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# RECENT RECHARGE POSSIBILITIES DETERMINATION OF THE PLEISTOCENE AQUIFER SYSTEM OF WADI EL-ASSIUTI BASIN, EGYPT, USING HYDROGEOCHEMICAL AND ENVIRONMENTAL ISOTOPIC CRITERIA

BY

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## ABSTRACT

*Wadi El-Assiuti is one of the largest dry wadis in Middle Egypt. It comprises prolific groundwater potentialities and suitable lands for agricultural expansion. Twenty one groundwater samples are recently collected from the drilled water wells tapping the Pleistocene groundwater aquifer. The groundwater salinity values vary generally from 580 mg/l to 2445 mg/l indicating fresh to brackish water. The variation in water genesis could reflect the diversity of the recharge sources for the Early Pleistocene aquifer. The resistivity method is used where thirty vertical electrical soundings are measured in the field. It was able to delineate the groundwater aquifers and some concealed normal faults.*

*The isotopic results of the collected surface and groundwater samples are widely varied from -8.9 to 2.81 ‰ for oxygen-18 and from -61.07 to 21.11 ‰ for deuterium. Almost 86 % of these samples fall in the depleted isotopic range, whereas the remaining percentage (14 %) is gradually enriched. Correlating the data points with respect to the Global Meteoric Water Line (GMWL) indicted the distribution of these points below the global line. The low slope and intercept values obtained from this correlation addresses the old origin of the main bulk of groundwater, which is represented by 86 % of samples. These samples carry the depleted isotopic signature of the paleowater characterizing the Eastern Desert of Egypt. The replenishment source of this water for the wadi proper could be from the local rainfalls on the upstream reaches of Wadi E-Assiuti, in addition to the underlying Nubia aquifer through a direct contact along deep seated faults. Towards the western reaches, at the entrance of the wadi (Nile Valley), the aquifer is almost recharged by the River Nile. The $^{14}C$ age determination for two samples indicated that the Pleistocene water of Wadi El-Assiuti is mostly paleowater with a significant portion of relatively recent water recharging the aquifer from the rainfalls of the Red Sea mountainous area, in addition to the local ones.*

## INTRODUCTION

Wadi El-Assiuti represents the eastern expansionable developmental corridor for Assiut Governorate. The main trunk channel of it reaches about 110 km in length with an area of about 2700 km$^2$. It is located between latitudes 27° 00' N and 27° 30' N and longitudes 31° 00' E and 31° 30' E. (Figs 1a & b). The catchment basin of this wadi is situated entirely in the elevated Maaza Eocene limestone Plateaux that forms a distinctive landscape feature in the desert east of the Nile Valley.

Wadi El-Assiuti includes potential soils for agricultural development if irrigation water is available. Thus, development plans should be accompanied by high activities in searching for new water resources, especially the groundwater. Recently, the determination of recent recharge possibilities of the Pleistocene aquifer system of Wadi El-Assiuti became an urgent issue.

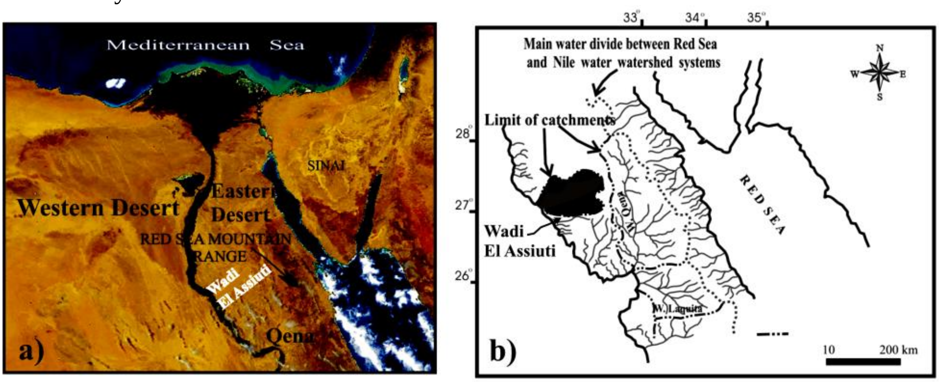


Fig. (1) Location map of the area of study: a) Satellite image showing the main catchment areas for Wadi El Assiuti watershed system. b) Wadi El Assiuti watershed and the main River Nile -Red Sea water divide

The area of study represents a part of the arid belt of North Africa, which is characterized by hot, dry and rainless climate in summer and being mild with rare rainfall in winter. Naturally, the air temperature increases during the summer periods and decreases during the winter periods.

### Methodologies and approaches

In the present study, the authors investigated the recent recharge possibilities of the Pleistocene aquifer system. Twenty one water samples are collected during the year 2004 from the Pleistocene groundwater and Nile surface water. Subsequently, these samples were analyzed for major constituents, environmental stable isotopes and $^{14}C$. The interpretations of these data, besides the available geological, hydrogeochemical and hydrogeophysical information are integrated to assess the recharge mechanism and possibilities. The drilled production water wells locations are determined using field truth Geographic Positioning System (GPS) and a location map is constructed (Fig. 2). The drilled water wells are partially penetrating the aquifer successions of the Early Pleistocene times. The number of drilled wells is about 85 water wells, especially with the involvement of the private sector into the rehabilitation activities of Wadi El-Assiuti.

A total number of 30 vertical electrical soundings (VESes) are carried out in this area. The Schlumberger four symmetrical electrodes configuration is used. From the gained results of both quantitative and qualitative interpretations, a hydrogeophysical cross-section A-A′ is introduced.

