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RECHARGE SOURCES AND THE CHEMICAL EVOLUTION OF GROUNDWATER, WEST ESNA, WESTERN DESERT, EGYPT

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The increase of the reclaimed land for agriculture, especially in the Western Desert of Egypt, aims to cope with the increase of the Egyptian population. The western region of Esna is one of the most promising areas where there are remarkable agricultural activities that depend mainly on groundwater. The present study aims at identifying the recharge sources as well as studying the chemical evolution of groundwater in the Quaternary aquifer which represents the main aquifer in the area. Twenty groundwater level measurements and analyses of the concentrations of trace elements and major ions in 23 groundwater samples, a Nile water sample, and an irrigation canal water sample were done in order to determine the sources of groundwater recharge and its chemical evolution. The subsurface sediment succession in some wells shows the impact of a clay lens on the groundwater salinity in the northwestern part of the area. There is also a significant water leakage from an irrigation canal into the subsurface aquifer causing a local rise of groundwater level. A shallow clay lenses cause water logging near a sewage station that discharges wastewater into drains to be used in the irrigation of a man-made tree forest. Contamination of the aquifer has been detected near the sewer station. This study proves that the main recharge source is the Nile system (the Nile and its irrigation-drainage network). The main geochemical evolution processes are: (1) freshening by Nile system waters, (2) cation exchange, and (3) mineral dissolution and precipitation.

Keywords: groundwater recharge, geochemical evolution, West Esna, Egypt

INTRODUCTION

The sustainable yield of an aquifer depends usually on its annual groundwater recharge (Dodson, 2009). The determination of the recharge sources is one of the most important hydrogeologic goals as it is necessary for aquifer protection and management. In arid and semiarid regions, recharge is the most important factor in aquifer evaluation (Wood and Sanford, 1995). In such regions, recharge predominantly occurs after flash flood events that may occur once every several years (Harrington, 1999 and Abu Risha, 2010). Where rivers exist, water infiltration from river beds into the underlying aquifers may occur to various degrees (Kalbus et al., 2006). In other cases, water may discharge from aquifers into rivers. The water flux between the two media can be done by several methods including direct measurement of water flux, heat tracers, pumping tests applying Darcy's law, and chemical mass balance approaches.

The relationship between the Nile system (Nile and its irrigation-drainage network) on one hand and groundwater aquifers on the other has been the focus of interest of many studies. Based on piezometric levels and isotopes, Kebede et al. (2017) found that the Nile course is a groundwater discharge zone, whereas the irrigation canals and drains represent sources of recharge of the Quaternary aquifer. However, these authors stated that recharge from the Nile used to occur during the high flood season before the construction of the High Dam. Heinl and Thorweihe (1993), Ebraheem et al. (2002) and Gossel et al. (2004) stated that the interaction between the Nile and the adjacent aquifers occurs in both directions at very local scales. Ghanem et al. (2011) found that the groundwater levels increase in the flooding season wherever the water levels in the Nile and canals are high. These authors found that the Asfoun Canal reach in Esna City is a discharge area, whereas the Ramady Canal represents a recharge source. At Abu Qurqas, Al Temamy and Abu Risha (2016) found that Bahr Yousef and the irrigation-drainage system represent sources of groundwater recharge, whereas the Nile course represents a discharge zone. In some areas, the stable isotope depletion of the water of the irrigation canals and drains compared to the Nile water (e.g., Awad et al., 1997 and Korany et al., 2013) has been attributed to groundwater discharge into them (El-Bakri et al., 1996 and Hamza et al., 1999).

Flash floods represent an important source of groundwater recharge in the desert fringes of the Nile Valley. Sultan et al. (2000), based on tritium and stable isotopes, attributed groundwater recharge mainly to sporadic flash floods. Gheith and Sultan (2002) estimated recharge rates of 21 to 31% of the 1994 flood event. Based on stable isotopes and inverse hydrogeochemical modeling, Al Timamy and Abu Risha (2016) estimated groundwater recharge contribution from local precipitation ranging from 3 to 77% of the studied groundwater samples. Based on stable isotopes, Hamza et al. (1999) concluded mixing with recent floodwater in the Nubian aquifer in Wadi Qena. Korany et al. (2013) estimated 24% recharge contribution to the Pleistocene aquifer at Wadi El Assyuti from flash floods. Tamer and Rashwan (1987), Awad et al. (1997) and Salem (2009) also attributed partial groundwater recharge in some localities in the Nile Valley and desert fringes to occasional floods.

The groundwater chemical evolution in the majority of hydrogeologic settings occurs gradually following a series of specific metasomatic reactions and processes which start even before the beginning of recharge. Each assemblage of dissolved salts is related to a specific metasomatic stage. In arid regions, most of the chemical evolution of groundwater is inherited from the evapoconcentration and interaction with the minerals of the soil and the thick unsaturated zone. Soils in such regions usually contain evaporites. Salt lakes exist in most of these regions. Accordingly, the recharging water may reach the aquifer with high content of solutes even before any interaction with the aquifer rocks takes place. In the Great Artesian Basin sandstone aquifer, Abu Risha (2010) attributed 25 to 41% of the ionic concentrations to evapotranspiration effect on the recharge water, whereas the water-rock interactions contributed only 0-31% of the dissolved ions and mixing contributed 7-25%. Thus, the climatic regime and recharge rates may strongly control the chemical evolution and quality of groundwater. In the absence of evaporites and the other minerals with high dissolution rates, groundwater has a buffering capacity that sets limits of the concentrations of each solute in groundwater (Appelo and Postma, 2005). Such buffering results in simultaneous dissolution and precipitation of the solutes containing the same ions.

The aim of this study is to investigate the sources of groundwater recharge and their impact on the chemical composition of the recharge water and the subsequent chemical evolution due to the subsurface water-rock interactions and mixing processes. To achieve this goal, this study uses a set of major ions and trace elements and introduces, for the first time, the river water concentration line and river water ratio line to graphically address the ionic mass transfer between the groundwater and aquifer material.

