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Hydrogeochemical Characterization and Assessment of Sharm El-Sheikh Ground water South Eastern Sinai Egypt

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Abstract

A total of 35 drilled wells penetrated the Middle and Lower Miocene (MM and LM respectively) aquifers at South Eastern region of Sinai, Egypt are studied to investigate the hydro-geological regime, and the hydrogeochemistry of the groundwater aquifer.The distribution and characteristics of the ions (K^+, Na^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-}) together with heavy metals (Fe, Mn, Zn and Cu) have been used to constrain the groundwater suitability. The results revealed that the pH values are within the neutral range (6.48 - 7. 3) while theTDS ranges from 28016 to 55268 mg/l.The TDS increases gradually north and eastwards due to seawater intrusion. The Cl^- and SO_4^{2-} ions acquired as the higher concentrations of the anions, while Na^+, Ca^{2+} and Mg^{2+} acquired as the higher concentrations of the cations. The high levels of TH and TDS turned the groundwater to beunsuitable for drinking and irrigation purposes. The sea water intrusion and brine water disposed in reject wells are the main sources of high salinity. Moreover, the heavy metal pollution index (HPI) values indicate that, the MM aquifer is uncontaminated with heavy metals while majority of thegroundwater samples of LM aquifer possesses critical contamination with Fe, Mn due to of lithologic source.

Keywords: Groundwater, South East Sinai, Seawater intrusion, Heavy metal pollution index (HPI).

Introduction

Coastal aquifers are generally vulnerable to salinization by seawater intrusion to be turned unsuitable for drinking or even for agricultural uses. Moreover, groundwater can be affected by rising salinity and other undesirable pollutants as heavy metals by the natural geologic processes and/or anthropogenic factors. In this circumstances watershed management is a principal component to gain water resources in arid and semiarid regions for sustainable development. Recently, the South Sinai region attracted the attention of numerous investments in the fields of tourism (marine sports and diving), fishing, medical treatment, agriculture, petroleum exploration, mining and quarrying as basis for local industries. Such activities require a simultaneous strategy for using the water resources since the water scarcity is expected in the upcoming years to be a major issue in Egypt.Groundwater is the main factor, which determine the type, size and location of economic sites for development in the arid Sharm EL Sheikh region as it is of scarce perennial or seasonal water resource. Due to the scarcity of fresh water, desalination Plant in South Sinai is the main source of fresh water. It is based on Reverse Osmosis technology (RO), which requires pretreatment system according to the types and quality of groundwater with regard of the effect of physico-chemical properties of groundwater which govern the performance, quality and quantity of water finally produced from this operation. In general, the using of groundwater wells rather than seawater has a lot of advantages:1). Less

affected by contamination of organisms and different types of bacteria except some anaerobic ones, 2) Constant temperature of groundwater all the time over year, contrast to the seawater having wide range of temperature degree due to seasonal climatic changes, 3) Represent near source of feed water and 4)No need to construct and design several pre-treatment systems.

Therefore, detailed hydrogeochemical study concerning the distribution of the different ions in the groundwater wells and the effect of country rock on the water aquifer is the aim of the present study.

Materials and methods

Study area

Sharm El-Sheikh city lies at the southernmost part of the Sinai Peninsula, near the bifurcation between the Gulf of Suez and the Gulf of Aqaba (Fig. 1). From the morphological point of view, the city is a narrow coastal strip, which is bounded by mountainous chain from the north and the Red Sea from the south. The soil of the area is generally sediments, especially at the coastal areas, which comprisechiefly from Pleistocene and Miocene formations.

Southern Sinai regions vary in climate from arid-tropical, to Mediterranean and to mountain-temperate, due to its long coasts and mountainous nature. It is generally a land of little rain. Sharm El Sheikh town in summer shows a day temperature range of 36º to 39º c, while night temperature range is 23º to 27º c. In winter, the temperature ranges between 22º to 27º c and drops in night to between 17º and 13º c. The humidity increases by the wind that is blow up from Gulf of Aqaba and Red Sea which filled with high moisture to evaporation of seawater surface. The relative humidity usually ranges from 30% to 60 %. The study area occupies about 385 km²of Sharm El-Sheikh city in southern Sinai on the gulf of the Aquaba. It extends from Ras Um Said in the southern part to Napq protectorate in northern part of the city. Geographically, the following coordinates delineate the study area: latitudes 27° 52' 12.2" N and 28° 3' 30.4" N, and longitudes 34° 18' 14 " E and 34° 25' 57.2" E, which penetrated by thirty-five water wells distributed along the coastal line.

The rock units outcropping in study areaat the southernmost part of the so-called Sinai massif are of Precambrian- Quaternary, comprising from oldest to youngest Precambrian granitic rocks, Cretaceous of the Nubian facies sandstones, Miocene, Pleistocene coral reefs and Quaternary sediments (Fig. 2).

The Miocene Formations represent the main water-bearing formations in Sharm El Sheikh area. Its sequence distinguished with low thickness of the successions of sedimentary rocks which settle over the basement rocks at shallow depth. In general, the Miocene succession, in the study area, is divided into two units which represent the two groundwater aquifers; Lower Miocene of sandstone, red shales and lenses of conglomerate and manganese oxides while and Middle Miocene of alternated beds of limestone, sandstone and clay (Mills and Shata, 1989).The is unconfined while the second in confined aquifer. The succession is dipping to southwest with an angle of 22^0 it is 185 m thick at GabalSo frat Deghij in the southern corner of Sinai EGSMA (1994).

