

Study the chemical characteristics of groundwater to determine the suitable localities desalination processes in the area between Mersa Alam and Ras Banas, Red Sea Coast Eastern Desert, Egypt

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Abstract: Egypt is characterized by an arid to semi-arid climate and its population is increasing at an annual rate. With such population growth rate and fast social-economical development, water demand and waste water production are steeply increasing, and the gap between water supply and demand is getting wider. The fast growing development in Egypt has required big movements of investments and people from the Nile Valley towards the east, with the fantastic Red Sea coastal zone, that has promising brackish groundwater potentialities. Fresh water supply is essential and desalination is a feasible option that can cover the wide gap between the available capacities and the accelerating demands. A major misconception in the design of membrane water treatment facilities is that if a groundwater source is used to feed the plant, chemical characteristic of water will be relatively stable with time. There are wide variations in the groundwater chemistry caused by pumping aquifers based on the local geology and hydrology. Modeling of these possible water chemistry studies should be accomplished prior to the final design of any membrane treatment facility. The primary geologic controls on groundwater chemistry within a subsurface aquifer system are the natural barriers which control the vertical inflow of water from adjacent aquifers containing water with different chemistries. This water chemistry change is caused by mixing of the leaked water with the seawater contained in the study area. Due to the complexity of groundwater chemistry, it is classified into several factors, these factors based on the total dissolved solids (TDS), hardness, the concentration of major, minor and trace components. The results of the analysis of water samples collected from the area of study show wide ranges of TDS (439-46341 mg/l), total hardness (236-14371 mg/l as CaCO₃) and chloride concentration (84-26664 mg/l). Also, the presence of metals such as iron and manganese is observed. Moreover, according to chemical characteristics of the groundwater, best sites for possible desalination projects were selected.

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1. Introduction

Needs of drinking water with good chemical quality are clearly increasing around the world and especially in Egypt. Egypt confinement governorates suffer from a big shortage of water resources. In a previous study [1], the problem has been resolved for North Sinai and South Sinai governorates. Meanwhile, the problem still exists for the Red Sea governorate which is considered a tourism attraction. In order to secure fresh water demand for this arid area, desalination concept has to be widely utilized. Desalination is currently being practiced in the Red Sea coastal area to supply tourist villages and resorts with adequate domestic water [2]. Desalination started in Egypt more than 100 years ago, its main objective at that time, was to produce fresh water for domestic use for areas far from the public water network, however, Egypt began to apply advanced desalination technologies in the mid seventies as a result of the

continuous population growth and the urban expansion along the coastal zone and in remote areas, which increased pressure on the existing water resources [3]. Simultaneously, the membrane processes meet a large expansion in desalting of brackish and seawater for the two last decades. The development of new membrane materials with enhanced permeation properties have give rise to numerous works focusing their attention on salt rejection and water flux improvement, fouling, limitation and ion transfer modeling for process optimization.

A major factor in the design and operation of any membrane treatment facility is the feed water chemistry. The water chemistry must be assessed prior to the design of a successful membrane treatment facility. Surface water sources are usually avoided because of their inherent instability, including both seasonal variation in chemistry and variable

particulate and organic debris content. Groundwater sources are preferred because of apperceived long-term water chemistry stability. The assumption of absolute stability of feed water quality from a groundwater source is not valid. The hydrogeology of the aquifer system in the vicinity of and around the well field site controls the future changes in the chemistry of the feed water.

The target of this study included survey of all water points in the area between Mersa Alam-Beranice, Red Sea governorate, to evaluate the chemical characteristics such as TDS, hardness and ion ratio of groundwater and how to select the appropriate sites for possible desalination projects to overcome water shortage, especially during summer.

2. Materials and Method

2.1. Sampling

In order to evaluate the seasonal variations in chemical compositions, fifty two groundwater samples were collected during April 2011. The collected water samples were selected from wells adjacent to Red Sea (within 50 km) at a depth of 6 to 150 m. The samples were stored in new one-liter HDPE bottles at a temperature below 4°C before analysis. For sample collection, preservation, and analysis, standard methods [4-8] were followed. The analyses were carried out by the authors at the laboratory of Hydrogeochemistry Dept., Desert Research Center (DRC). EC and pH were measured in the field immediately after the collection of the samples. Before each measurement, the pH meter was calibrated with a reference buffer solution of pH 4. Alkali metal ions (Na^+ and K^+) were measured using a flame photometer (Jenway PFP 7). Silica content was determined by the Molybdate Blue method using a UV-visible spectrophotometer. Total dissolved solids (TDSs) were computed by multiplying the EC (ds m^{-1}) by a factor of 640 [9]. Ca^{2+} and Mg^{2+} were determined titrimetrically using standard EDTA. Chloride was estimated by AgNO_3 titration. Turbidimetric technique was used for the analysis of sulfate [10]. Standard solutions for the above analysis were prepared from the respective salts of analytical reagent grade. Heavy and trace metals were analyzed by inductively coupled plasma method. The obtained chemical data are expressed in milligram per liter (mg/l) or part per million (ppm). The results of all chemical analyses are listed in tables (1 & 2).

3. Results and discussion

3.1. General features

The area of Mersa Alam-Beranice is located in the severe arid belt of Egypt where the rainfall is very scarce except some intermittent floods which occur every several years, (Fig. 1). To achieve development of this part, the first thing to be attended is the water supply.

Groundwater is considered the only available source for water supply besides flash floods which act as recharge source for groundwater in some parts [11].

3.2. Geomorphologic and geologic settings

Figure 2.a [12] suggested that the main geomorphologic units in the area under investigation as following:

- 1- Red Sea Coastal Plain comprises gently rolling northwest-southeast strip, stretching parallel to the Red Sea coast. This strip is slightly higher than the Red Sea level and varying between 20-196 m above sea level.
- 2- The eastern hilly area consists of table lands contain low lands such as the Red Sea-side drainage basins and the inland sandy plains.
- 3- The watershed areas consisting of the following:
 - A. The Red Sea mountainous terrain, main watershed area. It consists of igneous and metamorphic rocks and sometimes sedimentary rocks. The width of masses varies between 60 and 160 Km or more; increasing towards south. These masses are rugged and characterized by elevations up to 1978m above sea level as in Gebel Hamata [13].
 - B. The western sandstone table lands. These low land plain are Abu Ghoson and Beranice depressions.

