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Assessment of Groundwater Quality for Different Aquifers in Halaib and Shalatien Area at South Eastern Desert of Egypt

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ABSTRACT

This work aims at assessing the groundwater quality in Halaib and Shalatien area, the main water resource for irrigation and civic utilization is groundwater (springs and wells). The groundwater aquifers in this area could be classified into three aquifer systems according to their litho-stratigraphic as follows: Fractured basement aquifer system, Nubian sandstone aquifer system and Quaternary aquifer system. 13 samples from different aquifer systems were taken in the study area; four samples were taken from groundwaters of fractured basement aquifer, eight from the Nubian sandstone aquifer and one from the Quaternary aquifer. Assessment in terms of salinity and sodicity hazards according to USDA (1954). Evaluation of groundwater quality using irrigation water quality index (IWQI) method was established by Meireles *et al.* (2010) for agricultural purposes with help of the Geographic Information System (GIS) technique. Five chemical parameters were utilized to calculate the IWQI including EC, Na^+, Cl^-, HCO_3^- and SAR. The IWQI map results showed that 46.2 % of the samples classified as low restricted are suitable for irrigation directly without any processing, 23.1% of the samples classified as moderate to highly restricted and can be used only in soils with high permeability values, recommended leaching of salts to avoid soil degradation. The remaining (30.7%) of the studied samples classified as severe restricted are suitable only for soils that have high permeability values applied the excess of water for leaching to avoid the accumulation of salt. In brief, these samples should be avoided its use for irrigation under normal conditions.

Keywords: Halaib, Shalatien, Eastern desart, aquifers and groundwater.

INTRODUCTION

Geology of the Egyptian Eastern Desert is a result of the collision Arabian Nubian Shield with the Saharan Metacraton (Sabet, 1972; Greenwood *et al.*, 1980 and Lundmark *et al.*, 2011). The Eastern Desert of Egypt is occupied by igneous and metamorphic rocks (Stern, 1994 and Kusky *et al.*, 2003).The main rock formation of a large part of Egypt is of Quaternary formations of Pleistocene and Holocene ages and they varied and complex, the thickness of the Quaternary sediments ranges between 2 and 20 mas it increases towards the Red Sea coast (Said, 1962 and 1990; El-Fayoumy, 1968 and Abdel Moneim, 2005).The Quaternary limestone of the beach-dune ridges, bajadas and sabkha sediments with faulted mountains and hills are found to the west of the Nile inter finger with and descend beneath the deltaic deposits of the river (Abdel-Rahman, 1997a; Abdel Moneim, 2005; Zahran, 2008 and Soussa *et al.*, 2012).The Quaternary deposits are composed of beach sand and gravel in the western part while they are converted to clayey sand toward the east direction (Abdel Moneim, 2005; Yousef *et al.*, 2009 and Shawky *et al.*, 2012).The southern part of the Eastern Desert composed of ophioliticmelange rocks accompanied by extensive meta-sediments of oceanic character (Kroner *et al.*, 1987 and Greiling *et al.*, 1994).The Miocene sandstone formation is extended along the Red Sea coastal plain. This Miocene aquifer represents a good source of water (Abdel Moneim, 2005 and Soussa *et al.*, 2012).

The continued water deficiency in Egypt for supplemental deficits in Nile River water; lack of fresh water is the main problem affecting the development plans in Halaib and Shalateen (Abdel Moneim, 2005 and Al Temamy and Abu Risha, 2016).Surface and groundwater are the main sources of water supplies for agriculture activities in Halaib and Shalatien area (Yousef *et al.*, 2009), rainfall is considered the main source of groundwater (Flefil, 1996; Abdel Moneim, 2005; Yousef *et al.*, 2009; Shawky *et al.*, 2012; Soussa *et al.*, 2012 and Khalil, 2014). Groundwater is a precious natural gift and an important renewable resource having several inherent advantages over surface water. It is a good source of fresh water available on the earth (Nandini *et al.*, 2018). The number of fresh water sources is very limited in the world.

Although fresh water is a renewable resource, yet the world's supply of groundwater is steadily decreasing (Gleeson *et al.*, 2012).Various methods have been established to assess groundwater quality for different purposes, such as irrigation or drinking (Wilcox, 1955; Ayers and Westcot, 1985; Aller *et al.*, 1987; Simsek and Gunduz, 2007; Boyacioglu, 2010).The groundwater aquifers consist of four aquifer systems according to their litho-stratigraphic position as follows: Quaternary, Miocene Carbonate, Nubian Sand Stone and Fractured Basement aquifer. Sources of water points in the study area can be divided into three main types: Natural springs, hand-dug wells and drilled rotary wells (NARSS, 2000). Water quality index (WQI) is using to

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determine the suitability of the groundwater for drinking and irrigation purposes (Meireles *et al*., 2010; Omorogieva *et al*., 2016 and Abdulhady *et al*., 2018). The WQI is including five parameters are EC, Na^+, Cl^-, HCO_3^- and SAR which affecting water quality for irrigational use (Abbasnia *et al*., 2018 and Al-Hadithi *et al*., 2019). The water quality index (WQI) is a method for water quality analysis for different purposes and used largely in worldwide (Gazzaz *et al*., 2012; Massoud, 2012; Iticescu *et al*., 2013 and Lobo *et al*., 2015). The Geographical Information System (GIS) technique is the effective tool that helps in estimating irrigation water quality index (IWQI) and is very important for water quality management plans (Srivastava *et al*., 2011; Bairu *et al*., 2013; Magesh and Chandrasekar, 2013; Sadat-Noori, 2014; Selvam *et al*., 2014; Arkoc, 2016 and Al-Hadithi *et al*., 2019).

This work is aimed at assessing the groundwater quality of the Fractured Basement, Nubian Sand Stone and Quaternary aquifers in Halaib and Shalatien in the southeastern desert of Egypt. The purposes of this work are: 1) to assess the groundwater quality according to USDA classification, 2) to evaluate of groundwater for irrigation purposes using water quality index model (WQIM) by using Geostatistics and Geographical Information System (GIS) techniques and 3) to assess the geochemical characteristics for groundwater using Piper's diagram (Piper, 1944) and the Schoeller's diagram (Schoeller, 1962).

Location of the study area:

The concerned area lies to the southeast desert of Egypt between latitudes 22 ˚ 10 `50`` and 23 ˚ 31 ` 41.5`` N, and longitudes 34 ˚ 45 ` 4.4`` to 36 ˚ 19 ` 4.6`` E (Figure 1). It covers about 1718100 ha (17181 km^2) and is bordered in the south by Sudan, in the east by the Red Sea and in the west and the north by the Red Sea mountain range. Halaib and Shalatien area is described as an arid climate with long hot rainless summer, mild winter with very low or no rainfall. Halaib and Shalatien meteorological gauging station records for 30 years (1980–2010) were reported as follows; the air temperature varies from 7.5 °C in the January to 37.5 °C in July and August. Rainfall is very low; the maximum monthly is 2 mm in November, and the period from May to September is the dry season. The humidity varies from 26% in July to 55 % in January and February. The wind velocity ranges between 11.17 km h^{-1} in August and 14.3 km h^{-1} in January.

