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Research Article

ASSESSMENT OF THE GROUNDWATER QUALITY OF THE QUATERNERY AQUIFER IN RECLAIMEDAREAS AT THE NORTHWESTERN EL-MINYA GOVERNORATE – EGYPT, USING THE WATER QUALITY INDEX

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ABSTRACT

This work is aimed at assessing the groundwater quality of the quaternary aquifer in reclaimed areas at northwestern El–Minya governorate – Egypt, using the water quality index for sustainable development. 32 water samples representing the surface water and groundwater samples were collected. The hydrochemical characteristics, geochemical classification, geochemical evolution and statistical analyses as well as groundwater quality were done. The obtained results indicate that; the total dissolved solids increases in the south and north directions and confirm that there are two sources of recharge for the Pleistocene aquifer groundwater, and the recharge from the irrigation canals is occurring in a certain distance range from 8 to 15km. The water quality index model indicates that the majority of the groundwater samples is unsuitable for human drinking; most of groundwater samples can be used for irrigation. Also, most of the lands are suitable for plants with high salt tolerance.

INTRODUCTION

The Egyptian government has devoted attention to develop the desert hinterland of Upper Egypt governorates in order to find job opportunities for the youth and to decrease their migration to Cairo. This is achieved by reclamation more desert lands which needs more water resources. As surface water is insufficient for development of desert lands, groundwater will be fully relied upon to reclaim desert lands in the study area. This requires assessing the quality of groundwater to determine its suitability for different purposes.The availability and quality of groundwater resources have been affected by activities and projects associated with rapid development. Groundwater preservation and protection measures have been generally overlooked by the majority of the practices (Shaibani, 2008). The concerned area is one of the most promising areas for expanding agricultural land and increase employment opportunities for young people, where it is located between latitudes 28º 00` and 28º 18` N and longitudes30º 30` and 30º 48` E. The study area covers about 320km^2 (Fig. 1).Some studies have been focused on the quaternary aquifer in the study area, among them; (Koranyet *al*,2006), (El Kashouty and El Sayed, 2010), (El Kashoutyet *al*, 2012), (Ismail *et al*, 2015) and (Abdel Moneim*et al*, 2016).

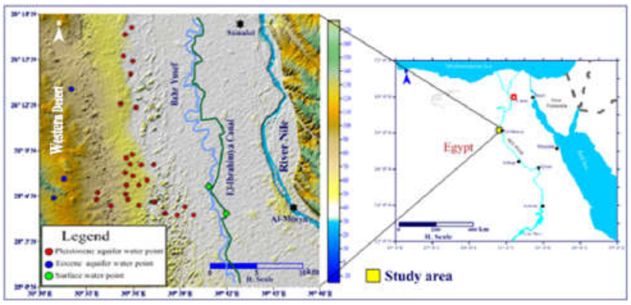

Figure 1 Location map and digital elevation model of the study area

The area is arid to semiarid, hot climate, dry, rainless in summer and mild with rare precipitation in winter. The rainfall average value forthe last fifteen years ranged from 23.05 to 33.15mm/y, while the evapotranspiration in El Minya is 4897.81mm/y (Korany, 1980 and Korany*et al*, 2006). The minimum temperature varies from 4.5 (January) to 20.5°C (August), while the maximum temperature varies from 20.7 (January) to 37.7°C (August). The mean monthly relative humidity during daytime ranges from 36% in May to 62%in December (Korany, 1984).Water quality index (WQI) is a valuable and unique rating to depict the overall water quality

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status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues. However, WQI depicts the composite influence of different water quality parameters and communicates water quality information to the public and legislative decision makers.This study is focused on the chemistry of the water resources in the study area and origin of the groundwater as well as the evaluation of the groundwater quality using a water quality index for different purposes.

Aquifer system

The evaluation of groundwater resources for development requires an understanding of the geomorphology, geology, hydrogeology and hydrology properties of the aquifer system. Geomorphologically, the study area is moderately elevated plateau with respect to River Nile as described in Fig.1, and composed of mainly limestone covered with alluvial deposits of sands and gravels. The Eocene rocks constitute the main outcrops, capped by poorly consolidated sand, gravel and clay (quaternary aquifer). Geologically, the stratigraphic sequence is built up from base to top as follows; Per-Tertiary Nubian sandstone; Middle Eocene limestone intercalated with shale; Pliocene undifferentiated sands, clays, and conglomerates; Plio-Pleistocene sand and gravel with clay and shale lenses; Pleistocene sand and gravel with clay lenses and Holocene silt and clay (Tamer *et al*, 1974), Fig.2.Hydrogeologically, the groundwater exists in the Pleistocene aquifer, which represents the main aquifer in the study area. The concerned aquifer is represented by Prenile sediments (Qena formation) and it is composed of massive cross-bedded sand and gravel of different sizes, with some clay intercalation. Generally, the thickness of this aquifer decreases gradually towards the Eocene Plateau, where it ranged from 25 to 300m, from the desert fringes to the central Nile Valley, respectively (Sadek, 2001 and Sanad, 2010). This aquifer is overlain by Holocene silt and clay layer (semi-permeable layer) in some localities nearby the River Nile, while itrests directly on the Pliocene clay and/or the fissured Eocene Limestone, which form the base of the Pleistocene aquifer. So, the groundwater of the Pleistocene aquifer is present under semi-confined conditions in some localities, while being under unconfined conditions in the major parts of the study area, i.e., the semi-confined bed (1-15m thickness) is missed outside the floodplain and the aquifer becomes unconfined. The investigated aquifer is hydraulically connected with the underlined Eocene aquifer through many faults mainly in a NW-SE direction (Fig.3).The groundwater flow generally from south to north and diverts towards to eastern part, where large volume of groundwater is drained from the River Nile (Tantawi, 1992and Sanad, 2010). The aquifer is recharged by Nile water, irrigation system, drains, agricultural, wastewater, vertical upward leakage from the deeper saline aquifers (Korany, 1984). In other words, the recharge of the Pleistocene aquifer in the study area takes place mainly from infiltration of the surface water (Nile water) after irrigation of the agricultural lands, local inflow from the irrigation canals and upward leakage from the deep aquifers (Eocene and Nubian sandstone) through the fault plains exist in the region (Tantawai, 1992).

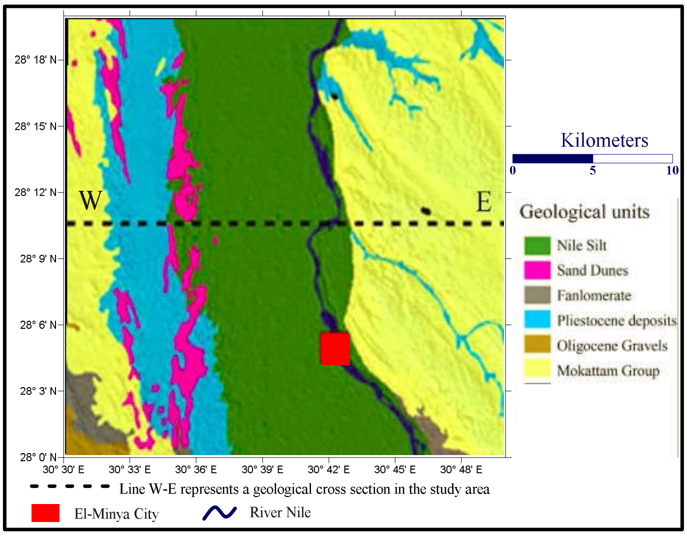

Figure 2 Geological map of the study area (After Conoco Coral of Egypt, 1987)

The discharge from this aquifer takes place through direct and indirect routes, the direct routes are; the lateral outflows (seepage) to the River Nile, outflow through the drainage system, and the discharge through the drilled wells for drinking and irrigation purposes. While the indirect routes are; are represented during the evaporationand evapotranspiration processes (IWACO and RIGW, 1986 and Ismail *et al*, 2015).The Pleistocene aquifer has effective porosity that varies between 30% and 35% (Hefny, 1982). The transmissivity of this aquifer ranges between 3500 and 2100m^2/day (IWACO and RIGW, 1986) indicatinghigh potentiality. The average storage coefficient amount is about 0.15 (Hefny, 1982).

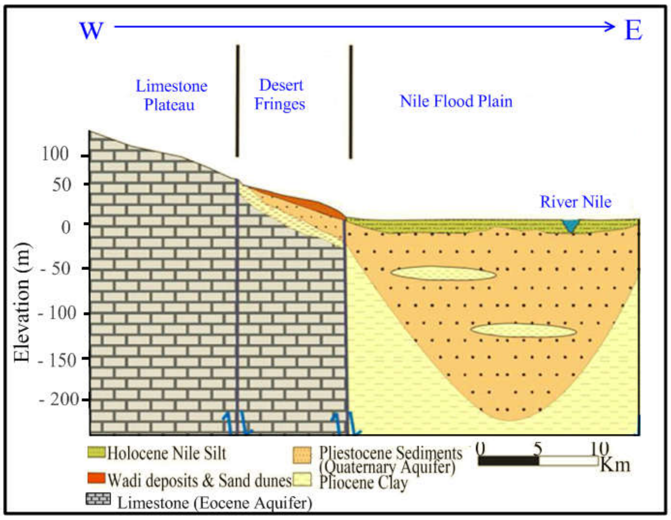

Figure 3 General hydrogeological cross section in El-Minya area (RIGW, 1992)

MATERIALS AND METHODS

The current study started by surveying 32 water points (two surface water samples and 30 groundwater samples) from the area under investigation. The locations (longitudes and latitudes) of the collected water samples were recorded using global positioning system (GPS) model etrex 10 (Germin) and therefore were plotted using a software program to generate the map of the sampling locations (Fig.4). Some parameters as depth to water, temperature T°C, EC and pH were conducted in situ for collecting water samples because some of these parameters (EC and pH) are likely to change on transit (Hem, 1985). The samples were collected in clean 500ml polyethylene bottles with all necessary precautions and analyze in the laboratory of Desert Research Centerfor the measurements of major cations and anions(Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-} and Cl^{-}) according to Rainwater and Thatcher (1960).The obtained chemical data were expressed in milligram per liter (mg/L) or part per million (ppm).

