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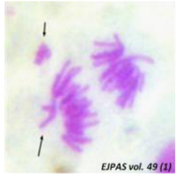

Geochemical Evidences for Possible Water Seepage from Lake Nasser to the Groundwater in the Area between Abu Simbel and Tushka

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ABSTRACT

In this paper, the geochemical modeling code NETPATH is used to calculate net geochemical mass – balance transfer of selected minerals and also to evaluate the main geochemical processes that take place in the system. The modeling results show that mixing occurs in the system by ratios vary widely between 1% and 93% of the sampled wells. Calcite and dolomite dissolution occurs in 50% and 40% of the investigated groundwater samples, respectively, while undersaturation state of gypsum, anhydrite and silica in almost all groundwater samples and surface water of Lake Nasser is remarkable.

Both the hypothetical salt assemblages and hydrochemical profiles show that there is seepage from Lake Nasser to the groundwater of the Nubian aquifer. Also the hydrochemical profiles determined the distance to which the seepage occurred. On the other hand, cluster analysis reveals a random spatial distribution of the different chemical components. Moreover, the distance to which the mixing process between Lake Nasser water and the Nubian aquifer groundwater was found to be 50-60 km from the Lake's borders.

Introduction

Recently, the investigated area has attracted the attention of the Egyptian government for agricultural development in order to create job opportunities for people and establish new communities far from the intense populated narrow valley. This area extends between Abu Simbel and Tushka within the southern sector of the Western Desert between latitudes 22° 15ˉ and 23° 06ˉ N and longitudes 31° 18ˉ and 32° 00ˉ E (Fig.1). It covers an area of about 7000 km^2. Climatically, this area is characterized by severe aridity, i.e., very hot weather in summer and warm weather in winter, scarce rainfall and high evaporation rate in summer.

The surface water-groundwater interaction plays an important role in controlling groundwater chemistry. The leakage into the groundwater system is the major process of such interaction. Therefore, the hydrochemistry of groundwater as a natural tracer to demonstrate the leakage process (seepage) was applied and discussed in the present paper. The hydrochemical model Netpath XL was used to study the water rock interaction by calculating the saturation indices for some minerals and mixing ratios. The groundwater situation, hypothetical salts assemblages, hydrochemical profiles, the model's results and also cluster analysis were used to estimate the seepage from Lake Nasser to the Nubian sandstone aquifer.

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Aquifer system

The Nubian sandstone aquifer constitutes the only source of groundwater in the area. It is composed of coarse to medium sandstone with intercalations of siltstone, clay and occasional conglomerate, predominately deposited in continental environment. The whole succession varies between 170 m and 320 m, generally increases towards South and East, i.e., towards Lake Nasser while decreases towards West and North, i.e., towards Nekhalai-Aswan uplift. The depth of the groundwater ranges between 20 m and 147m from the ground surface. The groundwater exists under unconfined and semi-confined conditions. The semi-confined behavior is more detected towards the middle parts of the area occasionally caused by the occurrence of clay and mudstone layers[1]. More than hundred wells were drilled for development projects, beside El Sheikh Zayed irrigation canal which carry surface water from

Lake Nasser. The origin of groundwater is mainly attributed to paleowater of the past wet periods associated with recent contribution from Lake Nasser.

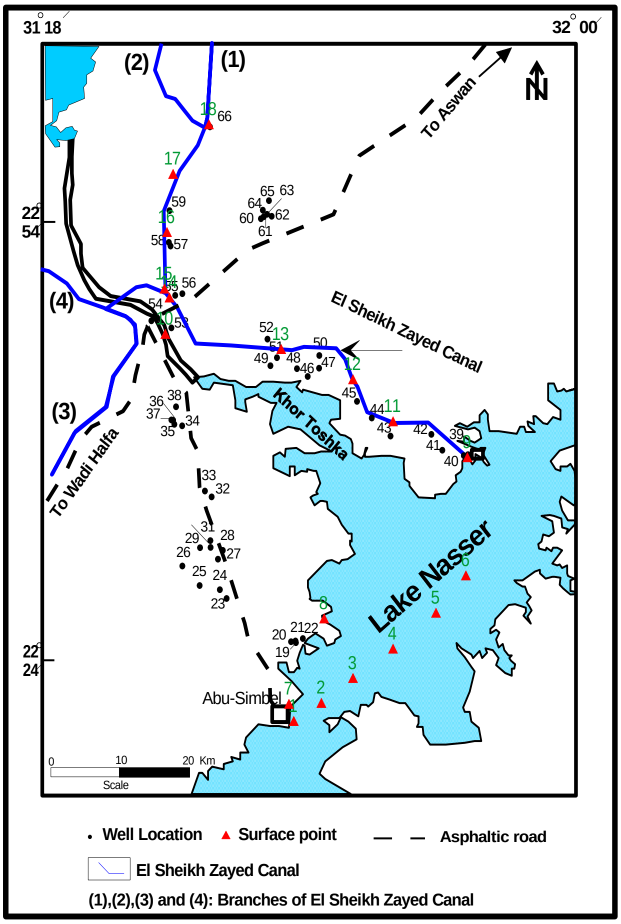

Fig. 1: Location map and sampling sites.

Samples and Methods

Sampling and hydrochemical measurements

Sixty-six water samples were collected from the study area during June 2009 (eighteen representing surface water samples and forty-eight representing groundwater samples). Locations and water points were delineated using GPS. Depth of water, total depth, EC, T^0C and pH were also measured for the collected water samples in situ. Chemical analyses were carried out for all collected water samples to determine the concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^-, Fe^{3+}, and SiO_2 according to the methods adopted by [2, 3] and [4]. Isotopic analysis was carried out using to determine deuterium and oxygen-18.

Geochemical modeling

Inverse geochemical modeling[5] has been widely used in interpreting geochemical processes. One of the most recent inverse geochemical modeling codes, NETPATH, is used in the present study. NETPATHXL[6] is an interactive Fortran 77 computer program that can be used to compute the mixing proportions of two to five initial waters and net geochemical reactions accounting for the observed composition of final water.

NETPATH contains two FORTRAN 77 codes: DB.FOR and NETPATH.FOR. In the present study, DB.FOR is firstly used to input and edit the chemical analysis data and then run WATEQFP included in DB to calculate mineral saturation indices. NETPATH.FOR is then run to calculate mixing ratios of surface water and Nubian sandstone groundwater and to interpret geochemical reactions of natural water.

Geostatistical methods (cluster analysis)

Cluster analysis was carried out to obtain information related to surface water seepage to the Nubian sandstone aquifer groundwater. Cluster analysis is a method which indicates associations between samples and/or variables[7-8]. These associations, based on similar magnitudes and variations in chemical and physical constituents, may indicate the presence of seasonal or human influences. Cluster analyses also help in grouping of samples by linking inter-sample similarities and illustrate the overall similarity of variables within the data set. The statistical package SPSS 10 for windows is used for calculations.

