# HYDROGEOCHEMICAL CHARACTERISTICS AND QUALITY EVALUATION OF GROUNDWATER AT SOHAG DISTRICT, SOHAG GOVERNORATE, EGYPT

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**Groundwater in Sohag Governorate is considered as the second source for freshwater used for domestic, agricultural and industrial uses. Groundwater resources of Sohag district are threatened by contaminants from agricultural and industrial activities. Groundwater chemical parameters are routinely used for characterizing and understanding the processes within hydro-chemical groundwater system. This study evaluates the quality of groundwater and its suitability for different purposes in Sohag district. To achieve this purpose, hydro-geochemical classification and spatial distribution model of the Quaternary aquifer have been carried out. Groundwater samples were collected from thirteen different stations and have been analyzed for figure physicochemical parameters (TDS, EC and pH) and concentration of major ions ($Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$, $HCO_3^-$ and $SO_4^{2-}$). The distribution of the major ions is in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > Cl^- > SO_4^{2-}$. Spatial distribution to both of major anions and cations in groundwater samples are demonstrating somewhat uncommon variety. Major ions in groundwater are within the permissible limits for drinking uses with the exception of bicarbonates $HCO_3^-$. The Sodium Absorption Ratio (SAR) and the Residual Sodium Carbonate (RSC) can indicate and evaluate groundwater suitability for irrigation. It is observed that, most of the water samples are plotted in C3-S1 field and display low Sodium Adsorption Ratio and high salinity hazard. The geochemistry of groundwater over investigated region is generally controlled by way of common natural geochemical processes such as rock water interaction, dissolution, and ion exchange. Furthermore, anthropogenic induced activities like over pumping aquifers, fertilizer influences and agricultural return flow slightly affected on groundwater quality of the Quaternary aquifer over study area.**

*Keywords:* Groundwater resources, hydro-geochemical classification, physicochemical parameters, Sohag district, Quaternary aquifer.

## INTRODUCTION

Much of rural area is dependent on the groundwater which is considered as one of the primary resources of clean water deliver, and it makes up about 20 % of the world's fresh water supply. Egypt is situated in the dry zone of North Africa wherein the crisp water resources are constrained to the settled offer from the Nile and groundwater systems. Urbanization, agricultural expansion and growing population have set an overwhelming interest on water resources which is a severe problem especially in arid and semiarid regions where water resources are restricted.

Generally, both of anthropogenic activities, and water rock interactions have great influence in many components which incorporate hydrologic gradient, residence time and the nature of the initial recharged water of groundwater (Kumar et al. 2012).

Recently, Sohag Governorate development has increasing towards the desert area surrounding the old cultivated lands. Many development projects including new villages, wastewater disposal plants, industrial zones, new urban areas, further other projects have been established in the desert areas. This is in addition to the uncontrolled urbanization caused by the very high population density in the Nile Valley. Most of these projects depend principally on the existing groundwater aquifers as the main source for water. These projects formed a great effect on water demand and water quality evaluation which form a real challenge in the present and the future.

Groundwater management and decision making should be started with the hydro-geochemical characterization. The groundwater quality is the resultant of all the processes and interactions that act on the water from the moment it condenses in the atmosphere to the time it is discharged by a well. Therefore, the importance of groundwater quality determination is to detect the suitability of water for a particular use. The problems of groundwater quality are very acute in areas that are densely populated and thickly industrialized and have shallow groundwater tube wells (Shivran et al. 2006). Groundwater can geochemically studied and providing a better understanding of possible changes in quality as development progress. Groundwater geochemistry is the determination factor for the suitability of groundwater for domestic and irrigation purposes (Satyanarayana et al. 2016).

Anthropogenic activities have the larger influence on the relative contributions for the variations of the natural causes and can also introduce the effects of contamination (Satyanarayana et al. 2016, Whittemore et al. 1989). Trends of contamination and its effects on an aquifer can be understood through the knowledge own about the natural baseline quality so that imposed environmental change can be estimated with an acceptable degree of confidence and safety (Edmunds et al. 2003).Water quality control must be effective. The main aim of the this study is to evaluate the hydro-chemical characteristics of groundwater in Sohag district and to evaluate the major factors influencing groundwater quality of Quaternary aquifer situated at the region, also, to hold up its suitability for different purposes.

**Study area**

Sohag governorate is localized in the halfway between Cairo and Aswan. Sohag Governorate is separated by Nile River into two parts. The first part exists in the west of the Nile River (major investigated region) where most of the cultivation and urbanization are taken place due to the large extension of the flood plain and the second part exists in the east of the Nile River where the flood plain is narrow with limited extension. The studied area is located between longitudes 31° 32′and 31° 46' E and latitudes 26°32′ and 26°36' N (Fig. 1) and localized from east and west by the limestone plateau dissected by many drainage basins running mainly in the E–W directions. Follow these plateaus inwards, there are regions of low desert land than the regions of agricultural land which surrounding the Nile River (Redwan et al. 2016).The entire valley is principally utilized for agricultural activities except for regions involved by settlement.

**MATERIALS AND METHODS**

In this study, thirteen groundwater samples (Fig. 1) were collected and analyzed for their major and minor components to achieve the goal of the present study. Water samples which are collected from the field were analyzed for electrical conductivity (EC), pH, total dissolved solids (TDS), major cations like magnesium, sodium,, calcium potassium and anions like chloride, bicarbonate, sulphate and carbonate in the laboratory using the standard methods given by the American Public Health Association (APHA 1995). Sampling was achieved using pre-cleaned polyethylene containers. According to the World Health Organization, evaluation of drinking water quality was achieved (WHO, 1984).The

control of the quality of analytical data was carried out routinely using blanks, duplicates, standards and by checking ion balances (Srinivasamoorthy, K. et al. 2013). The ionic charges balance errors in the study district samples were within 5%.The groundwater samples which are collected from the Quaternary aquifer at Sohag district have hydro-chemical parameters are shown in Table 1.

## Hydro – geologic setting

The geological setting of the study area and its vicinities had been studied by many researchers such as: Wendorf and Said, 1967; Wendorf and schild, 1976; Said, 1975 and 1981; Issawi and McCauley, 1992; Mahran, 1993; Mousa et al., 1994; Omer, 1996 and Omer and Issawi, 1998. In the study area, this sediment logical sequence is principally represented by the Lower Eocene limestone, Plio- Pleistocene sands, gravels, clays, and the recent sediments (Fig. 2a). Thebes Formation (thin bedded limestone with chert bands and flint nodules) is representing the rocks of the Lower Eocene which it formed the plateau bounding the Nile Valley on both sides. Sediments of the Post-Eocene (terraces in the Nile Valley) were described by Said (1981). He clarified that a great changes take place to the Nile River, since it's down cutting in Late Miocene times. Five rivers succeeded one another in the valley. These are from oldest to youngest, the Eonile (Late Miocene), Paleonile (Late Pliocene), Proto-Pre, and Neo-Niles (Pleistocene).

The hydrogeologic setting of Sohag area has been discussed by many researchers such as: Attia, 1974 ; Farrag, 1982 and 2005; Attia et al., 1986; Abdel Moneim, 1999; Omer and Abdel Moneim, 1998; Diab et al., 2002; Ali, 2005; Gomaa, 2006; Korany et al., 2006; Ahmed, 2007 and Abu ElMaged, 2008, Redwan et al. 2016. According to these studies, in Sohagarea each of the Nile River, irrigation canals and drains representing the surface water while both of Pleistocene sediments and Eocene fractured limestone representing the main water bearing. In the study area, the alluvial deposits of the Quaternary aquifer system composed of two layers having distinct hydraulic characteristics (Fig. 2b).