Fig. 1. Location map of the study area.

Geology of the study area.

Halaib and Shalatien area is occupied by fourteen rock formations belonging to Precambrian, Cretaceous, Miocene, Pliocene and Quaternary ages (Said, 1990, El-Rakaiby *et al*., 1996 and El-Alfi, 1997). The geological map of Halaib and Shalatien area according to (EGPA, 1987) is shown in Figure 2. The stratigraphic column in the study area consists of the following formations (in sequence from oldest to newest) as shown in Figure (3): Sand dunes, Sand sheets, Sabkha deposits, Wadi deposits and Undifferentiated Quaternary Deposits (Quaternary); Umm Mahara formation (Miocene), Ranga Formation (Pliocene); Timsah Formation, Bahariya Formation and Abu Aggag Formation (Upper Cretaceous) and Basement Rocks (Precambrian).

Hydrology.

According to Hammad (1994) and Zaghloul (1996), the water resources of Halaib and Shalatien through geological and hydrological investigations included groundwater resources that can be present in three types of aquifers, namely; fractured basement, Nubian sandstone and Quaternary (Figure 4). The groundwater of the fractured basement aquifer would have the best water quality of the three types.

Water analyses:

Groundwater samples were taken from 13 wells based on hydrogeological aquifer units in the studied area. The locations (longitudes and latitudes) of the collected water samples were recorded using the global positioning system (GPS) model etrex 10 (German). The locations of groundwater samples are displayed on Figure (4). Four samples were taken from groundwaters of fractured basement aquifer, eight from the Nubian sandstone aquifer and one from the Quaternary aquifer. Water analyses of the collected water samples included pH, salinity and water-soluble ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}) were done as described by ASTM (2002).

Natural vegetation and land use in the investigated area.

Halaib and Shalatien area is covered by mixed plant types, natural grasses, trees, shrubs and pasture grass. Most of the lands are suitable for plants with high salt tolerance. The density of plants varies according to the available water, increases with the increased rainfall (Girgis, 1971).

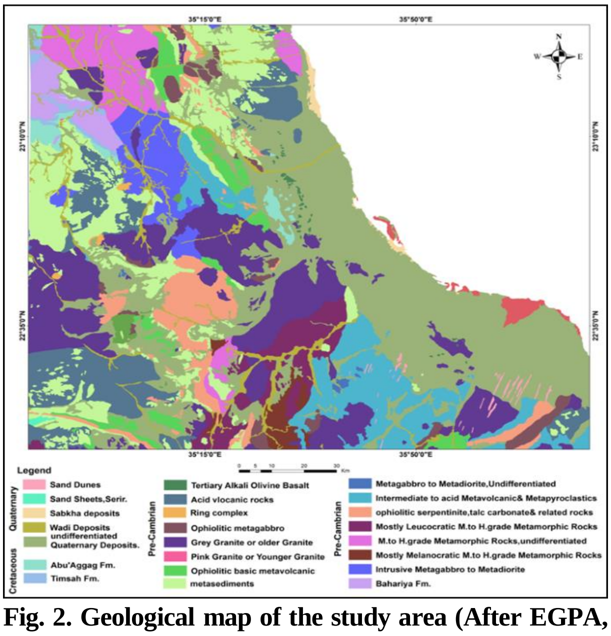


Fig. 2. Geological map of the study area (After EGPA, 1987).

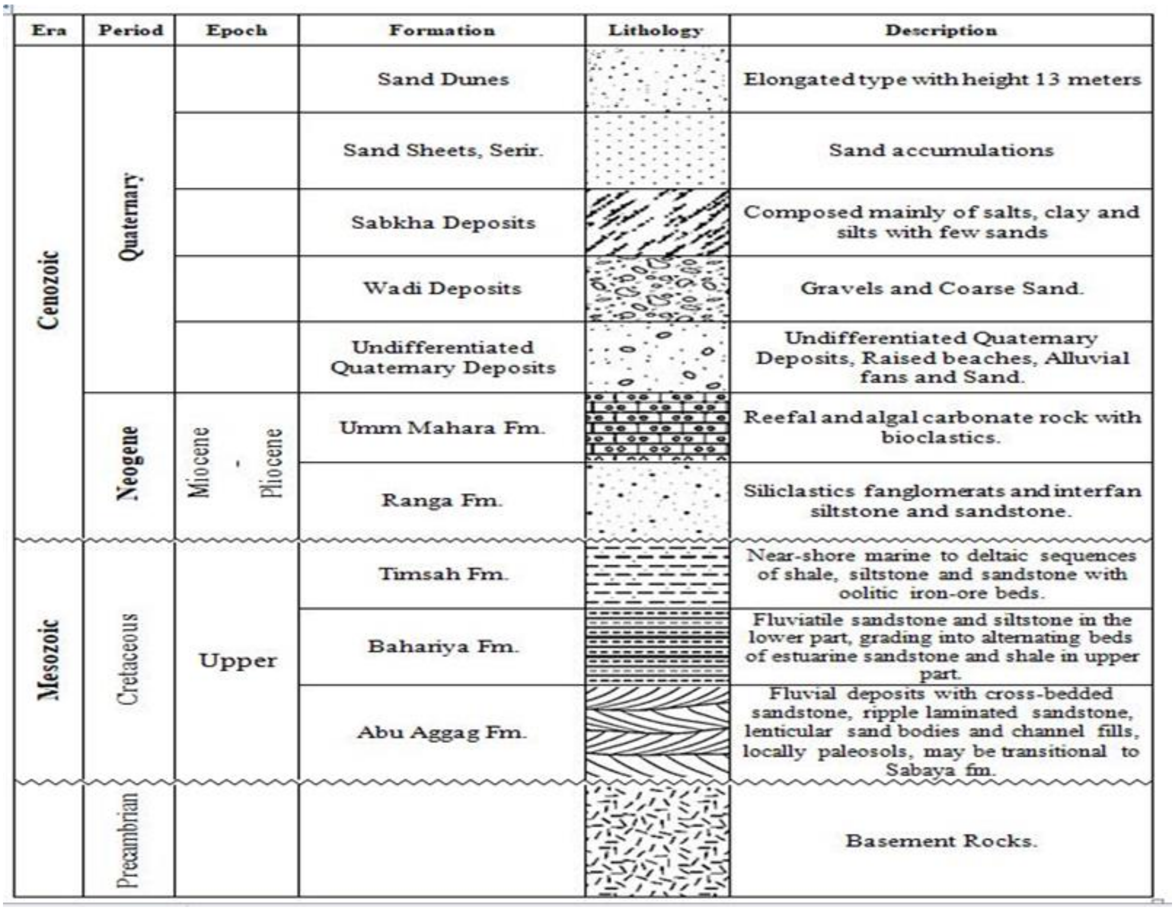


Fig. 3. Composite stratigraphic section in Halaib and Shalatien.

