

Applications of Hydrogeochemical Modeling to Evaluate Quaternary Aquifer in the Area Between Idfu and Aswan, Eastern Desert, Egypt

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Abstract: Application of the software package Mass-Balance Model (NETPATH for windows) to evaluate groundwater quality is the main target in this study. NETPATH was used to perform a variety of aqueous geochemical calculations including; the saturation indices (SI) of the major mineral phases, testing of water corrosivity, influencing of the River Nile on the groundwater and to apply water mixing models. To achieve the main target of the article, twenty-one groundwater samples representing the Quaternary aquifer, beside two surface water samples were collected from the study area and chemically analyzed. The hydrochemical results show that, the groundwater salinity increases eastward, where its quality varies between fresh in the west and slightly saline due east. Also groundwater varies from soft to highly hard. The saturation indices of the major mineral phases in the investigated groundwater samples show that:

- Most of groundwater are supersaturated with respect to iron mineral phases (hematite, goethite..etc). Such minerals reflect the sensitivity of iron to oxidation even in low concentrations.
- Groundwater is supersaturated with respect to the main carbonate minerals (calcite, aragonite and dolomite).
- Groundwater is supersaturated with respect to quartz and chalcedony, such minerals are considered indicators for erosion of dolomite as well as aluminum silicates that built up the local soils (feldspars, kaolinite and micas).
- Groundwater is supersaturated with respect to chrysotile, sepiolite, talc and rhodochrosite. This reflects the leaching effect of soil materials due to weathering of the surrounding rocks as well as agricultural activities.
- The investigated groundwater varies from mild corrosion (19%), faint coating forming in the majority of samples (67%) up to mild scale forming (14%).
- The contribution of recent recharge from Nile water to the Quaternary aquifer is noticed in the study area and varies from moderate to high.

Distributions of saturation indices for calcite, dolomite and gypsum indicate that the Quaternary development strength becomes weak from west to East. Mass balance approach interprets quantitatively the evolution of groundwater chemistry. Those results are very helpful to understand groundwater system in the future study. Nitrate concentrations in considerable mountainous groundwater were significantly elevated in response to increasing anthropogenic land uses toward the west. Also, mixing model was conducted between water from different sources. The obtained results reflect that, the mixing can be used as an effective method for water treatment (in particular, lowering nitrate levels).

Key words: Groundwater quality, Mass-Balance Model, Saturation indices, Groundwater chemistry

INTRODUCTION

Mostly, groundwater is more desirable than surface water for many reasons, as absence of pathogenic

organisms, color, turbidity, no radiochemical nor biological contaminations as well as its great storage. The area under investigation lies within the transition part between Eastern Desert and Nile valley covering about

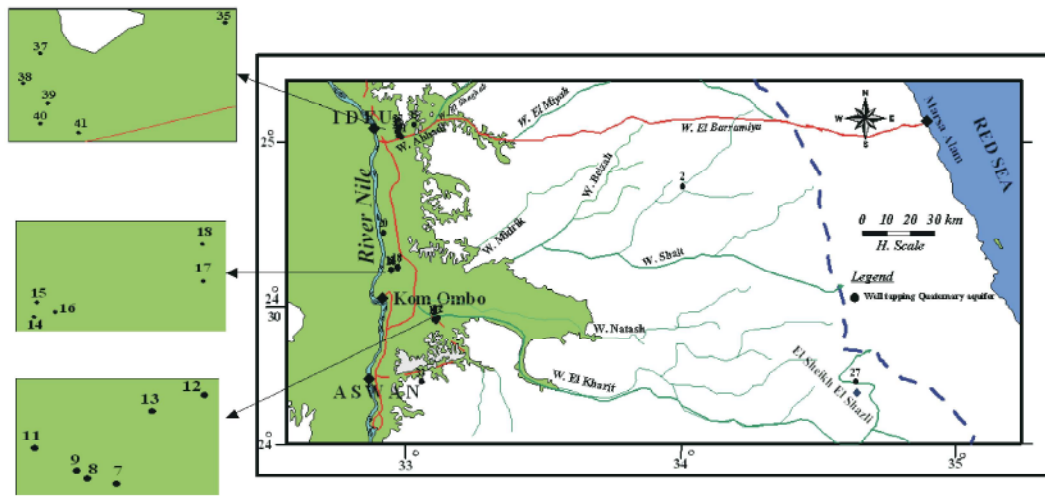


Fig. 1: wells' location map of Quaternary aquifer in the study area

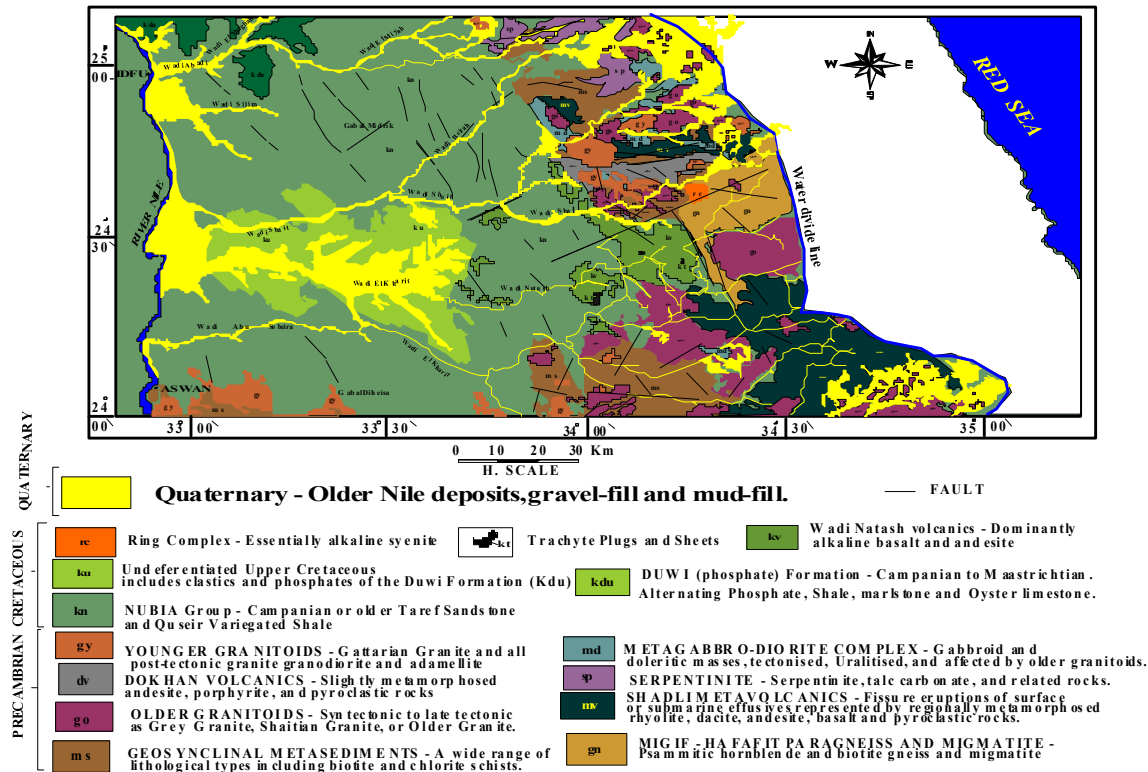


Fig. 2: Geologic map of the study area (Modified after geologic map of Aswan quadrangle, Egypt 1978)

22500 km² (Figure 1). It is limited by Latitudes 24°00' & 25°12' N and Longitudes 32°55' & 35°48' E. It is dominated by the flood plain and characterized by a gentle topographic slope towards Nile River. It has a wide range of geologic time from Pre-Cambrian to Recent (Figure 2). Its climate is hot, dry and rainless in summer and being mild with rare rainfall in winter (0.7 mm) as recorded in Aswan Governorate [1]. The Quaternary aquifer represents the

main groundwater resource in the study area. It is mainly composed of gravels, sands and silts with clay intercalations, varies in thickness from 40 to 120 m. It is subjected to semi-confined conditions due to the overlying silty clay layer. The depth to water surface ranges from 2m (Nos. 8, 13, 14 & 18) to 8.4 m (No. 2), (Table 1). The amount of water in this aquifer is low and represented by water lenses mostly accumulated from

Table 1: Depth to groundwater surface of the Quaternary aquifer

| Well No. | Water point name | Wadi | Depth to water (m) |
|----------|------------------|---------------------|--------------------|
| 2 | Muweilha | W. Muweilha | 8.4 |
| 7 | Sameh | W. El Kharit | 3 |
| 8 | Ahmed Huseen | W. El Kharit | 2 |
| 9 | Yousef | W. El Kharit | 2.5 |
| 11 | Hesham | W. El Kharit | 2.5 |
| 12 | Shaban | W. El Kharit | 3 |
| 13 | - | W. El Kharit | 2 |
| 14 | El Mashtal | W. Midrik | 2 |
| 15 | El Warsha | W. Midrik | 2.5 |
| 16 | - | W. Midrik | 3.5 |
| 17 | - | W. Midrik | 2.5 |
| 18 | - | W. Midrik | 2 |
| 20 | El Asfalt | W. Midrik | 3 |
| 27 | Umm Khrus | El Sheikh El Shazly | 5.5 |
| 33 | - | W. abbadi | 3 |
| 35 | El Haj Gamal | W. abbadi | 3 |
| 37 | Zakalona | - | 3 |
| 38 | Zakalona | - | 4 |
| 39 | Zakalona | - | 4 |
| 40 | Zakalona | - | 5.5 |
| 41 | Zakalona | - | 5 |

past rainy periods [2]. The main source of recharge is the direct precipitation, return flow after irrigation and flush floods coming from the mountainous region. The hydraulic conductivity of the investigated aquifer in the central portion is about 80 m/day [3].

