

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 the water 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, impact of River Nile on the groundwater and application of water mixing models. To achieve the main target of this research, twenty-one groundwater samples representing the Quaternary aquifer, besides three surface water samples from different sources were collected 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: 1-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. 2-Groundwater is supersaturated with respect to the main carbonate minerals (calcite, aragonite and dolomite). 3-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). 4-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. 5-The investigated groundwater varies from mild corrosion (19%), faint coating forming in the majority of samples (67%) up to mild scale forming (14%). 6- The contribution of recent recharge from Nile River to the Quaternary aquifer is noticed in the study area and varies from low to high. The distributions of saturation indices of 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. These results are very helpful to the understanding of groundwater system and to the future study in the study area. Nitrate concentrations in groundwater towards west significantly elevated in response to increasing anthropogenic land uses. 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, Quaternary aquifer, Hydrogeochemical Modeling Eastern Desert, Idfu and Aswan

Introduction

Mostly, groundwater is more desirable than surface water for many reasons, as absence of pathogenic organisms, no radiochemical or 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 22500 km² (Figure 1). It is limited by Latitudes 24° 00' & 25° 12' N and Longitudes 32° 55' & 35° 48' E. It is located within the flood plain of the Nile valley 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 (El wan, 2008). 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 past rainy periods (Abdel Kader, 2001). New information indicates recharge from return flow after irrigation and infiltration from flush floods coming from the mountainous region. The hydraulic conductivity of the investigated aquifer in the central portion is about 80 m/day (Abdel Kreem, 2000).

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 chemically analyzed for major elements and some minor ones. The analyses were performed in the central lab, Desert Research Center (DRC), Egypt, according to the methods adopted by the United States Geological Survey (Rainwater and Thatcher, 1960), methods of determination for inorganic substances in water and fluvial sediments (Fishman and Friedman, 1985 and American Society for Testing and Materials ASTM, 2002), (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:

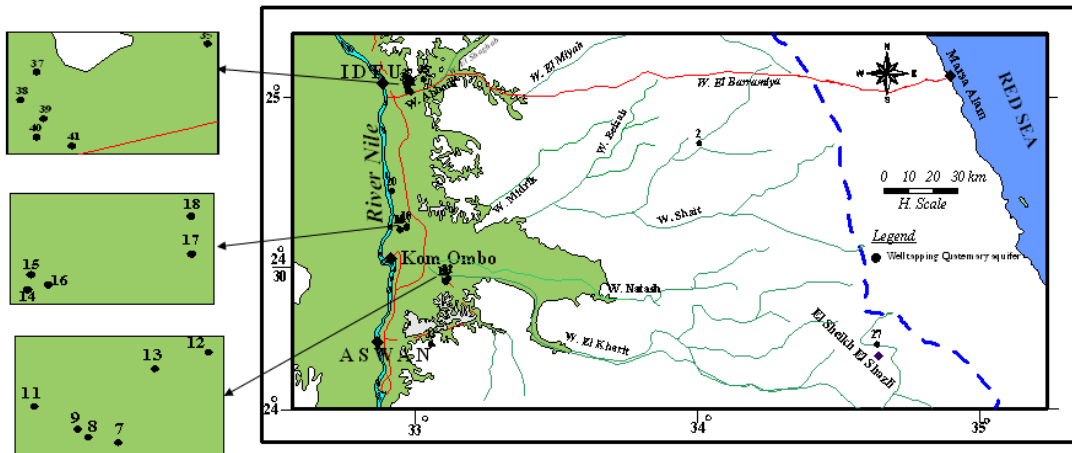


Fig. 1: wells' location map of Quaternary aquifer in the study area.