Methodology

A total of 35 productive wells were drilled in suitable sites near to reverse osmosis (RO) plant, the almost wells penetrating both the Middle Miocene and Lower Miocene aquifers.The wells are located along the Red Sea coast and clustered at three parts of the study area northern (NP), central (CP) and southern part(SP) as illustrated in Fig. 1. The NP and CP wells penetrate the Middle Miocene (MM) aquifer SP wells penetrate

theLower Miocene aquifer. The wells are equipped with submersible pump discharge water with capacity rates from 25 to more than 80 m³/hour/well with depth ranging from 78 to about 171 m.
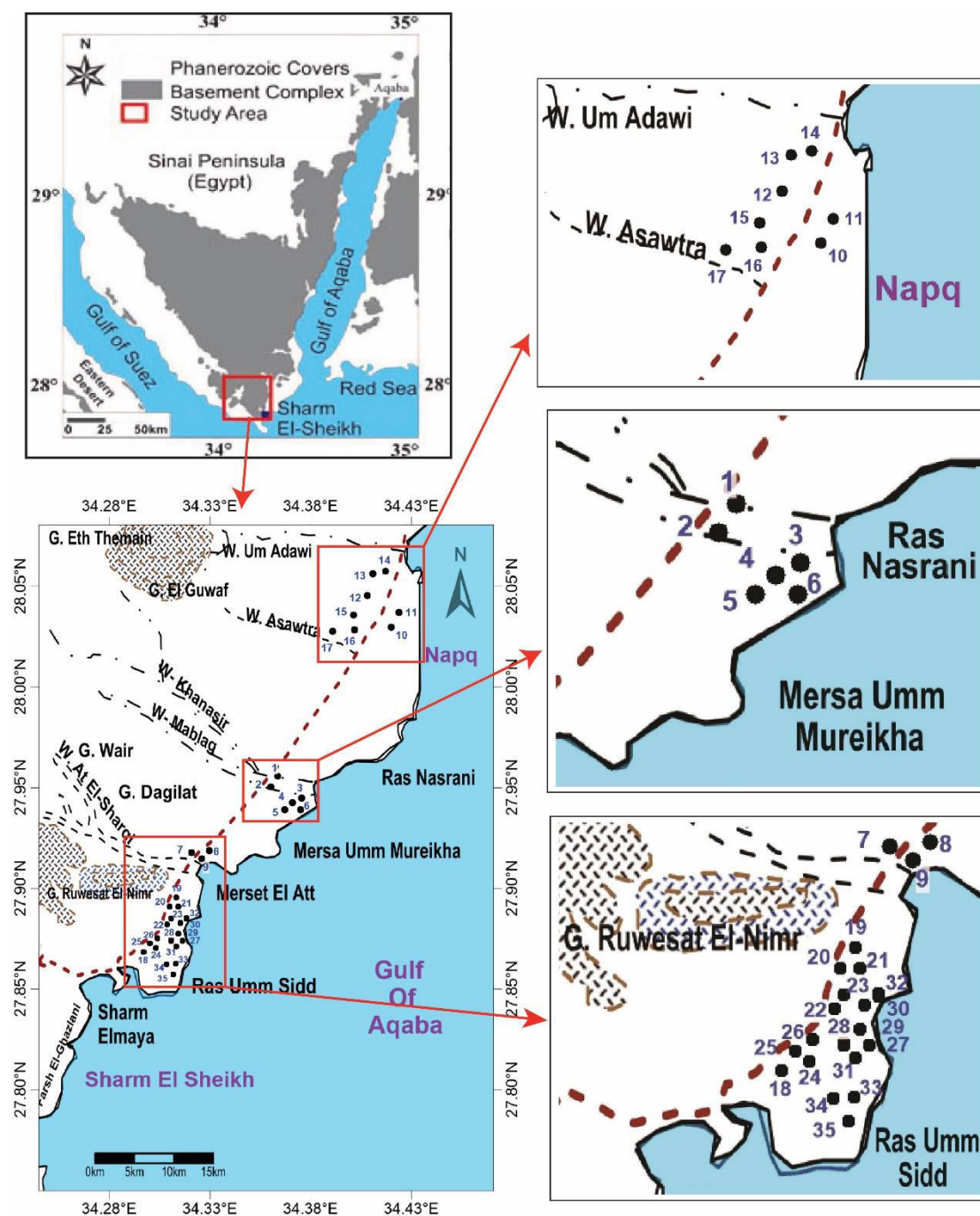

Fig. 1. Location Map of The Study Area and Sites of The Wells.

The chemical analysis of water samples raisedfrom the 35 wells are already in working and ready to collect water samples. The determined parameters and constituents are pH, Electrical conductivity (EC) in micromhos / cm at 25°c. total dissolved solid (TDS) in mg/l and the major cations and anions (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} and HCO_3^-) along with selected heavy metals (Mn, Fe and Zn).

The measurements of temperature, pH and redox potential (Eh) of the water were first carried out in situ. The chemical analyses were carried out in the laboratories of the Matrix Lab. for Water, Wastewaterand Soil Analysis, and in laboratory of Ridgewood for Desalination Company. Geochemical analyses were undertaken using spectrometric and chromatographic instruments calibrated with laboratory standards.

These standards are most accurately prepared by weighing soluble salts and added to weighed or measured volumes of distilled water.