The upper layer is composing from the clay–silt member, with low horizontal and vertical permeability. This upper layer is considered as a semi-confining layer to the underlying aquifer. The clay–silt member thickness showing lateral variation, thus it shows larger thickness near the river channel where as it shows thinning near the valley fringes where it is overlain by desert sands.  The lower layer which composing the graded

sand member forms the main aquifer which having high horizontal and vertical permeability. The presence of wide and thick deposits of the Pliocene clays of very low permeability leads to make the lower boundary of the aquifer impervious. The lateral boundaries along the sides of the Nile River valley are not impervious. The geometry, thickness and the width of the Quaternary aquifer differ from one locality to another (Attia, 1974 and Farrag, 1982). Quaternary aquifer thickness is about 260 m along the Nile River whereas the thickness decreasing toward the Eocene plateau is taken place.
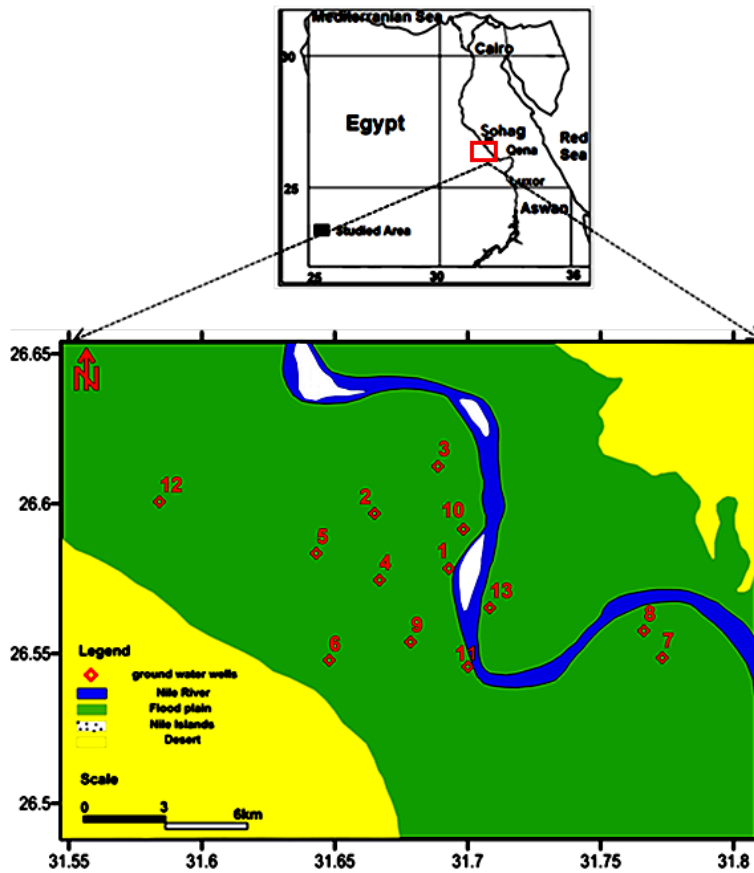


**Fig.1:** Location map of the sampling points in Sohag District.

The irrigation, draining canals and the rainfall are considered the main sources of aquifer' recharge (AbdelLatif and El Kashouty 2010). Generally, in the studied district, the flow of groundwater follows through two main directions, the first direction from the south to north following the land elevation, whereas the second direction is from the Nile River (the flood plain) to the desert fringe. The controlling of the local flow

takes place by the difference in the level of water in irrigation canals, drains and the water table. It is important to mention that Aswan High Dam construction has played an important role in the flow of groundwater in the area (Attia, 1974, Barber and Carre, 1981; and Abdel Moneim, 1992).

## RESULTS AND DISCUSSION

### *Groundwater chemistry*

It is a very important to understand the quality of the groundwater as it is the main factor which deciding its suitability for drinking, domestic, agricultural and urbanization activities (Selvakumar et al. 2017, Subramani et al. 2005, Satyanarayana et al. 2016, Nag and Das, 2017). Physical and chemical parameters including statistical measures such as minimum, maximum, and average, are given in Table 1.

### *Electrical Conductivity (EC)*

The EC values of groundwater vary from 641.33 to1215.00 µS/cm with an average value of  876.90 µS/cm.

### *Hydrogen Ion concentration (pH)*

The hydrogen ion concentration (pH value) of the groundwater ranges between 7.33 and 7.59, with an average value of 7.46. This refers to the alkalinity nature of the groundwater in the study area.

### *Total Dissolved Salts (TDS)*

In the studied district, total dissolved salts (TDS values) ranges from 434.20 to 810.00 mg/l with an average value of 585.73 mg/l. The most important role of TDS with respect to the quality of drinking water is its effect on taste. High concentrations of the total dissolved salts may cause the water to be salty or brackish taste, resulting in formation of a separated layer lead to decrease the efficiency of hot water heaters (Sawyer and McCarty, 1967, Orewole et al. 2007).

According to Hem (1970), groundwater was classified into four types of total salinity depending upon the total dissolved salts values (TDS); freshwater (TDS <1000 mg/l); moderately saline water (TDS 3.000 to10.000 mg/l); very saline water (TDS from 10,000-35,000 mg/l) and briny water (TDS >35.000 mg/l). Consequently, in the studied district, all the groundwater samples are fresh water (TDS <1000 mg/l).

**Fig. 2** a- Regional geological map of Sohag Governorate (After The Egyptian Geological Survey and Mining Authority 1989), b- General hydrogeologic section of the Sohag district (after RIGW 1990).

The Quaternary aquifer has iso-salinity distribution map in the studied district (Fig.3), it is obvious that, there is one general direction of water salinity increase from northwest toward the southeast.

**Table1:** Physical parameters and chemical composition of the thirteen analyzed samples.

| Sample | pH | EC (µS/cm) | TDS (mg/l) | $Na^+$ (mg/l) | $Ca^{2+}$ (mg/l) | $Mg^{2+}$ (mg/l) | $K^+$ (mg/l) | $Cl^-$ (mg/l) | $SO_4^{2-}$ (mg/l) | $HCO_3^{2-}$ (mg/l) | SAR (meq/l) | RSC (meq/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.39 | 674.05 | 456.62 | 37.83 | 59.29 | 21.88 | 3.47 | 49.16 | 37.18 | 236.21 | 1.07 | -0.89 |
| 2 | 7.33 | 1159.20 | 771.87 | 66.00 | 106.85 | 37.10 | 6.70 | 67.23 | 81.03 | 516.76 | 1.40 | 0.09 |
| 3 | 7.50 | 913.50 | 610.73 | 71.00 | 66.00 | 40.39 | 6.10 | 47.52 | 36.18 | 404.50 | 1.70 | 0.01 |
| 4 | 7.59 | 696.33 | 449.00 | 61.33 | 45.66 | 21.36 | 5.11 | 30.50 | 43.50 | 306.66 | 1.88 | 0.99 |
| 5 | 7.50 | 755.10 | 503.00 | 72.71 | 66.16 | 27.14 | 5.74 | 42.30 | 65.45 | 367.50 | 1.90 | 0.49 |
| 6 | 7.40 | 910.04 | 606.40 | 94.05 | 71.33 | 33.32 | 16.50 | 52.05 | 39.20 | 272.88 | 2.30 | -1.83 |
| 7 | 7.43 | 940.75 | 629.00 | 61.45 | 30.00 | 58.80 | 10.41 | 59.00 | 57.50 | 452.50 | 1.50 | 1.08 |
| 8 | 7.49 | 996.00 | 668.25 | 56.70 | 47.50 | 63.30 | 8.12 | 65.25 | 24.00 | 452.50 | 1.27 | -0.16 |
| 9 | 7.52 | 1215.00 | 810.00 | 140.22 | 36.16 | 42.06 | 8.10 | 58.40 | 64.60 | 434.80 | 3.76 | 1.86 |
| 10 | 7.50 | 651.80 | 434.20 | 31.20 | 77.12 | 29.57 | 4.78 | 31.00 | 33.80 | 320.40 | 0.77 | -1.03 |
| 11 | 7.54 | 994.13 | 663.75 | 114.48 | 33.33 | 51.81 | 6.47 | 61.63 | 39.00 | 374.91 | 2.89 | 0.22 |
| 12 | 7.37 | 641.33 | 438.00 | 38.83 | 55.66 | 26.48 | 4.95 | 47.79 | 36.46 | 229.71 | 1.07 | -1.19 |
| 13 | 7.40 | 750.00 | 501.00 | 44.00 | 60.00 | 45.00 | 5.60 | 37.00 | 47.60 | 220.00 | 1.05 | -0.93 |
| Max | 7.59 | 1215.00 | 810.00 | 140.22 | 106.85 | 63.30 | 16.50 | 67.23 | 81.03 | 516.76 | 3.76 | 1.86 |
| Min | 7.33 | 641.33 | 434.20 | 31.20 | 30.00 | 21.36 | 3.47 | 30.50 | 24.00 | 220.00 | 0.77 | -1.83 |
| Average | 7.46 | 876.90 | 585.73 | 70.75 | 59.46 | 38.86 | 7.47 | 49.77 | 47.37 | 355.07 | 1.74 | -0.10 |