MATERIALS AND METHODS

1. Area of Study

The area of study lies to the south of the famous archaeological city of Luxor between latitudes 25.153° and 25.4° N and longitudes 32.348° and 32.704° E. It represents a part of the Nile western desert fringes (Fig. 1). It lies in the downstream of wadis El Rukham and Esna. The climate is typically arid with very hot summer and mild to cold winter. The average annual rainfall is only 1 mm/y (Table 1). However, sporadic flash floods may take place every several years. The intensity of 1994 storm was 16 mm/h (Ogiso et al., 2017). Floods of 10mm and 15 mm occurred in December 2010 and January 2013, respectively (Moawad et al., 2014). Such floods may contribute recharge to the groundwater aquifers. The Nile valley in the area is relatively wide and merges gradually into the piedmont slope of Sin El Kaddab (tooth of the liar) Plateau. The area is accessible via a good network of highways and railways.

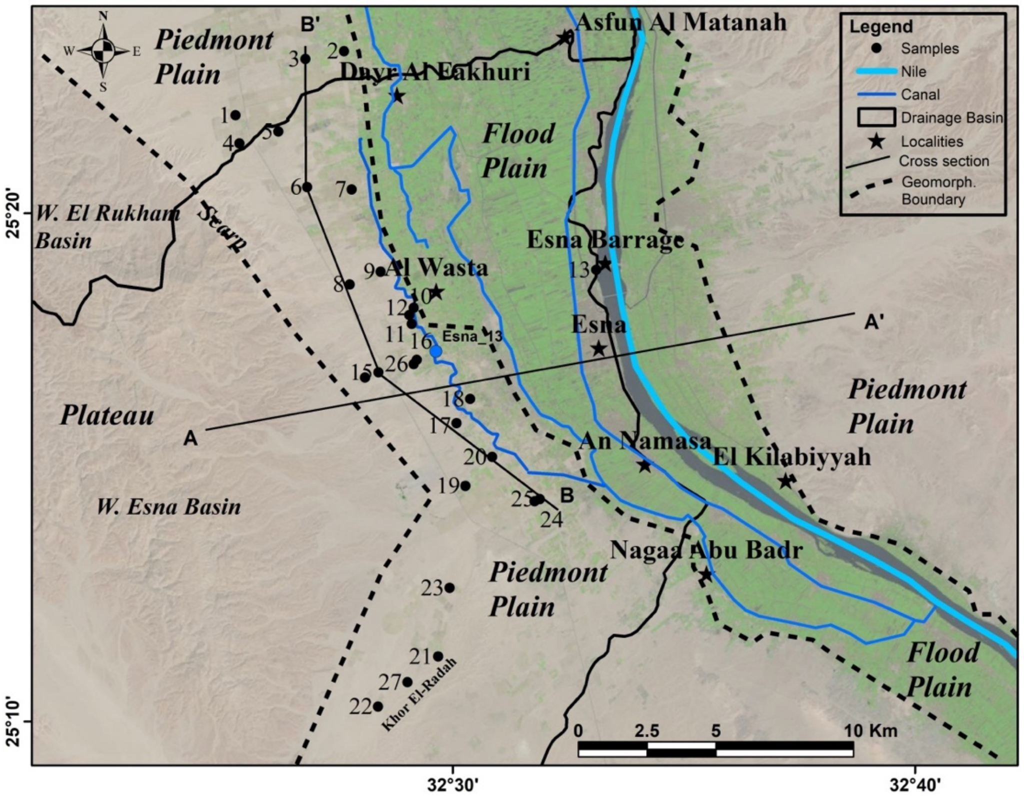

Fig. (1). Location map of the study area.

Table (1). Climate data of Luxor (NOAA; Weather2Travel for sunshine, 2015).

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Average daily T (°C)	13.8	15.9	20.2	25.6	29.6	32.2	32.3	31.8	29.7	25.9	20	15.1	24.3
Average rain (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0	0.0	1.0
Average rain/day	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.3	0	1.0	1.9
Average humidity (%)	55.0	47.0	39.0	31.0	29.0	27.0	30.0	33.0	37.0	43.0	51	57.0	39.9

Geomorphologically, the area can be subdivided into five geomorphic units namely the flood plain, the piedmont plain, the scarp, the plateau, and the drainage basins (Fig. 1). The flood plain occupies about 180 km^2 adjacent to the west bank of the Nile River. Its elevation ranges from about 60 to 80 masl. It is elongated and extends in the NNW direction. It may be affected by the Red Sea structural regime. This plain is covered by Nile silt (Fig. 2) which forms one of the most fertile soils in the world. The piedmont plain covers an area of about 320 km^2. It runs more or less parallel to the flood plain. It is covered mainly by Quaternary sands. Its elevation ranges from 80 to 120 masl in the middle of the study area and up to 260 masl in Khor El-Radah. It is bound from the east by the flood plain and from the west by the plateau scarp. It is elongated and highly dissected by drainage courses which cut through the bedrock that forms many isolated hills dotting its floor. The Plateau occupies the western part of the study area. It covers about 630 km^2. Its elevation varies from 500 masl to 590 masl. The plateau is composed of carbonate rocks of the Thebes Formation. Its eastern margin is a scarp composed mainly of Esna Shale. The plateau is dissected by the tributaries of wadis Esna and El Rukham. The area of the former is 430 km^2 and its perimeter is 97.6 km, whereas the area of the latter is 169 km^2 and its perimeter is 73 km.

Stratigraphically, the area is covered by rocks belonging to the Tertiary and Quaternary Eras (Fig. 2 and 3). The oldest exposed rock unit in the study area is the Esna Shale of Paleocene age which is overlain by the Thebes Formation (L. Eocene) which is, in turn, overlain by the Pliocene sediments. This Tertiary succession is overlain by the Quaternary sediments that include the protonile-, prenile-, neonile-, and wadi sediments in addition to the Recent Nile silt.

Structurally, Said (1962) concluded that the Nile occupies a rift Pliocene Gulf that must have been rejuvenated in post-middle Pliocene time. Luxor hills are bound by faults. South of Luxor, many north-south faults present. These faults are also parallel to the Nile. From Aswan to Esna, the cliffs bounding the Nile are made of Nubian Sandstone. From Esna to Cairo, the cliffs are made of limestones (Said, 1990). The geologic map shows structural lineaments of different directions (NNW, NE, WNW, E-W, NNE, and N-S). At Kom Ombo (one kilometer to the south of the study area) faulting affects the Quaternary succession (Fig. 3).

