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Sedimentological and Hydrogeochemical Studies of the Quaternary Groundwater Aquifer in El Salhyia Area, Sharkia Governorate, Egypt

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ABSTRACT

Allover the world, the urban growth increases the demand of fresh water supply. In some regions the groundwater (GW) is the main sources of fresh water especially when the surface water in not sufficiently available or scarce. Where it is the second source for freshwater used for domestic, agricultural and industrial purposes. The present study discusses the sedimentological and hydrogeochemical characteristics of the Quaternary groundwater aquifer in El Salhyia area. The study is based on the field and laboratory measurements. The Quaternary aquifer is mainly composed of sands intercalated with clays and shale lenses. The agricultural activities and irrigation system has great impact on groundwater levels and water quality of the Quaternary aquifer in the study area. Distribution patterns of grain size characteristics in the estuary sediments of El Salhyia area have been studied. The sediments are varying from medium to fine grained, moderately to poorly sorted, strongly fine skewed to very strongly coarse skewed and very platykurtic to very leptokurtic in nature. These textural parameters have been examined to understand hydrodynamics of the depositional environment. Petrographically, sandstone samples are classified as into quartz arenite type; highly enriched in quartz (90%) with subordinate feldspars and lithic fragments and quartz wacke type; enriched in argillaceous matrix. Sands reveal that quartz grains are predominant mono-crystalline with some poly-crystalline type, these led to the recognition of the following kinds of lithofacies associations. As well as the objective of this work is to evaluate of the groundwater in El Salhyia area; based on determine water quality parameters viz pH, electrical conductivity (EC), Total dissolved salt (TDS), Sodium (Na^{+}), potassium (K^{+}), calcium (Ca^{++}), chloride (Cl^{-}), sulphate (SO_4^{-2}), Bicarbonate (HCO_3^{-}), Total hardness (TH), Iron (Fe^{++}) and manganese contents (Mn^{++}). Groundwater quality of the Quaternary aquifer has a wide range from fresh, fairly fresh, brackish, slightly saline water which ranging from 252 to 3120 mg/l. The recharge is from surface water (El Ismailia, El salhyia and El Kassara Canals). The main types of El Salhyia GW are bicarbonate-sodium and bicarbonate-calcium (sample No. 1, 2, 7, 8, 10, 12, 13, 14, 20, 21, 22, 23, 24, 25 and 27) which indicated that meteoric water origin; it is suitable for irrigation purposes and the chloride-calcium and sulphate-sodium GW type which indicate that the effect of leaching and dissolution of the aquifer material and over pumping processes which is unsuitable for irrigation purposes (sample No. 4, 5, 6, 11, 15 and 26).

Key words: Grain size analysis, Groundwater (GW), Sharkia Governorate, El Salhyia, Quaternary Aquifer

Introduction

Water is vital for the existence for all life forms and is essential for all activities of human beings. Groundwater is used in large amount for industry, irrigation and domestic activity. Land reclamation projects in the desert region are of vital importance for development of countries. Egypt governments do a great effort to increase the land reclamation. The east of the Nile Delta, new desert settlements and land reclamation projects have been recently established, e.g. tenth of Ramadan city, El Salhyia and Mullak reclamation projects. Urban growth has increased the demands on GW supplies. The hydrogeochemistry of the area was investigated by many authors among them Shata & El Fayoumy (1968), El-Shazly *et al*., (1975), El Hefny (1980), Sallouma (1983), Geriesh (1989), Gad(1995), El Sharkawi (2008) and Atwa (2010).The present work deals with the sedimentological, hydrogeology and hydrogeochemistry of groundwater in El Salhyia area. One of these areas is E1 Salhyia. In study area, water samples were collected from pumping production wells of different areas in and around El Salhyia area. The groundwater samples collected from the various places in and around El Salhyia area and were analyzed for various physical and chemical parameters such as pH, EC, turbidity, TDS, total hardness as $CaCO_3$ content. Parameters were determined and the results were compared with the values of various water quality standards such as World Health Organization (WHO).The main objective of this work is to study the sedimentological, hydrogeochemical and hydrogeological characteristics of the shallow Quaternary

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aquifer in El Salhyia area as well as this research gives a guide lines for the suitability of groundwater for domestic and agricultural purposes. Twelve subsurface sands samples were collected and analyzed mechanical, mineralogical and petrographical. Twenty seven water samples were collected from the shallow Quaternary aquifer for chemical analysis.

Study Area:

El Salhiya area is located in the eastern Sharkia Governorate northeast Zagazig city, north Ismailia canal and bounded by latitudes 30° 35' and 30° 43' N and longitudes 31°49' and 32°05'E. (Fig. 1).

El Salhiya area is located in a portion of the desert belt of Egypt. Its climate is characterized by a hot summer and a short rainy winter. According to temperatures of climate information for studied area (Egyptian Meteorological Authority, 2011), during the summer ranging from 34C°- 36C° and lower temperature in the January up to about 13C°. Average rainfall of up to 24.8 mm and the relative humidity is higher in winter than in summer which the average humidity in the study area ranging from 45-56% in the month of May to November. While the evaporation intensity is generally higher in summer than that in winter. Wind speed often is less than 9 m/s with an annual average is 4 m/s.

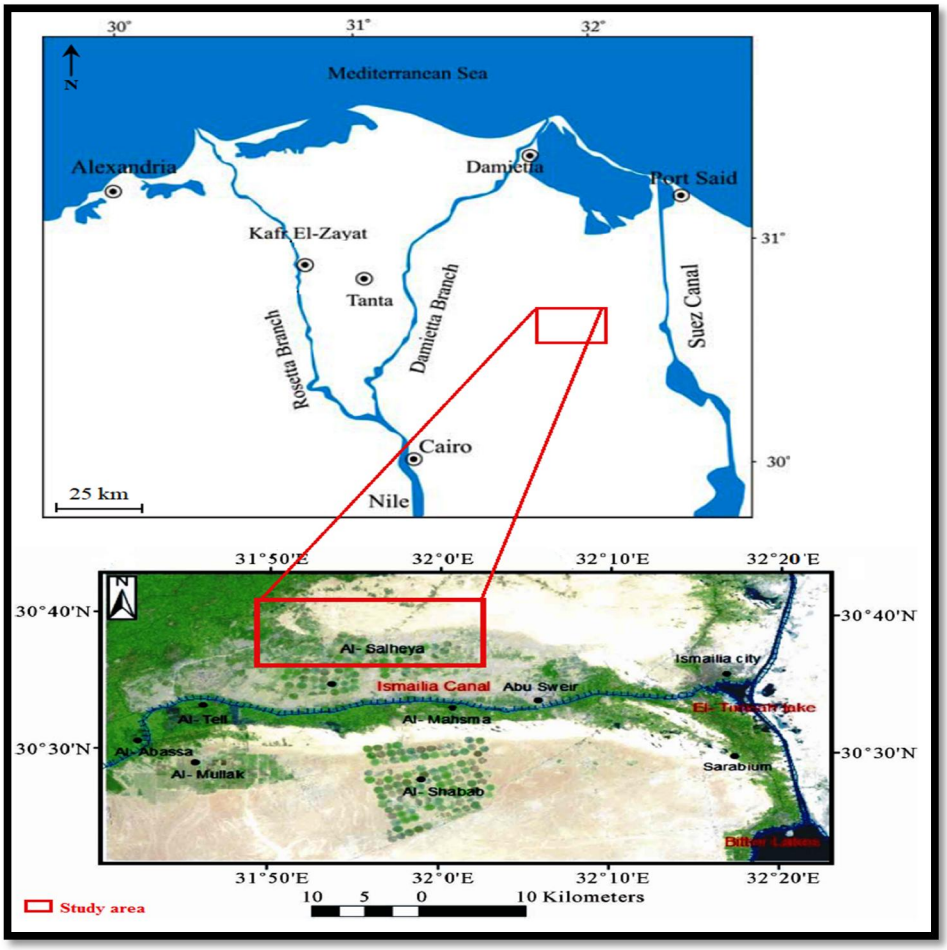

Fig. 1: Location map of study area.

Surface water and groundwater are the main sources for irrigation activities, surface water represented by El Ismailia, El Salhyia Canals and its branches (Fig. 2). The Quaternary groundwater aquifer represents the main sources of the groundwater in the study area. The uncontrolled uses of the groundwater causes large draw down in groundwater level and change the groundwater qualities.

General Geology Setting:

The geology of the study area is very important especially in the hydrochemistry of GW; it is lightly influenced by the type of rocks, surficial soils, and structures in the area. Geology of the eastern part of the Nile Delta has attracted the attention of many authors, e.g. Shukri and Ayouti (1956), Said and Beheri (1961), Shata

(1965), El Fayoumy (1968), Shata and E1 Fayoumy (1970), Bayoumy (1971), El Shazly *et al*. (1975), Zaghloul *et al*., (1977), Hefny (1980), Said (1981), Moussa (1990), Korany *et al*., (1997), Abd El Gawad (1997) and Ibrahim *et al*., (2005).

