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Evaluation of Groundwater Quality for drinking and irrigation purposes Case Study (El-Tur City).

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ملخص البحث :

نقص مصادر المياه العذبة فى شبه جزيرة سيناء بالاضافة للنمو السكانى السريع جعل هناك حاجة ملحة لادارة موارد المياه الجوفية .
تهدف هذه الدراسة الى تقييم جودة المياه الجوفية لاغراض كل من الشرب و الرى عن طريق دراسة و تحليل عينات المياه الجوفية المستخرجة من 15 بئر جوفى فى مدينة الطور .
تم تطبيق طرق مختلفة لتقييم جودة المياه الجوفية للشرب و الرى و اوضحت النتائج ان نسبة بسيطة فقط من الابار تصنف بانها صالحة لاغراض الشرب و الرى ، علاوة على اشارت نتائج مخطط بيبر و مخطط جيبس ان معظم الابار المدروسة هى من نوع كلوريد الصوديوم و تعتمد فى جودتها على صخور الخزان الجوفى .

Abstract:

The scarcity of fresh water in Sinai, coupled with rapid population growth, highlights the importance of groundwater management. The groundwater quality helps the decision-maker to manage the resources for either drinking or agricultural purposes.

This paper aims to investigate the quality of drinking and irrigation water in 15 pumping wells distributed in El-Tur City, Egypt. Eight hydro-chemical parameters that reflected the complexity of the water quality were considered and evaluated. Water quality index (WQI) and Total Dissolved Solids (TDS) analysis was applied to evaluate the groundwater quality for drinking and potable water, while Sodium absorption ratio (SAR), Sodium Percent (Na %) and Kelly ratio (KR) for evaluating the quality of groundwater for irrigation. the results based on WQI revealed that 7 % with Good quality, **53** % of the groundwater is classified with poor quality for drinking while **20** % with very poor quality, and 20 % unsuitable for drinking activities.
TDS results showed that 13 % were desirable for drinking activities, 53% of the wells were permissible for drinking , 27 % of the wells are unsuitable for drinking but could be used for agriculture activities and only 7 % were unfit for neither drinking nor irrigation activities.
furthermore, the groundwater quality for irrigation based on Kelly Ratio and Sodium

percent showed that all the wells were unfit for irrigation, while Sodium absorption ratio showed the same results except for the eastern part of the study area which was classified as permissible for irrigation. Results of piper diagram and Gibbs diagram indicated that most of the studied wells are from Sodium chloride type with rock dominance.

Keywords: Groundwater Quality, Drinking, Irrigation and Tur City

1. Introduction

Egypt depends mainly on the Nile river as the main source of fresh water with 72.64% of Egypt water resources (CAPMAS, 2004), Rapid population growth with constant received amount of water put Egypt in a serious situation due to the decrease of water share which is estimated to be 500 m3 per capita (FAO, 2016). Groundwater quality has a great impact on human health, quality of agricultural soil and sustained economic growth. Evaluation of Groundwater quality is an essential issue for good management of water resources (Abdelaziz et al., 2020)

Traditional methods to evaluate water quality include salinity (EC), soluble sodium percentage (SSP) Sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), permeability index (PI), Kelly's ratio (KR), and potential salinity (PS). These methods are frequently used to evaluate water quality for irrigation purposes (Gautam et al., 2015)

Groundwater quality index (GWQI) method first introduced by (Horton, 1965) is also an effective tool to evaluate spatial and temporal changes in groundwater quality. The method depends on selecting a number of chemical parameters and assuming a weight for each single parameter based on its importance. This weight is mainly assumed based on the researcher experience and background. Several researchers carried out GWQI to evaluate the validity of water for drinking and irrigation purposes.(Patterson, 1994), (Abdelaziz et al., 2020) ,(Abbasi & Abbasi, 2012), (Smith, 1990) and (Ott, 1978) are few examples.