Results and Discussion

Groundwater situation

In the study area, the groundwater situation has been assessed through two water table maps for the Nubian sandstone aquifer during the period 2002-2009, from which the following can be concluded:

I. ***The groundwater level situation in 2002[1] and in 2009[9]:***

A-The direction of groundwater flow, (Figs.2 and 3), is regionally towards North and Northwest that supports the assumption of recharging from Lake Nasser towards the middle part of the study area surrounding Tushka depression.

B- There is unsmooth shape at the contours +132, +128, +124, +120, +116 & +112 in 2002, and +136, +132, +128, +124, +120 & +11 in 2009. This is due to the seepage from Lake Nasser to the middle part.

C- The +132 contour line is located at a maximum distance of 4 km in 2002 while being at a distance of 45 km Northwest Lake Nasser in 2009, which means that seepage occurred from Lake Nasser to the groundwater of the Nubian sandstone aquifer towards the northwest direction.

D- The deviation from the general trend of the water flow is due to geologic structures (fractures and faults).

II. ***Reconsidering the groundwater level to construct a resultant water table map (Fig.4) during 2002 to 2009,*** from which the studied area is subdivided into several zones according to the groundwater fluctuation. These zones are distinguished as follows;

(1) Referring to the resultant water table map concludes that;

A- There is a recharge direction from Lake Nasser to the Nubian sandstone aquifer until reaching the maximum at +12 contour line (+4 to +12), this is observed by increasing the groundwater levels from +4 near Lake Nasser to +12 at the middle part of the study area.

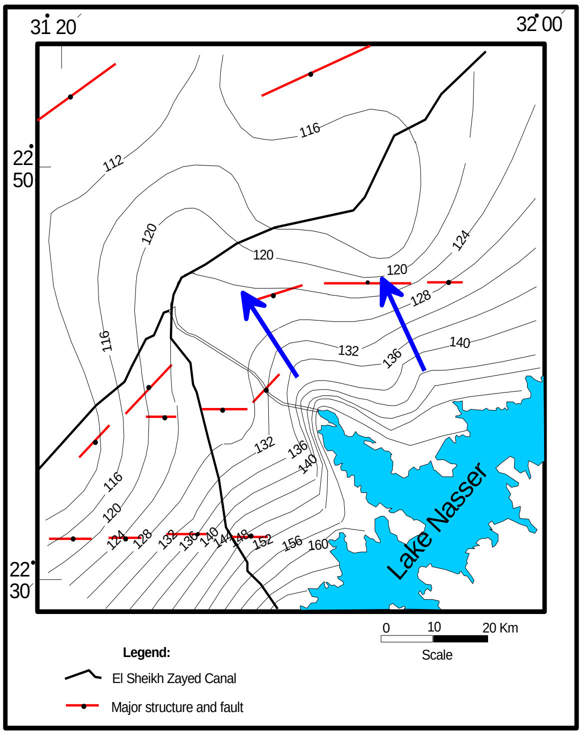

Fig. 2: Water table map of Tushka area, April 2002 (Modified after El Sabri[1]).

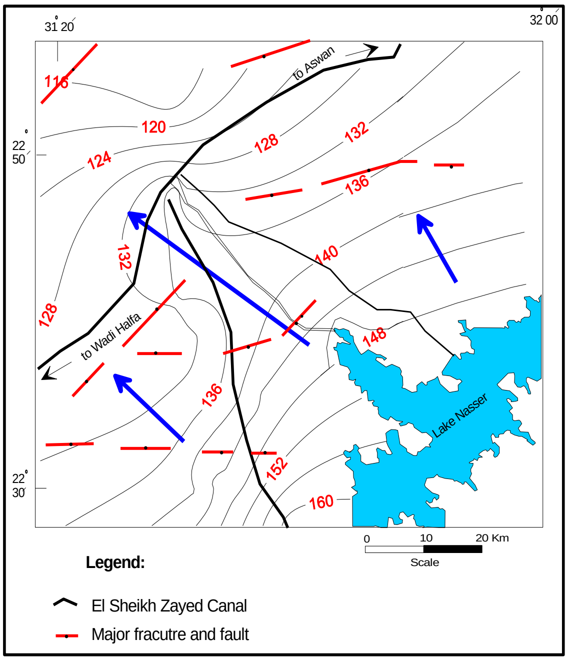

Fig. 3: Water table map of Tushka area, December 2009 (Modified after [9]).

B- The recharge decreases towards the Northwest due to the structure, i.e., the leakage (seepage) from Lake Nasser to the groundwater of the Nubian sandstone aquifer decreases Northwest, this is observed from the decrease in groundwater levels from +12 at the middle part to +4 at the end of the study area, i.e., recharging from Lake Nasser to the groundwater of the Nubian sandstone aquifer in the study area occurred to a distance towards northwest direction.

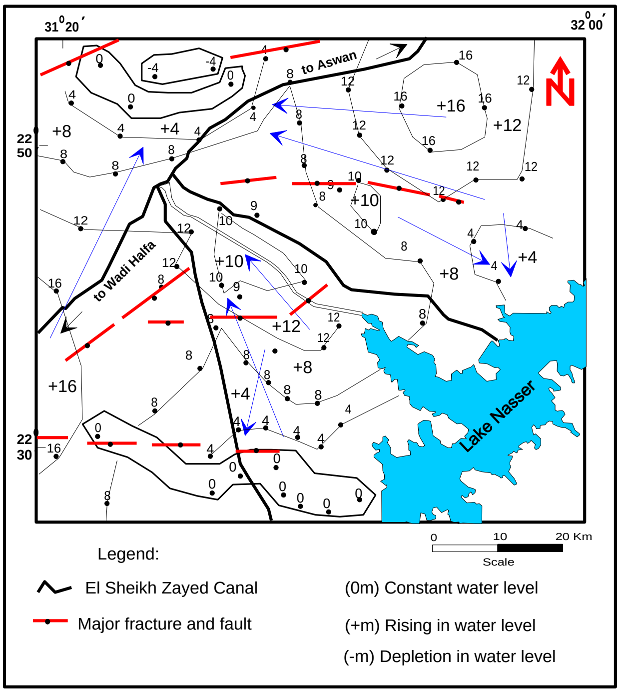

Fig. 4: Iso-resultant water table map of the study area.

C-Also, there are recharge directions from Lake Nasser to the groundwater of the Nubian sandstone aquifer in the study area from East to West direction. Noteworthy to mention that, the previous directions towards West, Northwest and Southwest were coincident with the general direction of groundwater flow.