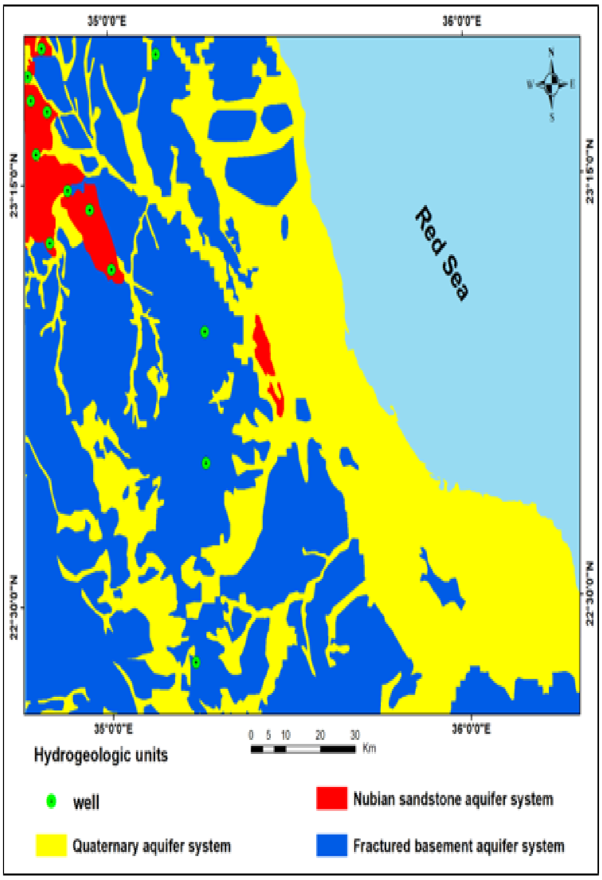


Fig. 4. Hydrogeological aquifer units and location of wells in the study area.

Criteria for water quality assessment on salinity/sodicity hazard according to USDA classification:

Assessment in terms of salinity and sodicity hazards according to USDA (1954). Salinity was in 6 grades (classes) (in terms of EC values) starting from low salinity water (< 0.25 dSm^{-1}) to moderate salinity water (0.25 - 0.75 dSm^{-1}), medium salinity water (0.75 – 2.25 dSm^{-1}), high salinity water (2.25 – 4.00 dSm^{-1}), very high salinity water (4.00- 6.00 dSm^{-1}), and excessively high salinity water (> 6.00 dSm^{-1}). Sodicity assessment was in 4 grades (classes) (in terms of SAR) of low sodicity water (< 10 for low salinity water "lsw" down to > 2.8 for high salinity water "hsw"); medium sodicity water (10 -18 for "lsw" down to 2.8 – 7 for "hsw"); high sodicity water (18 -26 for "lsw" down to 7 – 11 for "hsw"); and very high sodicity water (> 26 for "lsw" down to > 11 for "hsw"). Symbols for the 6 salinity classes are C1, C2, C3, C4, C5, and C6 respectively, while those for the 4 sodicity ones are S1, S2, S3, and S4 respectively. Limits and ranges for each sodicity class depend on the total salinity of the water. The limit for any sodicity class is wide if the water has low salinity, and narrow if the water has high salinity.

Calculation of the Irrigation Water Quality Index (IWQI)

The EC, Na^{+}, Cl^{-}, $HCO3^{-}$ and SAR parameters suggested by Meireles et al. (2010) have been used to calculate the IWQI. These parameters were measured in the laboratory and (SAR) was calculated as the ratio of sodium absorption.

Processing of remote sensing data and GIS database generation and analysis.

Digital image processing of Landsat-8 images (dated to 2018) was executed using ENVI 5.2 software (ITT, 2009). The analysis included pre-processing, and digital image processing. As for the pre-processing phase, it included data calibration to radiance according to Lillesand and Kiefer (2007), and data manipulation (image stretching, filtering, and histogram matching). ArcGIS 10.2 software was used for creating a water quality database in the study area, generation of spatial distribution map for each parameter, and production the final irrigation water quality index (IWQI) map.

RESULTS AND DISCUSSION

Digital Elevation Model (DEM).

Digital Elevation Model (DEM) is downloaded from the Shuttle Radar Topography Mission (SRTM). Stream networks were defined by those cells in the matrix that have flow accumulation value greater than an area threshold value. Stream networks were derived from the DEM model by applying an area threshold value to the flow accumulation grid using algebraic expressions. Figures 5 and 6 show the stream networks and basin in the area.

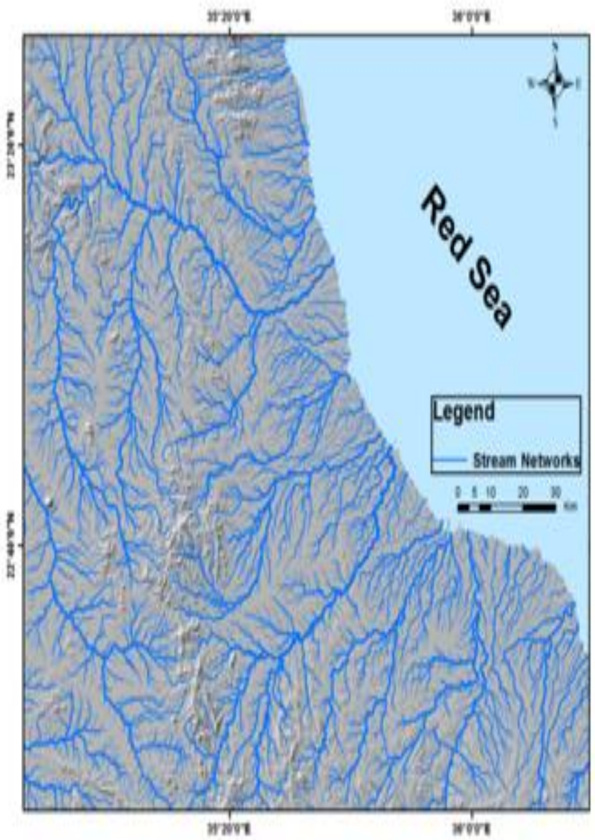


Fig. 5. Stream networks of Halaib and Shalatien area.