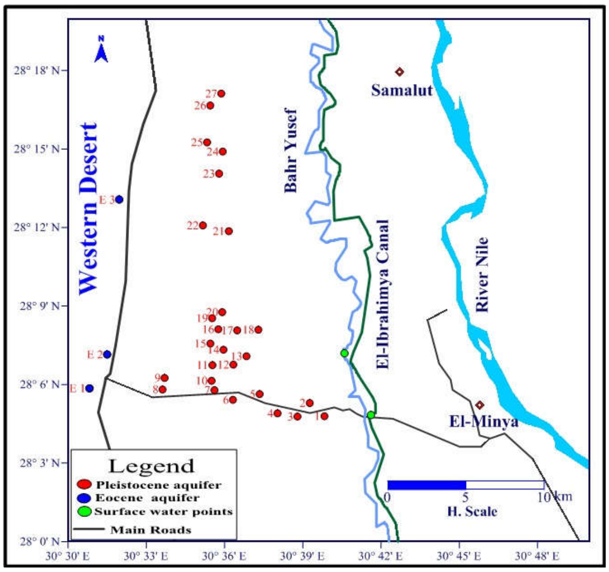

Figure 4 A map showing the surface water and, Pleistocene and Eocene aquifers groundwater samples sites

RESULTS AND DISCUSSION

Groundwater chemistry depends on geology, the degree of chemical weathering of various rocks, quality of recharge water. The study of groundwater chemistry mainly based on the results of the chemical analyses that was carried out for the collected water samples (32 water samples) in the study area (Table 1), to determine the hydrochemical characteristics of such groundwater and evaluate it for different purposes. This study was done under the following topics;

- The hydrochemical characteristics of groundwater (water salinity and hypothetical salts combinations).
- Geochemical classification of groundwater using the trilinear plotting system (Piper's diagram).
- Geochemical evolution of groundwater using hydrochemical profiles.
- The groundwater evaluation for different purposes (using water quality index model)

Hydrochemical characteristics of groundwater

To study hydrochemical characteristics of groundwater in the study area, the focus is on the water salinity (total dissolved solids) and the hypothetical salts combinations that characterize the surface water and groundwater in the study area.

Water salinity (total dissolved solids)

The total dissolved solids (TDS) are a measure of the total mass of ions dissolved in water. Different methods are used for water classification corresponding to its salinity value. According to Chebotarev (1955), the natural water is classified into three main categories of total salinity, fresh water (TDS up to 1500mg/L), brackish water (1500 – 5000mg/L) and saline water (TDS more than 5000mg/L).According to this classification, the surface water samples in the study area are related to the fresh water type. The total dissolved solids (TDS) of the groundwater samples in the study area range from 249mg/L to 6051mg/L, with a mean value of 2330mg/L (Table 1). Such groundwater salinity changes widely from fresh, brackish to saline water types,where, 47% of the groundwater samples are related to the fresh water type, 39% of the groundwater samples are related to brackish water type and the rest of the samples (14%) are related to the saline water type (Table 1). From the iso-salinity contour map of the quaternary aquifer in the study area (Fig.5), it is concluded that the salinity increase from 249mg/L (sample No.3) at the southeast of the study area to 6051mg/L (sample No.23) at the northeast of the study area. The low salinity is attributed to the contribution from El-Ibrahimiya and Bahr Yusef canals to the groundwater at different parts in the study area, i.e., there is a recharge from these canals to the groundwater in the study area. While, in the other parts of the study area, the high salinity in the groundwater is due to the leaching and dissolution processes of the Pliocene marine deposits intercalated with the Pleistocene aquifer matrix during the groundwater flow from south to north (general groundwater flow direction), and carbonate materials that transported from the limestone plateau by weathering and return flow after irrigation as well as over-pumping. In addition to, the hydraulic connection with the underlying saline deposits, this is confirmed by Korany (1984) that said that the Pleistocene aquifer is recharged by irrigation canals, vertical upward leakage from the deeper saline aquifers.In other words, the thickness of the quaternary aquifer, increased due to River Nile and decreased due to desert fringes (Sadek, 2001). So the Pleistocene aquifer receives a large quantity of fresh recharge water from El-Ibrahimya and Bahr Yusef canals due to the eastern part of the study area that dilute the groundwater salinity. On the other hand, the concerned aquifer receives a low quantity of fresh recharge water due to the western part, meanwhile the groundwater salinity increases.

Hypothetical salts combinations

The combination between major anions and cations reveals formation of one, five and three main groups of hypothetical salts combinations for the surface water and groundwater of the Pleistocene and Eocene aquifers, respectively (Table 2). Regarding the hypothetical salt combination in El-Ibrahimya and Bahr Yusef canals, water samples, one main assemblage are detected (I), the presence of Na_2SO_4 salt in this assemblage is a true indication of dissolution of terrestrial salts from the continental deposits. The presence of $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ salts indicates meteoric water condition. So, such water acquires its chemical composition from leaching and the dissolution of terrestrial salts processes.The majority of the groundwater samples (60%) of the Pleistocene aquifer in the study area is characterized by the assemblage of hypothetical salt combination (III) regardless of their total salinities, where three sulphate salts (Na_2SO_4, $MgSO_4$ and $CaSO_4$) which reflects the effect of leaching and dissolution of

Table 1 The concentrations of the major ions in the study area as ppm

No.	EC	pH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	SAR	RSC
Surface water													
El-Ibrahimya canal	306	6.7	148.27	19	11	20	5	0	130	13.49	14.78	1.28	0.278
Bahr Yusef	307	7.1	166	22	12	21	5	0	128	31	12	0.98	0.008
Rain water	340	8.5	178.19	31.57	5.19	25	7.59	8.52	121.27	11.37	28.31	1.1	-0.14
Seawater	79100	8.4	41713	438.6	1517	13400	431	0	207	3492.7	22330	0.215	-143.3
Pleistocene aquifer													
1	911	7.2	576.604	61.2	78.16	56	6	29.99	504.19	29.129	64.03	1.58	-0.219
2	1028	7.3	548.017	54	41.55	100	8	49.98	391.09	34.912	64.03	3.519	1.964
3	472	7.3	249.404	28.05	22.85	23	13	0	163.88	55.934	24.63	1.105	-0.593
4	755	7.3	384.955	47.09	32.46	47.58	25	0	376.85	5	39.4	1.848	1.157
5	1507	7.4	772.339	72	43.74	140	33	0	345.69	74.504	236.25	4.542	-1.524
6	7900	7.7	5445.06	149.6	53.2	1650	38	0	76.25	2210	1306.13	41.718	-10.59
7	9300	7.9	5826.81	47.8	209	1689	23	0	103.7	2098	1708.16	33.214	-17.87
8	2034	7.4	1124.65	90	57.74	260	12	0	315.04	5.64	541.75	7.442	-4.076
9	1979	7.3	949.855	83.6	53.24	208.23	10	0	279.47	1.95	453.1	6.196	-3.969
10	7050	7.8	4587.74	211.444	114.196	1211.45	21.2	0	183	1726.58	1211.34	23.6	-16.94
11	4850	7.7	3188.26	215.156	82.388	725.012	24.7	0	183	1553.94	495.608	15.07	-14.51
12	3220	7.4	1890.7	92.452	30.882	542.256	16.4	0	183	621.836	495.348	17.64	-4.154
13	5890	7.6	3657.98	256.564	114.322	806.764	28.6	0	213.5	1738.02	606.926	14.895	-18.71
14	4050	7.5	2669.64	130.892	61.074	711.904	22.6	0	176.9	1130.34	524.338	18.221	-8.655
15	2407	7.9	1484.5	100.556	32.032	366.642	18.3	0	185.2	658.53	215.873	11.531	-4.617
16	1298	7.8	830.261	97.31	36.146	122.704	19.5	0	189.1	422.297	37.782	3.815	-4.73
17	2252	7.3	1406.91	93.716	20.988	343.896	13.1	0	221.8	768.663	55.631	11.824	-2.767
18	3370	7.8	2182.65	146.636	81.254	486.376	18.8	0	237.9	1124.66	205.94	11.309	-10.1
19	836	7.6	432.596	76.556	12.816	61.14	6.75	0	214	137.092	31.244	2.409	-1.367
20	955	8.1	560.182	104.862	19.27	63.558	9.34	0	195.2	224.372	41.18	2.118	-3.618
21	2270	7.2	1157.39	128.067	48.097	203.787	12.2	0	244	465.667	177.595	5.512	-6.347
22	5990	7.6	3185.56	353.306	169.886	511.29	15.7	0	231.8	1066.74	952.766	7.913	-27.8
23	10490	7.6	6051.83	380.861	155.934	1329.14	27.5	0	169.1	3803.73	270.122	20.5	-29.05
24	4730	7.6	3032.2	280.064	156.522	506.964	23.3	0	152.5	1247.91	741.152	8.512	-24.35
25	3090	7.7	1981.56	187.164	102.352	363.872	17.6	0	183	671.194	547.87	7.512	-14.76
26	3920	7.7	2232.02	175.906	70.676	524.032	20.8	0	170.8	449.092	906.12	11.94	-11.79
27	4310	7.6	2492.86	332.09	136.774	376.802	23.9	0	115.9	279.574	1285.73	6.22	-25.92
Eocene aquifer (guidance samples)													
E1	1007	7.5	550.505	57.6	37.18	109.89	7	0	305.37	9	177.15	3.93	-0.927
E2	1035	7.3	533.46	36	24.24	145.8	6	0	324.9	16.89	142.08	6.516	1.535
E3	1587	7.4	873.39	64.8	26.24	233.1	9	0	304.9	43.05	344.75	8.734	-0.394

terrestrial salt (continental facies groundwater) with some contribution of cation exchange process as well as downward infiltration of the excess irrigation water of the cultivated soils and seepage of irrigation canals, where this aquifer is unconfined, that leads to the increase of water salinity. Also, 20% of the Pleistocene aquifer groundwater samples in the study area are characterized by the assemblages of hypothetical salts combinations (I and II) regardless of their total salinities, where three and two bicarbonate salts, respectively, and one and two sulfate salts, respectively.

The salts $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ characterizing for the irrigation canals, while the salts Na_2SO_4 and $MgSO_4$ reflects some contribution of the cation exchange process. On the other hand, 8% of the groundwater samples of the Pleistocene aquifer are characterized by the assemblage of hypothetical salt combination (IV), regardless of their total salinities. The assemblage (IV) includes two chloride and two bicarbonate salts, reflecting the effect of both terrestrial and marine salts (mixed facies groundwater, which indicates the effect of the upward leakage from the underlineaquifer). The rest of the groundwater samples (12%) of the Pleistocene aquifer are characterized by the assemblage of hypothetical salt combination (V), regardless of their total salinities.