(2) The resultant rising in water level ranges from +4 to +16 m (Table 1) as recorded all over the concerned area. The areas of groundwater rising referred to the rate of recharge that exceeds discharge. This indicates that seepage from Lake Nasser to the groundwater of the Nubian sandstone aquifer in the study area will be occurred to a distance ranging 50-60 km, this anticipation agrees, to a great extent, with [10] who stated that the maximum distance from the Lake beyond which its contribution to groundwater becomes negligible is about 50 km and also with El Sabry[1] who concluded that the hydraulic connection between Lake Nasser and Nubian aquifer is very effective within a distance of about 58 km from the Lake.

(3)In areas of water depletion which is located at the ending points of the boundaries (borders) at the northwest and southwest directions of the study area, the resultant drop in water level is -4m (Table 1), where the rate of discharge exceeds that of the recharge.

(4) Areas of constant water level that are recorded at the northwest and southwest of the study area (Table 1), where the rate of water recharge is nearly equal to the water discharge.

Table 1: Changes of the groundwater levels in the Nubian sandstone aquifer in the study area during the period 2002-2009.

Resultant water levels in m	Water level in 2002	Water level in 2009
+16	116	132
	124	140
	112	128
+12	120	132
	116	128
	128	140
	124	136
	132	144
+10	126	136
+9	127	136
+8	120	128
	116	124
	124	132
	132	140
	128	132
+4	136	140
	144	148
	120	124
	148	152
0	160	160
	156	156
	152	152
	148	148
	144	144
	116	116
	120	120
-4	120	116

Groundwater chemical properties

The hydrochemistry of groundwater as a natural tracer to demonstrate the seepage process is applied and discussed for 66 water samples, Fig.(1). The major ion concentrations, trace constituents and stable isotopes percentages are listed in Table (2).

a- Total salinity

It can be observed that, the surface water samples have the lowest TDS values (130 to 145 mg/l). Far from the surface water samples, the majority of groundwater samples (83%) has relatively low TDS (230-985 mg/l), while the rest of samples (17%), which are located at the middle part of the study area, has relatively high TDS (1044-1875 mg/l) due to the presence of gypsiferrous shale within the aquifer matrices in addition to the leaching and dissolution processes. The decrease in TDS concentrations of most samples is, therefore, most probably related to the mixing / dilution of the surface water and groundwater, through other flow paths before its discharge to the surface. Based on the iso-salinity contour map (Fig.5), the water salinity increases markedly from Southeast to Northwest and from East to West towards the middle of Tushka area, which matches, or follows the general direction of the groundwater flow, towards the middle of Tushka depression. This confirms that there is a recharge from Lake Nasser to the Nubian Sandstone aquifer groundwater.

Noteworthy to mention that seepage occurred from surface water to groundwater through faults. It is noticed that, the groundwater of wells Nos. 20 and 21 that located near the Lake, have higher salinity, this is due their locations far from faults. The presence of high sulfate concentrations in groundwater is possibly due to the presence of gypsiferrous shale.

b- The assemblages of hypothetical salts

All surface water in the study area is characterized by the assemblage of hypothetical salts (I), as shown in Table (3). This assemblage indicates a primary stage of water mineralization and reflects the meteoric origin, where metasomatic sequence is $HCO_3^- > Cl^- > SO_4^{2-}$. Most groundwater samples (83%) of the Nubian Sandstone aquifer in the study area are characterized by the hypothetical salts (II and III), which reflect the effect

Table 2: Results of chemical and isotopic analysis of surface water and groundwater samples in the study area.

Sample No.	TDS ppm	Ca^{2+} ppm	Mg^{2+} ppm	$Na^{+}+K^{+}$ ppm	HCO_3^{-} $+CO_3^{2-}$ ppm	SO_4^{2-} ppm	Cl^{-} ppm	SiO_2 ppm	Fe^{3+} ppm	D %0	O^{18} %0
Surface water											
1	130	24.048	7.417	17.00	129.347	7.00	9.95	5.03	Nd	11.4	0.18
2	129	24.048	7.417	16.00	129.347	7.00	9.95	4.41	0.048		
3	129	24.048	7.417	16.00	129.347	7.00	9.95	13.08	0.082		
4	138	24.449	7.417	18.00	136.059	10.00	9.95	3.88	Nd		
5	134	24.449	7.417	19.00	136.059	5.00	9.95	4.76	Nd		
6	139	24.449	7.417	20.00	136.059	9.00	9.95	3.96	0.21		
7	142	24.24	9.82	16.00	128.10	13.00	14.46	5.47	Nd	19.5	1.34
8	142	24.24	9.82	17.00	134.51	9.00	14.46	9.27	0.086		
9	128	22.272	7.296	18.00	122.026	9.00	9.95	10.07	4.4		
10	152	22.62	10.80	18.00	160.13	6.00	14.46	5.03	Nd		
11	149	24.449	9.914	19.00	150.702	10.00	9.95	4.41	0.048		
12	138	24.48	7.417	18.00	143.38	6.00	9.95	13.08	0.082		
13	138	24.449	7.417	19.00	143.38	5.00	9.95	3.88	Nd		
14	136	24.449	7.417	18.00	136.059	8.00	9.95	4.76	Nd		
15	143	24.449	7.417	18.00	143.380	11.00	9.95	3.96	0.21		
16	136	24.449	7.417	18.00	136.059	8.00	9.95	5.47	Nd		
17	137	20.441	9.970	20.00	136.059	9.00	9.95	9.27	0.086		
18	147	28.657	5.00	20.00	143.380	12.00	9.95	10.07	4.4		
Groundwater											
19	562	64.64	9.82	92	355.125	141	77.1	12.46	Nd		
20	1090	109.08	14.73	214	330.530	418	169	13.52	4.65		
21	732	92.92	9.82	117	367.315	227	101	10.43	Nd		
22	513	68.68	12.27	68	342.315	140	53.0	12.46	0.82		
23	632	68.68	17.18	93	380.290	167	96.4	13.35	1.00	-79.2	-10.1
24	261	8.16	4.96	86	35.88	44.00	99.5	8.212	Nd		
25	498	8.08	2.45	94	515.125	35	101	0.779	4.98		
26	300	8.08	2.45	78	203.835	18	91.6	0.000	6.46		
27	358	16.32	4.96	117	86.12	27.0	149	10.34	1.73		
28	321	6.12	1.24	115	42.94	77.78	99.5	5.735	0.55		
29	730	12.12	4.91	109	851.910	72	106	1.664	7.09	-74.4	-9.74
30	811	72.72	14.73	113	590.100	200	116	10.07	2.37	-78.2	-9.77
31	542	77.52	12.39	102	143.53	164.0	114	13.43	0.38		
32	648	8.08	1.47	142	609.530	37	154	0.000	0.59		
33	603	8.08	2.45	120	615.910	30	135	0.000	0.92	-78.3	-9.9
34	1387	137.36	24.54	275	433.100	406	328	9.186	0.22		
35	1208	121.20	22.09	235	371.530	335	308	11.04	Nd		
36	470	12.12	2.45	103	363.745	26	145	0.602	4.52		
37	1142	60.60	2.45	272	465.125	237	33	0.000	0.11		
38	1031	60.60	12.27	241	367.935	167	366	0.956	30.61	-75.2	-9.1
39	610	105.04	14.73	112	77.050	210	130	13.17	Nd		
40	494	88.88	17.18	97	0.000	190	101	12.99	0.22		
41	486	96.96	12.27	98	0.000	153	125	10.96	0.38		
42	472	80.80	14.73	103	0.000	143	130	13.79	Nd	-71.6	-8.7
43	570	84.84	17.18	128	0.000	195	145	13.17	0.16		
44	495	72.72	14.73	118	0.000	164	125	9.009	Nd		
45	614	69.36	12.39	130	150.59	188.0	139	10.78	0.24		
46	655	97.92	9.91	135	186.36	155.0	164	5.292	0.09		
47	643	80.80	19.63	149	0.000	220	174	13.17	1.46		
48	583	76.76	19.63	133	0.000	195	159	11.84	0.72		
49	987	118.32	17.35	213	150.71	300.0	264	7.416	0.22		
50	893	114.2	17.35	168	172.24	313	194.03	7.858	0.29		
51	829	105.0	19.63	189	0.000	265	250.64	15.646	0.93		
52	964	121.2	24.54	213	0.000	355	250.64	13.168	0.17	-75.5	-9.8
53	578	40.40	2.45	183	0.000	159	192.8	0.000	0.91		
54	1799	193.9	36.81	423	0.000	711	433.8	5.558	Nd		
55	1273	149.5	34.36	275	0.000	462	351.86	11.133	0.56		
56	1187	141.4	34.36	265	0.000	443	303.66	13.257	0.46	-77.8	-9.3
57	1558	183.6	22.31	315	208.01	550.00	383.08	12.018	1.68		
58	1172	149.5	19.63	263	0.000	475	265.1	9.894	0.07		
59	604	44.88	2.48	173	64.35	152.00	199.00	13.345	1.16		
60	676	89.76	9.91	132	179.30	215.00	139.30	13.788	0.06		

