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# Hydrogeologic Regime of Moghra aquifer, East Qattara Depression, Egypt

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ABSTRACT

The Lower Miocene Moghra aquifer is the main source of water needed for agricultural and human resources development in the North Western Desert. The objective of the present study is to investigate the hydrogeologic regime of Moghra aquifer, East Qattara Depression, North Western Desert, Egypt. It is defined through the flow pattern and geochemical composition of groundwater. Eleven groundwater samples are collected from wells tapping Moghra aquifer and one sample from the Mediterranean Sea. The groundwater flow paths were investigated from East to West. The hydrochemical and isotopic analyses of groundwater samples indicate many recharge sources for the Moghra aquifer in the study area (rainfall, sea water intrusion, Quaternary of Nile Delta, Post Moghra aquifer and Nubia sandstone aquifer system). The salinity characteristics reflecting brackish, Na-Cl- $SO_4$ water type and the groundwater chemical evolution is mainly controlled by Evaporation and Rock water interaction.

## Introduction

The Western Desert of Egypt represents a great part of the Egyptian land. It occupies about 68% of the total area of Egypt. Qattara Depression represents one of the most important areas in the North Western Desert of Egypt. The present work deals with the hydrogeological regime of the Moghra aquifer. It is the main source of groundwater for agricultural and domestic purposes.

The study area is located in the North Western Desert, East Qattara Depression, Egypt. It is located between latitudes 30° 00' and 30° 30' N and longitudes 28° 00' and 29° 30' E (**Fig 1**). Many geomorphological, geological, and hydrogeological studies have been carried out [1-16].

Fig (1). Location map of the study area with locations of groundwater samples

The study area comprises significant geomorphological features represented by Depressions, Ridges, Tablelands and Sand dunes. Locally, the area is characterized by low and moderate relief which is affected by weathering agents [7]. The low landforms are occupied by Qattara, Moghra, Nakhlet El Barrak Depressions where the ground elevations range between (-45m) and (-80m) below sea level. The high landforms are represented by Marmarica Limestone Tableland where the ground elevation reaching (+258m) above sea level. The surface of the study area is built of sedimentary rocks belonging to Lower Miocene (Moghra Formation), Middle Miocene (Marmarica Formation), Pliocene (Hagif Formation) and Quaternary geologic ages. The Moghra aquifer occurs under unconfined to semi confined conditions building of fine to medium sandstones with clay intercalations which deposited under fluviomarine conditions [4]. It represents a hydraulic connected system with the overlying and underlying aquifers.

## Materials and Methods

### Field measurements

The following field works were carried out:

a) Measurements of depth to groundwater in the wells and defining coordinates using the Global Positing system device (GPS, eTrex, Personal Navigator, Garmin LTD) with Topographic maps.

b) Collecting 11 groundwater samples from wells tapping Moghra aquifer as well as one sample from Mediterranean Sea for chemical and isotope analysis.

### Laboratory analysis

Two separates laboratories are used for the required chemical and isotopic analysis. Dissolved major cations ($Na^+$, $K^+$, $Ca^{+2}$ and $Mg^{+2}$) and anions ($Cl^-$, $SO4^{-2}$, $CO_3^{-2}$ and $HCO_3^-$) of groundwater samples determined at the Water and Soil Lab Unit, Desert Research Center, Cairo, Egypt, following the methods of American Society for Testing and Materials [17] (**Table 1**).

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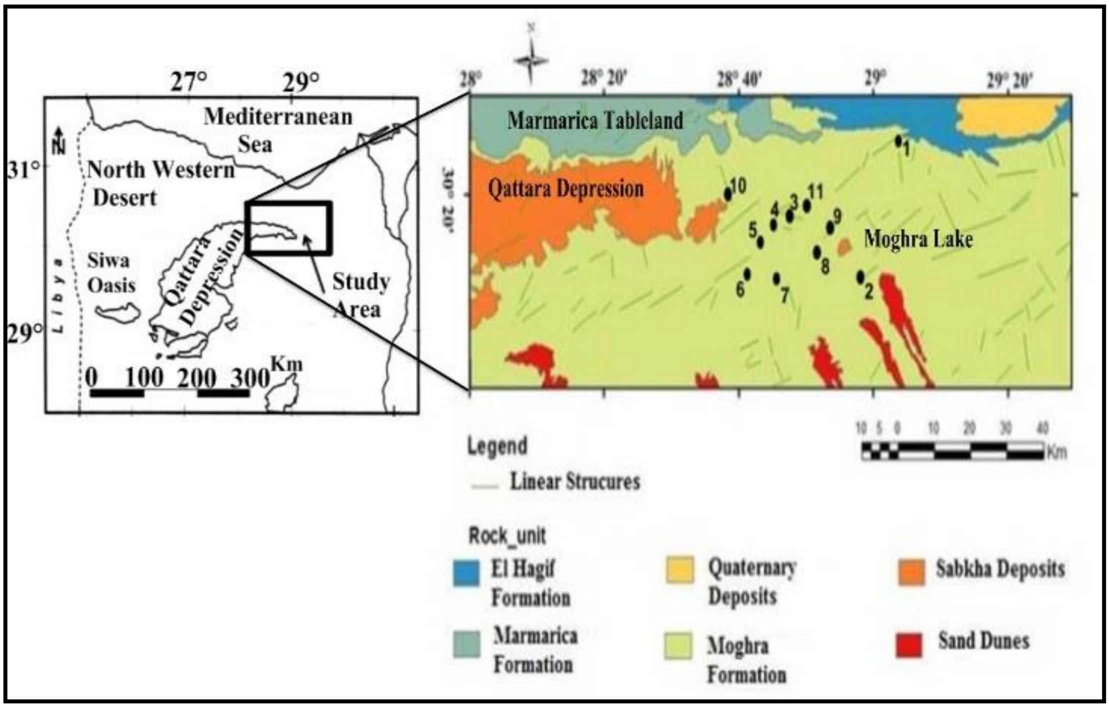