The assemblage (V) contains (two chloride salts, two sulfate salts and one bicarbonate salt), reflecting the effect of marine salt combination (marine facies groundwater) with some contribution of the cation exchange process.

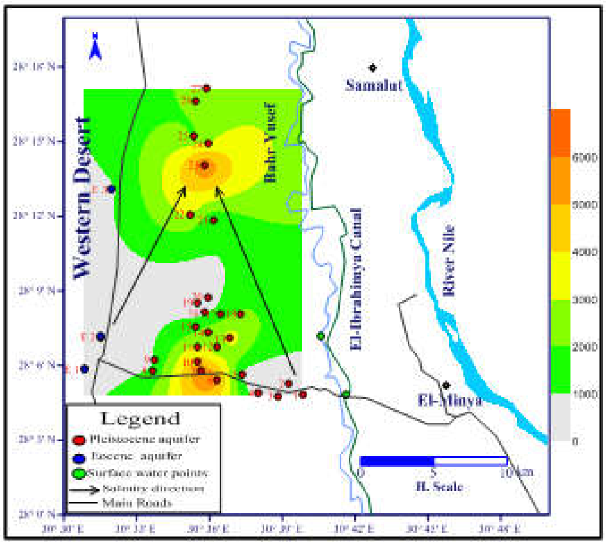

Fig 5 The iso-salinity contour map of the Pleistocene aquifer groundwater

Assemblages (I and II) represent an earlier and less advanced stages of chemical development than that of assemblage (III). Also, assemblages I and II (three and two bicarbonate salts, respectively) reflect the dilution effect of the surface system (El-Ibrahimya and Bahr Yousef canals) on the groundwater, while an assemblage (III)) characterizes groundwater affected byleaching and the dissolution of terrestrial salts. Aggradation (to progress by steps) in chemical development is noticed in groundwater dominated by salt assemblages I and II (earlier and less stages of chemical development), where three and two bicarbonate salts exist, to that dominated by assemblages IV and V (more advanced stage of chemical development), where two and three chloride salts are found. This assemblage IV ($MgCl_2$ and $MgCa(HCO_3)_2$ salts) is considered as a transitional stage between continental and marine facies of groundwater. This indicates meteoric water origin influenced by leaching the terrestrial salt or marine salts in this aquifer.

The presence of the assemblage of hypothetical salt (I) in the surface water and the Pleistocene aquifer groundwater confirms that this aquifer is recharged mainly from surface water (El-Ibrahimya and Bahr Yusef canals).Also, the presence of the assemblages of hypothetical saltcombination (I, II and IV) in both the Pleistocene aquifer groundwater and the Eocene aquifer groundwater (guidance sample) confirms that there is a hydraulic connection between the two aquifers.

Table 2 The hypothetical salts combinations for surface water (canals), and the Pleistocene and Eocene (guidance samples) aquifers in the study area

Assemblages	Hypothetical salts combinations
Surface water (El Ibrahimiya and Bahr Yusef canals)	
I	$NaCl$, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$, $Ca(HCO_3)_2$
Groundwater	
Pleistocene aquifer groundwater	
I	$NaCl$, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$, $Ca(HCO_3)_2$
II	$NaCl$, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$, $Ca(HCO_3)_2$
III	$NaCl$, Na_2SO_4, $MgSO_4$, $CaSO_4$, $Ca(HCO_3)_2$
IV	$NaCl$, $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$, $Ca(HCO_3)_2$
V	$NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$, $Ca(HCO_3)_2$
Eocene limestone aquifer groundwater (guidance samples)	
I	$NaCl$, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$, $Ca(HCO_3)_2$
III	NaCl, Na2SO4, MgSO4, CaSO4, Ca(HCO3)2
IV	$NaCl$, $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$, $Ca(HCO_3)_2$

Geochemical classification of groundwater using trilinear plotting system (Piper's trilinear diagram, 1944)

Nearly all groundwater originates as rainwater or snowmelt that infiltrates through soil into flow system in the underlying geologic materials. As groundwater moves along flow lines from recharge to discharge areas, its chemistry is altered by the effects of a variety of geochemical processes.The groundwater in the study area can be genetically classified to the exogenetic water, which is formed either from infiltration of surface water in already existing rock formations (meteoric water) or formed during the sedimentation times (marine water).By plotting the chemical data of the surface water (El-Ibrahimiya and Bahr Yusef canals) and groundwater samples (Pleistocene aquifer groundwater and the guidance samples of the Eocene aquifer) in the study area on the piper's trilinear diagram (Fig.6), it revealed that; 53% of the Pleistocene aquifer groundwater samples are located in the sub-area (7), which is dominated by alkalies and strong acids (primary salinity). Some groundwater samples of the Pleistocene aquifer (30%) are located in the sub-area (9), where no one cation – anion pair exceeds 50%. Some groundwater samples of the Pleistocene aquifer (14%) exist in the sub – area (5), where carbonate hardness (secondary alkalinity) is dominated by alkaline earths and weak acid {Ca, $Mg(HCO_3)_2$}. Finally, 3% of the groundwater samples of the Pleistocene aquifer in the study area are located in the sub-area (6), where non-carbonate hardness {secondary salinity, $CaMg(SO_4+Cl)$} exceeds 50%.Some groundwater samples of the Pleistocene aquifer (20%) that occupy the sub-areas (7 and 9) have marine facies, this is most probably due to the upward leakage from the deep horizon (Eocene limestone aquifer) as well as the effect of marine deposits that were transported by weathering from the Eocene limestone plateau.Also, most of the Pleistocene aquifer groundwater samples (62%) that are located in the sub-areas (7 and 9) have continental facies, this is due to the leaching and dissolution of terrestrial salts during the movement of groundwater from south to north. All irrigation canals, water samples and 14% of the Pleistocene aquifer groundwater samples are dominated by alkaline earth and weak acid {carbonate hardness $CaMg(HCO_3)_2$, secondary alkalinity} sub-area (5), this reflects that the effect of recharging processes of the concerned aquifer by the meteoric water (irrigation canal water) more than that by Eocene aquifer.

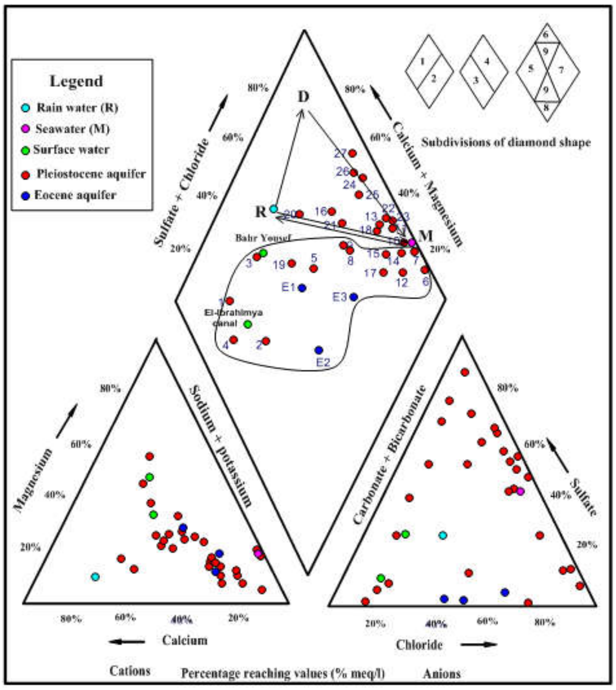

Figure 6 Trilinear diagram of the Pleistocene aquifer groundwater samples

From the trilinear diagram, it is clear that the guidance samples of the Eocene aquifer are located at the sub-areas (5, 7 and 9), which means that there are chemical similarity, to a great extent, between the groundwater of both the two aquifers. So, there is a hydraulic connection between the Pleistocene and Eocene aquifer in the study area.More than half of the Pleistocene aquifer groundwater samples (52%) and the guidance samples of the Eocene aquifer as well as the irrigation canals, water samples lie down the reaction pathways for evolution of Back and Hanshow's diagram, i.e., display less mineralization, indicating an uncontaminated recharge source (continental facies water). In other words, the groundwater samples of the Pleistocene aquifer and the guidance samples of the Eocene aquifer as well as the water of the irrigation canals are less mineralized (pure meteoric water, less advanced mineralized water) and do not undergo any chemical evolution process, where the metasomatic sequence do not reach final sequence of more advanced stage ($Cl^->SO_4^{2-}>HCO_3^-$). Also, this indicates that, the Pleistocene aquifer is recharged from meteoric water (water of irrigation canals).Some groundwater samples of the Pleistocene aquifer undergo down-gradient movement (R→D→M, encroachment), Back and Hanshow's (1979). In addition to pathway reaction M (marine facies groundwater)→R (recharge area), flushing took place in few groundwater samples of the Pleistocene aquifer display two reaction pathways for evolution to continental facies water as a result of the leaching and dissolution of terrestrial salts beside flushing by fresh water.

Geochemical evolution of groundwater using hydrochemical profiles

The geochemical properties of groundwater, generally, depend on the origin of water recharge (meteoric water or paleo-water) and on the subsurface geochemical processes within the aquifer system (dissolution, mixing, ion exchange, oxidation-reduction, precipitation, hydrolysis …. etc).These factors control the water quality during its movement from recharge to discharge areas.In this item of this study, an attempt is made to answer the question of how groundwater in the area of study acquired its present chemical composition through its down-gradient movement, and what changes may occur in it, this can be done by studying the spatial variation in groundwater chemistry.In the directions from south to north and from west to east, there are considerable variations in the dissolved chemical species from locality to another. This means that each locality has its own peculiarities in building up its water, chemical composition due to variations in water occurrence and rock properties as follows;

Along the South-North direction

As previously mentioned, regionally, groundwater in the study area moves through the general direction of flow, from south to north direction and other recharge sources are seepage from surface water (El-Ibrahimya and Bahr Yusuf canals) as well as the recharging from Eocene aquifer. The main changes in groundwater chemistry during its movement from south to north along the Pleistocene aquifer in the study area are well illustrated by the following hydrochemical profile (Fig.7).This profile passes through 6 wells along the concerned aquifer in the study area. The profile shows the rapid increase of water salinity from south (1485mg\L at well No.15) to north direction along the Pleistocene aquifer and reach its maximum salinity value (3186mg\L at well No.22), then decreases rapidly northward to reach 2493mg\L at well No.27, where a recharge (seepage from El-Ibrahimya and Bahr Yusef canals) may take place leading to an actual dilution of water salinity and ion concentrations.The high water salinity of the Pleistocene aquifer groundwater in the study area is due to leaching and dissolution of the terrestrial salts of the aquifer matrices and return flow after irrigation as well as the over-pumping.There is superiority for Na^+ over Cl^- in most groundwater samples (75%) of the Pleistocene aquifer along this profile in the study area; this is due to leaching and dissolution of the terrestrial salts. While, the superiority of Cl^- over Na^+ in rest of Pleistocene aquifer groundwater samples (25%) is due to the marine salt contamination. This is manifested by the ratio of rSO_4^{2-}/rCl^- which is more than unity for most of the Pleistocene aquifer groundwater samples (75%) along this profile which indicates the leaching and dissolution of the terrestrial salts of Pleistocene aquifer matrices as well as the marine salt contamination for the rest of the groundwater samples due to the upward leakage from the Eocene limestone aquifer (marine deposits).