Geologic setting studied through the aquifer material tends to control the type of chemical composition changes in the water yielded to the wells. There are two geologic and hydrogeologic settings in the study area posses some suitable properties to form groundwater aquifers, as shown in Figure 2. b [12]. The first is the Quaternary alluvial deposits that act as main resource for groundwater in the area extending along the coastal plain of the study area. Such deposits consist of beach sand and gravel with silt and clay intercalations and fragments of materials of basement origin. Its maximum thickness attains about 15m. The groundwater, along this plain is present at shallow depth due to salt water intrusion, elevation of ground surface with regard to sea level and dominance of salt marshes due to excessive evaporation. The aquifer system is widely distributed in the area; covering most of wadi floor. The second aquifer is the fractured basement which is formed from igneous and metamorphic rocks that crop out at the western part of the area. These rocks are highly and strongly weathered, jointed and faulted. Intersections of some dykes are present acting as barriers against groundwater movement.

The accumulated amount of water depends upon the depth, width and extension of fractures, where the water quantity is frequently limited but acts as water supply for local population. A fluctuation in water salinity is observed during seasons. Maximum

water salinity is attained at the end of summer season and before the beginning of the next time of rainfall. The population depends on this aquifer for drinking water due to low salinity.

3.3. Chemistry of groundwater in the study area

The chemistry of groundwater is shown to be strongly related to the physical, chemical and mineralogical properties of the rock deposits, and controlled by recharging sources (atmospheric, surface runoff, subsurface flow and marine water) as well as, surface geochemical processes affecting water chemistry during circulation.

3.3.1. pH of groundwater in the study area

The desalinated water is very corrosive and is "stabilized" to protect downstream pipelines and storages, usually by adding lime or caustic to prevent corrosion of concrete lined surfaces. Liming material is used to adjust pH between 6.8 and 8.1 to meet the potable water specifications, primarily for effective disinfection and for corrosion control. In the study area, pH ranges from 7.46 to 9.14 with mean value 8.32. The selection of water point must be chosen according to suitable value of pH. Where, the high value of pH increases scaling by carbonate in membrane of desalination process and the lower value causes corrosion

3.3.2. Water salinity

TDS is the main factor affecting desalination process, where TDS is formed of the salts of major cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and anions (SO_4^{2-} , Cl^- , HCO_3^- and CO_3^{2-}). The major cations and anions concentrations are responsible for the TDS level. Low TDS value is favorable in the desalination process. This means that, the slightly brackish or brackish water sites, which represented by 32% in the area of study, are the best localities for the desalination projects upon the other sites. Also, the types of major cation and anion are affecting on the desalination process where the reject of multivalent ions are greater than the monovalent ions. So, the selection of borehole or water point depends on the type of water and favorite the TDS related to multivalent ions [14]. Based on the TDS levels, the water salinity in the study area are classified to 4 % fresh, 32 % brackish, and 64 % saline water types (Fig. 3) [15]. The fresh water type is found in the fractured basement aquifer, while the saline water type is found in most Quaternary and Fractured basement aquifers. Another classification according to chloride concentration showed that, 58%, 23%, 11% and 8% of the samples are brackish-salt, salt, hyper-saline or brine and fresh to brackish, respectively [16].

Table 1 shows also that the concentration of major cations and anions are changed widely with average values of 1139 ppm, 842 ppm, 4328 ppm, 158 ppm, 2165 ppm and 9274 ppm for Ca^{+2} , Mg^{2+} ,

($\text{Na}^+ + \text{K}^+$), ($\text{HCO}_3^- + \text{CO}_3^{2-}$), SO_4^{2-} and Cl^- concentrations, respectively. The high concentration of chloride ion is accompanied by decreasing in bicarbonate concentration with enrich of sulfate concentration (Fig. 3). This is referred to leaching and dissolution of soluble salts through surface runoff during the groundwater movement from upstream to downstream (toward the Red Sea). In addition to that, the high salinity of groundwater of fractured basement may attributed to leaching and dissolution of water bearing formation of meta-sedimentary rocks of wadi Om El Abasy and successive pumping activities of Quaternary aquifer near the shore line which may lead to salt water intrusion or leaching, dissolution and cation exchange [12].

Moreover, water quality parameters in 96% of the samples shown in the same table exceed drinking water guidelines, in particular, the salt composition indicates a brackish and saline to extremely saline water nature of the majority of borehole [14].

3.3.3. Total hardness.

The solubility of calcium and magnesium salts in natural water is responsible for forming the so-called water hardness. Actually, the total hardness in the natural water occurs due to different types of salts such as CaCO_3 and CaSO_4 . Hardness is an important factor affecting the performance of desalination process, where the increase in Ca^{2+} , Mg^{2+} and HCO_3^- ions concentrations give high scaling which reduce the water flux. So, when choose the water points the samples must have low concentration of Ca^{2+} , Mg^{2+} and HCO_3^- ions or before desalination process these ions must be removed by soften in pretreatment.

According to the chemical analysis of the Quaternary groundwater samples, (Table 1), it is clear that the mean value of total, permanent and temporary hardness reaches 7093, 6099 and 103 mg/l as CaCO_3 , respectively. On the other hand, in fractured basement aquifer the mean value of total, permanent and temporary hardness reaches 3063, 2802 and 261 mg/l as CaCO_3 , respectively. These data indicate an increase in total and permanent hardness with increasing of water salinity. This is mainly attributed to the effect of leaching and dissolution of soluble salts leading to the increase of hardness with particular importance to the effect of NaCl concentration (effect of ionic strength) on increasing solubility of Ca^{2+} and Mg^{2+} [15,17]. Also, the results of the total hardness indicated that all samples of the study area are very hard and needed pretreatment before the desalination processes to protect the membrane from the effect of scaling, which decreases the water flux [18].