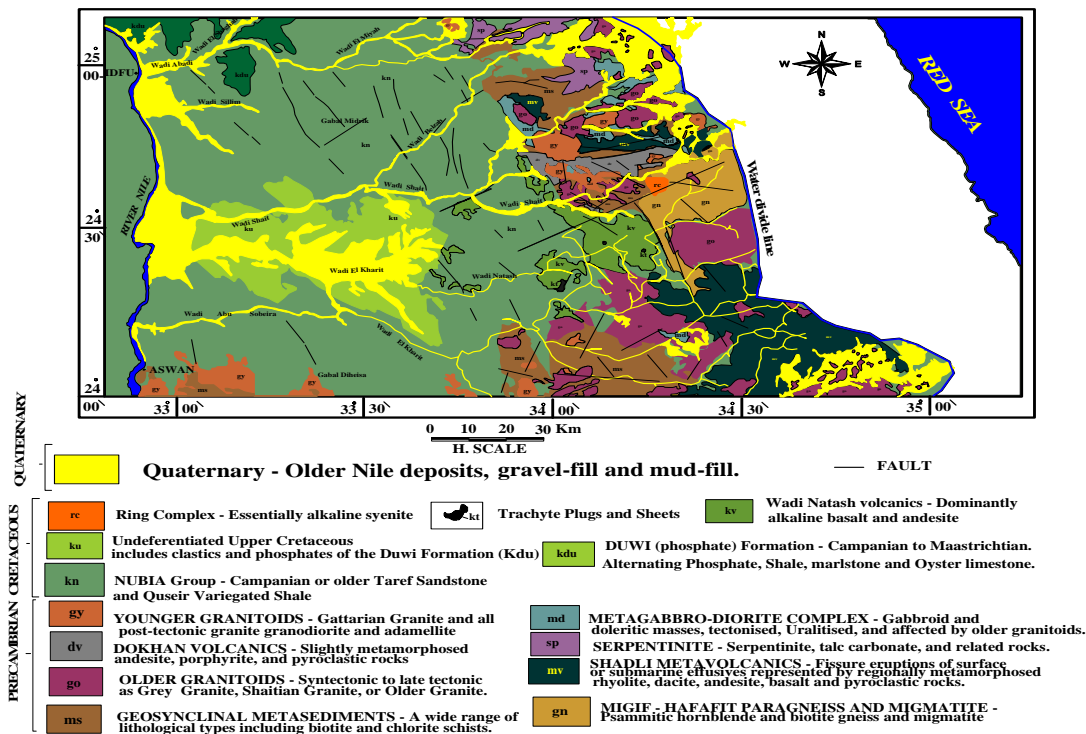


Fig. 2: Geologic map of the study area (After geologic map of Aswan quadrangle, Egypt 1978).

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

1- 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).

2- 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.

3- 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), relating to fresh and saline water categories. It was observed that 57% of the sampled wells are fresh (Nos. 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18 & 20) while 29% are brackish (Nos. 27, 35, 37, 38, 39 & 40) and 14% are saline (Nos. 2, 33 & 41). The salinity values decrease due west towards the cultivated land of the study area. This is mainly attributed to dilution processes from the irrigated lands.

4- Again, it was noticed that the mean values of total, permanent and temporary hardness attain 195.52, 34.65 and 259.25 mg/l as CaCO₃ in the fresh groundwater respectively and 1676.5, 1549.5 and 126.99mg/l in the brackish groundwater and 4159.08, 4036.09 and 122.98mg/l in the saline to highly saline groundwater. These data indicate an increase in total and permanent hardness with the increase of water salinity except the relation with temporary hardness, (Figure 4). This is mainly attributed to the effect of leaching and dissolution of soluble salts which lead to the increase of hardness with particular importance to the effect of NaCl on increasing solubility of Ca²⁺ and Mg²⁺ in water (Freeze and Cherry, 1979 & Hem, 1989), taking into consideration the contribution of the CO₂ and longer residence time as well as the influence of salty water and cation exchange processes.

5- Alkalinity ranges between 25.27 mg/l as CaCO₃ (No. 33) in Wadi Abbadi and 564.74 mg/l as CaCO₃ (No. 15) in Wadi Midrik.

Table 2: Hydrochemical analyses data of the investigated groundwater samples in mg/l. (2010).

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 (2003) and (Moore *et al.*, 2011).

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

Geochemical Modeling:

The software package NETPATH for windows, (El-Kadi *et al.*, 2010), (Figure 5) is used to evaluate the subsurface geochemical processes and to provide 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 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.

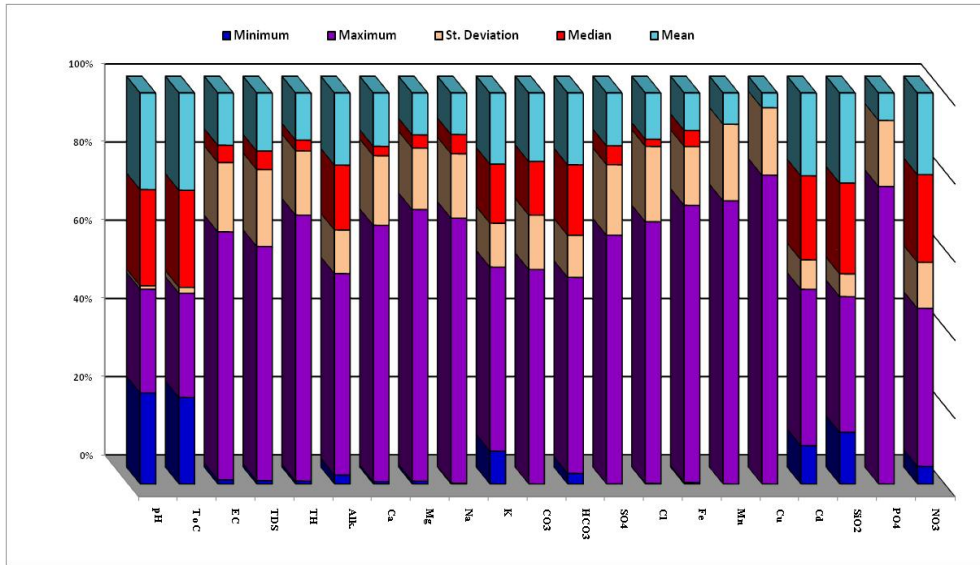


Fig. 3: Descriptive statistics of the investigated groundwater samples.