Results and discussion

Physicochemical characterization

The physicochemical parameters of the studied groundwater wells are tabulated in Table 1. The pH valuesof MM aquifer are ranging from slightly acidic 6.7 in the CP to slightly alkaline 7.4 in the NP of study area. For the LM aquifer, the pH values range from 6.9 to 6.48 in the SP. Practically all the studied water is in the neutral range of pH value (6.5- 7.5). For any water to be suitable for drinking and domestic uses, it should be colorless, odorless, tasteless, clear and free from excessive solids. The EC values for the groundwater of the MM aquifer ranges from 54,600 µs/cm NP wells to 76,730 µs/cm in the CP wells except well No. 2, which recorded EC up to 87,600 µs/cm, due most probably to salinization of groundwater by the anthropogenic reject (injected) wells of the residual brine waters (98,000 µs/cm) after desalination process (El Mandour et al., 2007;Herrera et al., 2008). It is may attributed also to the effect of salt marshes and sabkha sediments (halite, gypsum, anhydrite and Mg-calcite), formed within shallow lakes on the tidal flat region of the Nabq alluvial plain at the northern part of the study area (Friedman,1968).For the LMaquifer, at the NP, the EC ranges from 41,200 µs/cm to 66,620 µs/cm in the southern part of the study area with an average of 55,4 µs/cm.
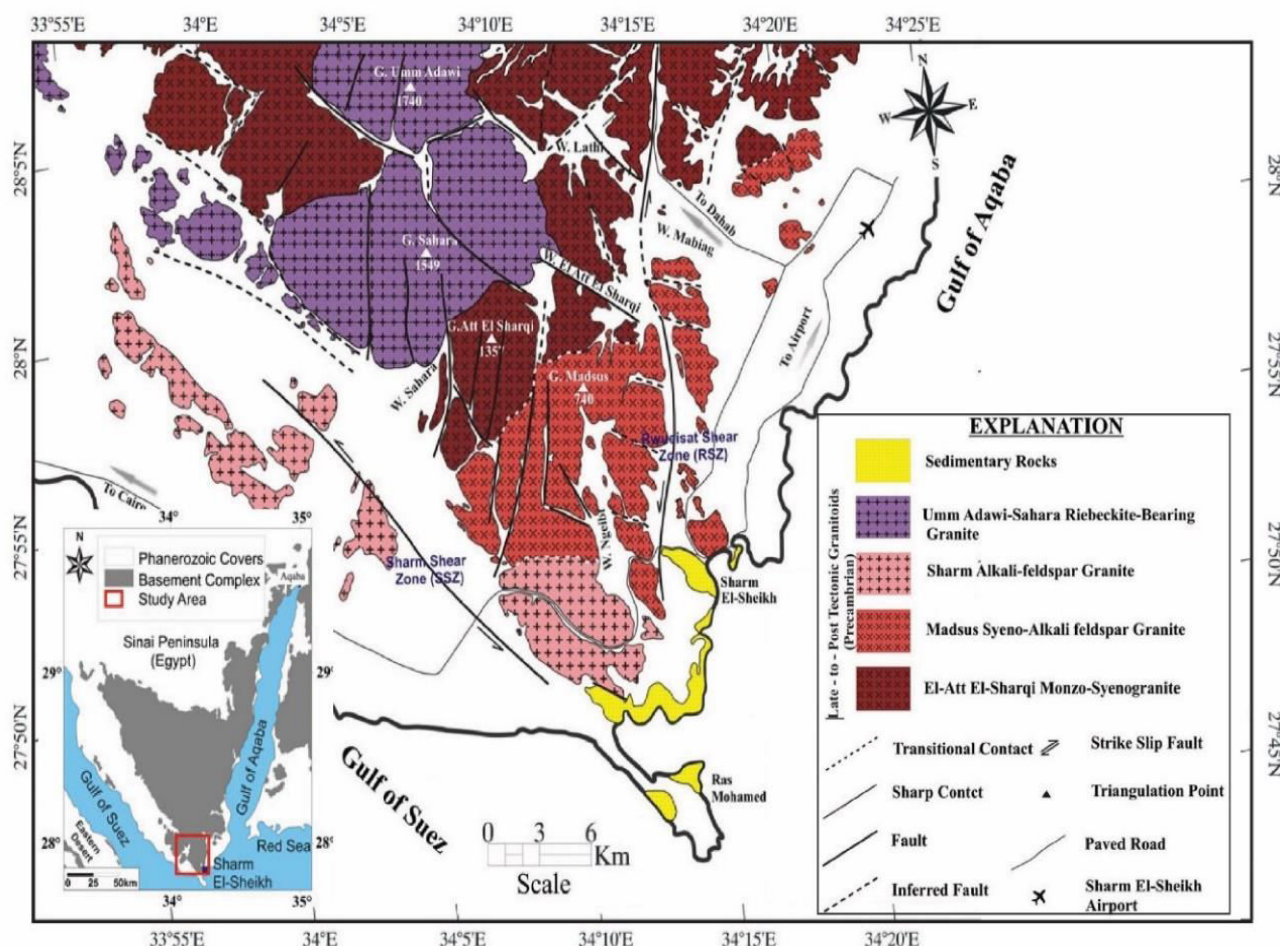

Fig. 2. Geological map of Sharm El-Sheikh area, South Sinai, Egypt, after Sherif et al., (2013).

Table. 1. Physicochemical parameter values, ion concentrations (in mg/l) for each groundwater.

Wells No.	PH	EC	TDS	Ca^{++}	Mg^{++}	Na$^+$	K$^+$	HCO$_3^-$	Cl$^-$	SO$_4^-$	TH	SAR
1	6.98	75160	53799	1267	2123	15760	345	98	29744	4481	11950	62.8
2	6.93	76730	55268	1250	2178	16193	329	107	29887	5345	12188	64.1
3	7.21	68400	47850	600	1903	14521	343	119	26195	4203	9417	65.4
4	7	68800	48125	550	1878	14758	330	110	26564	3951	9188	67.3
5	7.1	70400	49280	564	1856	14560	345	112	26670	4050	9220	66.6
6	7.13	76670	55181	575	2163	16897	396	128	29921	5123	10438	72.3
7	6.77	63210	43805	663	1735	13232	262	120	24110	3716	8875	61.4
8	6.87	63960	44715	640	1248	13706	270	110	25497	3260	6840	63.0
9	6.96	61840	42763	675	1653	12893	260	116	23044	4151	8568	60.9
10	7.23	54600	38220	315	1280	12804	480	80	20240	3514	6231	64.5
11	7.08	55760	38132	490	1460	11596	304	126	20608	3577	7300	59.3
12	7.18	73400	51627	714	2009	15659	436	128	28596	4131	10143	67.9
13	7.3	76480	51870	641	1769	17929	680	92	27065	3101	8910	71.9
14	7.43	87600	62196	686	2283	19262	583	147	34669	4625	11214	79.5
15	7.28	62000	43400	630	1515	13155	361	102	23850	3400	7900	64.8
16	6.92	61050	42186	660	1563	12833	349	111	23306	3396	8140	62.1
17	6.82	61840	42850	1314	1718	11963	352	90	22470	4915	10409	51.1
18	6.92	54190	37132	3037	1435	8687	196	92.2	21568	2112	13518	32.5
19	6.84	50630	34681	1377	1286	9490	202.5	108	18850	2228	8840	44.2
20	6.59	41200	28016	1178	1050	7862	154	106	15865	1793	7327	40.1
21	6.97	45940	30770	1225	1149	8420	170	123	16731	1986	7830	41.5
22	6.87	55720	37791	2943	1442	9003	259	102	21931	2149	13325	34.0
23	6.98	54586	37337	2999	1502	8642	210	109	21230	2657	13720	32.1
24	6.59	58800	41517	3320	1815	9411	345	85.4	24442	2117	15835	32.6
25	6.55	55270	37890	2886	1562	8900	295	116	22208	1939	13690	33.1
26	6.52	59290	40851	3300	1755	9249	346	71	23880	2262	15496	32.3
27	6.86	59980	41386	3186	1674	9790	261	89	24327	2075	14870	34.9
28	6.72	66580	46210	3357	1776	10895	295	95	26984	2778	15690	37.8
29	6.84	66620	45300	3287	1732	10666	310	105	26183	2870	15355	37.5
30	6.87	61940	42878	3120	2067	9684	340	110	24552	3032	16322	33.0
31	6.74	62810	43434	3313	1765	10297	201	134	25069	2685	15573	35.9
32	6.75	62100	43470	3226	1763	10307	347	78	24775	3031	N.D	36.2
33	6.62	46350	31333	2800	1157	7184	171	124	18492	1409	11813	28.8
34	6.92	47200	31448	2825	1192	7142	224	136.6	18769	1167	12020	28.4
35	6.48	49290	33567	2900	1382	7596	161	134	19772	1652	13000	29.1

