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Hydrogeochemical Characteristics of Groundwater from Wadi Asal and Wadi Queih, Quseir, Red Sea, Egypt

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Abstract: The study area in Wadi Asal and Wadi Queih at Quseir area, Red Sea, Egypt, suffers from different natural and anthropogenic processes due to rock variability, mining, and human activities. Groundwater is the only source of fresh water in the area. Three major hydrogeological units are recorded for groundwater in the study area; the Quaternary, the fractured Precambrian, and the Phanerozoic aquifers. The hydrogeochemical properties of groundwater were evaluated through the chemical analysis of 5 collected water samples from available wells in the study area. The resulting groundwater is characterized by Ca^{2+} > Na^{+} > Mg^{2+} and Cl^{-}> SO_4^{2-} > HCO_3^{-}, in Queih wells while Asal has Na^{+} > Ca^{2+} > Mg^{2+} and Cl^{-} > SO_4^{2-} > HCO_3^{-}. The hydrochemical facies in this area fall in the field of Ca-Na-Cl-SO_4 for Queih, and Na-Ca-Cl-SO_4 for Asal, indicating Ca^{2+} and Na^{+} are the dominant cations in the groundwaters from Queih and Asal areas with mixing or dissolution (for Queih water samples) and reverse ion exchange reactions (for Asal water samples) as the prevalent hydrochemical processes controlling their chemistry. High K^{+} and NO_3^{-} in Queih are due to agricultural activities accelerated by using potassium fertilizers. TDS is more than 3000 mg/L, and the Middle Miocene sandstone aquifer of Asal water is more saline than the Cretaceous aquifers of Queih due to the presence of faults and dykes that allows water to infiltrate with great leaching processes from surrounding aquifers lithologies. Monitoring the natural and anthropogenic activities that influence groundwater quality around Safaga-Quseir District, Red Sea, is essential for the future sustainable management of water resources.

Keywords: Groundwater characterization, Groundwater hydrogeochemistry, Wadi Asal and Wadi Queih, Red Sea, Egypt

1. Introduction

The development of countries is reliant on the availability of surface and groundwater. Groundwater is the second freshwater source in Egypt and constitutes about 12% of the water supply [1]. The Eastern Desert of Egypt has limited freshwater resources either by potable water transported from the Nile River by pipelines, seawater desalination, rainwater harvesting, or drilling through the different water-bearing aquifers (fractured basement and sedimentary). The study area gets attention from the Egyptian Government as an optimistic area for economic development, mainly in the tourism and mining sectors.

Many previous studies of [2-4] dealt chiefly with water resources in Safaga-Quseir District, where traditional hydrogeology and hydrogeochemistry methods were applied. Ref. [5] used stable environmental isotopes to explore the sources of recharge to the aquifers. They stated that salinity originated from the dissolution of terrestrial minerals and the leaching of soils via floods or ion exchange processes. Also, the sources of recharge are chiefly meteoric origin from paleowater of the Pleistocene pluvial period and local precipitation, as well as some contributions from marine water. Refs. [6-7] studied the hydrogeochemistry of water resources in the central Eastern Desert and the entire Eastern Desert. The GIS technique assessed the geomorphologic hazard for flooding zones and earth movement potential [8]. Ref. [9] studied Egypt's Red Sea coastal sensitivity to climate change. He deduced that global warming of seawater should impact the coastal zone due to the fringing of coral reef communities. Ref. [10] suggests different natural hydrogeochemical processes like simple dissolution, mixing, evaporation, weathering of carbonate minerals, silicate, and sulfates, as well as ion exchange, are the key factors controlling the groundwater quality in the study area.

The current study evaluates the hydrochemical characteristics of groundwater in Wadi Asal and Wadi Queih, Quseir area, Red Sea, Egypt.

2. Methodology

Five groundwater samples were collected from the available water wells in the studied area (Figure 1) using polyethylene plastic bottles. The groundwater samples were classified into: (a) unacidified groundwater samples to determine the different chemical parameters including, pH, EC, TDS, Cl^{-}, HCO_3^{-}, SO_4^{2-}, NH_4^{+}, NO_3^{-} and PO_4^{2-} using digital meters, titration, turbidimetric, and spectrophotometrically methods in the laboratory of Environmental Geochemistry, Geology Department, Faculty of Science, Sohag University, (b) the acidified groundwater samples to determine the major cations (Na^{+}, K^{+}, $Ca^{+2,}$ and Mg^{+2}) by the Atomic Absorption Spectrophotometer (AAnalyst 400) in the Atomic Absorption Unit, Geology Department, Faculty of Science, Sohag University.

