5 at the south and increases northward to reach 159.8 m at well No. 72.
(3) The general groundwater flow along this cross-section is from the south to the north, where it varies from +11.5 m at well No. 5 at the south to −36.8 m at well No. 72 at the north. On the other hand, well No.47 makes a cone of depression, where the water flow directed to this well from the north and from the south along this cross-section which is considered as an indication of the effect of the over-pumping at this well.
(4) The sedimentary succession along this cross-section is affected by eight normal faults, where the faults F5, F11, F6, F14 and F16 have their downthrown side at the north and the faults F12, F7 and F17 have their downthrown side towards the south. On the other hand, the faults F11 and F12 are making a horst at well No.10, the faults F6 and F7 are making a horst at wells 41 and 20 and the faults F16 and F17 are making a horst at well Nos.119 and 8.
(5) As mentioned in the cross-section B-B', also along this cross-section it can be concluded that the different aquifers in the study area are hydraulically connected through the existing faults.

5.2.2. Spatial maps (Fig. 6a,b,c & d)

The present measured depth to water and water salinity as well as the calculated aquifer thickness used to construct the areal distribution maps of these parameters as the followings:

5.2.2.1. Depth to water. In fact, the depth to water is very important for the groundwater exploitation where it is a function of the drilling depth. A map has been constructed for the depth to water surface (Figure 6(a)). From this map it can be concluded that the depth to water increases from the east, where the measured value is 34.2 m (Well 15), to the west where it reaches 180.8 m (Well 102).

5.2.2.2. Water level. The water level map (Figure 6(b)) shows that all values are below the sea level and the general water flow is from the east and southeast to the west and northwest, respectively. It decreases from −0.81 m (Well 22) at the southeast to −28.75 m (Well 77) at the northwest. This trend is confirmed with the general water flow in the West Nile Delta. However, there are some exceptions due to the presence of some cone of depressions at the well Nos. 48, 75 and 96, where the water level reaches its minimum values at well 75 (−32.79 m). The main factor making these cones of depressions is the over-pumping.