Resembling that of EC distribution, the TDS in the MM aquifer, varies from 38,132 mg/l to 55,268 mg/l with an average 46,816 mg/l.In the LMaquifer wells laying at the SP, the TDS values are lower than the NP and CP wells where it varies from 28,016 mg/l to 46,210 mg/l. The TDS values are usually used to ascertain whether groundwater is suitable for human consumption. Groundwater with TDS< 1000 mg/l is considered suitable for drinking (WHO, 2011). Spatial distribution map of iso- salinity lines (Fg. 3) shows distinct intervals between wells of the study area. The NP wells are distinguished with increasing in salinity northward near the Napq Protectorate, while CP wells, at the Sharks Bay, exhibit very high salinity groundwater. The SP,at the Umm Sidd Plateau, comprises the vast majority of wells belonging to the LM aquifer and display relatively low TDS values. The extracted wells at CP(El Tower)area are affected with two reject wells near that site which caused increase of salinity of wells No.28 and 29recording 46210 mg/l and 45300 mg/l respectively.

The total hardness (TH) represents the sum of the evaporites (Ca2+ and Mg2+) dissolved in groundwater. The TH values increase southward from MM aquifers at NP and CP wells (6231- 11214 mg/l) to the LM aquifer of the SP wells (6840- 16322 mg/l). National standards set < 500 mg/l as the allowable limit for TH in groundwater for drinking purposes (WHO, 2011).

The plot of TH versus TDS (Fig. 4) shows that, all groundwater samples are saline- hard water to indicating unsuitable water for drinking or irrigation. The increase in groundwater salinity is usually accompanied by a slow rise in reverse ionic exchange, which indicates a cationic exchange that increases the hardness of these waters (Zhu et al., 2008). It has been documented that, long term consumption of extremely hard water might lead to an increased incidence of urolithiasis, pre-natal mortality, some types of cancer and cardiovascular disorders (Agrawal and Jagetai 1997; Durvey et al 1991).
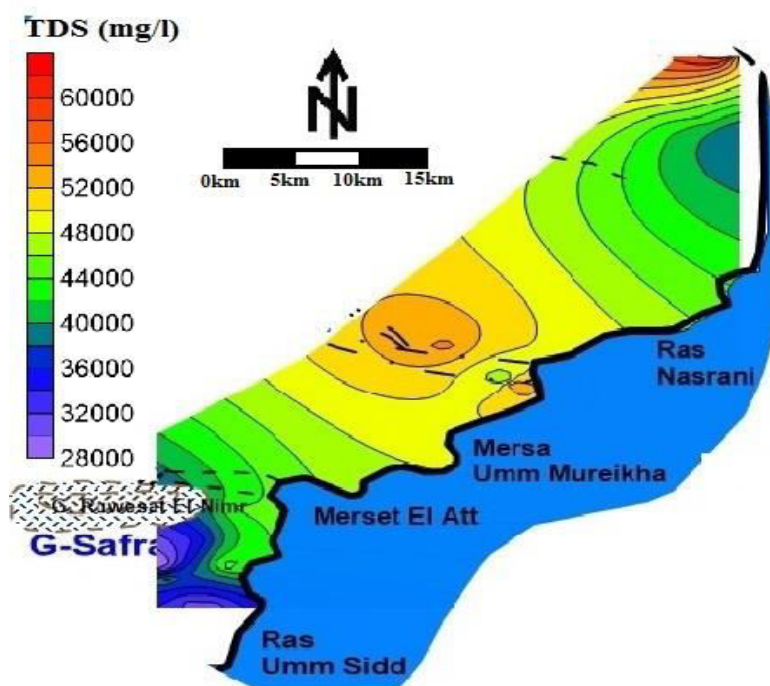
Fig. 3. Iso-Salinity contour map showed TDS distribution through the study area.
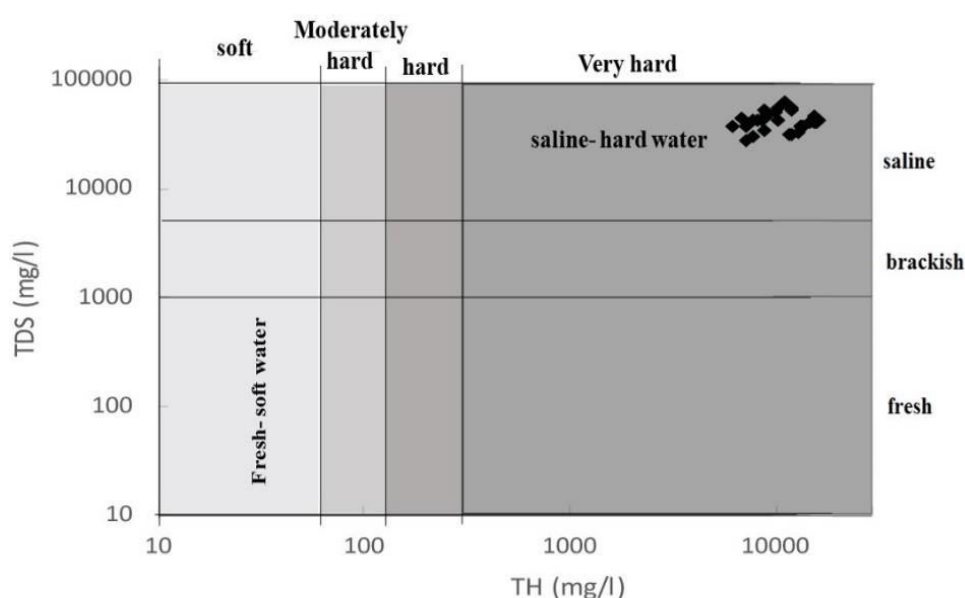
Fig. 4. Groundwater quality classification based on TDS (total dissolved solid) and TH, (total hardness).