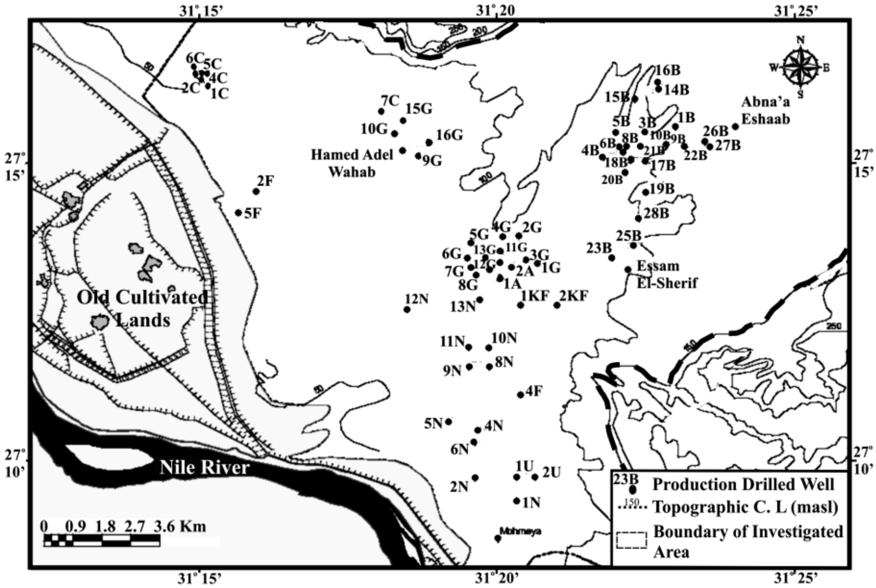


**Fig. (2) Location map of the drilled water wells of Wadi El-Assiuti**

## GEOLOGIC SETTING

According to Said (1981), the geological sequence in Wadi El-Assiuti is starting (from top to bottom) by the Neonile of the Holocene, followed by the Prenile of the Middle-Late Pleistocene, which is followed by the Proto/Prenile and the Protonile of the Early Pleistocene, followed by the Late Paleonile of the Late Pliocene and the Early Pliocene, and ends at last by the Early – Middle Eocene (Fig. 3).

According to the drilled production wells in the area (Fathy et. al. 2005), from top to bottom, the sequence starts by loose gravels, sands and carbonate materials with a thickness that could reach 18 m, followed by Qena Formation with a maximum thickness of 27 m, followed by the Issawia Formation

(Early Pleistocene) and finally the Armant Formation (Early Pleistocene).

The Armant Formation is made up of alternating beds of locally derived gravels and fine-grained clastic rocks. The fine-grained clastic beds are calcareous, sandy, shally, or phosphatic depending on the nature of the nearby source rocks. Issawia Formation overlies the Armant Formation and is made up of bedded travertines with minor conglomerate lenses, composed of limestone pebbles of local derivation and the overlying beds of red breccia with highly angular limestone pebbles cemented in a matrix of red muds.

The Eocene sediments represent the oldest outcropping rocks and form a plateaux land that occupies almost the entire basin. (Fig. 3).

The structural setting of the area of study and its surroundings was studied by different authors as a part of the Nile Valley. Youssef *et. al,* (1977) believed that the NW-SE faults that affect the Eocene rocks around Assiut are the result of a Post-Eocene uparching of rocks that caused the transmission of older NW-SE fractures vertically from the basement to affect the sedimentary cover.

The constructed hydrogeophysical cross-section A-A′ reveals the existence of two main trends for deep faults, the NW-SE and NE-SW (Fig. 4). These deep-seated faults are efficient conduits through which the upward leakage of Pre-Upper Cretaceous (Cenomanian) Nubia Sandstone groundwater takes place, thus providing an effective rechage source for the Early Pleistocene aquifer system of Wadi El-Assiuti. The upward leakage occurs where the low permeable cover of the Nubian strata is missing or its effects are reduced due to special lithological or structural conditions. However, the upward leakage of groundwater from the underlying Pre-Upper Cretaceous (Nubia Sandstone) aquifer to recharge the overlying Tertiary and Quaternary Formations is clearly indicated in the area occupied by Wells 6G, 7G, 12G, 13G, 9G and 10G by hydrochemical evidences given by the stable isotopes ($O^{18}$ & D), as will be discussed later. These wells are lying in the vicinity of a fault plane (F1) (Fig. 4).

## HYDROGEOLOGICAL SETTING

The hydrogeologic setting of Wadi El-Assiuti has been worked out by various workers, among them; Abu El-Ella (1999) and Mousa et al (1993), Yan et al (2004), Fathy et. al. (2005) and NARSS (2005).

The hydrogeological setting of the area of study is as follows, from top to bottom:

1. The subsoil aquifer: It has no significance as an aquifer due to its composition, and it is of very small thickness.
2. The Qena Formation aquifer: It represents the main groundwater aquifer in the Nile Valley and its vicinities that reach the entrance of Wadi El-Assiuti. Inside Wadi El-Assiuti, it looses its significance as an aquifer due to its small thickness and its altitude. It is of the Middle – Late Pleistocene age.
3. The Issawia Formation (Early Pleistocene aquifer): It is the aquifer that is tapped by the shallow drilled wells in the area of study.
4. The Armant Formation (Early Pleistocene aquifer): It underlies the Issawia aquifer, and most of the drilled deep water wells (± 260 m) are tapping its upper parts.