**Fig 1**: Location map of the study area with locations of groundwater samples

**Table 1:** Results of chemical analysis of Major Cations and Anions (mg/l), Moghra aquifer, North Western Desert, Egypt.

| well no | pH | Ec | TDS | Ca | Mg | Na | K | $CO_3$ | $HCO_3$ | $SO_4$ | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 7 | 12340 | 6848 | 488.2 | 276.7 | 1550 | 22 | 12 | 116 | 966.4 | 3475 |
| **2** | 7.7 | 4180 | 2376 | 192 | 66.92 | 600 | 7 | 9 | 58 | 252.3 | 1220 |
| **3** | 7.4 | 8930 | 5077 | 314.7 | 168.7 | 1250 | 11 | 12 | 97.6 | 881.2 | 2391 |
| **4** | 6.8 | 9570 | 5360 | 311.2 | 177.3 | 1450 | 8 | 0 | 54.9 | 625.4 | 2760 |
| **5** | 6.9 | 10390 | 6273 | 355.6 | 174.3 | 1650 | 13 | 0 | 97.6 | 1025 | 3007 |
| **6** | 6.8 | 8870 | 5123 | 313 | 142.6 | 1300 | 15 | 12 | 88.5 | 1004 | 2292 |
| **7** | 7.6 | 5800 | 4010 | 257.6 | 93.6 | 1020 | 10 | 15 | 48.8 | 840 | 1750 |
| **8** | 7.6 | 6770 | 4185 | 265.4 | 111.5 | 1050 | 5 | 15 | 76.3 | 950 | 1749 |
| **9** | 7.5 | 6720 | 4041 | 253.1 | 114.9 | 1000 | 8 | 12 | 97.6 | 866.8 | 1737 |
| **10** | 7.1 | 14450 | 8649 | 541 | 331.7 | 2250 | 23 | 15 | 97.6 | 1126 | 4312 |
| **11** | 7.6 | 8270 | 4978 | 299.5 | 151.8 | 1250 | 17 | 15 | 58 | 850 | 2365 |
| **sea water** | 7.5 | 59500 | 37841 | 680 | 1448 | 12000 | 5 | 12 | 54.9 | 3459 | 20209 |

The isotopic analysis for oxygen-18 and deuterium are determined at the Isotope Laboratory, Geoscience Department, College of Arts and Science, Western Michigan University, USA:

a) The chemical analysis for major and minor elements is operated for 11groundwater samples where Major ions Sodium ($Na^+$) and potassium ($K^+$) ions are measured using Flame Photometer, PFP 7, Jenway, UK. Calcium ($Ca^{+2}$) and Magnesium ($Mg^{+2}$) are determined by titration against $Na_2EDTA$. Sulphates ($SO_4^{-2}$) are determined by UV/Visible Spectrophotometer, Unicam UV 300, Thermo Spectronic, USA. Carbonates and bicarbonates ($CO_3^{-2}$, $HCO_3^-$) are measured by titration using sulphuric acid. Chloride ($Cl^-$) is determined by volumetric titration using silver nitrate. The concentrations were expressed by mg/l.

b) The isotopic analysis is operated for seven water samples are selected to determine oxygen-18 and deuterium using a Triple Liquid Isotopic Water Analyzer (Los Gatos). The isotopic results are expressed by δ notation in units of permil (‰) relative to Vienna Standard Mean Ocean Water (V-SMOW), whereby:

$\delta(sample)\ (\%) = [R(sample) - R(standard) / (R(standard)].\ 1000$

Where: R represents the isotopic ratios, $O^{18}/O^{16}$ or D/H, of the samples or V-SMOW standard. The precision of $\delta^2H$ and of $\delta^{18}O$ values were ±1%, ±0.1%, respectively.