Hydrogeologically, the Quaternary sediments host the main groundwater aquifer in the area (e.g., Faid and Brikowski, 1994). All of the wells were drilled in areas covered by Prenile sediments (Qena Formation, Qn2) which are underlain by the Protonile sediments (Idfu- or Armant Formation; Qn1). The maximum thickness of Qena Formation is 120 m at Luxor (30 km to the north of study area), whereas the maximum thickness of Armant Formation is 40 m at its type locality (20 km to the north of study area). The Armant Formation is bound from top and bottom by gravels (Said, 1981). The lower gravels are underlain by an aquitard composed mainly of Pliocene clays which act as an aquitard of the overlying Armant-Qena aquifer (Fig. 4). Armant Formation is composed of alternating beds of conglomerate and sands or marls over the eroded surface of the Paleonile sediments. The Qena Formation is composed of cross-bedded fluvial sands with minor conglomerate and clay beds (Fig. 4a). The clay interbeds are expected to increase the groundwater salinity in the wells that are not designed correctly. All of the sampled wells are less than 150m deep. Therefore, they are expected to extract groundwater from Qena-Armant aquifer. The N-S hydrogeologic cross section shows no structures affecting the aquifer. Well no. 3 is 140 m deep and ends in a shale layer which is expected to represent the underlying aquitard. Accordingly, the saturated thickness of the aquifer is about 90 m (Fig. 4b). The shale layers in the upper part of the aquifer (Fig. 4a) are very shallow in some places such as the area of well 24.

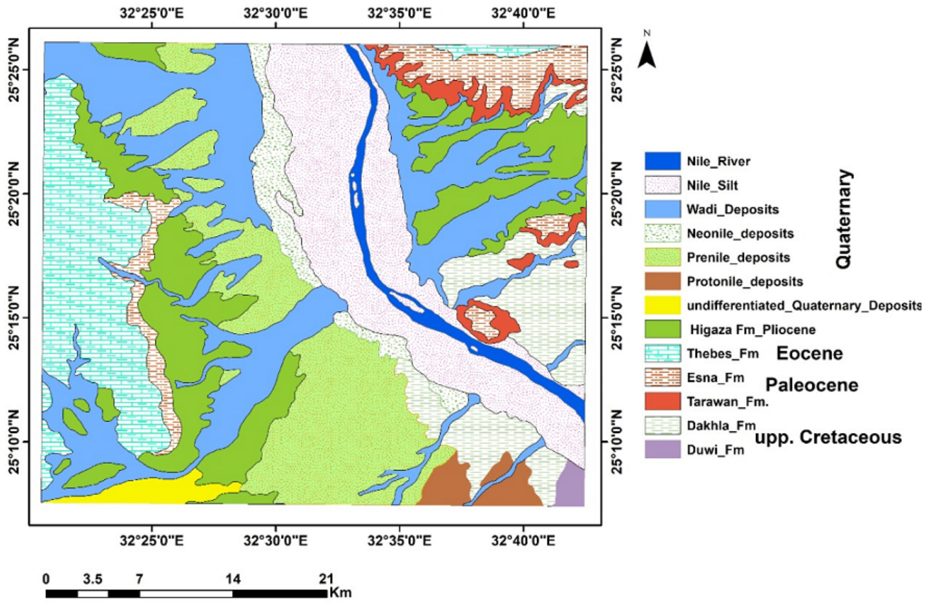

Fig. (2). Geology of Esna (CONOCO, 1987)

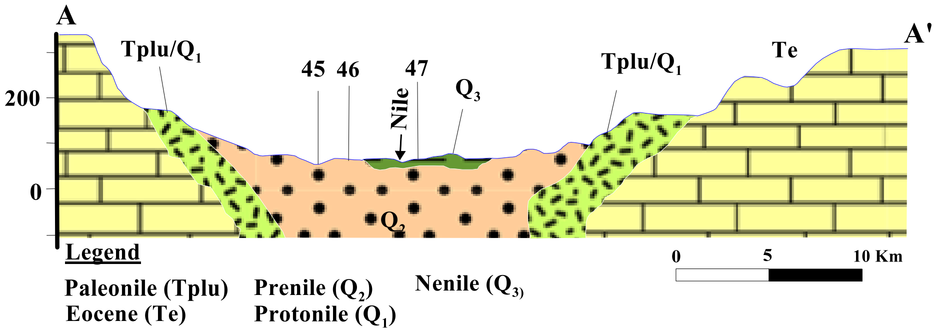

Fig. (3). Geologic cross section (Said, 1981).
For location, refer to fig. (1). Numbers 45, 46, and 47 are for wells used in the cross-section construction as in Said (1981).

2. Methodology

This study applies multiple GIS, geologic, and hydrogeologic techniques to define the sources of groundwater recharge. Garmin global positioning system model *e*trex 10 was used to determine the locations of the collected lithologic and water samples. Sediment samples have been collected from hand-dug wells and analyzed mechanically to determine their depositional environments following the method described by Selley (2000). Drilling data were acquired to characterize the subsurface setting. Groundwater samples were collected and in-situ measurements of conductivity (E.C.) and depth to water have been performed using sensitive meters. The major ion and trace element concentrations have been measured in the labs of the Desert Research Center using the ion chromatography (IC) and inductively coupled plasma (ICP) devices. The ionic charge balance was within ±5 %.

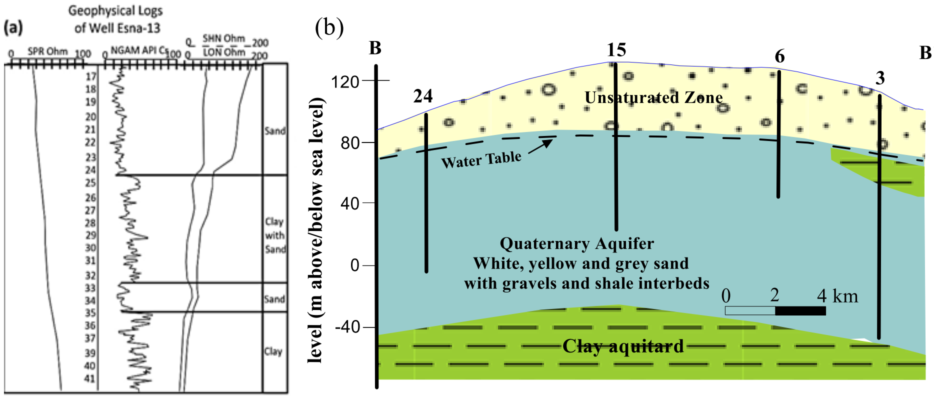

Fig. (4). Geophysical logs (4a) and hydrogeologic cross section. Depth in fig. (4b) is in meters.