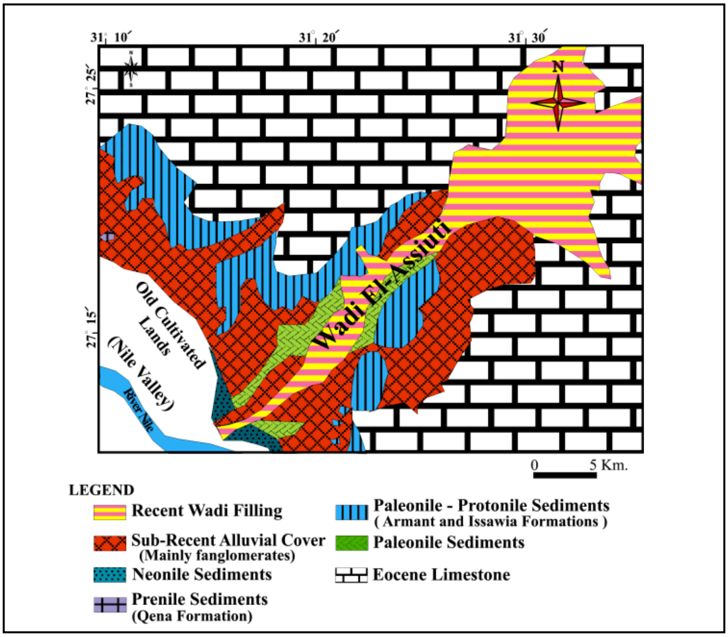


**Fig. (3) Geological map of the area study (after Said, 1981)**

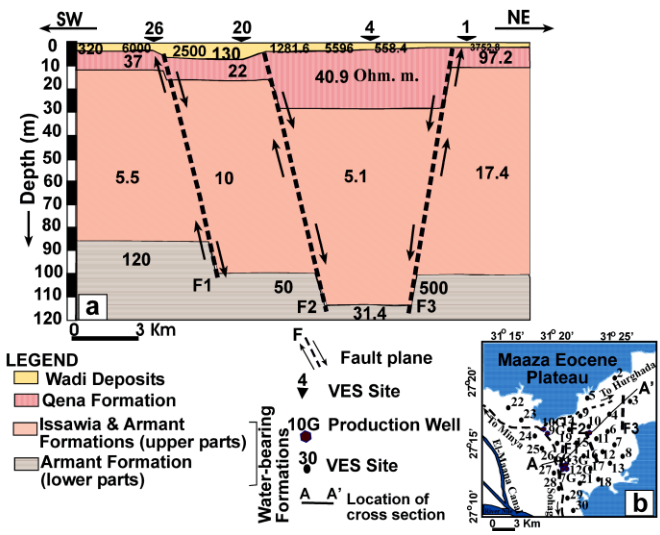


**Fig. (4) Illustrative subsurface aquifer situation by a) hydrogeophysical cross-section A-A′ across Wadi El-Assiuti. b) key map of cross-section**

Wadi El-Assiuti watershed is one of the main Eastern Desert wadis that depouchs towards the River Nile. Wadi El-Assiuty hydrologic system comprises two flow components: 1) the surface water system of the Wadi El-Assiuti watershed and 2) the Wadi El-Assiuti groundwater flow system. The watershed collects rainfalls over the area of 5589 km$^2$ and is channeled toward River Nile conveying precipitation over the Red Sea Hills and the adjacent mountains. The Quaternary alluvial aquifer floors the main channels within Wadi El-Assiuti watershed, whereas the surrounding outcrops are mainly Tertiary limestones (Fig. 3). Gheith and Sultan (2002) estimated that the infiltration to the limestone is limited and transmission loss to the alluvial aquifer along the stream channels is significant at an average annual rate of $6 \times 10^6$ m$^3$. The flow to the outlet of the watershed is also minimal, only about 7 % of the total rainfall (Yan et. al, 2004). At the adjacent areas of the Nile Valley (near the old cultivated lands), the Quaternary sediments are mostly influenced by Nile recharge, and to a less extent by the surface runoff water from the Eastern Desert wadis. Traveling farthest inside the eastern tributaries of Wadi El-Assiuti, the influence of the River Nile diminishes, and the main recharging sources are from the upward leakage from older formations such as Nubia Sandstone or from the Red Sea mountainous ridges, outcropping to the far northeast of the area of study, and the wadis.

The depth to water is topographically controlled. The groundwater is available at depths ranging between 27.5 m (Well 5F) near the Nile Valley and 44.2 m (Well Abna'a Eshaab) below ground surface. It increases generally from west to east-northeast directions (Fig. 5). However, the depth to water contours configure approximately the topographic features of the hills and valleys, where the water being low where the surface of the ground is high.

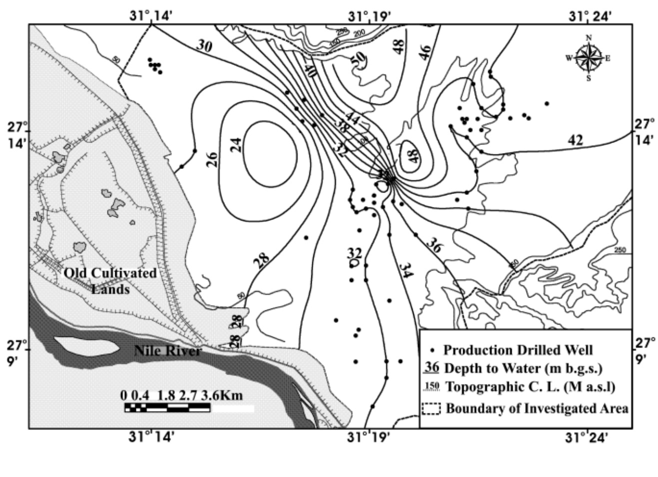


**Fig. (5) Depth to water contour map of the Early Pleistocene aquifer system**

It is noticed that the pumping of Well 9G started at 1992 with a depth of water of 31 m, and now its water depth became 34.1 m. Accordingly, there should be another recharge source that feeds these wells. This source could be the in situ local rainfalls on the wadis, such as Wadi Dahasa, Wadi Imu, etc, in addition to any other possible upward leakage through faults from older water-bearing formations.

## General hydrogeochemical characteristics and recharge sources of the Pleistocene groundwater aquifer

The routine chemical analysis was carried out for the major cations and anions. However, for the objective of this study, in order to determine the groundwater recharge processes, environmental stable isotopes determinations are also carried out.