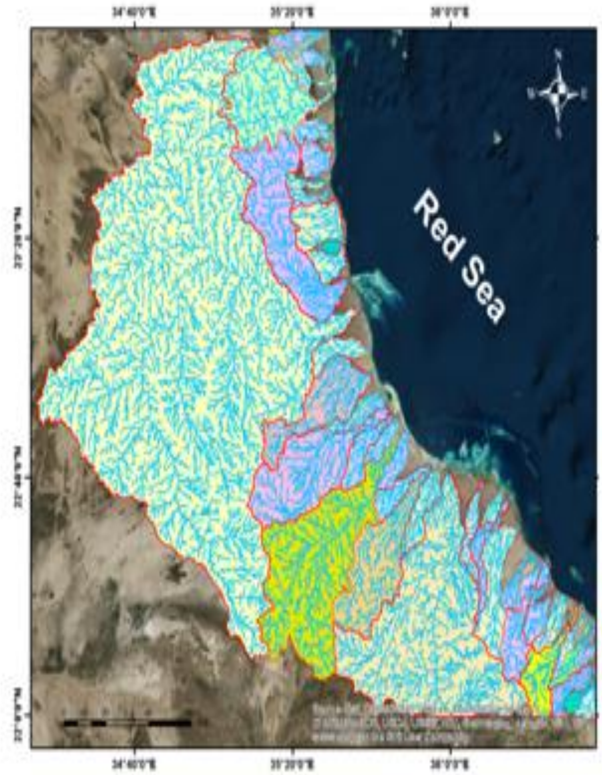


Fig. 6. Basins of Halaib and Shalatien area.

Water resources in the study area:

The sources of water in Halaib and Shalatien area can be divided into the following:

- **Natural springs:** springs issue naturally from rocks, either above or near ground level, without drilling. They are less common than wells. Some of them such as those of Abraq and Abu-saafa springs in field photographs as shown in Figure 7 (A and B) are sources of good waters.
- **Hand-dug wells:** The wells in the study area are mostly shallow excavations in the alluvial quaternary deposits of the wades. They tap the run-off waters that percolate underground seawards from the mountain ranges or in the surficial deposits weathered from the fractured Precambrian basement rocks, such as Wadi Hodien and wadi Rahaba wells in field photographs as shown in Figure 7 (C and D)
- **Drilled wells:** These wells were drilled in the Nubian sandstone sequences, north of the study area where reasonable promising deep water-bearing horizons occur. These wells are drilled in the vicinity of Wadi Abu Saafain field photograph as shown in Figure 7 (E), near to the Abu Saafa spring. The depth of these wells is around 95m, and the water is more saline than watersof the springs.

A. Ain Abraq

B. Ain Abo-Saafa.

C. Wadi Hodien well.

D. Wadi Rahaba well.

E. Drilled well in wadi Abu Saafa.

Fig. 7. (A-E): Field photographs showing water resources in the study area.

Groundwater aquifers in the study area and their salinity / sodicity.

Three aquifer systems in Halaib and Shalatien according to their litho-stratigraphic as follows:

1- Fractured basement aquifer.

Four samples were taken from groundwaters of fractured basement aquifer (Table 1). The fractured basement is the deeper aquifer in Halaib and Shalatien and characterized by its moderate salinity (Shawky *et al*., 2012). The fractured basement aquifer is detected at very shallow depth (started from around 10 m) in some wadis along the Red Sea coast (EGSMA, 1995). The deeper fractured basement aquifer is not highly recommended to be used as a source of water, as the supplement of groundwater from the aquifer is very limited (Abdel Moneim, 2005 and Khalil, 2014). The EC value in fractured basement aquifer ranges from 0.72 dSm^{-1} in El-Gahlia well to 2.78 dSm^{-1} in Mekeel well. The soluble cations could be arranged as follows $Na^{+}> Ca^{2+}>Mg^{2+}> K^{+}$. Bicarbonate is the dominant soluble anion. Soluble anions can be arranged as follows, $HCO3^{-}>Cl^{-} > SO4^{2-}> CO_3^{2-}$. The pH value ranges from 7.3 to 7.8. Sodium adsorption ratio (SAR) values range between 2.02 and 11.04.

2- Nubian sandstone aquifer.

Eight samples were taken from groundwaters of the Nubian sandstone aquifer (Table 1). The Nubian aquifer system is one of the world's largest aquifers, with areas in Egypt, Sudan, Chad and Libya (AbouHeleika and Niesner, 2009). In the Nubian sandstone aquifer, the EC value ranges from 0.69 dSm^{-1} in Abraq well to 2.24 dSm^{-1} in Abu-Saafa 4 well. The soluble cations could be arranged as follows $Na^{+}> Ca^{2+}>Mg^{2+}> K^{+}$. Bicarbonate is the dominant soluble anion. Soluble anions can be arranged as follows, $HCO_3^{-}>Cl^{-}> SO_4^{2-}> CO_3^{2-}$. The pH values range from 7.1 to 7.8, the SAR ranged between 1.9 to 8.9.

3- Quaternary aquifer.

One sample from the Quaternary aquifer (Table 1). Quaternary aquifer is described as a highly productive aquifer (Abdel Moneim, 2005). In the quaternary aquifer the EC value is 1.05 dSm^{-1} in El-Suinta well. The soluble cations could be arranged as follows $Na^{+}> Ca^{2+}>Mg^{2+}> K^{+}$. Bicarbonate is the dominant soluble anion. Soluble anions can be arranged as follows, $HCO_3^{-}>Cl^{-}> SO_4^{2-}> CO_3^{2-}$. The pH value is 7.4, the SAR value is 1.8.

Water quality assessment of the studied area:

Table 1 shows that the waters of Fractured basement aquifer are C2S1 class (moderate salinity - low sodicity), C3S2 class (medium salinity - medium sodicity) and C4S3 class (high salinity – high sodicity). Waters of the Nubian sandstone aquifer are C2S1 class (moderate salinity - low sodicity), C3S1 class (medium salinity – low sodicity) and C3S2 class (medium salinity - medium sodicity). Waters of the Quaternary aquifer are C3S1 (medium salinity – low sodicity).

Table 1. Well name, pH, EC, Cations, anions and USDA salinity, sodicity classification of the ground waters in Halaib and Shalatien area.