RESULTS AND DISCUSSION

Groundwater Chemistry: Twenty-one groundwater samples representing the Quaternary aquifer, besides two surface water samples were collected in October 2010 from the study area and analyzed

chemically for major and some minor constituents. The analyses were performed in the central lab, Desert Research Center (DRC), Egypt, according to the methods adopted by the United States Geological Survey [4], methods of determination for inorganic substances in water and fluvial sediments [5, 6], (Tables 2 & 3). The descriptive statistics of the chemical parameters (minimum, maximum, mean, median and standard deviation) for the collected samples were calculated and illustrated (Table 4 & Figure 3). According to the hydrochemical analyses data, the following could be deduced:

Table 2: Hydrochemical analyses data of the investigated groundwater samples in mg/l, (2011)

| Sample No | pH | Temp.°C | E.C | TDS mg/l | Ca | Mg | Na | K | CO ₃ | HCO ₃ | SO ₄ | Cl |
|-----------|-----|---------|----------|----------|---------|--------|---------|-------|-----------------|------------------|-----------------|---------|
| 2 | 7.7 | 29.5 | 19850.00 | 10575.33 | 315.75 | 294.12 | 3150.00 | 28.00 | 30.30 | 209.47 | 2978.89 | 3673.53 |
| 7 | 8.1 | 28.8 | 550.00 | 258.30 | 29.47 | 18.41 | 39.00 | 6.00 | 0.00 | 215.64 | 24.44 | 33.16 |
| 8 | 7.6 | 31 | 1390.00 | 839.41 | 98.33 | 76.73 | 85.00 | 12.00 | 9.09 | 203.31 | 262.72 | 193.88 |
| 9 | 7.9 | 28 | 340.00 | 166.70 | 23.21 | 14.41 | 19.00 | 8.00 | 9.09 | 150.94 | 4.76 | 12.76 |
| 11 | 7.6 | 29.8 | 338.00 | 154.44 | 24.12 | 16.88 | 10.00 | 7.00 | 9.09 | 144.78 | 2.20 | 12.76 |
| 12 | 7.7 | 28.3 | 1025.00 | 543.19 | 42.10 | 21.74 | 135.00 | 9.00 | 36.36 | 274.16 | 95.97 | 65.94 |
| 13 | 7.6 | 32 | 616.00 | 245.30 | 25.26 | 24.55 | 31.00 | 11.00 | 15.15 | 234.12 | 8.52 | 12.76 |
| 14 | 7.8 | 30.5 | 604.00 | 315.68 | 37.10 | 24.13 | 49.00 | 6.00 | 18.18 | 190.99 | 39.85 | 45.92 |
| 15 | 8.2 | 31.3 | 1820.00 | 1010.58 | 10.53 | 29.41 | 355.00 | 8.00 | 60.60 | 565.20 | 126.89 | 137.55 |
| 16 | 7.6 | 31.3 | 967.00 | 500.95 | 29.47 | 36.32 | 106.67 | 6.00 | 36.36 | 261.84 | 73.58 | 81.63 |
| 17 | 7.8 | 31.3 | 1089.00 | 787.34 | 12.63 | 22.51 | 228.97 | 5.00 | 24.24 | 285.23 | 308.00 | 43.37 |
| 18 | 7.9 | 28.9 | 1116.00 | 609.51 | 12.63 | 9.72 | 225.00 | 5.00 | 45.45 | 437.43 | 36.87 | 56.12 |
| 20 | 7.7 | 27.3 | 1225.00 | 582.25 | 33.68 | 45.52 | 115.00 | 14.00 | 18.18 | 255.68 | 98.89 | 129.14 |
| 27 | 7.4 | 28 | 3370.00 | 4576.38 | 523.32 | 264.71 | 680.50 | 9.00 | 9.09 | 204.89 | 1596.98 | 1390.33 |
| 33 | 7.3 | 29.1 | 16500.00 | 12563.75 | 1136.70 | 938.63 | 2012.00 | 28.00 | 0.00 | 30.81 | 3458.45 | 4974.57 |
| 35 | 7.3 | 30.4 | 7060.00 | 4108.04 | 494.65 | 213.05 | 600.00 | 20.00 | 0.00 | 49.29 | 1097.50 | 1658.19 |
| 37 | 7.5 | 27 | 4600.00 | 2179.14 | 314.67 | 105.09 | 280.00 | 8.00 | 15.15 | 154.03 | 869.00 | 510.21 |
| 38 | 7.4 | 26 | 4320.00 | 2967.55 | 385.20 | 166.22 | 370.00 | 9.00 | 15.15 | 113.98 | 1391.00 | 573.99 |
| 39 | 7.3 | 25.9 | 2830.00 | 2068.70 | 242.60 | 140.67 | 260.00 | 9.00 | 15.15 | 141.70 | 896.75 | 433.68 |
| 40 | 7.6 | 28.4 | 5240.00 | 3191.33 | 305.75 | 179.03 | 510.00 | 7.00 | 18.18 | 117.06 | 1296.50 | 816.34 |
| 41 | 7.2 | 29.5 | 12830.00 | 6740.73 | 863.05 | 393.61 | 1100.00 | 12.00 | 21.21 | 104.73 | 727.00 | 3571.49 |
| S1* | 8 | 27.8 | 261 | 180.88 | 25.26 | 18.16 | 14.00 | 6.00 | 9.09 | 129.38 | 37.30 | 6.38 |
| S2** | 7.6 | 27.1 | 285 | 144.11 | 27.03 | 11.35 | 13.00 | 4.00 | 12.12 | 123.22 | 0.54 | 14.46 |
| R1* | 6.9 | 25 | 136 | 110.46 | 16.8 | 8 | 6 | 4 | 0 | 43.13 | 38.8 | 15.30 |

S1* Nile water S2** Irrigation canal water R1* Rain water

Table 3: Concentrations of minor and trace constituents in mg/l

| Sample No. | Fe | Mn | Pb | Cu | Cd | SiO ₂ | PO ₄ | NO ₃ | TH | Alkalinity as CaCO ₃ |
|------------|-------|-------|-----|-----|-----|------------------|-----------------|-----------------|---------|---------------------------------|
| 2 | 0.317 | N.D | N.D | N.D | N.D | 39.458 | 0.817 | 42.54 | 1999.21 | 222.38 |
| 7 | 1.23 | N.D | N.D | N.D | N.D | 17.896 | N.D | 10.76 | 149.38 | 176.89 |
| 8 | 1.12 | N.D | N.D | N.D | N.D | 28.308 | 0.118 | 33.59 | 561.41 | 181.94 |
| 9 | 0.88 | N.D | N.D | N.D | N.D | 19.655 | 0.0624 | 8.55 | 117.28 | 138.99 |
| 11 | 0.76 | N.D | N.D | N.D | N.D | 25.596 | 0.0129 | 8.67 | 129.72 | 133.93 |
| 12 | 2.49 | N.D | N.D | N.D | N.D | 25.639 | N.D | 51.97 | 194.63 | 285.55 |
| 13 | 1.19 | N.D | N.D | N.D | N.D | 29.449 | 0.0251 | 16.05 | 164.14 | 217.33 |
| 14 | 1.01 | N.D | N.D | N.D | N.D | 20.002 | 0.179 | 25.34 | 191.98 | 187.00 |
| 15 | 0.49 | N.D | N.D | N.D | N.D | 35.851 | 0.0466 | 60.63 | 147.35 | 564.74 |
| 16 | 0.36 | N.D | N.D | N.D | N.D | 43.37 | N.D | 29.35 | 223.10 | 275.45 |
| 17 | 2.17 | N.D | N.D | N.D | N.D | 47.01 | 0.0757 | 45.62 | 124.20 | 274.42 |
| 18 | 0.1 | N.D | N.D | N.D | N.D | 31.922 | 0.223 | 28.37 | 71.55 | 434.65 |
| 20 | 8.44 | 0.314 | N.D | N.D | N.D | 31.495 | 0.0172 | 52.62 | 271.48 | 240.07 |
| 27 | 0.39 | 0.187 | N.D | N.D | N.D | 34.23 | N.D | 14.67 | 2396.57 | 183.24 |
| 33 | 0.41 | N.D | N.D | N.D | N.D | 31.914 | N.D | 58.98 | 6702.41 | 25.27 |
| 35 | 1.14 | 0.007 | N.D | N.D | N.D | 38.109 | N.D | 15.26 | 2112.32 | 40.43 |
| 37 | 0.31 | 0.428 | N.D | N.D | N.D | 41 | N.D | 59.14 | 1218.45 | 151.63 |
| 38 | 0.44 | 0.023 | N.D | N.D | N.D | 30.237 | N.D | 76.74 | 1646.22 | 118.77 |
| 39 | 0.048 | 0.014 | N.D | N.D | N.D | 24.816 | N.D | 60.57 | 1184.91 | 141.51 |
| 40 | 0.32 | 0.02 | N.D | N.D | N.D | 24.864 | N.D | 56.74 | 1500.52 | 126.35 |
| 41 | 0.32 | N.D | N.D | N.D | N.D | 33.807 | N.D | 75.55 | 3775.61 | 121.29 |
| S1* | N.D | N.D | N.D | N.D | N.D | 8.992 | N.D | 3.41 | 137.64 | 121.12 |
| S2** | 0.23 | N.D | N.D | N.D | N.D | 8.485 | N.D | 10.63 | 114.11 | 121.12 |

Note: Shadow numbers mean that the value is more than the standard limits according to WHO [17] and Moore *et al.* [18]