Twenty one groundwater samples are collected from the drilled production water wells tapping the Early Pleistocene aquifer of Wadi El-Assiuti area (Tables 1 and 2) during the year 2004.

The chemical analyses for the environmental isotopes ($^{18}O$ and D) and $^{14}C$ were performed in the laboratories of the Nuclear Energy Authority, which were funded by NARSS (NARSS, 2005) (Tables 3 and 4).

All the collected groundwater samples lie in the alkaline medium (pH > 7), in the range from 8.3 to 8.7.

The gradation of TDS in the investigated area can be considered to be graded from fresh to brackish water. However, most of the water samples of Wadi El-Assiuti are brackish. The groundwater salinity values vary generally from 580 mg/l to 2445 mg/l indicating fresh to brackish water. The relative decrease of salinity was directed toward the River Nile (southwestern direction). It could point to some recharge from the Nile water in the Nile Valley districts. However, the area located near to the old cultivated land of the River Nile (< 500 mg/l) reveals clearly the influence of the Nile water. The Pleistocene aquifer salinity is high at the far northeastern part of the area of study (2445 mg/l). The over consumption will lead to the advance of high salinity front found to the northeast of the area of study (Fig. 6). This is attributed to the fact that, there are two different environments confronting each others at the entrance of Wadi El-Assiuti (Fathy et. al. 2005).

## Ion Dominance and water type

The dominance of major ions in the groundwater samples are mainly following one order in the cationic sequence $Na^+ > Ca^{++} > Mg^{++}$, whereas they vary in the anionic sequence. Most samples have the sequence of $Cl^- > SO_4^{--} > H\ CO_3^-$. In the other samples the increase in $HCO_3$ ions reflects its dominance with respect to $SO_4$ group, where they are following the order of $Cl^- > H\ CO_3^- > SO_4^{--}$ or $H\ CO_3^- > Cl^- > SO_4^{--}$.

Sodium Chloride is the chemical water type in all the collected groundwater samples due to the prevalence of $Na^+$ and $Cl^-$ ions, except the Well no. 5 F (W. Delta) has $HCO_3$ – Na as typical fresh water character. However, the groundwater of Wadi El-Assiuti and its entrance in the Nile

Valley is considered as fresh water to slightly brackish.

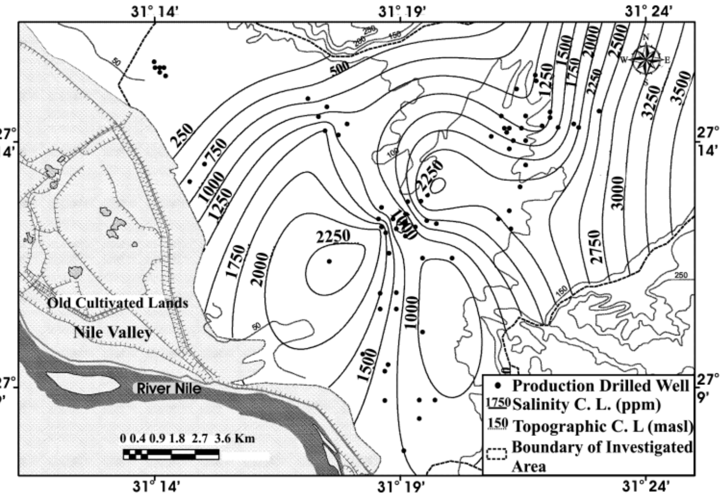


**Fig. (6) Isosalinity contour map of Wadi El-Assiuti Early Pleistocene aquifer system**

**Hypothetical salts combination**

Three salt assemblages are detected according to ions concentrations as (Table 1):

- Na Cl, Mg $Cl_2$, Mg $SO_4$, Ca $SO_4$, Ca $(HCO_3)_2$ in Wells 10G, Hamed Abdel Wahab, 9G ,16G, 6G, 7G, 2G, 13G, 3G, 1G, 1KF, Essam El-Sherif, 19B.

- Na Cl, $Na_2$ $SO_4$, Mg $SO_4$, Ca $SO_4$, Ca $(HCO_3)_2$ in samples 2F (Diab Salem), 4F, 8G, 12G (Assiut 2000), Abna'a El-Shaab.

- Na Cl, $Na_2$ $SO_4$, Na $HCO_3$, Mg $SO_4$, Ca $SO_4$, Ca $(HCO_3)_2$ in samples 5F, 9B (Gamal Abdel Motaal).

The first assemblage characterizes water of marine salts due to the presence of Mg $Cl_2$ salt. The enrichment of $SO_4$ minerals that are found in the form of $Na_2$ $SO_4$, Mg $SO_4$ in the second assemblage reflects the dissolution of terrestrial salts, which are represented by gypsum or anhydrite dominating the aquifer matrices. The second and third assemblages indicate the meteoric origin of water. It could be noticed that these groundwater wells of different water origins are located very close to each others (about 400 m distant from each others). The depth of penetration is about the same for these wells, but the well design is not the same. It was reported earlier by Fathy et al. 2005, that the wells tapping both the Issawia and Armant Formations are characterized by marine water genesis, whereas the wells that tap the Armant Formation only are characterized by meteoric water genesis. In addition to this, different recharge sources are resulted and expected from mixing of different recharge sources along the deep seated faults that, characterizes this area.