Table 2 continued...

Sample No.	TDS ppm	Ca^{2+} ppm	Mg^{2+} ppm	$Na^{+}+K^{+}$ ppm	HCO_3^{-} $+CO_3^{2-}$ ppm	SO_4^{2-} ppm	Cl^{-} ppm	SiO_2 ppm	Fe^{3+} ppm	D %0	O^{18} %0
Groundwater											
61	787	109.1	22.09	158	0.000	305	192.8	11.664	Nd		
62	565	88.88	17.18	124	0.000	205	130.14	10.159	0.07	-76.7	-9.6
63	516	84.84	17.18	115	0.000	178	120.5	9.982	Nd		
64	796	113.1	17.18	178	0.000	305	183.16	12.549	0.77		
65	473	82.42	13.74	95	0.000	195	86.76	12.283	Nd		
66	333	52.52	7.36	72	0.000	13	187.98	0.000	Nd	-76.4	-9.5

of leaching and dissolution of terrestrial salts (continental facies groundwater) by local infiltration of rain water during Pluvial and post Pluvial times as well as seepage from the surface water system (Lake Nasser) with some contribution of cation exchange process. Furthermore, 15% of the Nubian Sandstone groundwater samples are characterized by hypothetical salt assemblage (I) that is similar to that of Nile water (Lake Nasser). This confirms that the recharge is mainly from Lake Nasser. On the other hand, few groundwater samples of the Nubian Sandstone aquifer (2%) have the assemblage (IV) which contains the marine salts $MgCl_2$ and $CaCl_2$. The presence of $MgCl_2$ indicates the effect of marine facies while $CaCl_2$ indicates the contribution of paleowater.

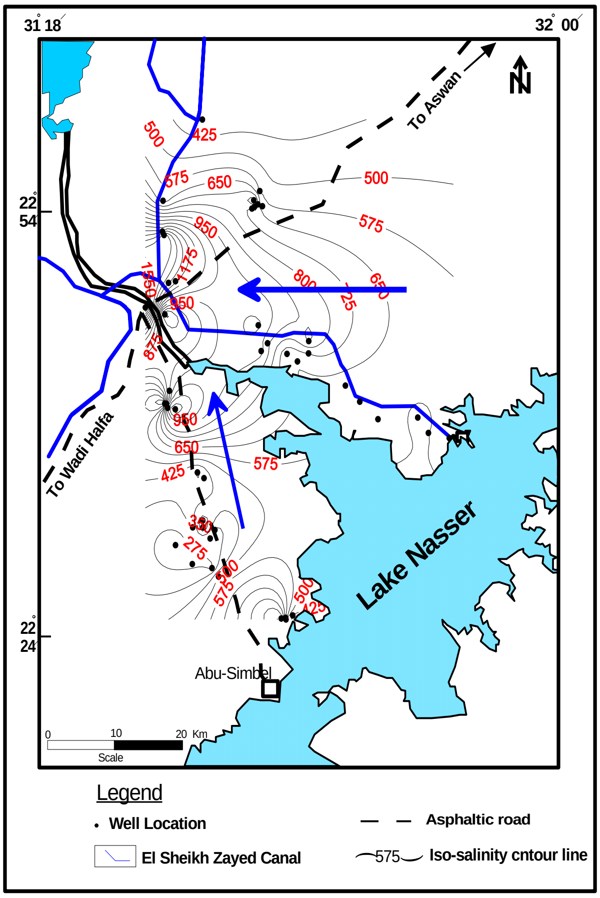

Fig. 5: Iso-salinity contour map of the Nubian sandstone aquifer at Tushka area.

In conclusion, the hypothetical salt assemblages indicate meteoric water origin influenced by leaching and dissolution of terrestrial salts with some contribution of cation exchange process.

From all previous discussions, it can be concluded that there is a recharge from Lake Nasser water to the Nubian sandstone aquifer groundwater.

c- Hydrochemical profiles

The profile (A-A′), Fig.(6), is directed from Southeast to Northwest direction and stars from Lake Nasser (sample No. 1) passing through eight wells along the Nubian sandstone aquifer showing an irregular pattern characterized by non conspicuous trend for increase or decrease of water salinity (the fluctuation of salinity) and ions concentration.

Generally, the hydrochemical properties along this profile reveal that TDS increases remarkably from fresh to brackish as shown by one peak, corresponding to over pumping sites leads to leaching and dissolution processes for the aquifer matrix, also reflect the presence of gypsiferrous shale within the building of the matrix of the Nubian sandstone aquifer in the study area. The irregularity in the content of the chemical species along this profile reflects the presence of two sources of recharging for the aquifer groundwater; the first source is from Lake Nasser at the Southeast direction that ends at the sample No. 54 and the latter one is from the old recharging source (paleowater of the past wet periods) at the Northwest direction that ends also at the samples No. 54. This is indicated by the salinity increasing direction from sample No. 1 to sample No. 54 (the drop in salinity at samples No. 28 and 33 referred to seepage from Lake Nasser through faults) at the Southeast direction and the salinity increasing direction from sample No. 66 to sample No. 54 at Northwest direction.