The present study aimed to evaluate and determine the quality of groundwater in El-Tur City, Egypt, based on 15 analyzed samples extracted from pumping wells within the study area (Yousif et al., 2020). GWQI method and TDS were used to evaluate the quality of this water for drinking and potable uses. Other methods include SAR, Na % and KR are used for evaluating the quality of groundwater for irrigation.

2. Study Area

El-Tur City, located in El Qaa plain in the south western part of Sinai Peninsula, lies between 27° 43' 44″ N to 28° 54 55″ N and 33° 11 50″ E to 34° 15 24″ E. It is an elongated strip along the right coast of Gulf of Suez (Figure 1).

It is bounded by the mountains from the right side and by the Red sea coast from the west with maximum ground elevation of 200 m above sea level and decreasing with mild slope towards the Gulf of Suez. The temperature reaches 34 degrees in summer and 9.5

degree in winter with high evaporation rate. The average annual rainfall varies between 10 to 60 mm/year. Several severe flash floods happened in the study area with maximum rainfall about 76 mm/day (Hussien et al., 2021). They were considered the main source for replenishing the aquifer

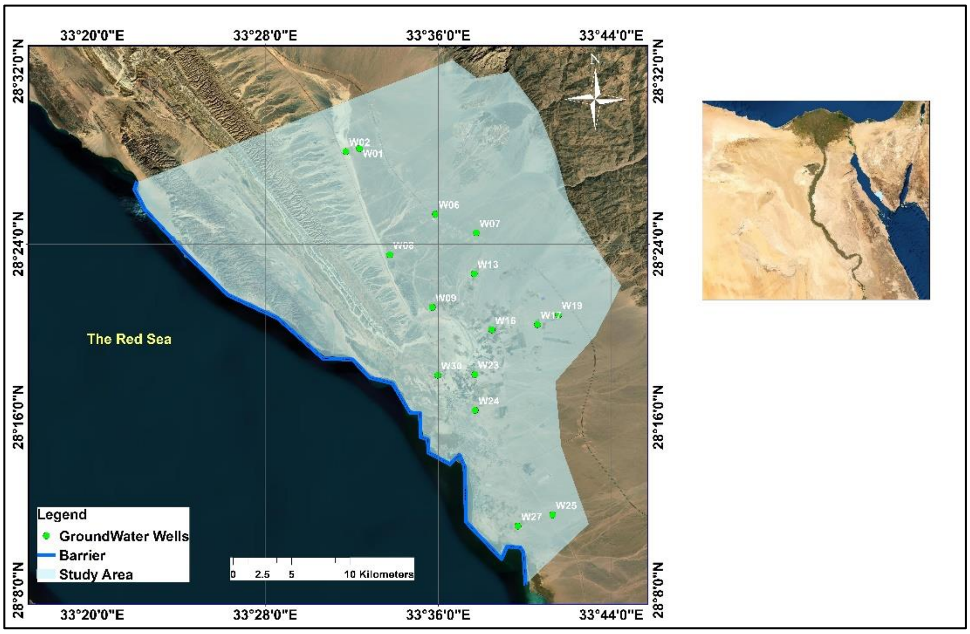

Figure 1: Location of the Study area with the groundwater wells

2.1.Geomorphology and Geology of the study area

Three main geomorphological zones characterize the study area; high mountain in the northeastern part, relatively high mountain in the northwestern part, and the low land zone. The rocks included in the study area have long range of geological time from the Precambrian basement rocks to Quaternary deposits. The south Precambrian basement is formed from the movement between mantle and crust processes (Badawy et al., 2008) as shown in Figure 2. The eastern side of the study area is Precambrian basement while the western side is quaternary sediments (Selim et al., 2016b, p. 7)

The area is characterized by three aquifers; the deep Precambrian aquifer which is not used due to the cost of drilling more than 2500 m, the saline water lower Miocene aquifer, and the Quaternary aquifer with great potential for both quantity and quality measures. The last one is composed of gravels, sands, silt, clay, limestone, coral reefs, and sabkha deposits. The thickness of these aquifers ranges between 50 m near the northwestern sedimentary hills , 1000 m in the central part of the area and 400 m in the eastern part (El-Sayed et al. (2011)).