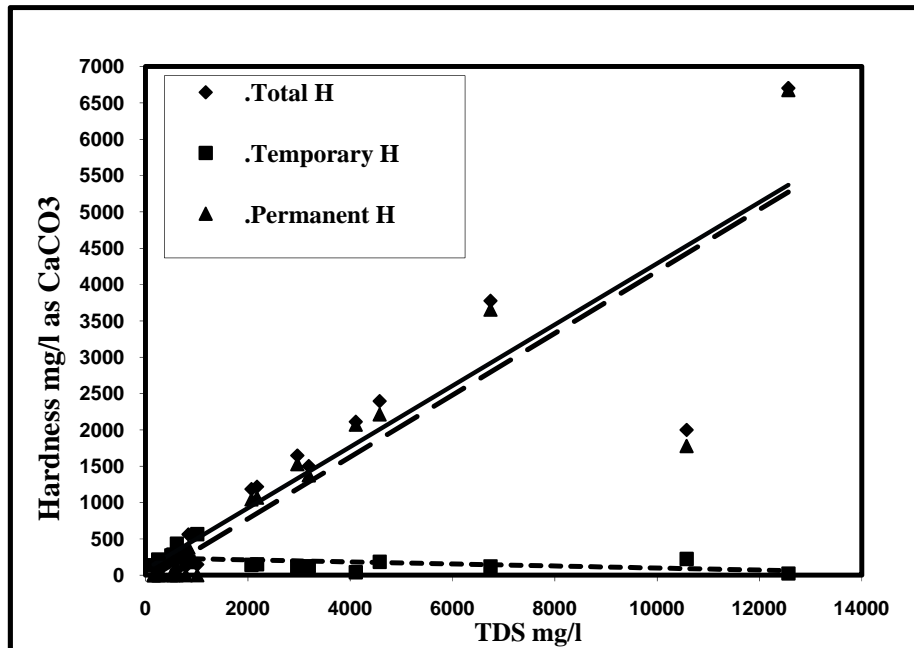


Fig. 4: Relationship between Salinity and Hardness in the Quaternary groundwater.

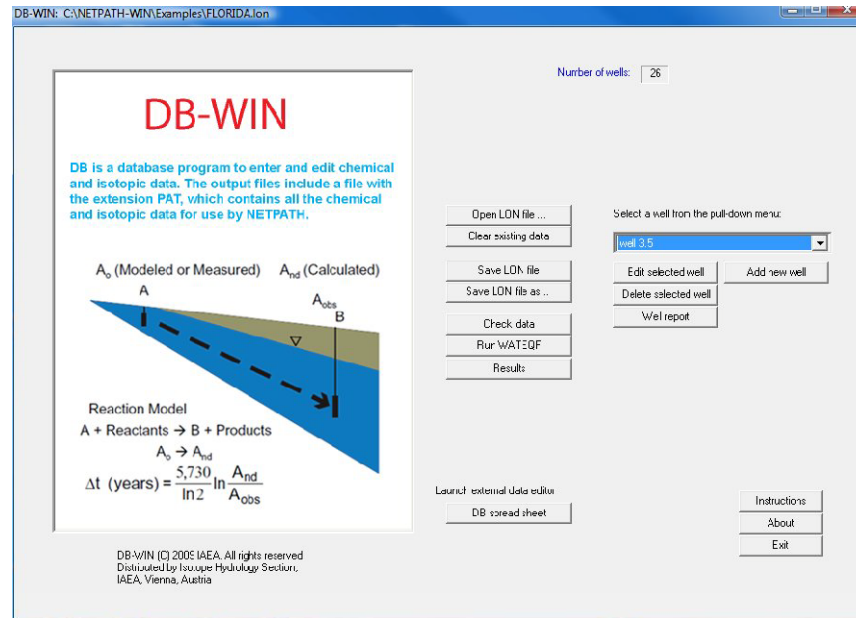
a) Chemical equilibrium and saturation indices (SI):

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.