The previously mentioned discussion indicates that there are two recharging sources meeting at sample No. 54, i.e., the end for each recharging source is at sample No. 54 which represents the boundary of each recharging source. Finally, there is a seepage from Lake Nasser to groundwater of the concerned aquifer and this seepage ends at the sample No. 54 at a distance of 50 km. Assemblages of hypothetical salts combinations (I and III) dominate this profile while the assemblage IV is

Table 3: Assemblages of the hypothetical salt combinations of surface water and groundwater of the Nubian sandstone aquifer.

The assemblages of hypothetical salt combinations	Percentage of water samples (%)	
	Surface water	Groundwater
I- NaCl, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$	100	15
II-NaCl, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$	0	4
III-NaCl, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	0	79
IV-NaCl, $MgCl_2$, $CaCl_2$, $CaSO_4$ and $Ca(HCO_3)_2$	0	2

recorded only at well No. 66. The presence of the bicarbonate salts in Lake Nasser and wells No. 23, 28, 33, 34, 54 and 59 indicates that the feedings from Lake Nasser is one of the recharging sources while the presence of $MgCl_2$ at well No. 66 indicates another recharging source which is from paleowater of the past wet periods.

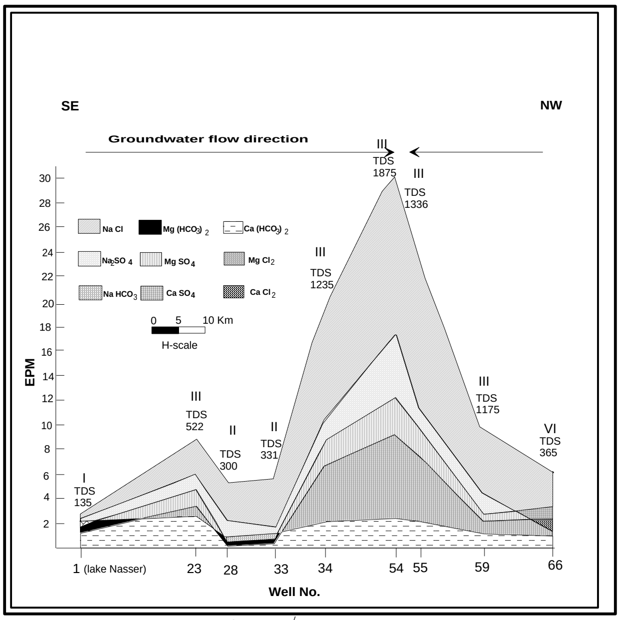

Fig. 6: Hydrochemical profile AA/ in SE-NW direction.

The ions dominance change follows a sequence from (HCO_3^- > Cl^- > SO_4^{2-}) at Lake Nasser to (SO_4^{2-} > Cl^- > HCO_3^-) at well No.(23), to (Cl^- > HCO_3^- > SO_4^{2-}) at wells No. 33 and 66 and then to (Cl^- > SO_4^{2-} > HCO_3^-) facies at wells No. 34, 54, 55 and 59. Finally the ion dominance changes from (HCO_3^- > Cl^- > SO_4^{2-}) to (Cl^- > HCO_3^- > SO_4^{2-}) due to leaching and dissolution processes during seepage from Lake Nasser until reach to the final well.

The hydrochemical profile (B-B/), Fig.7, is directed in a Southeast-Northwest direction that starts at Lake Nasser (sample No. 9) and passes through four wells along the Nubian sandstone aquifer. The water salinity rapidly increases from 552 mg/l at Southeast to 1337 mg/l at Northwest, indicating a seepage from Lake Nasser. This is manifested by increasing salinity from Southeast to Northwest, i.e. in the same direction of seepage.

Also, the hydrochemical processes as leaching and dissolution processes are shown by the increase of salinity from Southeast to Northwest direction which supports the seepage from Lake Nasser to the groundwater aquifer.

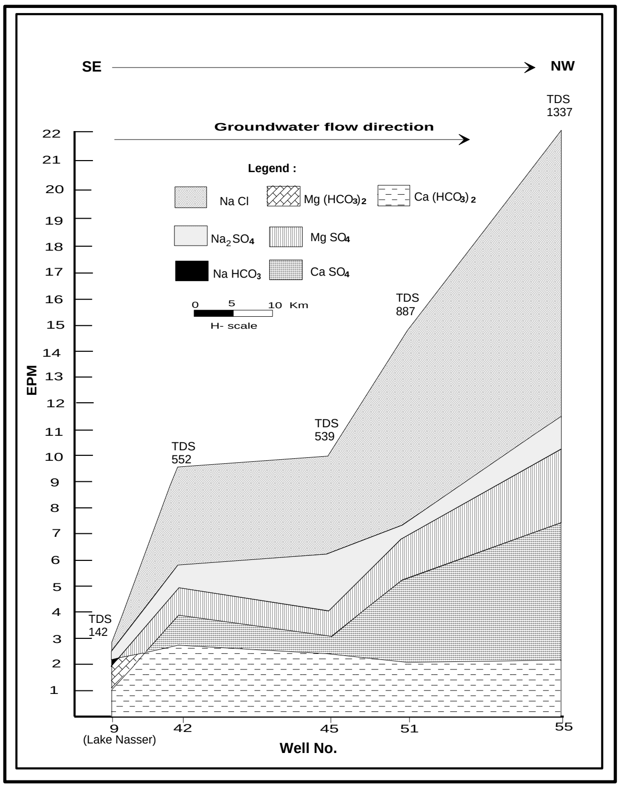

Fig. 7: Hydrochemical profile BB/ in SE-NW direction.

Concerning the metasomatic changes in water chemistry in the southeast-northwest direction, it is obvious that there is a change from HCO_3^- > Cl^- > SO_4^{2-} (less advantage stage of metasomatic sequence) to Cl^- > SO_4^{2-} > HCO_3^- (more advantage stage of metasomatice) at well No.(55), which means that there is a seepage from Lake Nasser to the groundwater of the Nubian sandstone aquifer. Noteworthy to mention that Lake Nasser is characterized by the hypothetical salt assemblage (I), where the groundwater samples (42, 45, 51 and 55) have hypothetical salt assemblage (III). The bicarbonate salts in assemblage III means that one of the recharging sources for the groundwater is Lake Nasser. From the previously mentioned, it is clear that seepage takes place from Lake Nasser to groundwater through this profile for a distance nearly equal to 60 km.