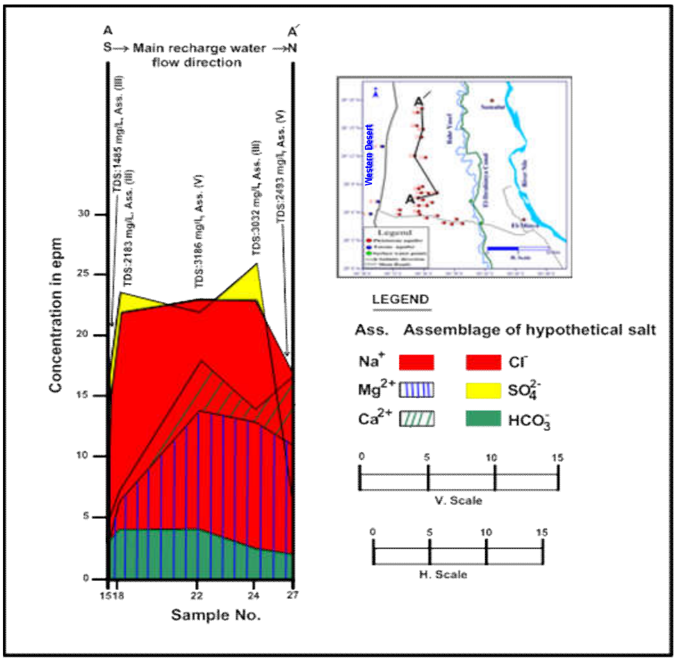

Figure 7 Hydrochemical profile of the Pleistocene aquifer groundwaterSamples in South – North direction in the study area

The presence of $MgCl_2$ salt in some groundwater samples of Pleistocene aquifer along this profile in the study area, reflects the effect of leaching and dissolution of marine sediments which confirms that there are hydraulic connection between the two aquifers (Pleistocene and Eocene limestone) in the study area.The presence of $CaSO_4$ and $MgSO_4$ salts in some groundwater samples along this profile in the study area is due to the effect of gypsum deposits in the aquifer matrices, which also confirms the upward leakage from the underline Eocene aquifer.The presence of Na_2SO_4 in some groundwater samples along this profile reflects the impact of leaching and the dissolution of terrestrial salt.The heterogeneity of the hypothetical salts combinations (III and V) along this profile of the Pleistocene aquifer in the study area indicates that the factors affecting groundwater quality are different, this heterogeneity is due to the feeding by fresh water from El-Ibrahimya and Bahr Yusef canals and depositional environment (continental and marine conditions). However, the Pleistocene and Eocene aquifers are hydraulically connected and this is manifested by the previous hydrogeological evidences.

Along the East-West direction

As previously mentioned, there is no water flow direction from east to west direction or from west to east direction, but the groundwater flow direction is from south to north direction.So, to evaluate the change in the chemical characteristics of the Pleistocene aquifer groundwater with distance along the east-west direction, a hydrochemical profile has been constructed (Fig.8). This figure is directed in the east-west direction and it passes through the surface water sample (El-Ibrahimiya canal) and four groundwater samples representing the Pleistocene and Eocene aquifers. Along this profile, it is shown that there is a gradual increase of water salinity from east to west until reach their maximum value (1125mg\L) at sample No.(8) due to over-pumping and then decrease other once to reach the value 551mg\L at sample No.(E1).This means that there is reached from El-Ibrahimya canal to the groundwater of concerned aquifer in the study area by seepage to a certain distance range from 8 Km to 15 Km.This can be confirmed by decreasing the bicarbonate content from 75% of TDS at El-Ibrahimiya canal water sample at east direction to 25% of TDS at sample no. (8) at west direction.The presence of $NaHCO_3$ and $Mg(HCO_3)_2$ salts in the Pleistocene aquifer groundwater samples along this profile in the study area is due to the direct effect of recharging by El-Ibrahimiya canal.The presence of a hypothetical salt combination (II) in 50% of the samples along this profile, where two bicarbonate salts are existed, this confirms the recharge of groundwater by the canal water where three bicarbonate salts. Also, the presence of the hypothetical salt combination (IV) at both sample No.(8) and the guide sample of the Eocene aquifer where $MgCl_2$ salt is existed, this indicates that there is an upward leakage of the Eocene aquifer to the groundwater of the concerned aquifer in the study area.Concerning the metasomatic changes in water chemistry in the lateral direction, it is obvious that, all of the Pleistocene aquifer along this profile has a more advanced stage of a metasomatic sequence ($Cl^- > SO_4^{2-} > HCO_3^-$). Thus, there is no prominent change in water chemistry from east to west direction because of there is no water flow from east to west direction, but occurred dilution from El-Ibrahimya canal.The heterogeneity of the hypothetical salt combination (IV and II) along this profile in the Pleistocene aquifer indicates that the factors affecting the groundwater quality are different; this heterogeneity is due to the feeding by fresh water from El-Ibrahimya canal and upward leakage from the underlying Eocene aquifer, which is manifested by the previous hydrogealogical evidences.Finally, the hydrochemical profiles confirm that there are hydraulic connection between the Pleistocene and Eocene aquifers, in addition to, the recharge of the Pleistocene aquifer from the irrigation canals by seepage is occurring at a certain distance range from 8 to 15km.

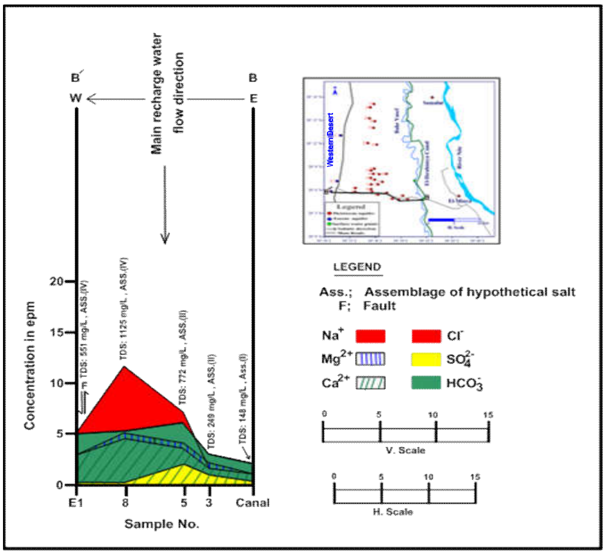

Figure 8 Hydrochemical profile of the Pleistocene aquifer

Statistical analysis

The multivariate statistical techniques are used in making the relationship between variables to interpret the water quality in the study area and to give meaningful results. In the study, statistical software(SPSS 16.0 for windows)was used to carry out the cluster analysis (CA).

Cluster analysis (Q-mode cluster analysis)

The cluster analysis (CA) technique is used to classify the examined parameters of groundwater into categories or clusters based on their similarities or dissimilarities in the variation of the datasets using hierarchical cluster analysis (HCA). The degree of association between two objects is maximal if they belong to the same group and minimal otherwise. In hierarchical cluster analysis, the distance between samples is used as a measure of similarity (Vega *et al*., 1998). One of the main purposes of cluster analysis in the study area is to identify samples affected by agricultural activities and seepage from the surface water system (El-Ibrahimyia and Bahr Yousef canals), as well as the leakage from the underline aquifer. The results of the cluster analysis (Dendogram) for the samples are presented in Fig.9. The CA grouped 32 sampling locations into 3 clusters named as 1, 2 and 3. Clusters of the samples are listed in table (3), which indicates that each cluster has a water quality of its own, which is different from the other clusters, with all the points falling along a straight line joining the highly saline water at one end and the clusters of fresh water points at the other end.Cluster No.1 is represented by 13 groundwater samples follow the Pleistocene aquifer and three guidance samples follow the Eocene aquifer as well as two surface water (El-Ibrahimyia and Bahr Yousef canals), table (3). The groundwater samples are distributed all over the study area, they are characterized by low TDS concentrations is ranging from 249.4 to 1484mg/L, with the following anion dominance, $Cl^- > SO_4^{2-} > HCO_3^-$ and cation dominance $Na^+ > Mg^{2+} > Ca^{2+}$. The groundwater samples in cluster No.1 are affected by the seepage from El-Ibrahimyia and Bahr Yusef canals, and upward leakage from the underline Eocene aquifer.Cluster No.2 is subdivided into two sub-clusters, each of them is represented by 5 groundwater samples (table 3). The groundwater samples are located at north and south the studied area. They are distinguished by higher salinity than the previous cluster, where the salinity ranges from 1890.7 to 3657.98mg/L, with anion dominance $Cl^- > SO_4^{2-} > HCO_3^-$ and cation dominance $Na^+ > Mg^{2+} > Ca^{2+}$. This is attributed to leaching and dissolution process as well as the return flow after irrigation. Cluster No.3 is subdivided into two sub-clusters; that contain 3 and 1 groundwater samples, respectively, table (3). The majority of these samples is located at the south of the study area. They are characterized by a higher salinity than the previous two clusters, where the salinity varies between 4587.7 and 6051.83mg/L. This is confirmed by the following anion dominance $Cl^- > SO_4^{2-} > HCO_3^-$ and cation dominance $Na^+ > Mg^{2+} > Ca^{2+}$. This is due to the over-pumping and return flow after irrigation.In general, the hydrochemical profiles and statistical analyses confirm that there is a hydraulic connection between the Pleistocene and Eocene aquifers. Also, the recharge of the Pleistocene aquifer from the irrigation canals by seepage is occurring at a certain distance range from 8 to 15km.