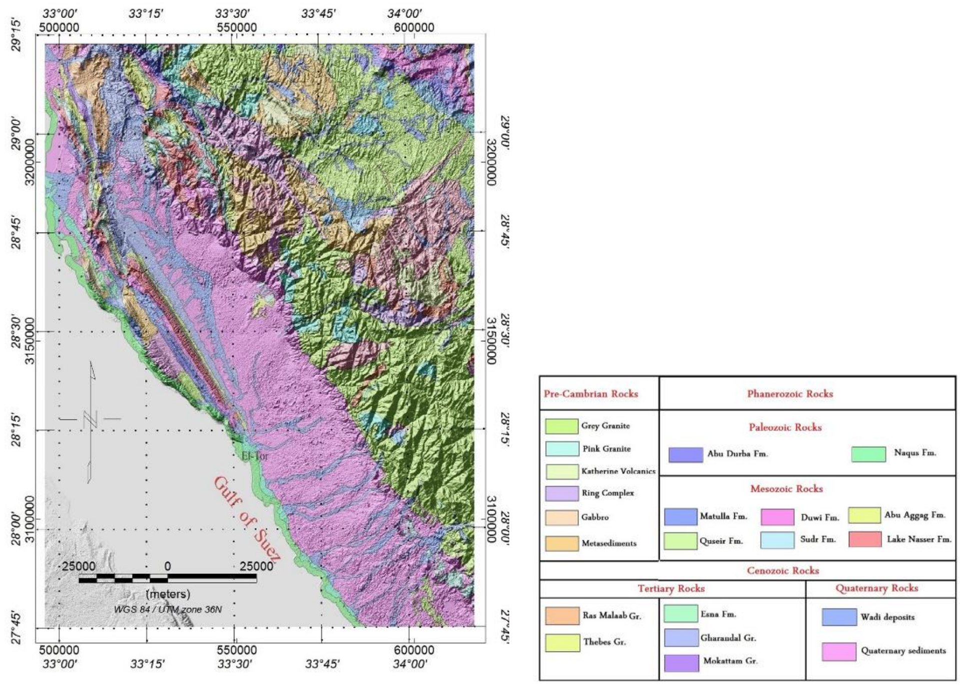

Figure 2: Geology of the study area after (Selim et al., 2016, p. 13)

3. Material and Methods

3.1.Data collection

The data used to evaluate the groundwater quality for irrigation and drinking purposes is extracted from previous work of (Yousif et al., 2020) who collected and analyzed the chemical concentration in fifteen groundwater samples tapping the post-Miocene alluvium aquifer. Figure 1 shows the location of these wells. The chemical concentrations include the major cations of Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}) and Magnesium (Mg^{++}), and the major anions of Bicarbonate (HCO_3^-), Sulfate (SO_4^-) and Chloride (Cl^-) in addition to the pH and Total Dissolved Solids (TDS) as shown in table 1. The table also contains the standard WHO limit for each parameter for drinking and potable water according to (WHO, 2018a) (WHO, 2018b), and (EWQS, 2007). Further, the weight score from one to five is given to each parameter according to its health effect based on (Vasanthavigar et al., 2010).

Table 2: Chemical Concentrations of groundwater wells year 2020.