3. Hydrogeological setting

Generally, three major hydrogeological units are present in the Eastern Desert; the Quaternary aquifer is represented by the wadi deposits at the main streams of the major wadis, the fractured Precambrian aquifer, and the Phanerozoic aquifers [3-4, 11]. Groundwater occurrence is mainly controlled by rock types, structural conditions, and topography of the area.

3.1. Wadi Queih

Groundwater aquifers in Wadi Queih are mainly recharged from sporadic rainfall and flash floods. This water infiltrates through the loose sediments and accumulates on basement depressions or is trapped by faults. The mean vertical infiltration rate value of the surface soil (aeolian gravel and well-sorted sand) is about 5.1 m/day [3]. The high vertical infiltration rate permits a high percentage of rainfall to infiltrate into the subsurface sediments. The Queih basin extends 67.5 km from west to east, and the average width is of about 26.6 km with a catchment area about 1,800 km^2 [12]. The Queih depression is morphotectonic [13], running NW–SE, and receives water from the surrounding mountains. The water-bearing formations in Wadi Queih can be classified into two main hydrogeological units (Table 1), sedimentary rocks and fractured Precambrian basement rocks [14] (Figure 2). The recognized aquifers in Wadi Queih are:

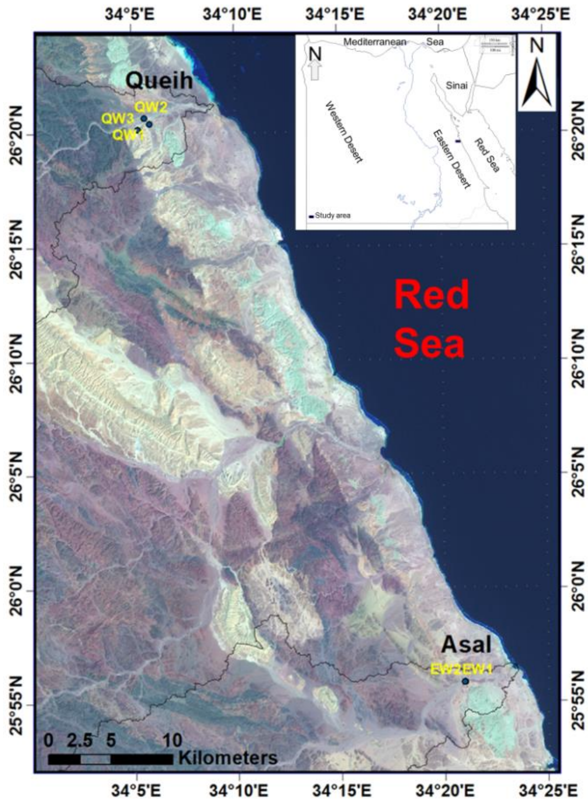

Figure 1. Location map of the groundwater samples in the study area.

3.1.1. Quaternary (alluvium) aquifer

The Quaternary water-bearing deposits in the area consist of alluvial sands, pebbles, boulders, and rock fragments with variable thicknesses reaching 20 m. These deposits capped the basement rocks at the upstream portions or rested on the sedimentary rocks (Dakhla Formation or shale–marl deposits) in the downstream areas. The infiltration rate of these deposits is relatively high, ranging between 182 and 282 m/day [15], indicating a high permeability of the aquifer material. Due to numerous flood events, the well of the Quaternary aquifer was filled with recent sediments.

3.1.2. Cretaceous aquifers

The Cretaceous aquifers are represented by three water-bearing formations as follows:

3.1.2.1. Duwi limestone aquifer

The Duwi Formation comprises oyster-fractured limestone, shale, and marl beds with sandstone phosphatic intercalations. The Duwi Formation overlies the Quseir Formation and underlies the Dakhla Formation, where water exists under confined conditions. Broad lenses of phosphate deposits are present in three members inside the Duwi Formation [16, 17]. The Duwi Formation is the main water-bearing formation in Queih mine area (wells No. QW2 and QW3). Its thickness ranges between 16 to 22 m [2]. The aquifer is recharged from the precipitation falls on the surrounding catchment basement rocks and the upward leakage along the fault planes from the deeper Nubian sandstone aquifer [4, 5]. The hydraulic gradient of groundwater in the Duwi Formation decreases from north to south, from +39.94 to +28.92 m above sea level. The water level drops in the southeast direction from +46.26 m in the Queih mining area to +22 m in the Abu Shigili mine area [2].