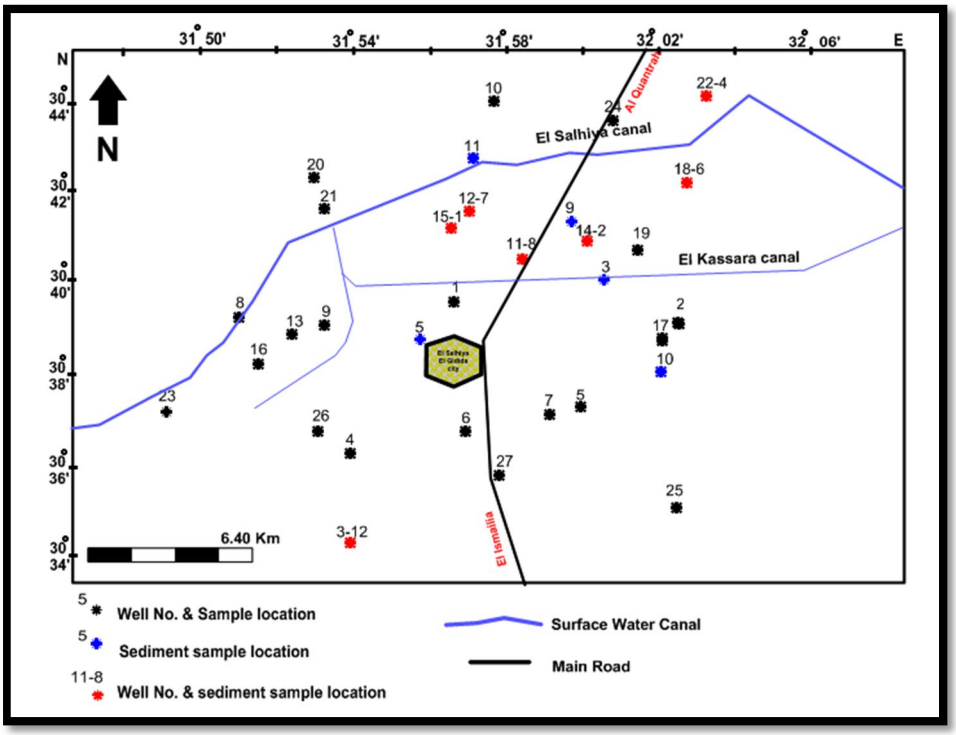

Fig. 2: Location map of groundwater and sediments samples in the study area.

Topography:

The study area elevation ranges between 15m to 30m above sea level (Shata *et al*., 1979) which the general slope towards the north (Fig. 3). It is dissected by a complex irrigation system, which has a direct influence on both the GW recharge and movement of the Quaternary aquifer.

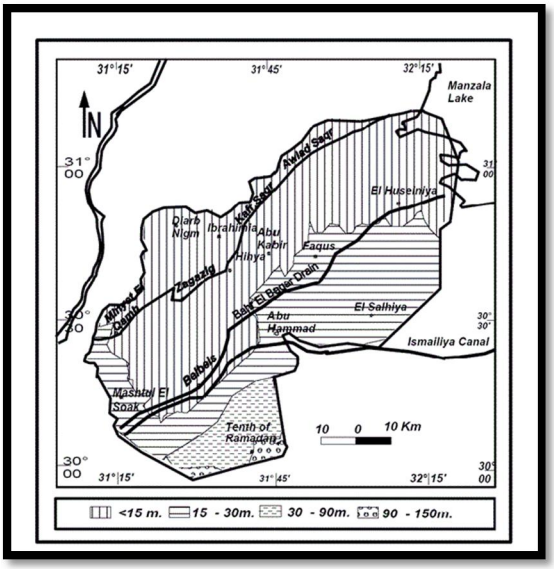

Fig. 3: Topographic map of the study area (compiled after Shata *et al*., 1979).

Geomorphological Setting:

The concerned area is natural extension of the Nile Delta it is a part of Belbies-El Tell El Kabier-El Salhyia old deltaic plains (Fig. 4). These plains occupy almost low relief areas that lying to the east of the Nile Delta flood plain and extended to the Suez Canal district to the east. These plains are bounded in the south by

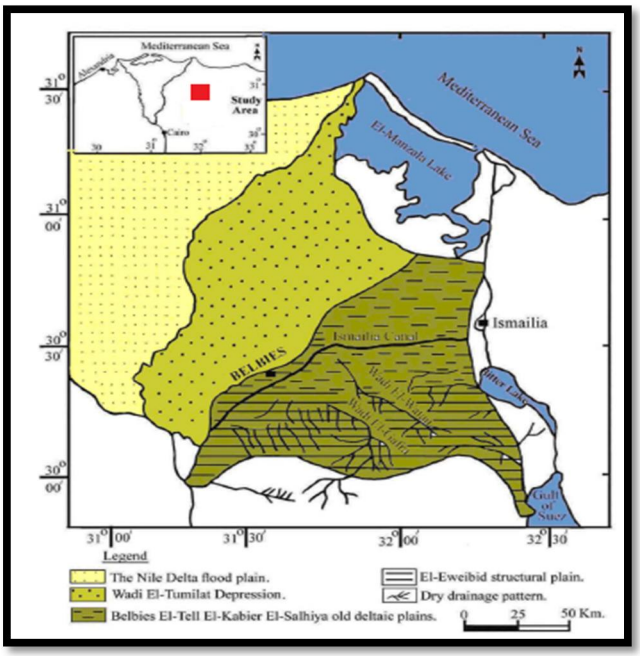

Fig. 4: Geomorphological map of study area.

Anqabia-Ewaibid structural plain and Gabel Mokattam - Ataqa structural plateau. El-Manzala Lake and lacustrine plain in the north.

Lithostratigraphy, the area east of the Nile Delta is essentially occupied by sedimentary succession belonging to Tertiary and Quaternary Ages. Tertiary rocks are represented by Eocene, Oligocene, Miocene and Pliocene rocks (Fig. 5).

Quaternary deposits have a wide distribution over the study area, they are represented by old deltaic deposits which are composed of fluviatile coarse quartz sands, cherty flinty pebbles and igneous fragments with few occasional fossil wood remains and young aeolian deposits composed of fine to coarse quartz sands with remarkable variable thickness (El Kilany, 2009).

Surface Geology:

The surface geology of the study area was studied by several geological studies eg. El Said (1981) and Zaghloul *et al*. (1990). According to GPC and CONOCO (1987), the rock units exposed in the study area can be mainly classified as Quaternary deposits:

Quaternary deposits:

Quaternary deposits represented by Nile silt, wadi deposits, alluvial fans and sand dunes. According to mode of formation (Schlumberger, 1984), Quaternary deposits are classified, from base to top, into Pleistocene and Recent Holocene (Fig. 5).

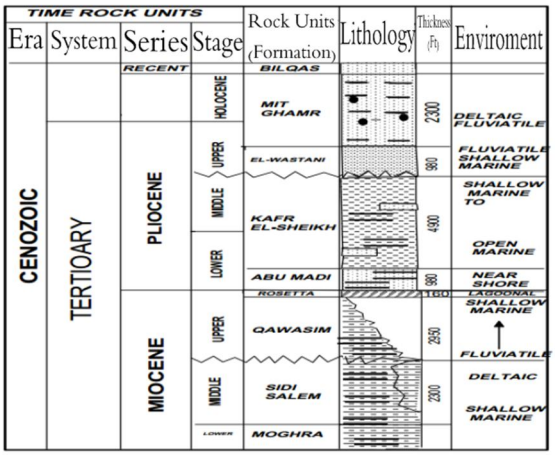

Fig. 5: Generalization Litho-stratigraphic column of the studied area (after Schlumberger, 1984).

The Pleistocene sediments:

The Pleistocene sediments are considered as the main GW aquifer in the study area. It includes three types of deposits, namely, the old Aeolian deposits or Mit Ghamr Formation, the old fluviomarine deposits and the old deltaic deposits (Fig. 5).

The Holocene deposits:

They are widespread and divided into the following types:

1) The young deltaic deposits Neonile (Bilqas Formation); which are composed of Nile silt, fine sands and clays. They show gradual increase in thickness (10 m) to the north direction (Fig.5).

2) The young Aeolian deposits; which are represented by loose fine to coarse sands with variable thickness from 2 to 10m.

Structural Setting:

The structural setting of the study area has been discussed by several researchers, among them are El Fayoumy (1968), El Diasty (1969), El Shazely *et al*., (1975), El Dairy (1980), El Ahwani (1982), El Gamili (1982), Sallouma (1983) and Khabar (1992). The sedimentary succession in the study area is strongly affected by structural elements. The regional geological structure of the study area increases the thickness of the Quaternary aquifer of 3 m/km towards north direction (Gad, 1995). It ranges from 300 to 400 m. Faults and folds are the most conspicuous structural elements affecting the landscape in the study area. Faults are dominantly represented by an NE-SW and NW-SE directions of normal type (Fig. 6). Vertical displacement along these faults varies from few meters to hundred meters.

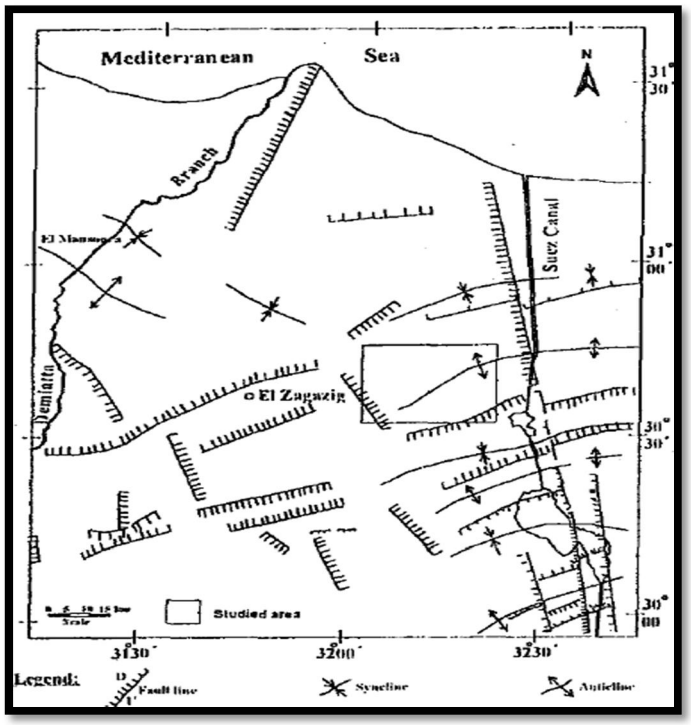

Fig. 6: Compiled structural map of the area east of the Nile Delta (After El- Dairy 1980).

