Australian Journal of Basic and Applied Sciences, 6(7): 483-496, 2012
ISSN 1991-8178

Remarks on the Hydrogeochemistry of the Area Between Idfu and Aswan, Eastern Desert, Egypt.

[1]M.M. Emara, [1]M.M.B. El-Sabbah, [2]M.A. Gomaa and [2]S.A. Mohallel

[1]Al-Azhar University, Faculty of science, Chemistry Dept.
[2]Desert Research Center, Hydrogeochemistry Dept

Abstract: The current research has been conducted to evaluate groundwater aquifers qualitatively in the area between Idfu and Aswan. Three aquifers are recognized; Quaternary, Upper-Cretaceous and fractured Pre-Cambrian in which their groundwaters vary between semi-confined and unconfined conditions. The chemical analyses of 39 samples from the different aquifers indicate that, 40% are fresh water (154 mg/l at wadi El Kharit to 1494 mg/l at wadi El Barramiya), 45% are brackish (2068 mg/l to 4941 mg/l at wadi Midrik). The rest 15% are saline to highly saline (5190 mg/l to 12563 mg/l at wadi Abbadi). Generally the total and permanent hardness increase as water salinity increases and vice-versa in case of temporary hardness within the Quaternary and Fractured Pre-Cambrian groundwaters. A decrease in total, temporary and permanent hardness with the increase of water salinity is recorded in the Upper-Cretaceous groundwater. The alkalinity has higher values in fractured Pre-Cambrian aquifer if compared with the others. The recorded hypothetical salts related to the studied aquifers reflect less to advanced stages of groundwater metasomatism. The chemical types and hypothetical salts as well as the ion ratios indicate meteoric origin for groundwaters and dissolution of terrestrial and marine salts. The constructed hydrochemical profile through wadi El Kharit indicates a decrease of water salinity due to dilution by the return flow after irrigation from River Nile and its branches.

Key words: Groundwater, water quality, Eastern Desert, Idfu and Aswan

INTRODUCTION

The study area constitutes a portion of the Nile valley between Idfu and Aswan and extending eastward to the water divide line, covering about 22500 km^2 of surface area (Figure 1). It is limited by Latitudes 24^{o}00$'$ & 25 ^{o} 12$'$ N and Longitudes 32 ^{o} 55$'$ & 35 ^{o} 48$'$ E. The area between Idfu and Aswan and its desert back represents one of the promising areas in Egypt for future sustainable development especially land reclamation and tourist expansions. Digital Elevation Map (DEM) indicates that the area is slopping westward (Figure 2). The study area is characterized by a long hot summer and short warm winter, low rainfall and high evaporation rates.

Geomorphologically, the investigated area is discriminated into four main units; Nile Valley, Nile drainage basins, Nubian Sandstone Plateau (Ababda tableland) and Basement Mountains (MPGAP, 1990 and Abdel Kreem, 2000). Each unit has its own characteristics reflecting the regional tectonic, lithologic, climatic and paleogeographic features (Figure 3).

Main Rock Units:

Due east, metamorphic rocks, including metasediments and metavolcanics intruded by serpentinite and epidiorite masses are dominated. Post metamorphic intrusions of gabbro, granite and volcanic rocks are overlaid by less extensive meta-sedimentary group (Hamamat series) of post granite age followed by the intrusion of the younger or Gattarian granites. The Pre-Cambrian belt is overlaid on its western side by Nubian sandstone that presumed Upper Cretaceous age and latter sedimentary formations extending to the Nile Valley, while on its eastern side, the belt is overlaid by sedimentary section mainly belonging to the Miocene and latter ages (Figure 4), (Abdel Kader, 2001).

Hydrogeologic Setting:

Based on both the geological and the hydrogeological maps shown in figures (4 & 5), the water bearing formations (aquifers) in the study area are distinguished into the Quaternary alluvial deposits, Upper Cretaceous deposits and fractured Pre-Cambrian rocks as follows:

Quaternary Aquifer:

The Quaternary aquifer is represented by twenty-one water points. It is mainly composed of gravels, sands and silts with clay intercalation, varies in thickness from 40 to 120 m. The concerned aquifer is considered semi-confined as it is capped with a silty clay layer. The depth to water surface ranges from 2m (Nos. 8, 13, 14 &18) to 8.4 m (No. 2) (Table 1). This aquifer is recharged through the main wadi channels draining the water divide

Corresponding Author: S.A. Mohallel, Desert Research Center, Hydrogeochemistry Dept
E-mail: mohallel_drc@yahoo.com

during flash floods as well as from irrigation water of the Nile River. The hydraulic conductivity of the aquifer in the central portion is about 80 m/day (Abdel Kreem, 2000).

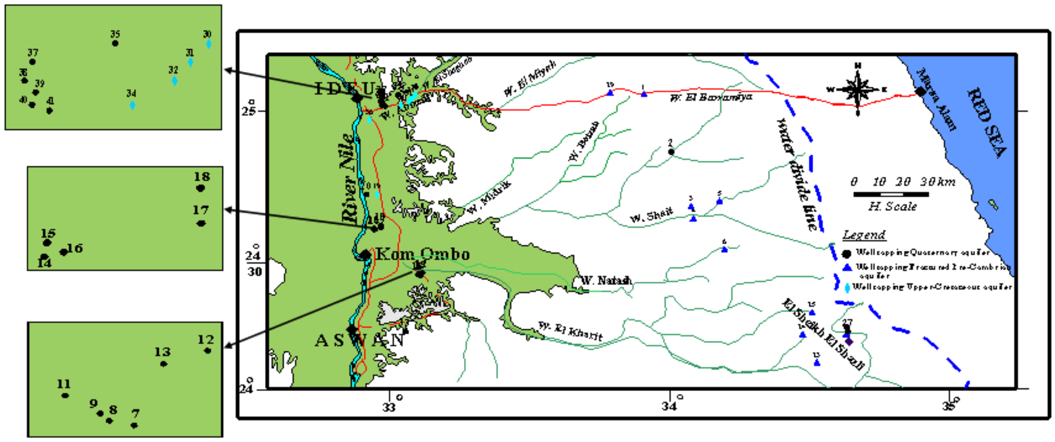

Fig. 1: Wells' location map of the study area.

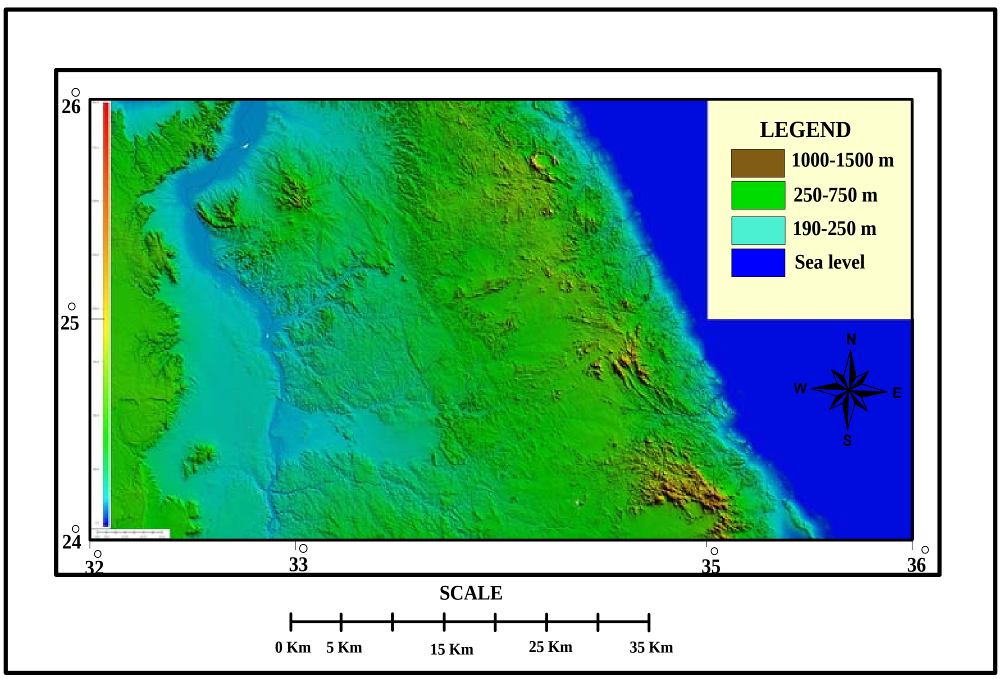

Fig. 2: Digital Elevation Model (DEM) of the study area.