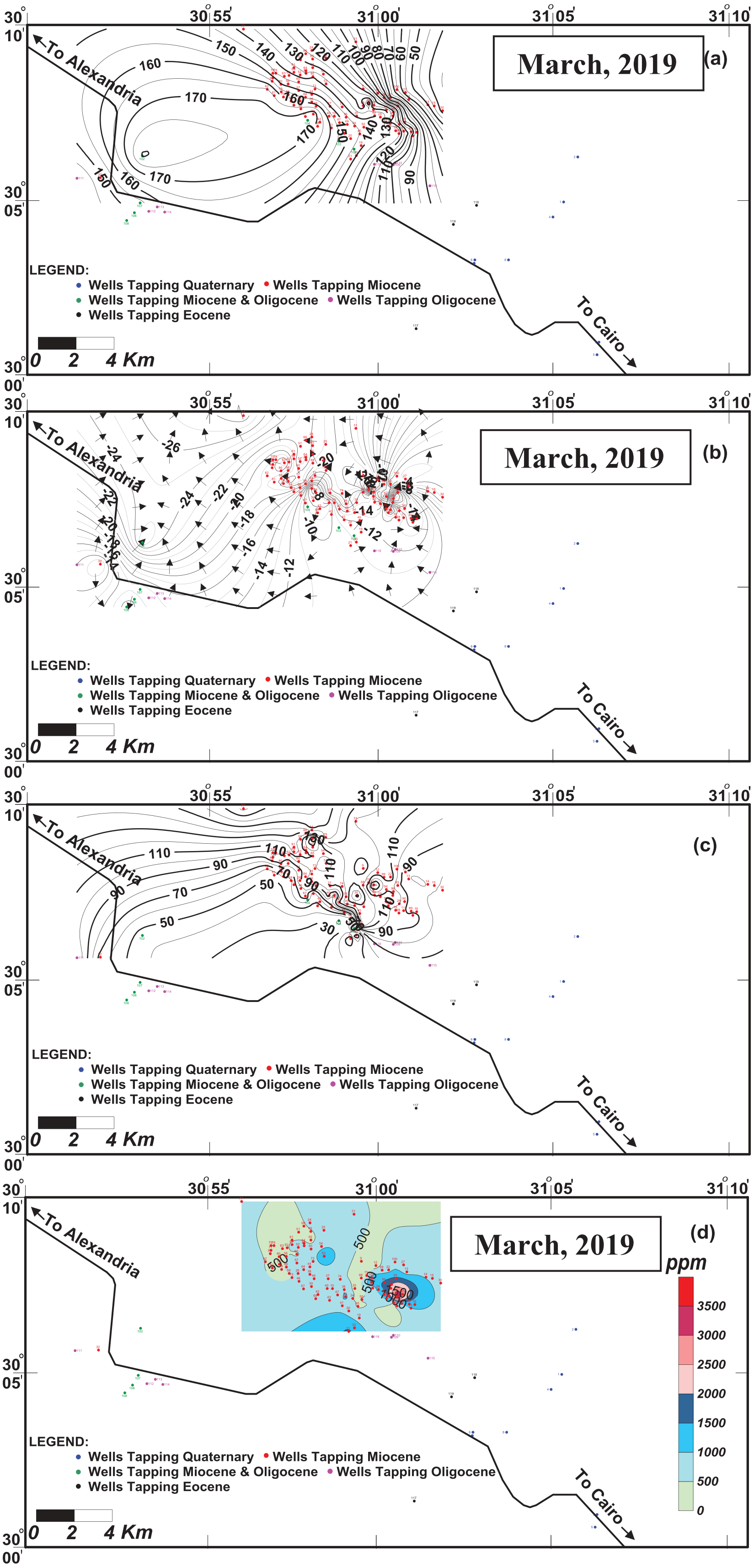

Figure 6. Maps of March 2019 showing (a): Depth to water (m),(b): Water Level with respect to sea level (m) (c): Thickness of Moghra aquifer (m) and (d): Water salinity (ppm).

5.2.2.3. Saturated thickness of lower miocene aquifer (Moghra aquifer). The tapping wells to the Moghra aquifer were used to construct an isopach map of this aquifer only (Figure 6(c)). It is clear from this map that the general trend of thickness increase is from the east and south to the west and to the north, respectively. The lowest recorded thickness is 12 m at well No. 33 in the southeast, while the highest recorded one is 183 m at well No. 77 in the northwest. The main factors affecting the thickness of this aquifer are the geological structures and the level of the basaltic sheet which separates the overlying aquifer (Lower Miocene) and the underlying aquifer (Oligocene).

5.2.2.4. Water salinity of lower miocene aquifer (Moghra aquifer). The total dissolved solids (TDS) of 54 water samples from the wells tapping the Lower Miocene aquifer (Moghra aquifer) were measured in the field on April 2019 using Portable Conductivity Metre to give an idea about the water salinity. Figure 6(d) shows that the groundwater salinity of the Moghra aquifer varies between 288 ppm at well No.58 and 3776 ppm at well No.28. Also, it is clear that the water salinity is not more than 1500 ppm at most of the wells except at few wells such as well Nos.28 and 90 at the southeast part of the study area.

5.3. Impact of the geological structures on the groundwater occurrences

One of the main objectives of this study is delineating the geologic structures and their impact on the groundwater occurrences. Through the collected data of the drilled wells, the basaltic sheet was considered as a marker bed that separates the overlying Lower Miocene aquifer (Moghra aquifer) and the underlying Oligocene aquifer. Also, the depth to the basaltic sheet and its level with respect to mean sea level was used to detect the inferred faults in the study area(Figure 7(a–c)). In the followings, a discussion of these maps will be illustrated:

5.3.1 Depth to basaltic sheet

The constructed depth to basaltic sheet map (Figure 7(a)) shows that the depth increases from the southeast to the