Well No	K+	Na+	Mg++	Ca++	Cl-	SO4-	HCO3-	TDS	pH
W01	63.7	212.1	0.2	22.7	250.4	146.5	71.4	731	7.2
W02	110.2	368	4.9	15.6	414.9	414.9	126.3	1228	7.4
W06	79.3	264	3	35.1	333	333	74.4	920	7.5
W07	78.6	262	4.3	35.1	323.4	323.4	88.5	910	7.6
W08	268.9	896.3	33.4	110.2	1244.3	1244.3	202.6	3226	7.4
W09	172.3	574.3	2.4	108.8	825.5	825.5	172.7	2146	7.5
W13	75	250.7	2.2	28.1	341.1	341.1	61.6	860	7.7
W16	68.8	228.8	6.4	41.7	327.7	327.7	96.4	841	7.8
W17	33.6	112.2	0.6	16.6	158.9	158.9	48.2	402	7.9
W19	54.7	181.9	3.4	28.7	241.5	241.5	101.3	650	7.8
W23	52.4	174.1	1.6	19.6	201.1	201.1	842	589	8
W24	73.1	243.8	4.3	15.6	288.7	288.7	125.7	826	8.2
W25	171.2	570.8	11.6	79.2	826.2	826.2	167.2	208	7.7
W27	93.8	313.3	4.9	39.7	462.4	462.4	75.7	1123	7.9
W30	239.6	798.5	25.9	122.9	1259.6	1259.6	234.3	2961	7.7
WHO standards	12	200	50	75	250	250	120	600	6-8
Weight	2	2	1	2	3	4	3	5	-
Relative Weight	0.09	0.09	0.05	0.09	0.14	0.18	0.14	0.23	-

3.2. Water Quality Index (WQI)

Water quality index is a widely used method to evaluate the groundwater quality for drinking purposes. A formula is used to estimate the overall quality of Water sample and present it with a single value. This value is estimated by adding the results of multiplying each quality rating value with the parameter relative weight. In order to determine the relative weight, a weight score (wi) from one to five is given to each parameter according to its health effect. The score five is assigned to the most effective parameter, while the score one is assigned to the least effective parameter. The relative weight for each parameter is estimated by dividing the score weight of this parameter by the sum of the scores given to all parameters (Vasanthavigar et al., 2010).

$$Wi = wi / \sum_{i=1}^{n}(\mathbf{w}_i) \qquad (1)$$

where

Wi is the relative weight of the i^{th} parameter,
wi is the score weight of the i^{th} parameter,
n is the total number of the studied parameters,

Then, a quality rating value (Ci) is calculated for each parameter by dividing its concentration by its permissible WHO standard value (Si).

$$qi = \frac{C_i - l_i}{S_i - l_i} \times \mathbf{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where,

qi is the quality rating scale of the i^{th} parameter,

Ci is the concentration in ppm of the i^{th} parameter,

Si is the drinking water standard value of the i^{th} parameter according to World Health Organization.

l_i is the optimum value of i^{th} parameter which normally equal zero,

Finally, the water quality sub-index value for the i^{th} parameter is estimated by multiplying its quality rating value with its relative weight the parameter relative weight. WQI is estimated as the additive aggregation of the estimated of sub-indices and then a classification is done based on this value into five categories as shown in table 2.

$$\boldsymbol{SI_i W_i} \text{ x } \boldsymbol{q_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\mathbf{WQI} = \sum \boldsymbol{SI_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where,

SIi is the sub-index of the parameter

Table 3: Water Quality Index Classification Ranges.

WQI Range	Type of water
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable for drinking

3.3.Total Dissolved Solids (TDS)

World Health organization classified the water quality for drinking and irrigation according to the concentration of TDS in the water sample (WHO, 2018b), The classification ranges are shown in

Range	Classification
<500	Desirable for drinking water
500-1000	Permissible for drinking water
1000-3000	Useful for irrigation
>3000	Unfit for drinking and irrigation

3.

Table 4: Total Dissolved Solids Classification Ranges (WHO, 2018b).