Aquifer	Well name	pH	EC (dS/m)	Cations (mmolc L^{-1})				Anions (mmolc L^{-1})				SAR	Water classification
				Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	CO_3^{2-}	HCO_3^{-}		
Fractured basement aquifer	El-Magal	7.82	1.86	5.20	0.60	2.90	10.00	5.20	3.20	0.00	10.30	4.97	C3-S2
	El-Gahlia	7.80	0.72	2.10	0.40	1.80	2.80	1.04	0.86	0.00	5.20	2.01	C2-S1
	BirEkat	7.50	2.37	2.20	0.87	3.50	17.20	7.00	9.87	0.00	6.90	10.19	C4-S3
	Mekeel	7.30	2.78	3.60	0.90	3.10	20.20	7.30	12.30	0.00	8.20	11.04	C4-S3
Nubian sandstone aquifer	Abraq	7.55	0.69	2.70	0.35	1.20	2.60	0.90	0.75	0.00	5.20	1.86	C2-S1
	Gambeet	7.50	0.81	0.58	0.85	1.15	5.52	1.11	0.74	0.00	6.25	5.94	C3-S2
	Abosaafa1	7.83	0.85	3.10	0.35	1.10	4.10	1.37	1.66	0.00	5.62	2.83	C3-S1
	Abosaafa2	7.07	0.76	3.36	0.35	1.03	2.90	1.22	1.00	0.00	5.42	1.96	C3-S1
	Abosaafa3	7.45	1.03	2.40	0.70	2.20	5.05	1.73	1.65	0.00	6.97	3.33	C3-S2
	Abosaafa4	7.16	2.24	3.54	0.70	2.59	15.60	7.77	6.55	0.00	8.11	8.91	C3-S3
	BirAbrak	7.10	1.39	2.70	0.40	2.30	8.50	5.30	3.90	0.00	4.70	5.38	C3-S2
	Abraq spring	7.50	0.62	2.20	0.30	1.00	2.80	1.20	0.80	0.00	4.30	2.21	C2-S1
Quaternary aquifer	El-suinta	7.40	1.05	4.90	0.60	1.50	3.30	1.80	1.80	0.00	6.70	1.84	C3-S1

Salinity hazards: C_1 to C_6: low, moderate, medium, high, very high and excessive high respectively (EC of < 0.25, 0.25-0.75, 0.75-2.25, 2.25- 4.00, 4.00- 6.00 and >6.00 dSm^{-1} respectively).

<u>Sodicityhazards</u>: S_1 to S_4: low, medium, high and very high respectively. (SAR "sodium adsorption ratio" of < 10 ; 2.5- 18 ; 7- 26 ; and > 26 respectively , for each class the limit is wide if water has low EC).

Irrigation Water Quality Index (IWQI).

Irrigation Water Quality Index Model (IWQI) is a specified method that was established by (Meireles *et al.*, 2010) and used for water quality assessment for agricultural purposes. IWQI model was applied on the results of water samples were taken from the investigated area, and is calculated in three steps:

1- In the first step, five chemical parameters were used for calculation of water quality index including EC, Na^+, Cl^-, and $HCO3^-$ and SAR. To calculate each of these parameters the accumulation witness (Wi) and the water quality measurement parameter value (Qi) were utilized.

2- The second step, values of the accumulation weights (Wi) suggested by (Meireles *et al.*, 2010) have been defined based on their relative significance to the irrigation water quality, are shown in Table 2. Based on different parameters recommended by (Ayers and Westcot, 1999), Qi value was estimated as shown in Table 2 and calculated using the equation (1):

$$Qi = Qimax - \frac{((Xobs - Xmin) \times Qiamp)}{Xmax}$$

Where **Qi represents the quality of the parameter from 0 to 100 and corresponding to the function of its concentration or measurement; Qimax is a maximal value of Qi for the class, Xobs is the observed value of chemical parameters, Xmin is the minimal limit of the class to each parameter belongs; Qiamp is class amplitude; and Xmax is a maximal limit of the class of each parameter.**

3- The third step, the irrigation water quality index (IWQI) was calculated as the following equation:

$$IWQI = \sum_{i=1}^{n} WiQi$$

In this equation, IWQI is none dimensional Irrigation water quality index ranged from 0 to 100.

Table 2. Parameter limiting values for quality measurement (Qi) calculation (Meireles *et al.*, 2010) and weights (Wi) for each parameter of the IWQI.

(Qi)	EC (µs/cm)	Na^+ (mmolc/L)	Cl^-(mmolc/L)	HCO_3^-(mmolc/L)	SAR
85-100	200 – 750	2 – 3	1 – 4	1 – 1.5	2 – 3
60-85	750-1500	3 – 6	4 – 7	1.5 – 4.5	3 – 6
35-60	1500-3000	6 – 9	7 – 10	4.5 – 8.5	6 – 12
0-35	EC< 200 or ≥ 3000	Na^+ < 2 or ≥ 9	Cl< 1 or ≥10	HCO_3^-< 1 or ≥ 8.5	SAR< 2 or ≥ 12
(Wi)	0.211	0.204	0.194	0.202	0.189

Irrigation Water Quality Index (IWQI) Map.

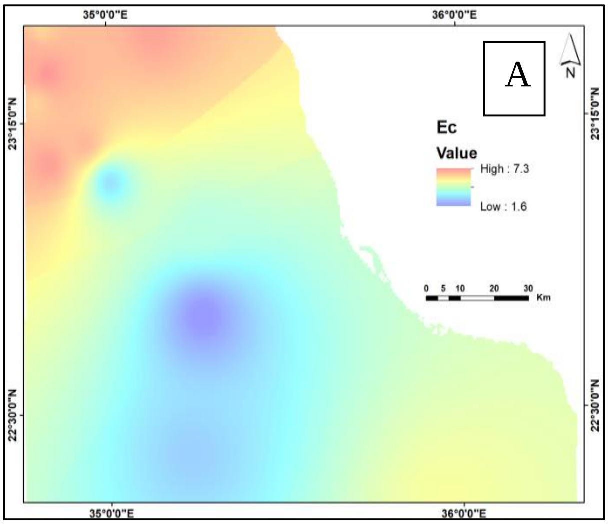
According to Meireles *et al*. (2010), the values of IWQI for the suitability of the groundwater for irrigation purposes divided into five restriction use classes (Table 3), these classes were defined based on soil water infiltration reduction, salinity hazard problems, and toxicity to plants. The water quality characteristics of five chemical parameters (EC, Cl^-, HCO_3^-, Na^+ and SAR) (Table 4) were used to create the database of water quality index from input to the GIS platform to produce a spatial distribution map for each parameter using the ArcGIS 10.2 software, as shown in Figures 8 (A-E). The IWQI map (Figure 9) was produced by the overlapping of the spatial distribution maps of five parameters. This map represents the spatial distribution of the groundwater quality for irrigation purposes to help the decision-makers to identify the suitable crops and irrigation systems. The suitability of groundwater in the studied area is divided into four classifications of water use restrictions as mentioned in Table (4). 46.2 % of groundwater fall in the low-restricted (LR) class and found in all aquifers in the studied area (Fractured basement, Nubian sandstone and Quaternary aquifers). The groundwater in this class is suitable for irrigation directly without any processing and can be used for irrigation of all plants with avoiding salt-sensitive plants. Only 15.4 % of the studied samples fall in the moderate-restricted (MR) class, which mainly found in Nubian sandstone aquifer and can be used in soils with moderate permeability values. Leaching of salts is recommended to avoid soil deterioration. Suitable for irrigation of plants with moderate tolerance to salts. Only 7.7 % of the studied groundwater samples fall in the high-restricted (HR) class, which found only in Fractured basement aquifer and can be used in soils with high permeability without impact layers and suitable for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, expect water with low Na, Cl, and HCO_3^- values. The remaining (30.7%) of the studied samples fall in the severe restriction (SR) class and found in the Fractured basement and Nubian sandstone aquifers. These groundwater samples are very poor groundwater quality for irrigation purposes. The groundwater in these aquifers is suitable only for plants with high salt tolerance, except for waters with extremely low values of Na^+, Cl^- and HCO_3^-, and soils have high permeability. In brief, this groundwater should be avoided its use for irrigation under normal conditions. The IWQI for groundwater samples in the studied area ranges from 31.16 to 83.03. The low values, because of increase the electrical conductivity (EC), Sodium and Chloride ions in the groundwater.