Table 4: Descriptive statistics of the investigated groundwater samples

| Items | Minimum | Maximum | Standard deviation. | Variance | Median | Mean | No. of samples |
|------------------|----------|----------|---------------------|-----------|----------|----------|----------------|
| pH | 7.2 | 8.2 | 0.264845 | 0.070143 | 7.6 | 7.63 | 21 |
| Temp. | 25.9 | 31.3 | 1.762263 | 3.105571 | 29.1 | 29.15714 | 21 |
| EC | 338 | 19850 | 5539.516 | 30686238 | 1390 | 4175.238 | 21 |
| TDS | 154.44 | 10575.33 | 3470.409 | 12043.737 | 839.405 | 2618.313 | 21 |
| TH | 71.55 | 6702.41 | 1618.377 | 2619143 | 271.481 | 1184.877 | 21 |
| Alk. | 25.26994 | 564.7355 | 122.1336 | 14916.63 | 181.9428 | 201.9917 | 21 |
| Ca | 10.53 | 1136.7 | 308.3168 | 95059.27 | 42.1 | 236.201 | 21 |
| Mg | 9.72 | 938.63 | 212.4744 | 45145.37 | 45.52 | 144.5457 | 21 |
| Na | 10 | 3150 | 765.4783 | 585957 | 228.97 | 493.3876 | 21 |
| K | 5 | 28 | 6.67 | 44.56 | 9 | 10.809 | 21 |
| CO ₃ | 0 | 60.6 | 15.37 | 236.39 | 15.15 | 19.334 | 21 |
| HCO ₃ | 30.805 | 565.2 | 121.59 | 14785.24 | 203.31 | 206.918 | 21 |
| SO ₄ | 2.204 | 3458.45 | 980.19 | 960776.9 | 262.72 | 733.084 | 21 |
| Cl | 12.76 | 4974.57 | 1432.597 | 2052335 | 137.55 | 877.4914 | 21 |
| Fe | 0.048 | 8.44 | 1.78906 | 3.200735 | 0.49 | 1.139762 | 21 |
| Mn | 0 | 0.43 | 0.116398 | 0.013548 | 0 | 0.047286 | 21 |
| Pb | 0 | 0 | 0 | 0 | 0 | 0 | 21 |
| Cu | 0 | 0.042 | 0.00916 | 0.00008 | 0 | 0.002 | 21 |
| Cd | 0.042 | 0.171 | 0.032179 | 0.001035 | 0.092 | 0.090476 | 21 |
| SiO ₂ | 17.896 | 47.01 | 7.874043 | 62.00055 | 31.495 | 31.17276 | 21 |
| PO ₄ | 0 | 0.817 | 0.181337 | 0.032883 | 0 | 0.07509 | 21 |
| NO ₃ | 8.55 | 76.74 | 22.32048 | 498.204 | 42.54 | 39.60524 | 21 |

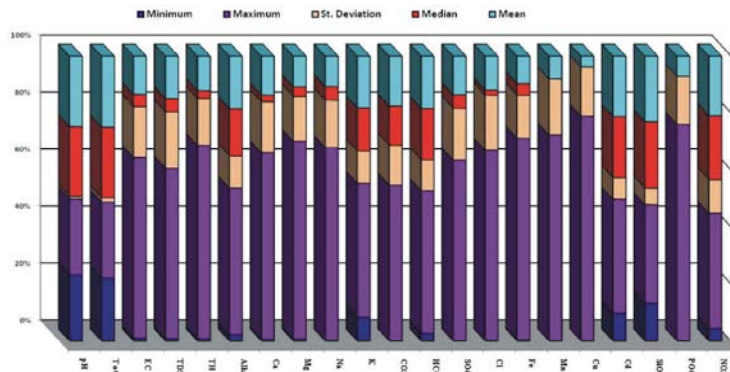


Fig. 3: Descriptive statistics of the investigated groundwater samples

- The groundwater temperature ranges between 25.9°C (No. 39) in Zakalona area and 31.3°C (Nos. 15, 16 and 17) in Wadi Midrik, where the aquifer is mainly subjected to the atmospheric pressure (phreatic aquifer).
- pH values of the examined groundwater samples range from 7.2 (No. 41) in Zakalona area to 8.2 (No. 15) in Wadi Midrik, reflecting a neutral to slightly alkaline groundwater.
- The groundwater salinity has a wide range from 154.4 mg/l at Wadi El Kharit (No. 11) to 12563 mg/l at Wadi Abbadi (No. 33), reflecting fresh to saline categories. It is clear that 57% of water samples are fresh (Nos. 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18 & 20), 29% of total samples are brackish (Nos. 27, 35, 37, 38, 39 & 40) while 14% of the total samples are saline (Nos. 2, 33 & 41). Salinity values decrease due west toward the cultivated land in the study area. This is mainly due to the dilution processes from the irrigation surface water.
- It is clear that, the mean values of total, permanent and temporary hardness reaches 195.52, 34.65 and 259.25 mg/l as CaCO₃, respectively in the fresh groundwater and 1676.5, 1549.5 and 126.99mg/l, respectively in the brackish groundwater and 4159.08, 4036.09 and 122.98mg/l, respectively in saline to highly saline groundwater. These data indicate an increase in total and permanent hardness with the increase of water salinity and vice versa in case of temporary hardness, (Figure 4). This is mainly attributed to the effect of leaching and dissolution of soluble salts which lead the increase of hardness with particular importance to the effect of NaCl on increasing solubility of Ca²⁺ and Mg²⁺ in water [7, 8] taking into consideration the contribution of the CO₂ and longer residence time as well as the influence of salty water and cation exchange processes.
- Alkalinity ranges between 25.27 mg/l as CaCO₃ (No. 33) in Wadi Abbadi to 564.74 mg/l as CaCO₃ (No. 15) in Wadi Midrik.

Geochemical Modeling: The software package NETPATH for windows, [9], (Figure 5) is used to evaluate the subsurface geochemical processes and provides an indication of the reaction potential of the system, also it is used to perform a variety of aqueous geochemical calculations including the saturation indices (SI) of the major mineral phases, testing of water corrosivity and to apply water mixing models. NETPATH is a computer

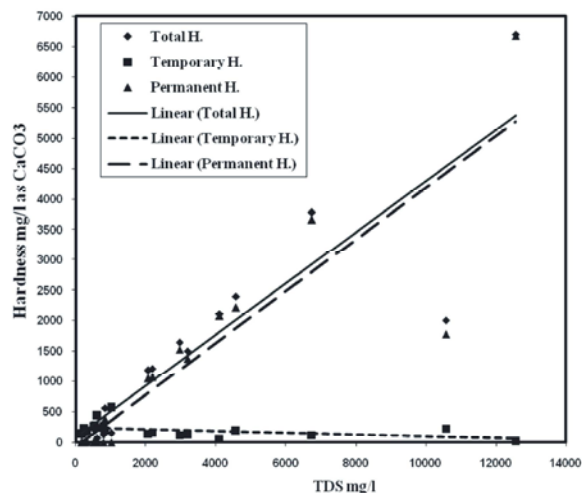


Fig. 4: Relationship between Salinity and Hardness in the Quaternary groundwater

program for simulating chemical reactions and transport processes in natural or polluted water. The program is based on equilibrium chemistry of aqueous solutions interacting with minerals, gases, solid solutions, exchangers and sorption surfaces.

Chemical Equilibrium and Saturation Indices (SI):

The quality of the recharge water and its interactions with soil and rocks during its percolation, movement and storage in the aquifers represent the key factors in the groundwater chemistry. These interactions involve mainly the chemical reactions and their results through both dissolution and precipitation processes, which are controlled by the solubility products of the different involved mineral phases.

Generally, the saturation indices are used to express the water tendency towards precipitation or dissolution. The degree of water saturation with respect to a mineral is given by: $SI = \log (K_{IAP} / K_{SP})$, where K_{IAP} is the ionic activity product, K_{SP} is the solubility product and SI is the saturation index of the concerned mineral. When SI is equal to zero, the water is at equilibrium or saturated with the mineral phase, SI less than zero (negative value) indicates under-saturation and that the mineral phase tends to dissolve, whereas SI over zero (positive value) indicates super-saturation and that the mineral phase tends to precipitate. The saturation indices (SI) of the major mineral phases in the investigated groundwater samples were calculated using the software package (NETPATH-WIN). The obtained results (Table 5 and Figure 6) reflect that:

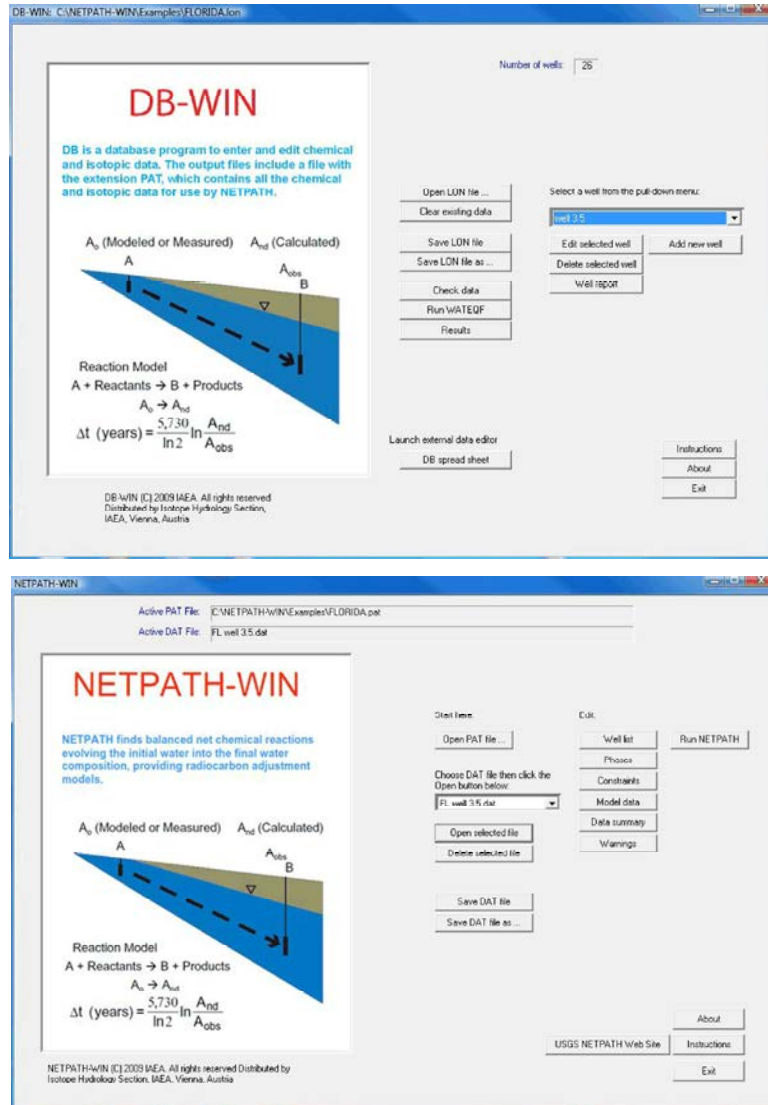


Fig. 5: Data base and NETPATH opening pages in the NETPATH-Win Model, (after El-Kadi et al., 2010)