Range	Classification
<500	Desirable for drinking water
500-1000	Permissible for drinking water
1000-3000	Useful for irrigation
>3000	Unfit for drinking and irrigation

3.4.Sodium Percent (NA%):

High concentration of Sodium in a water sample is a reference of bad water quality. The following formula is used to calculate Na% (Wilcox, 1955). All parameters concentration is in meq/l.

$$\mathbf{Na\%} = \frac{\mathbf{(Na+K)}}{\mathbf{(Ca+Mg+Na+k)}}\ \mathbf{x\ 100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The classification ranges of The Na% are shown in

Range	Classification
<500	Desirable for drinking water
500-1000	Permissible for drinking water
1000-3000	Useful for irrigation
>3000	Unfit for drinking and irrigation

4.

Table 5: Sodium Percent Classification Ranges (Wilcox, 1955).

Range	Quality
<20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

3.5.Kelly Ratio (KR)

Kelly ratio (KR) is a good indicator used to evaluate the groundwater quality for irrigation activities. The following formula is used to calculate the value of Kelly ratio (Kelly, 1951). All parameters concentration is in meq/l. If the estimated KR value is greater than one, then the water is classified as unsuitable for irrigation.

$$\boldsymbol{KR} = \frac{\boldsymbol{Na}}{\boldsymbol{Ca+Mg}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

3.6.Sodium Absorption Ratio

Sodium absorption ratio (SAR) is the most common method to evaluate the groundwater quality for irrigation purposes as a result of sodium hazard. It is a ratio between the sodium concentration with respect to magnesium and calcium concentration in the water sample. Its calculated using the following equation (Patterson, 1994). The classification ranges of SAR are shown in Table 5.

$$\mathbf{SAR} = \frac{\mathbf{Na}}{\sqrt{\frac{\mathbf{Mg+Ca}}{\mathbf{2}}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Table 5: Sodium Absorption Ratio (SAR) Classification Ranges.

Parameter	Range	Degree of Restriction on Use
SAR meq/l	0-10	Excellent
	10 – 18	Good
	18-26	Doubtful
	>26	Unsuitable

3.7.Piper Diagram and Gibs diagram

Piper diagram introduced firstly by Piper (1944) is a widely used graph for classification of groundwater based on the percentages of major anions and cations. While the Gibbs diagram introduced by Gibbs (1970) is another widely used graph to establish the relationship of water composition and aquifer lithological characteristics based on the atmospheric precipitation, water-rock interaction, and the evaporation crystallization process (Gibbs, 1970).

3.8.Spatial interpolation of the water quality classification

In this paper, the estimated WQI are interpolated to create spatial maps of the water quality using the inverse distance weight (IDW). The interpolation results depends on the value of the measured data of groundwater wells and the distance between wells (Arsalan et al., 2004) and (Buchanan & Triantafilis, 2009). The weight of each point is calculated by taking the inverse of the distance between this point and the surrounded measured wells location (WEIHE et al., 1999). The coastline is added to the measured well with the assumption that it has the worst water quality.as shown in Figure 3.

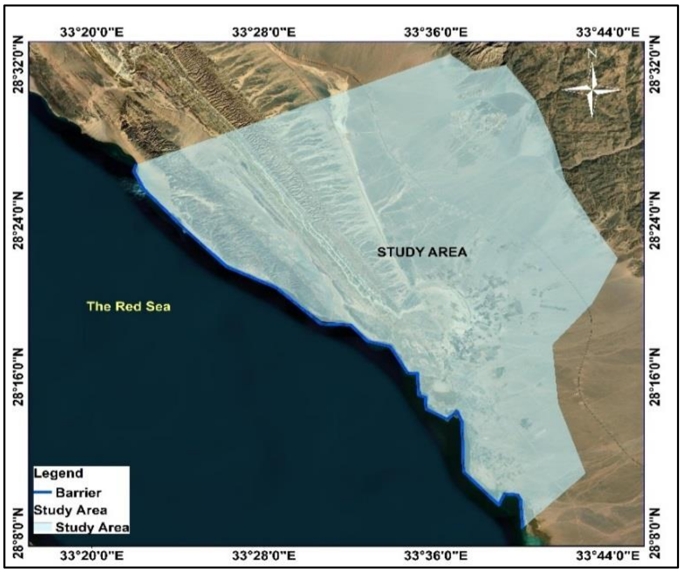

Figure 3: Assumed Barrier along the Coastline.