3.3.4. Ion dominance

A. Piper diagram

Piper diagram provides a convenient method to classify and compare water types based on the ionic

composition of different water samples [19-21]. Piper trilinear diagram shows that the groundwater is characterized by Na-Cl (83% of total samples) type (Fig. 4). These results reveal the relatively polluted nature of groundwater recharged from surface run off through leaching and dissolution processes. While 15% and 2% of the total samples are represented by Ca-Cl₂, Na-HCO₃, respectively. These types of groundwater are affected the salt rejection and water flux during the desalination processes [22].

B. Stiff diagram

The cation and anion concentrations are connected to form an asymmetric polygon known as a stiff diagram, where the size is a relative indication of the dissolved-solids concentration [23]. Figure 5 reflects that groundwater in the study area can be represented and divided into three main groups as follow:

- Group I: Samples characterized by Na-HCO₃ water type. Such type is present in fracture basement (2%) and is an indication to rainwater origin of groundwater.
- Group II: Samples of higher Na-Cl water type (83% from total samples) are present in Quaternary (79%) and fractured basement (4%).
- Group III: Samples characterized by the lowest ion concentration with Ca-Cl water type. This water type is present in Quaternary (5%) and fractured basement (10%).

Based on these models of the Ca-Cl water type present in (15%) of total samples and is the best for desalination process followed by the Na-HCO₃ (2%) and then the worst Na-Cl (83%).

3.3.5. Minor and heavy metals

A. Silica

The problem of increasing silicate in water samples not only affect the human health but also, the higher probability of forming silicate scaling which will harm a lot the membrane elements resulting in shortage lifetime [22]. The distribution of silica in the study area shows a range from 0.3-35.58 mg/l with an average of 10.1 mg/l, as shown in Table 2. The high concentration of silica may be due to the effect of leaching and dissolution processes of silicate salts present in basement rock.

B. Iron and manganese

Iron and manganese ions concentration in the Quaternary aquifer groundwater ranged between 0.02 and 3.67 mg/l and 0.01 and 2.26 mg/l respectively, while in the fractured basement aquifer, their concentrations are higher and ranged between 0.02 and 7.02 mg/l and 0.01 and 10.8 mg/l respectively. This is due to the enrichment of feldspars rich in the water bearing basement rocks. So, the chance of water points suitable for desalination is in low limit < 1 ppm or a

pretreatment process for high iron and manganese must be done [22].

C. Phosphorous

Phosphorous affects desalination processes by superior over the polymer antiscalants, [22]. Phosphorous concentration in the Quaternary aquifer has a wide variation. It ranged between 0.002 and 4.25 mg/l, while in the fractured basement aquifer, the concentration of phosphorous ranged between 0.002 and 53.5 mg/l. This can be explained by the effect of fecal pollution.

D. Strontium

The concentration of strontium ion in the Quaternary aquifer has a wide variation as shown in Table 2. It ranges between 4.58 and 66.17 mg/l, while in the fractured basement aquifer, this concentration ranged between 0.19 and 27.9 mg/l. Sr and Ba are always associated with calcium scales over the full range of proposed water types in spite of the concentrations of Sr and Ba which are above the saturation level in many cases. Such observation is in full agreement with the geochemical affinity concept of mineral formation theory [24]. At pH 10 precipitation of all of carbonate, bicarbonate and sulfate of Ca, Mg, Ba and Sr, in addition to a limited part of MgCl₂ took place, so the choose of samples close to this value should be considered [25].

E. Strontium/calcium rate

The dosage of strontium is significant because it indicates the evaporate formations. Calculated Sr²⁺/Ca²⁺ ratios vary between 1.99% and 22.68%, revealing different origins of salinity. Some authors [26, 27] highlighted the existence of a direct link between the evaporate formations and the salinity of water. The calculation of Sr²⁺/Ca²⁺ ratios for the area determined the classes of Sr²⁺/Ca²⁺ under or up percent using the evaporate salinity. By studying Sr²⁺/Ca²⁺ ratios for the groundwater samples in the study area, two categories of water are identified:

The first is characterized by Sr²⁺/Ca²⁺ ratio varying between 1 and 3%. It is situated in the two samples (No. 50 and 51) of the fractured basement aquifer, the salinity may have several origins: marine, or dissolution of the evaporate formations. The second important category is the values of Sr²⁺/Ca²⁺ greater than 3%. The ratio values confirm the effect of the evaporitic formations on the salinity of water. The study of the Sr²⁺/Ca²⁺ ratios show that the evaporitic formations are the origin of salinity in the study area. i.e. The strontium confirms the aquifers influence by evaporitic formations.

3.3.6. Origin of groundwater mineralization

The Na⁺-Cl⁻ couple in natural water is often related to the dissolution of halite (Na-Cl). Na⁺ evolution is studied according to the chloride contents because it is considered as a conservative tracer and its

displacement is not deferred in the water runoff. In Figure 6a, the samples of Quaternary aquifer show that the distribution of Cl^- and Na^+ is on distinct which show a tendency of the points to align. However, the sodium pole does not dominate due to the heterogeneous origins of the Na^+ and Cl^- concentrations. On the other hand, the samples of the fracture basement aquifer show not distinct pole, (Fig. 6b). This distribution is produced by factors such as climate (evaporation) and the clayey matrix. The interaction between these factors by dilution contributes to enriching the water.

The relation of $(\text{Ca}^{2+}/(\text{HCO}_3^- + \text{SO}_4^{2-}) - \text{Na}^+/\text{Cl}^-)$, in the Quaternary aquifer shows that the majority of samples is in equilibrium state, while others are submitted to base exchange or calcium excess (Fig. 7a). In Figure 7b, the samples of fractured basement aquifer show no trend. This means that, both aquifers are not chemically governed by the same factors. The Ionic Exchange index is more important in the Quaternary aquifer.