Hydrogeochemical characterization
The ionic dominance in the groundwater of the Miocene aquifers follows the following orders: $rCl > rSO_4 > rHCO_3$ /r Na >r Ca >r Mg > r K for Wells No.18, and 22-35 of the LM aquifer SP while

$rCl>rSO_4>rHCO_3$ /r Na >r Mg >r Ca > r K for Wells No. 1-17and 19-21 At NP and CP of the MM aquifer. The K^+ in the groundwater of the MM aquifer ranges from 260 mg/l to 680 mg/l while withLMaquifer it ranges from 154 mg/l to 347 mg/l. The Na^+ content in the MM aquifer ranges from 11596 mg/l to 19262 mg/l while in the LMaquifer range from 7142 mg/l to10895 mg/l.of course, Na >> K where the later is naturally ready removed from groundwater to adsorbed on clay minerals than sodium. The Mg^{2+} content in the groundwater of MM aquifer ranges from 1280 mg/l to 2283 mg/l while in the LMaquifer ranges from 1050 mg/l to 2067 mg/l.The magnesium content is strongly correlated with TDS (Fig.5).Adsorption of Mg^{2+} by clay minerals in near-shore marine environments have been investigated in many studies. Powers, (1957) suggested that diagenesis of such minerals may occur when they are transferred from fresh-water to sea-water by river action.Kelley and Liebig (1934) showed experimentally that a bentonite preferentially adsorbed more magnesium than sodium from sea-water. Hendricks and Ross (1941) suggested that adsorption of magnesium ions was important in the genesis of glauconite in marine sediments which are represented in the area by the Miocene fragments. Moreover, Mg salts are to be concentrated due to its solubility in the rejected brines. The Ca^{2+} content in the groundwater of the MM aquifer ranges from 490 mg/l to1314 mg/l while in the L M aquifer it ranges from 1178 mg/l to 3357 mg/l. The high concentrations of calcium ion in the studied groundwater cause serious problem in desalination process which almost originated from gypsum and under circumstances of temperature and pressure may cause calcium bicarbonate or calcium carbonate scales according water alkalinity. In the MM aquifer, the magnesium ion concentrations exceed of calcium ion which can be attributed to seawater intrusion of high TDS. On the other hand, the LM aquifer contains Ca more than Mg which can be attributed to the most soluble minerals as calcic and dolomitic carbonate and sulphate sediments.
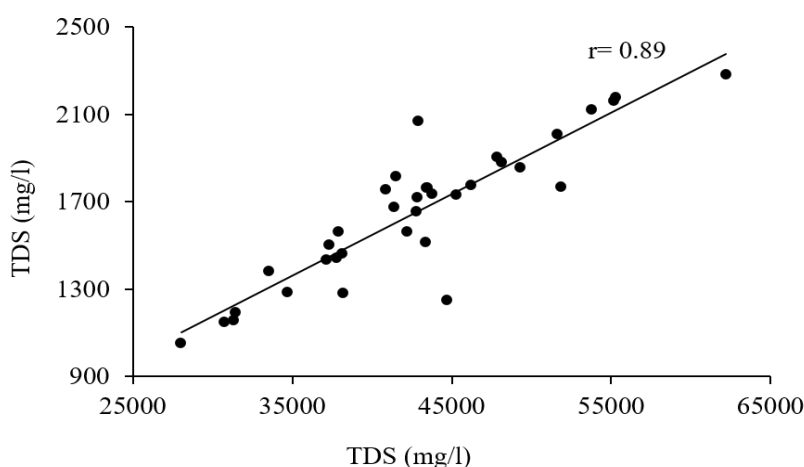

Fig.5. The relationships between Mg^{2+} ions and TDS values of the groundwater.

The Cl^- content in the groundwater of the MM aquifer ranges from 20608 mg/l to 34669 mg/l while in the LMaquifer it ranges from 15865 mg/l to 26984 mg/l. The Cl^- content increases towards the north due to increasing TDS as a result of seawater intrusion.The Na^+ concentration is often used with reference to Cl^+ (Na^+/Cl^+) in surface and groundwater samples to differentiate different sources of salinity. Seawater has a molar Na^+/Cl^+ of (0.85:1) and if Na^+/Cl^+ values which lie above the seawater dilution line, it is indicating that, Na^+ is derived from water-rock interaction related to silicate weathering and cation exchange.The rNa/rClratio (Table 1) is less than unity (0.59- 0.88) in all of the collected groundwater samples which refers to marine water effect and possibly sediments of marine origin. The binary relation between Cl^- and Na^+ (Fig. 6) shows two distinctive correlation fields. Filed A which grouped the groundwater samples of the MM aquifer which characterized by relatively high Na^+ than the ML aquifer samples that grouped in field B. the

relatively high Na$^+$ content may be related to the disposal brine water via reject wells and /or salt marshes and sabkha sedimentat the northern part.
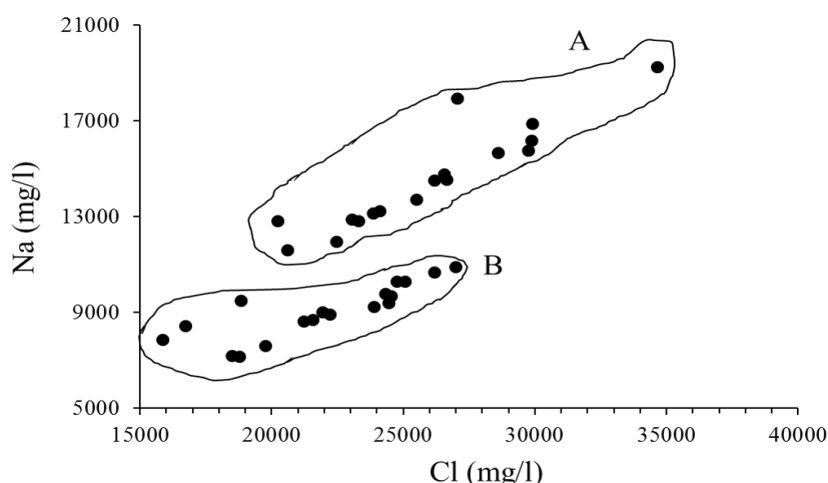