Table 3. Classifications and characteristics of water quality index according to Meireles *et al*. (2010).

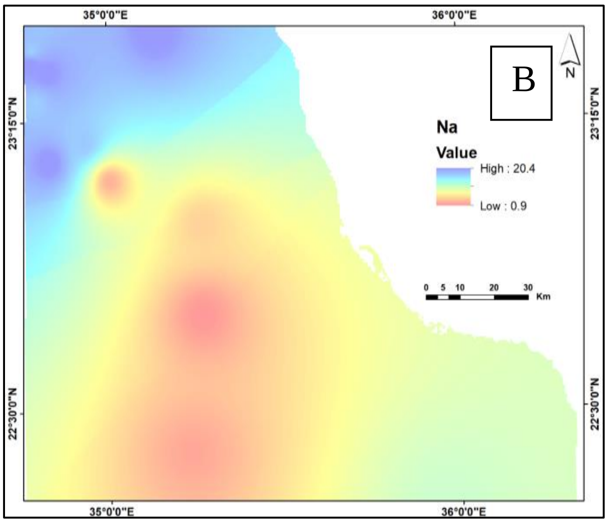
Restriction use class	IWQI	Recommendation: Soil	Recommendation: Plant
No restriction (NR)	85 -100	Water can be used for almost all types of soil. Soil is exposed to lower risks of salinity/sodicity problems	No toxicity risk for mast plants.
Low restriction (LR)	70 -85	Irrigation soil with a light texture or moderate permeability can be adapted to this range. To avoid soil sodicity in heavy texture, soil leaching is recommended.	Evaluated risks for salt sensitive plants
Moderate restriction (MR)	55 – 70	The water in this range would be better used for soils with moderate to high permeability values. Moderate leaching of salts is highly recommended to avoid soil degradation.	Suitable for irrigation of plants with moderate tolerance to salts.
High restriction (HR)	40 – 55	This range of water can be used in soils with high permeability without compact layers. High frequency irrigation schedule.	Suitable for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, expect water with low Na, Cl, and HCO3 values.
Severe restriction (SR)	0 – 40	Using this rang of water for irrigation under normal conditions should be avoid.	Only plants with high salt tolerance, expect for waters with extremely low values of Na, Cl and HCO3.

Table 4. qi ×wi of individual parameters and Irrigation Water Quality Index (IWQI).

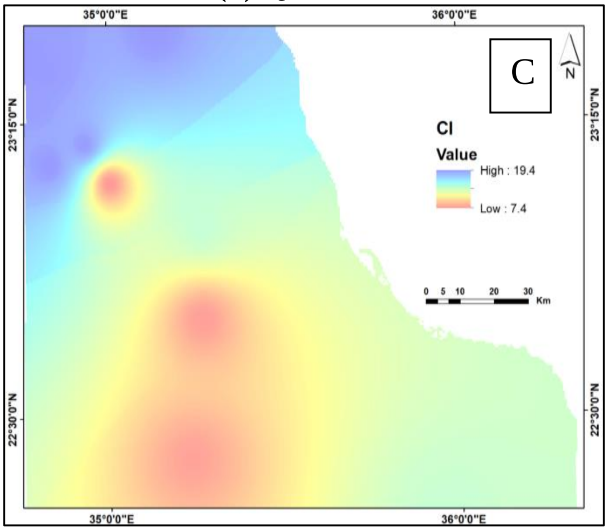
Aquifer /Well name	Qi of EC	Wi × Qi of EC	Qi of Na^+	qi × wi of Na^+	Qi of Cl^-	qi × wi of Cl^-	Qi of HCO_3^-	qi × wi of HCO_3^-	Qi of SAR	qi × wi of SAR	IWQI value	IWQI class
Fractured basement aquifer												
El-Magal	19.40	4.10	22.18	4.52	71.16	13.81	14.61	2.95	77.91	14.72	40.10	HR
El-Gahlia	33.74	7.12	99.85	20.37	99.73	19.35	57.81	11.68	99.77	18.86	77.38	LR
BirEkat	12.97	2.74	9.70	1.98	40.37	7.83	53.67	10.84	41.10	7.77	31.16	SR
Mekeel	7.81	1.65	4.50	0.92	39.41	7.64	50.53	10.26	39.17	7.40	27.87	SR
Nubian sandstone aquifer												
Abraq	34.12	7.20	100	20.40	100.00	19.40	57.81	11.68	99.97	18.90	77.58	LR
Gambeet	32.61	6.88	81.39	16.60	99.61	19.32	55.27	11.16	75.72	14.31	68.27	MR
Abosaafa1	32.10	6.77	83.14	16.96	99.10	19.23	56.80	11.47	98.65	18.64	73.07	LR
Abosaafa2	33.24	7.01	99.78	20.36	99.38	19.28	57.28	11.57	99.84	18.87	77.10	LR
Abosaafa3	29.84	6.30	81.41	16.61	98.42	19.10	53.52	10.81	81.63	15.43	68.25	MR
Abosaafa4	14.60	3.08	12.48	2.55	37.90	7.35	50.75	10.25	44.00	8.32	31.55	SR
BirAbrak	25.31	5.34	52.70	10.75	70.84	13.74	59.03	11.92	77.01	14.55	35.55	SR
Abraq spring	35.00	7.39	99.85	20.37	99.42	19.29	85.00	17.17	99.50	18.81	83.03	LR
Quaternary aquifer												
El-suinta	29.59	6.24	84.13	17.16	98.26	19.06	54.17	10.94	100	18.90	72.30	LR