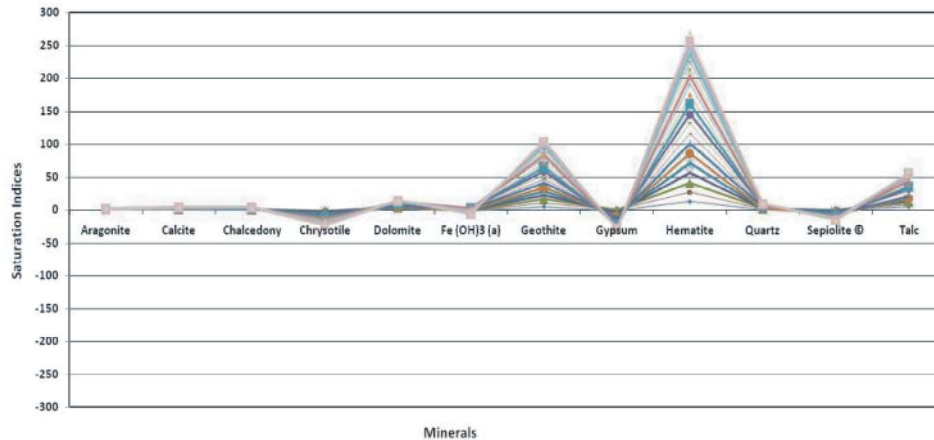


Fig. 6: Saturation indices with respect to minerals in the investigated groundwater samples

Table 5: Saturation indices of minerals in the study area

| Saturation indices of minerals | | | | | | | | | | | |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Minerals | 2 | 7 | 8 | 9 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Aragonite | 0.49 | 0.340 | 0.257 | -0.034 | -0.299 | 0.221 | -0.079 | 0.170 | 0.354 | 0.008 | -0.246 |
| Calcite | 0.64 | 0.480 | 0.396 | 0.108 | -0.158 | 0.363 | 0.060 | 0.310 | 0.493 | 0.148 | -0.107 |
| Chalcedony | 0.34 | 0.160 | 0.156 | 0.026 | 0.123 | 0.142 | 0.160 | 0.007 | 0.245 | 0.336 | 0.370 |
| Chrysotile | 0.49 | -0.890 | -0.890 | -1.439 | -2.562 | -2.040 | -1.748 | -1.146 | 1.699 | -1.165 | -0.766 |
| Dolomite | 1.62 | 1.089 | 1.089 | 0.394 | -0.069 | 0.824 | 0.533 | 0.841 | 1.860 | 0.802 | 0.439 |
| Fe (OH) ₃ (a) | -0.65 | -0.030 | -0.030 | 0.810 | -0.070 | 0.591 | 0.120 | 0.598 | 1.114 | -0.479 | 0.835 |
| Goethite | 5.08 | 5.650 | 5.652 | 6.595 | 5.653 | 6.366 | 5.767 | 6.297 | 6.786 | 5.192 | 6.507 |
| Gypsum | -0.38 | 1.290 | -1.288 | -3.297 | -3.619 | -1.928 | -3.084 | -2.289 | -2.520 | -2.194 | -2.006 |
| Hematite | 12.82 | 14.180 | 14.176 | 15.635 | 14.008 | 15.220 | 14.548 | 15.395 | 16.49 | 13.300 | 15.929 |
| Quartz | 0.76 | 0.390 | 0.566 | 0.446 | 0.538 | 0.560 | 0.568 | 0.419 | 0.654 | 0.746 | 0.780 |
| Sepiolite © | 0.52 | -0.385 | -0.764 | -1.237 | -1.889 | -1.457 | -1.364 | -1.164 | 1.099 | -0.656 | -0.334 |
| Talc | 4.94 | 3.711 | 3.197 | 2.352 | 1.446 | 1.985 | 2.361 | 2.638 | 5.968 | 3.288 | 3.755 |
| Saturation indices of minerals | | | | | | | | | | | |
| Minerals | 18 | 20 | 27 | 33 | 35 | 37 | 38 | 39 | 40 | 41 | |
| Aragonite | 0.094 | 0.020 | 0.458 | -0.337 | -0.242 | 0.368 | 0.169 | 0.018 | 0.326 | 0.294 | |
| Calcite | 0.235 | 0.162 | 0.600 | -0.196 | -0.102 | 0.510 | 0.312 | 0.161 | 0.468 | 0.435 | |
| Chalcedony | 0.228 | 0.243 | 0.283 | 0.263 | 0.302 | 0.366 | 0.248 | 0.162 | 0.135 | 0.270 | |
| Chrysotile | -1.703 | -1.047 | -1.394 | -0.526 | -1.728 | -1.636 | -2.198 | -3.020 | -0.784 | -1.761 | |
| Dolomite | 0.755 | 0.831 | 1.275 | -0.082 | -0.173 | 0.905 | 0.606 | 0.433 | 1.074 | 0.938 | |
| Fe (OH) ₃ (a) | -0.333 | 1.110 | -1.359 | -1.701 | -1.054 | -1.071 | -1.279 | -2.497 | -0.770 | -1.989 | |
| Goethite | 5.421 | 6.920 | 4.427 | 4.048 | 4.649 | 4.750 | 4.577 | 3.363 | 5.001 | 3.746 | |
| Gypsum | -2.822 | -2.050 | -0.241 | 0.078 | -0.382 | -0.503 | -0.315 | -0.595 | -0.447 | -0.492 | |
| Hematite | 13.416 | 16.183 | 11.300 | 10.702 | 12.086 | 11.801 | 11.309 | 8.866 | 12.506 | 10.153 | |
| Quartz | -1.703 | 0.665 | 0.703 | 0.680 | 0.715 | 0.789 | 0.674 | 0.588 | 0.553 | 0.685 | |
| Sepiolite © | -1.110 | -0.590 | -0.780 | -0.278 | -1.058 | -0.766 | -1.301 | -1.990 | -0.635 | -1.103 | |
| Talc | 2.503 | 3.168 | 2.912 | 3.755 | 2.646 | 2.822 | 2.011 | 1.014 | 3.230 | 2.538 | |

- The groundwater is supersaturated with respect to the main carbonate minerals (calcite, aragonite and dolomite) nearly at the most samples. This is clear where the pH values reflect slightly alkaline character. The main source of CO₂ in this aquifer is the atmosphere when reacts with rain water to form bicarbonate ion in addition to leaching of carbonate materials.
- The groundwater is supersaturated with respect to quartz and chalcedony. Quartz and chalcedony are indicators for erosion of aluminum silicates that built up the local soils composed of feldspars, kaolinite and micas [10].
- The groundwater is supersaturated with respect to iron mineral phases (hematite, goethite..etc). Hematite, goethite and Fe(OH)₃ reflect iron sensitivity to oxidation, even in low concentrations.
- The groundwater is supersaturated with respect to chrysotile, sepiolite and talc. This reflects the leaching effect of soil materials due to weathering of the surrounding rocks as well as agricultural activities.
- Results of saturation indices using WATEQFP contained in NETPATH are plotted (Figures 7, 8 & 9). From these isograms, it is clear that the trends of variation in the saturation indices of different minerals were nearly similar. The values of the indices are smaller in the recharge area if compared with those in the downgradient area. Those isograms provide information on the recharge and resident time (water-minerals reaction time) of groundwater [11].
- Within Quaternary aquifer, groundwater seems to be undersaturated with respect to gypsum (Fig. 9). It is undersaturated with respect to calcite and dolomite in the west area and oversaturated in the east area. This indicates that dissolution ability of groundwater is stronger in west than east. It can be inferred herein that the Quaternary aquifer development strength would become weak from west to east from the point of view of chemical thermodynamics, [11].