Sampling and Methodology:

The location site is determined by GPS instrument. Twelve subsurface sediments samples were collected from the study area in January 2014 (Fig. 2) and subjected to several laboratory investigations using collaborative techniques to determine their textural and mineralogical characters. For grain size analysis the composite samples were subjected to dry sieving technique adopting by Tucker (1988). The cumulative frequency curves were drawn graphically and the four statistical grain size parameters (M_z, δ_I, Sk_I and K_G) were calculated according to Folk and Ward (1957). The separated mud fraction was analyzed using the pipette method to determine the distribution of the particle sizes within the total silt and clay fractions (Folk, 1974). Grain mounts for sand fractions in Canada balsam were made for detailed microscopic examination. Twenty seven groundwater samples were collected in January 2014 (Fig. 2) and analyzed for major ions, besides the hydrogeological data. PH and EC are measured in situ. Cl^-, HCO_3^-, Ca^{++}, and Mg^{++} were measured by titration,

while SO_4^{--} is estimated by turbidity method, and Na^+ and K^+ were analyzed by flame photometer, they were analyzed at the Branchial Laboratory of Western Desert, Tanta.

Sedimentlogical Studies:

The sedimentlogical studies include three main parts: grain size analysis, petrography and mineralogical composition.

Grain Size Analysis:

Grain size analysis is used for different purposes, such as textural, description, testing the behavior of sediments during transportation and deposition. It is also used to interpret the depositional environments under which these sediments were deposited and to evaluate the subsurface sediments for groundwater aquifer. Grain size analysis is required for classifying the sediments. The results of the mechanical analysis are tabulated in table (1) and the data are represented by histogram and cumulative curve (Figs. 7-A and B). The constructed histogram (Fig. 7-A) shows the average of the particle size distribution for El Salhiya sediments.

Table 1: Grain size data of the studied sands subsurface samples of El Salhiya area.

Characters		Minimum	Maximum	Average
Weight % of fraction	>2 mm (G)	0	13.59	3.60
	2- 1 mm (V.c.s)	0.36	12.04	5.34
	1- 0.5 mm (C.s)	1.5	35.44	22.18
	0.5 - 0.25 mm (M.s)	28.3	52.22	38.2
	0.25 - 0.125 mm (F.s)	1.73	31.42	13.63
	0.125- 0.063 mm (V.f.s)	1.79	20.98	12.42
	<0.063 mm (silt + clay)	0.76	17.2	4.48
Grain size percentiles	ϕ5	-1.76	1.16	0.17
	ϕ16	-0.59	1.52	0.53
	ϕ25	0.18	1.65	0.7
	ϕ50	1.03	2.08	1.46
	ϕ75	1.63	3.36	2.35
	ϕ84	1.94	4.08	3.01
	ϕ95	2.58	5	3.81
Textural parameters	Mz	1.04	2.35	1.64
	δI	0.123	1.86	1.16
	SkI	-1.86	0.44	0.02
	KG	0.26	1.57	1.09
	KG\	0.2	0.61	0.50

Abbreviations: Sk_I= Inclusive graphic skewness; δ_I= Inclusive standard deviation; Mz=Mean size; K_G= Kurtosis; G= Gravel V.c.s= Very coarse sand; C.s= Coarse sand; M.s= Medium sand; F.s= Fine sand; V.f.s= Very fine sand.

The cumulative curve (Fig.7-B) shows the textural parameters, the graphic mean size with an average of 1.64 ϕ falling in the medium sand grade. The sorting (δI) with an average of 1.16 ϕ falling in the poorly sorted. The skewness with an average 0.02 ϕ the studied samples are near symmetrical. The kurtosis has an average of 1.09 ϕ falling in mesokurtic.

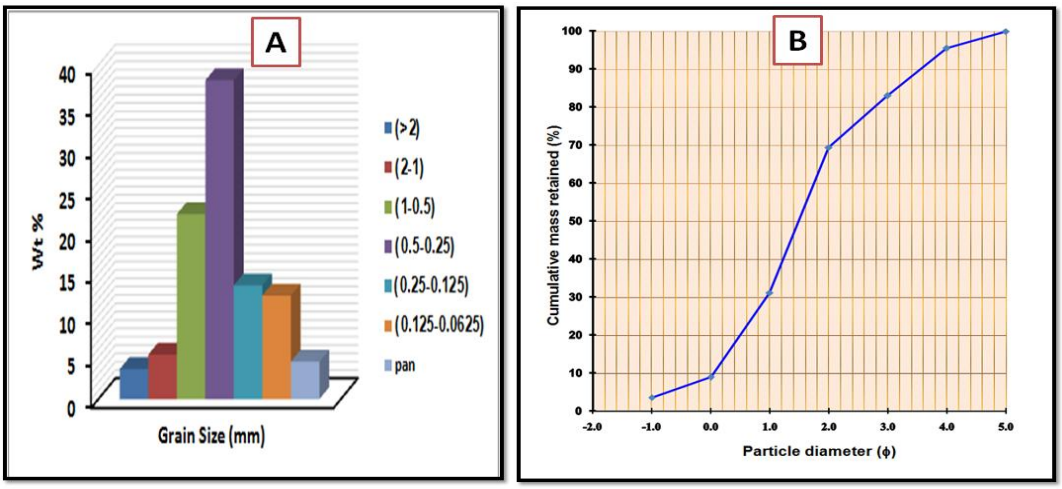

Fig. 7: A-Histogram shows the average of the particle size distribution of subsurface sands sediments of study area. B-Cumulative curve of the average of the subsurface sands sediments of study area.

The average of studied sediments represents river sands which the central parts of the curves has a gentle slope (Fig.7-B).

X-Ray Diffraction Analysis:

The x-ray diffraction analysis of seven clay fraction samples selected from different localities of a study area, were carried out in order to identify the non clay and clay minerals. As unoriented mount (powder samples) was prepared for each sample using the fine fraction of clay samples in order to determine the clay minerals.

The identification of the clay minerals involved the standard technique of oriented grains on glass slides often drying in air, glycolating and heating at 550^{o}c for two hours.

Clay mineral composition:

Three oriented particle mounts were prepared from the pure clay fraction (< 2 mm) and X-rayed for the semi-quantitative identification of clay minerals. They were prepared by pipetting of the clay suspension on glass slides. One of these mounts was used to X-ray in its original state (untreated). The second were X-rayed after saturation with ethylene glycol (glycolated) and the third after heating at 550˚C for two hours (heated). The X-ray diffractograms of oriented particle amounts of selected samples are represented in table (2) and figure (8) and their analytical data showing the presence of the following clay minerals:

Table 2: X-Ray diffraction data of treated clay fractions of studied samples.

Sample No	Untreated			Glycolated			Detected Minerals
	2θ	dA˚	I/I$_o$	2θ	dA˚	I/I$_o$	
1 (well No. 15)	-----	-----	-----	5.56	15.9	100	Smectite, Kaolinite and Illite
	7.122	12.412	100	-----	-----	-----	
	12.29	7.196	21.49	12.44	7.11	12.01	
	-----	-----	-----	16.91	5.24	3.26	
	-----	-----	-----	20.94	4.24	1.45	
	24.894	3.577	12.72	24.955	3.57	11.98	
	26.605	3.351	6.06	26.66	3.34	18.23	
	-----	-----	-----	27.74	3.22	10.43	
	28.1526	3.17	23.63	-----	-----	-----	
3	-----	-----	-----	5.55	15.93	100	Smectite, Kaolinite and Illite
	7.039	12.56	100	-----	-----	-----	
	12.344	7.17	83.79	12.45	7.11	80.74	
	24.88	3.58	57.41	24.96	3.57	84.57	
	26.567	3.355	19.89	26.71	3.34	52.3	
	37.62	2.39	6.1	-----	-----	-----	
6 (well No. 18)	-----	-----	-----	5.23	16.91	53.2	Smectite, Kaolinite and Illite
	7.08	12.48	100	-----	-----	-----	
	-----	-----	-----	8.584	10.30	8.11	
	12.33	7.18	95.49	12.311	7.18	82.21	
	24.836	3.59	54.7	24.815	3.59	100	
	26.59	3.35	52.72	26.565	3.355	94.02	
7 (well No. 12)	-----	-----	-----	5.21	16.953	46.67	Smectite, Kaolinite and Illite
	7.134	12.392	77.98	-----	-----	-----	
	12.213	7.247	100	12.296	7.198	63.92	
	24.862	3.58	75.51	24.79	3.59	100	
	26.6719	3.34	83.26	-----	-----	-----	
10	-----	-----	-----	5.346	16.53	100	Smectite, Kaolinite and Illite
	6.97	12.69	100	-----	-----	-----	
	12.30	7.194	16.37	12.277	7.21	13.17	
	-----	-----	-----	16.74	5.295	6.46	
	24.81	3.58	13.67	24.84	3.58	17.57	
	26.57	3.355	11.54	-----	-----	-----	
	-----	-----	-----	27.66	3.22	12.97	
	28.11	3.17	18.43	-----	-----	-----	
11	-----	-----	-----	5.308	16.65	35.77	Smectite, Kaolinite and Illite
	6.8708	12.865	70.1	-----	-----	-----	
	12.31	7.189	100	12.327	7.18	54.75	
	24.855	3.582	39.69	24.802	3.5899	100	
	26.53	3.359	37.2	26.51	3.362	88.15	
12 (well No. 3)	-----	-----	-----	5.448	16.22	100	Smectite, Kaolinite and Illite
	7.081	12.484	100	7.39	11.96	25.37	
	-----	-----	-----	8.696	10.17	18.02	
	12.31	7.188	37.9	12.27	7.21	39.57	
	24.86	3.58	31.09	24.83	3.585	46.26	
	26.648	3.345	14.62	26.60	3.35	39.08	
	-----	-----	-----	27.588	3.23	24.92	
	-----	-----	-----	30.159	2.96	11.74	

Smectite:

It is the most common mineral of the Smectite group, which has important Base Exchange properties, is built up of 3 layer units comprising two silicon layer separated by an aluminum layer. Some aluminum is usually replaced by magnesium or iron, and small amounts of sodium or calcium are then attached, as ions lying between the 3 layer units or around the edges of the minute crystals. The layers are held together by weak van der waals forces and exchangeable ions. Water can easily enter the bond and separate the layers in smectite. It is identified by X-ray diffraction peak that appears at (12A^{o}).The Smectite is the most predominant clay mineral in the studied samples.