UPPER-CRETACEOUS AQUIFER (Extensive and highly to moderately productive aquifer) (Figure 5):

The investigated aquifer is represented by six water points. It is mainly composed of medium to coarse-grained sandstone representing the oldest porous sedimentary unit, overlying the Pre-Cambrian complex in the Eastern Desert. The depth to water from ground surface varies from 7.4 (No. 19) to 15.5m (No. 36) (Table 1). The measured thickness of the Nubian Sandstone aquifer in Wadi Abbadi and Wadi El-Shaghab is about 150 m (Abdel Kader, 2001). The groundwater occurs under semi-confined conditions in some places, where Nubian Sandstone is overlain by wadi fill deposits and confined conditions in the other places where Quseir variegated shale is overlying it. This aquifer can be classified as high to moderate potential aquifer containing paleo-water mixed with surface runoff water as well as subsurface inflow from the adjacent fractured basement rocks (Figure 5).

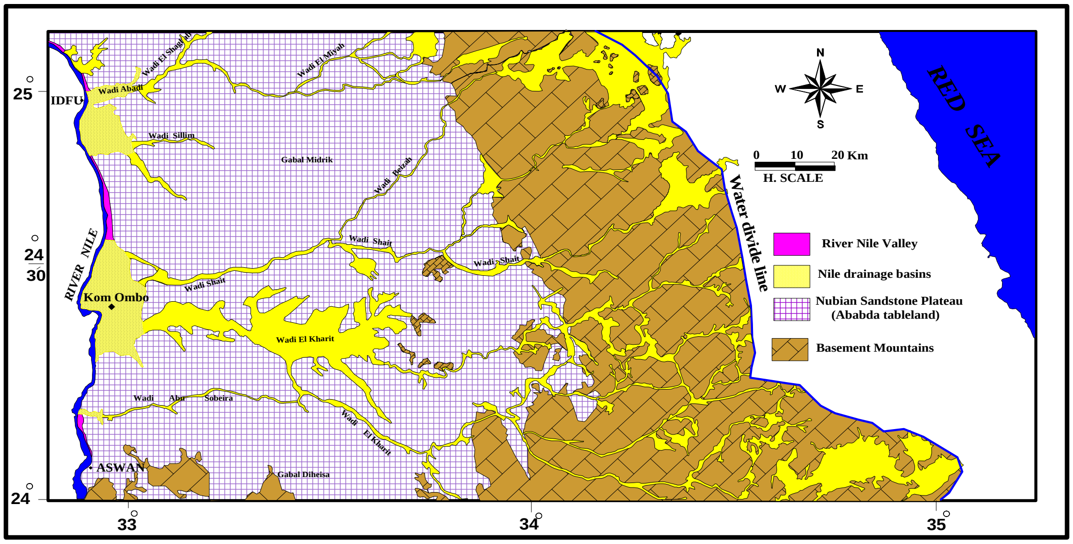

Fig. 3: Geomorphological map of the study area.

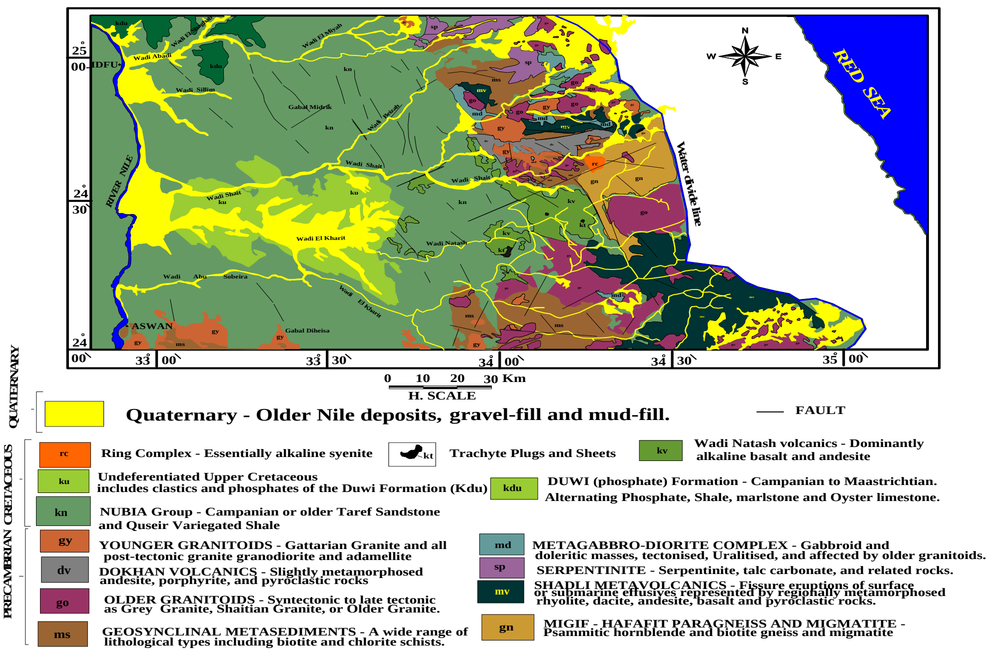

Fig. 4: Geologic map of the study area (After geologic map of Aswan quadrangle, Egypt 1978).

FRACTURED PRE-CAMBRIAN AQUIFER (local groundwater occurrences in fissured and weathered zones in hard rocks) (Figure 5):

The mountainous region represents the watershed area in the study area. Most of the local groundwater occurs in the fissured and weathered zones within the Pre-Cambrian complex. The studied aquifer is recognized through twelve water points. The depth to water ranges from 3.8m (No. 21) to 31.5m (No. 29) (Table 1). The aquifer is covered by thin to highly weathered alluvial deposits increasing gradually in thickness from the upstream to the downstream. The main recharging source is the rainfall. A limited amount of this water is kept in catchment areas of the wadis and fractured or weathered beasement rocks, while the rest is discharged through the fault planes or along the wadi floors towards the coastal zone due east or to the Nubian plateau due west. The water is discharged by means of productive wells, which are distributed in the main wadi courses. Generally, the amount of water depends on the degree of weathering, intensity of fractures, faults and thickness of the water bearing formation.