Table 3 Cluster groups and their members of the surface water and groundwater samples in the study area

Cluster group	Sub-clusters / Members (Sample No.)
1	El Ibrahimya canal, Bahr Yusef canal, E1, E2, E3, 1, 2, 3, 4, 5, 8, 9, 15, 16, 17, 19, 20 and 21
2	12, 18, 25, 26 and 27
	11, 13, 14, 22, 24
3	6, 7and 10
	23

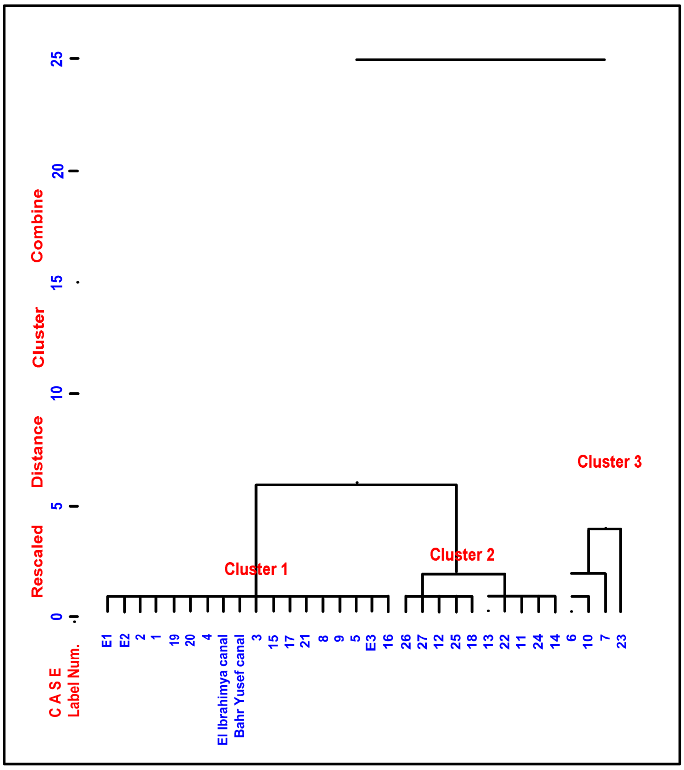

Figure 9 Dendogram of cluster analysis

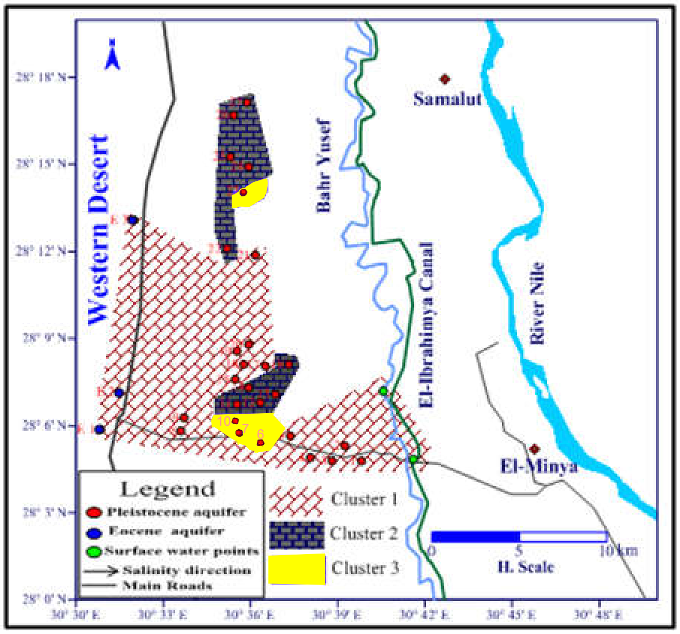

Figure 10 The cluster distribution map

Evaluation of groundwater for different purposes

In the study area (new reclaimed lands), there is no surface water (irrigation canals) as they are located at a distance ranges from 8 to 15km from the groundwater points, i.e., the surface water may reach to the scarcity state. So, the groundwater is considered as the only source of human drinking and irrigation purposes in the study area.Evaluation of water resource for different purposes depends on the water quality; and this was done in this study using the water quality index model.Noteworthy to mention that, chemical characteristics are one of the most important sectors of unstandard water quality and comparing their lives with standards to support the different uses including human drinking and irrigation uses.

a. Evaluation of groundwater for human drinkingpurposes using drinking water quality index model

As a result of the scarcity of safe drinking water resources as municipal water in the study area.So, one of the main objectives of this paper is to study the suitability of the groundwater in the study area for drinking purposes.Different methods were used for evaluation water resources for drinking purposes; water quality index is auseful and efficient method for assessing and communicating the information on the overall quality of water (Asadi *et al*. 2007 andPradhan *et al*. 2001). After the 1960s, different water quality index (WQI) methods have been developed (Horton, 1965;Harkins, 1974andGibrilla *et al*, 2011). In this study, the evaluation of the groundwater sources for drinking purposes depending on the results of groundwater chemistry, according to Egyptianstandards for drinking water that statedin the Minister of Health decree Number (458) for 2007 and WHO, 2011.

Estimation of the Water Quality Index

To assess the groundwater in the study area for drinking purposes, i.e., for calculating the DWQI, the following parameters have been considered; pH, total dissolved solids, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride. The WQI which employ by Tiwari and Mishra (1985) was used.

$$WQI = Antilog\left(\sum_{n=1}^{n} w_n \log_{10} q_n\right)$$

Table 4 Water quality parameters, their standard values, their ideal values and theassigned weighting factors

Parameter	Standard value (Si)	Ideal value (Vi)	1/Si	Assigned weighting factor, Wi
pH	8.5	7	0.117647	0.514635
TDS	1000	0	0.001	0.004374
Ca^{2+}	200	0	0.005	0.021872
Mg^{2+}	150	0	0.006667	0.029163
Na^{+}	200	0	0.005	0.021872
k^{+}	12*	0	0.083333	0.364533
HCO_3^-	500*	0	0.002	0.008749
SO_4^{2-}	250	0	0.004	0.017498
Cl^-	250	0	0.004	0.017498
The values according to Egyptian standards (2007) and WHO (2011)			$\sum = 0.229$	$\sum = 1$

Table 5 Water quality index scale

Water quality	Description
0 - 25	Excellent
26 – 50	Good
51 - 75	Poor
76 - 100	Very Poor
> 100	Unfit for Drinking (UFD)

Where Wn is the Weighting factor, calculated from the following equation:

$Wn = K/(Si)$

K: is the proportionality constant derived from:

$$K = 1/\left[\sum_{n=1}^{n} 1/S_i\right]$$

Where, Si is the standard value of the water quality parameter (Egyptian Higher Committee, 2007 and WHO, 2011). The calculated Weighting factors of each parameter are given in table (4). Quality rating (q_n) was calculated using the formula;

$$q_n = \left[\frac{V_{actual} - V_{ideal}}{V_{standard} - V_{ideal}}\right] * 100$$

Where, q_n is the quality rating of i_{th} parameter for a total of n water quality parameters; V_{actual} is the value of the water quality parameter obtained from laboratory analysis; V_{ideal} is the value of that water quality parameter which can be obtained from the standard tables, V_{ideal} for pH = 7, and for other parameters, it is equivalent to zero; $V_{standard}$ is the standard of the water quality parameter (Egyptian Higher Committee, 2007; WHO, 2011). The groundwater samples were classified according to WQI rate as excellent, good, poor, very poor and unfit for human consumption (table 5). The obtained results of the groundwater samples (pH, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-} and Cl^{-}) in the study area were used to predict the suitability for drinking purposes using the water quality index depending on the standard values of drinking water (Egyptian Higher Committee, 2007 and WHO, 2011). The results of the computed WQI values of the study area range from 34.5 to 136.2 (Table 6 and Figure 11), these results show that most of the groundwater samples in the study area (45.2%) are unfit for drinking, 22.6% of the groundwater samples are poor quality for drinking, 19% of the groundwater samples are good for drinking and the rest of the groundwater samples in the study area (12.9%) are very poor quality for drinking. The high value of WQI has been found to be mainly from the higher values of sulphate and chloride in the groundwater. In conclusion, the majority of the groundwater samples in the study area (81%) is unsuitable for human drinking as they have sulphate and chloride concentrations more than the permissible limits for drinking water. The results of analyses have been used to suggest models for predicting water quality. The analysis reveals that the groundwater of the area needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination.

Table 6 water quality index results for drinking purposes (DWQI) for the groundwater samples in the study area.

Well No.	DWQI	Quality	Well No.	DWQI	Quality
1	34.5	Good	17	103.8	Unfit for Drinking
2	46.0	Good	18	56.4	Poor
3	47.1	Good	19	117.2	Unfit for Drinking
4	64.7	POOR	20	57.0	Poor
5	93.1	Very Poor	21	89.9	Very Poor
6	136.2	Unfit for Drinking	22	46.3	Good
7	135.3	Unfit for Drinking	23	101.1	Unfit for Drinking
8	90.8	Very Poor	24	123.5	Unfit for Drinking
9	63.7	Poor	25	111.6	Unfit for Drinking
10	49.3	Good	26	105.8	Unfit for Drinking
11	129.6	Unfit for Drinking	27	111.5	Unfit for Drinking
12	122.8	Unfit for Drinking	28	107.4	Unfit for Drinking
13	73.9	Poor	E1	55.4	Poor
14	124.1	Unfit for Drinking	E2	40.1	Good
15	97.3	Very Poor	E3	56.9	Poor
16	114.4	Unfit for Drinking			

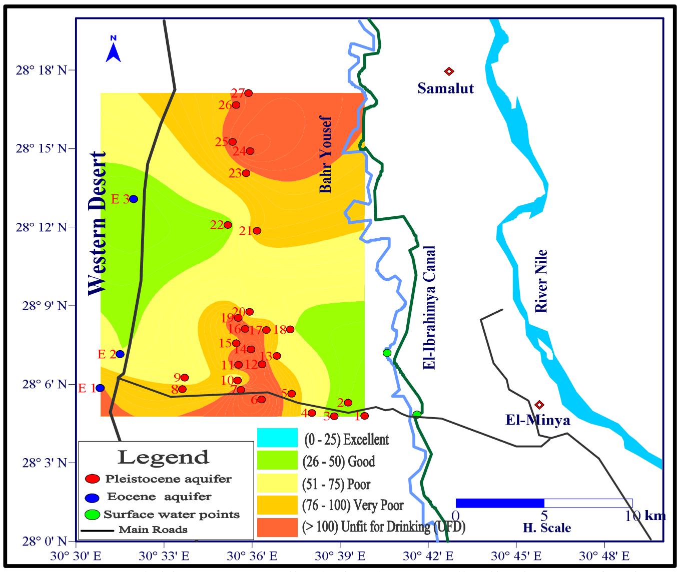

Figure 11 Drinking water quality index (DWQI) distribution map for the groundwater samples in the study area

b. Evaluation of groundwater for irrigation purposes using irrigation water quality index model

Commonly the problems originated from irrigation water quality vary in type and severity as a function of numerous factors, including the type of the soil and the crop, the climate of the area as well as the farmer who utilizes the water (Celalettin Smisek and Orhan Gunduz, 2007). These problems can be categorized into major groups, salinity hazards, infiltration and permeability problems, toxicity hazards and miscellaneous problems (Ayers and Westcot, 1985).