Kaolinite:

Kaolinite, $Al_2Si_2O_5$ $(OH)_4$ is composed of a single tetrahedral and a single alumina octahedral sheet combined in units. The kaolinite mineral is formed staking the layer of 7A° thick one above the other with base of the silica sheet bonding to hydroxyls of the gibbsite sheet by hydrogen bond, the kaolinite sheets are difficult to dislodge. Kaolinite is generally formed in warm moist regions as a residual weathering product or sometimes by hydrothermal alteration of other aluminosilicates. Kaolinite is the second mineral of abundance in the studied clay samples.

Illite:

Illite is characterized by a series of weak broad peaks of lines 9.9A°, 4.44A° and 3.35A° that are not appreciable affected by glycolation or heat treatment. It is similar in many respects to white mica, but has less potassium and more water in its composition. It has a much lower Base Exchange capacity than smectite. Illite consists of repeated layers of one alumina sheet sandwiched by two silicate sheets.

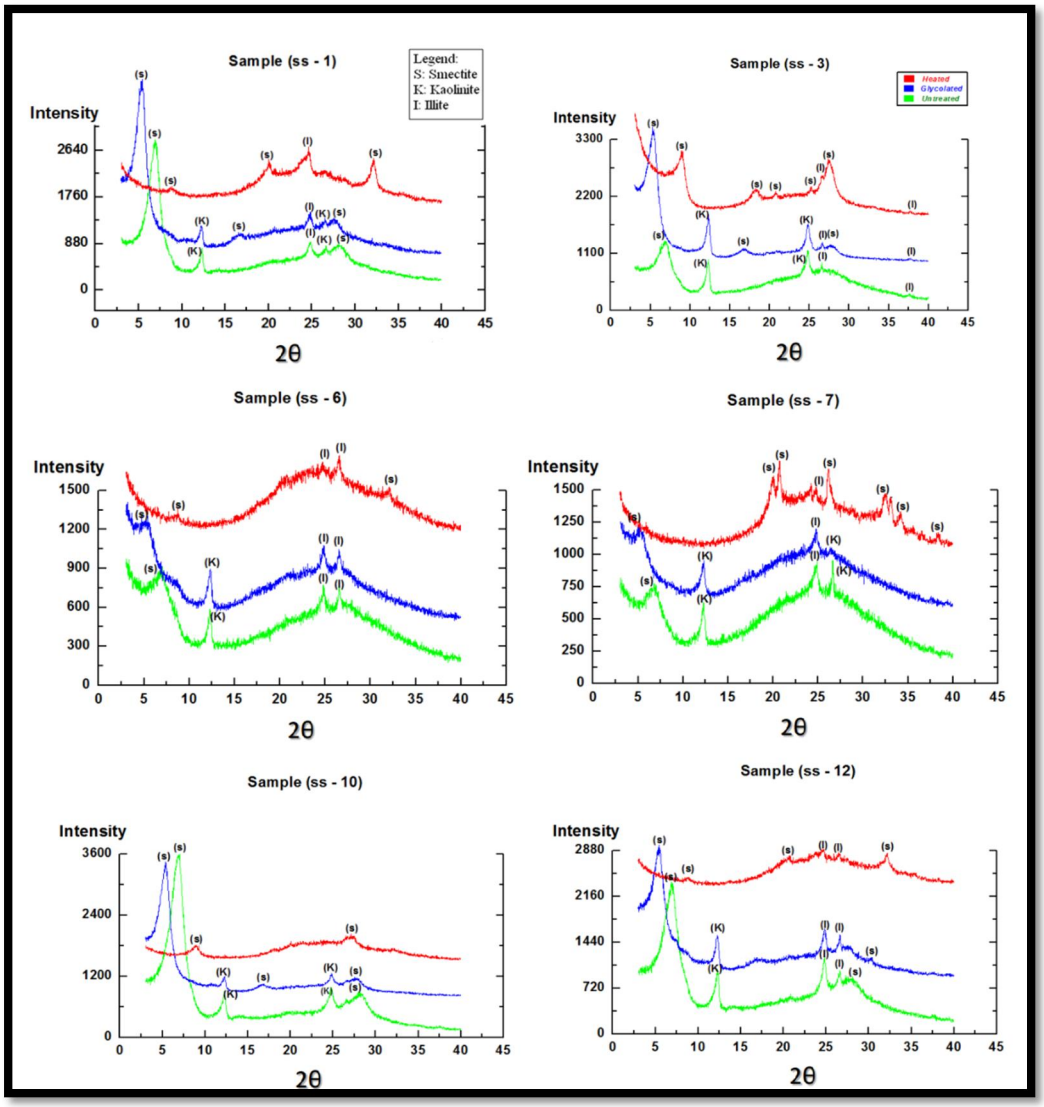

Fig. 8: X-ray diffraction of the studied clay fractions samples.

Petrography:

The thin section petrography is one of the most practical methods to express specific characteristics of the depositional environments. To accomplish this study more than 20 thin sections were prepared representing the encountered lithologies. The microscopical study of the analyzed samples according to the classifications of Folk (1956, 1962 and 1974), Pettijhon (1975) and Tucker (1981), the petrographical analysis of El Salhyia area indicated the presence of two sandstone lithofacies association; Quartz arenite and Quartz wacke lithofacies. These are as following:

Quartz Arenite:

The quartz arenite lithofacies is very common at all studied wells Petrographically, this lithofacies is composed of about 85-90% quartz grains and (3-5%) of fresh and altered plagioclase-feldspars (3-5%), glauconitic pellets (up to 5%) and iron oxides (3-5%).

The quartz grains are fine to medium size grained some grains are coarse size grained, subangular to subrounded and few grains are elongated shape, poorly and moderately sorted. Most of the quartz grains are monocrystalline with few polycrystalline disoriented. The grains are coated by iron oxides and fractured grains, open packed, point and straight contacts. Quartz grains are single type, showing straight to slightly undulose extinction with scattered iron oxides grains and glacuonite pellets. Texurally quartz grains are mature stage (Fig. 9).

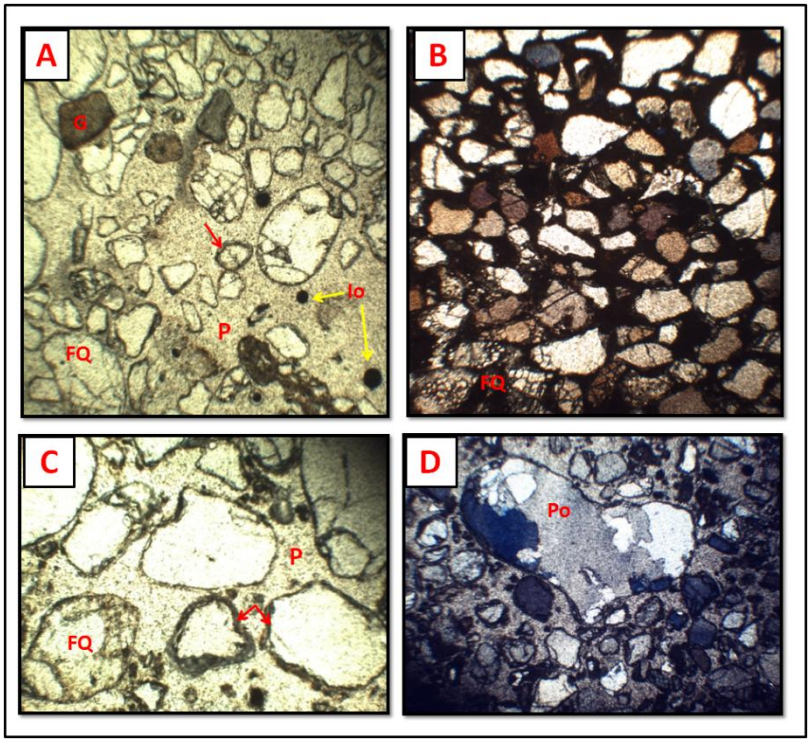

Fig. 9: Photomicrographs showing, (A) Quartz arenite, quartz grains coated by iron oxides and fracture in some quartz grains (FQ) and show high porosity (P) with few glauconite pellets (G) and iron oxides(Io).,sample No. (ss-1) P.P.L., X-4. (B) Quartz arenite, quartz grains are subangular to subrounded, poorly sorted, open packed, and fracture qz grains (FQ)., sample No. (ss-12) C.N., X-4.(C) Quartz arenite, quartz grains have overgrowth on their surfaces and coated by iron oxides (Io), high reliefs, fracture quartz grains (FQ) and high porosity (P).,sample No. (ss-5) P.P.L.,X-10. and (D) Quartz arenite, fracture qz grain (FQ) with overgrowth on the surface of some qz grains, some grains are poly crystalline (Po) with andulose extinction and high relief., sample No. (ss-5) C.N., X-4.

Quartz Wacke:

Petrographically, it is composed of quartz grains (60-70%), glauconitic pellets (up to 10%), feldspars (3-5%) and argillaceous materials (>15%) with iron oxides (3%). Most grains are subrounded to subangular and moderately to poorly sorted. The quartz grains are fine to coarse size grained. subangular to angular and moderate to poorly sorted and mature stage. It is predominantly monocrystalline with sub-ordinate

polycrystalline. Quartz grains show undulose extinction and displayed uniform wavy extensions and closely packed of float, point and line contacts between grains. The quartz grains are embedded in argillaceous ground mass matrix. Iron-oxides are present as scattered spots (Fig.10).