3.1.2.2. Quseir variegated shale.

It comprises sandy, gypsiferous shale and marl overlain by the Duwi Formation and underlain by the Nubian sandstone aquifer. The water depth in this aquifer is 14 m from the ground surface, and the total depth is 17 m [3]. Due to numerous flood events and especially the flooding event at the end of 2004, the penetrating well was filled with recent sediments.

3.1.2.3. The Nubian sandstone aquifer

The Nubian sandstone facies unconformably overlies the basement rocks and is capped by Quseir variegated shale [3]. The Nubian facies are represented by fine-coarse sandstone alternating with shale and clay thick succession. The thickness of the Nubian sandstone ranges between 60 m at the Hamrawein area to 230 m at the low hills along Quseir-Qena road [4], and it is detected as a water-bearing formation at Wadi Queih (well No. QW1). The recent recharge of the Nubian sandstone aquifer occurs chiefly through the infiltration of rainwater that occurs occasionally in the area along the fault planes, in addition to the water stored during the pluvial times [2, 5].

3.1.3. The fractured basement aquifer

It comprises weathered, fractured, jointed, and faulted igneous and metamorphic basement rocks. Groundwater occurs under free water table conditions because fractures act as good conduits for water. The fractured basement aquifer is directly recharged from the local precipitation, where the amount of water accumulated within these rocks depends on the fractures' depth, width, and extension. In general, water trapped at the basement rocks is limited and usually used as a water supply for the residents. No water samples were collected from this aquifer.

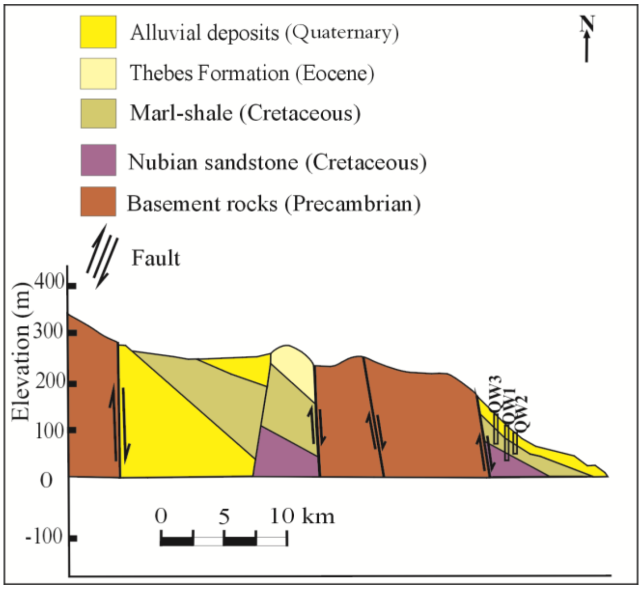

Figure 2. Schematic hydrogeological profile of Wadi Queih area (modified after [2]).

3.2. Wadi Asal

The study basin has an area of about 716.8 km^2 and length of all tributaries of about 240 km that drains into the Red Sea. The main channel of Wadi Asal runs nearly in an east-west direction. The headwaters of Wadi Asal arise in Gebels Hamadat (+432 m), Melgi (+774 m), El Atwi (+1078 m), and Gebel El Sibai (+1433 m) which scour numerous fingers tip channels, e.g., Wadis El-Tarfawi, El Atshan, El Dabah, and Wadi Abu Tundab (Figure 3) [11]. The majority of these wadis are narrow (± 200 m width), meandered, gently sloping and bounded with steep vertical cliffs. These wadis join Wadi Asal main trunk before it flows to the Red sea. Wadi Asal basin has an elongated shape which allows runoff water to take place for longer period of time giving more chance to feed the shallow water bearing formations. Groundwater occurrences in Wadi Asal basin is encountered in three bearing formations, the Precambrian fractured Hammamat, Middle Miocene sandstone and Quaternary alluvial aquifers. The recognized aquifers in Wadi Asal are (Table 1; Figure 3):

3.2.1. Quaternary (alluvium) aquifer

The Quaternary alluvial deposits consist of sand pebbles interbeds more than 5 m thick. The alluvial water-bearing formation is found in the delta of Wadi Asal, where the groundwater exists at low depths (2-5 m). The aquifer recharge was through local rainfall and surface runoff. At the upstream portion, the alluvial aquifer rests on the fractured Precambrian rocks and at the downstream portion it rests on the Middle Miocene evaporites and shale. [11]. This aquifer is found at the entrance of Wadi Asal but was filled with recent sediments during flood events.