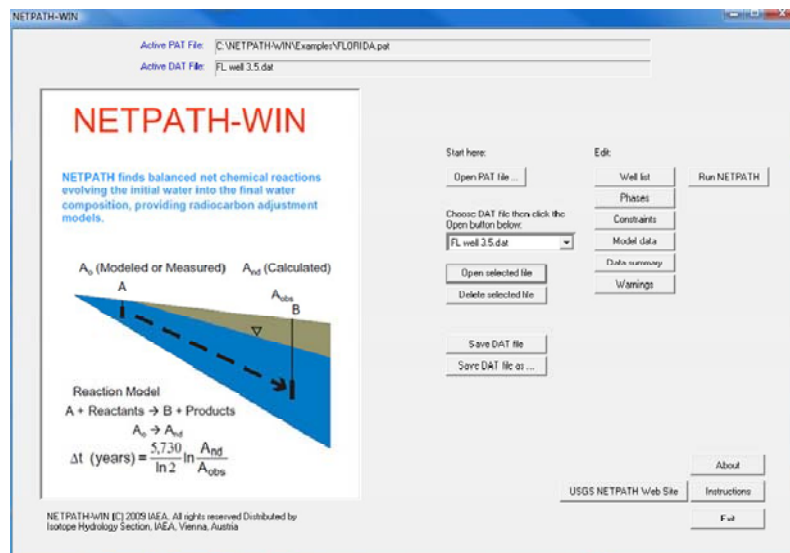
Generally, the saturation indices are used to express the water tendency towards precipitation or dissolution. The degree of water saturation with respect to a mineral is given by: $SI = \log (K_{IAP} / K_{SP})$, where K_{IAP} is the ionic activity product, K_{SP} is the solubility product, and SI is 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 & Figure 6) reflect that:

1-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.



(a)



(b)

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

2-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 (Mahmoud, 2005).

3-The groundwater is supersaturated with respect to iron mineral phases (hematite, goethite..etc). Hematite, goethite and Fe(OH₃) reflect iron sensitivity to oxidation, even in low concentrations.

4-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.

Table 5: Saturation indices of minerals in the study area

Minerals	Well numbers										
	2	7	8	9	11	12	13	14	15	16	17
Aragonite	0.49	0.34	0.257	-0.034	-0.299	0.221	-0.079	0.170	0.354	0.008	-0.246
Calcite	0.64	0.48	0.396	0.108	-0.158	0.363	0.060	0.310	0.493	0.148	-0.107
Chalcedony	0.34	0.16	0.156	0.026	0.123	0.142	0.160	0.007	0.245	0.336	0.370
Chrysotile	0.49	-0.89	-0.89	-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	-0.03	-0.03	0.810	-0.070	0.591	0.120	0.598	1.114	-0.479	0.835
Geothite	5.08	5.65	5.652	6.595	5.653	6.366	5.767	6.297	6.786	5.192	6.507
Gypsum	-0.38	1.29	-1.288	-3.297	-3.619	-1.928	-3.084	-2.289	-2.520	-2.194	-2.006
Hematite	12.82	14.18	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

Minerals	Well numbers									
	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
Geothite	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

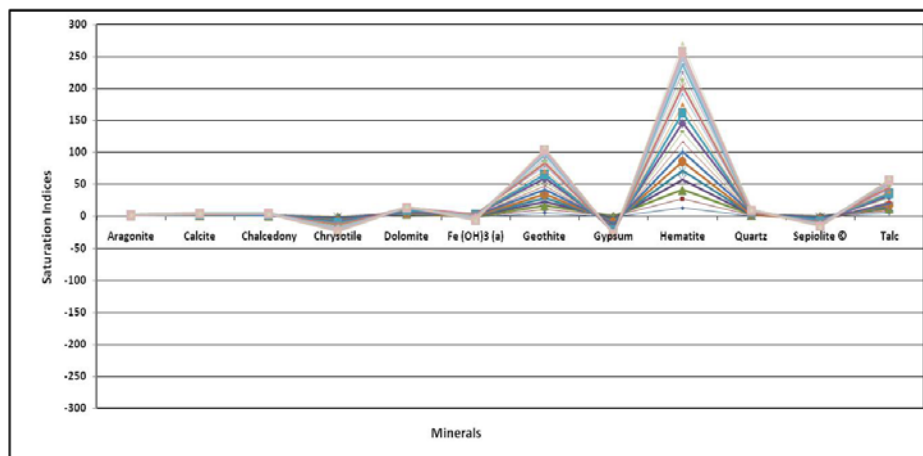


Fig. 6: Saturation indices with respect to minerals in the investigated groundwater samples

5- 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 (Wang *et al.*, 1998).

6- Within Quaternary aquifer, groundwater seems to be undersaturated with respect to gypsum (Figure 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, (Wang *et al.*, 1998).

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-HCO₃ major ion composition, (Wang *et al.*, 2001).