Thus, it can be concluded that groundwater of quaternary aquifer is chemically controlled by the climatic condition, the aquifer condition, the sea water as well as clay matrix in the following manner:

1. The drought increases drop in water levels and evaporatrnspiration and both causes an imbalance between inflow and outflow in the system.
2. The clay activates the ionic exchange processes between calcium and sodium.
3. No evidence for the effect of Red Sea, where all samples belong to the evaporate water domain.

On the other hand, to explain the possible influence of limestone, clay, and sand in the concentrations observed in Quaternary and fractured basement aquifers, the graphs Ca^{2+} versus HCO_3^- and $\text{HCO}_3^- + \text{SO}_4^{2-}$ are used to examine the origin of calcium with regard to the bicarbonates and sulphates. These two chemical anions indicate two principal origins, the carbonates and the gypsum.

For Quaternary aquifer, the graphic representation of the evolution of calcium with regard to bicarbonates, Fig. 8 (a and b) illustrates two tendencies. The first tendency, where some points align themselves, showing a carbonated origin of calcium's ions and a second tendency, where the majority of the samples show an excess of calcium contents, indicates the probable dissolution of gypsum. These can be controlled by the shallow depth of groundwater (static level varies between 1.5 and 22 m); the nature of the aquifer (major sand constituent); and water recharge by wadis.

In the fractured basement region, the elaborated diagram, Fig. 9 (a and b) shows two identical tendencies. However, the carbonated pole is very distinct, indicating recharge from the massif of

marbles and shows the calcium pole presenting calcium excess. The majority points aligned along the downright are the result of the dissolution of carbonated formations or evaporation process. Water from Fractured basement shows some additional points aligned upright. This well-marked carbonated pole demonstrates the dissolution of the carbonated formations (marbles).

The lithology of the sediments is dominated by limestones and dolomites, while deposits are marly limestones with evaporitic levels. Hence, the dominant major ionic species in water are HCO_3^- , Ca^{2+} and Mg^{2+} . The Ca+Mg/alkalinity report ranges from 0.4 to values up to 122. Water with similar characteristics is mainly controlled by the carbonate dissolution (Hendry and Was-senaar 2000). Waters with a Ca+Mg/alkalinity report from 0.8 to 1.2 are influenced by carbonate and evaporate minerals dissolution. But waters with high values suggest that Ca and Mg mainly originate from evaporate minerals dissolution. This means that all samples are affected by evaporate minerals.

The interpretation demonstrates that salinity in Quaternary aquifer is related to the dissolution of evaporite formations, the carbonated formations, and the cations exchange. But in fractured basement aquifer, the dissolution of carbonates or evaporation is more important. It also explains the relationship of chemical elements in the waters of the region. Cation exchange constitutes one of the sources of the water's salinity.

3.3.7. Sea water intrusion

As the study area is in the coastal area, it is presumed that the marine influence on groundwater quality is also important. The marine influence is characterized by high chloride content which is well identified in some of the wells tapping to the Quaternary aquifer. In a strict sense, alkalinity can also be influenced by seawater. However, the change is only minor, if any, because alkalinity is negligible relative to the total cation in seawater (0.4% in equivalent ratio) [28]. The plot of total cations versus chloride illustrates the seawater influences as well in Fig. (10). In this plot, many of the aquifer waters are plotted along the seawater mixing line. The upward deviations from the mixing line seem to be caused by other chemical reactions providing cations without changing chloride concentration.

A most likely cause for such cation release is mineral weathering. Because of the seawater influence, it is likely that the chemistry of different aquifers is highly affected by cation exchange. Ion exchange between Na and Ca often occurs in groundwater of coastal aquifers [29, 30] and is explained by the relation between $(\text{Ca}+\text{Mg})-(\text{Alk}+\text{SO}_4)$ and $\text{Na}-\text{Cl}$ Fig.. (10). If cation exchange is a significant groundwater composition controlling

process, the relation between these two parameters should be linear with a slope of ≈ 1.0 [31]. Fig. (11) illustrates that, the groundwater of Quaternary aquifer define a straight line ($R^2=0.81$) with a slope of 1.39, suggesting that Na, Ca and Mg are involved in the ion exchange reaction. Therefore, the chemistry of Quaternary aquifer waters that is highly affected by seawater is also influenced by cation exchange. In the case of the fractured basement aquifer, such a good linear relationship between $(Ca+Mg)-(Alk+SO_4)$ and Na-Cl is minor or absent, suggesting that cation exchange process is not dominant.

3.3.8. Evaluation of groundwater quality for human drinking

According to the total dissolved solid, 96% of the total groundwater samples of Quaternary aquifer are unsuitable for human drinking. This aquifer is the target for the extension of the reclamation area. With regards to heavy metals, Cd^{2+} , Cu^{2+} and Pb^{2+} concentrations are less than the permissible limit for drinking (0.003, 2.0 and 0.01 mg/l, respectively) for all the investigated groundwater samples.

The concentration of iron and manganese in the investigated groundwater samples exceeds the maximum recommended limit of drinking water (0.3 and 0.05 mg/l, respectively) and most of the samples in the study area have values of phosphorous concentration higher than the permissible limit for drinking water (1.0mg/l).

3.3.9. Evaluation of groundwater quality for drinking of livestock and poultry

Water is involved in every aspect of poultry metabolism. It plays important roles in regulating body temperature, digesting food, and eliminating

body wastes. Excessive salinity in livestock drinking water can upset the animal's balance and cause death.

According to McKee and Wolf,[32] and based on TDS values, the suitability of the collected samples for livestock drinking is given as: 4% of the total samples have excellent class, 4% very satisfactory, 11% satisfactory and 81% have risk class.

In conclusion, all groundwater samples of the studied area are unsuitable for human drinking, while some groundwater samples are suitable for livestock drinking. The quality of water varies greatly depending on lithology variation, rate of recharge and the influence of salt water encroachment.