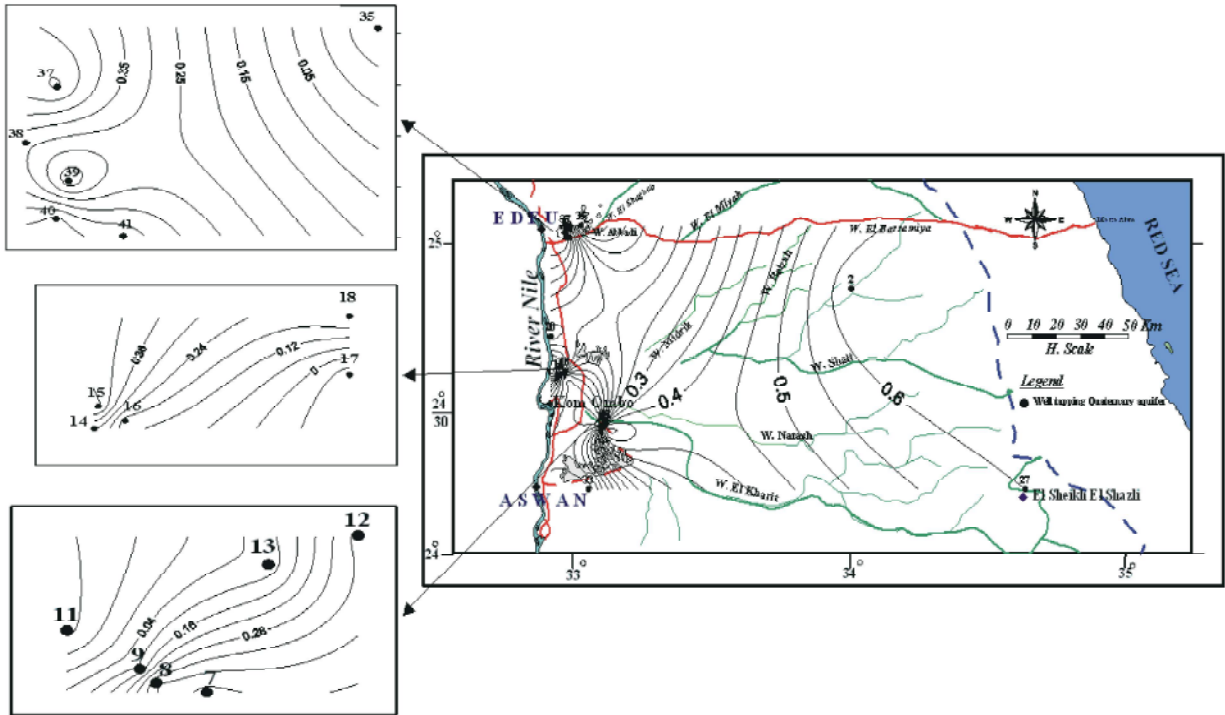


Fig. 7: Isogram of SI_{Calcite} in Quaternary aquifer

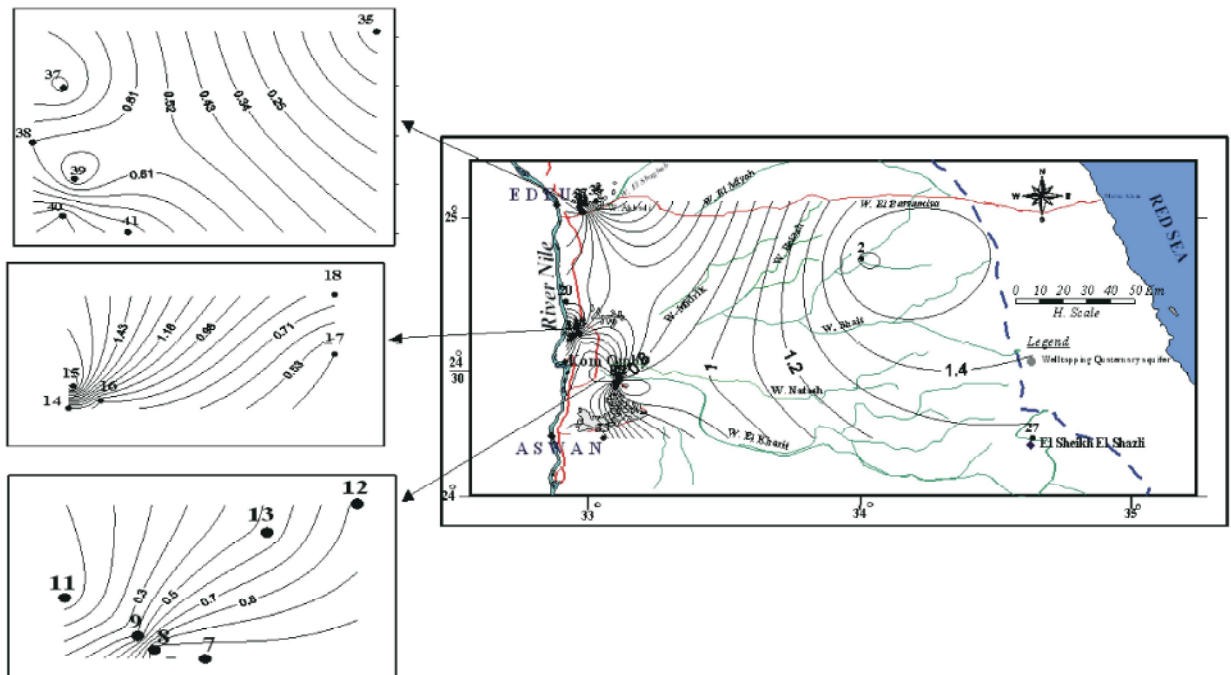


Fig. 8: Isogram of SI_{Dolomite} in Quaternary aquifer

As mentioned before, the groundwater samples are undersaturated with respect to Gypsum and oversaturated with Calcite and Dolomite (Figures 7, 8 & 9). The main reason for such widespread should be the

dilution caused by the mixing of the Quaternary groundwater with surface water which commonly has a low salinity and a Ca-HCO_3 major ion composition, [12].

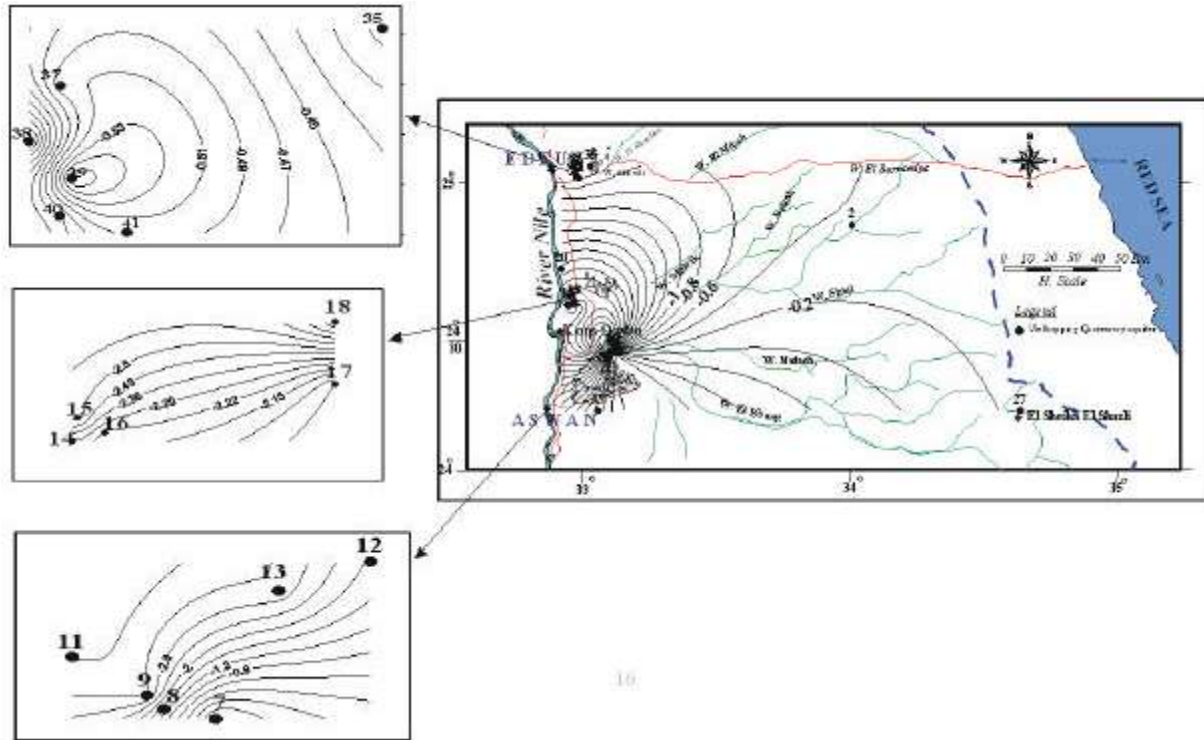


Fig. 9: Isogram of SI_{Gypsum} in Quaternary aquifer

Corrosivity and Scale Formation: Corrosion is a complex series of reactions between water and metal surfaces as well as materials in which the water is stored or transported. The corrosion process is an oxidation/reduction reaction that returns refined or processed metals to their more stable ore state. The primary concerns of the corrosion potential of water include the potential presence of toxic metals as lead and copper, deterioration and damage of the household plumbing as well as aesthetic problems such as; stained laundry, bitter taste and greenish-blue stains around basins and drains. In soft water, corrosion occurs due to the lack of dissolved cations such as calcium and magnesium, while in hard water a precipitate or coating of calcium or magnesium carbonate accumulate on the internal wall of pipes. This coating can inhibit the corrosion of the pipe, because it acts as a barrier, but it can also clog the pipe. Water with high levels of sodium, chloride, or other ions will increase water conductivity and promoting corrosion [12]. Saturation indices were used as an indicator of water corrosivity or scale formation. Table (6) presents a typical range of SI of calcite that may be encountered in a drinking water and a description of the nature of the water as well as the general recommendations regarding treatment [13].

According to the saturation indices of minerals in the investigated groundwater samples (Table 7) as indicator of water corrosivity or scale forming, the following could be deduced:

- The majority of groundwater samples (67%) are faint coating. Faint coating in the municipal wells (Nos. 7, 8, 9, 12, 13, 14, 15, 16, 18, 20, 38, 39, 40 & 41) may (by the time) lead to clog the pipes, which transport the water to the inhabitants, so, treatment is strongly recommended.
- About 19% of the investigated groundwater samples are mild corrosion (Nos. 11 in Wadi El Kharit, 17 in Wadi Midrik, 33 & 35 in Wadi Abbadi).
- About 14% of the investigated groundwater samples are mild scale forming (Nos. 2 in Wadi Muweilha, 27 in El Sheik El Shazly & 37 in Zakalona area).

Mass Balance Approach [11]: Mass balance of groundwater composition was simulated along the two paths (I and II) mentioned above (Figure 1). Path I is from initial samples Nos. 14, 15 & 20 at northwest to final sample No. 12 at southeast, while path II is from initial samples Nos. 2 & 27 at east to the final samples No. 35 at west.

Table 6: Classification of water corrosion potential based on the calcite saturation indices values and recommended treatments

| Saturation indices (SI) | Description | General recommendations | Saturation indices (SI) | Description | General recommendations |
|-------------------------|--------------------|--------------------------------|-------------------------|------------------------|--------------------------------|
| -5.0 | Severe corrosion | Treatment recommended | 0.5 | Some faint coating | Treatment typically not needed |
| -4.0 | Moderate corrosion | Treatment recommended | 1.0 | Mild scale forming | Some aesthetic problems |
| -3.0 | Moderate corrosion | Treatment recommended | 2.0 | Mild scale forming | Some aesthetic – considered |
| -2.0 | Moderate corrosion | Treatment should be considered | 3.0 | Moderate scale forming | Treatment should be considered |
| -1.0 | Mild corrosion | Treatment should be considered | 4.0 | Severe scale forming | Treatment probably required |
| -0.5 | Mild corrosion | Treatment probably not needed | 5.0 | Severe scale forming | Treatment required |
| 0.0 | Balanced | Treatment typically not needed | - | - | - |

Table 7: Classification of groundwater samples in the study area based on its tendency to be corrosive

| Sample No. | (SI) Calcite | Corrosivity | Sample No. | (SI) Calcite | Corrosivity |
|------------|--------------|--------------------|------------|--------------|--------------------|
| 2 | 0.64 | Mild scale forming | 27 | 0.6 | Mild scale forming |
| 7 | 0.48 | Faint coating | 33 | -0.196 | Mild corrosion |
| 8 | 0.396 | Faint coating | 35 | -0.102 | Mild corrosion |
| 9 | 0.108 | Faint coating | 37 | 0.51 | Mild scale forming |
| 11 | -0.158 | Mild corrosion | 38 | 0.312 | Faint coating |
| 12 | 0.363 | Faint coating | 39 | 0.161 | Faint coating |
| 13 | 0.06 | Faint coating | 40 | 0.468 | Faint coating |
| 14 | 0.31 | Faint coating | 41 | 0.435 | Faint coating |
| 15 | 0.493 | Faint coating | | | |
| 16 | 0.148 | Faint coating | | | |
| 17 | -0.107 | Mild corrosion | | | |
| 18 | 0.235 | Faint coating | | | |
| 20 | 0.162 | Faint coating | | | |