Fig. 6. The relationships between Na$^+$ ions and Cl$^-$ ions of the groundwater.

The SO$_4^{2-}$ content in the groundwater of the MM aquifer ranges from 3396 mg/l to 5345 mg/ while in the LMaquifer it ranges from 1167 mg/l to 3032 mg/l.The ploted of SO$_4^{2-}$vs Cl$^-$(Fig. 7) illustrates storing correlation of most of the water wells. This suggests that their accumulation in the groundwater as a result of a surface common process (evapo-concentration or dissolution of secondary anhydrite).

Groundwater types
The plotted Piper (1944) diagram (Fig. 8) directly reflects the hydrogeochemical characteristics and types of the studied wells showing clearly that, both the groundwater aquifers are dominated by alkali elements (Na + K) rather than alkali earth elements (Ca + Mg). The position of groundwater in the anions triangle indicates that Cl$^-$ is the dominant ion followed by SO$_4$ $^{2-}$. The pattern indicates that, strong acids (Cl+ SO$_4$) dominate the weak acids (HCO$_3$). It is clearly noted that, Cl-Na is the main water type that represents about 90 % of the collected groundwater samples of both the Miocene aquifers. Cl-Na-Ca is a secondary type, which is represented by only four samples collected from the MM aquifer at the NP of the study area.
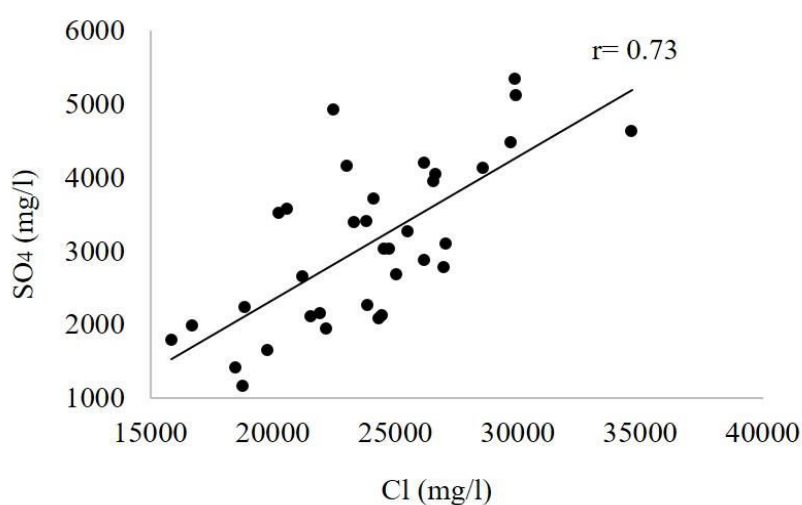

Fig.7. The relationships between Cl$^-$ ions and So$_4$ $^{2-}$ ions of the groundwater.
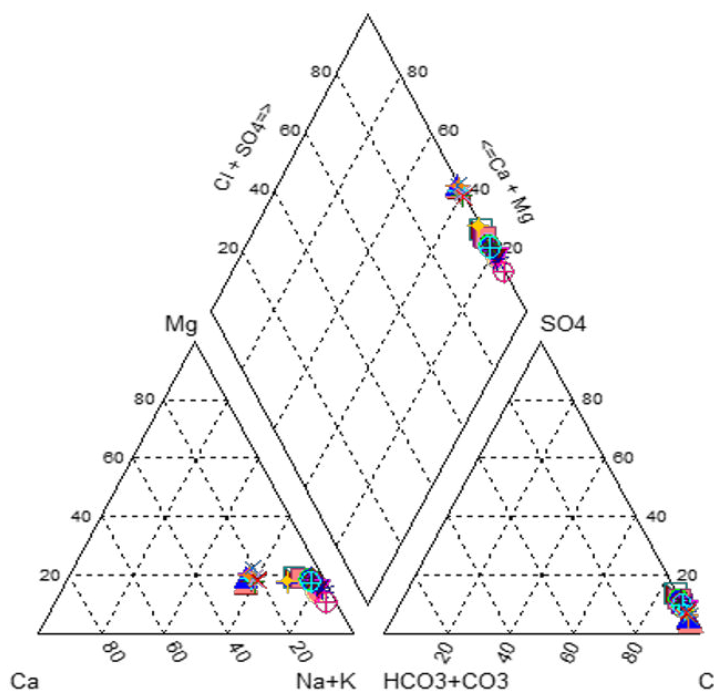
Fig. 8. Piper diagram for the studied groundwater samples.

Sodium Adsorption Ratio (SAR)

The U.S. Salinity Staff's Classification (1954) is used to evaluate the concerned water samples for irrigation purpose. This classification depends on the relationship between the sodium adsorption ratio (SAR) and the electric conductivity (EC) of the groundwater samples.SAR is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops. SAR is calculated by the following formula:

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{Na}{\sqrt{Ca + Mg/2}}$$

When SAR values are greater than 9, the irrigation water will lead to the development of an alkaline soil (Todd 1980), while a high salt concentration in water leads to formation of saline soil. In this study, the SAR values range from 28.4 to 79.5 and as illustrated in Fig .9 all collected groundwater samples indicates unsuitable for irrigation and require high leaching before their usage.