4. Results and discussion

4.1. Water quality for drinking

The results of WQI classified 53 % of the studied wells as poor quality for drinking, 20% as unsuitable for any activities, 7% as good for drinking and 20 % as unsuitable. Table 6 summarize the results of the WQI while Figure 4 shows its spatial distribution. On the other hand, the results of TDS revealed a similar result with 53 % of the wells classified as permissible for drinking, 13% good for drinking, 27 % unfit for drinking but could be used in irrigation with care and 7% of the wells can't be used either drinking or agriculture activities. Table 7 summarize the results of the TDS while Figure 5 shows its spatial distribution.

Table 6: Results of Water Quality Index.

Range	Quality	percent
>50	Excellent	0%
50 -100	Good	7%
100-200	poor	53%
200-300	Very Poor	20%
>300	Unsuitable	20%

Table 7: Results of Total Dissolved Solids.

Range	Quality	percent
<500	Desirable for drinking water	13%
500-1000	Permissible for drinking water	53%
1000-3000	Useful for irrigation	27%
2000-3000	Unfit for drinking and irrigation	7%

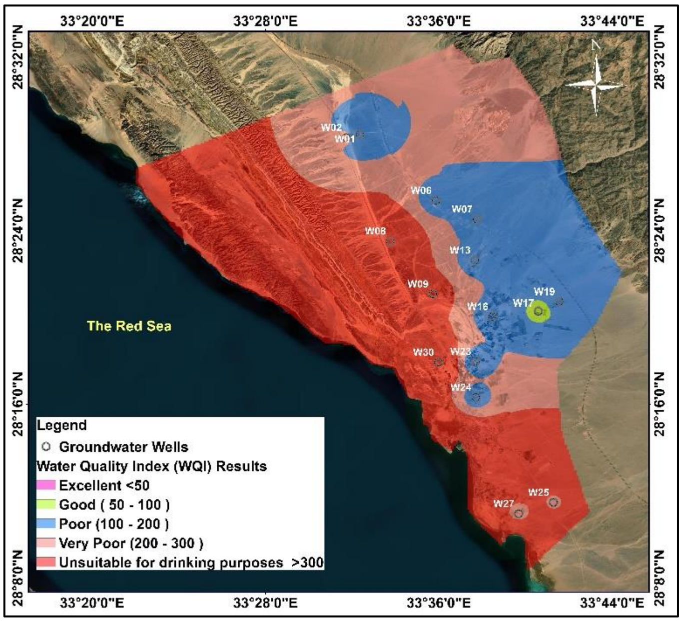

Figure 4: Spatial Distribution of Water Quality Index Results.

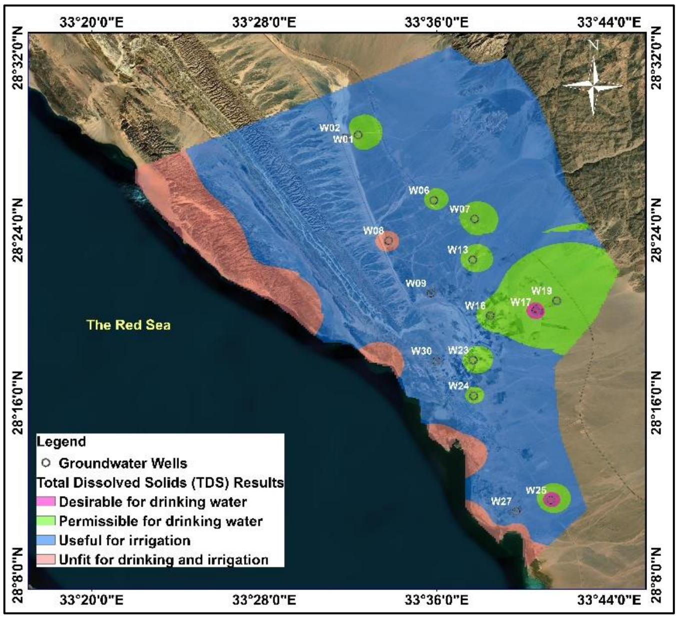

Figure 5: Spatial Distribution of Total Dissolved Solids Results.