RESULTS

The groundwater conductivity and levels ranged from 600 to 5400 µmho•cm and 69 to 91 masl, respectively (Table 2). The water levels upstream of Esna Barrage fluctuated between 79.5 and 77.0 masl during the year while the downstream levels fluctuated between 75.5 and 74.6 masl (Mansour and Kamal El-Dein, 2001). The measured Nile level upstream of Esna Barrage during the field campaign was 79 masl (Table 2). The collected sediment samples were mechanically analyzed to determine their depositional environments. The samples were deposited in river and beach environments (Fig. 5). The collected water samples were analyzed for major ion and trace element concentrations (Table 2).

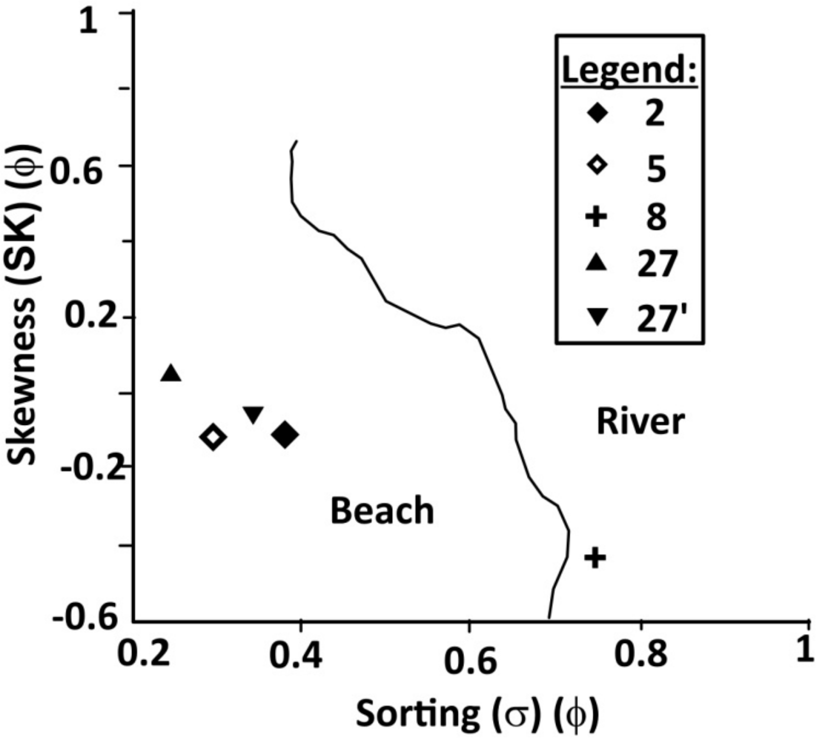

Fig. (5). Depositional environments of sediment samples from dug wells tapping the aquifers

1. Source of Groundwater Recharge

The salinity (expressed as total dissolved solids, TDS, in mg/l) distribution shows abrupt decrease from saline water (III) to fresh water (I) in the direction of irrigation canals reflecting significant recharge from these canals (Fig. 6). This is supported by the formation of groundwater mound at canal 3 (Fig. 7). Sample No. 10 which lies next to the bank of canal 3 has salinity of 298 (mg/l) which is close to the salinity of canal water (206 mg/l). The water level in the Nile upstream of Esna Barrage is 79 masl (MWRI website). It is higher than the groundwater levels of the wells that lie away from the canals at the northwestern part of the study area. It can be concluded that the regional recharge of the aquifer is from the Nile, whereas recharge from the canals represents a local phenomenon. Recharge from the Nile was stronger before the construction of the High Dam as the water levels in the Nile were 2-4 meters higher than the current levels.

Table (2). Groundwater major ion and trace element concentrations (mg/l); March-April 2018.

No	E.C	T.D	D.T.W	W.L	pH	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	TDS	SiO_2	Sr
1	5250				7.78	223	197	565	21	0	141	1448	550	3074	18.9	9.2
2	1180		20.4	80.6	7.97	34	58	106	9	43	325	152	39	604	46.5	1.9
3	5400	140	40	72	7.39	209	124	680	28	38	288	1336	481	3041	24.4	9.6
4	3800				7.16	197	116	497	19	0	61	1101	548	2509	15.9	6.1
5	2950	115	55	77	7.22	89	70	505	11	0	98	842	384	1951	18.2	3.0
6	2100	80	45	75	7.2	66	46	333	10	0	129	588	234	1341	18.8	2.4
7	1150	65	14	91	6.95	32	56	174	11	31	205	274	95	776	34.9	3.2
8	3470				7.07	120	76	532	16	0	73	889	504	2172	11.9	4.4
9	810	64	12	89	7.33	13	20	135	10	24	239	106	34	460	30.2	2.3
10	600		8.5	89.5	7.25	35	31	38	6	31	176	51	19	298	24.2	2.1
11	850	52	11	90	7.02	27	51	69	10	54	163	96	58	447	33.7	2.9
12	370			95	7.38	32	12	29	6	0	151	32	19	206	1.7	0.3
13	285			79	7.06	29	11	18	6	17	107	18	11	165	0.9	0.2
14	2500				7.01	166	105	307	10	0	117	694	466	1806	14.3	4.5
15	2200	96	36	82	7.33	120	75	257	11	19	83	565	329	1417	16.1	3.2
16	895	50	20	84	7.22	18	37	97	3	43	159	104	48	431	24.0	1.8
17	1950	30	20	77	7.55	93	75	236	17	14	198	487	227	1249	25.8	4.0
18	900		15	82	7.15	30	30	107	10	26	234	111	36	468	32.6	2.3
19	1980				7.42	76	70	240	13	14	149	426	353	1267	16.1	3.1
20	2000		35	69	7.47	56	73	246	10	41	105	453	317	1248	20.4	3.2
21	1800	110	62	84	7.4	38	44	286	9	41	120	269	275	1022	17.5	2.3
22	2200	146	80	80	7.3	131	107	288	15	19	146	445	491	1570	17.2	4.2
23	1800	110	50	81	7.05	60	70	228	9	50	90	295	282	1040	16.3	2.9
24	3000	100	20	77	7.2	141	76	443	14	12	142	565	614	1935	13.3	3.1
25	1800	108	20	76	7.24	25	21	345	8	24	142	197	348	1041	14.5	0.9
26			20.4	83.6												
27			73.4	80.7												