So, from the geochemical characteristics of the groundwater in the study area, it is clear that most groundwater suffers from the problem of high salinity that is unsuitable for the drinking of human, livestock and poultry. Reverse osmosis desalination process of such groundwater might be the essential solution to overcome such problems. With regard to the previous discussion, and to select the best localities for the desalination process, the following items must be taken into consideration:

- 1- Groundwater points with lower and constant TDS value over time are favorable.
- 2- Groundwater wells with lower depth to water value are favorable from the economical point of view.
- 3- Wells of high production of the feed water (m^3/h) are needed.
- 4- Water points of $Ca-HCO_3$ chemical type and with low iron and silica is the best to choose.

Figure 12 represents a zonation map of the best sites for the desalination plant on the area of study.

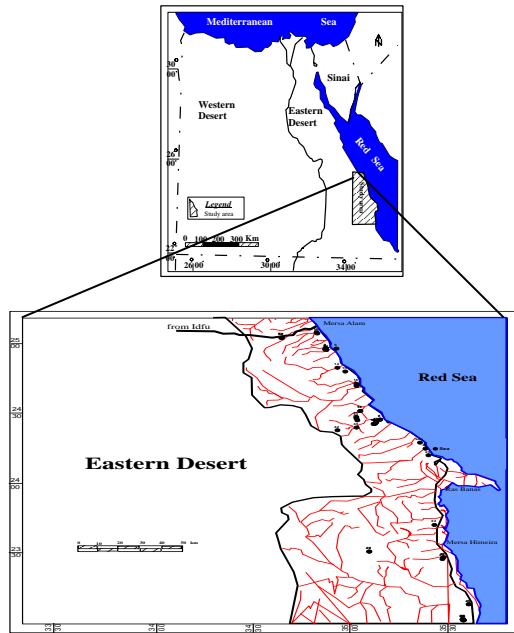


Figure 1. Study area and well locations of groundwater samples.

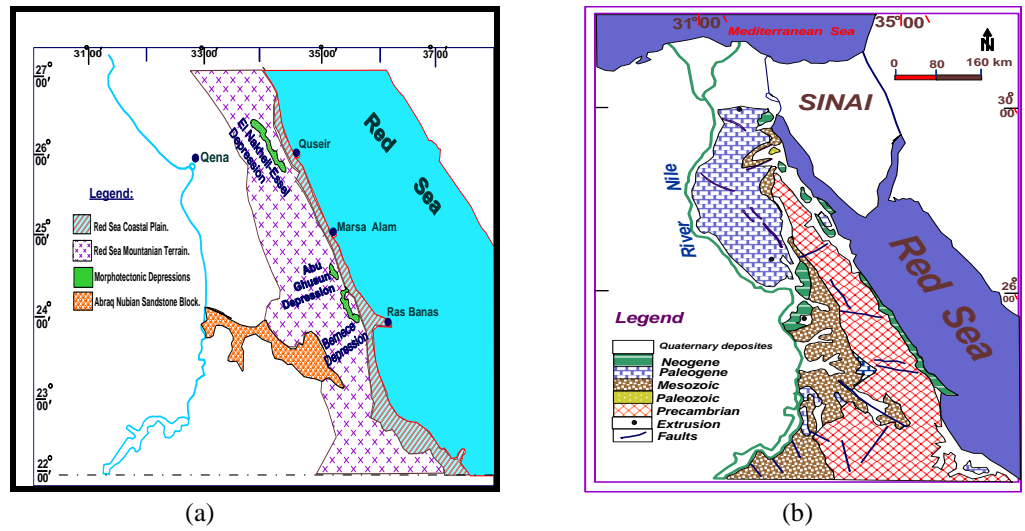


Figure2. Geomorphological (a) and geological (b) maps, Eastern Desert, Egypt.

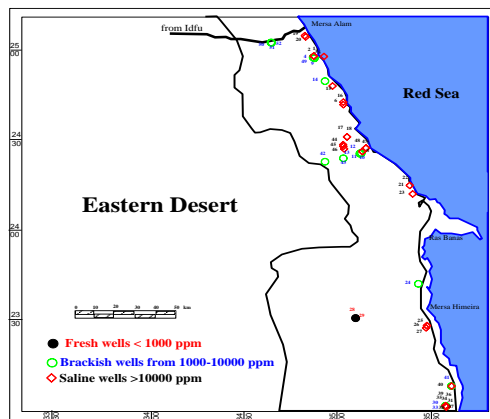


Figure 3. Salinity distribution of the groundwater.

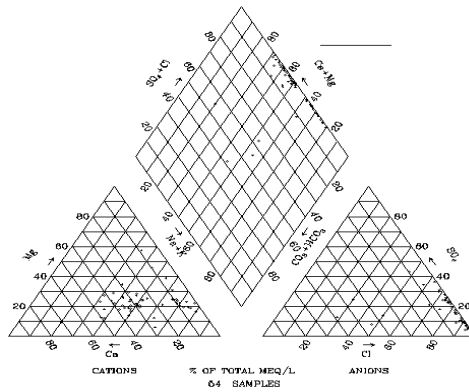


Figure 4. Piper diagram for ion dominate of groundwater.

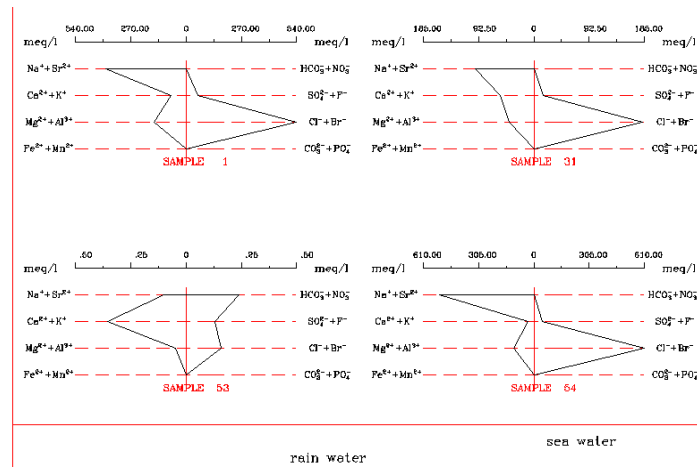
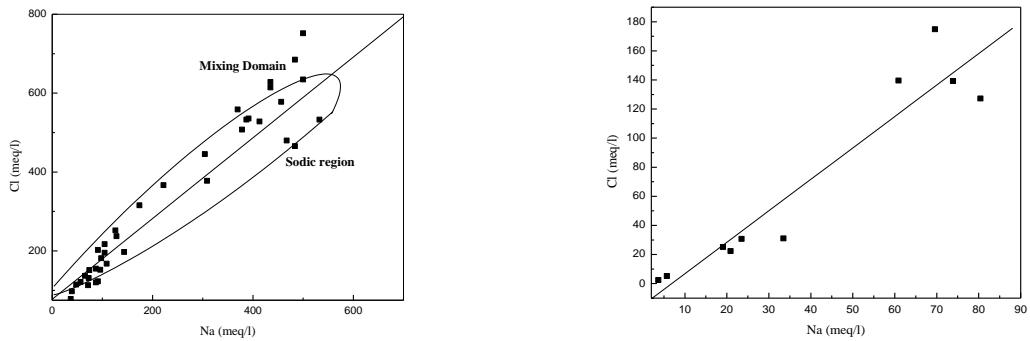