The groundwater conditions in the different types of such rocks in the study area are discussed as follows:

1- The fractured metavolcanic aquifer

2- The fractured metasediments aquifer
3- The fractured Plutonic aquifer
4- The fractured Hammamat aquifer

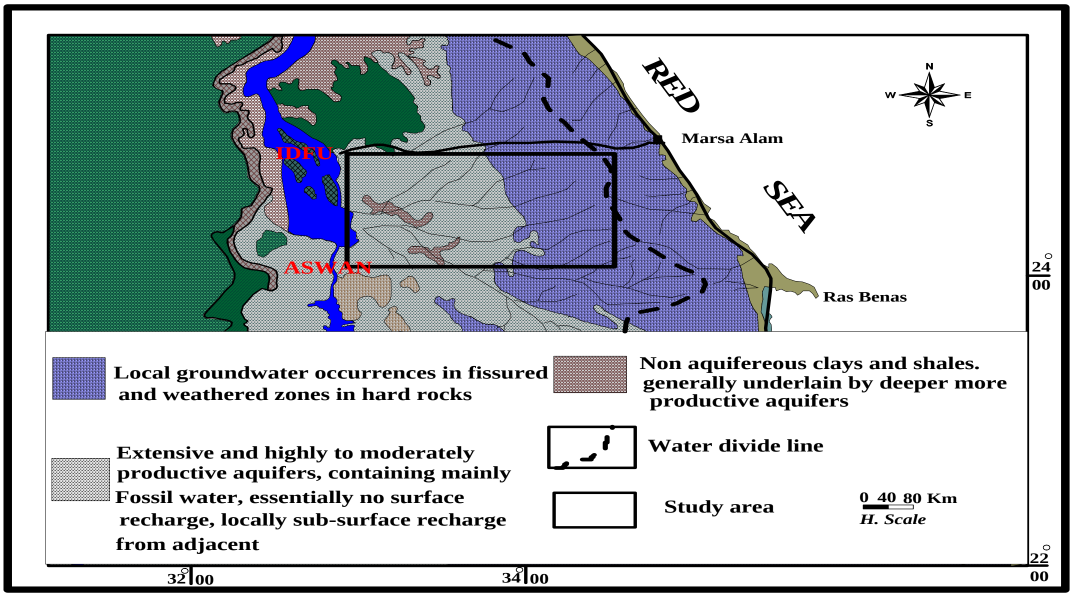

Fig. 5: Hydrogeologic map of the study area (After hydrogeologic map of Egypt, Second Edition 1999).

Fractured Metavolcanic Aquifer:

The fractured metavolcanic rocks are detected as water-bearing formation in Wadi Abu-Hammamid and El-Sheikh El-Shazly. The thickness of the aquifer is ranging from 5 to 35 m (Abdel Kader, 200). The maximum thickness was detected in the middle parts of the wadis. The groundwater is detected at shallow depths (about 3.80 to 5 m at El-Sheikh El-Shazly (Nos. 21, 22 & 26), and 5.40 m in Wadi Abu-Hammamid (No. 24). The fractured metavolcanic aquifer is directly recharged from the local rainfall by infiltration through Wadi fill deposits. The groundwater discharge occurs naturally through evaporation and artificially through water extraction or withdrawal from the old dug wells.

Table 1: Depth to water (m) of the different aquifers in the study area.

Well No.	Name	Wadi	Depth to wate (m)	Well No.	Name	Wadi	Depth to water (m)
	Quaternary			Upper-Cretaceous			
2	Muweilha	W. Muweilha	8.4	19	Selwa	W. Midrik	7.4
7	Sameh	W. El Kharit	3	30	El Faway	W. Abbadi	12
8	Ahmed Huseen	W. El Kharit	2	31	El Faway	W. Abbadi	10
9	Yousef	W. El Kharit	2.5	32	El Faway	W. Abbadi	9.5
11	Hesham	W. El Kharit	2.5	34	-	W. Abbadi	15
12	Shaban	W. El Kharit	3	36	El Mohandesa	W. Abbadi	15.5
13	-	W. El Kharit	2	Fractured Pre-Cambrian			
14	El Mashtal	W. Midrik	2	1	Beizah	W. Beizah	11.50
15	El Warsha	W. Midrik	2.5	3	Al Berka	W. Shait	6.00
16	-	W. Midrik	3.5	4	Umm Qubur	W. Shait	11.80
17	-	W. Midrik	2.5	5	El Moureer	W. Shait	4.00
18	-	W. Midrik	2	6	Abu Massour	W. Natash	10.70
20	El Asfalt	W. Midrik	3	21	El Haja Zakeya	El Sheikh El Shazly	3.80
27	Umm Khrus	El Sheikh El Shazly	5.5	22	El Haj Ali	El Sheikh El Shazly	4.80
33	-	W. abbadi	3	23	Hileiyi	W. El Kharit	8.00
35	El Haj Gamal	W. abbadi	3	24	Abu Hamamid	W. El Kharit	5.40
37	Zakalona	-	3	25	Miteiwit	W. El Kharit	9.00
38	Zakalona	-	4	26	El Masjed	El Sheikh El Shazly	5.00
39	Zakalona	-	4	29	El Kameen	W. El Barramiya	31.50
40	Zakalona	-	5.5				
41	Zakalona	-	5				

Fractured Metasediments Aquifer:

The fractured metasediments include the Migif-Hafafit para-gneiss and magmatite rocks in wadi Hafafit. The thickness of this aquifer varies from 20 to 40 m increasing towards the south (Abdel Kader, 2001). The depth to water is about 19 m from the ground surface (Abdel Kader, 2001).

This aquifer is covered by highly weathered alluvial deposits, which vary in thickness from 5 to 15 m (Abdel Kader, 2001). The aquifer is recharged from direct rainfall on the mountainous areas and by infiltration through the sedimentary cover while the discharge of groundwater is naturally towards Wadi El Gemal into the Red Sea. The artificial discharge occurs through some drilled wells.

Fractured Plutonic Aquifer:

The fractured granitoid is recognized as a water-bearing formation in Wadi Natash. The thickness of this aquifer is so thin, especially in the upstream portion, where the massive Pre-Cambrian outcrops on the surface. The depth to water is about 10.70 m (Bir Abu Masour, No. 6). A thin sheet of water may be expected in this aquifer.

Fractured Hammamat Aquifer:

This aquifer is mainly composed of fine to coarse grained breccias and conglomerates derived from Dokhan Volcanic (Akaad and Noweir, 1969). The fractured Hammamat aquifer is tapped in Wadi Igli. The depth to water in Bir Igli is about 12m from the ground surface (Abdel Kader, 2001). The groundwater occurs under unconfined conditions, where the thickness of wadi deposits is about 4 m. The recharge occurs through downward infiltration from direct rainfall through the wadi deposits. The discharge occurs through evaporation and drilled or hand dug wells.