## Results and Discussion

### Groundwater flow patterns

The groundwater occurs under unconfined to semi confined conditions in the Moghra aquifer. The main trend of groundwater flow is directed from East to West where the groundwater levels changes from (-6m) at the East to (-50.78m) at the eastern side of Qattara Depression. The investigated flow patterns in the study area reflect an obvious hydrologic impact of the Qattara Depression where it acts as a regional discharge area in the North western Desert (**Fig. 2**). These hydrologic conditions are relatively coinciding with the hydrologic conditions in 2010; where the groundwater flow was from the east (-7.013m) to the west (-40m) at Qattara Depression [15] (**Fig.3**).

The Moghra aquifer is connected hydraulically with the overlying Middle Miocene (Marmarica) aquifer and post Miocene (Quaternary) aquifer in the study area. The aquifer is connected with the underlying Nubia Sandstone aquifer in the North Western Desert through faults and fractures. The aquifer is affected by salt water intrusion from the Mediterranean Sea. The outcrops of the water bearing rocks acting as catchment areas for local rainfall and affected by Evaporation.

### Hydrogeochemical Characteristics and evolution

### Spatial distribution and classification of groundwater

The pH values of groundwater in the Moghra aquifer vary from 6.8 to 7.7 reflect slightly acidic to slightly alkaline. The TDS values increase in the north-eastwards ranges from 2376 ppm to 8649 ppm.

The groundwater in the Moghra aquifer are characterized by Sodium chloride and sulphate water type reflecting primary salinity [18-19] (**Figs 5 & 6**). The same water type was investigated from previous studies [5,12,15]. This may attribute to the same hydrogeological conditions.