## Water Hardness (TH)

Weathering of limestone, sedimentary rock and calcium bearing minerals such as calcite, gypsum and dolomite lead to naturally arising of the total hardness in most groundwater. The total hardness of water is described as the sum of calcium ($Ca^{2+}$) and   magnesium ($Mg^{2+}$) ions and can be calculated by the following equation:

$$TH = Ca^{2+} * 2.497 + Mg^{2+} * 4.116.$$

Where values of $Ca^{2+}$ and $Mg^{2+}$ are in ppm. According to Hem (1970), the values of water hardness (in ppm)  classified  the groundwater into four types; soft (0 - 60 mg/L); moderately hard (61-120 mg/L); hard (121-180 mg/l) and very hard (> 180 mg/l).The domestic uses of water should not contain more than 80 ppm as a total hardness. Limestone or gypsum

aquifers of groundwater may contain 200 to 300 ppm hardness or more. In the studied district, the total hardness values range from 201.93 to 419 .50 mg/l with an average value of 299.67.Consequently, all groundwater samples of the studied district are hard water according with the TH classification. Special distribution of total hardness is given in figure 3-c.

## Sodium ($Na^+$) and Potassium ($K^+$)

The concentration of sodium cation varies from31.20 mg/l to 140.22mg/l, with an average70.751 mg/l. Also, the concentration of potassiumrangesfrom3.47mg/lto16.50mg/l with average value 7.47 mg/l. Generally, small concentrations of potassium ions may stand related in conformity with depletion by vegetation through the elevation of principal activities via the minimum using of potassium fertilizers in the previous years and after natural fertilization halting by silt as a result to Aswan High Dam' construction (Ahmed,2011).

## Calcium ($Ca^{2+}$)

Dissolution of carbonate minerals such as calcite, aragonite ($CaCO_3$), and dolomite $CaMg(CO_3)_2$ of the country rocks leads to originally arising the calcium salts of the groundwater. In the studied district, a calcium concentration ranges from 30.00 mg/l to 106.85 mg/l with an average 59.46 mg/l. All the groundwater samples have lower $Ca^{2+}$ than permissible limits of 200 mg/l as per standards (WHO, 1984). Spatial distribution (Fig. 3-d)of the calcium cations in the groundwater of the studied district shows a general increase toward the northwestern direction in order to recharged and mixed with fertilizer-rich returned flow of irrigation water in order  to agriculture of old lands.

## Magnesium ($Mg^{2+}$)

Magnesium concentrations in the studied district range from 21.36 mg/l to 63.30 mg/l with an average 38.86mg/l. Dissolution of dolomite at the old agricultural lands leads to its higher magnesium content than that of the new reclaimed lands due to the following reaction:

$$CaMg(CO_3)_2 + 2H_2CO_3Ca^{2+} \rightarrow Mg^{2+} + 4HCO_3^-$$
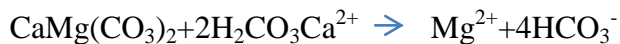
The distribution map of the magnesium ions is conformable with the previous TDS map(Fig.3-b).

*Chloride (Cl⁻)*

In the study district, Chloride concentrations have a range from30.50 to 67.23 mg/l and average49.77C. Chlorides may get into groundwater from several sources such as rocks leaching, sediments containing chloride, industrial wastes and effluent wastewater which come from wastewater treatment plants which may carry high contents of sodium chloride. The distribution map of the chloride ions (Fig.3-h) shows a general increase toward the northwestern direction and decrease toward the southeastern.

*Bicarbonate (HCO3⁻)*

In the studied district, the bicarbonate ion concentrations of the groundwater are found in the range from 220.00 mg/l to516.76 mg/l. All the groundwater samples have higher HCO3⁻ than permissible limits of 200 mg/l as per standards (WHO, 1984).The content of bicarbonate anions depends mainly on the carbon dioxide pressure, the pH value of solution and temperature. The content of bicarbonate anions increases with pH value more than 7. The solubility of calcium carbonate takes place in the presence of carbon dioxide in water which in turn leads to highly soluble bicarbonate formation. Bicarbonate concentration of more than 200 ppm is not uncommon in groundwater, and higher concentrations can occur where $CO_2$ is produced in the aquifer. The distribution map of the bicarbonate anion shows a general increase toward the northern part where these anions are related to calcium and magnesium (Figs.3-d &3-e).

*Sulfate ($SO_4^{2-}$)*

In general, concentration of sulfate ions in most wells is not high. The concentrations of sulfate anions range is 24.00 - 81.03 mg/l. The distribution map of the sulfate anions (Fig. 3-j) shows a general conformable direction with the previous distribution maps of major ions, and it is conformable with the TDS and general flow direction of groundwater.

**Groundwater quality for drinking purposes**

Consistent with the World Health Organization (WHO, 1984), the maximum suitable concentration for the water used for drinking purposes is shown in Table 2. The comparison between the data of chemical analysis of water samples in the considered area and the WHO standards

indicates the suitability of groundwater for drinking and domestic uses except bicarbonate for all samples (Fig. 4).
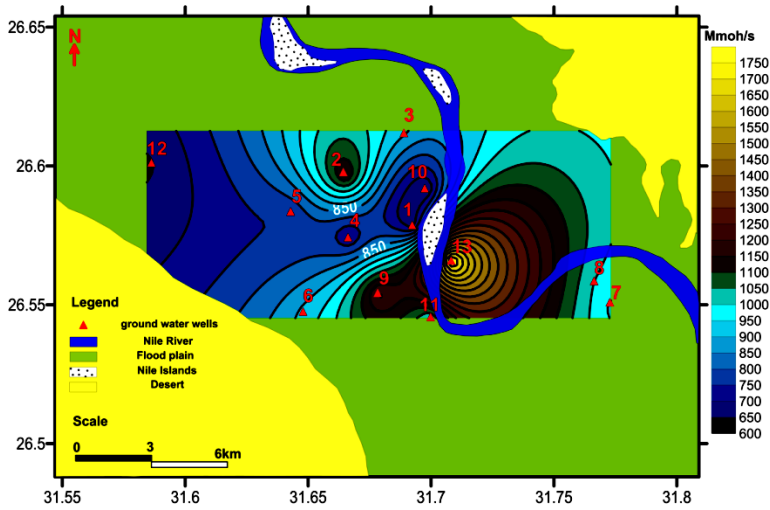