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

Sample No	Eh	pH	Temp.ºC	E.C	TDS mg/l	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl
Quaternary aquifer													
2	140	7.7	29.5	19850	10575.33	315.75	294.12	3150.00	28	30.30	209.47	2978.89	3673.53
7	150	8.1	28.8	550	258.30	29.47	18.41	39.00	6	0.00	215.64	24.44	33.16
8	146	7.6	31	1390	839.41	98.33	76.73	85.00	12	9.09	203.31	262.72	193.88
9	145	7.9	28	340	166.70	23.21	14.41	19.00	8	9.09	150.94	4.76	12.76
11	194	7.6	29.8	338	154.44	24.12	16.88	10.00	7	9.09	144.78	2.20	12.76
12	192	7.7	28.3	1025	543.19	42.10	21.74	135.00	9	36.36	274.16	95.97	65.94
13	151	7.6	32	616	245.30	25.26	24.55	31.00	11	15.15	234.12	8.52	12.76
14	168	7.8	30.5	604	315.68	37.10	24.13	49.00	6	18.18	190.99	39.85	45.92
15	172	8.2	31.3	1820	1010.58	10.53	29.41	355.00	8	60.60	565.20	126.89	137.55
16	172	7.6	31.3	967	500.95	29.47	36.32	106.67	6	36.36	261.84	73.58	81.63
17	172	7.8	31.3	1089	787.34	12.63	22.51	228.97	5	24.24	285.23	308.00	43.37
18	172	7.9	28.9	1116	609.51	12.63	9.72	225.00	5	45.45	437.43	36.87	56.12
20	87	7.7	27.3	1225	582.25	33.68	45.52	115.00	14	18.18	255.68	98.89	129.14
27	85	7.4	28	3370	4576.38	523.32	264.71	680.50	9	9.09	204.89	1596.98	1390.33
33	92	7.3	29.1	16500	12563.75	1136.7	938.63	2012.00	28	0.00	30.81	3458.45	4974.57
35	92	7.3	30.4	7060	4108.04	494.65	213.05	600.00	20	0.00	49.29	1097.50	1658.19
37	103	7.5	27	4600	2179.14	314.67	105.09	280.00	8	15.15	154.03	869.00	510.21
38	114	7.4	26	4320	2967.55	385.20	166.22	370.00	9	15.15	113.98	1391.00	573.99
39	114	7.3	25.9	2830	2068.70	242.60	140.67	260.00	9	15.15	141.70	896.75	433.68
40	114	7.6	28.4	5240	3191.33	305.75	179.03	510.00	7	18.18	117.06	1296.50	816.34
41	114	7.2	29.5	12830	6740.73	863.05	393.61	1100.00	12	21.21	104.73	727.00	3571.49
Upper Cretaceous aquifer													
19	172	7.6	31.3	4491	2484.67	147.35	111.25	1425.00	23	21.21	215.64	1651.70	1454.11
30	98	7.2	31	5700	4092.85	510.46	349.08	600.00	14	0.00	77.01	1978.00	1271.59
31	90	7.5	33	6110	4229.84	420.48	335.04	480.00	15	24.24	144.78	1062.00	1683.70
32	95	7.3	30	7160	4761.64	557.83	340.33	440.00	14	12.12	73.93	1241.00	1587.59
34	96	7.3	33.1	7950	4941.44	214.71	262.41	310.00	13	6.06	154.03	479.00	1122.47
36	72	7.9	30.7	10150	5190.74	115.78	99.75	1785.00	17	0.00	33.89	146.00	3010.26
Fractured Pre-Cambrian aquifer													
1	108	7.7	29.1	12100	7389.07	863.26	498.73	1013.54	26	24.24	92.42	2340.53	2576.57
3	98	7.8	30.6	940	590.10	71.57	49.11	59.00	18	18.18	240.28	197.98	56.12
4	92	7.4	30.4	2500	1234.58	126.30	90.79	194.21	9	21.21	314.21	310.98	324.98
5	118	7.9	30.5	5310	3138.76	252.60	194.38	546.00	17	27.27	224.88	1287.53	701.54
6	2	7.9	30	834	534.29	85.64	42.06	32.00	14	18.18	163.27	212.30	48.47
21	104	7.5	33.4	7390	4444.11	505.20	260.87	669.00	10	12.12	144.78	1639.00	1275.53
22	96	7.5	33.9	8650	5240.80	526.25	284.12	895.00	11	15.15	126.30	1941.00	1505.13
23	107	7.6	30	4400	3579.64	402.00	216.00	485.00	28	42.42	486.72	1789.97	372.89
24	123	7.7	29	4230	3149.11	168.40	106.14	720.00	5	24.24	209.47	1433.85	586.74
25	99	7.8	29.3	5430	3715.44	252.60	130.44	885.00	5	27.27	219.94	1323.00	982.16
26	84	7.6	30	3097	4474.91	484.15	259.59	680.00	4	15.15	101.66	1922.50	1058.69
29	120	7.8	30	2500	1494.88	31.58	88.24	360.00	15	48.48	341.94	512.75	267.86
Surface water													
S1*	114	8	27.8	261	180.88	25.26	18.16	14.00	6	9.09	129.38	37.30	6.38
S2**		7.6	27.1	285	144.11	27.03	11.35	13.00	4	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 sample from the study area

Groundwater Chemistry:

Thirty nine groundwater samples, representing the studied aquifers were collected in October 2010 and chemically analyzed. The analyses were performed in the Hydrogeochemistry Department, Desert Research Center (DRC), Egypt, according to the methods adopted by Rainwater and Thatcher (1960), Fishman and

Friedman, (1985) and American Society for Testing and Materials (ASTM, 2002). The analyses include the determination of EC, PH, TDS and major ions Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{3-} SO_4^{2-}, Cl^{-} and inorganic substances. According to the obtained results the following could be deduced (Table 2).

Groundwater Salinity Distribution:

According to Chebotarev classification (1955), the salinity of the collected water samples representing the different aquifers shows wide variation as shown in table (3). This is generally attributed to lithology variation, rate of evaporation degree of weathering, fractures intensity and amount of recharge.

Table 3: The frequency distribution of groundwater salinity in the study area.

Water salinity (mg/l)			% Frequency distribution			Total Samples
Average	Max.	Min.	Saline to highly saline water T.D.S>5000mg/l	Brackish water T.D.S 1500-5000mg/l	Fresh water T.D.S<1500mg/l	
3062.08	12563.75	154.44	15%	45%	40%	39

In the Quaternary aquifer, the groundwater salinity ranges from 154.4 mg/l at wadi El Kharit (No. 11) to 12563 mg/l at wadi Abbadi (No. 33), indicating that 57% of the total samples are fresh (Nos. 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18 & 20) and 29% are brackish (Nos. 27, 35, 37, 38, 39 & 40), while 14% are saline (Nos. 2, 33 & 41). Salinity values increase due east towards the new reclaimed and desert lands.

In the Upper-Cretaceous aquifer, the groundwater salinity ranges from 2484.67 mg/l at wadi Abbadi (No. 34) to 5190.74 mg/l at El Edwa area (No. 36) with a mean value of about 4283.53 mg/l. obviously, 83% of the total samples are brackish (Nos. 19, 30, 31, 32 & 34), while 17% are saline (No. 36).

In the Fractured Pre-Cambrian aquifer, the groundwater salinity ranges from 534.29 mg/l at wadi Natash (No. 6) to 7389.07 mg/l at wadi Beizah (No. 1) with a mean value of about 3248.81 mg/l, indicating that 50% of samples are brackish (Nos. 5, 21, 23, 24, 25 & 26), while 33% are fresh (Nos. 3, 4, 6 & 29) and the rest (17%) are saline water (Nos. 21 & 22).

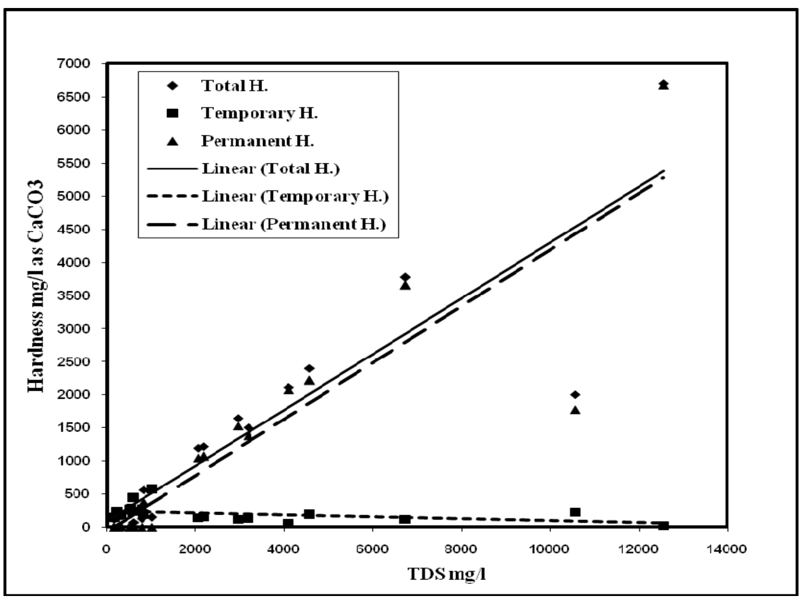

Fig. 6: The relationship between salinity and Hardness in the Quaternary groundwater.