Table 8: Mass Balance Model for Quaternary groundwater aquifer

| Mineral Phase | Path I | | Path II | |
|---------------------|------------------|--|------------------|--|
| | Initial to Final | Process | Initial to Final | Process |
| Aragonite | 0.33 | Dissolution | -3.23 | Precipitation |
| Calcite | 0 | Dissolution | -3.23 | Precipitation |
| Dolomite | -0.48 | Precipitation | -2.64 | Precipitation |
| Gypsum | 0 | Dissolution | -8.41 | Precipitation |
| NaCl | -1.13 | Precipitation | -33.75 | Precipitation |
| Pyrite | - | - | -3.1 | Precipitation |
| Kaolinite | - | - | - | - |
| Quartz | - | - | - | - |
| Ca-Na Exchange | -0.64 | Na Exch. In the mineral and Ca released into groundwater | -17 | Na Exch. In the mineral and Ca released into groundwater |
| Goethite | -0.01 | Precipitation | 3.1 | Dissolution |
| CO ₂ gas | -0.66 | released | -6.5 | released |

The results of modeling I show that groundwater dissolves aragonite, calcite and gypsum from initial (water) points to final point, while dolomite, halite and goethite tend to precipitate along this path. Ca-Na ion exchange occurs where Na is exchanged in the mineral and Ca is released into groundwater. In addition, groundwater dissolves only the goethite from initial (water) points to final point in Path II, while aragonite, calcite, dolomite, gypsum, halite and Pyrite are precipitated along this path. Ca-Na ion exchange occurs (Table 8). The results indicate a groundwater flow from east to west (more chemical reactions, Path II).

Influence of River Nile on the Quaternary Aquifer:

The first initial water is sample No. 35 which represents the Quaternary aquifer, the second initial water is the sample S1 from the River Nile and the third initial water is the sample R1 from rain water (Table 9). The contribution of recent recharge from the River Nile to the Quaternary aquifer in the study area varies from low to high.

Also, plotting groundwater samples of the Quaternary aquifer on Trilinear diagram (Figure 10) showed that, some samples are clustered around the River Nile sample (inside the circle), indicating the effect of leakage on their chemistry [12]. In addition, all samples

Table 9: Mixing ratios for River Nile/Quaternary aquifer

| S.N | Final Sample | Initial 1% Groundwater (35) | Initial 2% River Nile (S1) | Initial 3% Rainwater R1 | Mixing degree With River Nile (S1) |
|-----|--------------|-----------------------------|----------------------------|-------------------------|------------------------------------|
| 1 | 2 | - | - | - | No Mixing |
| 2 | 7 | 1 | 97 | 2 | High |
| 3 | 8 | 11 | 86 | 3 | High |
| 4 | 9 | 0.3 | 76 | 23.7 | High |
| 5 | 11 | -- | -- | -- | No Mixing |
| 6 | 12 | 4.4 | 95.5 | 0.1 | High |
| 7 | 13 | 91 | 8.8 | 0.2 | Low |
| 8 | 14 | 0.8 | 66 | 33.2 | Moderate |
| 9 | 15 | 9 | 54 | 37 | Moderate |
| 10 | 16 | 3 | 85 | 12 | High |
| 11 | 17 | 22 | 74 | 4 | High |
| 12 | 18 | 1 | 62 | 37 | Moderate |
| 13 | 20 | 7 | 24 | 69 | Low |
| 14 | 27 | -- | -- | -- | No Mixing |
| 15 | 33 | -- | -- | -- | No Mixing |
| 16 | 37 | 30 | 58 | 12 | Moderate |
| 17 | 38 | 34 | 37 | 29 | Low |
| 18 | 39 | 25 | 59 | 16 | Moderate |
| 19 | 40 | 49 | 25 | 26 | Low |
| 20 | 41 | -- | -- | -- | No Mixing |

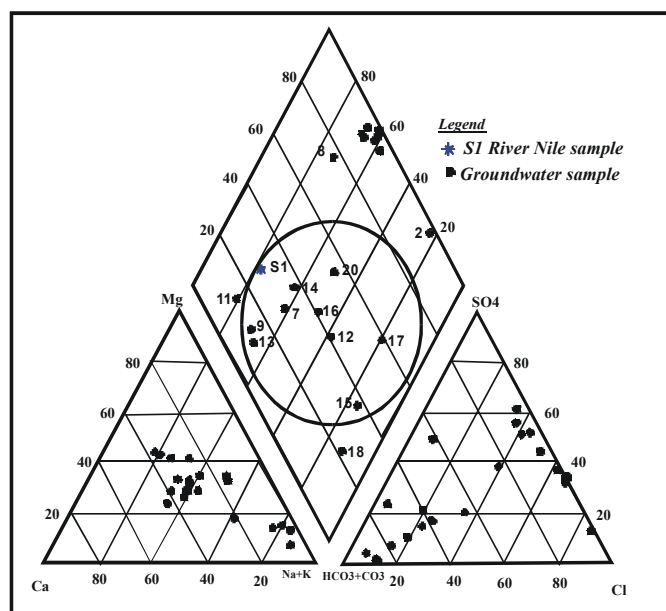


Fig. 10: Trilinear diagram for the Quaternary groundwater samples

located inside the circle are highly similar in water type (HCO_3^- - Na for all). Such similarity between these samples reflects high degree of mixing between various sources of waters [14].

Effect of Nitrate Concentration: The Quaternary groundwater samples had a wide range of nitrate concentrations from 8.55mg/l (No. 9) to 75.55 mg/l (No. 41) (Table 3), with standard deviation of about 22.32. This feature can be attributed to the different groundwater

ages [14], which resulted from the mixing between different water types.

Nitrate concentrations in groundwater were restricted to a low range in areas higher than 250 m a.s.l. (Figure 12). This feature is more clearly shown in the mountainous regions (Nos. 27, & 35). The extent of nitrate contamination is dramatically increased in the lower areas (Figure 11). This increase represents a change in land use from largely natural cover to residential and agricultural area [15].

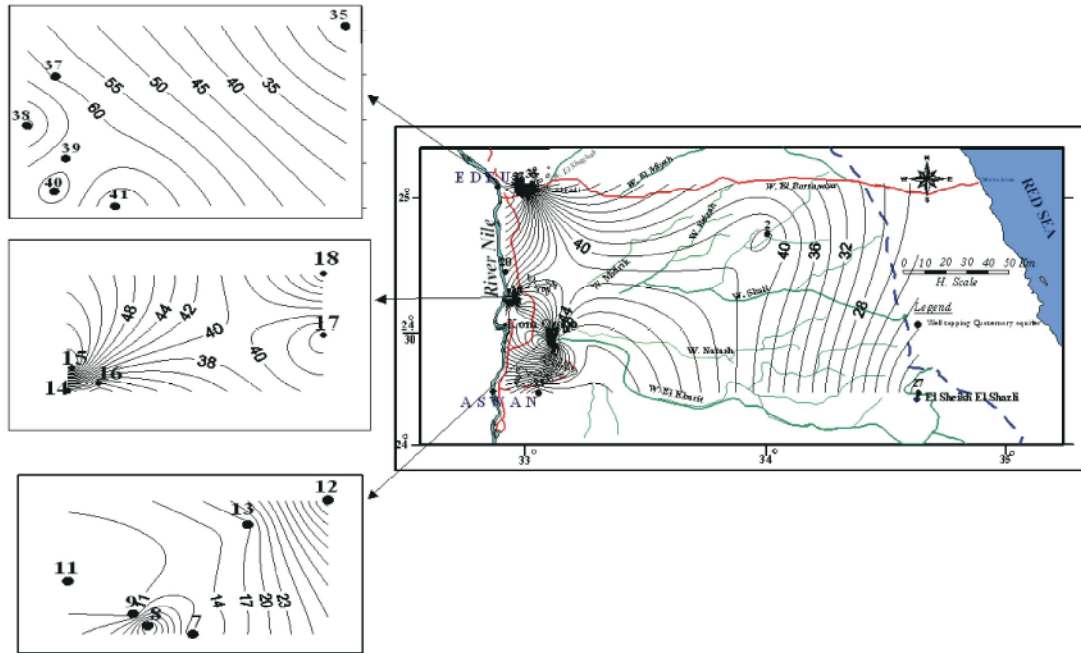


Fig. 11: Isogram of Nitrate distribution in Quaternary aquifer

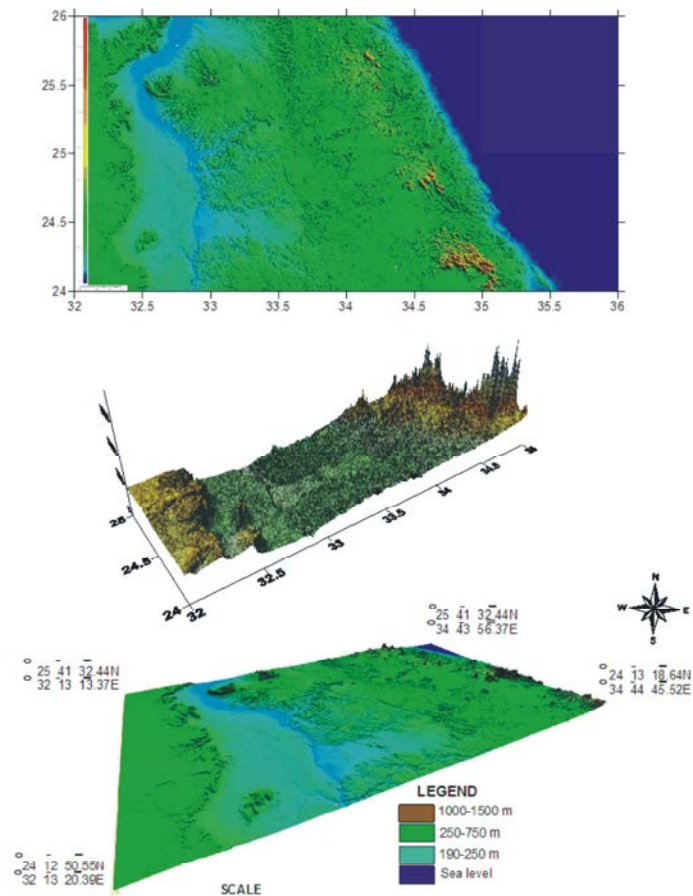


Fig. 12: Digital Elevation Model (DEM) of the study area

Table 10: The concentration of nitrate in samples (15 & 38) after mixing with samples (S1, S2 & 18)