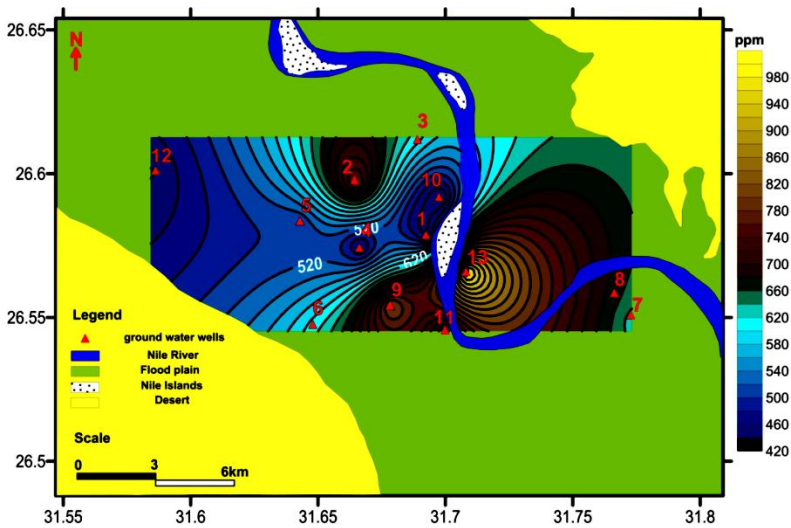**Figure 3.a:** EC distribution map of groundwater in the study area



**Figure 3.b:** TDS distribution map of groundwater in the study area.
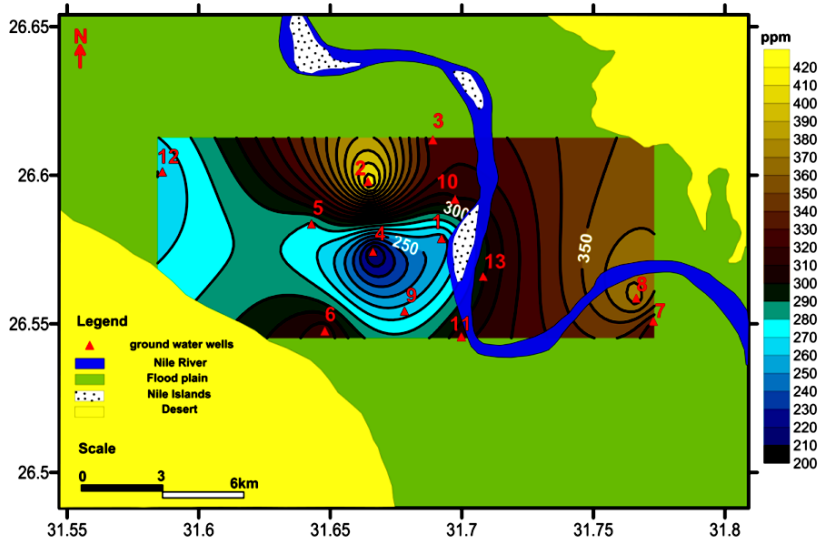
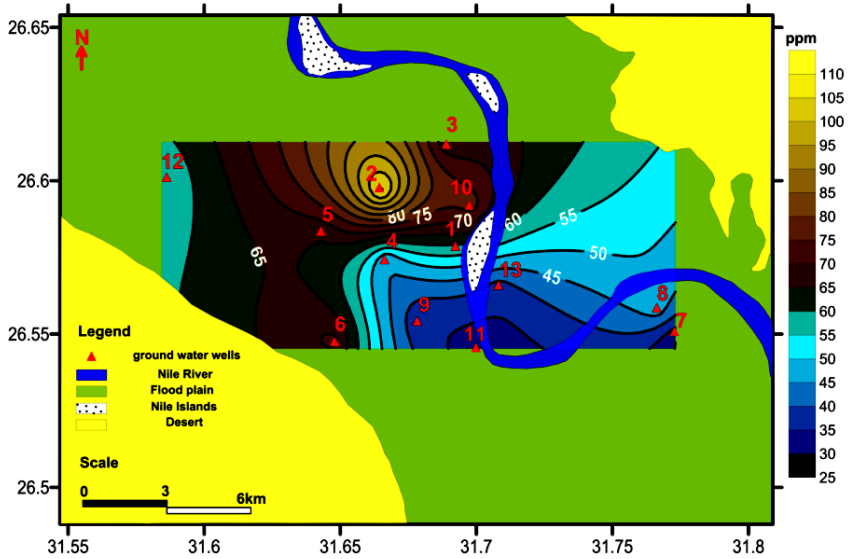**Figure 3.c:** TH distribution map of groundwater in the study area



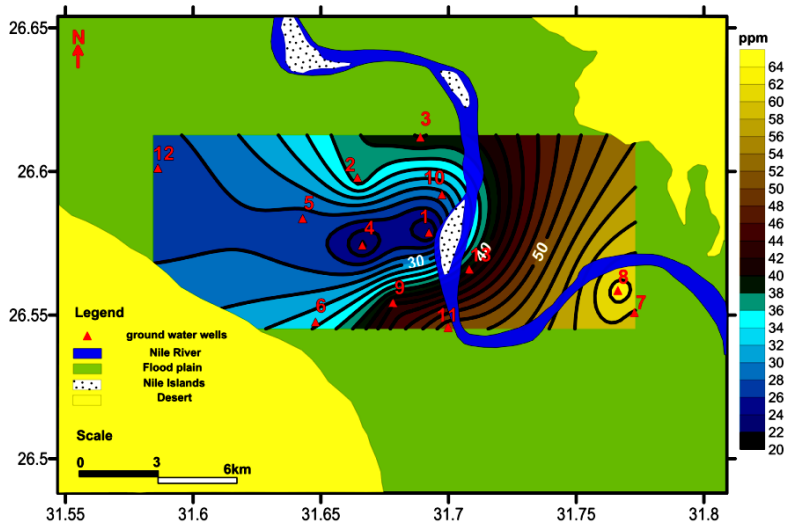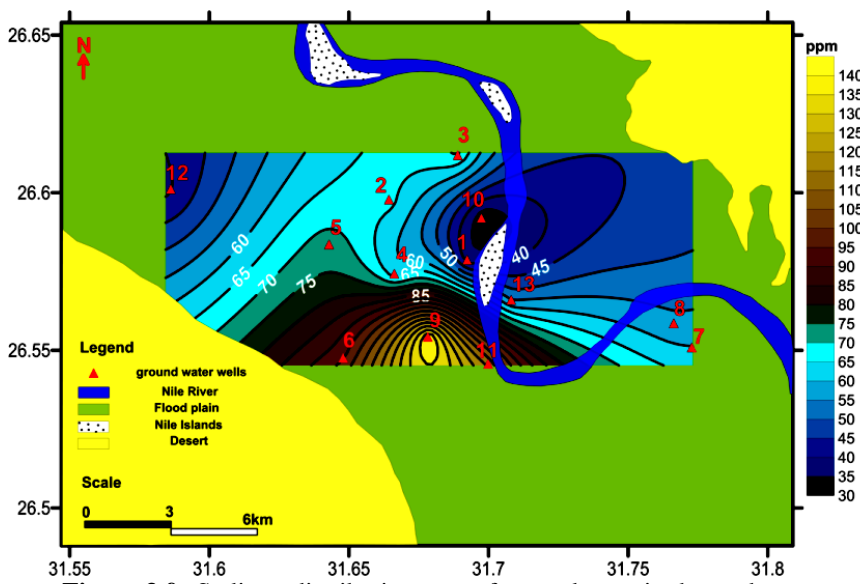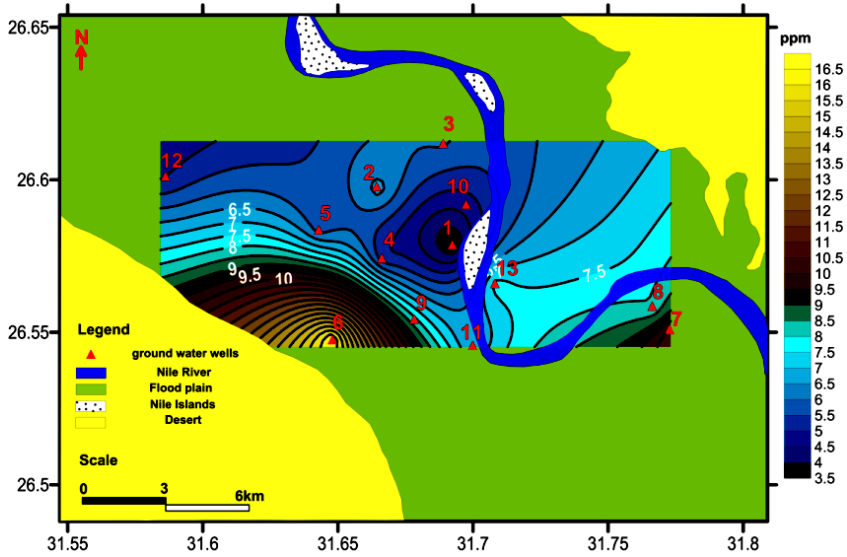**Figure 3.d:** Calcium distribution map of groundwater in the study area.