**Table 1** Hydrochemical aspects of the collected water samples of the area of study

| S. No. | Well Name | Depth (m) St. level (masl) | Depth (m) Well depth (mbgl) | PH | EC µS/cm | TDS Mg/l | Na | $NH_4$ | K | Mg | Ca | Cl | $SO_4$ | $HCO_3$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Concentration in epm | | | | | | | | |
| 1 | 10 G | 38 | 120 | 8.63 | 1.65 | 1056 | 11.97 | ---- | 0.11 | 1.19 | 3.39 | 12.98 | 1.87 | 3.00 | ---- |
| 2 | Hamed Abdel W. | 28 | 130 | 8.50 | 2.48 | 1487 | 14.11 | ---- | 0.16 | 6.18 | 8.80 | 20.29 | 5.00 | 2.11 | ---- |
| 3 | 4 F | 37 | 120 | 8.60 | 1.49 | 954 | 10.78 | 0.27 | 0.17 | 2.98 | 3.32 | 9.64 | 2.71 | 3.89 | ---- |
| 4 | 5 F | 18 | 100 | 8.60 | 0.907 | 580 | 5.85 | 0.11 | 0.20 | 1.94 | 2.34 | 2.94 | 2.05 | 4.11 | 0.99 |
| 5 | 9 G | 30 | 158 | 8.72 | 1.87 | 1199 | 10.96 | 0.30 | 0.14 | 2.64 | 6.71 | 13.34 | 3.41 | 2.78 | ---- |
| 6 | 16 G | 31 | 133 | 8.30 | 1.71 | 1092 | 11.32 | ---- | 0.15 | 2.86 | 5.87 | 13.08 | 3.53 | 2.66 | ---- |
| 7 | 6 G | 38 | 160 | 8.60 | 2.32 | 1485 | 15.96 | ---- | 0.15 | 4.41 | 6.14 | 18.66 | 4.40 | 2.44 | ---- |
| 8 | 7 G | 34 | 158 | 8.47 | 2.40 | 1882 | 11.32 | 0.23 | 0.14 | 5.83 | 8.92 | 13.74 | 8.06 | 2.78 | 0.65 |
| 9 | 8 G | 37 | 210 | 8.70 | 1.57 | 1007 | 11.50 | 0.42 | 0.09 | 2.03 | 4.28 | 11.36 | 2.24 | 3.33 | 0.11 |
| 10 | 2G | 37 | 158 | 8.56 | 3.32 | 2061 | 19.45 | 0.22 | 0.30 | 6.90 | 11.76 | 25.66 | 7.86 | 2.00 | 0.70 |
| 11 | 13G | 30 | 220 | 8.43 | 1.905 | 1219 | 12.30 | 0.26 | 0.19 | 2.46 | 5.67 | 14.71 | 6.46 | 2.33 | ---- |
| 12 | 12G | 33 | 220 | 8.60 | 1.64 | 1052 | 11.65 | ---- | 0.17 | 3.61 | 3.72 | 11.46 | 4.17 | 3.00 | ---- |
| 13 | 2KF | 36 | 180 | 8.80 | 1.64 | 1052 | 10.67 | 0.68 | 0.80 | 2.60 | 3.50 | 11.16 | 2.97 | 4.22 | ---- |
| 14 | 3G | 40 | 160 | 8.45 | 2.86 | 1702 | 16.87 | ---- | 0.36 | 6.55 | 9.57 | 2.10 | 7.07 | 2.89 | ---- |
| 15 | 1G | 42 | 150 | 8.30 | 2.71 | 1651 | 17.82 | 0.16 | 0.08 | 4.39 | 5.88 | 19.68 | 5.80 | 2.78 | ---- |
| 16 | 1KF | 34 | 220 | 8.65 | 1.603 | 1026 | 11.33 | 0.38 | 0.12 | 3.33 | 3.59 | 11.16 | 3.45 | 3.33 | ---- |
| 17 | Essam Sh. | 40 | 221 | 8.50 | 3.15 | 2016 | 24.69 | ---- | 0.16 | 3.91 | 6.90 | 25.34 | 6.41 | 3.33 | 0.64 |
| 18 | 19B | 42 | 160 | 8.60 | 2.87 | 1837 | 22.50 | ---- | 0.13 | 2.92 | 4.82 | 24.34 | 4.21 | 3.00 | ---- |
| 19 | 9B | 45 | 200 | 8.70 | 1.87 | 1200 | 17.65 | ---- | 0.11 | 0.75 | 1.83 | 13.79 | 2.43 | 3.33 | 0.18 |
| 20 | Abna'a Shaab | 60 | 190 | 8.30 | 3.82 | 2445 | 35.80 | ----- | 0.18 | 2.49 | 3.12 | 32.05 | 5.38 | 3.55 | ---- |
| 21 | River Nile | — | ---- | 8.00 | 0.10 | 194 | 1.018 | ----- | 0.138 | 0.543 | 0.699 | 0.228 | 0.214 | 1.934 | ---- |
| 22 | Nubia S.S. (Eastern D.)* | Flowing | 420 | 8.00 | 3.25 | 2080 | 31.42 | ---- | ---- | 2.00 | 1.12 | 15.55 | 8.33 | 1066 | ---- |

*** Data obtained from Nubia Sandstone of the Eastern Desert (Wadi Qena) (Elewa et al 2001)**

### Ion ratios (hydrochemical parameters)

Five ion ratios (hydrochemical parameters) were calculated to detect the mineralization sources in the Pleistocene aquifer (Table 2). The high concentration of sodium and chloride ions among cations and anions in most samples indicates the abundance of marine leached salts, as presented in low ratios of rNa/rCl, rCa/rNa and $rSO_4/rCl$. However, the increase of rCa/rMg ratio indicates a fingerprint of calcareous facies, represented by calcite, dolomite and or limestone rocks prevailing in the surrounding limestone plateaux and the deep-seated carbonate rocks. These facies are leached by the deeply percolated Nubia Sandstone groundwater via the deep seated geological structures. The evidence of Nubia Sandstone as one of the sources of old groundwater recharging to the Pleistocene aquifer is obtained from the results of stable isotopes ($^{18}O$ & D) and $^{14}C$ age determination, as will be discussed later. Furthermore, the positive values obtained from the calculation of ion base exchange {(rCl-rNa)/rCl} in some samples refer to the marine origin of this water as previously indicated.