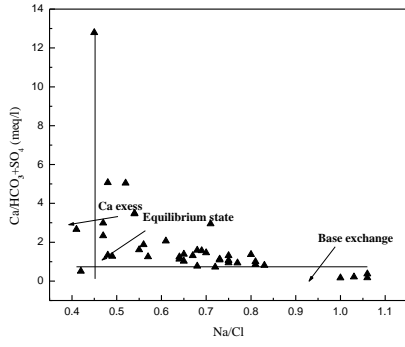
Figure 5. Stiff diagram for ion dominate of groundwater.



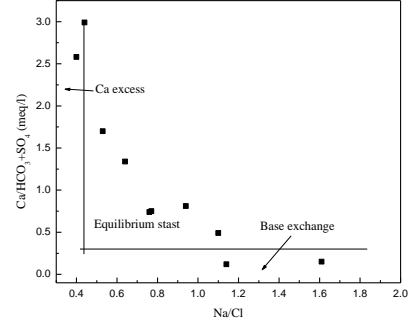
(a)

(b)

Figure 6. Na and Cl bonds of Quaternary (a) and Fractured basement aquifers (b) (me/l).

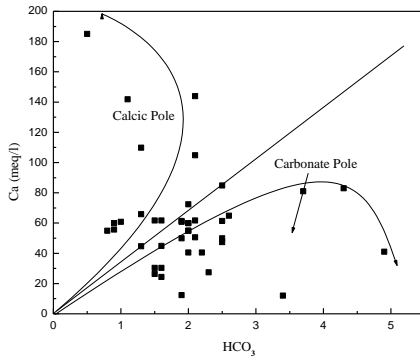


(a)

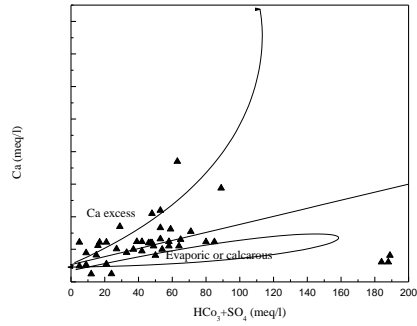


(b)

Figure 7. Base exchanges of Quaternary (a) and Fractured basement (b) aquifers.

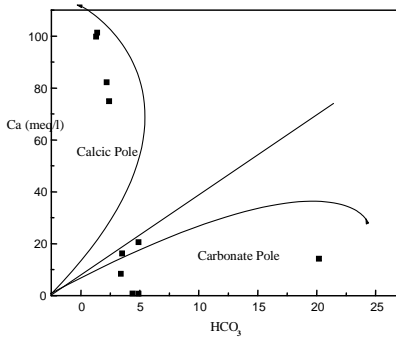


(a)

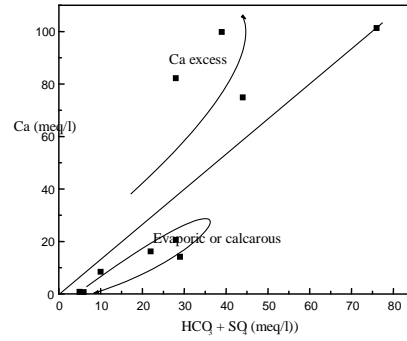


(b)

Figure 8. Ca versus HCO₃ (a) and Ca versus HCO₃+SO₄ (b) in Quaternary aquifer.



(a)



(b)

Figure 9. Ca versus HCO₃ (a) and Ca versus HCO₃+SO₄ (b) in fractured basement aquifer.

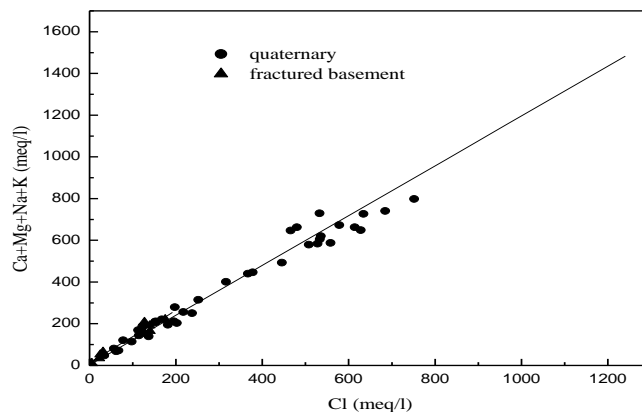


Figure 10. Cl vs Total cations as meq/l of groundwater in study area.

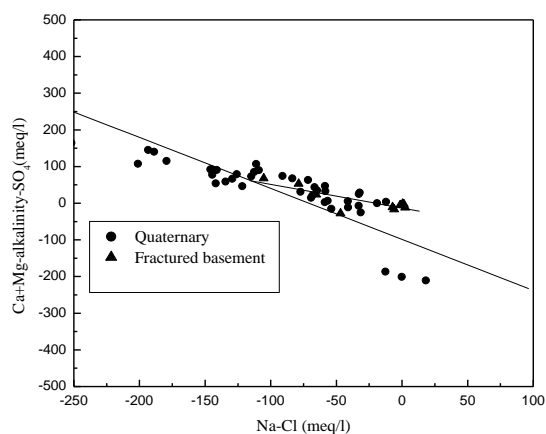


Figure 11. A plot of Ca+Mg-alkalinity-SO₄ versus Na-Cl.