E.C: Electric conductivity (μmho/cm) TD: Total Depth (m) DTW: Depth to water (m below ground surface, mbgs) WL: water level (m above sealevel, masl) TDS: Total Dissolved Solids

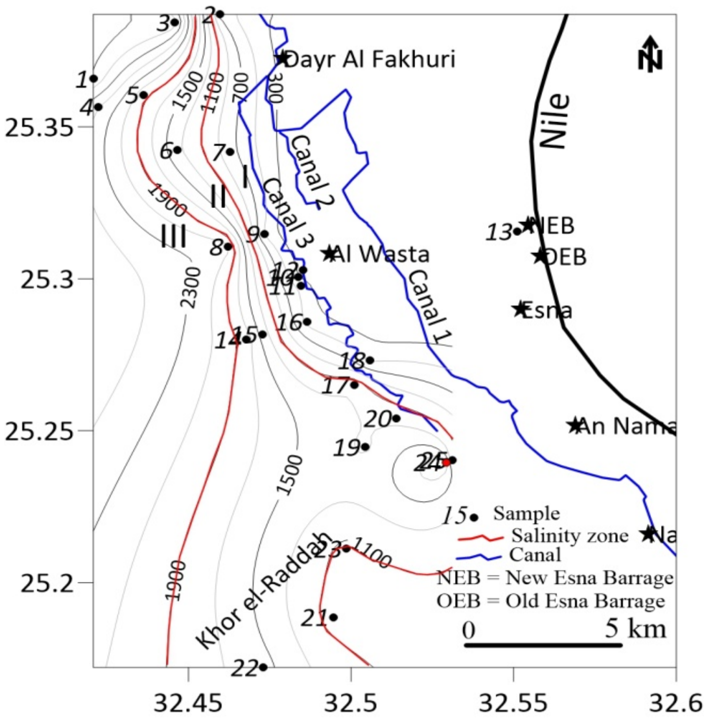

Fig. (6). TDS (mg/l) of groundwater.

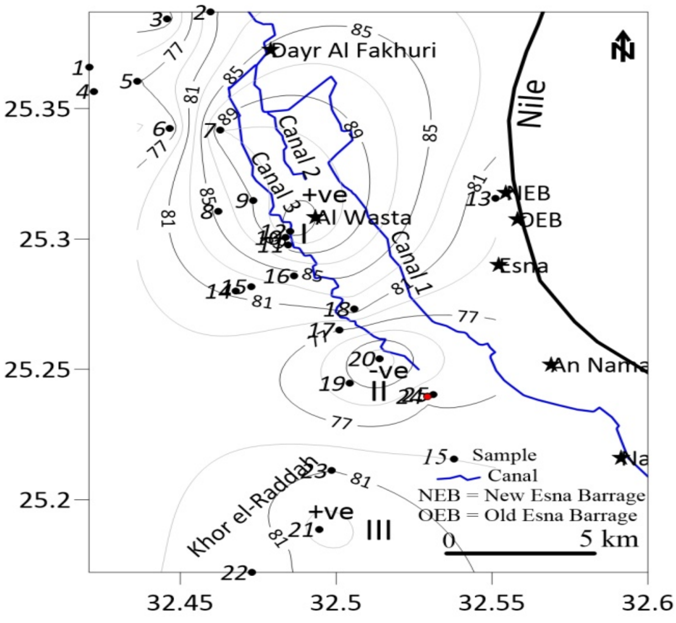

Fig. (7). Groundwater levels (masl).

The Nile and canal waters are characterized by high weight ratios of Ca, K, and HCO_3 and low ratios of Na, SO_4, and Cl relative to their salinity. The distribution of these parameters in the aquifer strongly reflects recharge from the Nile and canals. The Nile and canal samples have extremely low concentrations of silica and strontium (Fig. 8). These concentrations increase as the groundwater flows away from the Nile and canals reflecting their addition via the dissolution of aquifer rocks.

2. Chemical Evolution of Groundwater Using Cl

The possible mechanisms of groundwater evolution are the evapoconcentration and the water-rock interactions. In the studied aquifer, chlorine is expected to be conservative as the presence of its minerals in the aquifer rocks is not expected. Any halite that was present in the aquifer must have been leached completely to the deepest parts, so that the studied part is now free from halite. Adopting this assumption enables the determination of the groundwater evolutionary processes (e.g., Love, 2003 and Abu Risha, 2010).

2.1. Ion-Cl relationship

Assuming that chloride is conservative in the aquifer, all ions sourced from Nile water and evaporated Nile water only without subsequent addition or removal due to water-rock interactions or mixing with different waters will plot on the Nile water evapoconcentration line (NWEL; Fig. 9). The ions that are added from sources other than the evapoconcentrated recharge water plot to the left of the NWEL, whereas the ions removed from the groundwater plot to the right. Generally, there is removal of all ions from groundwater at intermediate and high salinities (Group II and III). In most low salinity samples (Group I), some ions are removed (Ca, K, and HCO_3), some ions are added (Na and SO_4), and other ions show neither addition nor removal and plot on the NWEL (Mg). The intermediate salinity samples (Group II) are expected to be Group III saline groundwater diluted by canal water. Mixing causes buffering of the bicarbonate concentrations.