Geochemical processes analysis

The hydrogeochemical data also, have been used to identify the saturation indices and mixing ratios as follows:

Table 4: Selected constraints, phases and parameters in geochemical modeling using NETPATH.

Constraints	Phases	Parameters
Carbon Calcium Sulfur Magnesium Sodium Chloride Iron SiO_2	Calcite Dolomite Gypsum Anhydrite Silica	Dilution/evaporation; yes

a. Saturation state with respect to minerals

The saturated state of water is an important concept because it can help for better understanding of the chemical history of the water. In a groundwater system, the saturation state of minerals may indicate the type of rocks which contact the groundwater. The saturation index (SI) is the logarithm of the ion activity product (Q) divided by the equilibrium constant for a particular reaction, and represents the degree of saturation of water with respect to a particular mineral.

$$SI = Log\ Q/KT$$

The saturation index of a mineral indicates whether the water is oversaturated (positive saturation index), undersaturated (negative saturation index), or in equilibrium (near zero saturation index). Oversaturated condition may result in precipitation of the mineral, while undersaturation condition may result in dissolution or alteration of the mineral phase.

Results of saturation index calculation using WATEQFP contained in NETPATH are tabulated in Table (5), where the positive values refer to the mass entering the solution, and the negative values refer to the mass leaving the solution. To run NETPATH, constraints and models are first selected (Table 4). Calcite, dolomite, gypsum, anhydrite and silica are the five major minerals of the Nubian sandstone aquifer groundwater, and correspondingly, are constrained by the dominant ions carbon ion, Ca^{2+}, Mg^{2+}, S^{2-}, Na^{+} and Cl^{-}. The results (Table 5) showed that; all surface water samples are undersaturated with respect to the concerned minerals (calcite, dolomite, gypsum, anhydrite and silica). For groundwater 50% of the samples are undersaturated with respect to calcite mineral, while 60% of the samples are undersaturated with respect to dolomite mineral. The presence of calcite and dolomite minerals is referred to the hypothesis of [11] and [12], which stated that the groundwater of the Nubian sandstone basin is mainly formed by rainfall infiltration on some highlands of basement rock rich in mafic minerals which are enriched in calcium and magnesium ions, located southwest the regional Nubian sandstone basin as Tibesti, Ennedi and Eridi highlands. On the other hand, the rest of the groundwater samples (50% and 40%) are saturated with respect to calcite and dolomite minerals, respectively. Noteworthy to mention that, all groundwater samples are undersaturated with respect to gypsum, anhydrite and silica. The major reason for such widespread under-saturation state with respect to the predominant mineral phases of the aquifer matrix should be the dilution caused by the mixing of the concerned aquifer groundwater with dilute, leaked surface water, which commonly has low TDS and HCO_3-Ca major ion composition[13], which confirmed the seepage of surface water of Lake Nasser to groundwater of the Nubian sandstone aquifer in the study area.

b. Mixing proportions of two initial waters

The NETPATHXL program has been used to calculate the mixing ratio in the final water sample resulted between two initial water samples. The first initial groundwater sample No. 62 represents the Nubian sandstone groundwater which has no leakage from Lake Nasser. The second initial one is a sample from Lake Nasser. The final water is the sample which we need to estimate the mixing ratio between the two initial waters (Tables 6 & 7). The two cross sections AA$^{/}$ and BB$^{/-}$ were taken to represent the final samples (Fig.8).

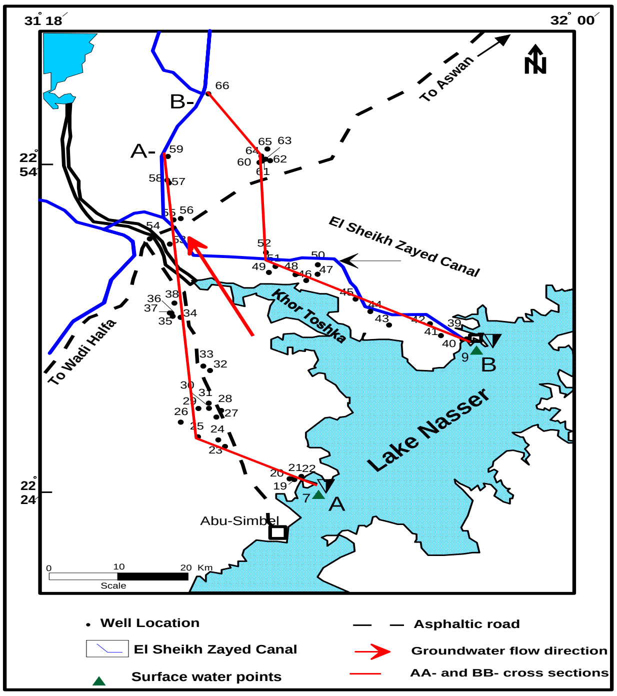

Fig. 8: Locations of the two cross sections A-A$^{/}$ and B-B$^{/}$.

The contribution of recent recharge from Lake Nasser to the Nubian sandstone aquifer groundwater in the study area varies largely from 1% to 93%, avg. 48% (Tables 6 & 7). This is actually controlled by the lithological and structural elements which either facilitate the recharge or act as barriers against it. This coincides with Aly[10] who used the dipole mixing model of O-18 to calculate the percentage of recent recharge received by each sampled well and it was found quite variable (from 0% to 68%, average 23%). It is obvious from the two paths modeled (AA/ and BB/) that mixing ratios between the surface and groundwater have been calculated. The mixing ratio in the final Nubian sandstone aquifer groundwater (Wells Nos. 59 and 66) is quite high. Of course, this is a clear indication of the vital importance of surface water leakage to the Nubian sandstone aquifer groundwater system.

Cluster analysis

The purpose of cluster analysis is to identify groups or clusters of similar sites on the basis of similarity within a class and dissimilarities between different classes[14]. In hierarchical cluster analysis the distance between samples is used as a measure of similarity[15]. In order to classify the objects of the system into categories or clusters based on their nearness or similarity[16]. Agglomerative hierarchical clusters are formed sequentially, by starting with the most similar pair of objects and forming higher cluster step by step.