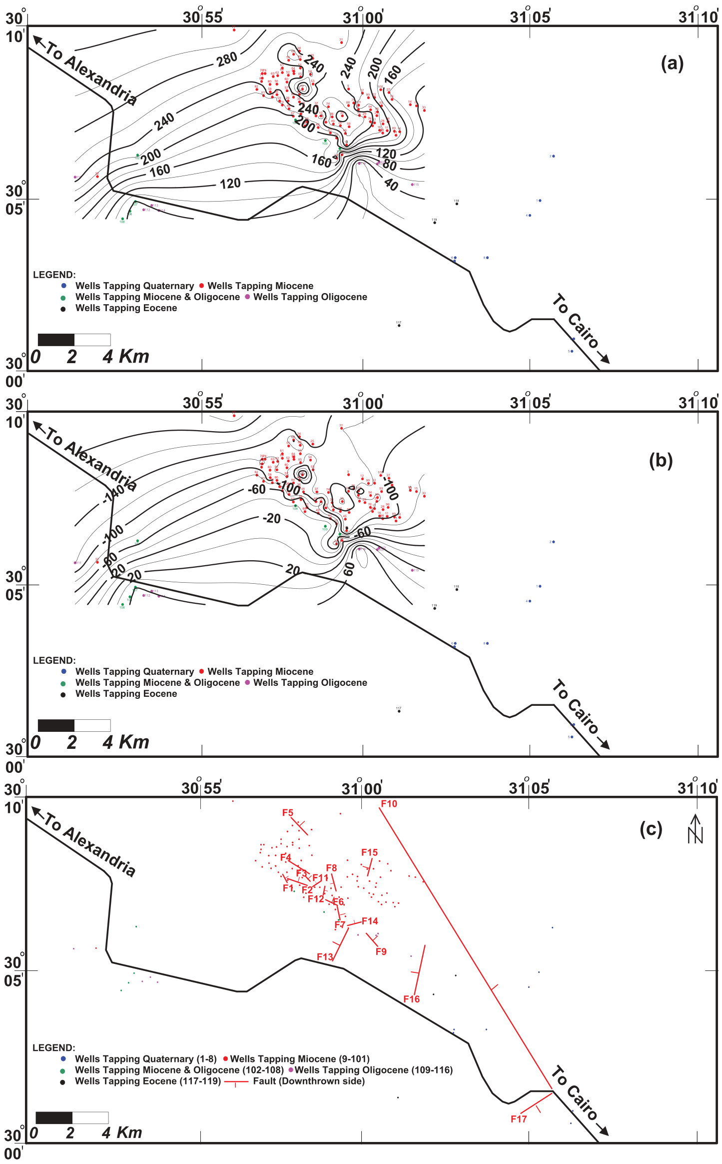

Figure 7. Maps showing (a): Depth to basaltic sheet (m), (b): Level of top surface of basaltic sheet with respect to sea level (m) and (c): Inferred faults.

northwest. The basaltic sheet is exposed at the surface at Well No.116 and dipping downward to the northwest to be at depth of 320 m at Well No.77. The main factor controlling the depth of the basaltic sheet is the geologic structures which are represented here by a series of normal faults.

5.3.2. Basaltic sheet level

Figure 7(b), shows that the level of the top surface of the basaltic sheet varies from 98.42 m above sea level at well No. 116 to −210.85 m below sea level at well No. 77 at the northwest. This map contributes to the detection of the inferred faults that affected the study area.

5.3.3. Inferred faults

From the detected inferred faults map (Figure 7(c)), it is clear that the study area is affected by a number of 17 normal faults forming grabens and horsts. The fault Nos. 1–10 have a NW-SE trend, while the fault Nos. 11–17 have a NE-SW trend. These trends are confirmed with the regional fault trends that affected the West Nile Delta area. These faults play an essential role in the change of the thickness of Lower Miocene aquifer and its water quality through the hydrological connection with the underlying Oligocene aquifer which has a higher salinity than that of the Lower Miocene aquifer.

5.4. Aquifer hydraulic parameters

The results obtained from the long duration pumping tests (Table 1 and Figures 8 & 9) reflect the followings:

(1) The transmissivity values are (1352 and 197.5), 92.9 and 150 m^2/day in the Miocene, Oligocene and Eocene aquifers, respectively.
(2) The wells tapping the Miocene aquifer are fully penetrating and the saturated thickness (b) in these wells ranges between 119.8 m in well No. 34 and 119.7 m in well No.36. The hydraulic conductivity is calculated and attains values of 11.28 m/day in well No. 34 and 1.4 m/day in well No. 36.
(3) For the Eocene fractured limestone aquifer (heterogeneous system), it is suitable to depend

Table 1. Analysis of long duration pumping test data and well productivity according to Sen (1995) for represented wells tapping the Tertiary aquifers.