**Figure 3.e:** Magnesium distribution map of groundwater in the study area



**Figure 3.f :** Sodium  distribution map of groundwater in the study area

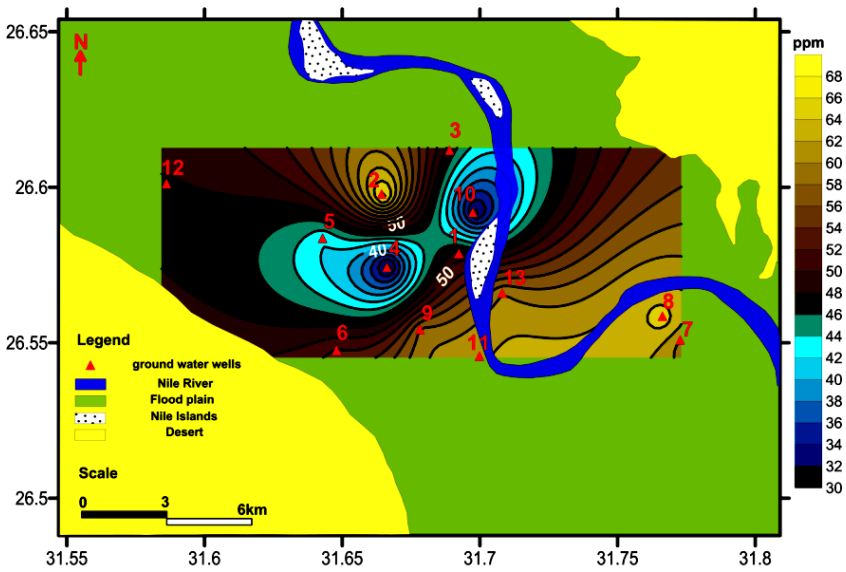**Figure 3.g:** Potasium distribution map of groundwater in the study area



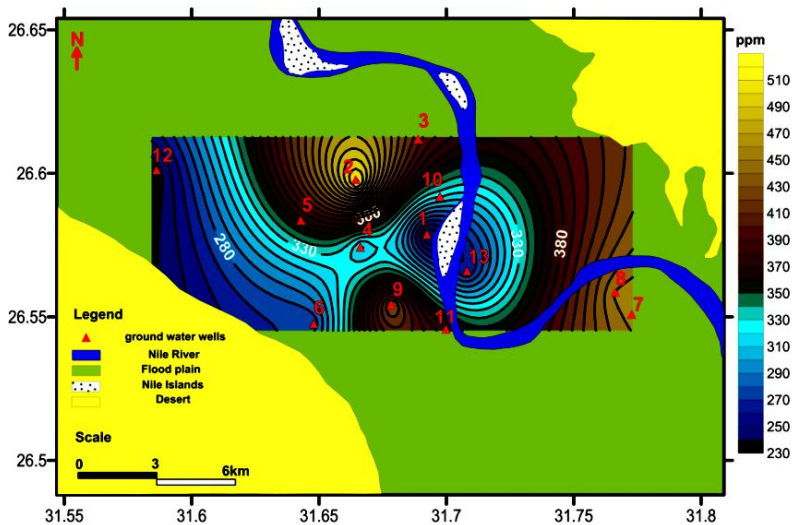**Figure 3.h:** Chloride distribution map of groundwater in the study area.

**Figure 3.i:** Bicarbonate distribution map of groundwater in the studyarea.
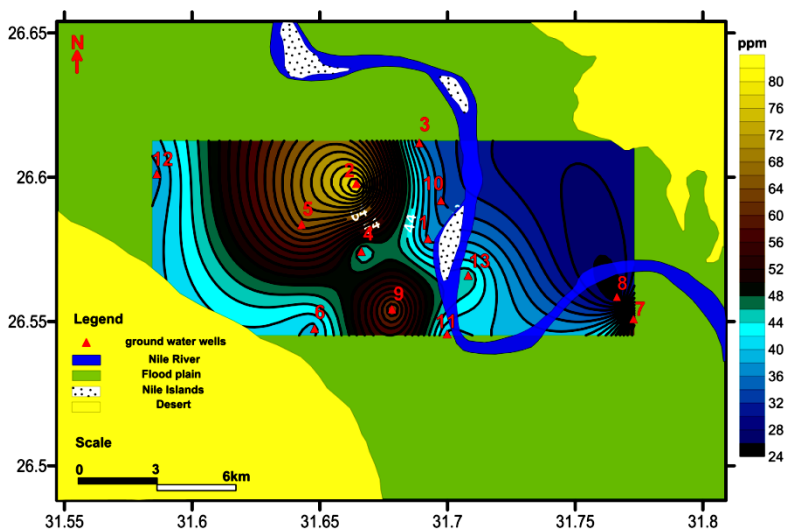


**Figure 3.j:** Sulphate distribution map of groundwater in the study area.

**Table.2:** The maximum permissible concentrations for drinking water according to the WHO, (1984); and the related measurements in the studied district

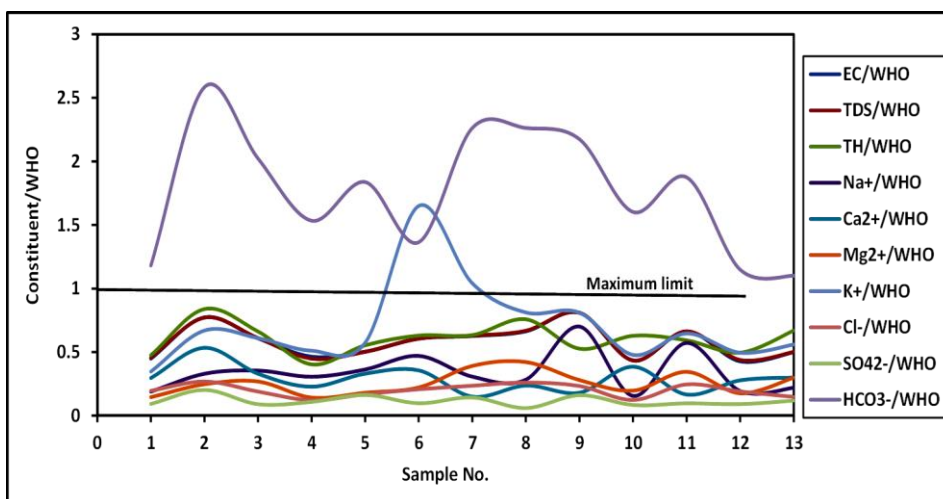| Element | Unit | Maximum permissible Concentration | Concentration range for the studied samples |
|---|---|---|---|
| Ph | | 6.5-8.5 | 7.46- 7.59 |
| EC | μmhos/cm | 1500 | 641.33-1215 |
| TDS | ppm | 1000 | 434.20-810 |
| TH | mg/l (CaCO3) | 500 | 201.93-419.50 |
| $Na^+$ | ppm | 200 | 31.20-140.22 |
| $Ca^{++}$ | ppm | 200 | 30.00-106.85 |
| $Mg^{++}$ | ppm | 150 | 21.36-63.30 |
| $K^+$ | ppm | 10 | 3.47-16.50 |
| $Cl^-$ | ppm | 250 | 30.50-67.23 |
| $SO4^{--}$ | ppm | 400 | 24.00-81.03 |
| $HCO_3^-$ | ppm | 200 | 220.00-516.76 |



**Fig.4**: Ion concentrations in the available groundwater samples from the studied district, showing their relations with the WHO, 1984 standards

### The groundwater quality for irrigation purposes

Groundwater quality is very important in any appraisal of salinity or alkalinity conditions in an irrigated area. Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are used to determine the suitability of groundwater for irrigation (Satyanarayana et al. 2016).