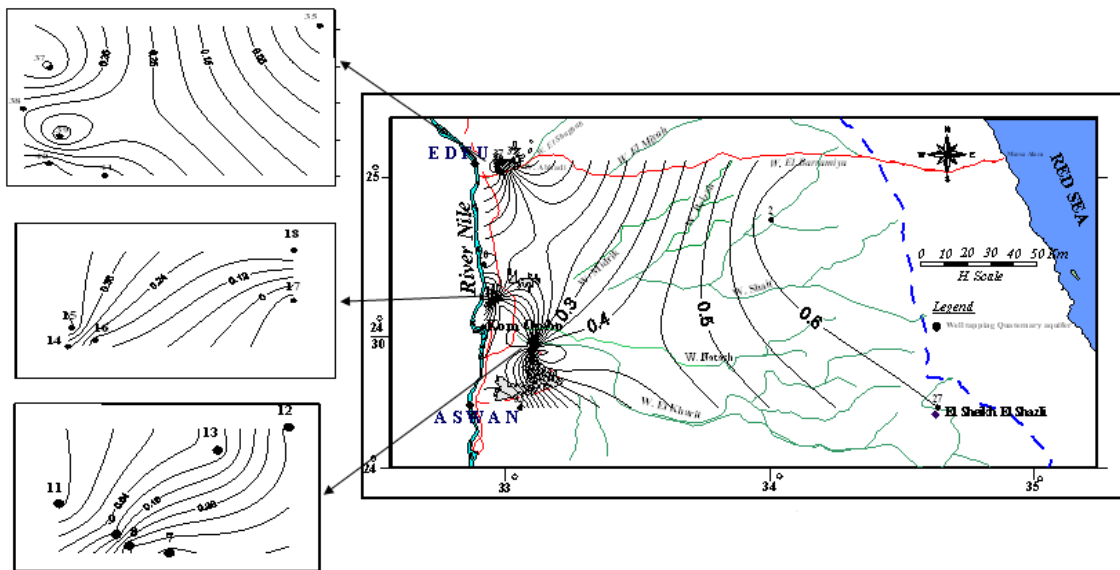


Fig. 7: Isogram of $SI_{Calcite}$ in Quaternary aquifer

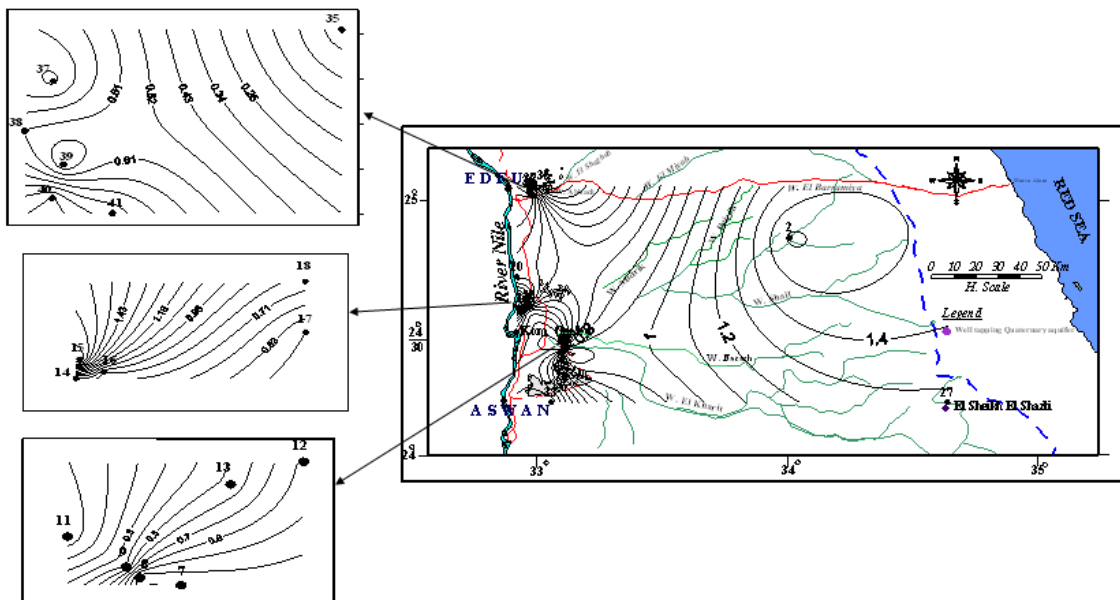


Fig. 8: Isogram of $SIDolomite$ in Quaternary aquifer

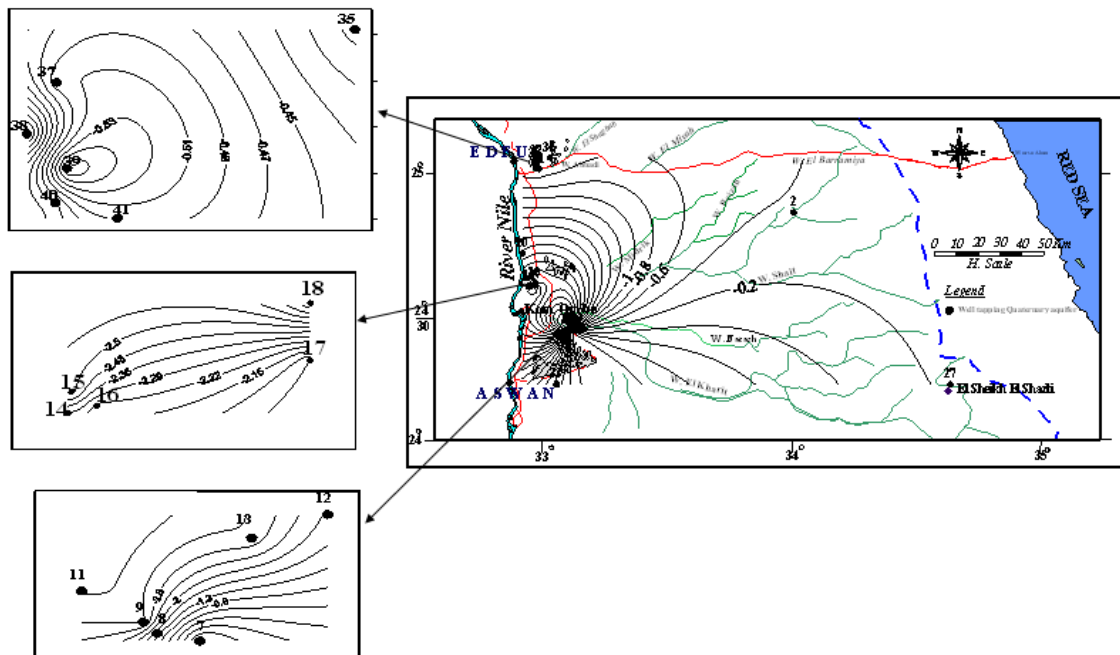


Fig. 9: Isogram of SIGypsum in Quaternary aquifer

b) 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 (W.U., C.E.G, G.S.E. Dept., 2002). 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 (W.U., C.E.G, G.S.E. Dept., 2002).

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:

1-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.

2-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).

3-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)

c) Mass balance approach (Wang et al., 1998):

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.

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).