4.2. Water quality for Irrigation.

The groundwater quality in the study area classified all the studied groundwater wells as unsuitable for irrigation activities. Results of Na % and KR are identical. Both methods showed that all the wells are unfit for agriculture. While SAR revealed that 80% of the wells are not suitable for any agriculture activities and 20% could be used but with recommendations. Tables 8, 9 and 10 summarized the results of the three methods.

Table 8: Results of Sodium Percent.

Range	Quality	percent
<20	Excellent	0%
20-40	Good	0%
40-60	Permissible	0%
60-80	Doubtful	0%
>80	Unsuitable	100%

Table 9: Results of Kelly Ratio.

Range	Quality	percent
<1	Suitable	0%
>1	Unsuitable	75%

Table 10: Results of Sodium Absorption Ratio.

Range	Quality	percent
<3	Excellent	0%
3-6	Good	0%
6-9	doubtful	20%
>9	unsuitable	80%

4.3.Piper Diagram and Gibs diagram

The results of the study area revealed that almost all the groundwater wells which being studied were unsuitable for irrigation and drinking purposes except one or two water wells. Piper diagram for the studied wells revealed that only one groundwater well belongs to mixed type while the remaining wells belong to Sodium chloride type as shown in Figure 6. These results indicate conformity with the prescribed results as sodium chloride type indicates saltwater intrusion that deteriorates the water quality in the study area.

Results of Gibbs plots showed that most of the groundwater wells were rock dominance which indicates the dominance of rock weathering in controlling groundwater chemistry with the minor influence of evaporation on the groundwater as shown in Figure 7 a and b.

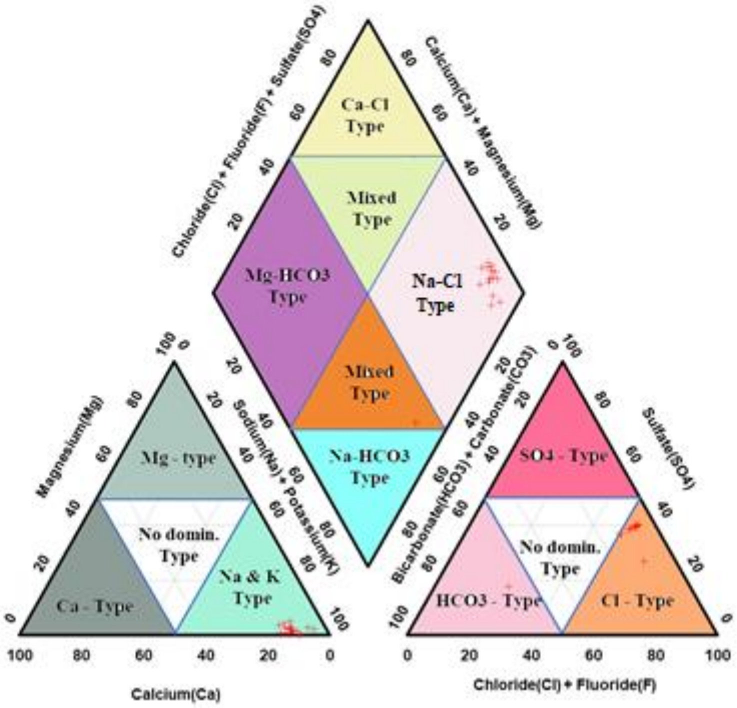

Figure 6: Piper Diagram for the studied groundwater wells and the classification classes