### Sodium Absorption Ratio (SAR)

An approximation of the SAR for the groundwater in the studied district can calculate by the following formula:

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad ,$$

where $Na^+$, $Mg^{2+}$, and $Ca^{2+}$ are in epm. According to Wilcox L.V. (1955), SAR values of the groundwater samples less than 10 are considered excellent, from 10 to 18 are good, from 18 to 26 are fair and more than 26 are unsuitable for irrigation scheme(Satyanarayana et al. 2016).In Sohag district, all groundwater samples collected fall within excellent scale(Table 1).

### Residual Sodium Carbonate (RSC)

Harmful effects to both of the carbonate and the bicarbonate anions on the ground water quality for agricultural activities, residual sodium carbonate have been utilized (Satyanarayana et al. 2016).  RSC is determined by the formula:

$$RSC= (CO_3^{2-}+HCO_3^-) - (Ca^{2+}+Mg^{2+})$$

RSC classification for irrigation scheme depends on ionic concentrations in meq/l(Wilcox L.V., 1955).The water samples having more than 2.5 meq/l are unsuitable for irrigation. The RSC values vary from -1.83to 1.86. It is noticed that all water samples exist in the safe class for irrigation (non hazard to low hazard).

Irrigation water graph classification representing 16 classes which refer to SAR value as analyst for Sodium hazards (S) and EC as analyst of salinity hazards (C) has been developed by the United States Salinity Laboratory (USSL) (Richards, 1954).

Salinity areas are classified as C-1, C-2, C-3 and C-4; and termed as low (EC ≤ 250 μS/cm), intermediate (EC = 250-750 μS/cm), high (EC = 750-2250 μS/cm) and very high (EC >2,250 μS/cm)according to the total concentration of irrigation water soluble salts (Richards 1954).Salinization is considered as outstanding amongst the most adverse natural effects related with irrigation. Saline soil can be developed under the high salt concentrations and a high concentration of sodium ions result in alkaline soil formation. Choice of crop and the harmfully affects of crop fertilization mainly depending on the saline conditions and gives up soils difficult to work on (Satyanarayana et al. 2016).

Irrigation water which has un reasonable solutes are primitive issue in arid district where the maximum evaporation occur resulting in water loss. Salinity issues encountered in irrigated districts is particularly thanks to poor drainage system. This leads to arising of the water table near to the plants root zone, which in turn leads to the sodium cations aggregation through the capillary rise and thus arriving to the soil solution (Richards 1954, Satyanarayana et al. 2016).

Sodium adsorption ratio (SAR) can suggest the absolute and relative concentration of cations which lead to the sodium or alkali hazard in most groundwater used for irrigation. Irrigation water is classified into four classes depend on sodium adsorption ratio (SAR) as:S-1 (<10), S-2 (10-18), S-3 (18-26) and S-4 (>26). There is a significant relationship between SAR values of irrigation water and the extent to which sodium is adsorbed by the soil. Cation exchange between water and soil due to both of high sodium and low calcium in water and is obligated for saturated sodium in an irrigated area. This can harm the soil structure by scattering of sodium ions in the clay particles (Satyanarayana et al. 2016). The calculated SAR values range from 0.77 to 3.76. Plotting the groundwater samples on USSL diagram (Fig.5), shows that five of samples fall in C2-S1 field. Eight samples fall in C3-S1 field. It is noticed that, the greater part of the samples is plotted in C3-S1 field demonstrating low Sodium Adsorption Ratio and high salinity hazard (Fig.5).

## Groundwater classification

Hydro-chemical is a function of solution kinetics; interactions between the water and the rocks, geology and sources of contamination used for clarification of the variation of the chemical composition of water quantities. The proper method to classify and correlate the types of water based on ionic composition is suggested by Piper (1944**).**
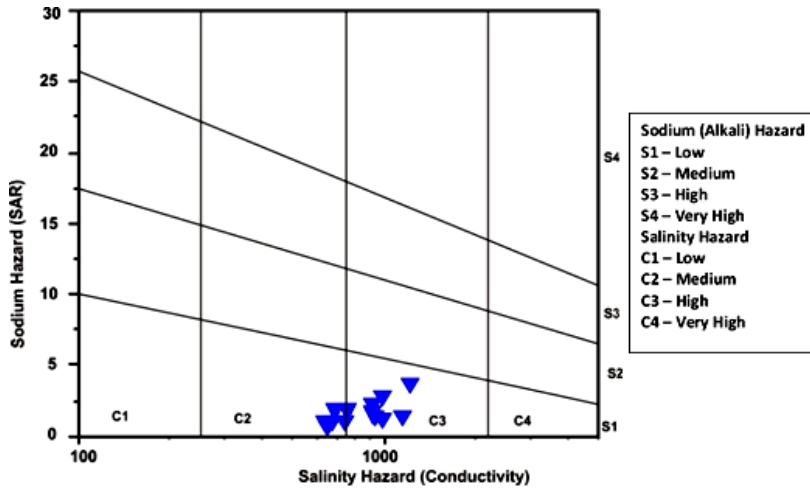
**Fig.5:** Groundwater samples by using US salinity diagram

Dispersion of the different cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$) and anions ($HCO_3^-$, $Cl^-$ and $SO_4^{2-}$) constituents in the groundwater samples can be illustrated by Piper's diagram (Fig. 6), which indicates both of the origin of groundwater and the source of their dissolved salts in addition to interpret different processes affecting on the quality of the groundwater. Mixing various sources of water or expansion pathways can also be illuminated by this diagram (Freeze and Cherry, 1979; Karmegam et al., 2011, Redwan et al. 2016). Plotting the groundwater samples on the Piper's diagram demonstrates that ultimate of groundwater samples are of $Mg-HCO_3$ and $Ca-HCO_3$ type (Fig. 6). Variation of the hydro-chemical and distribution facies of groundwater throughout the study district shows that 77 percent samples exist as magnesium-calcium facies; which designated by sufficient recharge coming from fresh water and water with changeable hardness (SarathPrasanth et al. 2012,Handa, 1979).