Well No.	Aquifer	Aquifer type	Q m^3/day	Drawdown (m)	Specific Capacity m^3/h/m	b (m)	K m/day	T m^2/day	Well productivity
34	Miocene	Semi-confined	960	6.73	5.9	119.8	11.28	1352	Moderately productive
36	Miocene	Semi-confined	3984	13	12.7	119.7	1.4	197.5	
110	Oligocene	Semi-confined	2592	14.2	7.6			92.9	
117	Eocene	Un-confined	1560	12.5	5.2			150	

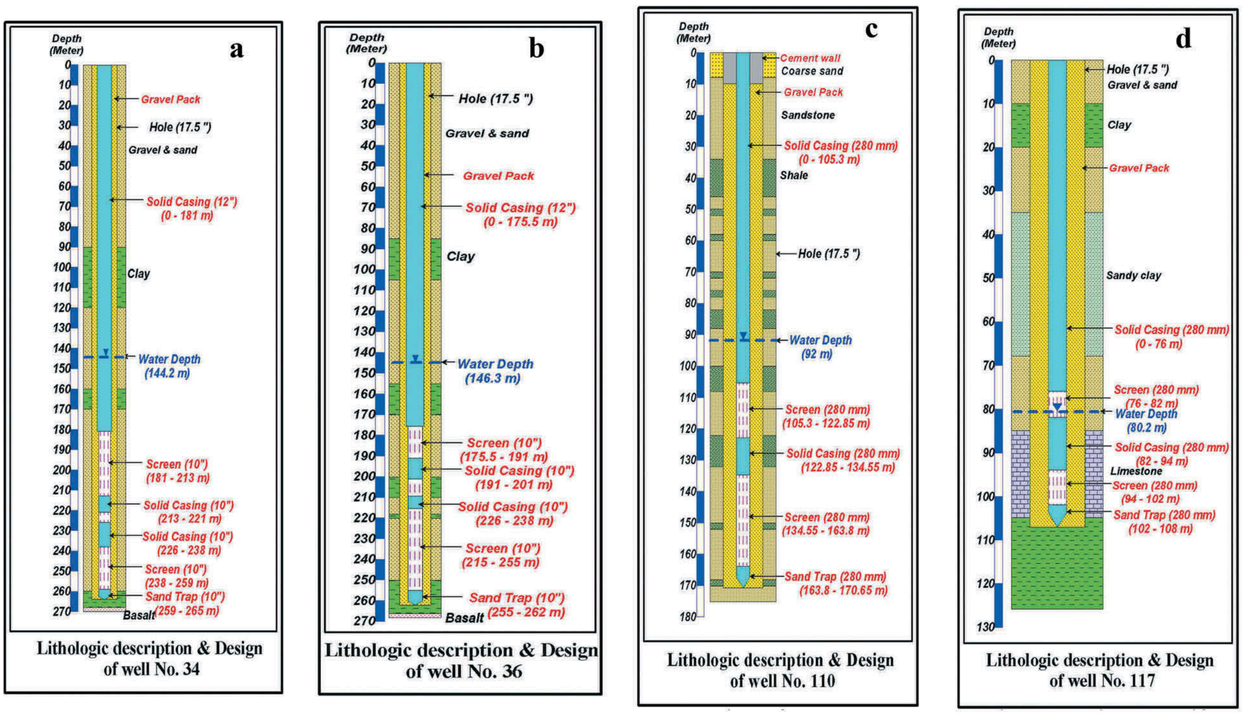

Figure 8. Lithology and design of the tested wells tapping the existed aquifers in the study area: a & b: Miocene aquifer, c: Oligocene aquifer and d: Eocene aquifer.