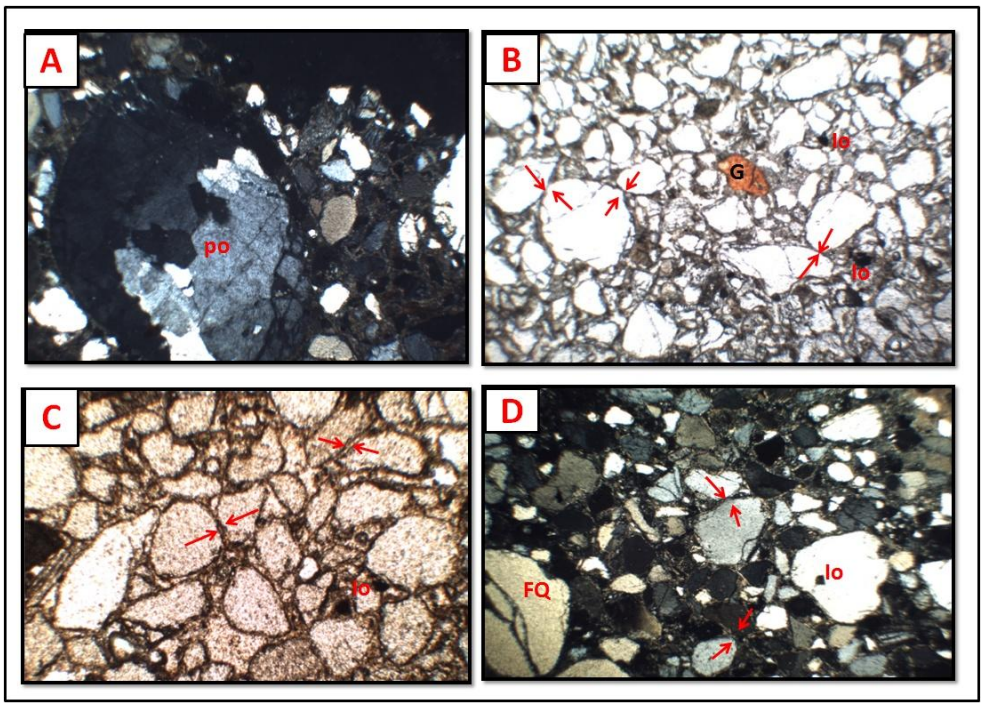

Fig. 10: Photomicrographs showing, (A) Quartz wacke, quartz grains poly-crystalline (Po) has undulose extinction and poorly sorted., sample No. (ss-2) C.N., X-4. (B) Quartz wacke, fine quartz grains and argillaceous materials as a matrix, with concavo-convex and point contacts, mature grains with high relief, few glauconite pellets (G) and iron oxidesare noticed(Io).,sample No. (ss-2) P.P.L., X-4. (C) Quartz wacke, subangular to subrounded qz grains, mature, line and point contacts, closed packed with iron oxide scatters (Io)sample No. (ss-8) P.P.L., X-4.(D) Quartz wacke, fracture quartz grains (FQ), close packed and point contacts, iron oxides (Io) inclusions in some quartz grains., sample No. (ss-8), C.N., X-4.

Hydrological Studies:

Hydrogeoloical Setting:

The Quaternary water bearing formation constitutes the main source of groundwater aquifer in the study area. It is mainly composed of sands and gravels intercalated with clay stone and shale lenses. The Quaternary water bearing formation rest directly on Pliocene clays and Miocene sandy limestone. The saturated thickness of the Quaternary aquifer is strongly affected by normal faults with downthrown sides towards the east, this lead to increase the thickness toward north and northeast directions; it ranges from 300 m to 400 m in the study area while it reaches more than 900 m in the north direction toward the Mediterranean Sea.

Ismailia and El Salhyia Canals in addition to excess irrigation water represent the main recharge resources of the Quaternary aquifer in the study area while pumping groundwater through productive drilled wells represents the main discharging sources. The Quaternary aquifer is hydraulically connected with the underlain Miocene saline water aquifer through deep seated normal faults; this may because local vertical upward leakage of Miocene saline water. Depth to water and groundwater levels were measured of 27drilled wells tapping the Quaternary aquifer.

Quaternary Aquifer (Nile Delta Aquifer):

The Quaternary aquifer is the principal reservoir of the GW of the study area. It is underlined by the Pliocene plastic clay that acts as an aquiclude, the lateral and vertical variations in the facies of the Quaternary sediments, lead to their classification into a number of distinguishable horizons. Each of these horizons has its own characters such as porosity, hydraulic conductivity, ability for retaining and yielding water, and mode of water occurrence rather than water quality. These horizons are:

a) Nile silt, sandy clays and clayey sands (Holocene).

b) Fine and medium sands with related sediments (Late Pleistocene).
c) Coarse sands and gravels (Early Pliocene).

Recharge and discharge of the aquifer and relationship between surface water and GW:

The main GW aquifer (Quaternary aquifer) in the study area is considered as free aquifer relating to Pleistocene age and composed of loose quartz sand with pebbles and granules with intercalated thin claystone beds. The aquifer mainly was recharged from the irrigation and draining canals and the rainfall. The aquifer is recharged mainly by three sources, the seepage from the Nile Delta aquifer, seepage from fresh water of Ismailia Canal, surface irrigation canals and drains and seepage from agricultural water uses and rainfall from desert wadis.

The occurrence of GW is highly controlled by the surface water. The relationship between GW and surface water is strongly influenced by the following factors, canal or lake depth, height of the water table relative to the surface and surface water levels, type of sediments forming the bottom and banks of surface water courses, rate of horizontal and vertical hydraulic boundary conditions of the GW system and Hydraulic conductivity of the aquifer.

Hydrogeochemical Studies:

The hydrogeochemistry at the study area, has been studied by many workers among them Shata and El Fayoumy (1968), El-Shazly *et al*., (1975), El Hefny (1980), Sallouma (1983), Geriesh (1989), Gad (1995) and Dahab *et al*. (2009).

Hydrochemical characteristics of the Quaternary aquifer in the study area were discussed through the results of the chemical analyses of' the collected twenty seven GW samples which collected from the production wells during field trip in Jan and May in 2014 (Fig.2 and Table 2)**.** The wells have depths varying from 18 to 126 m.

Hydrochemical parameters:
pH value:

The pH is a measure of alkalinity and acidity of water. The pH value is normally affected by the percentage of salts in water, which results from leaching of soil and/or the intrusion of sea water. The pH values higher than 7.0 indicate alkaline water conditions.

$PH = \log_{10} [H^+]$ ……(1)

The value of pH in the collected water samples ranges from 6.9 (wells No. 16 and 17) to 8.9 (well No. 13). This indicates that, the groundwater is slightly acidic to alkaline water type

Electrical conductivity (EC):

Is defined as the ability of a substance to transmit electrical current. Electrical Conductivity (EC) is measured in units of (µmhos/cm).It depends on temperature and on the type of water and the concentration of dissolved ions. It is usually defined at 25C^o the electrical conductivity ranges from 420 µmhos/cm (well No. 2) to 5200 µmhos/cm (well No. 11) with average 2247.2 which meaning salty water and it is a good conductor of electricity

Total dissolved salts (TDS):

It is an important factor in determining the water type. The total salinity of groundwater is represented as the sum of all mineral substances detected by the chemical analyses. Salinity content of groundwater of the Quaternary aquifer in El salhyia area has wide ranges from fresh, fairly fresh, brackish to slightly saline water. TDS in study area ranging from 252 ppm (well No.2) fresh water to 3120 ppm (well No. 11) slightly saline water.

Major cations:
a-Distribution of potassium (K^+):

The distribution of K^+ is mainly due to the existence of clay minerals. The concentration of K^+ in the GW of the Quaternary aquifer is ranging from 2 ppm (wells No. 17, 18 and 19) to 91 ppm (well No. 11).

b-Distribution of sodium (Na^+):

The sodium ion (Na^+) is the most important alkali metal in natural water. It represents the dominant cation in the groundwater. The sodium ion (Na^+) concentration in the investigated water samples varies widely from 12 ppm (well No. 2) to 744 ppm (well No. 9).

c-Distribution of Magnesium (Mg^{++}):

Its concentration in the groundwater increases by the increase of solubility of magnesium carbonate minerals (dolomite and magnesite). The concentration of Mg^{++} is generally ranging from 3.7 ppm (well No. 2) to 142 ppm (well No. 11).

d-Distribution of Calcium (Ca^{++}):

Calcium ion (Ca^{++}) occurs in the groundwater in the form of carbonate (limestone or dolomite). The increase in calcium content is due to leaching and dissolution processes of gypsum. The concentration of calcium ion (Ca^{++}) in the study water sample varies widely from 12.8 ppm (well No. 2) to 230 (well No. 25).

Major anions:

a-Distribution of Chloride (Cl^-):

The source of chloride ion (Cl^-) in the GW is the sedimentary rocks (evaporites, e.g. halite mineral). The GW of the Quaternary aquifer in the study area of study has concentration of chloride ion (Cl^-) values ranging from 21 ppm (well No. 2) to 940 ppm (well No. 26).

b-Distribution of Sulfate ($SO4^{-2}$):

Gypsum and anhydrite are the most important source of sulfates. The concentration of sulfates ion (SO_4^{--}) in the Quaternary aquifer in the study area ranging from 12 ppm (well No. 20) to 595 ppm (well No. 11).

c-Distribution of bicarbonate ($HCO3^-$):

It represents the dominant anion in the analyzed groundwater samples. The concentration of bicarbonate values ranging from 34 ppm (well No. 2) to 904 ppm (well No. 25).