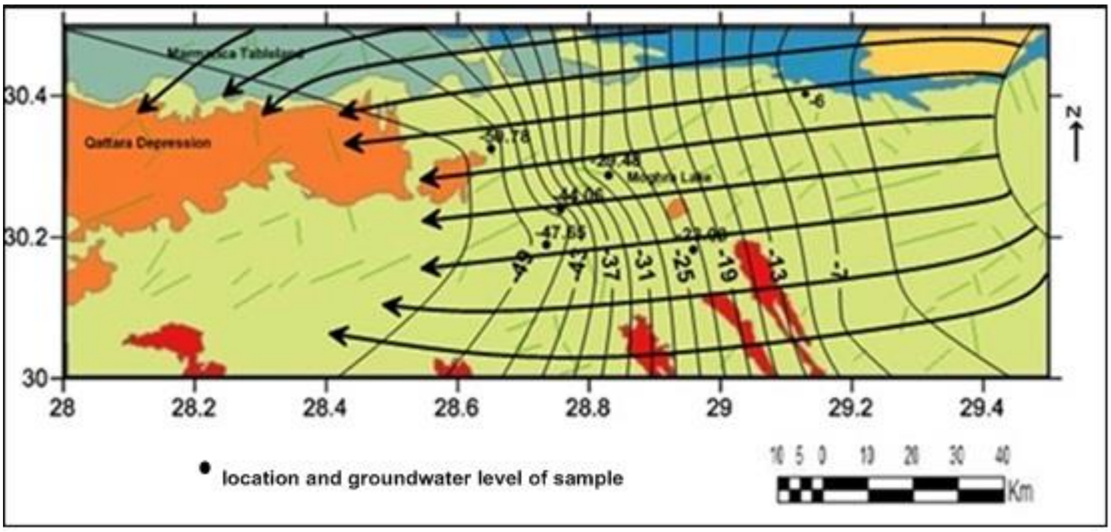


**Fig 2**: Flow net of The Moghra Aquifer, East Qattara Depression, North Western Desert, Egypt

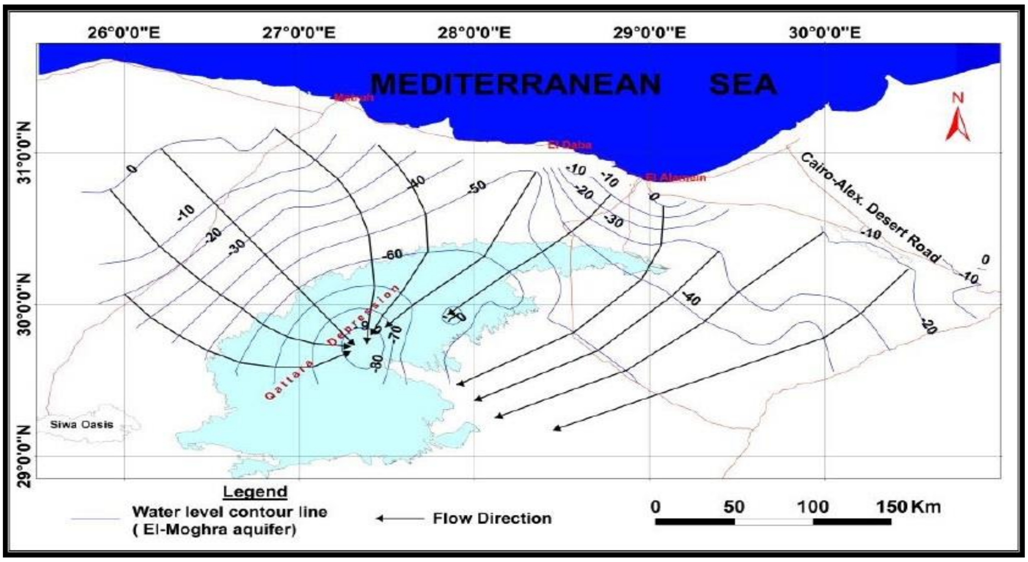


**Fig 3**: Flow net of The Moghra Aquifer (2010).

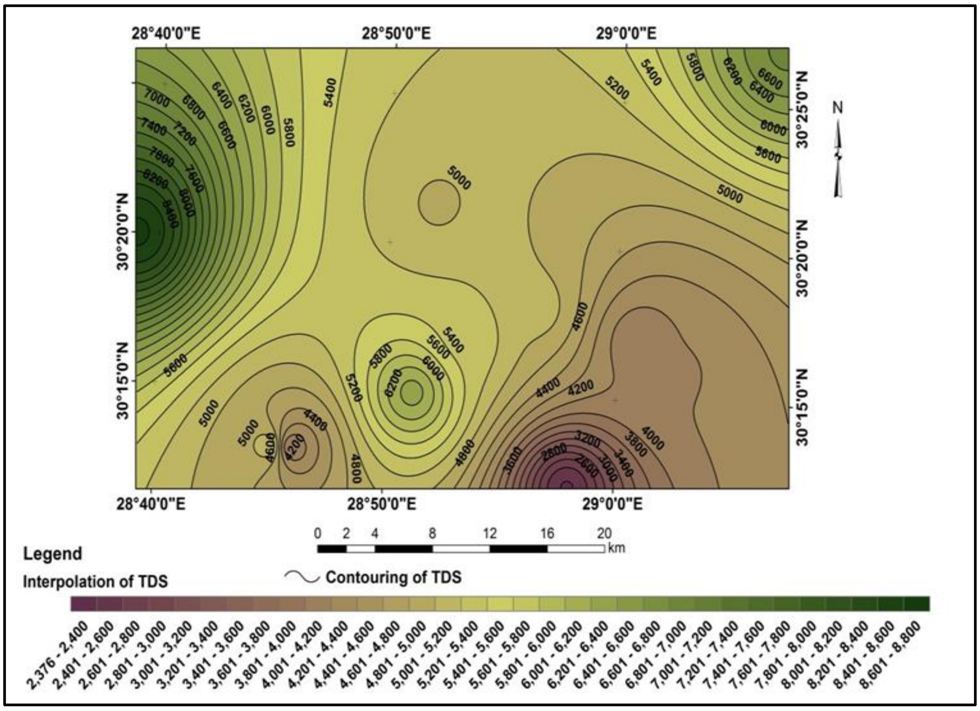


**Fig 4**: Iso-salinity contour map of Moghra aquifer, Western Desert, Egypt

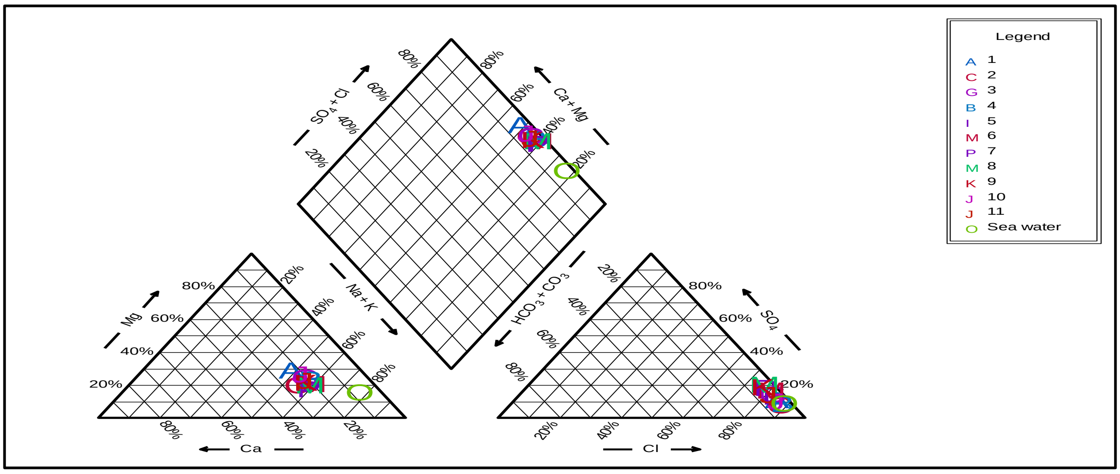


**Fig 5**: Piper diagram of Groundwater samples of Moghra aquifer, East of Qattara Depression, Egypt.

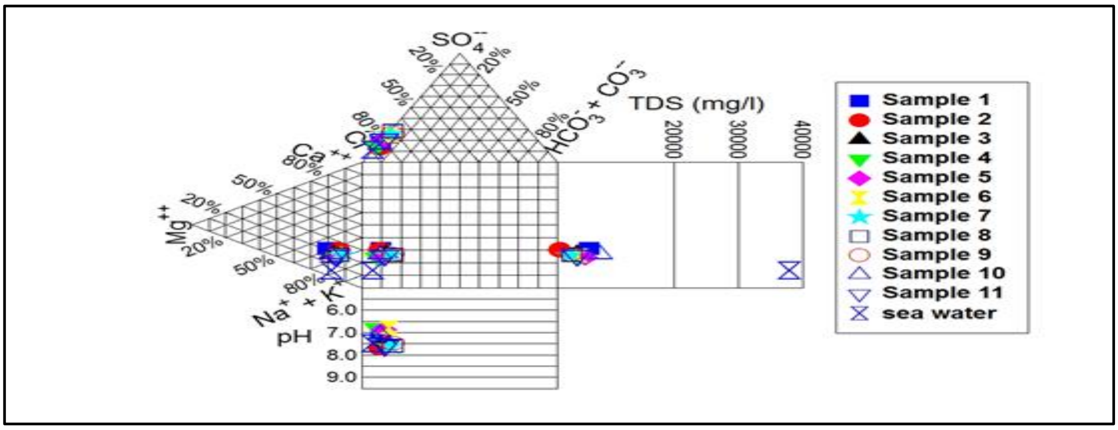


**Fig 6**: Durov's diagram for the Moghra aquifer groundwater, East of Qattara Depression, Egypt.

**Hydrogeochemical evolution of the groundwater**

Gibbs diagram [20] (**Fig. 7**) is introduced to assess the influence of Evaporation, Rock and Precipitation of groundwater geochemistry. The sample points of groundwater are lying between Evaporation and Rock dominance indicating that the hydrogeochemistry is dominantly controlled by Rock water interaction and Evaporation. This may indicate the dissolution of salts such Halite which are spread along the Quaternary deposits or preexisting salts in the host rock. Relations of major ions are presented in (**Figs. 8 & 9**). In the relation between $Na^+$ and $Cl^-$, all samples are situated along the Halite dissolution line but in the relation between $Ca^{+2}$ and $HCO_3^-$, samples plotted away from the Calcite and Dolomite dissolution line suggesting that Halite dissolution can affect the groundwater chemical composition while the contribution of Calcite and Dolomite can be very limited. This may be attributed to the effect of recharge from Middle Miocene limestone aquifer (Post Moghra aquifer).

Groundwater saturation state was computed to calculate saturation index (SI). The results (**Table 2**) showed that the groundwater in Moghra aquifer are under saturation (SI<0) with respect to Halite, Anhydrite and Gypsum but, they are super saturated (SI>0) with respect to Quartz and Tridymite (Silicate minerals). This reflects that chemical composition of the groundwater was contributed by minerals of Halite and Gypsum in the water bearing rocks.