3.2.2. Middle Miocene sandstone aquifer

The Middle Miocene aquifer sediments are greatly distributed in the coastal plain south of Quseir. They are composed of basal sandstone, shale and limestone unit (Ranga Formation) and upper gypsum, shale, and marl (Abu Dabbab Formation). These sediments, having an exposed thickness of 243.5 m [18], are unconformably underlain by the basement rocks. The basal sandstone is the water-bearing formation at the lower reaches of Wadi Asal (wells No. EW1 and EW2). These water wells are located about 6 km inland from the Red Sea coast. These wells tap this aquifer at depths between 32 and 35 m from the ground surface. Faults and dykes have significant impacts on the water flow in the Middle Miocene aquifer of Wadi Asal, as indicated by field observations that allow the water to infiltrate downward. Also, local rainfall and flash floods on the sandstone outcrops infiltrate downward to the subsurface [5]. The groundwater in this aquifer exists mainly under semi-confined conditions due to the presence of impervious evaporites and shales of Abu Dabbab Formation that capped the sandstone aquifer and prevented its feeding from the surface. It must be mentioned that the existence of this aquifer above the basement rocks with the prevailing faulting system allows the possible recharge from the underlying fractured basement rocks. The groundwater flows eastward. The discharge rate at Wadi Asal is 19.4 m^3/h [11].

3.2.3. Precambrian fractured Hammamat aquifer

The Precambrian aquifer in Wadi Asal is composed of conglomerate, gritstone, sandstone, siltstone, and claystone and is found in the upstream parts of Wadi El Tarfawi. The surface of these rocks is dissected by a network of wide fractures and joints. This aquifer is recharged directly from local precipitation [11].

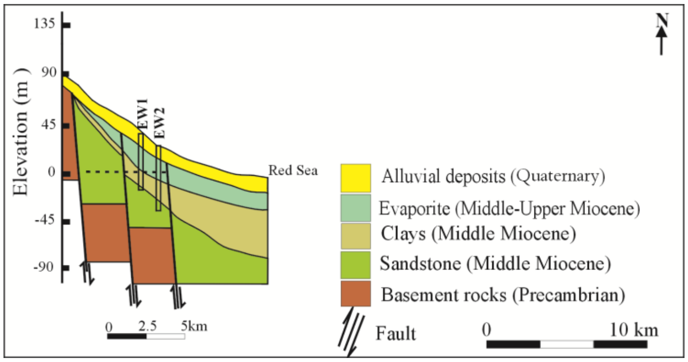

Figure 3. Schematic hydrogeological profile of Wadi Asal area modified after [4, 11].

Table 1. Hydrogeological data of the wells tapping the studied aquifers.

Well No.	Well type	Geologic unit	Depth to water (m)	Aquifer type
EW1	Drilled	Middle Miocene sandstone	32	Semi-Confined
EW2	Drilled	Middle Miocene sandstone	35	Semi-Confined
QW1	Drilled	Nubian sandstone	75	Confined
QW2	Drilled	Duwi Formation	60	Confined
QW3	Drilled	Duwi Formation	64	Confined

4. Results and Discussion

4.1. Hydrochemical characteristics of Groundwater

Many factors can influence the geochemistry of groundwater, such as rock type, residence time in the host rock, the original composition of the groundwater, and other characteristics of the water flow path [19].

The pH values of groundwater in the study area range from 7.12 to 7.5, which are in the range of neutral water (Table 2). Queih water samples have a high average pH (7.35) compared to Asal water samples (7.23). The groundwater salinity values (TDS) in the study area range between 3650 to 4630 mg/L for Queih and 4800 to 5190 mg/L for Asal. The Middle Miocene sandstone aquifer of Asal is more saline than the Duwi limestone aquifers (3650-3820 mg/L) and the Nubian sandstone aquifer of Queih (4630 mg/L). The TDS is greater than 3000 mg/L, and Asal water samples are more saline than Queih due to the presence of faults and dykes that allows water to infiltrate downward and from the basement with significant leaching processes, water stagnancy, low rate of recharge and alteration due to hydrothermal activity [11].