**Table 2. Hydrochemical parameters of the Early Pleistocene aquifer system.**

| Well No. | SAR | Na % | rNa/rCl | rCa/rMg | (rCl-rNa)/rCl | rCa/rNa | $rSO_4/rCl$ |
|---|---|---|---|---|---|---|---|
| 10 G | 7.91 | 71.84 | 0.93 | 2.84 | 0.08 | 0.28 | 0.14 |
| Hamed Abdel Wahab | 5.16 | 48.25 | 0.70 | 1.43 | 0.30 | 0.62 | 0.25 |
| 4 F | 6.07 | 61.53 | 1.14 | 1.11 | -0.12 | 0.31 | 0.28 |
| 5 F | 4.00 | 56.05 | 2.06 | 1.20 | -0.99 | 0.40 | 0.70 |
| 9 G | 5.07 | 53.07 | 0.83 | 2.54 | 0.18 | 0.61 | 0.26 |
| 16 G | 5.41 | 55.17 | 0.85 | 2.06 | 0.13 | 0.52 | 0.27 |
| 6 G | 6.95 | 59.87 | 0.86 | 1.39 | 0.15 | 0.38 | 0.24 |
| 7 G | 4.17 | 43.19 | 0.83 | 1.53 | 0.18 | 0.79 | 0.59 |
| 8 G | 6.47 | 63.42 | 1.02 | 2.10 | -0.01 | 0.37 | 0.20 |
| 2 G | 6.37 | 50.09 | 0.77 | 1.70 | 0.24 | 0.60 | 0.31 |
| 13 G | 5.76 | 56.36 | 0.85 | 1.64 | 0.16 | 0.46 | 0.44 |
| 12 G | 6.09 | 60.02 | 1.03 | 1.03 | -0.02 | 0.32 | 0.36 |
| 2 KF | 6.14 | 60.97 | 1.03 | 1.35 | 0.04 | 0.33 | 0.27 |
| 3 G | 5.94 | 49.57 | 0.82 | 1.46 | 0.20 | 0.57 | 0.34 |
| 1 G | 7.86 | 63.24 | 0.91 | 1.34 | 0.09 | 0.33 | 0.29 |
| 1 KF | 6.09 | 61.15 | 1.03 | 1.08 | 0.02 | 0.32 | 0.31 |
| Essam Sh. | 10.62 | 68.51 | 0.98 | 1.76 | 0.03 | 0.28 | 0.25 |
| 19 B (Abdel Hafez) | 11.44 | 74.08 | 0.93 | 1.65 | 0.08 | 0.21 | 0.17 |
| 9 B (G | 15.55 | 86.81 | 1.29 | 2.43 | -0.28 | 0.10 | 0.18 |
| Abna'a Shaab | 21.37 | 86.07 | 1.12 | 1.25 | -0.12 | 0.09 | 0.17 |

**Table 3 The isotopic results of the collected water samples**

| Well name | δ $O^{18}$ | δ D | d* |
|---|---|---|---|
| | ‰ | ‰ | ‰ |
| **10 G** | **-4.88** | **-34.89** | **4.15** |
| **Hamed Abdel Wahab** | **-7.73** | **-57.25** | **4.59** |
| **4 F** | **-7.69** | **-55.73** | **5.79** |
| **5 F (Delta)** | **2.81** | **21.11** | **-1.37** |
| **9 G** | **-5.73** | **-42.45** | **3.39** |
| **16 G** | **-6.38** | **-46.48** | **4.56** |
| **6 G** | **-8.16** | **-59.14** | **6.14** |
| **7 G** | **-8.02** | **-57.79** | **6.37** |
| **8 G** | **-6.35** | **-43.49** | **7.31** |
| **2 G** | **-7.65** | **-56.39** | **4.81** |
| **13 G** | **-6.99** | **-49.59** | **6.33** |
| **12 G** | **-7.55** | **-53.32** | **7.08** |
| **2 KF** | **-7.63** | **-53.22** | **7.82** |
| **3 G** | **-8.94** | **-63.29** | **8.23** |
| **1 G** | **-8.31** | **-61.07** | **5.41** |
| **1 KF** | **-8.25** | **-60.11** | **5.89** |
| **Essam Sh.** | **-6.49** | **-49.16** | **2.76** |
| **19 B (Abdel Hafez)** | **-6.76** | **-53.66** | **0.42** |
| **9 B (G Abdel Motaal)** | **-6.72** | **-44.5** | **9.26** |
| **Abnaa Shaab** | **-7.01** | **-47.87** | **8.21** |
| **Nubia Sandstone**** | **-10.66** | **-78.10** | **12.2** |
| **River Nile *** | **-0.5** | **+ 6.3** | **--** |

*** & ** referenced data taken from GMBH, 1979.**

**Discussions about the isotopic data of Wadi El-Assiuti groundwater**

The most important elements in this study are the isotopes of hydrogen and oxygen (D & $^{18}O$), the two constituents of water molecule which occur naturally. As previously mentioned, these isotopes are used as natural tracers to investigate the origin of water or the processes that have affected water since it was formed. The isotopic measurements are carried out for 21 groundwater samples. The results obtained are shown in Table 3.

The isotopic results of the collected surface and groundwater samples in the studied area are widely varied from -8.9 to 2.81o/oo for $O^{18}$ and from -61.07 to 21.11 o/oo for Deuterium.