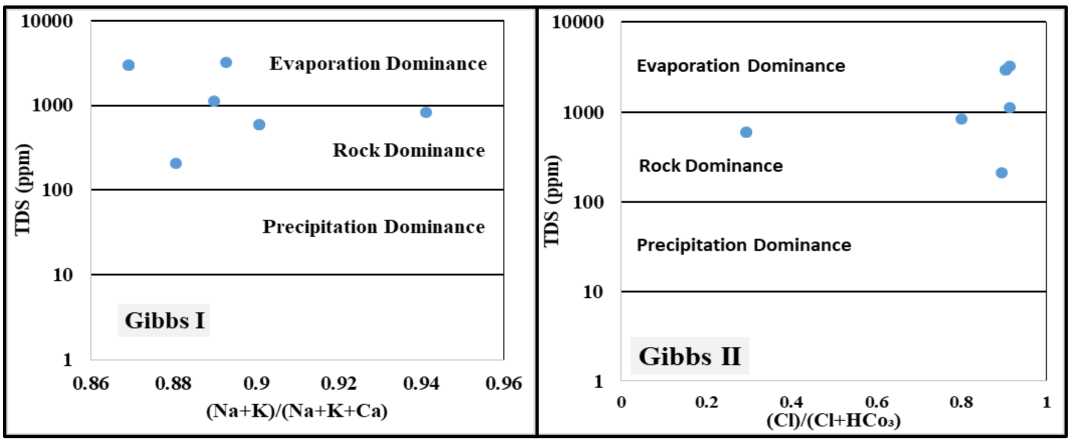

Figure 7: Gibbs I, II   diagrams controlling groundwater chemistry.

El-Sayed et al. (2011) introduced a map that describes the different chemical zones in the study area . The area near the sea is the chloride zone area which is characterized by medium to very high sodium hazard and high to very high salinity. The other two zones including carbonate and sulphate zones have low sodium hazard and medium to very high salinity. This map gives a good explanation of the bad groundwater quality in the current research as most of the studied wells are located in the chloride zone which is considered unfit for any drinking or irrigation activities.

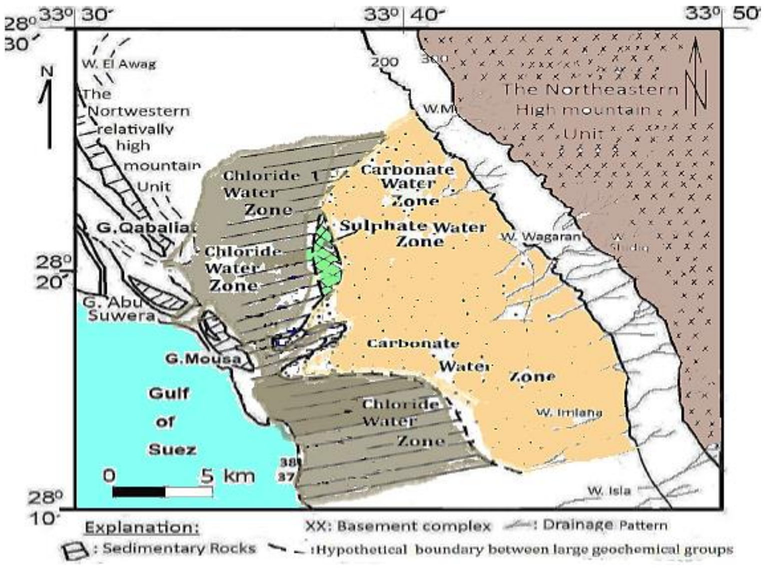

Figure 8: Different Chemical Zones in the study Area after, ((El-Sayed et al., 2011).

5. Conclusions

El-Tur City faces a serious problem due to saltwater intrusion from the Red sea. The excess pumping from the aquifer results in high concentration of Salt in the groundwater. All the methods used in the evaluation of groundwater quality revealed that almost all the studied wells were unfit for irrigation or drinking activities.

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