Schoeller diagram (Figure 4) shows the distribution of major ions in the groundwater in Queih wells in one category of chemical composition, i.e., Ca^{2+} > Na^+ > Mg^{2+} and Cl^-> SO_4^{2-} > HCO_3^-, while Asal has Na^+ > Ca^{2+} > Mg^{2+} and Cl^- > SO_4^{2-} > HCO_3^- (Table 3). The Na^+ concentration ranges from 388 to 564 mg/L for Queih and 606 to 752 mg/L for Asal. The Middle Miocene sandstone aquifer of Asal contains more Na^+ than the Duwi limestone aquifer (388-508 mg/L) and the Nubian sandstone (564 mg/L) aquifers of Queih. The Ca^{2+} concentration varies from 596 to 894 mg/L for Queih and 303 to 392 mg/L for Asal. The Duwi limestone aquifer (718-894 mg/L) aquifer of Queih contains more Ca^{2+} than the Nubian sandstone (596 mg/L) aquifer. Elevated Ca^{2+} for Queih may regard to the Duwi Formation lithology that enriched in Ca^{2+} (Table 2). The Mg^{2+} concentrations range between 30 to 34 mg/L for Queih and 28 to 38 mg/L for Asal. The Nubian sandstone (34 mg/L) aquifer of Queih contains more Mg^{2+} than the Duwi limestone aquifer (30–32 mg/L). The concentration of K^+ ranges between 5.7 to 20.3 mg/L for Queih and 2.6 to 5.5 mg/L for Asal. More K^+ is recognized in the Duwi limestone aquifer (9.5 to 20.3 mg/L) than in the Nubian sandstone (5.7 mg/L). The low contribution of K^+ may be due to its resistance to weathering and increase in Queih due to the agricultural activities accelerated by the use of potassium fertilizers. The Cl^- concentration ranges from 746 to 1062 mg/L for Queih and 1183 to 1267 mg/L for Asal. Low Cl^- is detected in the Duwi limestone aquifer (746 - 884 mg/L) than in the Nubian sandstone (1062 mg/L). The higher chloride content reflects the dissolution of Cl^- bearing deposits such as salt, gypsiferous shale, and clay minerals [20, 21]. The SO_4^{2-} concentrations range from 508 to 813 for Queih and 457 to 578 mg/L for Asal. SO_4^{2-} values are a little lower in the Duwi limestone aquifer (508 - 715 mg/L) compared to the Nubian sandstone (813 mg/L). However, higher values of sulfates in groundwater may be due to dissolved gypsum-anhydrite and/or potassium sulfates fertilizers added [22] especially in the agricultural soil of Queih or oxidation of sulfides in the aquifers [14]. The HCO_3^- concentrations range from 140 to 200 mg/L for Queih and 215 to 275 mg/L for Asal. Higher HCO_3^- is detected in the Nubian sandstone (200 mg/L) than the Duwi limestone aquifer (140 - 185 mg/).

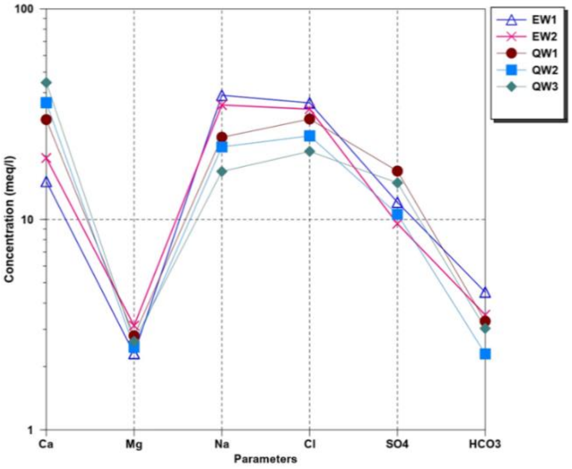

Figure 4. Schoeller diagram of major ions of the groundwater samples in the investigated area.