Almost 86% of these samples fall in the depleted isotopic range with a mean value equal -7.45o/oo, whereas the remaining percentage (14%) is gradually enriched in isotopes (Figs 7 and 8). Plotting the data points with respect to the Global Meteoric Water Line (GMWL: $\delta D = 8\,\delta^{18}O + 10$) in the conventional relationship of $\delta O^{-18}$ and $\delta D$ is indicted in Fig. 9. The distribution of these points fall below the global line with a regression line following the equation:

$$\delta D = 7.08\,\delta^{18}O - 1$$

Low slope and intercept values obtained from this equation indicate the old origin of the main bulk of water that is represented by 86% of these samples, which have the depleted isotopic signature of the paleowater in Eastern Desert of Egypt.

The replenishment of this water is attained from the underlying Nubia Sandstone aquifer through the deep seated faults, which provide active recharge zones or conduits through which the Nubian water upwardly leaked to recharge the overlying aquifers (upper and lower Eocene fissured limestone aquifer or the Pleistocene aquifer). However, the groundwater in the Nubia Sandstone aquifer system is confined by the upper shaly members of the Nubian Formation. The drilled boreholes in the Nile Valley (i. e. Wadi Qena wells (Elewa et al. 2001) demonstrate that free-flowing artesian conditions develop in the Nile Valley itself, and in the lower sections of the tributary wadis of its eastern flank. It is most likely that the shallow aquifers, which are regularly encountered saturating the alluvial fill of these wadis are fed by discharge of the Nubian aquifer. The groundwater from deep artesian Nubian aquifer has the lightest isotopic composition (GMBH, 1979). This fact clearly proven by Piper (1944) trilinear diagram, as the two water groups nearly occur in the same water class (Sample 22 in Fig. 10) confirming the idea of direct hydraulic interconnection of the Pre-Upper Cretaceous aquifer (Nubia Sandstone) with the Early Pleistocene aquifer system by upward leakage, as deduced also from the isotopic composition.

On the other hand, the obvious shift of the enriched samples towards the Nile point confirms the existing of two different aquifers, confronting each others at the entrance of Wadi El-Assiuti. The eastern one is the main Early Pleistocene aquifer of the Wadi proper. This aquifer could be recharged by the Nubian aquifer through a direct contact (through the deep-seated faults) between them. The western one is the main aquifer of the Nile Valley, which is recharged by the River Nile. This part of the aquifer is characterized by exceptionally high hydrogen and oxygen values which are found in samples of 2F, 5F, and 10G. Compared with the isotopic composition of the Nile water it becomes obvious, that the groundwater in this area must have been recharged from the River Nile. The trend of water evolution is clearly given by Piper (1944) trilinear diagram (Fig. 10).