2.2. Ion/Cl-Cl relationship

The plots of ion molar ratios to chloride versus chloride concentrations (Fig. 10) can also be used to determine the evolutionary processes of groundwater clearer than the ion-Cl plots (Love, 2003 and Abu Risha, 2010). On these plots, the ions that are added to groundwater plot above the Nile water ratio line (NWRL) and vice versa. The previously determined three groundwater groups (Fig. 9) are also distinguishable on these plots (Fig. 10). In Groups II and III all ions are removed from all samples. Only SO_4 shows both addition and removal at these intermediate and high salinities. In Group I, Ca, K, and HCO_3 are removed from all samples. Two samples show addition of Mg. Only one sample shows removal of Na. Three samples show insignificant Na change compared to the NWRL. Also, three samples show similar SO_4 behavior, whereas the remaining samples show SO_4 addition.

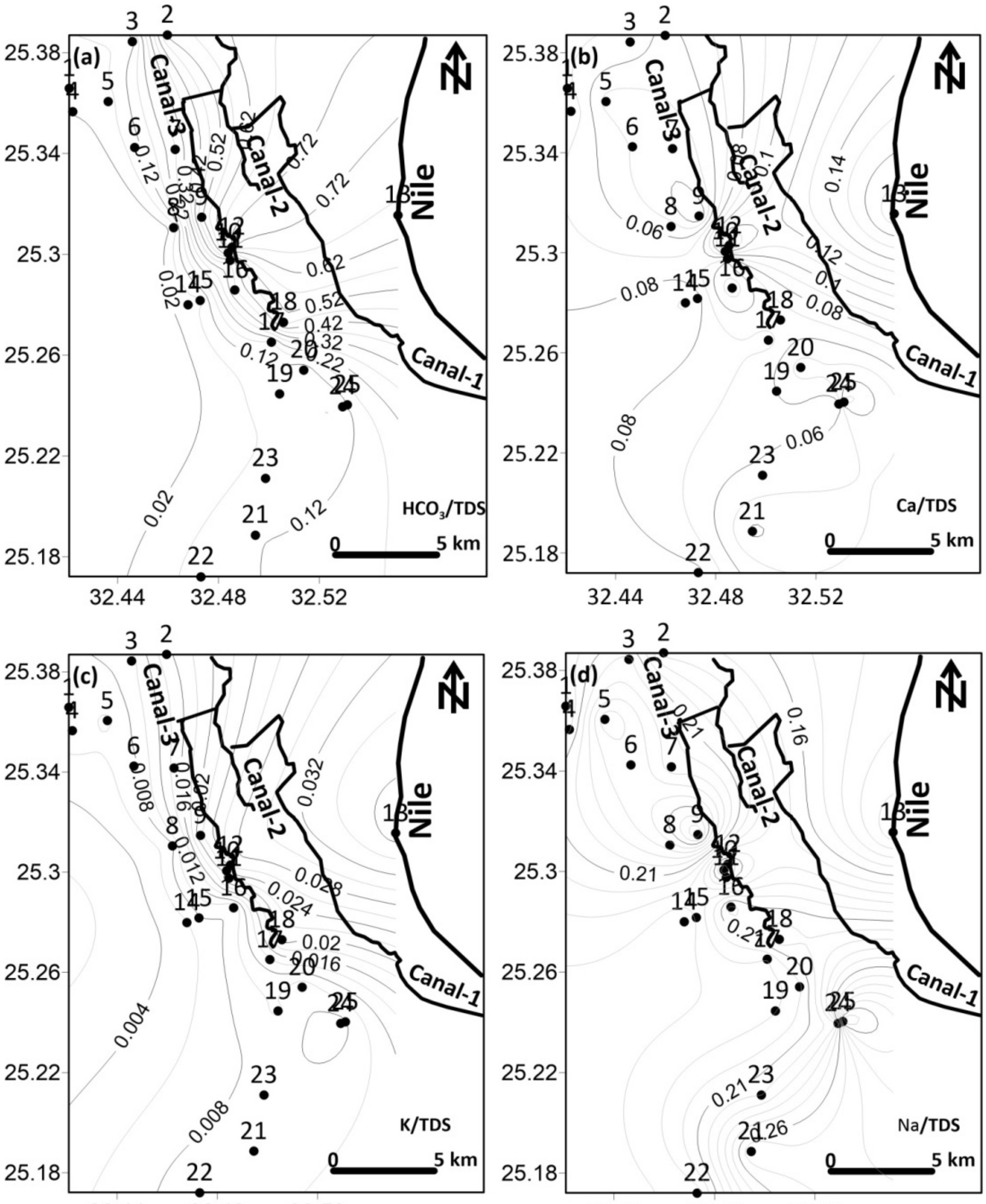

Fig. (8). Evidences on recharge from the Nile and irrigation canals.