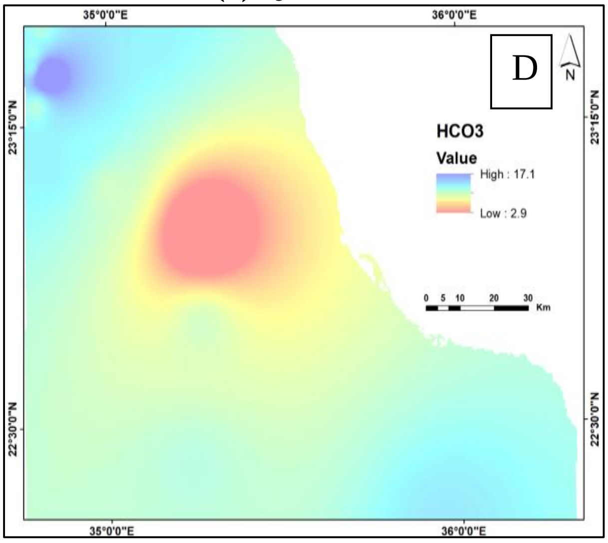
(A). Qi*Wi of EC



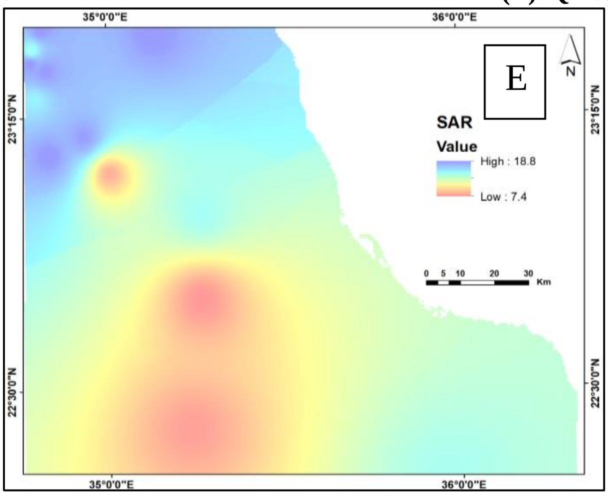
(B). Qi*Wi of Na^+



(C). Qi*Wi of Cl^-



(D). Qi*Wi of $HCO3^-$



(E). Qi*Wi of SAR.

Fig. 8. Spatial distribution maps (A) Qi*Wi of EC, (B) Qi*Wi of Cl^-, (C) Qi*Wi of $HCO3^-$, (D) Qi*Wi of Na^+, (E) Qi*Wi of SAR.

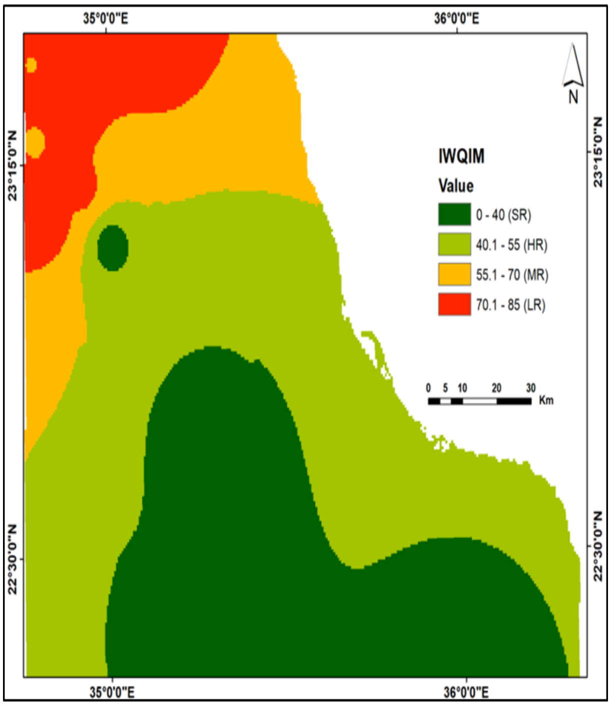


Fig. 9. IWQI spatial distribution map of the study area.

Application of trilinear plotting system (Piper's Trilinear diagram, 1944) for Geochemical classification of groundwater quality:

The Trilinear diagram for water quality assessment of Piper (1944) was adopted using UN-GWW software program (1994). It is useful for water assessment. This type of classification is based on the equivalent per million percentages of cations and anions. The Piper trilinear diagram combines three distinct fields of plotting, two triangular fields at the lower left and lower right, and a diamond-shaped field intervening the two triangles, at the upper part. The three fields have a scale in 100 parts. In the lower left triangular field, the percentage values of the three cations: Na^{+}, Mg^{2+} and $Ca^{2+}$are plotted as a single point. The three–anions: Cl^{-}, SO_4^{2-} and $HCO_3^{-}$are plotted in the lower right triangular field. Thus, two points on the diagram, one in each of the two triangular fields are plotted. The diamond shaped field consists of two equal triangular fields. Generally, the water samples appear in the upper triangle have secondary salinity properties, where $SO_4^{2-}$and Cl^{-} exceed Na^{+} and K^{+}. On the other hand, those which appear in the lower triangle are considered to have primary alkalinity properties, where $CO_3^{2-}$and HCO_3^{-}exceed $Ca^{2+}$and Mg^{2+}. The results of the water samples collected in the current study are plotted on Piper diagrams (Figure 10). The shape indicates that they are of similar origins. In the outlet and intermediate areas, Na^{+} ions represent the dominant cations, while $HCO_3^{-}$is the dominant anions.

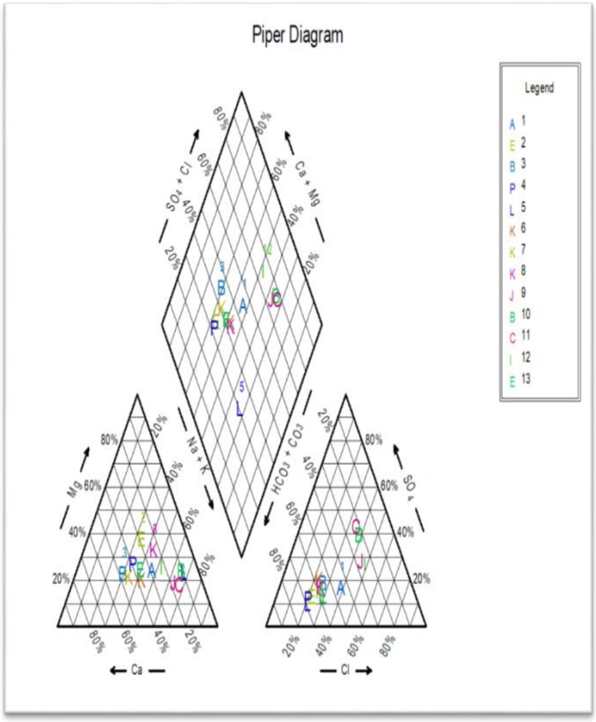


Fig. 10. Piper's trilinear diagrams showing classification of the studied groundwater samples (springs and wells) in the study area.