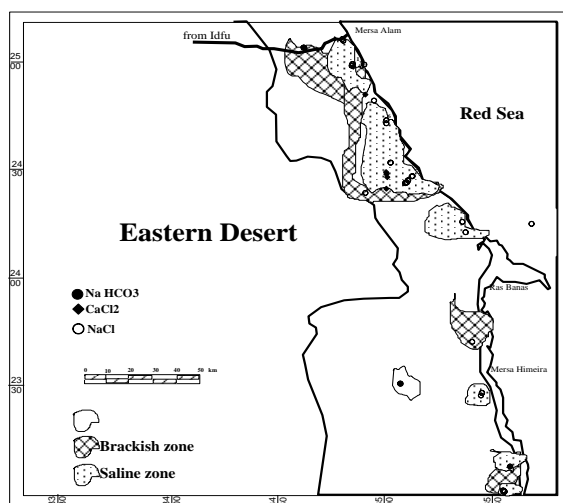


Figure 12. Zonation map of the best localities for desalination processes in the study area.

Table 1. Chemical analysis of major cations and anions for the groundwater samples.

Well	pH	TDS	unit	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	CO ₃ ⁻⁻	HCO ₃ ⁻	SO ₄ ⁻⁻	Cl ⁻
Quaternary aquifer											
1	8.42	37460	ppm	1236	1900	9000	420	7	126	2700	19000
2	8.46	35306	ppm	1200	1800	8900	400	7.0	120	2100	18900
3	8.44	34078	ppm	1000	1700	8700	420	10	113	2500	18000
4	8.47	5840	ppm	247	1001	1100	31	0	113	1079	4059
5	8.38	30058	ppm	1236	1752	10000	249	0.0	93	1951	22275
6	8.38	27175	ppm	1236	1752	8500	450	0.0	100	1781	19800
7	8.16	9084	ppm	1100	700	2200	81	0.0	50	2300	5400
8	8.1	10628	ppm	1200	750	2000	35	0.0	123	2200	5500
9	8.5	4066	ppm	550	185	860	13	0.0	140	900	2000
10	8.3	8022	ppm	893	350	1500	28	0.0	80	360	4851
11	8.48	3284	ppm	487	148	800	11	0.0	96	156	2376
12	8.68	3321	ppm	528	148	670	12	3	93	350	2200
13	8.22	7806	ppm	1015	345	1675	15	0.0	126	1200	4653
14	8.24	5096	ppm	824	400	900	34	0	299	506	3465
15	8.25	34546	ppm	1230	2242	11125	410	0.0	113	4000	24284
16	8.1	36186	ppm	1230	2740	11500	410	0.0	153	3720	26664
17	7.76	15140	ppm	1700	800	2400	34	0.0	150	1300	7700
18	7.86	16471	ppm	2100	1001	2900	35	0.0	130	2200	8936
19	8.22	26243	ppm	812	1100	7100	260	0	133	2300	13400
20	9.01	39775	ppm	609	1850	10750	500	33	93	8966	17021
21	8.27	43268	ppm	812	1727	12250	550	0.0	106	8983	18894
22	8.31	34349	ppm	900	1400	9500	420	0.0	100	1500	18723
23	8.98	31312	ppm	609	1480	11125	420	29	96	8750	16511
24	8.72	2064	ppm	240	165	500	9	0.0	209	400	1200
25	8.1	21569	ppm	1662	1263	7000	71	11	264	2348	15797
26	8.23	41674	ppm	1300	1800	11500	525	0.0	156	3000	22500
27	7.95	38569	ppm	1100	1800	10500	505	0	120	3000	20500
30	7.96	10540	ppm	1319	370	1650	25	0.0	76	2500	3999
31	7.95	8848	ppm	1218	617	2100	21	0.0	60	181	7177
32	8.16	9695	ppm	1218	555	2400	21	0.0	60	791	6930
33	8.15	9660	ppm	950	400	2000	20	0.0	150	1900	4255
34	8.14	10987	ppm	1100	500	2100	18	0	120	2700	4350
35	8.23	8979	ppm	1116	493	2250	21	0.0	53	731	6435
36	8.42	11330	ppm	1218	740	2950	14	0.0	116	903	8415
37	9.03	31908	ppm	3708	501	10000	67	0.0	30	2994	21780
38	8.46	15582	ppm	1550	700	3300	22	0.0	130	3300	7000
39	8.22	16207	ppm	1200	872	1700	20	0.0	57	2200	5361
40	8.44	9888	ppm	1624	370	2500	36	20	226	2650	5940
41	8.4	6300	ppm	1450	350	1300	23	0.0	120	1400	4300
47	8.42	21035	ppm	2884	1001	4000	28	3.0	126	4200	11200
48	8.3	24070	ppm	2200	1300	5100	39	0.0	76	2500	13000
49	8.15	4516	ppm	1000	400	850	32	0.0	150	1681	2772
Fractured basement aquifer											
28	9.14	1491	ppm	14.21	52	130	10	0	299	43	183
29	8.61	1427	ppm	16.4	47	85	5	16	266	52	84
42	8.75	1644	ppm	169.3	51	480	5	7	209	336	792
43	7.8	7562	ppm	1648	250	1400	12	0	133	1218	4950
44	8.04	10155	ppm	2000	623	1600	10	0.0	80	1800	6200
45	7.46	10556	ppm	1500	514	1700	13	0.0	146	2000	4936
46	7.71	9394	ppm	2030	308	1850	17	0.0	86	3569	4511
50	8.6	2252	ppm	324.8	148	540	5	3	213	868	1089
51	8.16	2219	ppm	412	150	440	3	0.0	299	1093	891
52	8.99	3411	ppm	284.2	197	770	27	82	1230	420	1100

Table 2. Heavy metal analysis for the groundwater samples.