Total Hardness:

According to the chemical analysis of the groundwater samples, it was noticed that in Quaternary aquifer the mean values of total, permanent and temporary hardness attain 195.52, 34.65 and 259.25 mg/l as $CaCO_3$ 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 (table 4). These data indicate an increase in total and permanent hardness with the increase of water salinity except the relation with temporary hardness, (Figure 6). 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 Ca^{2+} and Mg^{2+} in water (Freeze and Cherry, 1979 & Hem, 1989), taking into consideration the contribution of the CO_2 and longer residence time as well as the influence of salty water and cation exchange processes.

With regard to the total (TH), permanent (NCH) and temporary (CH) hardness relative to water salinity (TH/TDS, NCH/TDS and CH/TDS %) in the Quaternary aquifer, the obtained ratios are 50%, 4% and 46%, respectively in the fresh type, 63%, 58% and 5%, respectively in the brackish type, 48%, 46% and 2%, respectively in the saline to highly saline type (Table 4).

In the Upper-Cretaceous aquifer the mean values of total, permanent and temporary hardness attain 2075.44, 1945.05 and 130.4 mg/l as $CaCO_3$ in the brackish groundwater respectively and 699.74, 671.94 and 27.8 mg/l in the saline groundwater samples. These data reflecting a decrease in total, temporary and permanent hardness with the increase of water salinity (Figure 7 and table 4).

Also the total, permanent and temporary hardness relative to water salinity (TH/TDS, NCH/TDS and CH/TDS %) are 60%, 56% and 4%, respectively in the brackish groundwater, 15%, 14.5% and 0.6%, respectively in the saline groundwater (Table 4).

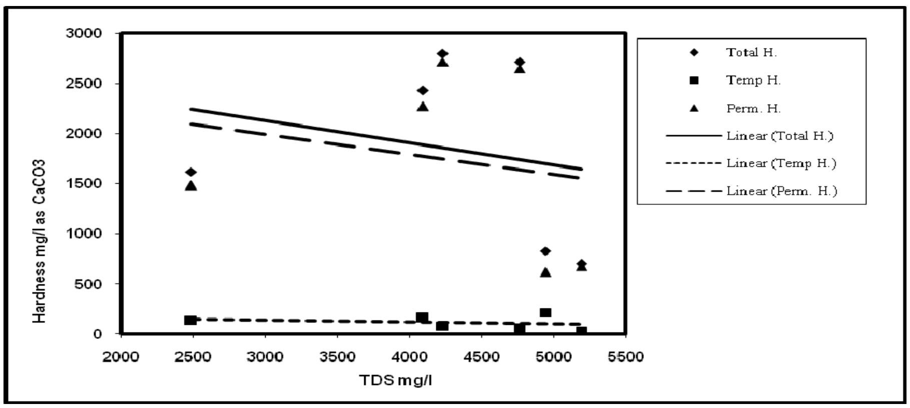

Fig. 7: The relationship between salinity and Hardness in the Upper-Cretaceous groundwater.

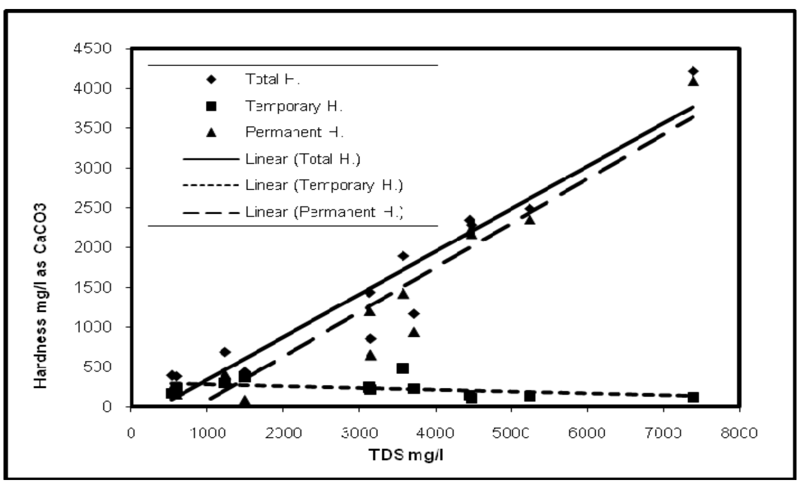

Fig. 8: The relationship between salinity and Hardness in the fractured Pre-Cambrian groundwater.

Concerning the fractured Pre-Cambrian groundwater (Table 4), the mean value of total, permanent and temporary hardness reach 963.46, 213.23 and 261.55mg/l as $CaCO_3$, respectively in the fresh groundwater and 1660.41, 1429.43 and 230.97mg/l, respectively in the brackish groundwater and 3346.29, 3223.73 and 122.56mg/l, respectively in the saline groundwater. The obtained results indicate an increase in total and permanent hardness with the increase of water salinity and vice versa in case of temporary hardness (Figure 8). This is mainly attributed to the effect of leaching and dissolution of soluble salts leading to the increase of hardness with particular importance to the effect of NaCl ionic strength on increasing solubility of Ca^{2+} and Mg^{2+} in water (Freeze and Cherry, 1979 & Hem, 1989).

With regard to the total, permanent and temporary hardness relative to water salinity (TH/TDS, NCH/TDS and CH/TDS %) in the fractured Pre-Cambrian groundwater, the obtained ratios are 62.5%, 28% and 34%, respectively in the fresh groundwater, 52%, 44% and 8%, respectively in the brackish groundwater and 60.5%, 58% and 2.5%, respectively in the saline groundwater (Table 4).

Alkalinity:

If the alkalinity is less than the total hardness, then the alkalinity equals to the temporary hardness (CH). If the alkalinity is greater than the total hardness, then all hardness is temporary. Like hardness, alkalinity is measured in mg/l of calcium carbonate. According to the alkalinity values (Table 5), the Quaternary groundwater has alkalinity ranges between 25.27mg/l (No. 33) and 564.7mg/l (No. 9), whereas it ranges between 27.8mg/l (No. 36) and 212.28mg/l (No. 19) in the Upper-Cretaceous groundwater and it varies between 108.67mg/l (No. 26) and 470.03mg/l (No. 23) in the fractured Pre-Cambrian groundwater. The alkalinity has higher values in the fractured Pre-Cambrian aquifer (mean value is 223.1 mg/l) if compared with the Quaternary and Upper-Cretaceous aquifers (mean values are 202 and 113.3 mg/l, respectively). The main source of the alkalinity is the atmospheric CO_2 which reacts with water in addition to leaching of carbonate minerals (Fayez, 1993).

Table 4: Average and relative values of total, temporary and permanent hardness of the different aquifers in the study area.