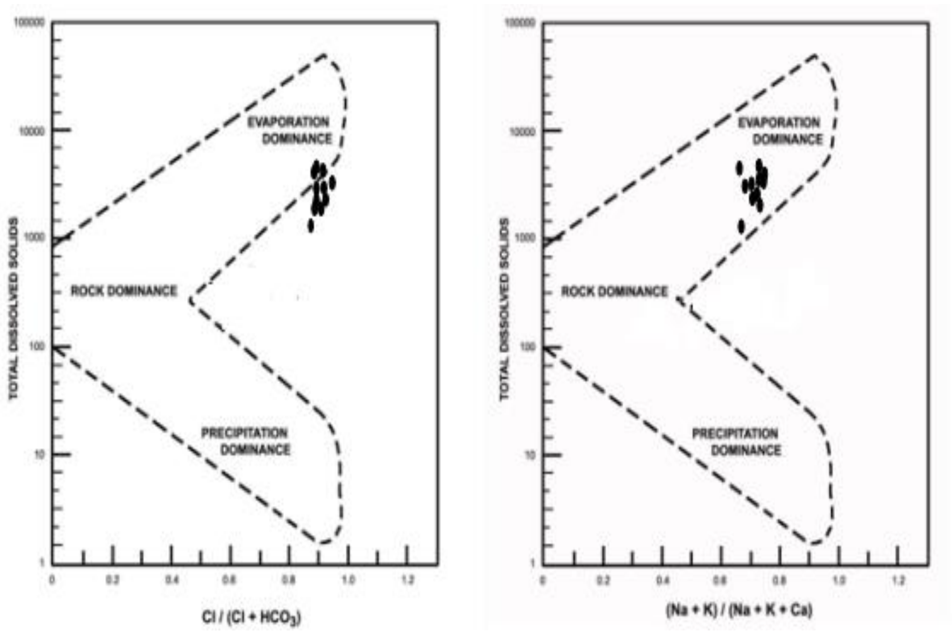


**Fig 7**: Gibbs ratio for groundwater samples (Cations and Anions).

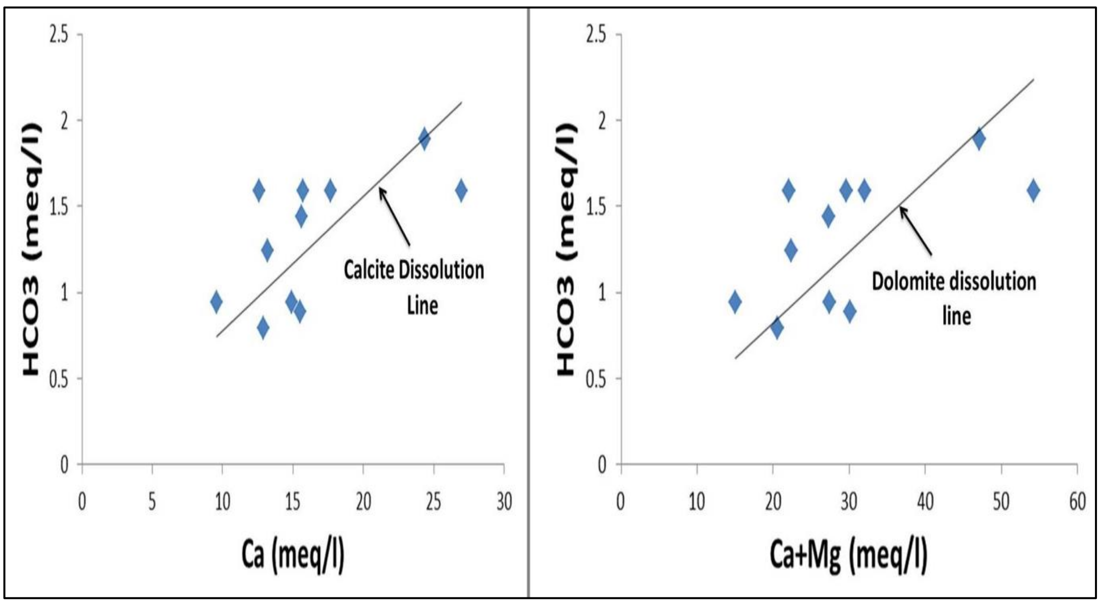


**Fig 8**: Bivariate plot of different ions showing the correlation of major ions.

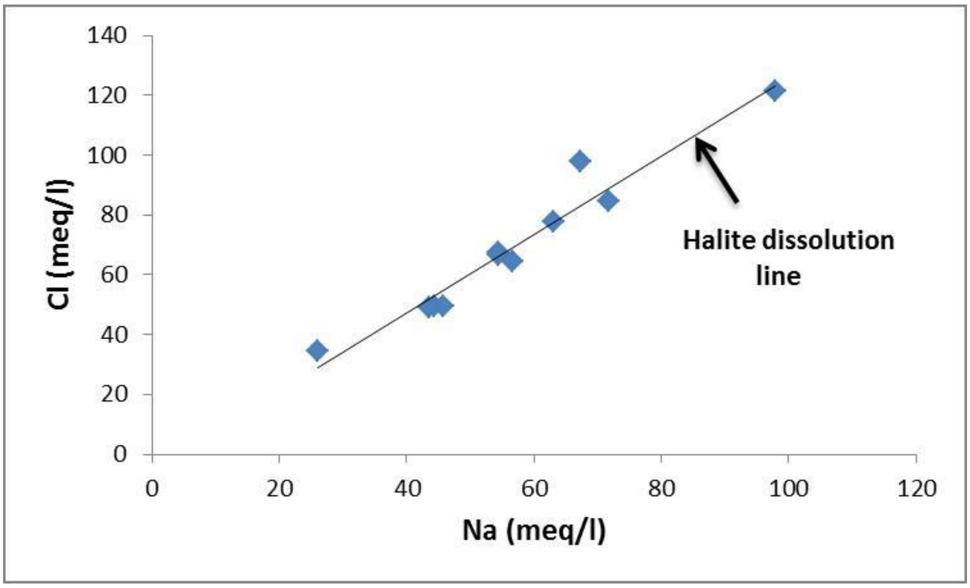


**Fig 9**: Bivariate plot of Na vs Cl ions showing the correlation of major ions.

**Table 2:** Calculated saturation indices of groundwater of Moghra aquifer, East Qattara Depression, North Western Desert, Egypt.

| Well no | Saturation Index | | | | |
|---|---|---|---|---|---|
| | Quartz | Tridymite | Halite | Anhydrite | Gypsum |
| **1** | 0.2497 | 0.0839 | -4.0471 | -0.8946 | -0.7193 |
| **2** | 0.3914 | 0.2256 | -4.8307 | -1.4969 | -1.3198 |
| **3** | 0.3528 | 0.187 | -4.2758 | -1.0015 | -0.8253 |
| **4** | 0.0966 | -0.0692 | -4.1529 | -1.1642 | -0.9883 |
| **5** | 0.1958 | 0.03 | -4.0713 | -0.9467 | -0.771 |
| **6** | 0.0575 | -0.1083 | -4.2772 | -0.9474 | -0.7711 |
| **7** | 0.3544 | 0.1886 | -4.4799 | -1.0199 | -0.8432 |
| **8** | 0.3348 | 0.169 | -4.4718 | -0.977 | -0.8003 |
| **9** | 0.3464 | 0.1806 | -4.4932 | -1.0239 | -0.8473 |
| **10** | 0.1956 | 0.0298 | -3.8102 | -0.8636 | -0.689 |
| **11** | -0.5777 | -0.7435 | -4.278 | -1.0251 | -0.8489 |
| **Sea water** | -2.4017 | -2.5675 | -2.5148 | -0.8645 | -0.7023 |