Table 3: Ranges and average of chemical analysis of groundwater samples of the Quaternary aquifer in El Salhyia area (ppm, epm and epm%).

Elements	Unit	Minimum Value	Maximum value	Average value
PH		6.6	8.9	7.5
E.C. at 25^0 C	µmohs/cm	420	5200	2247.4
TDS	ppm	252	3120	1366.74
K^+	ppm	2	91	20.73
	epm	0.05	2.32	0.53
	%	0.52	6.5	3.24
Na^+	ppm	12	744	198.9
	epm	0.52	32.4	8.7
	%	13	84.12	43.49
Mg^{++}	ppm	3.7	142	59.16
	epm	0.3	12	4.88
	%	7.47	48.6	29.2
Ca^{++}	ppm	12.8	230	80.62
	epm	0.63	11.18	4
	%	7	43	24.03
Cl^-	ppm	21	940	298.1
	epm	0.6	27	8.4
	%	17	73	47.66
SO_4^{--}	ppm	12	595	162.06
	epm	0.25	12.37	3.37
	%	4.35	28	18.35
HCO_3^{--}	ppm	34	904	322.80
	epm	0.56	14.8	5.29
	%	15.5	60.41	34

Ion Dominance and Water Chemical Types:

Semilogarithmic graph (Schoeller, 1956) was used to identify ion dominance and main water type. The studied samples showed that the sodium is the most dominant cation followed by magnesium and calcium cations ($Na^+ > Mg^{++} > Ca^{++}$) (Table 4). Chloride is the most dominant anions followed by Bicarbonate and sulfate ($Cl^- > HCO^-_3 > SO_4^{--}$) of the majority of samples (Fig. 11).

According to the concentration of cations and anions in the groundwater samples of the Quaternary aquifer in the study area. The following main orders of ions and consequent chemical types are recognized in table 4:

1- **Cl -Mg water type:** this type of water has wide spreading in the study area. It's represented 37% of the total samples (Fig. 12)

2- **Cl-Na water type:** this type may be related to salt water intrusion which occurred from Suez Canal or from upward leakage from the underline saline Miocene groundwater aquifer. This due to the daily over pumping discharge for the agricultural projects in the study area.

3- **HCO_3 –Na water type:** this type indicated that beside the meteoric origin, a recharge from surface water canal has been taken place due to its occurrence closed to these canals.

4- **HCO_3-Mg water type:** this type indicated the meteoric origin and dissolution processes caused the excess of calcium element.

Table 4: Ion dominance and water chemical types

Ion dominance	Samples No.	Water chemical type	Percentage %
Mg^{++}> Na^{+}> Ca^{++}& Cl^{-}> HCO_3^{-}>SO_4^{--}	1-12-13-14-20	Mg-Cl	18.5%
Ca^{++}> Na^{+}> Mg^{++}& Cl^{-}> HCO_3^{-}> SO_4^{--}	2	Ca-Cl	3.7%
Na^{+}> Mg^{++}> Ca^{++}& Cl^{-}> HCO_3^{-}> SO_4^{--}	3-4-5-6-7-9-11-26	Na-CL	29.7%
Mg^{++}> Ca^{++}> Na^{+}& Cl^{-}> HCO_3^{-}> SO_4^{--}	8	Mg-Cl	3.7%
Ca^{++}> Mg^{++}> Na^{+}& Cl^{-}> HCO_3^{-}> SO_4^{--}	10	Ca-Cl	3.7%
Na^{+}> Mg^{++}> Ca^{++}& HCO_3^{-}> Cl^{-}> SO_4^{--}	15-16-17-18-19	Na-Hco_3	18.5%
Mg^{++}> Ca^{++}> Na^{+}& Cl^{-}> HCO_3^{-}> SO_4^{--}	21-22-23-24	Mg-Cl	14.8%
Mg^{++}> Ca^{++}> Na^{+}& HCO_3^{-}> SO_4^{--}>Cl^{-}	25	Mg-Hco_3	3.7%
Na^{+}>Ca^{++}> Mg^{++}& Cl^{-}>HCO_3^{-}> SO_4^{--}	27	Na-Cl	3.7%

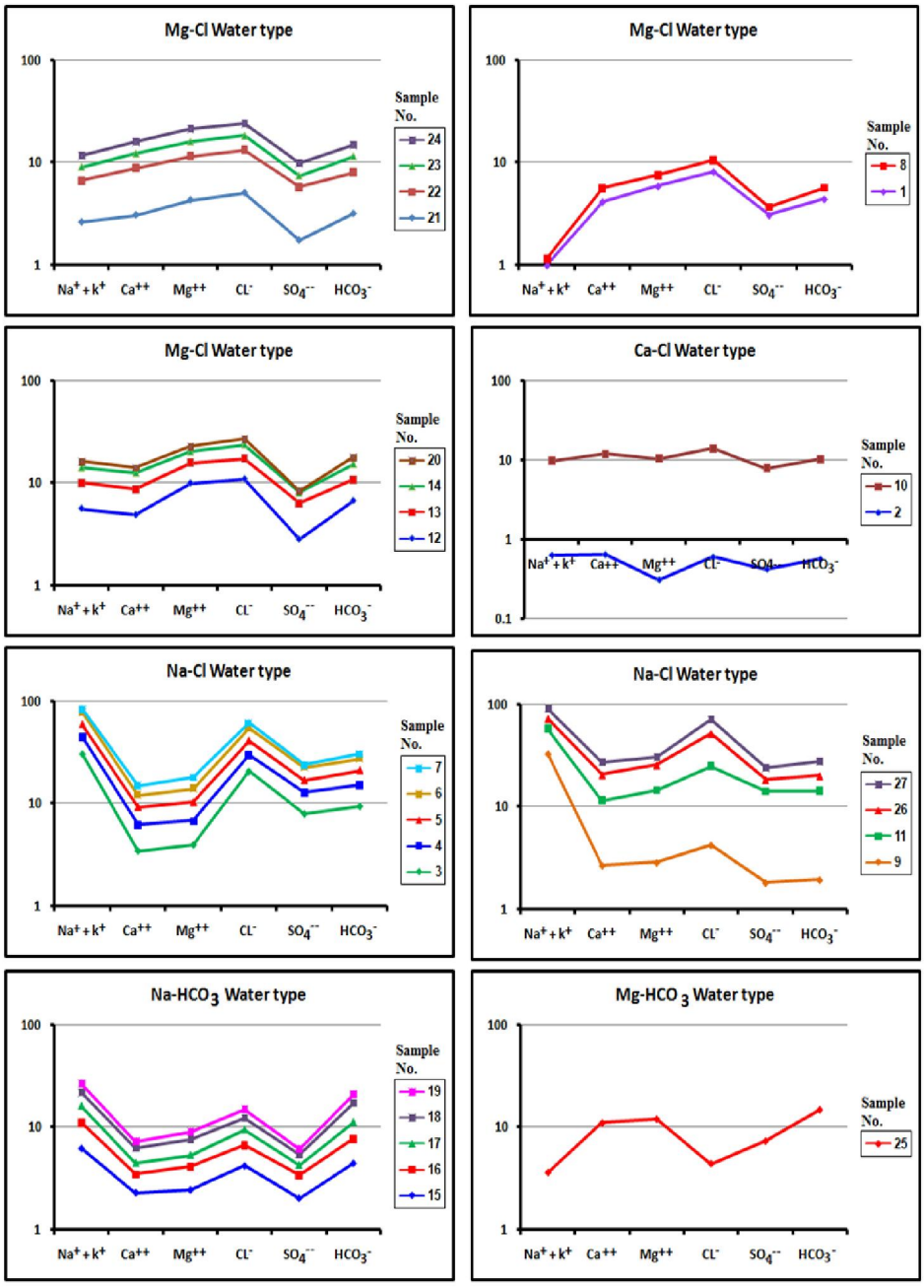

Fig. 11: Schoeller Semi logarithmic graph of the groundwater of the Quaternary aquifer in El Salhiya area.

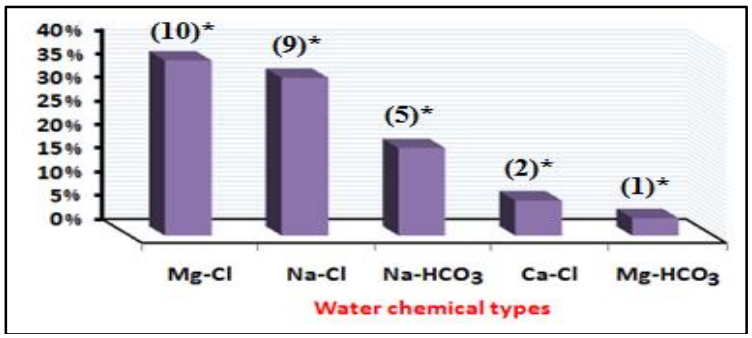

Fig. 12: Water chemical types of the groundwater in the study area.
* Numbers of wells

Hypothetical Salt Combinations:

The hypothetical salt combination of the groundwater is the combination between major ions in groundwater reveals the occurrences of four main groups of salt assemblages are detected.

Group (1): KCl, NaCl, $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ detected in fifteen groundwater samples (1, 2, 7, 8, 10, 12, 13, 14, 20, 21, 22, 23, 24, 25 and 27) represented 55.56 % of total samples. Sulfate salts are the results of leaching and dissolution of sediments rich in evaporites salts (mainly gypsiferrous shale) and $MgCl_2$ is marine salt with bicarbonate salts(Two bicarbonate salts) (Fig. 13-A).