Nitrate concentration in the study area ranges between 0.6 and 4.4 mg/L for Queih and 0.2 to 0.6 mg/L for Asal. The Nubian sandstone (4.36 mg/L) aquifer of Queih contains higher NO_3^- than the Duwi limestone aquifer (0.63–3.11 mg/L). The upward leakage and downward infiltration along the fault planes are possible sources of aquifer recharge/discharge [4, 5]. The NO_3^- is a non-lithological source. Numerous factors influence groundwater pollution caused by nitrates, such as agricultural activities, land uses (agricultural land, village, town center, poultry factory, etc.), and water-rock interaction [23, 24]. The presence of NO_3^-, NH_4^- and/or SO_4^{2-} in quantities greater than anticipated from marine contributions (i.e., NO_3^-/Cl^-, NH_4^+/Cl^-, and SO_4^{2-} /Cl^- mass ratios > 0.0002 > 0.07 and > 0.14, respectively) are an indication of groundwater contamination by domestic septic tanks ore livestock wastes [25, 26]. The tremendous agricultural activities in Queih area may responsible for the increased nitrate content in water samples. The phosphate (PO_4^{-3}) concentration ranges between 0.7 and 0.85 mg/L for Queih and 0.83 to 0.87 mg/L for Asal. The Nubian sandstone aquifer of Queih contains PO_4^{-3} of 0.82 mg/L, while the Duwi limestone aquifer ranges between 0.7 – 0.85 mg/L. The PO_4^{-3} for Queih is higher than other studies [14] in groundwater by up to five times. Higher phosphate concentrations were also recognized near the Um Gheig Pb/Zn mine site of Um Gheig area [27].

Table 2. Major cations and anions in the studied groundwater samples (in mg/L).

Well No	pH	TDS	Mg^{+2}	K^+	Na^+	Ca^{+2}	Cl^-	HCO_3^-	SO_4^{-2}	NO_3^-	PO_4^{-3}
EW1	7.2	5190	28	5.5	606	303	1267	275	578	0.21	0.83
EW2	7.3	4800	38	2.6	752	392	1183	215	457	0.58	0.87
QW1	7.4	4630	34	5.7	564	596	1062	200	813	4.36	0.82
QW2	7.5	3650	30	9.5	508	718	884	140	508	3.11	0.70
QW3	7.1	3820	32	20.3	388	894	746	185	715	0.63	0.85

The enrichment of Na^+ and Cl^- in the Middle Miocene sandstone aquifer of Asal and followed by the Nubian sandstone aquifer of Queih mainly from the leaching of evaporites and shale of Abu Dabbab Formation [4, 11]. The increase of Ca^{2+} over Na^+ of Queih reflects the effect of the Duwi Formation lithology on groundwater.

Table 3. Hydrochemical parameters of groundwater samples in the study area.

Well No.	Ion Sequence	Water Type
EW1	$Na^+>Ca^{2+}> Mg^{2+}/ Cl^->SO_4^{2-}>HCO_3^-$	Na-Ca-Cl-SO4
EW2	$Na^+>Ca^{2+}> Mg^{2+}/ Cl^->SO_4^{2-}>HCO_3^-$	Na-Ca-Cl
QW1	$Ca^{2+}> Na^+> Mg^{2+}/ Cl^->SO_4^{2-}>HCO_3^-$	Ca-Na-Cl-SO4
QW2	$Ca^{2+}> Na^+> Mg^{2+}/ Cl^->SO_4^{2-}>HCO_3^-$	Ca-Na-Cl-SO4
QW3	$Ca^{2+}> Na^+> Mg^{2+}/ Cl^->SO_4^{2-}>HCO_3^-$	Ca-Na-Cl-SO4

5. Conclusions

This study aimed to evaluate the hydrochemical characteristics of groundwater and to investigate the impact of the water–rock interaction on the chemistry of groundwater in Wadi Asal and Wadi Queih, Quseir area, Red Sea, Egypt. The groundwater in the area is neutral. TDS ranges between 3650 to 4630 mg/L for Queih and 4800 to 5190 mg/L for Asal. The Middle Miocene sandstone aquifer of Asal is more saline than the Duwi limestone (3650-3820 mg/L) and the Nubian sandstone (4630 mg/L) aquifers of Queih. Schoeller diagram shows the sequence of major ions in the groundwater in Queih wells in the category $Ca^{2+} > Na^+ > Mg^{2+}$ and $Cl^- > SO_4^{2-} > HCO_3^-$, while Asal has $Na^+ > Ca^{2+} > Mg^{2+}$ and $Cl^- > SO_4^{2-} > HCO_3^-$. The enrichment of Na^+ and Cl^- in the Middle Miocene sandstone aquifer of Asal and followed by the Nubian sandstone aquifer of Queih mainly from the leaching of evaporites and shale of Abu Dabbab Formation. The increase of Ca^{2+}over Na^+ of Queih reflects the effect of the Duwi Formation lithology on groundwater). The phosphate concentration ranges between 0.7 - 0.85 mg/L for Queih and 0.83 - 0.87 mg/L for Asal. The results of this study will assist in identifying and monitoring natural and anthropogenic activities that affect groundwater quality around the Safaga-Quseir District, Red Sea area, progressively altering the quality of the groundwater systems that require supervision by the government.

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