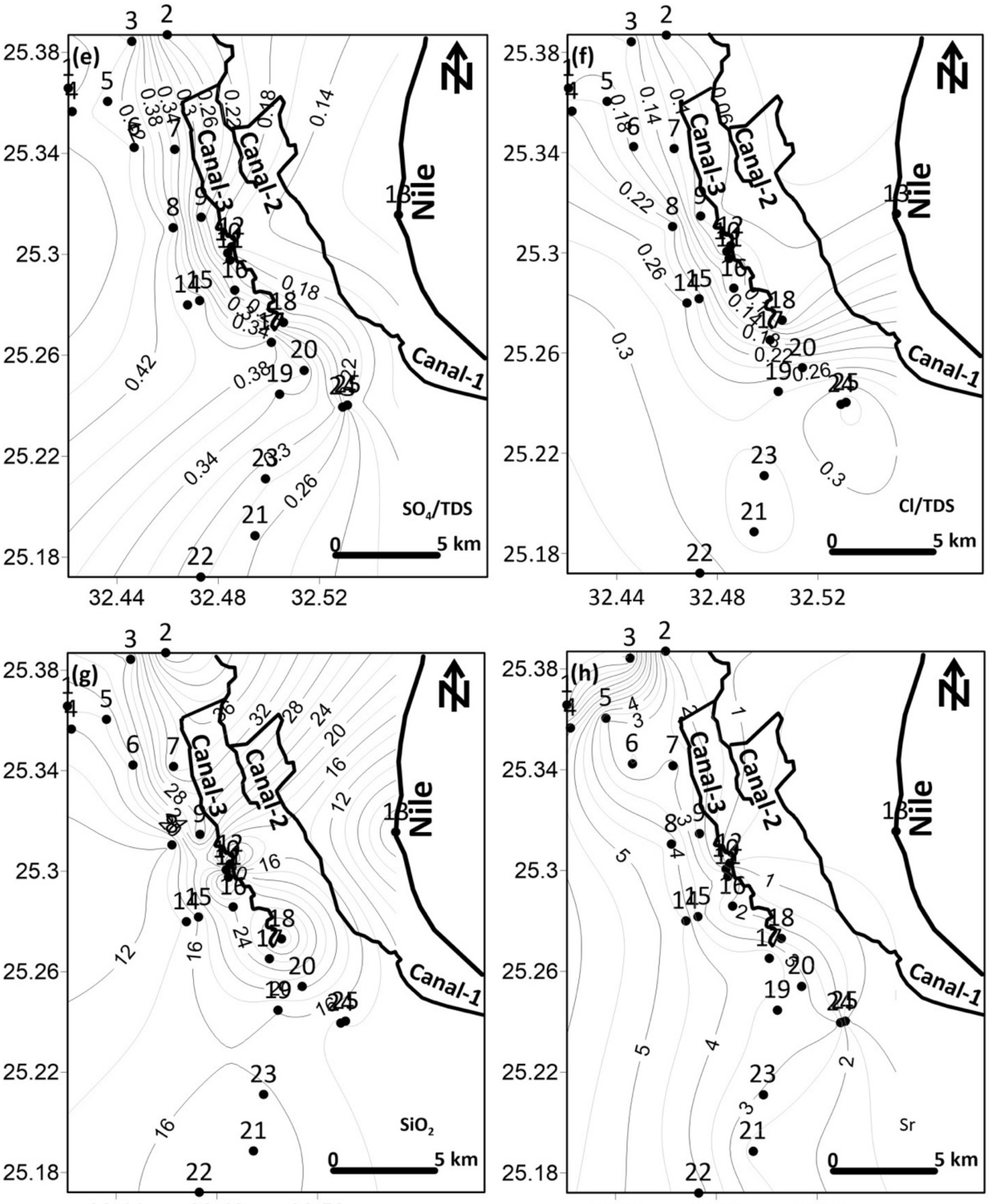
(e)
SO$_4$/TDS
(f)
Cl/TDS
(g)
SiO$_2$
(h)
Sr
Canal-1
Canal-2
Canal-3
Nile
N
0
5 km
25.38
25.34
25.3
25.26
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Fig. (8). Cont.

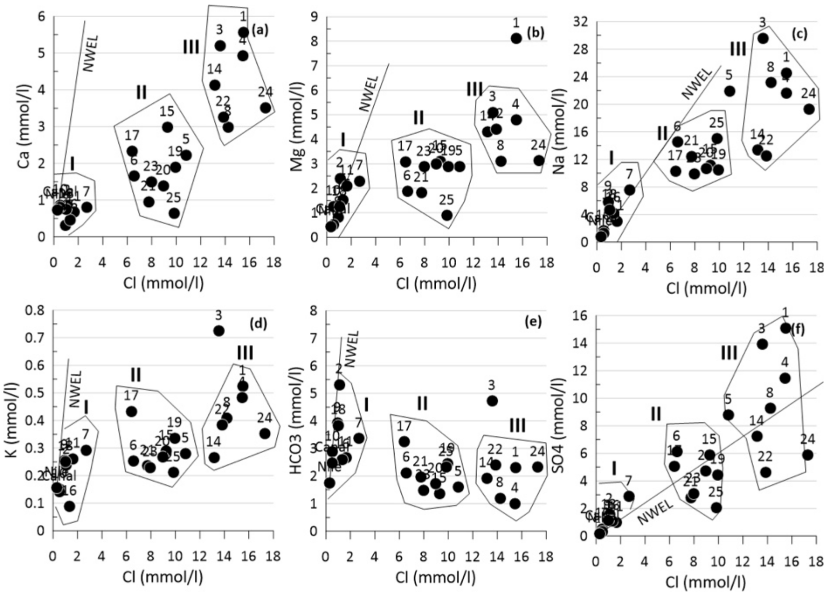

Fig. (9). Relationship between concentrations of major ions and Cl concentration.

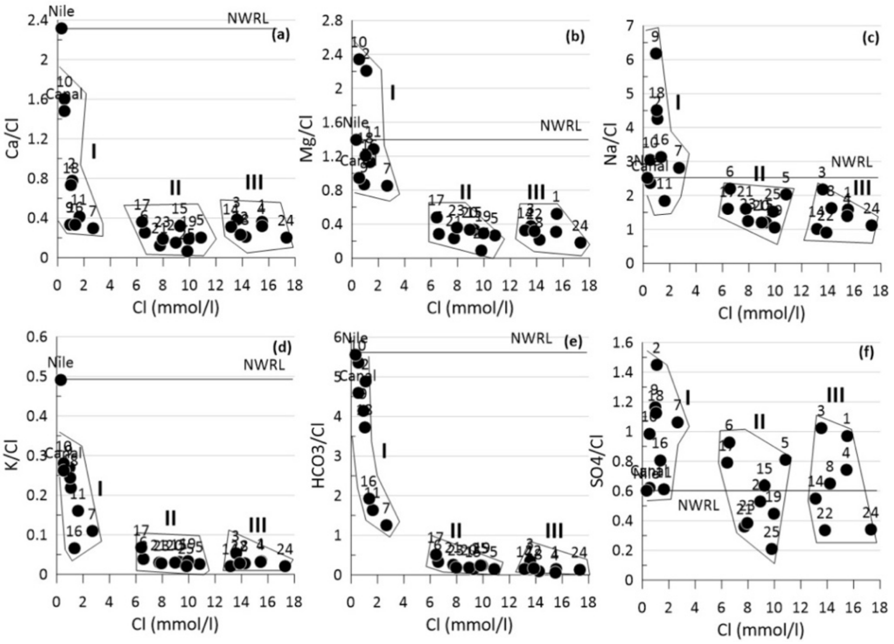

Fig. (10). Relationship between ratios of major ion concentrations to Cl concentration. The dark solid line represents the major ionic molar ratios to Cl of the Nile water.