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

d) 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 (Wang *et al.*, 2001). In addition, all samples located inside the circle are highly similar in water type (HCO₃ – Na for all). Such similarity between these samples reflects high degree of mixing between various sources of waters (Koh *et al.*, 2012).

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

e) Effect of nitrate concentration:

The Quaternary groundwater samples have wide range of nitrate concentrations from 8.55mg/l (No. 9) to 75.55 mg/l (No. 41) (Table 3 & Figure 11), with standard deviation of about 22.32. This feature can be attributed to the different groundwater ages (Koh *et al.*, 2012), 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 (Jung *et al.*, 2010).

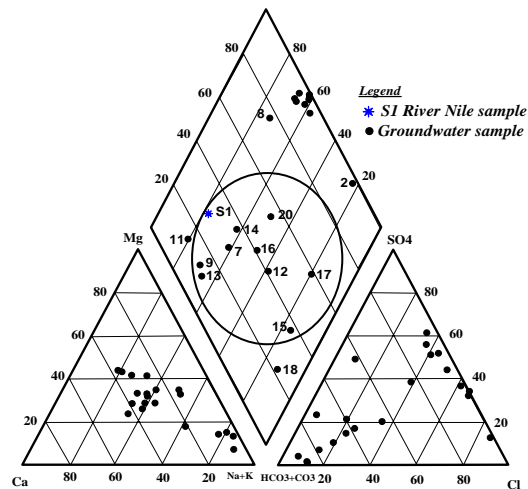


Fig. 10: Trilinear diagram (piper, 1944).