Well no.	Fe	Mn	Cd	Cu	Pb	Sr	P	Si
Quaternary aquifer								
1	0.2283	0.0462	<0.001	0.0349	<0.004	9.203	0.2699	5.807
2	0.5010	0.0658	<0.001	0.0244	<0.004	9.871	0.2375	5.903
3	0.0052	0.0394	<0.001	0.0335	<0.004	6.775	0.1859	5.576
4	0.4587	0.0246	<0.001	0.0262	0.0064	12.26	0.1752	12.31
5	<0.02	<0.001	<0.001	0.0303	<0.004	12.72	0.1913	6.137
6	0.1087	0.2816	<0.001	0.0400	<0.004	14.01	0.2463	6.801
7	1.5	0.0803	<0.001	0.0312	<0.004	14.8	0.6491	10.21
8	3.678	0.5548	<0.001	0.05	0.0076	19.58	4.254	17.98
9	0.9495	0.0849	<0.001	0.0423	0.006	6.121	1.142	16.43
10	0.5423	0.0103	<0.001	0.0398	<0.004	9.959	0.5812	11.24
11	2.165	0.1487	<0.001	0.0347	0.0072	5.591	1.893	17.83
12	0.6657	0.0216	<0.001	0.0449	<0.004	5.286	0.284	15.5
13	0.9649	2.269	<0.001	0.0349	<0.004	10.61	0.5023	14.16
14	2.146	2.041	<0.001	0.042	<0.004	12.96	1.494	13.11
15	<0.02	<0.001	<0.001	0.037	<0.004	7.029	0.1995	2.679
16	<0.02	<0.001	<0.001	0.029	<0.004	12.54	0.138	7.476
17	1.047	0.8388	<0.001	0.0345	<0.004	30.75	0.249	9.198
18	0.3585	0.3044	<0.001	0.0417	<0.004	44.64	0.011	8.822
19	<0.02	0.004	<0.001	0.0232	<0.004	8.239	0.0539	<0.02
20	0.3172	0.1636	<0.001	0.037	<0.004	15.59	0.0921	10.14
21	<0.02	0.0048	<0.001	0.0357	<0.004	6.937	0.042	<0.02
22	<0.02	<0.001	<0.001	<0.003	<0.004	10.7	<0.02	3.607
23	<0.02	0.0058	<0.001	<0.003	<0.004	14.19	<0.02	4.145
24	<0.02	0.0053	<0.001	0.0319	<0.004	8.023	0.074	<0.02
25	<0.02	0.0082	<0.001	0.0041	0.0081	4.587	0.1422	35.58
26	<0.02	0.0196	<0.001	0.0122	<0.004	36.77	0.0377	9.352
27	<0.02	<0.001	<0.001	0.0067	<0.004	18.15	0.0312	4.555
30	<0.02	0.32	<0.001	0.0051	<0.004	16.9	<0.02	3.533
31	<0.02	<0.001	<0.001	<0.003	<0.004	21.71	<0.02	14.78
32	<0.02	0.0028	<0.001	0.0069	<0.004	22.1	<0.02	9.682
33	<0.02	0.0069	<0.001	0.0052	<0.004	22.16	<0.02	7.884
34	<0.02	0.005	<0.001	0.0074	<0.004	20.71	<0.02	10.2
35	<0.02	<0.001	<0.001	0.009	<0.004	20.61	<0.02	8.347
36	<0.02	<0.001	<0.001	0.0042	<0.004	19.99	<0.02	5.966
37	<0.02	0.0023	<0.001	0.0088	<0.004	25.19	<0.02	7.952
38	<0.02	0.003	<0.001	0.0174	<0.004	66.17	<0.02	<0.02
39	<0.02	0.0024	<0.001	0.005	<0.004	28.38	<0.02	8.015
40	<0.02	0.0083	<0.001	0.0212	<0.004	70.37	0.1519	6.094
41	<0.02	0.0049	<0.001	0.0065	<0.004	22.33	<0.02	7.594
47	<0.02	<0.001	<0.001	0.0119	<0.004	23.19	0.1722	1.629
48	<0.02	<0.001	<0.001	0.0074	<0.004	22.02	<0.02	14.31
49	0.5303	0.0799	<0.001	0.0591	0.0141	37.27	1.064	17.44
Fractured basement aquifer								
28	<0.02	<0.001	<0.001	<0.003	0.0095	0.2302	<0.02	13.56
29	<0.02	<0.001	<0.001	<0.003	0.0068	0.1931	<0.02	13.07
42	1.63	0.0206	<0.001	0.0437	0.0079	1.678	<0.02	13.51
43	0.2916	4.438	<0.001	0.0518	0.006	16.15	0.2671	1.88
44	0.7358	0.1548	<0.001	0.0556	0.0187	24.81	0.7928	3.138
45	7.025	10.08	<0.001	0.1326	0.6189	27.9	25.58	17.77
46	2.143	0.9728	<0.001	0.0802	0.2335	22.11	11.51	13.08
50	1.321	0.0434	<0.001	0.0507	0.0073	2.133	0.9703	7.344
51	<0.02	<0.001	<0.001	<0.003	<0.004	1.798	<0.02	11.51
52	<0.02	<0.001	<0.001	0.0195	0.0111	2.319	53.5	24.02

5. Conclusion

The present study shows that groundwater of Mersa Alam – Beranice area is rich in natural salts which are unsuitable for human drinking, while some groundwater samples are suitable for drinking of livestock which makes this water not to be used directly for different purposes without proper treatment such as desalination process. The Egyptian experience is rapidly building up in this field, but more efforts are needed to cope with the world trend to reduce the cost of desalination to a minimum. Finally, this research concluded that, the water desalination as a conventional water resource should be considered as an imperative measure for water security in Egypt. The best sites for groundwater desalination process in the area of study are that characterized with lower and constant TDS, lower depth to water wells, higher water production and with Ca-HCO₃ chemical type.

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