TDS mg/l	mg/l as $Ca(CO_3)_2$ TH	CH	NCH	(TH/TDS) %	(CH/TDS) %	(CH/TH) %	(NCH/TDS) %	(NCH/TH) %
Fresh water in Quaternary aquifer TDS up to 1500								
501.14	195.52	259.25	34.65	50	46	92	4	8
Brackish water in Quaternary aquifer (TDS=1500 – 5000mg/l)								
3181.85	1676.50	126.99	1549.51	63.43	5.45	8	57.98	92
Saline to highly saline water in Quaternary aquifer (TDS > 5000mg/l)								
9959.93	4159.08	122.98	4036.09	47.93	1.63	3	46.30	97
Water salinity in Quatenary aquifer								
2618.31	1184.88	201.99	1039.10	54	28	52	26	48
Water salinity class in Upper-Cretaceous aquifer								
Brackish water in Upper-Cretaceous aquifer (TDS=1500 – 5000mg/l)								
4102.09	2075.44	130.40	1945.05	60.35	3.94	7	56.41	93
Saline water in Upper-Cretaceous aquifer (TDS > 5000mg/l)								
5190.74	699.74	27.80	671.94	15.19	0.63	4	14.56	96
Water salinity in Upper-Cretaceous aquifer								
4283.53	1846.16	113.30	1732.86	52.82	3.39	6	49.43	94
Fresh water in fractured Pre-Cambrian aquifer TDS up to 1500								
963.46	474.78	261.55	213.23	62.48	34.04	54	28.45	46
Brackish water in Fractured Pre-Cambrian aquifer (TDS=1500 – 5000mg/l)								
3750.33	1660.41	230.97	1429.43	52.07	8.03	15	44.05	85
Saline to highly saline water in Fractured Pre-Cambrian aquifer (TDS > 5000mg/l)								
6314.94	3346.29	122.56	3223.73	60.56	2.45	4	58.12	96
Water salinity in Fractured Pre-Cambrian aquifer								
3248.81	1546.18	223.10	1323.08	56.96	15.77	28	41.19	72

Note:

1-Total hardness (TH% of TDS)= [$Mg(HCO_3)_2$ + $Ca(HCO_3)_2$ + $MgSO_4$ + $CaSO_4$ + $MgCl_2$ + $CaCl_2$] salts as percent.

2- Carbonate hardness or temporary hardness (CH% of TDS) = [$Mg(HCO_3)_2$ + $Ca(HCO_3)_2$] salts as percent

3 - Non-carbonate hardness or permanent hardness (NCH% of TDS) = [$MgSO_4$ + $CaSO_4$ + $MgCl_2$ + $CaCl_2$] salts as percent

Table 5: Values of total, temporary, permanent hardness, alkalinity and total dissolved solids of the studied groundwater samples.

Alkalinity mg/l $CaCO_3$	CH mg/l $CaCO_3$	NCH mg/l $CaCO_3$	TH mg/l $CaCO_3$	TDS	Sample ID
Quaternary aquifer					
222.38	222.38	1776.83	1999.21	10575.33	2
176.89	176.89	0.00	149.38	258.30	7
181.94	181.94	379.47	561.41	839.41	8
138.99	138.99	0.00	117.28	166.70	9
133.93	133.93	0.00	129.72	154.44	11
285.55	285.55	0.00	194.63	543.19	12
217.33	217.33	0.00	164.14	245.30	13
187.00	187.00	4.98	191.98	315.68	14
564.74	564.74	0.00	147.35	1010.58	15
275.45	275.45	0.00	223.10	500.95	16
274.42	274.42	0.00	124.20	787.34	17
434.65	434.65	0.00	71.55	609.51	18
240.07	240.07	31.41	271.48	582.25	20
183.24	183.24	2213.33	2396.57	4576.38	27
25.27	25.27	6677.14	6702.41	12563.75	33
40.43	40.43	2071.89	2112.32	4108.04	35
151.63	151.63	1066.82	1218.45	2179.14	37
118.77	118.77	1527.44	1646.22	2967.55	38
141.51	141.51	1043.39	1184.91	2068.70	39
126.35	126.35	1374.16	1500.52	3191.33	40
121.29	121.29	3654.31	3775.61	6740.73	41
Upper-Cretaceous aquifer					
212.28	212.28	613.65	825.92	4941.44	19
63.17	63.17	2648.55	2711.72	4761.64	30
159.20	159.20	2270.01	2429.21	4092.85	31
80.87	80.87	2713.15	2794.01	4229.84	32
136.46	136.46	1479.88	1616.35	2484.67	34
27.80	27.80	671.94	699.74	5190.74	36
fractured Pre-Cambrian aquifer					
116.25	116.25	4092.56	4208.80	7389.07	1
227.43	227.43	153.46	380.89	590.10	3
293.13	293.13	396.00	689.14	1234.58	4
229.96	229.96	1200.99	1430.96	3138.76	5
164.26	164.26	222.75	387.01	534.29	6
138.98	138.98	2196.52	2483.78	4444.11	21
128.88	128.88	2354.90	1893.07	5240.80	22
470.03	470.03	1423.04	857.46	3579.64	23
212.27	212.27	645.19	1167.77	3149.11	24
225.91	225.91	941.86	2277.66	3715.44	25
108.67	108.67	2169.00	442.08	4474.91	26
361.37	361.37	80.70	2483.78	1494.88	29

Chemical Water Types:

According to the water type zonation map shown in figure (9) the distribution of water chemical types in the study aquifers are classified according to the dominant anions and cations into:

1- Chloride – Sodium; characterizing 25% of the Quaternary groundwater samples, 33% of the Upper-Cretaceous samples and 43% of the Pre-Cambrian samples. This type represents the most advanced stage of groundwater metasomatism.

2- Sulfate – Sodium; characterizing the majority of the brackish water samples (42%) of the Pre-Cambrian aquifer and 5% of the Quaternary aquifer.

3- Sulfate – Calcium; dominating 14% of the samples of the Quaternary aquifer and 8% of the Pre-Cambrian one.

4- Sulfate – Magnesium; characterizing only two samples (sample No. 8 for Quaternary and No. 30 for Upper-Cretaceous).

5- Bicarbonate – Magnesium and Bicarbonate – Sodium chemical types:

Both types are very significant in the Quaternary groundwater samples where they are encountered in 14% and 33% of samples respectively. Both reflect the effect of fresh irrigation water used in agriculture.

6- Chloride - Magnesium water type; dominating 50 % of the Upper-Cretaceous groundwater samples indicating the effect of marine shale interbeds within the aquifer sediments.

Hydrochemical coefficients (ion ratios)

From table (6) the` following can be deduced:

(rNa^+/rCl^-)

Values of rNa^{+}/rCl^{-} for the majority of Quaternary and Fractured pre-Cambrian groundwater samples (57% & 58%, respectively) are more than unity. This indicates fresh meteoric water recharge from the country rocks. The rest of samples (43% and 42%, respectively) in the same aquifers have values of rNa^{+}/rCl^{-} less than unity. This in turn may be attributed to the adsorption of sodium ions on the fine argillaceous sediments (Starinsky et al., 1983). In case of the Upper-Cretaceous groundwater the most of samples (83%) have rNa^{+}/rCl^{-} values less than unity which is due to the leaching and dissolution processes of marine interbeds.

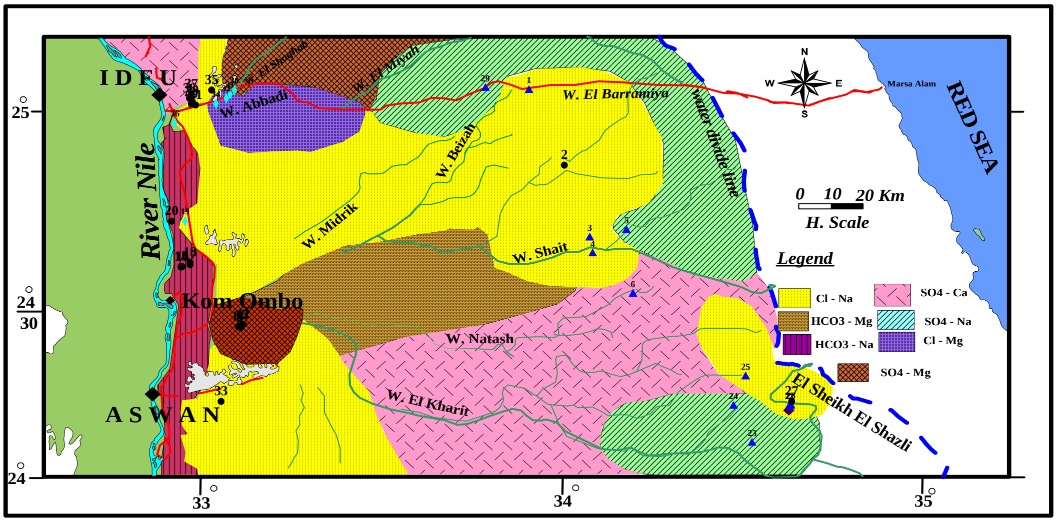

Fig. 9: Water type zonation map.