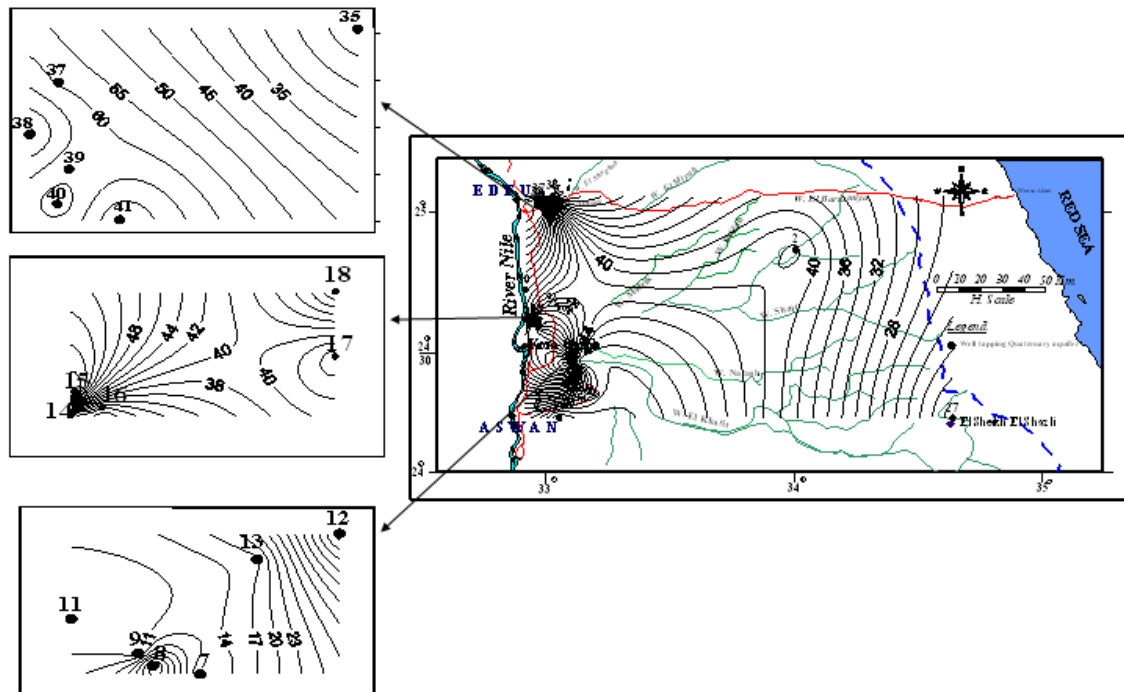


Fig. 11: Isogram of Nitrate distribution in Quaternary aquifer

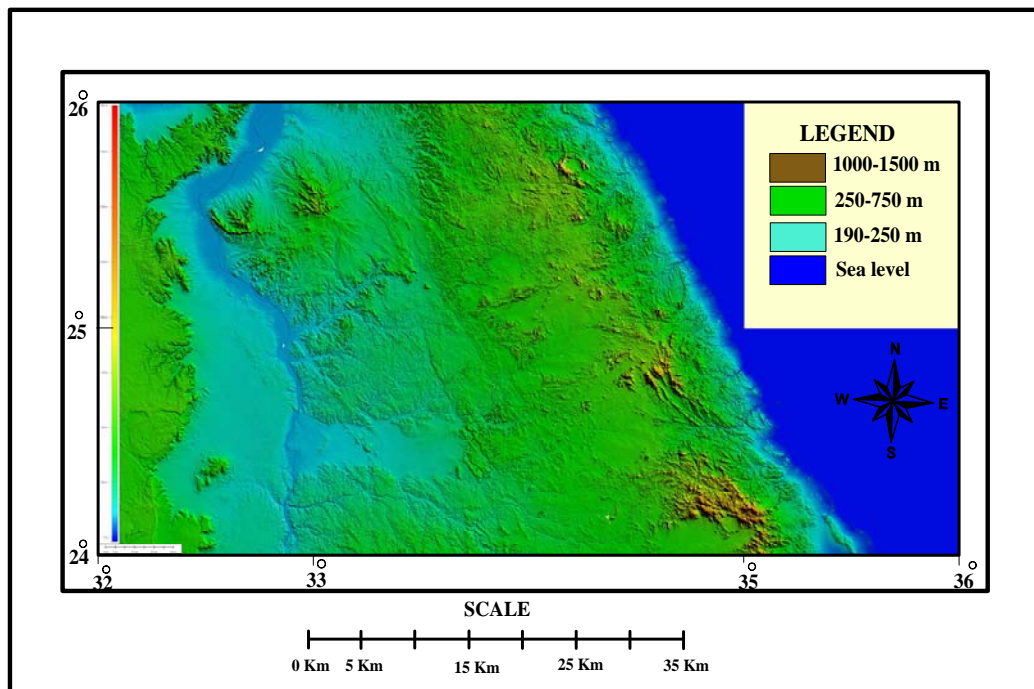


Fig. 12: Digital Elevation Model (DEM) of the study area

f) 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 (Parkhurst and Appello, 1999)

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: 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)	(S2)	(18)	(S1)	(S2)	(18)
		3.41 mg/L	10.63 mg/L	28.37 mg/L	3.41 mg/L	10.63 mg/L	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)

Item	Mixing water		sample (15)	Mixing percentages (well 15 : mixing water)								
	(S1)	(S2)		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	

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.

Summary and Conclusion:

Several approaches including hydrogeochemistry and Modeling have been used to investigate the Quaternary groundwater systems in the area between Idfu and Aswan, Eastern Desert, Egypt, in recent years. 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 research, twenty-one groundwater samples representing the Quaternary aquifer, besides three 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:

1-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.

2-Groundwater is supersaturated with respect to the main carbonate minerals (calcite, aragonite and dolomite).

3-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).

4-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.

5-The investigated groundwater varies from mild corrosion (19%), faint coating forming in the majority of samples (67%) up to mild scale forming (14%).

6- The contribution of recent recharge from Nile water to the Quaternary aquifer is noticed in the study area and varies from moderate to high.

The distributions of saturation indices of 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. These results are very helpful for understanding the groundwater system in the study area. 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).