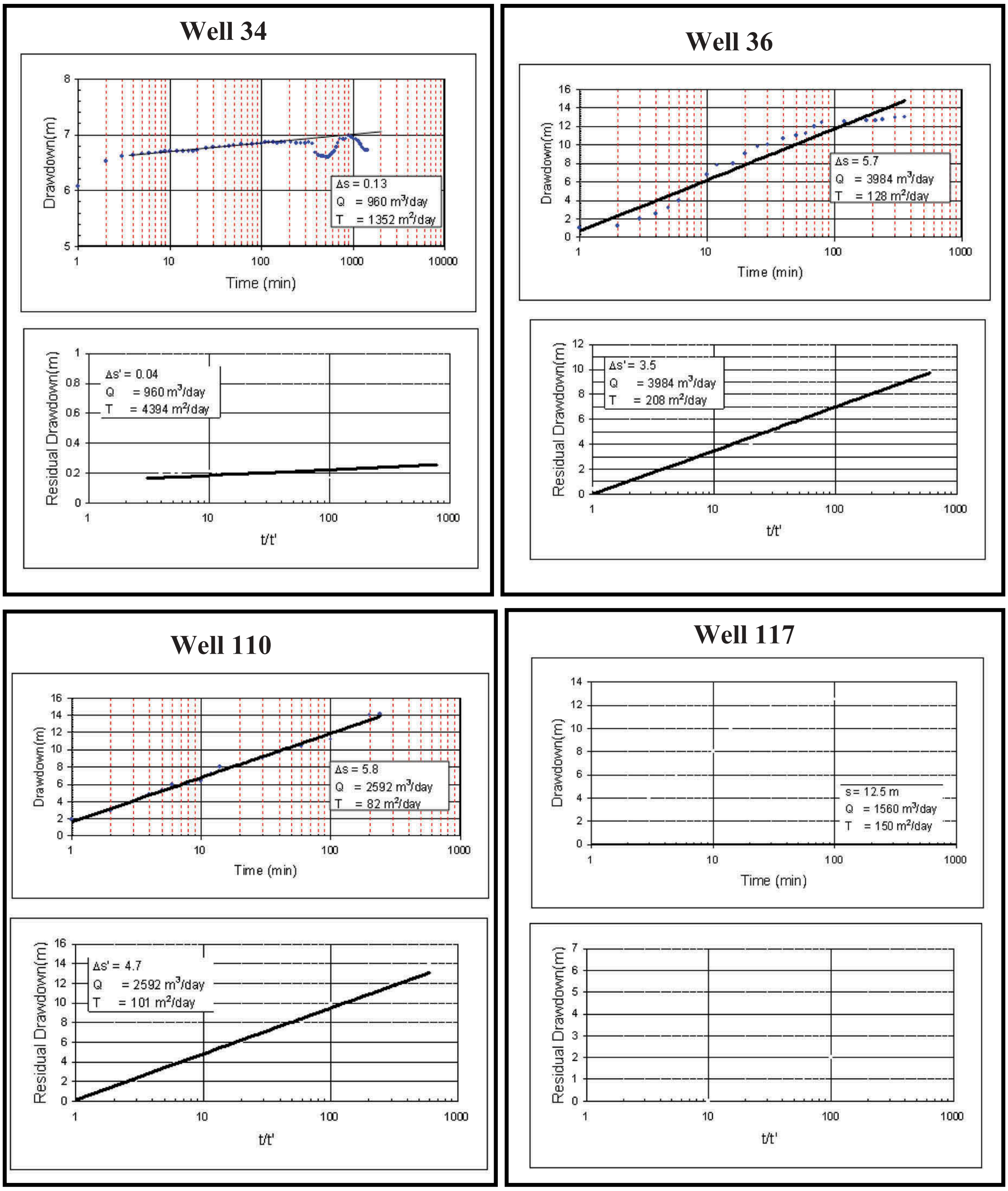

Figure 9. Long-duration and recovery test data analysis for some wells tapping the existed aquifers in the study area: Miocene aquifer (Wells 34 &36), Oligocene aquifer (Well 110) and Eocene aquifer (Well 117).

Table 2. Analysis of step test data for represented wells tapping the Tertiary aquifers.