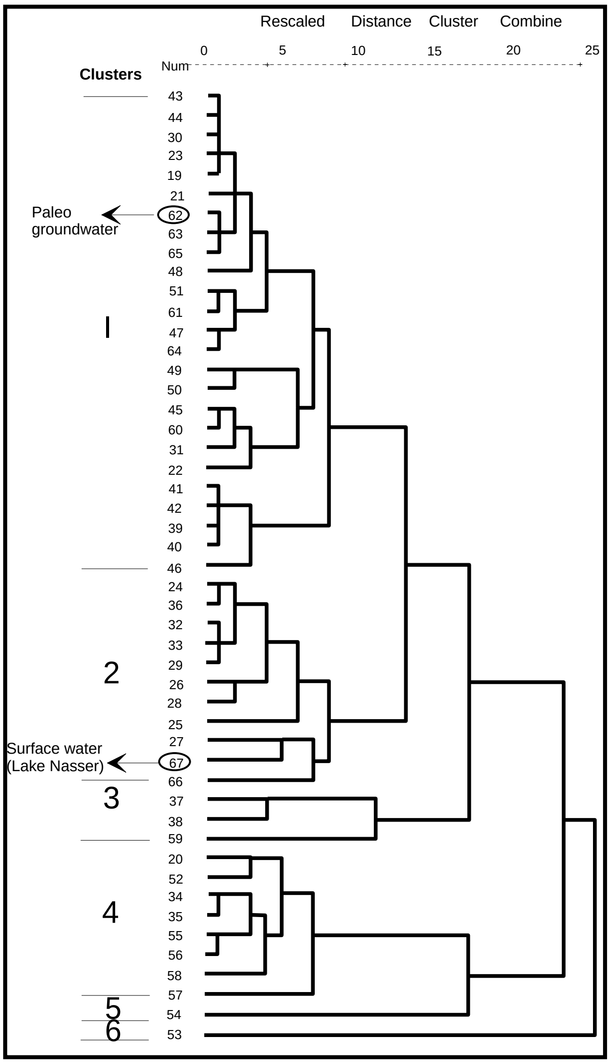

Fig. 9: Dendrogram of cluster analysis.

One of the main purposes of cluster analysis in this study is to identify samples affected by recharge from Lake Nasser.

To detect spatial similarity among groups, cluster analysis (CA) was applied on 48 groundwater samples and one sample from Lake Nasser. The Ward`s method[17] was applied (Linkaged). This method using squared Euclidean distance as a measure of similarity possesses a small space distorting effect between groups. This method using square Euclidian distance and synthesized in dendrogram (Fig. 9). The 49 water sampling sites fall into 6 major clusters. These clusters are also represented spatially in Fig. 10.

Cluster No.1 represents the less affected samples by recharge from the Lake, where the TDS ranges between 419 and 1175 mg/l, with an average value of 995 mg/l. This is confirmed by the following ions dominance; $SO_4^{2-} > Cl^- > HCO_3^-$ /$Na^+ > Ca^{2+} > Mg^{2+}$.

Cluster No. 2 is composed of samples with a high influence of Lake Nasser seepage because the locations of the samples are lying on faults, so it represents the most affected samples by recharge from Lake Nasser, where TDS ranges between 145 and 388 mg/l, with an average value of 294mg/l. This is confirmed by the ions dominance; $Cl^- > HCO_3^- > SO_4^{2-}$ / $Na^+ > Ca^{2+} > Mg^{2+}$.

Cluster No. 3 is represented by three samples. TDS ranges between 828 and 1175 mg/l, with an average value of 995mg/l. This is confirmed by the ions dominance; $Cl^- > SO_4^{2-} > HCO_3^-$ / $Na^+ > Ca^{2+} > Mg^{2+}$.

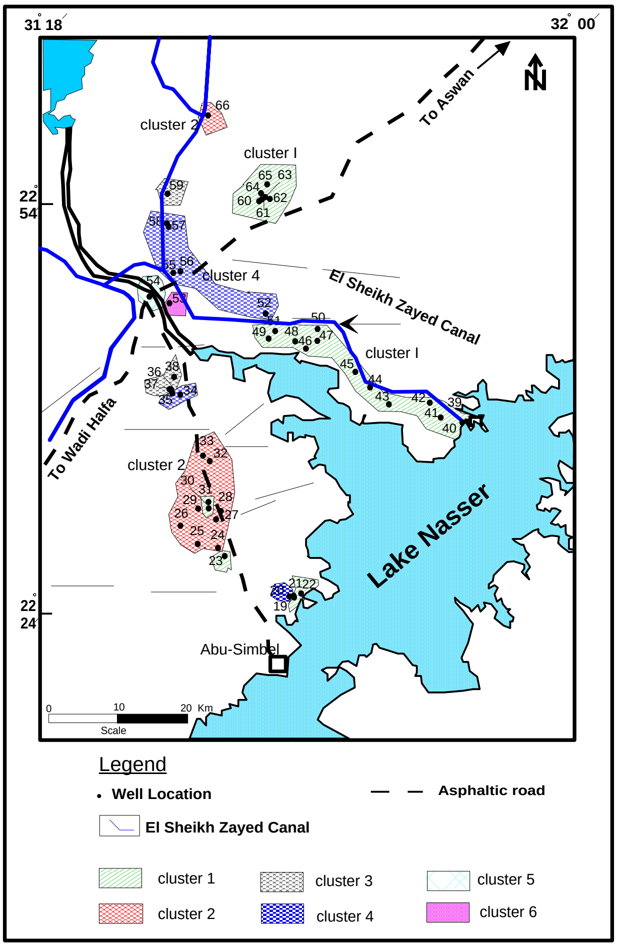

Fig. 10: Spatial distribution of clusters in the study area.

Table 5: Saturation indices of selected minerals of surface water and groundwater at the study area using NETPATH program.