| Sample | | Sample (15) (60.63 mg NO ₃ /L) | | | Sample (38) (76.74 mg NO ₃ /L) | | |
|-------------------|-----------|---|-----------------|-----------------|---|-----------------|-----------------|
| Mixing water | | (S1) 3.41 mg/L | (S2) 10.63 mg/L | (18) 28.37 mg/L | (S1) 3.41 mg/L | (S2) 10.63 mg/L | (18) 28.37 mg/L |
| Mixing Percentage | 1.0 : 0.0 | 60.63 | 60.63 | 60.63 | 76.74 | 76.74 | 76.74 |
| | 0.9 : 0.1 | 54.908 | 55.63 | 57.404 | 69.407 | 70.129 | 71.903 |
| | 0.8 : 0.2 | 49.186 | 50.63 | 54.178 | 62.074 | 63.518 | 67.066 |
| | 0.7 : 0.3 | 43.464 | 45.63 | 50.952 | 54.741 | 56.907 | 62.229 |
| | 0.6 : 0.4 | 37.742 | 40.63 | 47.726 | 47.408 | 50.296 | 57.392 |
| | 0.5 : 0.5 | 32.02 | 35.63 | 44.5 | 40.075 | 43.685 | 52.555 |
| | 0.4 : 0.6 | 26.298 | 30.63 | 41.274 | 32.742 | 37.074 | 47.718 |
| | 0.3 : 0.7 | 20.576 | 25.63 | 38.048 | 25.409 | 30.463 | 42.881 |
| | 0.2 : 0.8 | 14.854 | 20.63 | 34.822 | 18.076 | 23.852 | 38.044 |
| | 0.1 : 0.9 | 9.132 | 15.63 | 31.596 | 10.743 | 17.241 | 33.207 |
| | 0.0 : 1.0 | 3.41 | 10.63 | 28.37 | 3.41 | 10.63 | 28.37 |

Table 11: Chemistry changes of sample (15) due mixing with samples (S1, S2 & 18)

| | | | Mixing percentages (well 15: mixing water) | | | | | | | | |
|-------------------------------|--------------|-------------|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Item | Mixing water | Sample (15) | 0.9 : 0.1 | 0.8 : 0.2 | 0.7 : 0.3 | 0.6 : 0.4 | 0.5 : 0.5 | 0.4 : 0.6 | 0.3 : 0.7 | 0.2 : 0.8 | 0.1 : 0.9 |
| pH | (S1) 8 | 8.2 | 8.18 | 8.16 | 8.14 | 8.12 | 8.1 | 8.08 | 8.06 | 8.04 | 8.02 |
| | (S2) 7.6 | | 8.14 | 8.08 | 8.02 | 7.96 | 7.9 | 7.84 | 7.78 | 7.72 | 7.66 |
| | 18 7.9 | | 8.17 | 8.14 | 8.11 | 8.08 | 8.05 | 8.02 | 7.99 | 7.96 | 7.93 |
| TDS | (S1) 180.88 | 1010.58 | 927.61 | 844.64 | 761.67 | 678.7 | 595.73 | 512.76 | 429.79 | 346.82 | 263.85 |
| | (S2) 144.11 | | 923.933 | 837.286 | 750.639 | 663.992 | 577.345 | 490.698 | 404.051 | 317.404 | 230.757 |
| | 18 609.51 | | 970.473 | 930.366 | 890.259 | 850.152 | 810.045 | 769.938 | 729.831 | 689.724 | 649.617 |
| Ca ²⁺ | (S1) 25.26 | 10.53 | 12.003 | 13.476 | 14.949 | 16.422 | 17.895 | 19.368 | 20.841 | 22.314 | 23.787 |
| | (S2) 27.03 | | 12.18 | 13.83 | 15.48 | 17.13 | 18.78 | 20.43 | 22.08 | 23.73 | 25.38 |
| | 18 12.63 | | 10.74 | 10.95 | 11.16 | 11.37 | 11.58 | 11.79 | 12 | 12.21 | 12.42 |
| Mg ²⁺ | (S1) 18.16 | 29.41 | 28.285 | 27.16 | 26.035 | 24.91 | 23.785 | 22.66 | 21.535 | 20.41 | 19.285 |
| | (S2) 11.35 | | 27.604 | 25.798 | 23.992 | 22.186 | 20.38 | 18.574 | 16.768 | 14.962 | 13.156 |
| | 18 9.72 | | 27.441 | 25.472 | 23.503 | 21.534 | 19.565 | 17.596 | 15.627 | 13.658 | 11.689 |
| Na ⁺ | (S1) 14 | 355 | 27.869 | 26.328 | 24.787 | 23.246 | 21.705 | 20.164 | 18.623 | 17.082 | 15.541 |
| | (S2) 13 | | 27.769 | 26.128 | 24.487 | 22.846 | 21.205 | 19.564 | 17.923 | 16.282 | 14.641 |
| | 18 225 | | 48.969 | 68.528 | 88.087 | 107.646 | 127.205 | 146.764 | 166.323 | 185.882 | 205.441 |
| K ⁺ | (S1) 6 | 8 | 7.8 | 7.6 | 7.4 | 7.2 | 7 | 6.8 | 6.6 | 6.4 | 6.2 |
| | (S2) 4 | | 7.6 | 7.2 | 6.8 | 6.4 | 6 | 5.6 | 5.2 | 4.8 | 4.4 |
| | 18 5 | | 7.7 | 7.4 | 7.1 | 6.8 | 6.5 | 6.2 | 5.9 | 5.6 | 5.3 |
| CO ₃ ²⁻ | (S1) 9.09 | 60.6 | 55.449 | 50.298 | 45.147 | 39.996 | 34.845 | 29.694 | 24.543 | 19.392 | 14.241 |
| | (S2) 12.12 | | 55.752 | 50.904 | 46.056 | 41.208 | 36.36 | 31.512 | 26.664 | 21.816 | 16.968 |
| | 18 45.45 | | 59.085 | 57.57 | 56.055 | 54.54 | 53.025 | 51.51 | 49.995 | 48.48 | 46.965 |
| HCO ₃ ⁻ | (S1) 129.38 | 565.2 | 521.618 | 478.036 | 434.454 | 390.872 | 347.29 | 303.708 | 260.126 | 216.544 | 172.962 |
| | (S2) 123.22 | | 521.002 | 476.804 | 432.606 | 388.408 | 344.21 | 300.012 | 255.814 | 211.616 | 167.418 |
| | 18 437.43 | | 552.423 | 539.646 | 526.869 | 514.092 | 501.315 | 488.538 | 475.761 | 462.984 | 450.207 |
| SO ₄ ²⁻ | (S1) 37.3 | 126.89 | 117.931 | 108.972 | 100.013 | 91.054 | 82.095 | 73.136 | 64.177 | 55.218 | 46.259 |
| | (S2) 0.54 | | 114.255 | 101.62 | 88.985 | 76.35 | 63.715 | 51.08 | 38.445 | 25.81 | 13.175 |
| | 18 36.87 | | 117.888 | 108.886 | 99.884 | 90.882 | 81.88 | 72.878 | 63.876 | 54.874 | 45.872 |
| Cl ⁻ | (S1) 6.38 | 137.55 | 124.433 | 111.316 | 98.199 | 85.082 | 71.965 | 58.848 | 45.731 | 32.614 | 19.497 |
| | (S2) 14.46 | | 125.241 | 112.932 | 100.623 | 88.314 | 76.005 | 63.696 | 51.387 | 39.078 | 26.769 |
| | 18 56.12 | | 129.407 | 121.264 | 113.121 | 104.978 | 96.835 | 88.692 | 80.549 | 72.406 | 64.263 |
| NO ₃ ⁻ | (S1) 3.41 | 60.63 | 54.908 | 49.186 | 43.464 | 37.742 | 32.02 | 26.298 | 20.576 | 14.854 | 9.132 |
| | (S2) 10.63 | | 55.63 | 50.63 | 45.63 | 40.63 | 35.63 | 30.63 | 25.63 | 20.63 | 15.63 |
| | 18 28.37 | | 57.404 | 54.178 | 50.952 | 47.726 | 44.5 | 41.274 | 38.048 | 34.822 | 31.596 |
| Fe | (S1) 0 | 0.49 | 0.441 | 0.392 | 0.343 | 0.294 | 0.245 | 0.196 | 0.147 | 0.098 | 0.049 |
| | (S2) 0.23 | | 0.464 | 0.438 | 0.412 | 0.386 | 0.36 | 0.334 | 0.308 | 0.282 | 0.256 |
| | 18 0.1 | | 0.451 | 0.412 | 0.373 | 0.334 | 0.295 | 0.256 | 0.217 | 0.178 | 0.139 |