Irrigation water quality criteria

The kind and amount of salt determine the suitability of irrigation water. Potential severity problems expecting to progress over a long-term use verdict water quality or suitability for use (Ayres and Westcot, 1985). In general and as mentioned by (Ayers and Westcot, 1985), there are four main groups for limitations which are associated with the quality of irrigation water:

1. Concentration of total soluble salts (Salinity hazard)
2. The relative proportion of sodium to the other cations (Sodium hazard).

3. pH values and concentrations of bicarbonate (Diverse effects)
4. Specific ion toxicity, such as Chloride,.etc.

Appropriateness of water irrigation in addition to the probability of plant toxicity can be defined by the amounts and combinations of these substances (Fipps, 2003).

Salinity hazards

The Salinity hazard can happen when salts accumulate in the zone of the crop to reduce the root sum of water existing at the roots.The available amount of the reduced water occasionally hits such levels that are adversely affecting the crop yield. Plant's growth gets slow rate and drought-like symptoms begins to build up when this water pressure is extended (Ayers and Westcot, 1985). A high osmotic potential is caused by high salinity in the water (or soil solution). Plant roots can be burnt and/or flagged by some salts with a toxic effect. The elevated rates of some metals may intervene with proportional availability and plant absorption of other micronutrients (Porter and Marek, 2006). Salinity of water irrigation is expressed in terms of both indicators of Electrical Conductivity (EC) and Total Dissolved Solids (TDS).EC is used to measure the electrical conductivityof water. It is closely related to Total Dissolved Solids (TDS) due to the function of the ionic solute concentrations. The usual range of EC as mentioned by (Ayers and Westcot, 1985) is between 0-3000(µS/cm).The electrical conductivity (EC) is considered as agood parameter for detecting the salinity hazard, and there is a full choice to grow the crop when the irrigation water has EC less than 1500µs/cm (Gupta and Gupta, 2003). (Todd and Meys, 2005) were classified the groundwater based on salinity hazard into these categories;

- Excellent groundwater (EC < 250µs/cm)
- Good groundwater (EC ranges from 250 – 750µs/cm)
- Allowed groundwater (EC ranges from 750 – 2250µs/cm)
- Unsuitable groundwater (EC > 2250µs/cm)

According to EC values of the groundwater in the study area (Table 1), it was shown that; most of the groundwater in the study area (58%) is unsuitable for irrigation as they have EC values more than 2250µs/cm reflecting high salinity problem, while 39% of the groundwater samples are considered as allowed water as they have EC values range from 750 – 2250µs/cm. On the other hand, the rest of groundwater samples (3%) in the study area are good water for irrigation as they have EC values ranging from 250 – 750µs/cm.

Sodium hazard

There are large amounts of sodium in the irrigation of water which is of special concerns because of sodium effects on the soil and forms a sodium risk (Fipps, 2003). A problem to occur with higher sodium concentrations when the infiltration rate is reduced to such a rate that the availability of the water for a crop is not enough or when the hydraulic accessibility of the soil profile is very low to supply sufficient drainage. An excess of Na^+ could cause other problems to the crop such as formatting crusting the beds of seed, temporal saturation of soil surface, escalated pH and the more potential for diseases, weeds, soil corrosion, scarcity of oxygen and insufficient nutrient obtainability. There are several factors related to these problems such as the rate of salinity and soil type. For example, the soil of sandy type (which comprise most study areas) may be different from other soils in getting the damage when it is irrigated with water of high Na^+ concentration. Sodium Hazard is usually expressed in terms of Sodium Absorption Ratio (SAR), (Fipps, 2003).

Sodium Absorption Ratio (SAR)

The proportional concentrations of sodium are considered as the most public water quality factor that influences the common amended of permeation of water, magnesium and calcium ions in the water. The role of calcium and magnesium is important to maintain the constitution of soils that contain clay. Applying water with excessive rate of sodium and low rate of calcium and magnesium is common to clay soils. Sodium, on the other hand, tends to move calcium and magnesium on clay particles to result in collapse of components, deposition of organic substance, and decreased permeability. The sodium adsorption ratio (SAR) represents the relative concentration of sodium, magnesium and calcium ions in the water and it can be defined as:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{(\mathrm{Ca} + \mathrm{Mg})/2}}$$

What SAR provides a beneficial pointer of water irrigation potential detrimental effects on soil structure and permeability. The concentration of the constituents is expressed in (meq/l). (Richard̕s, 1954) classified the irrigation water according to SAR values into the following categories;

- Good water (SAR up to 10)
- Moderate water (SAR ranges from 10 – 18)
- Intermediate water (SAR ranges from 18 – 26)
- Unsuitable water (SAR > 26)

According to SAR values of the groundwater samples in the study area (Table 1), most of the groundwater samples (58%) in the study area are good water for irrigation as they have SAR values up to 10, while 26% of the groundwater samples are moderate water for irrigation as they have SAR values range from 10 – 18, and 10% of the groundwater samples in the study area are considered as an intermediate water for irrigation as they have SAR values ranging from 18 – 26. On the other hand, the rest of the groundwater samples (6%) are unsuitable water for irrigation as they have SAR values more than 26.

Diverse effects (alkalinity – carbonate and bicarbonate)

Besides the risks and consequences considered in the former sections, there are other parameters and, the existence of such parameters should be estimated strictly in water irrigation. These parameters are thought to be in the field of the diverse effectsof sensational crops and involve the concentrations of bicarbonate ions (Simsek and Gunduz, 2007). Where, both bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions are the main component of alkalinity and in charge for large pH values (more than 8.5). So, the excess amounts of carbonate and bicarbonate in groundwater over the sum of Ca^{2+} and Mg^{2+}influence the suitability of groundwater for irrigation. An excess of sodium carbonate and bicarbonate is considered to be determined by the physical properties of soils as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying, this excess amounts are denoted by residual sodium carbonate (RSC). RSC is computed from the following equation,where all the ionic concentrations are expressed in meq/L(Eaton, 1950).

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

(Eaton, 1950) classified the irrigation water according to the RSC values into the following categories;

- Good water for irrigation (RSC < 1.25meq/L)
- Doubtful water for irrigation (RSC varies from 1.25 – 2.5meq/L)
- Unsuitable water for irrigation (RSC >2.5meq/L)

According to the RSC values of the groundwater in the study area (Table 1), it is clear that 94% of the groundwater samples in the study area are good water for irrigation as they have RSC values less than 1.25 meq/L, while the rest of the groundwater samples in the study area (6%) are considered as doubtful water for irrigation as they have RSC values range from 1.25 – 2.5meq/L.

Specific ion toxicity

Specific ions such as sodium and chloride as well as boron are causing problems of toxicity for plants when their concentrations are at higher rates in water or soil. In case the plant takes up such ions until they get accumulated in high concentrations, the ions will cause crop damage or reduction and they will be labeled as toxic. Toxicity level depends on plant type and its rate of uptake.The crops that permanent and perennial have more sensitivity to such kind of toxicity as compared to the crops of yearly types. It is a famous fact that toxicity caused by ion is regularly co-occur with other hazards such as salinity and permeation (Ayers and Westcot, 1985).The toxicity risks can be more categorized as troubles that are linked with certain ions and hazards connected with the trace elements and weighty metals. Despite the fact that chloride is vital for plants in very little amounts, it may cause toxicity to sensitive crops in case of its availability with high concentrations. The immediate toxic effects include leaf burns or leaf tissue deaths. As in the case with sodium, high concentrations of chloride lead to additional problems when applied with sprinkler irrigation.Noteworthy to mention that, most effective ion which is essential for plants at very low concentration is chloride ion, where it can cause toxicity to sensitive crops at high concentrations. (Mass, 1990) classified the irrigation water according to the concentration of chloride ion into the following categories;

- Safe water for all plants ($Cl^- < 2$meq/L)
- Groundwater suitable for irrigation of sensitive plants that show injury (Cl^-ranges from 2 – 4meq/L)
- Groundwater suitable for irrigation of moderately tolerant plants that show injury (Cl^-ranges from 4 – 10meq/L)
- Groundwater can cause severe problems ($Cl^- >$ 10meq/L)

According to the concentration of chloride ion concentrations in groundwater samples at the study area (Table 1), it is cleared that 42% of the groundwater samples in the study area can cause severe problems as they have Cl^- ion concentration more than 10meq/L, and 32 % of the groundwater samples are safe water for irrigation all plants as they have Cl^- ion concentration less than 2meq/L, while the rest of the groundwater samples in the study area (26%) are suitable for irrigation of moderately tolerant plants that show injury as they have Cl^- ion concentration range from 4 – 10meq/L.