2.3. Conceptual model

Based on the available data and the information, derived from the previous section, it can be stated that, the regional recharge of groundwater is from the Nile and its irrigation canals and drains. The saline groundwater in the western part of the study area was recharged from the Nile before the construction of the canals. The fresh groundwater was recharged from the Nile and was diluted by local recharge from the leakage of irrigation canals. Sodium and SO_4 are predominantly added to the water recharges from the Nile, whereas Ca, K, and HCO_3 are removed. The addition of Na is by cation exchange for Ca which is removed from groundwater via calcite precipitation. The addition of SO_4 is likely due to gypsum dissolution.

2.4. Hydrogeochemical modeling

Netpath (Plummer et al., 1994) inverse hydrogeochemical models enable the determination of groundwater evolution processes along flow paths between the recharge areas and the sampling points. The proposed models use the actual mineral composition of aquifer material as phases. Mixing and evaporation are constrained using conservative tracers. Based on the sedimentological and mineralogical studies (Said, 1962, 1981 and 1990), the aquifer sediments are composed of silts, sandstones, tufas, limestone and chert gravels and boulders. These lithologies were found in the aquifer in the area of study. The aquifer rock-forming minerals are quartz and carbonates. These minerals in addition to cation exchange are used in the proposed models as the reactive phases of the aquifer. Gypsum, K-montmorillonite or K-feldspar and Strontianite are assumed to exist in the aquifer. The saline samples in the extreme west of the area are assumed to be recharged from the Nile before the construction of the canals. The evolution of this water is described by model 1 (Table 3). The brackish and fresh waters are assumed to be recharged from the Nile. They were saline like Group III water but received recharge from the leaking canals. The evolution of these groups is described by model 2 (Table 3). As the area is hot and dry, the effect of evaporation of the recharge water from the Nile and the canals has been taken into account. The evaporation (Model 1) and dilution (Model 2) factors were determined by Cl.

Table (3). Results of the inverse hydrogeochemical modeling. Negative figures mean removal from solution (i.e., precipitation of solute) and vice versa.

	Model	**Recharge from Nile+evaporation (Model 1)**		**Mixing of saline water with canal water (Model 2)**		
	Water	Initial	Final	Initial 1	Initial 2	Final
		Nile	1	1	Canal	6
	Contributions			0.4	0.6	
	Phases	Cal, SiO_2, Strontianite, +Gyp, Ex (exchange), Mg/Na Ex (exchange), Pyr. K-Mont.		Cal, SiO_2, Strontianite, +Gyp, Ex (exchange), Mg/Na Ex (exchange), Pyr. K-Mont.		
	Constraints	Ca, Mg, Na, K, S, C, Sr, SiO_2, Cl		Ca, Mg, Na, K, S, C, Sr, SiO_2, Cl		
Reactions (mmol/l)	Exchange	-0.426		0.202		
	Mg/Na Exchange	0.277		1.707		
	Calcite	-2.027		-1.159		
	SiO_2	1.607		0.654		
	Strontianite	-0.001		-0.017		
	Pyrite	-0.432		0.450		
	K-Mont	-0.44		-0.132		
	Gypsum	0.981		-0.712		
	Evaporation factor	49.034				
	H_2Or (remaining grams of water	20.394				

CONCLUSIONS

It can be concluded from this study that, the studied groundwater is recharged regionally from the Nile before and after the construction of High Dam. The irrigation canals leaked water in large quantities that raised the groundwater table to high levels. Recharge from local precipitation is negligible. The main water-rock interactions are dissolution, precipitation, and cation exchange. The shallow clay beds cause water logging and salinization of the wells opened in these beds. This work demonstrates the usefulness of using the major ionic relationship and trace element concentrations in tracing the sources of groundwater recharge and chemical evolution.

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مصادر التغذية والتطور الكيميائي للمياه الجوفية، غرب إسنا، الصحراء الغربية، مصر

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تستهدف زيادة رقعة الأراضي المستصلحة للزراعة، خاصة في الصحراء الغربية لمصر، إلى مواكبة الزيادة في عدد السكان. تعد منطقة غرب مدينة إسنا من أكثر المناطق الواعدة حيث تتواجد الأنشطة الزراعية وتزداد بصورة ملحوظة، وتعتمد بشكل أساسي على المياه الجوفية. تهدف الدراسة الحالية إلى تحديد مصادر التغذية وكذلك دراسة التطور الكيميائي للمياه الجوفية في الخزان الجوفي الرباعي الذي يمثل الخزان الرئيسي في المنطقة. تم إجراء العديد من القياسات الحقلية والمعملية شاملة تحديد مستوى المياه الجوفية وكذلك تقدير تركيزات العناصر الرئيسية والشحيحة لعدد 23 عينة مياه جوفية، إضافة إلى عينة واحدة تم جمعها من مياه النيل وعينة أخرى من مياه إحدى قنوات الري المتواجدة بمنطقة الدراسة، وذلك لتحديد مصادر تغذية المياه الجوفية ودراسة تطورها الكيميائي. أظهرت تتابعات الرواسب التحت سطحية في بعض الآبار تأثير العدسات الطينية على ملوحة المياه الجوفية في الجزء الشمالي الغربي من المنطقة. كما أوضحت النتائج أيضًا وجود تسرب كبير للمياه من قنوات الري إلى طبقة المياه الجوفية مما يؤدي إلى ارتفاع في منسوب المياه الجوفية. أوضحت الدراسة أن تواجد بعض العدسات الطينية الضحلة بالقرب من محطة الصرف الصحي أدى الى ظهور غدق للمياه حيث تقوم هذه المحطة بتصريف المياه العادمة في المصارف بغرض استخدامها في ري الغابات الشجرية. تم الكشف عن تلوث في طبقة المياه الجوفية بالقرب من محطة الصرف باستخدام الأدلة الهيدروكيميائية. أثبتت الدراسة أيضًا أن مصدر التغذية الرئيسي هو نظام النيل (نهرالنيل والقنوات المتفرعة منه)، وأن العمليات الرئيسية المختلفة التي أثرت على نوعية المياه الجوفية هي: (١) التغذية بمياه النيل، (٢) التبادل الكاتيوني، و(٣) عمليات الغسيل والإذابة وكذلك الترسيب لبعض الأملاح.