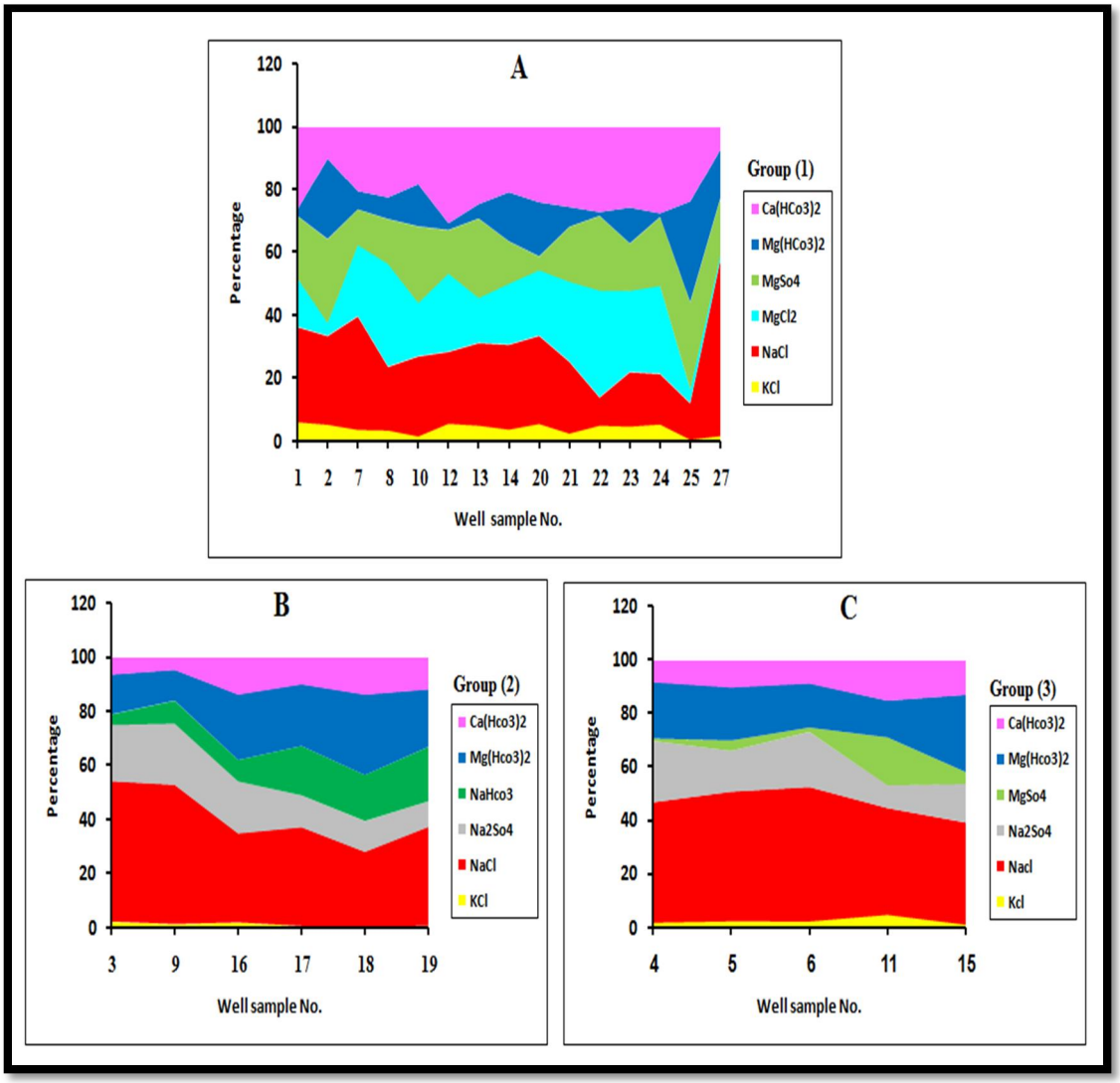

Fig. 13: Cross sections show the change in hypothetical salts at wells in study area.

Group (2): KCl, NaCl, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ detected in six groundwater samples (3,9,16,17,18 and 19) represented 22.22 % of the total samples. The richness in bicarbonate salts (three bicarbonate salts $NaHCO_3$, Mg $(HCO_3)_2$ and $Ca(HCO_3)_2$) represents an earlier stage of chemical development than that of the other assemblages, it reflects a pure meteoric fresh water origin. The recharge most probably from irrigation canals in the study area (ElIsmailia Canal, El Salhiya Canal and El Kassara Canal). Moreover, these salts reflect the continental origin of the aquifer sediments (Fig 13- B).

Group (3): KCl, NaCl, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$ and Ca $(HCO_3)_2$ detected in five water samples (4, 5, 6, 11and 15) represented 18.52 % of total samples. (Two bicarbonate salts $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$, two sulfates salts Na_2SO_4 and $MgSO_4$) They are rich in sulfate salts. These salts are the result of leaching and dissolution of evaporites salts (mainly gypsiferrous shale). Also they are rich in bicarbonate salts that reflect the meteoric fresh water origin (Fig. 13-C). It is considered as a transitional stage between continental and marine water facies.

Group (4): KCl, NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$ detected in one water sample (26) represented 3.7 % of total samples. They are rich in sulfate salts These salts are the results of leaching and dissolution of sediments rich in evaporites salts (mainly gypsiferrous shale) in addition to some $MgCl_2$ marine salt (marine facies water).

Geochemical classification of groundwater:

Different techniques for graphical representations of hydrochemical data are used for the geochemical classification of groundwater, the most common are the trilinear diagram of Piper (1944) which is useful tool for comparison or classification of the water qualities of the studied aquifer at different localities. The classification of groundwater is based on the ion relationships.

Hydrochemical facies variation (Piper diagram):

The Trilinear diagram consists of two separate equilateral triangles and a diamond shape. This classification is based on the percentage of equivalents per million of the major anions (HCO_3^-, CO_3^{--}, SO_4^-, and Cl^-) and the major cations (Na^+, K^+, Mg^{++}, Ca^{++}) from a water analysis. The scatter and distribution of points indicates various degrees of mixing and dissolution processes through the interconnection between the recharged water and the groundwater from one side and between groundwater and rock from other side.

The groundwater chemical analysis data of the Quaternary aquifer on the piper diagram (Fig. 14) represents the hydrochemical facies and trends of salinity evolution.

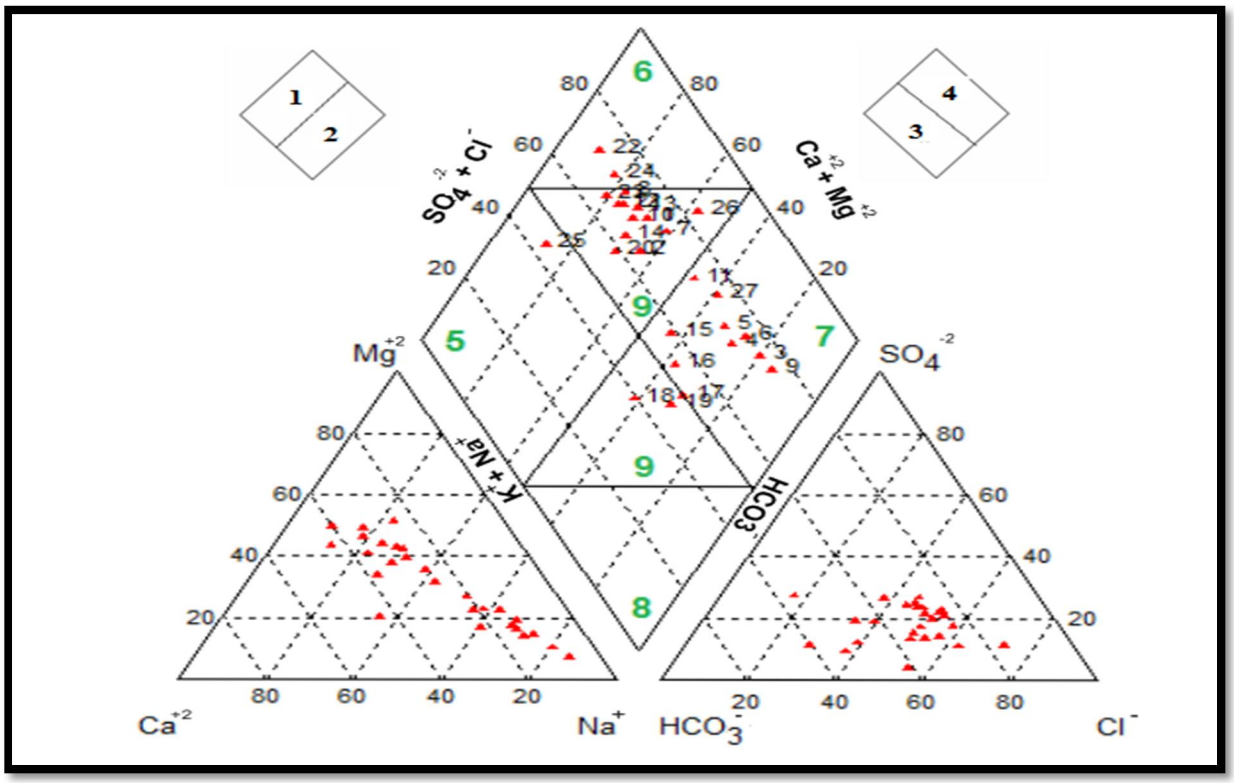

Fig. 14: Piper diagram of the groundwater samples of the study area.

Most of the studied GW samples (No.3, 4, 5, 6, 9,11, 15,16,17 and 27) are located within part (7) (primary salinity) of the diamond shaped field which are characterized by the dominance of SO_4^{-2} + Cl^- as anions and Na^++K^+ as cations. However, some samples are deviated towards the HCO_3^-+CO_3^- domination due to fresh water recharge (Fig. 14). Some samples are characterized by $NaHCO_3$ type and $CaHCO_3$ type. The general distribution of the samples reveals that, three processes affect the groundwater which is the mixing between NaCl and fresh Ca $(HCO_3)_2$ water type, seawater intrusion and freshening toward $NaHCO_3$ water type. Samples (No. 1, 2, 7, 8, 10, 12, 13, 14, 20, 21, 23, 25and 26) located within part (9) where SO_4^{-2}+Cl^- and Na^++K^+ are dominant reflecting advanced mineralization stage. Few samples are deviated toward the HCO_3^-+CO_3^- domination.