Table 12: Chemistry changes of sample (38) due mixing with samples (S1, S2 & 18)

| Item | Mixing water | | Sample (38) | Mixing 'percentages (well 38: mixing water) | | | | | | | | |
|-------------------------------|--------------|--------|-------------|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | | | | 0.9 : 0.1 | 0.8 : 0.2 | 0.7 : 0.3 | 0.6 : 0.4 | 0.5 : 0.5 | 0.4 : 0.6 | 0.3 : 0.7 | 0.2 : 0.8 | 0.1 : 0.9 |
| pH | S1) | 8 | 7.4 | 7.46 | 7.52 | 7.58 | 7.64 | 7.7 | 7.76 | 7.82 | 7.88 | 7.94 |
| | (S2) | 7.6 | | 7.42 | 7.44 | 7.46 | 7.48 | 7.5 | 7.52 | 7.54 | 7.56 | 7.58 |
| | 18 | 7.9 | | 7.45 | 7.5 | 7.55 | 7.6 | 7.65 | 7.7 | 7.75 | 7.8 | 7.85 |
| TDS | (S1) | 180.88 | 2967.55 | 2688.883 | 2410.216 | 2131.549 | 1852.882 | 1574.215 | 1295.548 | 1016.881 | 738.214 | 459.547 |
| | (S2) | 144.11 | | 2685.206 | 2402.862 | 2120.518 | 1838.174 | 1555.83 | 1273.486 | 991.142 | 708.798 | 426.454 |
| | 18 | 609.51 | | 2731.746 | 2495.942 | 2260.138 | 2024.334 | 1788.53 | 1552.726 | 1316.922 | 1081.118 | 845.314 |
| Ca ²⁺ | (S1) | 25.26 | 385.2 | 349.206 | 313.212 | 277.218 | 241.224 | 205.23 | 169.236 | 133.242 | 97.248 | 61.254 |
| | (S2) | 27.03 | | 349.383 | 313.566 | 277.749 | 241.932 | 206.115 | 170.298 | 134.481 | 98.664 | 62.847 |
| | 18 | 12.63 | | 347.943 | 310.686 | 273.429 | 236.172 | 198.915 | 161.658 | 124.401 | 87.144 | 49.887 |
| Mg ²⁺ | (S1) | 18.16 | 166.22 | 151.414 | 136.608 | 121.802 | 106.996 | 92.19 | 77.384 | 62.578 | 47.772 | 32.966 |
| | (S2) | 11.35 | | 150.733 | 135.246 | 119.759 | 104.272 | 88.785 | 73.298 | 57.811 | 42.324 | 26.837 |
| | 18 | 9.72 | | 150.57 | 134.92 | 119.27 | 103.62 | 87.97 | 72.32 | 56.67 | 41.02 | 25.37 |
| Na ⁺ | (S1) | 14 | 370 | 334.4 | 298.8 | 263.2 | 227.6 | 192 | 156.4 | 120.8 | 85.2 | 49.6 |
| | (S2) | 13 | | 334.3 | 298.6 | 262.9 | 227.2 | 191.5 | 155.8 | 120.1 | 84.4 | 48.7 |
| | 18 | 225 | | 355.5 | 341 | 326.5 | 312 | 297.5 | 283 | 268.5 | 254 | 239.5 |
| K ⁺ | S1) | 6 | 9 | 8.7 | 8.4 | 8.1 | 7.8 | 7.5 | 7.2 | 6.9 | 6.6 | 6.3 |
| | (S2) | 4 | | 8.5 | 8 | 7.5 | 7 | 6.5 | 6 | 5.5 | 5 | 4.5 |
| | 18 | 5 | | 8.6 | 8.2 | 7.8 | 7.4 | 7 | 6.6 | 6.2 | 5.8 | 5.4 |
| CO ₃ ²⁻ | (S1) | 9.09 | 15.15 | 14.544 | 13.938 | 13.332 | 12.726 | 12.12 | 11.514 | 10.908 | 10.302 | 9.696 |
| | (S2) | 12.12 | | 14.847 | 14.544 | 14.241 | 13.938 | 13.635 | 13.332 | 13.029 | 12.726 | 12.423 |
| | 18 | 45.45 | | 18.18 | 21.21 | 24.24 | 27.27 | 30.3 | 33.33 | 36.36 | 39.39 | 42.42 |
| HCO ₃ ⁻ | (S1) | 129.38 | 113.98 | 115.52 | 117.06 | 118.6 | 120.14 | 121.68 | 123.22 | 124.76 | 126.3 | 127.84 |
| | (S2) | 123.22 | | 114.904 | 115.828 | 116.752 | 117.676 | 118.6 | 119.524 | 120.448 | 121.372 | 122.296 |
| | 18 | 437.43 | | 146.325 | 178.67 | 211.015 | 243.36 | 275.705 | 308.05 | 340.395 | 372.74 | 405.085 |
| SO ₄ ²⁻ | (S1) | 37.3 | 1391 | 1255.63 | 1120.26 | 984.89 | 849.52 | 714.15 | 578.78 | 443.41 | 308.04 | 172.67 |
| | (S2) | 0.54 | | 1251.954 | 1112.908 | 973.862 | 834.816 | 695.77 | 556.724 | 417.678 | 278.632 | 139.586 |
| | 18 | 36.87 | | 1255.587 | 1120.174 | 984.761 | 849.348 | 713.935 | 578.522 | 443.109 | 307.696 | 172.283 |
| Cl ⁻ | (S1) | 6.38 | 573.99 | 517.229 | 460.468 | 403.707 | 346.946 | 290.185 | 233.424 | 176.663 | 119.902 | 63.141 |
| | (S2) | 14.46 | | 518.037 | 462.084 | 406.131 | 350.178 | 294.225 | 238.272 | 182.319 | 126.366 | 70.413 |
| | 18 | 56.12 | | 522.203 | 470.416 | 418.629 | 366.842 | 315.055 | 263.268 | 211.481 | 159.694 | 107.907 |
| NO ₃ ⁻ | (S1) | 3.41 | 76.74 | 69.407 | 62.074 | 54.741 | 47.408 | 40.075 | 32.742 | 25.409 | 18.076 | 10.743 |
| | (S2) | 10.63 | | 70.129 | 63.518 | 56.907 | 50.296 | 43.685 | 37.074 | 30.463 | 23.852 | 17.241 |
| | 18 | 28.37 | | 71.903 | 67.066 | 62.229 | 57.392 | 52.555 | 47.718 | 42.881 | 38.044 | 33.207 |
| Fe | (S1) | 0 | 0.44 | 0.396 | 0.352 | 0.308 | 0.264 | 0.22 | 0.176 | 0.132 | 0.088 | 0.044 |
| | (S2) | 0.23 | | 0.419 | 0.398 | 0.377 | 0.356 | 0.335 | 0.314 | 0.293 | 0.272 | 0.251 |
| | 18 | 0.1 | | 0.406 | 0.372 | 0.338 | 0.304 | 0.27 | 0.236 | 0.202 | 0.168 | 0.134 |

Mixing Models: The mix samples generate concentrations as a result of the step-wise mixing of specified proportions of two selected samples from the investigated samples. The parameters that will be included in the mixing calculations could be selected (typically you should select parameters that you know are common to each sample). Such mixings can show that the evolution of the brackish water is possibly due to hydraulic mixing of fresh and saline waters within the aquifer matrix and/or in well mixing. In this section, mixing models were conducted between water from different sources as a proposed solution for lowering the chemical content, specially nitrate levels in the highly contaminated wells to the acceptable limits. For mixing each of the input solutions, it is multiplied by its mixing fraction and a new output solution is calculated stoichiometrically [16].

In this model, the water samples (Nos. 15 and 38) were mixed with Nile water (S1), irrigation canal water (S2) and water sample (No. 18). The mixing model in this section mainly aims to lower the chemical content of water sample (No. 15) for using it in drinking, irrigation and industrial targets by mixing with Nile water, water of irrigation canal or fresh water sample (No. 18). The model aims also to lower the high nitrate concentration in the water samples (No.15 and 38) to a level below the acceptable level of nitrates for drinking water (45 mg/l) with the same mixing samples. The mixing could be done in the house cisterns, the roof tanks and in the pools. The averaged chemical composition of the water samples (Nos. 15 and 38) was mixed with different percentages (0.9:0.1, 0.8:0.2, ..., 0.1:0.9) from water samples (Nos. S1, S2 and 18). The changes in the nitrate concentration in

the water samples (Nos. 15 and 38) as a result of the mixing processes are summarized (Table 10), while the changes in the concentrations of the major cations and anions are tabulated (Tables 11 & 12).

Table (10) shows that, 30% or less mixing percentage of water samples (Nos. 15 and 38) with 70% or more of mixing water (Nos. S1, S2 and 18) is necessary to lower nitrate concentration in the water even to less than acceptable level of nitrate (45 mg/l) in drinking water. Nitrate content is only an example of the water characteristics that could be improved and controlled by mixing, thus mixing could be considered as an effective water treatment method. Mixing is used also for lowering the total salinity (TDS) of the saline water in the desert or in the coastal areas by mixing with fresh water samples to use it in industrial and agricultural projects.

CONCLUSIONS

Recently, several approaches including hydrogeochemistry and modeling have been used to investigate the Quaternary groundwater system in the area between Idfu and Aswan, Eastern Desert, Egypt. The software package Mass-Balance Model, NETPATH for windows was used to perform a variety of aqueous geochemical calculations including; the saturation indices (SI) of the major mineral phases, testing of water corrosivity, influencing of the River Nile on the groundwater and to apply water mixing models.

To achieve the main target of the article, twenty-one groundwater samples representing the Quaternary aquifer, beside two surface water samples were collected from the study area and chemically analyzed.

The hydrochemical results show that, the groundwater salinity increases eastward, where its quality varies between fresh in the west and slightly saline due east. Also groundwater varies from soft to highly hard.

The saturation indices of the major mineral phases in the investigated groundwater samples show that:

- Most of groundwater are supersaturated with respect to iron mineral phases (hematite, goethite..etc). Such minerals reflect the sensitivity of iron to oxidation even in low concentrations.
- Groundwater is supersaturated with respect to the main carbonate minerals (calcite, aragonite and dolomite).
- Groundwater is supersaturated with respect to quartz and chalcedony, such minerals are considered

indicators for erosion of dolomite as well as aluminum silicates that built up the local soils (feldspars, kaolinite and micas).

- Groundwater is supersaturated with respect to chrysotile, sepiolite, talc and rhodochrosite. This reflects the leaching effect of soil materials due to weathering of the surrounding rocks as well as agricultural activities.
- The investigated groundwater varies from mild corrosion (19%), faint coating forming in the majority of samples (67%) up to mild scale forming (14%).
- The contribution of recent recharge from Nile water to the Quaternary aquifer is noticed in the study area and varies from moderate to high.

Distributions of saturation indices for calcite, dolomite and gypsum indicate that the Quaternary development strength becomes weak from west to East. Mass balance approach interprets quantitatively the evolution of groundwater chemistry. Those results are very helpful to understand groundwater system in the future study. Nitrate concentrations in considerable mountainous groundwater were significantly elevated in response to increasing anthropogenic land uses toward the west.

Also, mixing model was conducted between water from different sources. The obtained results reflect that, the mixing can be used as an effective method for water treatment (in particular, lowering nitrate levels).

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