Well No.	Aquifer	$Q_{(max.)}$ m^3/h	S_t m	S_a %	S_b %	$A*10^{-2}$ day/m^2	$B*10^{-6}$ day^2/m^5
34	Miocene	40	6.72	91	9	0.6378	0.5765
36		150	14.5	93.8	6.2	0.3778	0.0699
110	Oligocene	40	6.82	41.9	58.1	0.298	0.04292
117	Eocene	23	8.6	63	37	0.9824	0.001066

Abbreviations: $Q_{max.}$ = maximum rate of pumping; S_t = total drawdown corresponding to Q_{max}; A = aquifer loss coefficient; B = well loss coefficient. S_a = aquifer loss. S_b = well loss.

on the specific capacity (Q/s) as a good indicator for the aquifer's potential where it is 5.2 m^3/h/m in well No. 117 and the aquifer can be classified, according to (Sen 1995), as moderate productive aquifer.

(4) According to Sen (1995) all aquifers are moderately productive, where the specific capacities (Q/s) are (5.9 & 12.7), 7.6 and 5.2 m^3/h/m in Miocene, Oligocene and Eocene aquifers, respectively (Table 1).

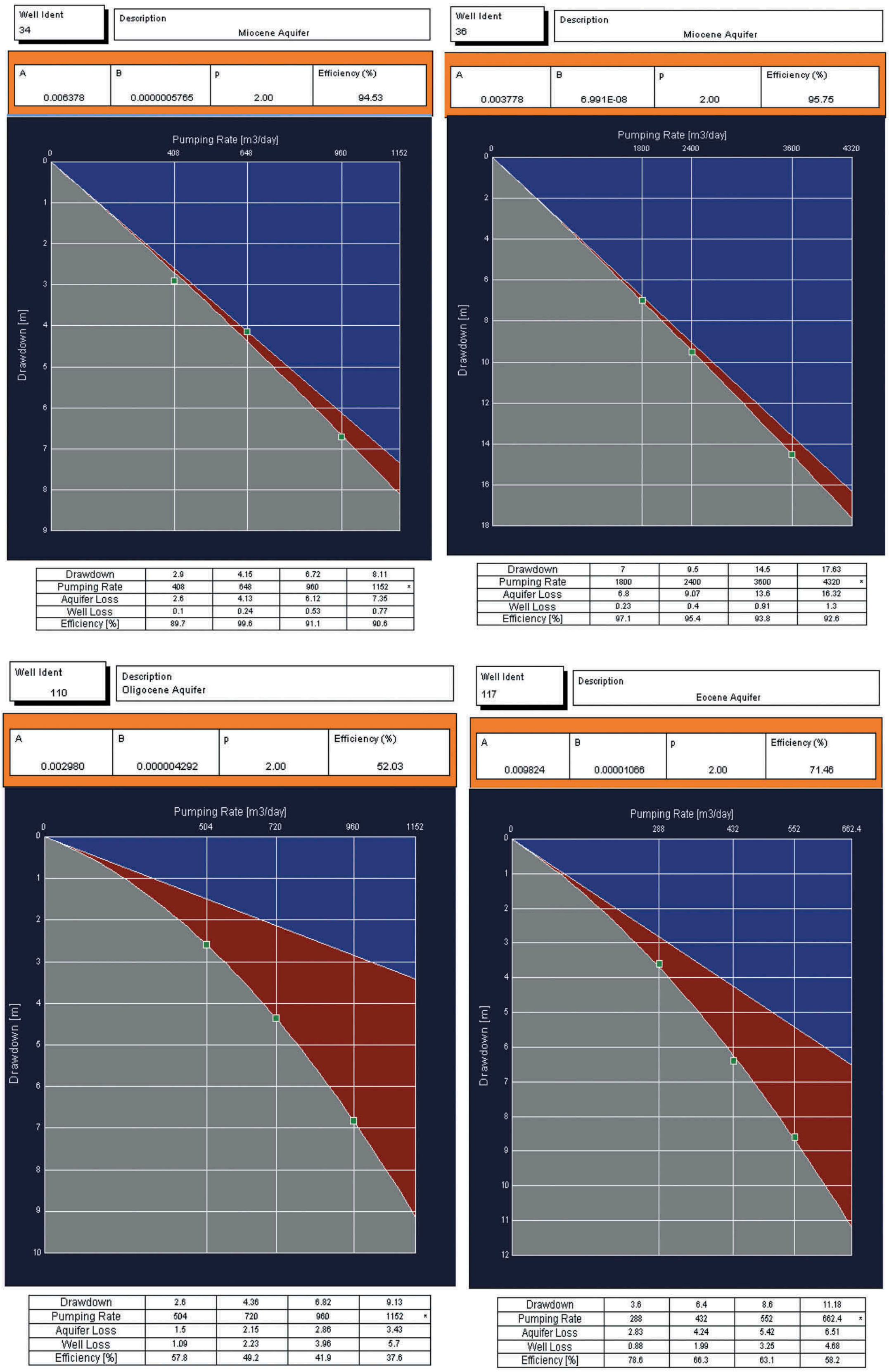

Figure 10. Step test data analysis for some wells tapping the existed aquifers in the study area: Miocene aquifer (Wells 34 & 36), Oligocene aquifer (Well 110) and Eocene aquifer (Well 117).

5.5. Well performance test (step drawdown test)

A number of four step test in the different dominant aquifers were carried out for four wells in the study area. The tests were conducted on three rates of discharge to calculate the aquifer loss, well loss, and well efficiency using **GWW Software** (Ver. 1.10). The results of the analysis are shown in Table 2 and Figure 10.

In order to analyse the data, it is necessary to understand the nature of the drawdown in a pumping well. The total drawdown (s_t) in most, if not all, pumping wells consists of two components. One is the drawdown (s_a) in the aquifer, and the other is the drawdown (s_b) that occurs as water moves from the aquifer into the well and up the well bore to the pump intake.

From Table 2 and Figure 10, one can conclude that the contribution of the aquifer loss percentage (S_a %) in the total drawdown (S_t) for the wells representing the Miocene aquifer ranges between 91% in well No. 34 and 93.8 % in well No. 36, 41.9 % in well No.110 (Oligocene) and 63% in well No.117 which represent the fractured aquifer (Eocene fractured limestone). On the other hand, the well loss percentages (S_b%) are 9%, 6.2%, 58.1% and 37% for the Miocene (Well Nos. 34 and 36), Oligocene and Eocene aquifers, respectively.