## Hydro-geochemical processes identification

Significant part of the total dissolved solids which exist in groundwater called major ions. Major ions concentrations within groundwater are regarding to processes of the hydro-geochemical that occurred along the aquifer system. Hydro-geochemical processes appear when the groundwater moves toward equilibrium in the concentration of the major ions. Contributing ions in the groundwater for the different sources can be recognized by using the Gibbs diagram (Gibbs, 1970, Nag and Das,

2017). Gibbs plot diagram has three distinct areas: precipitation dominance, rock dominance and evaporation dominance. Both ratio of $Na^+/ (Na^+ + Ca^{2+})$ for cations and $Cl^-/ (Cl^- + HCO_3^-)$ for anions of water samples have been existed separately against the respective Total dissolved salts on the Gibbs plot diagram. Both types had been indicated the dominance of the rocks in the control of the constituent ions of the groundwater (Fig.7a and b).
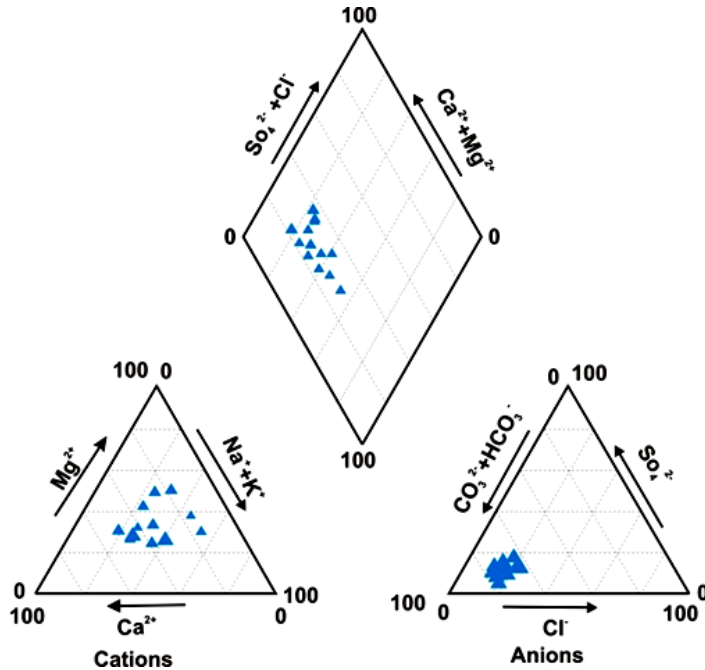


**Fig. 6:** Cations and Anions of the study district by usingPiper Trilinear diagram

Chemical interaction between both of the aquifer rock forming minerals and the groundwater is the main mechanism in contributing ions to the groundwater which suggested by using Gibbs plot diagram (Gibbs, 1970, Nag and Das, 2017).

Geo-chemical affinities of groundwater indications can be introduced by the equilines diagram (Fig. 8)for the different ions. $(Ca^{2+} + Mg^{2+})$ versus $HCO_3^-$ scatter diagram (Fig. 8) was concluded by Atta and Tyagi (1996) where the ionic concentrations fall above the 1:1 equiline, this means that the groundwater composition result from carbonate weathering, while those falling along the equiline are due to the weathering to both of the silicate and the carbonate rocks. Most of the quaternary groundwater samples are falling along the 1:1 equiline as

clarified    by    Fig.8, which indicating the silicate and carbonate weathering occurrence. ( $Ca^{2+}+ Mg^{2}$) concentrations against $HCO_3^-$ plotting(Fig. 8) shows that water samples majority have excess of  $Ca^{2+} + Mg^{2+}/HCO_3$ ratio (<1) which can be used to present fresh recharge or the groundwater meteoric nature which in turn suggested that only nine samples show meteoric nature.

Most of the water samples in the studied district (61.54%) lying below the 1:1 equiline with few along the equiline and above as showing by$Ca^{2+}+Mg^{2+}$ verses $HCO_3^-+SO_4^{2-}$ diagram . This suggests that carbonate weathering is not the main source of groundwater constituent ions (Dehnavi et al., 2011). By drowning of $Ca^{2+}+Mg^{2+}$vs.  $HCO_3^-+SO_4^2$ is expected to fall near to the 1:1 equiline if the dissolution reactions of calcite, dolomite, and gypsum are dominant in along groundwater system. The common ratio of both of $Na^++K^+$with total cations (TC) is 0.33 and that of $Ca^{2+}+Mg^{2+}$with TC is 0.67 which indicated that the predominance of alkaline earth over the alkalis metal ions could be concerning to carbonate rocks weathering and severe aridity (Al-Amry 2008), ion exchange at auspicious lithology (Al-Bassam et al. 1997),and to some extent lack of recent recharge.

Average ratio to both of $HCO3^-+ SO_4^{2-}$ with total anions (TA) is 0. 82 and that of $Cl^-$ with TA is 0.18, indicating the dominance to both of bicarbonate and sulfate ions. Most important supply regarding of $HCO_3^-$ ions into groundwater typically comes from the carbonate rocks dissolution.

Excess of $HCO_3^-+ SO_4^{2-}$lead to shift the points to the right of the equiline which due to Ion exchange reactions proceeding (Fisher and Mulican, 1997; Senthilkumar and Elango, 2013, Satyanarayana et al. 2016).  Points will shift toward the left side of the equiline as a result of reverse ion exchange reactions if the reins wide spread extra of $Ca^{2+}+Mg^{2+}$over $HCO_3^-+ SO_4^2$ ions. In the study district, the plot of $Ca^{2+}+Mg^{2+}$ vs. $HCO_3^-+ SO_4^{2-}$displays that some of the values fall above the equiline (Fig. 7) proposing that ion exchange/reverse ion exchange reactions had been existed. In the studied district, generally the molar ratios of $Na^+/Cl^-$ for the groundwater samples are from 0.77 to 2.40.
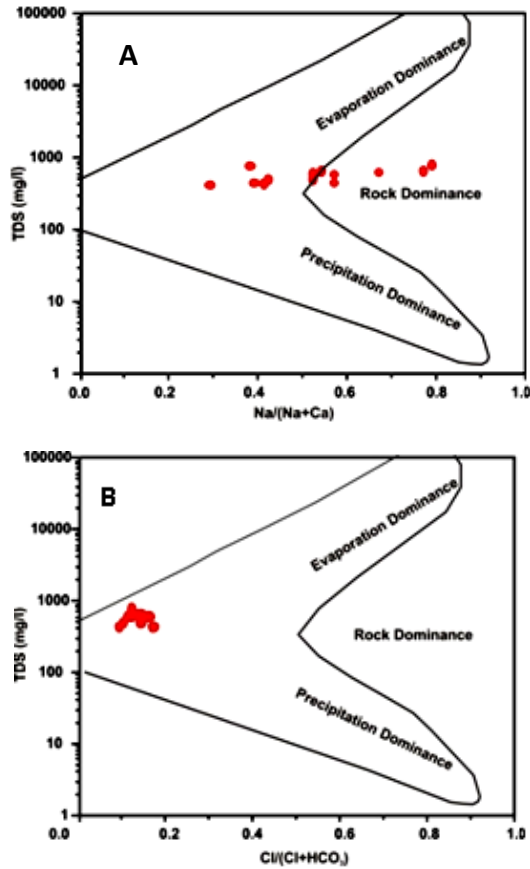
**Fig.7:** The mechanisms controlling groundwater quality shown by Gibbs diagram, (A) for cations and (B) for anions.

Silicate (exists in the Qena Formation) weathering is the major process enrich sodium cations in groundwater due to the molar ratio greater than the unit (Stallard and Edmond, 1983; Senthilkumar and Elango, 2013), which is prevalent in this region in most of the water samples collected (except samples No. 1, 8, and 11). $Ca^{2+}/Mg^{2+}$ ratio equals one means dolomite dissolution, whereas$Ca^{2+}/Mg^{2+}$ratio is higher than one will indicate the contribution of calcite (Maya and Loucks, 1995).