(rCa^{2+}/rMg^{2+})

Most of the analyzed Quaternary, Upper Cretaceous and Fractured Pre-Cambrian groundwater samples (81%, 100% and 92%, respectively) have rCa^{2+}/rMg^{2+} close to unity indicating that groundwater is flowing entirely through carbonate (Dolomite and Calcite) terrain and Mg rich minerals in the fractured Pre-Cambrian aquifer.

(rSO_4^{2-}/rCl^{-})

Most of the analyzed Quaternary, Upper Cretaceous and Fractured Pre-Cambrian groundwater samples (67%, 50% and 100%, respectively) have values of rSO_4^{2-}/rCl^{-} close to/or more than unity, reflecting the dissolution of sulfate minerals as gypsum and anhydrite.

[$rCl^{-} - r(Na^{+}+K^{+})]/rCl^{-}$ (ion-exchange index)

This ratio has either negative or positive values. The negative values mean that alkaline earths (Ca^{2+} and Mg^{2+}) in water replace alkalis ($Na^{+}+K^{+}$) on the surface of clay minerals in the aquifer and vice versa in case of positive values.

Some of the groundwater samples (38%) of the Quaternary aquifer have positive values of cation exchange index and vice versa in case of the majority groundwater samples (62%) which have negative values of cation exchange index, regardless of water salinity (Table 6).

In addition 83% and 42% of Upper-Cretaceous and fractured Pre-Cambrian groundwater samples respectively have positive values of this ratio. While the rest of samples (17% and 58%) in Upper-cretaceous and fractured Pre-Cambrian aquifers respectively have negative values.

Hypothetical Salts Assemblages:

The combination between major anions and cations reveals the formation of five groups of hypothetical salts in the investigated aquifers as shown in table (7). From the table the following points are interesting:

i- Assemblage V composed of NaCl, $MgCl_2$, $CaCl_2$, $CaSO_4$ and $Ca(HCO_3)_2$ (marine group) is encountered in 9% of the Quaternary groundwater samples and 17% of Upper-Cretaceous one. This reflects the marine facies effect.

ii- Assemblage IV composed of NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$ (marine group) is encountered in 66% of the Upper-Cretaceous groundwater samples and 33% of both the Quaternary groundwater samples and the fractured Pre-Cambrian samples, this also reflects the marine interbeds effect within the Quaternary and Upper-Cretaceous aquifers.

iii- Assemblages I and II (Bicarbonate groups); composed of:

- NaCl, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$

- NaCl, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$

Both are encountered in 48% and 5% of the Quaternary groundwater samples respectively and 17% of the fractured Pre-Cambrian samples. This indicates the effect of meteoric water and the continental facies of the Quaternary aquifer deposits.

iiii- Assemblage III composed of NaCl, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$
(sulphate group) characterizes 50% of the fractured Pre-Cambrian samples, 17% of the Upper Cretaceous and 5% of the Quaternary aquifer samples. This assemblage represents the mixed type water origin (mixed type).

Table 6: Hydrochemical coefficients of the groundwater samples in the investigated aquifers.

Sample No.	TDS mg/l	rNa^+/rCl^-	rCa^{2+}/rMg^{2+}	rSO_4^{2-}/rCl^-	$[rCl^- - r(Na^+ + K^+)] / rCl^-$
Quaternary aquifer					
2	10575.33	1.32	0.65	0.60	-0.33
7	258.30	1.81	0.97	0.54	-0.98
8	839.41	0.68	0.78	1.00	0.27
9	166.70	2.30	0.98	0.28	-1.87
11	154.44	1.21	0.87	0.13	-0.71
12	543.19	3.16	1.18	1.07	-2.28
13	245.30	3.75	0.62	0.49	-3.53
14	315.68	1.65	0.93	0.64	-0.76
15	1010.58	3.98	0.22	0.68	-3.03
16	500.95	2.02	0.49	0.67	-1.08
17	787.34	8.14	0.34	5.24	-7.25
18	609.51	6.18	0.79	0.49	-5.27
20	582.25	1.37	0.45	0.57	-0.47
27	4576.38	0.76	1.20	0.85	0.24
33	12563.75	0.62	0.73	0.51	0.37
35	4108.04	0.56	1.41	0.49	0.43
37	2179.14	0.85	1.82	1.26	0.14
38	2967.55	0.99	1.41	1.79	-0.01
39	2068.70	0.92	1.05	1.53	0.06
40	3191.33	0.96	1.04	1.17	0.03
41	6740.73	0.48	1.33	0.15	0.52
Upper-Cretaceous aquifer					
19	4941.44	1.51	0.80	0.84	-0.53
30	4761.64	0.73	0.89	1.15	0.26
31	4092.85	0.44	0.76	0.47	0.55
32	4229.84	0.43	0.99	0.58	0.56
34	2484.67	0.43	0.50	0.32	0.56
36	5190.74	0.91	0.70	0.04	0.08
Fractured Pre-Cambrian aquifer					
1	7389.07	0.61	1.05	0.67	0.38
4	1234.58	0.92	0.84	0.71	-0.91
5	3138.76	1.20	0.79	1.35	0.05
6	534.29	1.02	1.24	3.23	-0.22
3	590.10	1.62	0.88	2.60	-0.28
21	4444.11	0.81	1.18	0.95	0.18
22	5240.80	0.92	1.12	0.95	0.08
23	3579.64	2.01	1.13	3.54	-1.07
24	3149.11	1.89	0.96	1.80	-0.90
25	3715.44	1.39	1.18	0.99	-0.39
26	4474.91	0.99	1.13	1.34	0.01
28	2811.89	2.06	0.42	1.07	-1.12
29	1494.88	2.07	0.22	1.41	0.38

Spatial variations in groundwater chemistry

To express spatial variation of groundwater chemistry within the investigated area, a representative hydrochemical profile along wadi El Kharit is constructed (Figure 11).

This profile passes through four water points in Wadi El Kharit from west to east. The analytical data displays intermediate hydrochemical development due east ($SO_4^{2-}>Cl^->HCO_3^-$) while being at an early stage of hydrochemical evolution due west ($HCO_3^->SO_4^{2-}>Cl^-$ at discharge area). Such change is strongly confirmed by the recorded water salinity, which rapidly decreases from 3579.64 mg/l at east to 543.19mg/l at west. This decrease is due to the dilution effect by irrigation water from the River Nile and its branches.

Table 7: Assemblages of the hypothetical salts in the different aquifers.

Aquifer	Assemblages of hypothetical salts in the study area	% of water samples
Quaternary	I-NaCl, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$	48
	II-NaCl, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$	5
	III-NaCl, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	5
	IV-NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	33
	V-NaCl, $MgCl_2$, $CaCl_2$, $CaSO_4$ and $Ca(HCO_3)_2$	9
Upper Cretaceous	III-NaCl, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	17
	IV-NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	66
	V-NaCl, $MgCl_2$, $CaCl_2$, $CaSO_4$ and $Ca(HCO_3)_2$	17
Fractured Pre-Cambrian	II-NaCl, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$	17
	III-NaCl, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	50
	IV-NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	33

The finding is aligned with Freeze and Cherry (1979) who mentioned that the general occurrence of Cl^- as a dominant anion is only in deep groundwater or groundwater that moved for a long distance, therefore, can generally be accounted for by the paucity of these minerals along the flow paths.