Heavy Metal Evaluation

The studied heavy metal concentrations (Table 2) exhibit different behavior regarding the well locations. Heavy metals based on the average concentration are ranked as;Mn (1.64 mg/l)>Fe (0.95 mg/l)>Zn (0.14 mg/l)>. In the studied groundwater Zn concentration in all samples exhibit values lower than the permissible limit (3.0 mg/l) for drinking water. On the other hand, Fe concentration of 12 well (Nos.1, 2 and of MM aquifer at the central part and 22, 24, 26, 27, 29, 30, 31, 33, 1nd 35 of LM aquifer at the southern part of the study area) which represent 34 % of total samples violate the permissible limit (0.3 mg/l). Moreover, 18 wells (No. 12 of MM at the northern part and all samples of LM at the southern part) which represent 51 % of the studies samples are critically exceed the standard limit (0.1 mg/l). Spatially, (Fig. 10) the groundwater samplesof the LM aquiferat SPdisplays relatively high concentration of Mn (0.01- 7.22 mg/l) and Fe(0.08-5.6 mg/l)those at Np and CP(0.07- 0.2 mg/l and 0.02- 0.09 mg/l) and central parts (0.01- 0.12 mg/l and 0.04-0.39 mg/l) respectively. On the other hand, the wells of the MM aquifer at NP and CP exhibit high content

of Zn (mg/l 0.17 mg/l) exhibit relatively high concentration of Zn than the others. The high concentration of Mn and Fe in the southern part is most probably attributed to the geogenic source of the ferruginous sandstone, red shales and manganese oxides of the LM as well as the Oligocene manganese occurrence recorded by Omara et al., (1955, from Hassaan ,1990). On the other hand, high Zn content in the central part is attributed to the anthropogenic source as a result of rejected wells which contains considerable amount of chemicals that contaminate the surrounding groundwater. Also, it may be related to draining of the recorded polymetal deposits in El Kidarea (Hassaan, 1997)
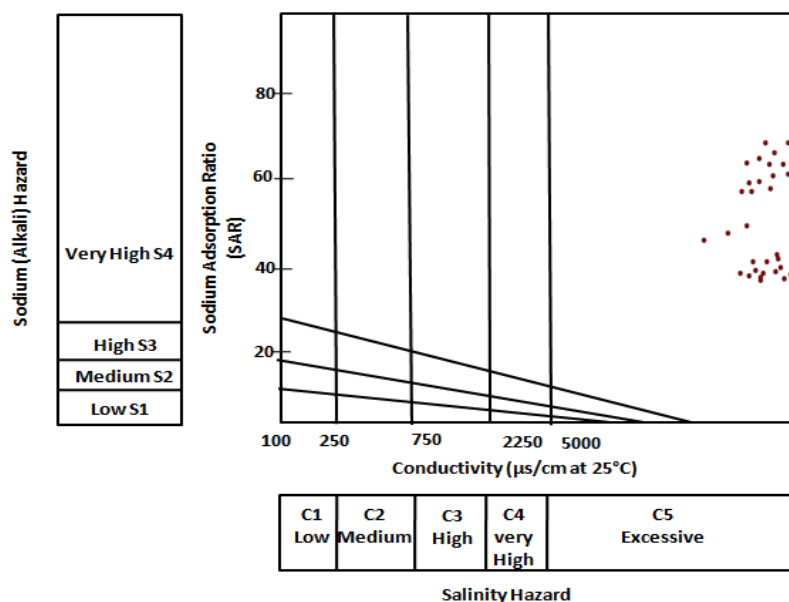

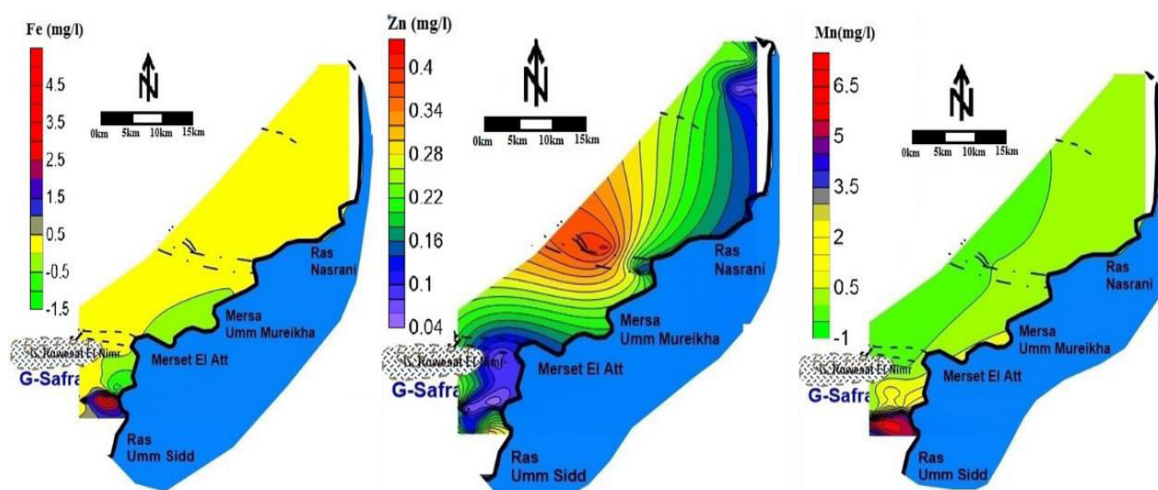**Fig. 9.** Classification of groundwater based on US salinity diagram.

Fig. 10. Spatial distribution of heavy metals in groundwater.

Heavy metal pollution index (HPI)
Different studies (Edet and Offiong, 2002; Prasad and Sangita, 2008; Reza, and Singh, 2010; Prasanna *et al.*, 2012) applied HPIto verify suitability of groundwater for drinking and irrigation based on the heavy metal contents. The HPI is a method of rating thatshows the composite influence of individual heavy metalon the overall quality of water (Prasad and Sangita 2008; Sheykhi and Moore 2012). It is determined using the following equation (Mohan et al. 1996);

$$HPI = \frac{\sum_{i=1}^{i=n} (Q_i \times W_i)}{\sum_{i=1}^{i=n} W_i}$$

Where; W_i is the unit weight of ith parameters, Q_i is the sub-index of the ith parameter, n is the number of parameters considered. In this indexing, weights (W_i) between 0 and 1 wereassigned for each metal. The rating is based on the relativeimportance individual quality considerations and defined as inversely proportional to the recommended standard (S_i) for each parameter.