References

- Abdel Kader, A.A., 2001. "Application of some Geophysical and Hydrogeological techniques for Groundwater resources Investigation in selected Areas between Idfu – Marsa Alam (Eastern Desert, Egypt).", Unpubl. M.Sc. Thesis. Fac. Sci., Assiut Univ., Assiut, Egypt, p: 159.
- Abdel Kreem, W.F.M., 2000. "Chemical and Isotopic Investigation of groundwater Aquifers in Idfu Region on the fringes of Qena Governorate." Unpubl. M.Sc., Thesis, Fac. Sci., Cairo Univ., Cairo, Egypt, p: 137.
- American Society for Testing and Materials, ASTM, 2002. "Water and environmental technology." Annual book of ASTM standards.
- El-kadi, A.I., N.L. Plummer and p. Aggarwal, 2010. "NETPATH-WIN: An Interactive User Version of the Mass-Balance Model, NETPATH." Department of Geology and Geophysics and Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii., 96822(808): 956-6331.
- Elwan, A.A., 2008. "Classification and Evaluation of soils in Wadi El- Saieda area, Aswan Governorate, Egypt." Unpubl. M.Sc. Thesis, Fac. Agriculture, Zagazig Univ., Egypt, p: 172.
- Fishman, M.J. and L.C. Friedman, 1985. "Methods for determination of inorganic substances in water and fluvial sediments." U.S. Geol. Surv. Book 5, Chapter A1. Open File Report 85-495, Denver, Colorado, U.S.A (84).
- Freeze, R.A. and J.A. Cherry, 1979. "Groundwater." Prentice Hall, Inc., Englewood Cliffs, New Jersey, U.S.A.
- Geological Survey of Egypt, 1978. "Geological map of Aswan and Qena quadrangles". Scale 1:500,000, Geol. Surv. of Egypt, Cairo, Egypt.
- Hem, J.D., 1989. "Study and interpretation of the chemical characteristics of natural water." U. S. Geol. Surv. water- supply paper 2254, third Edition, 116: 93.
- Jung, Y.Y., D.C. Koh, Y.J. Yu and K.S. Ko, 2010. "Analysis of groundwater flow systems for springs in the southern slope of Jeju Island using hydrogeochemical parameters". J. Geol. Soc. Korea., 46: 253-273.
- Koh, D.C., K. Ha, K.S. Lee, Y.Y. Yoon and K.S. Ko, 2012. "Flow path and mixing properties of groundwater using hydrogeochemistry and environmental tracers in the southwestern area of Jeju volcanic island" Journal of Hydrology, 432-433(2012): 61-74.
- Mahmoud, A.M., 2005. "Hydrogeological and hydrogeochemical evaluation of the area between Qena and Qus, Eastern Desert, Egypt". M.Sc. thesis, Fac. Sci., South valley Univ., p: 272.
- Moore, E., E. Matalon, C. Balazs, J. Clary, L. Firestone and M. Guzman, 2011. "The Human Costs of Nitrate-contaminated Drinking water in the San Joaquin Valley." Pacific institute 654 13th Street, Preservation Park Oakland, CA 94612, (WWW.Pacinst.org), 510.251.1600.
- Parkhurst, D.L. and C.A.J. Appello, 1999. "User's guide to PHREEQC (Version2), A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations". U.S. Geological Survey, Water-Resources Investigations Report, pp: 312.
- Piper, A.M., 1944. "A graphic procedure in the geochemical interpretation of water analyses." Trans. Amer. Geophys. Union, 25: 914-923.
- Rainwater, F.H. and L.L. Thatcher, 1960. "Methods for collection and analysis of water samples." U. S. Geol. Survey water supply, pp: 301.
- Sawyer, C.N. and P.L. McCarty, 1967. "Chemistry for sanitary engineers". 2nd edition. McGraw-Hill Series in Sanitary Science and Water Resources Engineering, McGraw-Hill, Toronto.
- Wang, G., S. Tao, Z. Shen and Z. Zhong, 1998. "Geochemical modeling of groundwater in karst area and its application at Pingdingshan coalfield" Science in China (series D), 41(4): 377-381.
- Wang, Y., T. Ma and Z. Luo, 2001. " Geostatistical and geochemical analysis of surface water leakage into groundwater on a regional scale: a case study in the Liulin Karst system, northwestern China" J. of hydrology, 246: 223-234.
- Wilkes University-Center of Environmental Quality, Geoenvironmental Sciences and Engineering Department (W.U., C.E.G. G.S.E. Dept.) (2002): "Corrosion, saturation index, balanced water in drinking water systems - Source and cause of corrosion". (<http://wilkes.edu/~eqc/corrosion.htm>).
- World Health Organization WHO, 2003. "Chromium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality". Geneva, World Health Organization (WHO/SDE/WSH/03.04/4).