Application of Schoeller's diagram for water quality:

The Schoeller semi-logarithmic diagram (Schoeller, 1962). In this diagram, each line representing an analysis is drawn by connecting points representing gravimetric concentrations of ions. The Scholler diagram shows the total concentration values of major ions in logarithmic scales. The logarithmic scale has some disadvantages for the water of low dissolved solids concentration. Results obtained in samples of the current study are shown in Figure 11. Chemical analysis of the surface and groundwater samples are plotted in equivalent per million (eq/m). The major ions are expressed on the graph by slopes of straight lines connecting the different ions. According to this diagram the following general patterns were recognized. All water types have $K^{+}< Mg^{2+}< Ca^{2+}< Na^{+}$, $SO_4^{2-}<Cl^{-}< HCO_3^{-}$. This reflects a high concentration of sodium, calcium, bicarbonate and chloride ions indicating that the dominant salts are $NaHCO_3$and NaCl. The parallelism observed between the zigzag lines refers to the closeness in the ionic ratio, which in turn ensures a strong relationship between all water resources in the area.

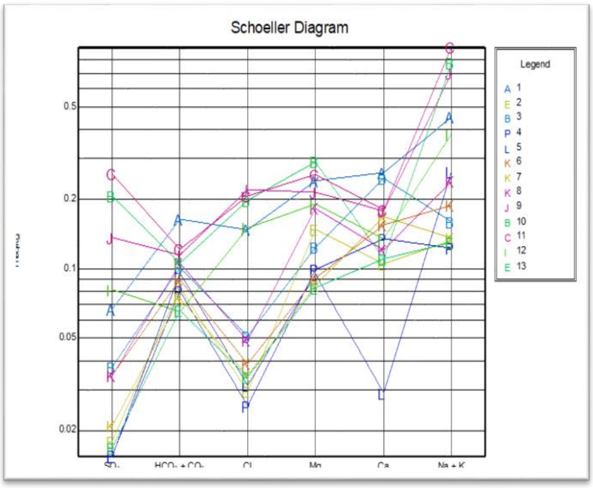


Fig. 11. Schoellers diagrams of ground waters (Spring's and Wells) in the area.

Types and origins of groundwater in the studied area.

The five hydro-chemical ratio parameters of K/Cl, Na/Cl, Mg/Cl, Ca/Cl, and SO4/Cl were calculated for water samples. These parameters are useful in comparing the waters of different resources. The standard values for seawater are 0.0181, 0.8537, 0.198, 0.0385 and 0.103 for the above-mentioned parameters respectively (Ovchinnikov, 1955). The meteoric genesis of groundwater can be divided into two types shallow and deep meteoric water, most of the studied groundwater samples belong to shallow meteoric origin (Table 5).

Table 5. Type and origin of water samples at Halaib and Shalatien area.

Aquifer/Well name	Water Type	$\{(K^{+}+Na^{+}) - Cl^{-}\} \div SO_4^{2-}$	Origin
	Fractured basement aquifer		
El-Magal	$Na\text{-}HCO_3$	1.69	shallow meteoric water
El-Gahlia	$Mg\text{-}HCO_3$	2.51	shallow meteoric water
BirEkat	$Ca\text{-}HCO_3$	1.17	shallow meteoric water
Mekeel	$Ca\text{-}HCO_3$	2.73	shallow meteoric water
	Nubian sandstone aquifer		
Abraq	$Na\text{-}HCO_3$	7.11	shallow meteoric water
Gambeet	$Na\text{-}HCO_3$	1.86	shallow meteoric water
Abosaafa1	$Ca\text{-}HCO_3$	2.03	shallow meteoric water
Abosaafa2	$Na\text{-}HCO_3$	2.44	shallow meteoric water
Abosaafa3	Na-Cl	1.30	shallow meteoric water
Abosaafa4	$Na\text{-}SO_4$	1.12	shallow meteoric water
BirAbrak	$Na\text{-}SO_4$	1.12	shallow meteoric water
Abraq spring	Na-Cl	0.92	deep meteoric water
	Quaternary aquifer		
El-suinta	$Na\text{-}HCO_3$	2.38	shallow meteoric water

CONCLUSION

Groundwater is considered one of the most important sources of water especially in the arid country for many uses. Halaib and Shalatien area is suffering from a shortage of fresh water, so the groundwater is the most important source of water for agricultural purposes. Groundwater in this area is the alternative solution to face the gap between the water demand and available water for sustainable development in this area. The integration between the groundwater characteristics of five parameters (EC, Na^{+}, Cl^{-}, HCO_3^{-} and SAR) and the GIS technique to give the IWQI map as a result of the geostatistical analysis. The IWQI for groundwater samples in the studied area ranges from 31.16 to 83.03. The low values, because of increase the electrical conductivity (EC), Sodium and Chloride ions in the groundwater. The IWQI map to help the decision-makers to identify the suitable crops and irrigation systems.

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تقييم جودة المياه الجوفية للخزانات الصخرية الجوفية المختلفة فى منطقة حلايب وشلاتين جنوب الصحراء الشرقية – مصر

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يهدف هذا البحث لتقييم جودة المياه الجوفية فى منطقة حلايب وشلاتين جنوب الصحراء الشرقية – مصر. وحيث أن المصدر الرئيسى للمياه المستخدمة فى الرى والأستخدام المدنى هى المياه الجوفية (الآبار والعيون). يوجد ثلاث خزانات جوفية حاملة للمياه بمنطقة الدراسة وهى: (أ) خزان المياه الجوفية فى التشققات القاعدية (Fractured Basement Aquifer)و (ب) خزان الحجر الرملى النوبى (Nubian Sandstone Aquifer) و (ج) الخزان الجوفى الرباعى (Quaternary Aquifer). تم أخذ 13 عينة مياه من الخزانات الجوفية المختلفة: 4 عينات من الخزان التحتى المكسور، و8 عينات من الخزان النوبى، وعينة واحدة من الخزان الرباعى. وتم تقييم المياه من حيث الملوحة والصودية طبقا لمعمل الملوحة والقلوية الامريكى(USDA, 1954). تم تقييم جودة المياه الجوفية من حيث مدى ملائمتها للرى بإستخدام طريقة دليل جودة مياه الرى (IWQI) للأغراض الزراعية والتى أنشئت بواسطة (Meireles *et al*., 2010) بمساعدة نظم المعلومات الجغرافية (GIS). خمس مؤشرات كيميائية أستخدمت فى هذا التقييم وهى: EC، Na^+، Cl^-، HCO_3^-, SAR. وقد أظهرت خريطة IWQI ان 46.2% من عينات المياه مصنفة على أنها أقل خطورة تكون مناسبة للرى مباشرة، 23.1% من عينات المياه مصنفة على أنها متوسطة الى عالية الخطورة ونستطيع أستخدام هذا النوع من المياه فقط فى رى الأراضى عالية النفاذية وتتطلب غسل الأملاح من التربة لتجنب تدهور التربة. أما باقى عينات المياه وهى 30.7% مصنفة على أنها عالية الخطورة وتكون ملائمة فقط للأراضى العالية جدا فى نفاذيتها مع تطبيق عمليات الغسيل باستمرار لمنع تراكم الأملاح ويجب تجنب أستخدام هذا الماء لرى الأراضى تحت الظروف العادية.