**Recharge mechanism of groundwater**

Stable isotopes form a powerful tool to examine the water provenance and recharge characteristics of groundwater. It ranges from -0.31 % to 5.82 % with an average value of about 1.59 % for $\delta^{18}O$ values and from -13.92 % to 13.73 % with an average value of about 2.09 % for δD (**Table 3**). This indicates that the content increase from North and Northeast to South along flow path which may also indicate the presence of Northeast recharge front (**Figs. 10 & 11**).

Five reference points are taken to investigate the contribution from the underlying and overlying aquifers in addition to World Meteoric Water Line (WMWL).

1) The isotopic composition of the Mediterranean Sea water ($\delta^{18}O$ =1.87 % and δD = 9.8 %) [21-22].

2) The average isotopic compositions of the Quaternary aquifer, the western front of the western Nile Delta ($\delta^{18}O$ = 3.31 % and δD = 23.89 %) [23].

3) The average isotopic composition of Nubia sandstone aquifer system, the Western Desert, Egypt ($\delta^{18}O$ = -10.55 % and δD = -80.4 %) [24].

4) The average isotopic composition of Post Moghra aquifer ($\delta^{18}O$ = -4.53 % and δD = -19.77 %) [21].

5) The average isotopic composition of 40 monthly data at Alexandria station ($\delta^{18}O$ = -4.52 % and δD=-21.4 %) [25].