Silicate minerals dissolution is result in higher $Ca^{2+}/Mg^{2+}$ molar ratio than 2 (Satyanarayana et al. 2016).   In the study area the Dissolution of calcite from the nearby limestone plateau occur in the rainy seasons due to about53.85% of the groundwater samples have a $Ca^{2+}/Mg^{2+}$molar ratio between 1 and 2 while 46.15% of the samples elucidate $Ca^{2+}/Mg^{2+}$molar ratio to be >2, which proves the silicate minerals dissolution originate

from the Qena Formation that is mainly consist of silicate rocks (Redwan and Abdel Moneim; 2015).
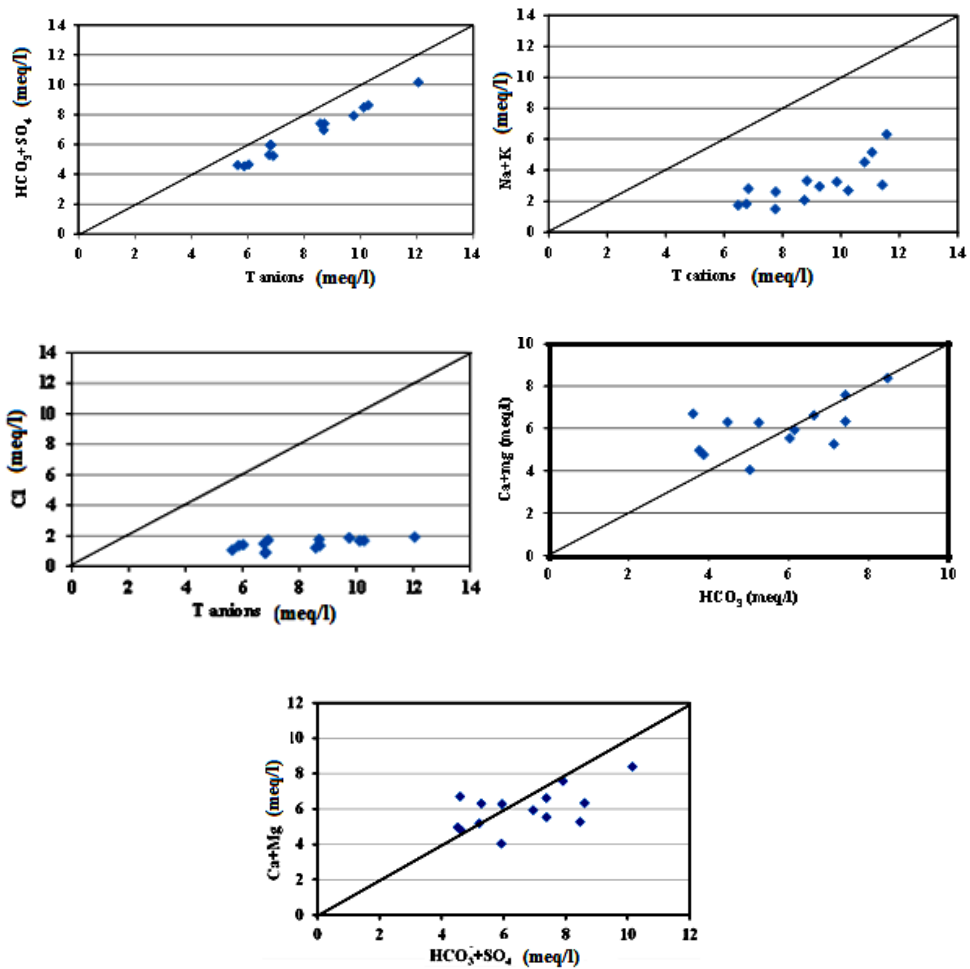


**Fig.8:** Equilines diagrams showing the correlation of major ions in the study district and distinguishing the entire Quaternary aquifer processes

Groundwater was analyzed for major elements ionic' concentrations to obtaining the relative abundances and ionic affinity. Most water samples have $Ca^{2+}$ + $Mg^{2+}$ concentrations greater than alkalis. of $Ca^{2+}$ and $Mg^{2+}$ cations concentration have the predominance over $Na^+$ and $K^+$ cations concentration and influences of $Na^+$ with $Ca^+$ concentration, individually are suggestive of ion-exchange reactions (SubbaRao et al. 2012).

## CONCLUSIONS

The current study gives critical facts about groundwater quality in Sohag district. Groundwater samples had been gathered and investigated according to distinctive physico-chemical parameters. The groundwater quality has been assessed for drinking and irrigation activities using a variety of suited hydro-chemical parameters. Spatial distribution of major anions and cations in groundwater samples were shown demonstrating somewhat uncommon variety.  The predominant hydro-geochemical facies were $Mg\text{-}HCO_3$ and $Ca\text{-}HCO_3$ in general, which associated to sufficient recharge from fresh water and water with transient hardness. Major ions in groundwater are within the permissible limits for drinking with the exception of bicarbonates $HCO_3^-$. The suitability of groundwater for irrigation is evaluated via Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC). It is concluded that, the most of the samples is plotted in C3-S1 field demonstrating low Sodium Adsorption Ratio and high salinity hazard. It is indicated that the hydrochemistry of these groups have been influenced by the rock dominance, including carbonate and silicate rocks weathering. The plot of $Ca^{2+}+Mg^{2+}$ vs. $HCO_3^-$ + $SO_4^{2-}$ suggests that a part of the values fall above the equiline appearance that ion exchange/reverse ion exchange reaction occurred. The geochemistry of groundwater over investigated region is generally controlled by way of common natural geochemical processes such as rock water interaction, dissolution, and ion exchange. Furthermore Anthropogenic induced activities like over pumping aquifers, fertilizer influences and agricultural return flow slightly affected on groundwater quality of the Quaternary aquifer over study area.

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**تقييم الخصائص الهيدروجيوكيميائية و جودة المياه الجوفية في منطقة سوهاج بمحافظة سوهاج ، مصر**

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تعتبر المياه الجوفية في محافظة سوهاج المصدر الثاني للمياه العذبة المستخدمة في الاغراض المنزلية والزراعية والصناعية. موارد المياه الجوفية في محافظة سوهاج مهددة بالملوثات من الأنشطة الزراعية والصناعية. تستخدم الخصائص الكيميائية للمياه الجوفية بشكل روتيني لتحديد خصائص الكيميائية للعمليات المائية الجوفية وفهمها. تقيم هذه الدراسة جودة المياه الجوفية وملاءمتها للأغراض المختلفة في منطقة سوهاج. ولتحقيق هذا الغرض ، تم عمل التصنيف الهيدروكيميائي الجيولوجي ونموذج التوزيع المكاني لخزان المياه الجوفية الرباعي . تم جمع عينات من المياه الجوفية من ثلاث عشرة محطة مختلفة وتم تحليلها من أجل الخصائص الفيزيائية والكيميائية (EC ،TDS، و pH) وتركيز الأيونات الرئيسية ($Na^+$، K $^+$، $Ca^{2+}$، $Mg^{2+}$، $Cl^-$، $HCO3^-$، $SO4^2$). ترتيب توزيع الأيونات الرئيسية $K^+ > Na^+ > Mg^{2+} > Ca^{2+}$ و $SO4^2 > Cl^- > HCO3^-$ . يظهر التوزيع المكاني لكل من الأنيونات والكاتيونات الرئيسية في عينات المياه الجوفية تنوعًا غير مألوف إلى حد ما. الأيونات الرئيسية في المياه الجوفية هي ضمن الحدود المسموح بها لاستخدامات الشرب باستثناء البيكربونات $HCO3^-$. يشير تقييم معدل امتصاص الصوديوم (SAR) وكربونات الصوديوم المتبقية (RSC) إلى مدى ملاءمة المياه الجوفية للري. ويلاحظ أن معظم عينات المياه تم توقبعها في النطاق C3-S1 وعرض نسبة امتزاز الصوديوم المنخفضة ومخاطر ملوحة عالية. يتم التحكم في جيوكيمياء المياه الجوفية بمنطقة البحث بشكل عام عن طريق العمليات الطبيعية المشتركة مثل تفاعل الماء الصخري ، الذوبان ، وتبادل الأيونات. وعلاوة على ذلك ، فإن الأنشطة التي يسببها الإنسان مثل السحب الجائر للمياه الجوفية ، وتأثير الأسمدة ، وتدفق العائد الزراعي قد أثر بشكل طفيف على جودة المياه الجوفية لخزان المياه الرباعي فى منطقة الدراسة.

**الكلمات المفتاحية:** موارد المياه الجوفية ، التصنيف الهيدروجيوكيميائى ، المعاملات الفيزيوكيميائية ، منطقة سوهاج ، خزان المياه الجوفي الرباعي .