Two assemblages of hypothetical salts are characterizing the whole profile as follows:

Na Cl, Na_2SO_4, $MgSO_4$, $CaSO_4$ and Ca $(HCO_3)_2$ (wells Nos. 24 & 23 tapping the fractured Pre-Cambrian)

NaCl, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ (well No. 12 tapping the Quaternary aquifer).

The first assemblage indicates the effect of leaching and dissolution process of terrestrial salts rich in sulphate salts. While the second assemblage indicates that the groundwater is diluted by the irrigation water of the Nile River.

Summary and Conclusion:

This study helps in understanding the geochemistry of groundwater in three main aquifers dominating the area between Idfu and Aswan and the back desert to the east till the water divide between the Read sea drainage and Nile valley drainage with surface area of about 22500 Km^2.

The studied aquifers are the Quaternary aquifer between Idfu and Aswan, the Upper-Cretaceous aquifer at the north sector and the fractured Pre-Cambrian aquifer bordering the water divide at east. The flash floods resulting from heavy rainfall on the Red sea mountainous range is considered the main source of recharge for such aquifers besides the Nile water used in irrigation for the Quaternary aquifer. This study depends on the results of chemical analyses of 39 groundwater samples collected from the studied aquifers. These analyses include the determination of salinity and major cations and anions besides the hardness of groundwater. In this study the following parameters are discussed for every aquifer in detail:

Salinity, water chemical types, ion ratios, hypothetical salts assemblages and hardness, the spatial variations in groundwater chemistry are also discussed in one representative drainage line (wadi El Kharit).

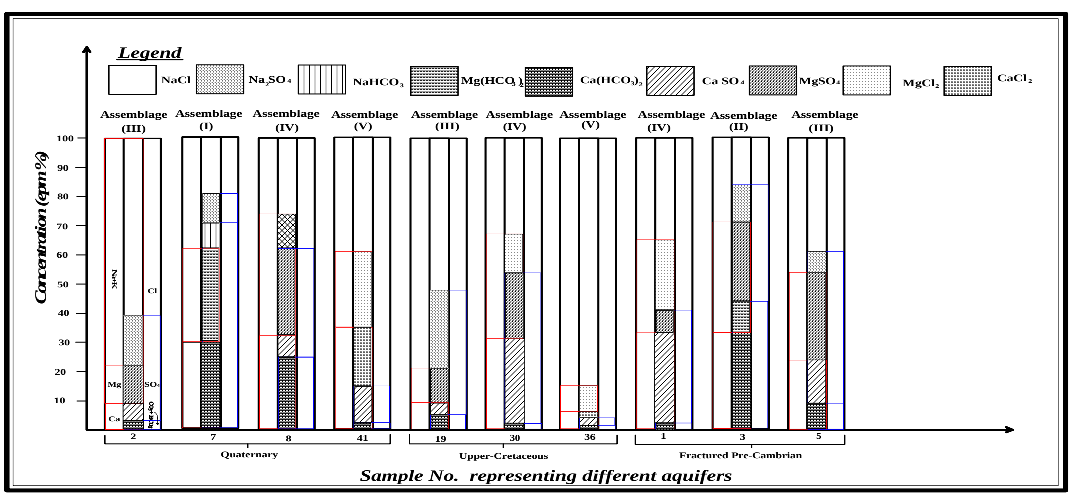

Fig. 10: Bar graphs for representative groundwater samples in the study area.

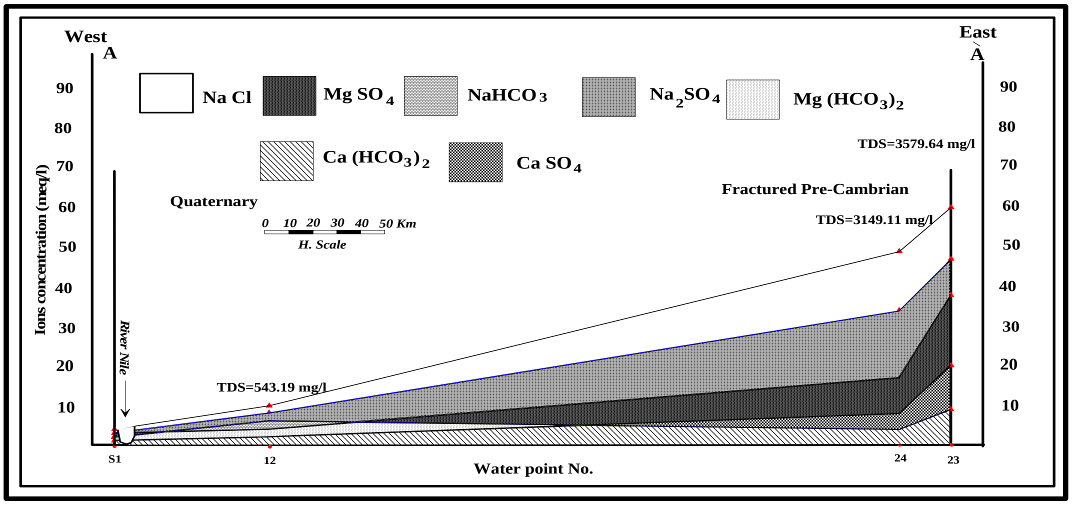

Fig. 11: Hydrochemical profile for groundwater chemical changes along wadi El Kharit in W-E direction.

The study indicated the role of the different chemical processes in the evolution of the present chemical characteristics of aquifers groundwater.

The main conclusions are:

- Salinity values vary generally between 154 mg/l and 12563 mg/l indicating fresh to highly saline water. Brackish water is also detected as the water salinity values vary between 2068 mg/l and 4940 mg/l.
- The relationship between hardness and salinity indicates general increase of total and permanent hardness as the water salinity increases in Quaternary and fractured Pre-Cambrian aquifers, while the total and permanent hardness decrease with the increase of water salinity in upper-Cretaceous aquifer.
- The recorded hypothetical salts in the groundwater of aquifers reflect less to advanced stages of groundwater metasomatism.
- The chemical types and hypothetical salts as well as the ion ratios indicate meteoric origin for groundwaters and dissolution of terrestrial and marine salts.

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, pp: 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, pp: 137.

Akaad, M.K. and A.M. Noweir, 1969. "Lithostratigraphy of the Hammamat-Umseleimat district." Eastern Desert, Egypt." Nature., 223: 284-285.

American Society for Testing and Materials, ASTM, 2002. "Water and environmental technology." Annual book of ASTM standards.

Burdon, D.J., 1958. "Metasomatism of groundwater at depth." UNESCO course on hydrogeology, Desert Institute, Cairo, Egypt.

Chebotarev, I.I., 1955. "Metamorphism of natural waters in the crust of weathering." Geochemica et. Cosmochimica Acta, 8(I): 22-48, (II), pp: 137-170 and (III), pp: 198-212.

Fayez, M.S., 1993. "Hydrogeological and hydrochemical studies on some localities in South Eastern Desert. Egypt" Unpubl., Ph.D. Thesis. Suez Canal Univ., Egypt, pp: 314.

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.

Hem, J.D., (1989): "Study and interpretation of the chemical characteristics of natural water" U.S. Geological Survey Water -Supply Paper 2254, pp: 263.

MPGAP, Minerals Petroleum & Groundwater Assessment Program, 1990. "Groundwater supplies in selected mining and petroleum districts C – Quseir – Mersa Himeira" Aid Project 2633-0105 Desert research Center, Ministry of Land Reclamation, volume II.

Rainwater, F.H. and L.L. Thatcher, 1960. "Methods for collection and analysis of water samples." U.S. Geol. Survey water supply, 301P.

Starinsky, A., M. Bielski, A. Ecker and G. Steinitz, 1983. "Tracing the origin of salts in groundwater by Sr isotopic composition (The crystalline complex of the southern Sinai), Egypt." Isotope Geoscience, 1: 257-267.