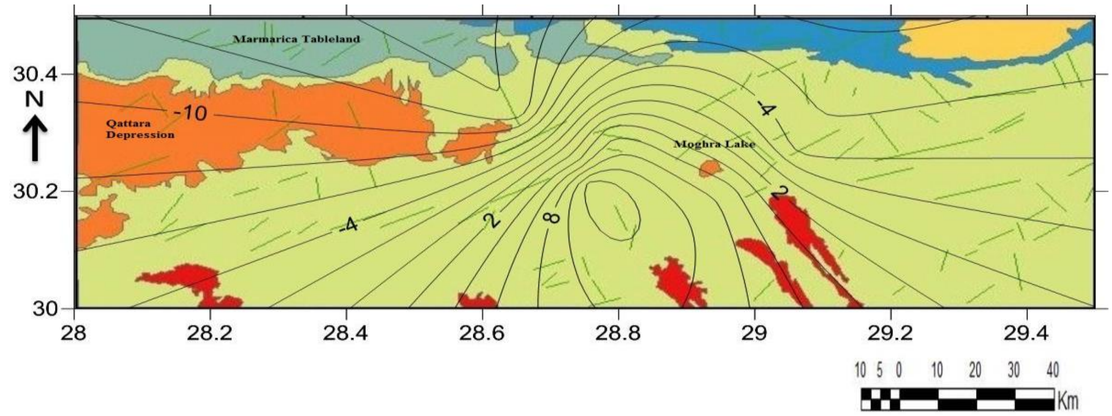


**Fig 10**: Distribution of δD of Moghra aquifer, East Qattara Depression, Northwestern Desert, Egypt.

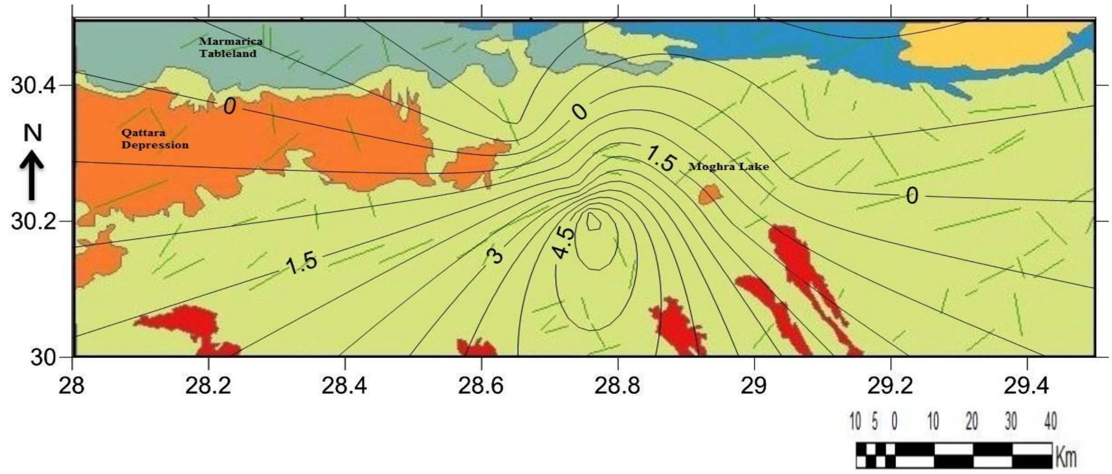


**Fig 11**: Distribution of δ18O of Moghra aquifer, East Qattara Depression, Northwestern Desert, Egypt.

**Table 3:** Results of isotope analysis of groundwater samples of Moghra aquifer, East Qattara Depression, Egypt.

| Sample No | $\delta^2H$ | $\delta^{18}O$ |
|---|---|---|
| 1 | -5.16 | -0.31 |
| 2 | 7.00 | 1.53 |
| 3 | 5.42 | 1.90 |
| 5 | 3.93 | 1.88 |
| 7 | 13.37 | 5.82 |
| 8 | 3.99 | 1.38 |
| 10 | -13.92 | -1.05 |

From the $\delta^{18}O$ and δD plot (**Fig. 12**), the evaporation line converges with the local Meteoric water line (LMWL) of Egypt which suggests the recharging from rainfall on the outcrps which moves downward through post Moghra water bearing rocks. The samples are linearly correlated (δD = 3.64δ18O – 3.72 %, an evaporation line) with a correlation coefficient of 0.89.

Two groups of groundwater are distinguished. The first group (samples 1 & 10) has a negative $\delta^{18}O$ and δD compositions and occur nearly to the mixing line between two end member points of Nubia sandstone aquifer system and Quaternary of Nile Delta. The second group (samples 2, 3, 5, 7 & 8) has a positive $\delta^{18}O$ and δD compositions which affected by Evaporation and occur very close to sea water sample point. It is investigated from the isotope analysis and confirms that Moghra aquifer is affected by Evaporation process. The aquifer is recharged from different possible sources including; rainfall, Mediterranean Sea intrusion, groundwater of Marmarica aquifer (post Moghra aquifer), Nubia sandstone aquifer systems and Quaternary aquifer in the western Nile Delta.

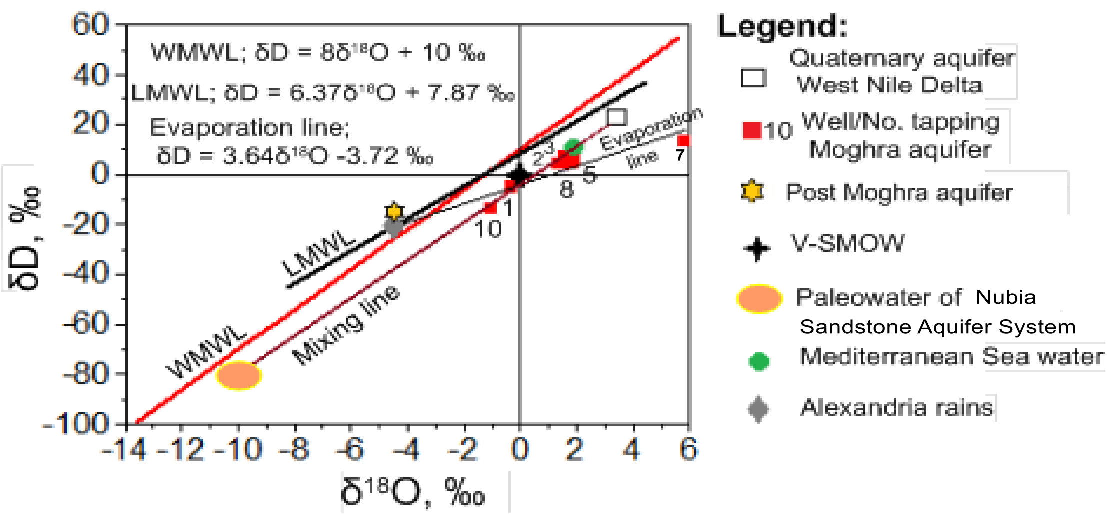


**Fig 12**: Plot of $\delta^{18}O$ vs δD in groundwater of the Moghra aquifer, East Qattara Depression, Northwestern Desert, Egypt.

**Conclusion**

The hydrogeological regime of the Moghra aquifer, East Qattara Depression, Egypt is represented by the investigated flow patterns and the hydrogeochemical characteristics and evolution of the groundwater of the aquifer. It is defined by groundwater flow patterns in all directions recharge and discharge routes. The groundwater type of Moghra aquifer is brackish water and the water type is Na-Cl-SO4 water type. The geochemical evolution of groundwater is controlled by different processes including; The Evaporation, Rock water interaction and Mixing between different sources of water are the dominant factors controlling the groundwater hydrochemistry. The stable isotopes confirm that the groundwater in Moghra aquifer is recharged from different sources: rainfall, sea water intrusion, Quaternary aquifer of Nile Delta, post Moghra aquifer and Nubia sandstone aquifer system. The mixing between different sources affected the groundwater salinity in the Moghra aquifer as well as its geochemical evolution.

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