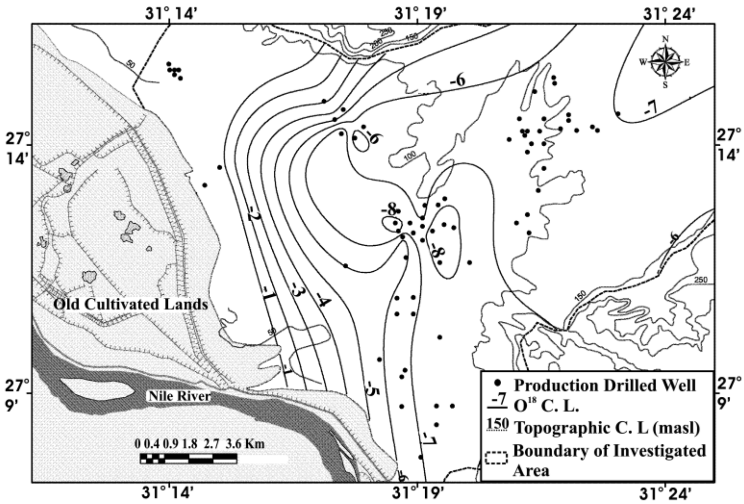


**Fig. (7) $O^{18}$ contour map of the Early Pleistocene aquifer of Wadi El-Assiuti**

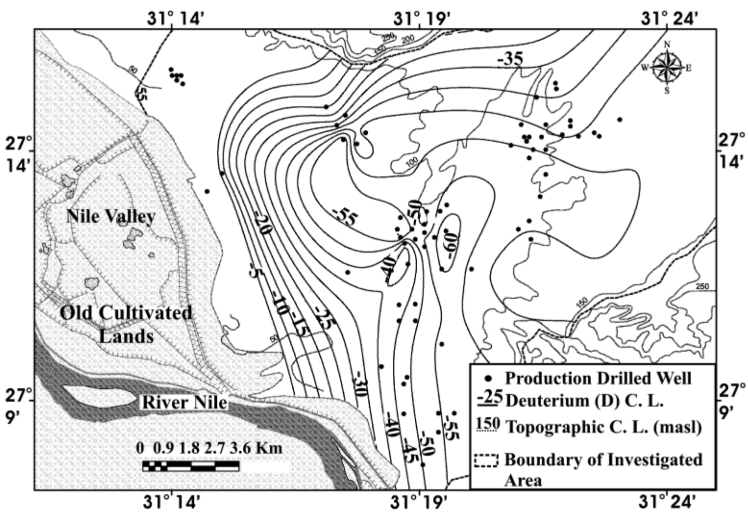

**Fig. (8) Deuterium contour map of the Early Pleistocene aquifer system of Wadi El-Assiuti**

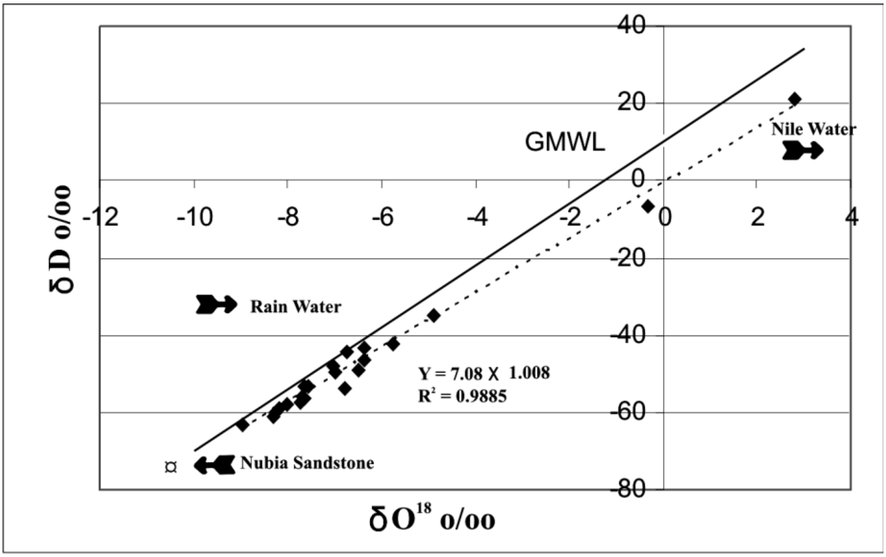


**Fig. (9) Relationship of Delta $O^{-18}$ versus Delta D (in per mil)**

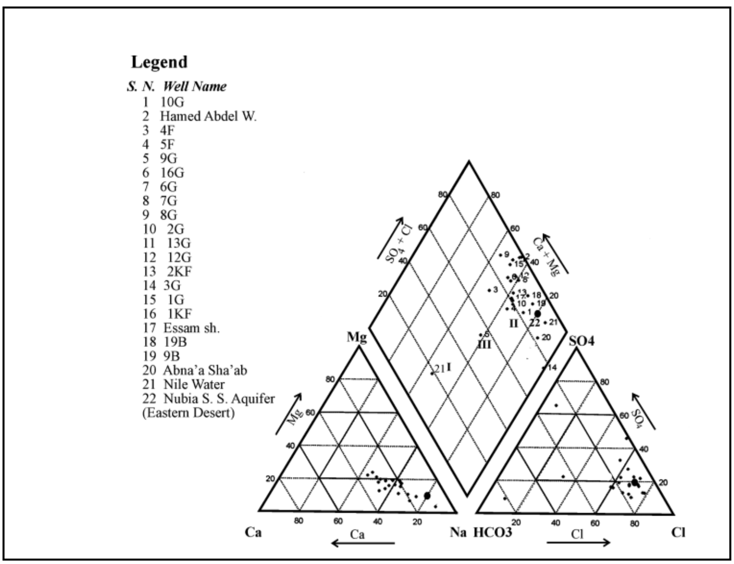


**Fig. (10) Groundwater hydrochemical evolution trend by Piper's trilinear diagram**

**Evidence of groundwater old age by Carbon -14**

The idea of the old age of the Early Pleistocene aquifer, which is diluted at certain areas under certain circumstances by the recent ground and surface water, was confirmed by carrying out the $^{14}C$ activity measurements of DIC precipitated from two selected groundwater samples at the northeastern boundary (Well 9B) and the center of the basin (Well 3G) (Table 4). These samples were precipitated in the field as barium carbonate. The precipitate was converted to $CO_2$ gas and synthesized to benzene. Accordingly, radiocarbon activity was measured by Beta Liquid Scintillation Counter. The calculated value of $^{14}C$ activity measurements in the sample of Well 9B reach 24.7 pmc (percent modern carbon) indicating water age up to 10,000 yBP. Whereas, at the center of the basin, low pmc was recorded in Well 3G (pmc = 3), where the age of this water reaches 27,000 yBP. Both results are consistent with the stable isotopic values of $^{18}O$ and D. The relative enrichment in stable isotopes and short age detected in the northeastern mountainous front zone gives evidence about the significant amount of recent precipitation replenishing the aquifer. On the other hand, at the center of the basin, high isotopic depletion and long age confirm the upward leakage of paleorecharge water from the Lower Cenomanian aquifer (Nubia Sandstone aquifer), where the major replenishment occurs in this part could point to an area of a major fault zone (Fig. 4).

The estimated travel time of the groundwater along the flow path from the norteastern boundary to the center of the basin is very long, which is attributed to the low hydraulic conductivity of the aquifer (0.030 m/day) (NARSS 2005). The distance from the catchments mountainous northeastern areas and the center of the basin of the area of study is about 90 km. Accordingly, the average travel time needed is about 8219 years via the subsurface to reach the center of the aquifer basin. Thus, this water gives another positive recharge contribution side–by-side with the original stored groundwater from the pluvial periods and the water coming from the upward leakage via the deep-seated faults from the Nubia Sandstone aquifer system.

**Table 4: $C^{14}$ data and results of the Pleistocene aquifer of Wadi El-Assiuti:**

| Sample no. | PMC % (percent modern carbon) | Age (yr.b.p) Years before present |
|---|---|---|
| Well no.3G | 3 | 25,000 – 27,000 |

| | | |
|---|---|---|
| Well no. 9B | 24.7 | 8000 – 10,220 |

## CONCLUSION

The hydrogeological, hydrogeophysical and hydrochemical tools of investigation elaborated different recharge sources and environments in the Early Pleistocene aquifer system of Wadi El-Assiuti area. These recharge sources includes the River Nile water in the neighborhood area of the Nile Valley, the local rainfall of the northeastern and surrounding mountainous areas and the upward leakage of the deeply penetrated Nubia Sandstone aquifer system.

The $^{14}C$ results indicate that the Pleistocene water of Wadi El-Assiuti is mostly paleowater. This is obvious in the sample taken from Well 3G, whereas at the Well 9B, which is located in the northeastern part of the study area, reveals a significant portion of relatively recent water recharging the aquifer from the local rainfalls in addition to that of the Red Sea mountainous area. This confirms the slight enrichment in stable $O^{18}$ and D in the second sample than the former one.

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