Proposed water quality evaluation model (Irrigation water quality index, IWQI)

The objective of this item is to develop the IWQI which established by (Meireles *et al*, 2010) through integrated it with GIS in order to identify places with the best water quality for irrigation by mapping irrigation water quality index (IWQI). GIS-integrated method is built on combining five varied groups of parameters used to assess irrigation water quality that may have negative consequences or hazards on both the quality of soil and crop productivity(Omran I.hammed and Marwa Falih Hassan, 2015). All five groups, In this technique, are at once involved in the analysis, and combined to form a single index value meant to be assessed to identify the irrigation water suitability. IWQI model was applied based on the results of samples were taken from the water resourcesin the study area. This model was developed by (Meireles*et al*, 2010) via conducting two steps. The first step involves identifying the parameters that participate in causing most variability of irrigation water quality. For the sake of developing the suggested WQI; The EC, Na^+, Cl^-, HCO_3^- and SAR parameters were adopted. The best water quality is defined through these major factorial loads. The second step witnesses defining quality mensuration values (Qi) and accumulated weights (w_i). The values of (q_i) are to be implied according to every parameter value, based on the criteria recognized by Ayers and (Westcot, 1999), as listed in Table (7).By using a non-dimensional number, water quality parameters were represented; the higher the value, the better water quality.For calculating the IWQI, the following parameters have been considered: EC, sodium, bicarbonate, chloride and Sodium Adsorption Ratio.

Table 7 Parameter limiting values for quality measurement (q_i) calculation (Ayers and Westcot, 1999).

q_i	EC (µS/cm)	SAR	Na^+ (meq/l)	Cl^- (meq/l)	HCO_3^- (meq/l)
85-100	$200 \leq EC < 750$	$SAR < 3$	$2 \leq Na^+ < 3$	$Cl^- < 4$	$1 \leq HCO_3^- < 1.5$
60-85	$750 \leq EC < 1500$	$3 \leq SAR < 6$	$3 \leq Na^+ < 6$	$4 \leq Cl^- < 7$	$1.5 \leq HCO_3^- < 4.5$
35-60	$1500 \leq EC < 3000$	$6 \leq SAR < 12$	$6 \leq Na^+ < 9$	$7 \leq Cl^- < 10$	$4.5 \leq HCO_3^- < 8.5$
0-35	$EC<200$ or $EC \geq 3000$	$SAR \geq 12$	$Na^+ < 2$ or $Na^+ \geq 9$	$Cl^- \geq 10$	$HCO_3^- < 1$ or $HCO_3^- \geq 8.5$

Where the values of q_i were calculated using the equation (1), based on the tolerance limits shown in Table (7) and the chemical analysis data of the collected water samples from the investigated area (Table 1);

$$q_i = \frac{(x_{ij} - x_{inf}) \text{ x } q_{iamp}}{q_{imax}} \qquad (1)$$

Where;
q_{imax}= comes as the maximal value of $q_i$in the category;
x_{ij}= comes as the parameter spotted value;
x_{inf} = is the value that corresponds to the minimal border of the category to each parameter;
q_{iamp} = is the category ampleness;
x_{amp} = is the category ampleness to each parameter.

Each parameter weight used in the IWQI was obtained by (Meireles *et al.*, 2010) as shown in Table (8). The w_i values were normalized such that their sum equals one.The irrigation water quality index (IWQI) was calculated as;

$$\text{IWQI}= \sum_{i=1}^{n} q_i \times w_i \qquad (2)$$

IWQI is division in classes based on the proposed water quality index was based on existing water quality indexes, and classes were defined considering the risk of salinity problems, soil, water infiltration reduction, as well as toxicity to plants Table (10) (Bernardo, 1995& Holanda and Amorim, 1997).

Table 8 Weights for the IWQI parameters (Meireles *et al.*, 2010).

Parameter	Weight (w_i)
EC	0.211
Na^+	0.204
HCO_3^-	0.202
Cl^-	0.194
SAR	0.189
Total	1.0

According to the chemical analysis data (Tables 1 and 9) for all water samples and the water quality index characteristics(Table 10), the IWQI map was produced by overlapping of the thematic maps (EC, Na^+, Cl^-, HCO_3^- and SAR) as a result of geostatistical analysis, and this integration gives the IWQ index map that shoed in Figure (12).This map represents the distribution of the groundwater quality for irrigation purposes for about 320km^2 of the study area based on IWQI values to help the decision makers to select the suitable sites for sustainable agricultural development as well as identifying the suitable crops and irrigation systems.According to this classification, it was shown that most of the Pleistocene aquifer groundwater samples (56%) are located in north and south of the study area and they areclassified as severe restriction (S.R.) irrigation water, i.e., very poor groundwater quality for irrigation purposes. These groundwater samples occupied an area of about nearly 148km^2 (46% of the total studied area). The groundwater in this area is suitable only for plants with high salt tolerance (as sugar beet), except for waters with extremely low values of Na^+, Cl^- and HCO_3^-, and soils have high permeabilityand with good agricultural drainage system to avoid salt accumulation. In brief, this groundwater should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally.15% of the Pleistocene aquifer groundwater samples in the study area are classified as high restriction (H.R) irrigation water and they are located to the east and south of the study area, and they occupied of about 80km^{2}of the study area (25% of the total studied area), this water should be used forirrigation of plants with moderate to high tolerance to salts with special salinity control practices (as tomato), except water with low Na^+, Cl^- and HCO_3^-values, and soils with high permeability without compact layers.7% of the Pleistocene aquifer groundwater samples in the study area are classified as moderate restriction (M.R.) irrigation water and they are located in the center and to the west and southeast of the study area. Also, they occupied of about 80km^{2}of the study area (25% of the total studied area), this water should be used forirrigation of plants with moderate tolerance to salts may be grown (as grapes) and may be used in soils with moderate to high permeability values, being suggested moderate leaching of salts.The rest of the Pleistocene aquifer groundwater samples (12%) in the study area are classified as low restriction (L.R.) irrigation water and they are located in the center and to the southeast of the study area. Also, they occupied only 10km^{2}of the study area (4% of the total studied area), this water can be used forirrigation of all plants (as beans) with avoiding salt sensitive plants. Recommended for use this water in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay. The IWQI for these samples ranges from -60.49 to 85.04. The high value of WQI has been found to be mainly from the higher values of chloride in the groundwater.

In conclusion, most of the Pleistocene aquifer groundwater samples (56%) are located in north and south of the study area and they areclassified as severe restriction (S.R.) irrigation water, i.e., very poor groundwater quality for irrigation purposes. These groundwater samples occupied an area of about nearly 148km^2 (46% of the total studied area).

Table 9 The irrigation water quality index values of the surface and groundwater samples in the study area

Sample No.	q_i EC	q_i SAR	qi Na	q_i Cl	q_i HCO_3	IWQI
Surface water						
El-Ibrahimya canal	20.43	17.69	0	19.1	16.16	73.38
Pleistocene aquifer						
1	19.96	17.48	19.18	18.09	7.45	82.16
2	19.14	15.28	15.04	18.09	9.72	77.27
3	19.38	17.86	3.55	18.89	15.18	74.86
4	17.89	17.16	20.22	18.599	10.1	83.969
5	12.47	13.7	12.09	12.29	10.73	61.28
6	-4.67	-7.99	-42.04	-11.4	18.988	-47.112
7	-8.12	-5.07	-44.06	-19.26	16.02	-60.49
8	10.75	10.24	5.3	3.21	11.36	40.86
9	10.98	11.18	7.09	4.94	12.02	46.21
10	-2.58	0.32	-26.93	-9.5	14.66	-24.03
11	13.42	4.96	-10.7	4.09	14.6	26.37
12	6.84	3.53	-4.43	4.1	14.6	24.64
13	0.274	6.59	-13.46	1.96	13.82	9.184
14	4.8	3.19	-10.28	3.55	14.5	15.76
15	9.47	7.1	1.67	13.13	14.59	45.96
16	14.07	14.82	13.4	18.6	14.65	75.54
17	10.02	6.77	2.46	18.25	13.58	51.08
18	6.47	7.16	-2.45	13.58	13.13	37.89
19	17.44	16.63	18.41	18.76	13.8	85.04
20	16.49	16.91	18.07	18.56	14.3	84.33
21	9.95	12.13	7.49	14.87	13.13	57.57
22	0.0422	9.84	-3.1	-4.62	13.47	15.6322
23	-10.97	1.93	-31	10.67	15.5	-13.87
24	3.12	9.37	-3.16	-0.61	15.5	24.22
25	7.17	10.15	1.75	3.39	14.6	37.06
26	5.12	6.76	-3	-3.76	14.99	20.11
27	4.16	11.32	1.28	-11.1	16.51	22.17
Eocene aquifer (guide samples)						
E1	16.85	14.91	14.46	15.04	11.19	72.45
E2	15.94	10.94	13.4	16.49	11.05	67.82
E3	12.35	9.21	5.61	7.28	11.5	45.95

Table 10 Water Quality Index Characteristics (Meireles*et al.*, 2010)

IWQI	Water use restrictions	Recommendation	
		Soil	**Plant**
85-100	No restriction (NR)	May be used for the majority of soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability.	No toxicity risk for most plants
70-85	Low restriction (LR)	Recommended for use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay	Avoid salt sensitive plants
55-70	Moderate restriction (MR)	May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts.	Plants with moderate tolerance to salts may be grown
40-55	High restriction (HR)	May be used in soils with high permeability without compact layers. The high frequency irrigation schedule should be adopted for water with EC above 2000 µS cm^{-1} and SAR above 7.0.	Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO_3 values
0-40	Severe restriction (SR)	Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water, soils must have high permeability, and excess water should be applied to avoid salt accumulation.	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl andHCO_3.

SUMMARY, CONCLUSION AND RECOMMENDATION

The study area is one of the most promising areas for expanding agricultural land and increase employment opportunities for young people, where it is located between latitudes 28º 00` and 28º 18` N and longitudes 30º 30` and 30º 48` E. The water resources in the study area are surface water (El Ibrahimya and Bahr Yusef canals) and groundwater. The groundwater in the study area exists in the Pleistoceneaquifer, which considers the main aquifer in the study area.The surface water samples in the study area are related to the fresh water type, while,the total dissolved solids (TDS) of the groundwater samples in the study area range from 249mg/L to 6051mg/L, with a mean value of 2330mg/L. Such groundwater salinity changes widely from fresh, brackish to saline water types. The low salinity is attributed to the contribution from El-Ibrahimiya and Bahr Yusef canals to the groundwater at different parts in the studyarea, i.e., there is a recharge from these canals to the groundwater in the study area. While, in the other parts of the study area, the high salinity in the groundwater is due to the leaching and dissolution processes of the Pliocene marine deposits intercalated with the Pleistocene aquifer matrix during the groundwater flow from south to north (general groundwater flow direction), and carbonate materials that transported from the limestone plateau by weathering and return flow after irrigation as well as over-pumping.The assemblage of hypothetical salts and piper trilinear diagramas well as the hydrochemical profiles confirm that the Pleistocene aquifer groundwater is recharged mainly from surface water (El-Ibrahimya and Bahr Yusef canals). Also, confirm that there is a hydraulic connection between the two aquifers(Pleistocene and Eocene aquifer groundwater). Also, the hydrochemical profiles and statistical analyses confirm that the recharge of the Pleistocene aquifer from the irrigation canals by seepage is occurring at a certain distance range from 8 to 15km. The majority of the groundwater samples in the study area (81%) are unsuitable for human drinking as they have sulphate andchloride concentrations more than the permissible limits fordrinking water.In conclusion, most of the Pleistocene aquifer groundwater samples (56%) are located in north and south of the study area and they areclassified as severe restriction (S.R.) irrigation water, i.e., very poor groundwater quality for irrigation purposes. These groundwater samples occupied an area of about nearly 148km^2 (46% of the total studied area).The analysis reveals that the groundwater of the area needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination.