Evaluation of Groundwater Quality:

Evaluation of groundwater quality usually consider three main purposes including drinking, irrigation, and industrial uses. The criteria for industrial purposes are variable and each industry usually cares more about specific constituents than others. Because the major part of the water budget of the study area is used in irrigation, two different techniques Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) have been applied to evaluate the suitability of irrigation use.

Drinking purpose:

According to Hem classifications for the groundwater (1970) depending on its total dissolved salts (Table 5), the studied GW samples No.2, 7, 8, 9, 16, 17, 18, 19, 20 and 21 are fresh water.

Table 5: Water salinity classification (after Hem, 1970).

Quality	TDS (ppm)
Fresh	<1000
Moderately saline	3000- 10000
Very saline	10000-35000
Brine	>35000

Irrigation purpose:

Sodium Adsorption Ratio (SAR):

Sodium Adsorption Ratio (SAR) measures the relative concentration of sodium to calcium and Magnesium. High sodium ions in water affect the permeability of soil and causes infiltration problems. Sodium replaces calcium and magnesium adsorbed on the soil clays and causes dispersion of soil particles. Therefore, the soil when dry becomes hard and compact with low permeability. According to the U.S. Salinity Laboratory Staff diagram (1954), the analyzed water samples are related to the following categories (Fig. 15).

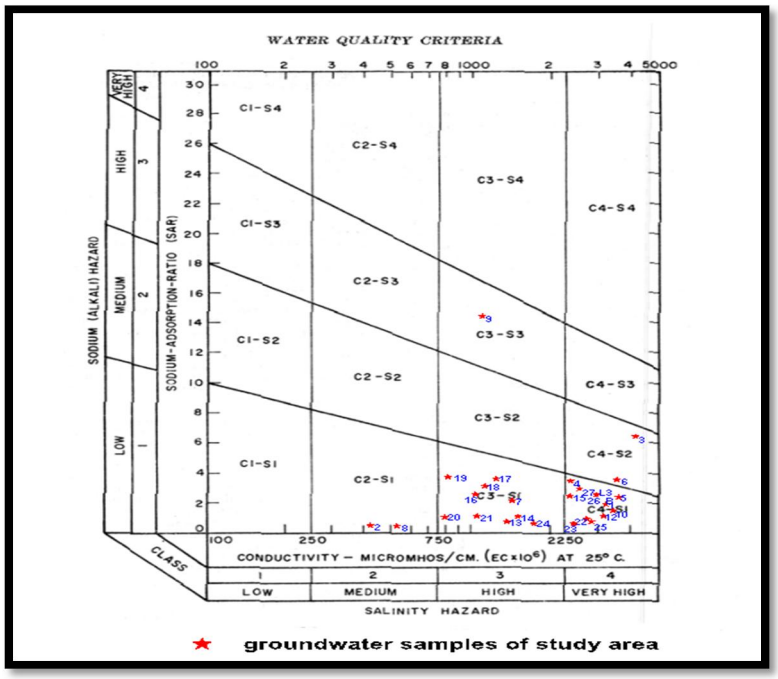

Fig. 15: Diagram of U.S. Lab. 1954 of suitability of groundwater evaluation for irrigation.

1) Medium salinity and low SAR (C2-S1), it is used for irrigation for all crops. (GW samples No.2 and 8)

2) High salinity and low SAR (C3-S1), it applies in soil of medium texture. (GW samples No. 7, 13, 14, 16, 17, 18, 19, 20, 21 and 24)

3) High salinity and high SAR (C3-S3), it is hazardous to most soils and requires good drainage and chemical amendments. (GW sample No.9)

4) Very high salinity and medium SAR (C4-S2), it is not suitable due to its harmful water management for salinity control and leaching is necessary to remove the excess salts and is hazardous to most soils requires good drainage and chemical amendments. (GW samples No.3 and 6)

5) Very high salinity and low SAR (C4-S1); recorded in (GW samples No. 1, 4, 5, 10, 12, 15, 22, 23, 25, 26 and 27)

6) One sample No. 11 is out of scale due to excessive salinity water, not advice to use for irrigation.

Sodium percentage (Na %):

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. Soil containing a large proportion of sodium with carbonates as the predominant anions is termed alkali soil, that with chlorides or sulfates as the predominant anions are saline soil. Ordinarily, both types of sodium-saturated soil will support little or no plant growth. From quality classification of water for irrigation (Table 6). According to Wilcox (1955) depending on the percentage of sodium; sample of well No. 25 is excellent for irrigation while samples of well No. 1, 8, 10, 12, 13, 14, 20, 21, 22, 23 and 24 are good for irrigation while samples of wells No. 2, 7, 11, 15, 18 and 26 are permissible for irrigation but wells No. 4, 5, 6, 16, 17, 19 and 27 are doubtful for irrigation and samples of well No. 3 and 9 are unsuitable for irrigation purposes.

Table 6: Results of the (RSC), (SAR) and (Na%) of analyzed GW samples in study area.

Well No.	RSC	SAR	Na%	Well No.	RSC	SAR	Na%	Well No.	RSC	SAR	Na%
1	-5.60	2.12	36.44	10	-11.69	2.61	30	19	1.49	4.50	67.67
2	-0.39	0.76	40	11	-8.01	7.06	54.83	20	-1.40	1.17	33.97
3	2.01	15.45	80.53	12	-8.12	1.65	27.51	21	-4.23	1.22	26.19
4	0.32	8.44	72.3	13	-5.42	1.70	31.80	22	-8.17	1.26	23.81
5	-0.81	7.47	68.10	14	-3.97	1.75	35.46	23	-4.48	0.94	23.06
6	-0.15	10.17	74.39	15	-0.31	3.92	56.56	24	-5.56	0.87	22.07
7	-3.79	2.29	40.75	16	0.40	3.92	62.74	25	-8.16	1	13.5
8	-2.04	0.75	25.33	17	1.29	4.75	69.25	26	-14.34	4.68	43.3
9	-3.62	19.39	85.5	18	1.88	3.99	58.49	27	-4.11	7.46	60.65

Residual Sodium Carbonate (RSC):

Bicarbonate and carbonate ions combined with calcium or magnesium cations will precipitate as calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) when the soil solution concentrates in drying conditions. The concentration of Ca^{+2} and Mg^{+2} decreases relative to Na^{+} and the SAR index will be bigger, causing an alkalizing effect and increasing the pH (Lenntch, 2007).

According to Eaton (1950) the RSC is classified into three classes: the first class contains RSC <1.25 meq/L and is considered as safe, the second class has RSC that ranges between 1.25 and 2.5 meq/L and is considered as marginal. The third class has RSC >2.5 meq/L and is considered as not suitable.

The calculated RSC values for the studied GW samples indicate that most of the groundwater has <1.25 meq/L RSC (Class 1), which is good quality and suitable for using in irrigation for all types of soils. Class 2 is represented in wells No.3, 17, 18 and 19. It can be used in state of good drainage (Table 6).

Table 7: Quality classification of water for irrigation (after Wilcox, 1955).

Water Class	Na %
Excellent	< 20
Good	20 – 40
Permissible	40 - 60
Doubtful	60 – 80
Unsuitable	> 80

Conclusions:

1- This study describes the sedimentary properties of subsurface sediments in El Salhyia area, the statistical grain size parameters reveal that the twelve subsurface sediment samples investigated sands show that the graphic mean value indicates the dominance of medium sand size, moderately sorted to poorly sorted, mostly positively skewed, accordingly most of the studied samples are leptokurtic to mesokurtic.

2-The textural characteristics strongly suggest that river and Aeolian conditions were most probably the dominating factors controlling the transportation and accumulation of the investigated sands.

3-The salinity content vary greatly from 252 mg/L (freshwater) to 3120 mg/L (brackish water) with an average of 1367 mg/L.

4-The aquifer is mainly recharged by the infiltration from irrigation network and excess of irrigation water through the upper clay layer.

5-The groundwater is alkaline with pH's ranging from 6.6 to 8.9 (neutral to alkaline) with an average of 7.5 (alkaline).

6- The ionic sequence of abundant ions indicates the presence of abundance $Na^{+}>Mg^{++}>Ca^{++}$&$Cl^{-}>HCO_3^{-}>SO_4^{--}$.

7- The hydrochemical composition reflects the Na-HCO_3 water type for the study area (Quaternary) aquifer indicating recent meteoric water. Another major water type Na-Cl is recorded in the high salinity areas of southern and central parts.

8- According to the U.S. Salinity Laboratory diagram, Most of studied GW samples are located in the high salinity and low alkalinity hazard (C_4S_1).

9-The groundwater has less than 1.25 meq/L RSC, which is good quality and suitable for using in irrigation for all types of soils.

10- The concentrations of the trace elements are lower than the standard limits such as Fe and Mn ions concentration are low which not have any considerable impact for this water to use for drinking and cooking purposes.

12-Wilcox classification (1955) shows nine GW samples No. 3, 4, 5, 6, 9, 16, 17, 19 and 27 falls in the field of doubtful to unsuitable for irrigation while eighteen samples No.1, 2,7, 8, 10, 11, 12, 13, 14,15,18, 20, 21, 22, 23, 24, 25 and 26 fall in the field of good to permissible for irrigation.

Recommendations:

1-According to the groundwater potentiality, the modern irrigation system must be taken into consideration for new reclaiming areas

2- Field water well design criteria should be taken into consideration to achieve good management including minimizing well losses, developing well productivity and efficiency, and to keep wells working for long possible time without failure.

3-The distance between each two successive production wells should not be less than 1km in order to minimize the cone of depression of groundwater level.

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