Weighted arithmetic index method has been used for calculation of HPI. The unit weight (W_i) has been found out using formula:

$$W_i = K/S_i$$

where K is the proportionality constant and S_i is the standard permissible value of ith parameter.

The sub-index of Q_i of the parameter is calculated by:

$$Q_i = 100 * V_i / S_i$$

Table 2: Heavy metal concentrations (mg/l) and HPI for the individual samples.

Well No.	Fe	Mn	Zn	HPI
1	0.39	0.02	0.39	46.7
2	0.15	0.12	0.42	100.3
3	0.36	0.02	0.12	44.0
4	0.14	0.04	0.31	40.9
5	0.04	0.01	0.25	10.8
6	0.09	0.06	0.29	51.5
7	0.39	0.02	0.16	46.5
8	0.09	0.01	0.01	14.6
9	0.09	0.01	0.06	14.7
10	0.09	0.01	0.01	14.6
11	0.04	0.07	0.12	54.6
12	0.09	0.21	0.24	161
13	0.09	0.01	0.01	14.6
14	0.02	0.13	0.17	96.9
15	0.08	0.10	0.01	79.7
16	0.09	0.10	0.01	80.5
17	0.07	0.18	0.19	137
18	0.30	7.22	0.13	5307
19	0.24	1.43	0.17	1066
20	0.22	0.19	0.32	157.2
21	0.08	0.12	0.06	94.4
22	1.50	3.22	0.01	2478
23	0.14	1.99	0.01	1467
24	1.09	4.51	0.14	3388
25	0.11	2.12	0.09	1560
26	3.66	4.25	0.17	3407
27	5.67	3.66	0.29	3139
28	0.41	0.94	0.01	721
29	3.94	0.41	0.01	620
30	1.41	1.98	0.01	1563
31	5.61	3.91	0.01	3317
32	0.08	3.15	0.01	2311
33	1.32	5.49	0.32	4124
34	0.60	4.68	0.10	3473
35	0.80	3.18	0.20	2392
Max	5.67	7.22	0.42	5307
Min	0.02	0.01	0.01	10.8
Average	1.0	1.6	0.1	1268.0

After completion of the result, the concentration of each pollutant was converted into HPI. The higher HPI value causes greater damage to the health. In this study, the S_i value is taken from the Egyptian standards for

drinking water quality (MoHP, 2012). Generally, the critical heavy metal pollution index HPI values are > 100. The concentration and the calculated HPI are presented in Table 2 and the details of the calculation are presented in Table 3. The calculated HPI values indicated that, the groundwater samples of the MM aquifer(excepttwo samples 2, 17) found to be below the critical pollution index value of 100 (Fig. 11) while the all LMaquifer wellsare considered highly contaminated with studied heavy metals and unacceptable for drinking water which are far higher than the critical limit.
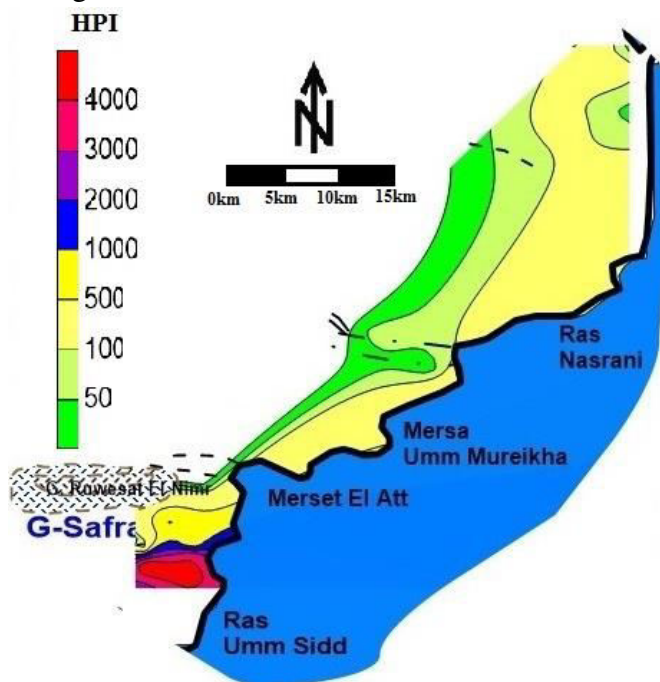

Fig. 11. Spatial distribution of HPI in groundwater.

Table. 3. Calculation of HPI of groundwater in the studied area.

	V_i (mean Con. In mg/l)	S_i	W_i	Q_i	W_i*Q_i
Fe	0.95	0.3	3.3	316.9	1056
Mn	1.64	0.1	10.0	1643	16432
Zn	0.14	3	0.3	4.7	1.6
	0		$\sum$ 13.7		$\sum$17490
Mean HPI Value = 1280					

Conclusion

The hydrogeochemical investigation of the groundwater from the Lower and Middle Miocene aquifers in Sharm El Sheikhregion, southeastern Sinai, Egypt reveals the following:

- The majority (up to 90 %) of the groundwater wells are mainly Cl-Na water type.
- The TDS ranges from 28016 to 55268 mg/l and increases gradually north- and eastwards while the TH ranges from 6231 to 16 322 mg/l and increases from the northern to the southern part via the central part.
- The extremely high values ofTH and TDS turned the groundwater to be unsuitable for drinking and irrigation purposes.
- Cation exchange reactions via seawater intrusion exceeds the Ca^{2+} and Mg^{2+} contents in groundwater aquifers particularly of the Lower Miocene aquifers at the southern part whereas dissolution of carbonate minerals in the recharge area increases Ca^{2+} and Mg^{2+} contents.

- Regarding to heavy metals contamination, Mn and Fe of the most studied samples of the Lower Miocene aquifer at the southern part exceed the permissible limits of drinking water.
- It can be concluded that, geological setting, seawater intrusion and rejected wells by brine water are the main factors that impact the groundwater quality in the Sharm El-Sheikhregion.

Acknowledgments

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