Sample No.	Calcite	Dolomite	Gypsum	Anhydrite	Silica
Surface water					
1	-0.402	-1.061	-3.05	-3.292	-1.308
2	-0.451	-1.062	-3.05	-3.292	-1.308
3	-0392	-1.061	-3.06	-3.292	-1.308
4	-0.422	-1.071	-3.05	-3.292	-1.308
5	-0.385	-1.061	-3.05	-3.292	-1.308
6	-0.402	-1.063	-3.06	-3.292	-1.308
7	-0.402	-1.061	-3.05	-3.292	-1.308
8	-0.455	-1.061	-3.05	-3.292	-1.308
9	-0.402	-1.020	-3.24	-3.292	-1.308
10	-0426	-1.061	-3.05	-3.292	-1.308
11	-0.402	-1.061	-3.04	-3.292	-1.308
12	-0.478	-1.061	-3.05	-3.292	-1.308
13	-0.402	-1.011	-3.06	-3.292	-1.308
14	-0.465	-1.061	-3.05	-3.292	-1.308
15	-0.402	-1.061	-3.05	-3.292	-1.308
16	-0.510	-1.061	-3.06	-3.292	-1.308
17	-0.402	-1.061	-3.05	-3.292	-1.308
18	-0.402	-1.061	-3.05	-3.292	-1.308
Groundwater					
19	-0.153	-0.739	-1.529	-1.731	-1.005
20	0.368	0.242	-1.007	-1.21	-0.971
21	0.268	-0.055	-1.237	-1.438	-1.085
22	0.399	0.427	-1.504	-1.71	-1.002
23	-0.17	-0.541	-1.464	-1.658	-0.989
24	-0.177	-0.169	-2.769	-2.966	-1.239
25	-0.833	-1.8	-2.862	-3.067	-2.211
26	-0.653	-1.431	-3.131	-3.332	-2.211
27	-1.101	-2.311	-2.715	-2.909	-1.099
28	-0.989	-2.28	-2.667	-2.867	-1.353
29	0.817	1.659	-2.479	-2.676	-2.088
30	-0.011	-0.312	-1.38	-1.571	-1.117
31	0.246	0.095	-1.421	-1.616	-0.987
32	-0.51	-1.344	-2.879	-3.068	-0.987
33	-0.601	-1.304	-2.949	-3.139	-0.987
34	0.107	-0.137	-0.967	-1.159	-1.154
35	0.148	-0.047	-1.066	-1.259	-1.072
36	-0.701	-1.692	-2.83	-3.026	-2.339
37	-0.17	-1.347	-1.419	-1.618	-2.339
38	-0.522	-1.341	-1.578	-1.775	-2.127
39	0.928	1.34	-1.232	-1.455	-0.953
40	0.634	0.864	-1.32	-1.55	-0.933
41	0.571	0.554	-1.364	-1.595	-1.006
42	0.676	0.928	-1.459	-1.689	-0.913
43	-0.03	-0.379	-1.343	-1.55	-0.973
44	-0.014	-0.332	-1.456	-1.656	-1.149
45	0.285	0.215	-1.423	-1.621	-1.078
46	0.78	0.98	-1.38	-1.567	-1.407
47	-0.273	-0.77	-1.33	-1.528	-0.987
48	0.277	0.267	-1.377	-1.608	-0.969
49	0.539	0.553	-1.091	-1.322	-1.175
50	0.52	0.529	-1.076	-1.306	-1.149
51	-0.011	-0.431	-1.172	-1.4	-0.855
52	0.56	0.768	-1.037	-1.257	-0.951
53	-0.001	-0.833	-1.683	-1.884	-0.951
54	0.663	0.968	-0.695	-0.903	-1.346
55	0.324	0.327	-0.893	-1.12	-1.004

Table 5 continued…

Sample No.	Calcite	Dolomite	Gypsum	Anhydrite	Silica
Groundwater					
56	0.356	0.473	-0.934	-1.138	-0.974
57	0.703	0.883	-0.778	-0.972	-1.034
58	-0.016	-0.531	-0.873	-1.071	-1.109
59	0.223	-0.405	-1.656	-1.846	-1.007
60	0.286	0.012	-1.281	-1.477	-0.973
61	0.097	-0.119	-1.111	-1.313	-1.033
62	-0.252	-0.828	-1.307	-1.506	-1.098
63	-0.23	-0.782	-1.372	-1.58	-1.09
64	-0.22	-0.906	-1.093	-1.308	-0.976
65	-0.055	-0.511	-1.334	-1.54	-1.004
66	-0.377	-1.216	-2.571	-2.775	-2.211

Table 6**:** Mixing ratios for AA/ section.

Sample No.	Nubian S.S% No. (62)	Lake Nasser%	Mixing degree
19	6.7	93.3	High
23	66	33	Moderate
24	52	48	Moderate
25	59.6	40.4	Moderate
29	83	16	Low
34	11	89	High
38	46	54	Moderate
53	75	25	Low
55	99	1	Low
58	36	64	High
59	20	80	High

Table 7**:** Mixing ratios for BB/ section.

Sample No.	Nubian S.S% No. (62)	Lake Nasser%	Mixing degree
40	77	23	Low
42	78.1	21.9	Low
45	45.6	54.4	Moderate
46	21	79	High
51	23.5	76.5	High
52	25.5	74.5	High
40	77	23	Low
42	78.1	21.9	Low
60	9.1	90.9	High
64	51.4	48.6	Moderate
66	11	89	High

Cluster 4 is represented by eight samples, where the TDS ranges between 985 and 1454mg/l, with an average value of 1206mg/l. This is confirmed by the ions dominance; $SO_4^{2-} > Cl^- > HCO_3^-$ / $Na^+ > Ca^{2+} > Mg^{2+}$.

Clusters 5 and 6 represent an independent cluster (i.e. the samples, 54 and 53 are dissimilar with respect to both the initial lake Nasser and the initial groundwater samples), i.e., there is no evidence of Lake Nasser water dilution (seepage) because the samples Nos.54 and 55 are lying away of the region that affected by seepage from Lake Nasser.

In conclusion, clusters Nos. 1, 3 and 4 are composed of samples with less dilution from Lake water Nasser than cluster No.2 (although cluster No.1 and a part of cluster No.4 are lying near Lake Nasser). This is due to their samples locations far from the faults that facilitate the seepage from Lake Nasser.

Noteworthy to mention that cluster No. 2 with its two parts indicates that there is seepage from Lake Nasser to groundwater, because of two reasons, the first is, the samples of cluster No.2 have the lowest TDS values while the second one is the sequence of anions $Cl^- > HCO_3^- > SO_4^{2-}$ which indicates a middle stage of metasomatism. The distance between the two parts and Lake Nasser border which indicates that seepage from the Lake to the Nubian sandstone aquifer is varying from 50 to 60 km. Also, this result matches with the NETPATH result, hydrochemical profiles and the previous studies.

Conclusions

The results obtained in the present study showed that using of groundwater situation, hypothetical salts assemblages, hydrochemical profiles with hydrochemical modeling and cluster analysis is an effective approach of the interaction between the surface water (Lake Nasser) and Nubian sandstone aquifer groundwater in the study area. The major conclusions are as follows;

1-Groundwater situation (iso-resultant water table map) confirms seepage process from Lake Nasser to The Nubian sandstone groundwater

2- Hydrochemical data (hypothetical salts assemblages and hydrochemical profiles) provide important information about the impact of leakage (seepage) on the groundwater resource. Also, the hydrochemical profiles proved that the distance to which the seepage occurred is 50-60 km.

3- Surface water leakage (seepage) into the Nubian sandstone aquifer occurs proportionally in all parts of the study area. The leakage (seepage) has a widespread influence on the chemistry of the Nubian sandstone aquifer groundwater.

4- Geochemical modeling results show a widespread undersaturation state of the surface water and groundwater from the Nubian sandstone aquifer with respect to the major mineral phases (calcite, dolomite, gypsum, anhydrite and silica), this resulted from the dilution effect and short residence time of the leaked surface water.

5- Major geochemical reactions occurring in the system include mixing, calcite, dolomite, gypsum, anhydrie and silica dissolution.

6- The contribution of recent recharge from Lake Nasser to the Nubian sandstone aquifer groundwater in the study area varies largely from 1% to 93% with an average value of 48%.

7- The application of statistical technique (cluster analysis) showed a set of groundwater samples clustered around surface water sample (cluster No. 2) which indicates surface water seepage into groundwater at the study area, and the distance to which the seepage occurred is about 50-60 km.

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