6. Conclusions and recommendations

From the abovementioned discussion, the followings can be concluded:

(1) In the study area, the main water resource for agricultural activities is the groundwater, where four aquifers exist namely Pleistocene, Lower Miocene (Moghra Formation), Oligocene and Eocene aquifers which are particularly influenced by the structural features and thus affect the groundwater occurrences.
(2) The general flow direction of the groundwater is from east to west and from southeast to northwest with some local change which may be attributed to the over-exploitation in these locations.
(3) The Tertiary existed aquifers in the study area are considered as moderately productive where the aquifer has average transmissivity values of the order of 197.5 &1352, 92.9 and 150 m^2/day for the Miocene, Oligocene and Eocene aquifers, respectively.
(4) The specific capacity of the Miocene, Oligocene and Eocene aquifers is 5.9 & 12.7, 7.6 and 5.2 m^3/h/m, respectively.
(5) The water salinity of these aquifers ranges between 288–3776, 2000–3100 and 2715–13,120 mg/l in the Miocene, Oligocene and Eocene aquifers, respectively.
(6) The study area is affected by a number of normal faults having NW-SE and NE-SW directions and play a great role on the basaltic sheet level which consequently affected the groundwater potentialities as well as the hydraulic connections between the existed aquifers.

According to the abovementioned discussion the followings can be recommended:

(1) Generally, the whole area should be subjected to a monitoring network of wells representing the different aquifers. The monitoring system includes both water levels and salinity on a periodical basis.
(2) Since the study area is considered as a well-developed area, it is highly recommended to punish the violation of cultivating high water consumption as bananas.
(3) The management should be taken into consideration the safe distance between drilled wells as well as the pumping rates.
(4) The modern irrigation system should be applied.
(5) The coordination between the Ministry of Irrigation & Water Resources and the Ministry of Agriculture and Land Reclamation is very important to make the required management on the groundwater exploitation in the study area.

Disclosure statement

No potential conflict of interest was reported by the author.

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