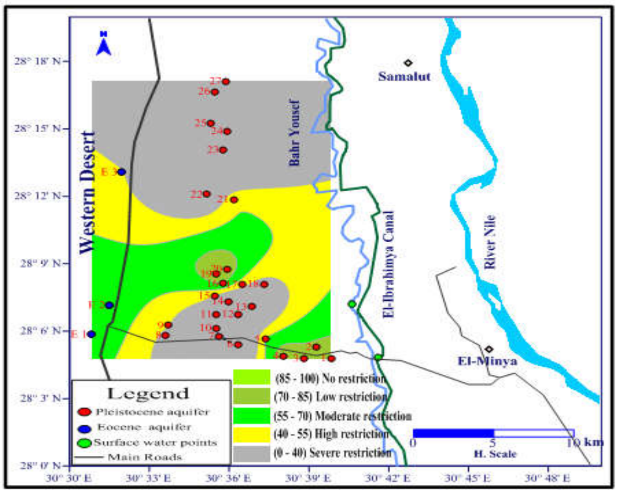

Fig 12 Irrigation water quality index (IWQI) distribution map forthe groundwater samples in the studied area

References

Abdel Moneim, A.A., Fernandez-Alvarez, J.P., AbuEl-Ella, E.M. and Masoud, A.M., 2016. Groundwater management at west El-Minia desert area, Egypt using numerical modeling. *Journal of Geoscience and environmental protection*, 4; 66-76.

Asadi, S.S., Vuppala, P. and Reddy, M.A., 2007.Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V) India. *International Journalof Environmental Research*. Public Health, 4(1):45–52

Ayers R.S. and Westcot D.W., 1985. Water quality for agriculture, Irrigation and Drainage Paper No.29, Rev.1, Food and Agriculture Organization of the United Nations Rome(FAO), Rome, Italy.Reprinted 1989, 1994.ISBN 92-5-102263-1.

Ayers, R.S. and Westcot, D.W., 1999. The water quality in agriculture. 2ndedition. Campina Grande: UFPB. (Studies FAO Irrigation and drainage, 29).

Back, W. and Hanshow, B.B., 1979. Major geochemical processes in the evolution of carbonate aquifer system. Elsevier scientific publishing company, Amesterdam, the Netherlands.

Bernardo, S., 1995.Manual of Irrigation. (4thedition), Vicosa: UFV, 488p.

Celalettin Simsek and Orhan Gunduz, 2007. IWQ Index: A GIS-Integrated Technique to Assess Irrigation Water Quality, Environ. Monit. Assess., 128:277–300.

Chebotarev, I.I., 1955. Metamorphism of natural waters in the crust of weathering. Geochemia et. Cosmochimica, Acta, 8, part I. pp.22-48, part II. pp.137-170 and part III. pp.198-212, London and New York.

Conoco Coral of Egypt, 1987. Geologic map of Egypt (scale 1:500000). General petroleum company, Cairo, Egypt.

Decree of Health Minister No.458 / 2007. Egyptian standards for drinking water and domestic uses (in Arabic).

Eaton, F.M., 1950. Significance of carbonate in irrigation water, Soil science, 69(2), pp 123-133.

Egyptian Higher Committee for Water, 2007. Water quality guidelines for human drinking, domestic andlaundry uses, Egypt (in Arabic).

El Kashouty, M. and El Sayed, E., 2010. The hydro-chemical characteristics and evolution of groundwater and surface water in western part of River Nile, El Minia district, upper Egypt. International conference “Trnsboundary Aquifers: challenges and new directions” (ISARM); 1-7.

El Kashouty, M., El Sayed, E., Elewa, A.M.T. and Morsi, M., 2012. Environmental impact of anthropogenic activity on surface and groundwater systems in western part of the River Nile, between El-Edwa-Der Mawas area, El-Minia Governorate, upper Egypt. *Journal of American science*, 8(5); 150-161.

Fipps, G., 2003. Irrigation water quality standards and salinity management. Fact Sheet B-1667. Texas Cooperative Extension. The Texas A&M University System, College Stations, TX.

Gibrilla, A., Bam, E.K.P.,Adomako,D., Ganyaglo, S., Osae, S., Akiti, T.T.,Kebede, S., Achoribo, E., Ahialey, E., Ayanu, G.and Agyeman, E.K.,2011. Application ofWater Quality Index (WQI) and Multivariate Analysis for Groundwater Quality Assessment of the Birimianand Cape Coast Granitoid Complex: Densu River Basin of Ghana. Water Qual. Expo. Health, 3:63-78

Gupta, I.C. and Gupta, S.K., 2003. Use of Saline water in Agriculture. A study of Arid and Semiarid Zones of India. Revised third edition. Scientific Publishers, Jodhpur, India. pp. 297.

Harkins, R.D., 1974.An objective Water Quality Index. *Journal of Water Pollution Control Fed.,* 46(1):588-591.

Hefny, K., 1982. Groundwater studies project for greater Cairo. Internal report, research institute for groundwater, and academy of scientific research and technology, Cairo, Egypt, 190p., (in Arabic and annex in English).

Hem, J.D., 1985. Study and interpretation of the chemical characteristics of natural water. U.S. Geol.Survey Water Supply, paper 2254, 3rdedition, third printing, p: 248.

Holanda, J.S. and Amorim, J.A., 1997.Management and control salinity and irrigated agriculture water. In: Congresso Brasileiro de Engenharia setting, 26, Campina Grande, pp. (137-169).

Horton, R.K., 1965.An index-number system for Rating Water Quality. *Journal of Water Pollution Control* Fed., 37(3):300-306

Ismail, E., Zaki, R. and Kamel, A., 2015. Hydro-chemistry and evaluation of groundwater suitability for irrigation and drinking purposes in west El-Minia district, north upper Egypt. Eighteenth international water technology conference (IWTC 18), Sharm El-Sheikh; 158-172.

IWACO and RIGW, 1986. Feasibility of vertical drainage in the Nile Valley, Minya pilot area. Ministry of irrigation, Cairo, Egypt.

Korany, E., 1980. Peak runoff calculations and preventing the risk of occasional flooding in Sannur drainage basin, Eastern Desert, Beni Seuf Governorate, Egypt. 5th Intern. Confer. Statist. Comput. Sci., Cairo; 505-534.

Korany, E., 1984. Statistical approach in the assessment of the geohydrologic profiles. 9th Intern. Confer. Statisr. Comp. Sci. Social and demogrres. Cairo, Ain Shams University Press; 161-176.

Korany, E., Sakr, S., Darwish, M. and Morsy, S., 2006. Hydrogeologic modeling for the assessment of continuous rise of groundwater levels in the quaternary aquifer, Nile Valley, Egypt: Case study. The 8th international conference on the geology of the Arab world (GAW 8), Cairo University; 703-711.

Mass, 1999. Crop salt tolerance. Agricultural salinity assessment and management manual. K.K. Tanji (ed.). ASCE, New Yourk, pp.262-304.

Meireles, A., Andrade E.M., Chaves L., Frischkorn, H., and Crisostomo, L.A., 2010. A new proposal of the classification of irrigation water, Revista Ciencia A gronomica, Vol.(41), No.(3), p.349-357.

Omran I. Mohammed and Marwa F. Hassan, 2015. Evaluation of drainage water quality for irrigation by integration between irrigation water quality index and G.I.S. *International Journal of Technical Research and Applications* e- Volume 3, Issue 4 (July-August 2015), PP. 24-32.

Piper, A.M., 1944. A graphic procedure in the geochemical interpretation of water analyses. Trans. Am. Geophy. Union, 25, Washington, DC, 6:914-923.

Pradhan, S.K., Patnaik, D. and Rout, S.P., 2001.Water quality index for the groundwater in and around a phosphatic fertilizer plant. *Indian Journal of Environment Protection,* 21:355-358.

Porter and Marek, 2006. Irrigation Management with Saline Water. Texas A&M University, Agriculture Research and Extension Center.

Rainwater F.H. and Thatcher, L.L., 1960. Methods for collection and analysis of water samples. U.S. Geol. Surv. Water Supply. Paper No.1454, U.S.A., 301.

Research Institute for groundwater (RIGW), 1992. Hydrogeological map of Egypt, scale 1:100000, 2nd edition, map sheet of El-Minya.

Richard, L.A., 1954. Diagnosis and improvement of saline and alkali soils. Agric. Handbook 60, USDA, Washinon DC.

Sadek, M., 2001. Isotopic criteria for upward leakage in the alluvial aquifer in north El Minia district, Egypt. The Egyp. Geol. Surv. and Mining Authority, 19p.

Sanad E.Y., 2010. Geophysical and hydrogeological studies for evaluation the groundwater potentiality in the reclaimed area, west Minia district, Egypt. Depart. of geology, Fac. of Science, El-Minia University.

Shaibani, A., 2008. Hydrogeology and hydro-geochemistry of a shallow alluvil aquifer, west Saudi Arabia. *Hydrogeology journal*, 16; 155-165.

Simsek, C. and Gunduz, O., 2007. IWQ index: A GIS integrated technique to assess irrigation water quality. Environmental Monitoring and Assessment, Vol. (128).

Tamer, M., El Shazly, M. and Shata A., 1974. Geology of El Fayum, Beni Suef regions. *Bull. Desert Inst., Egypt*, 25 (1-2):27-47.

Tantawi, M., 1992. Isotopic and hydrochemical application to the surface and groundwater assessment in El Minia district, Egypt. Ph.D. fac. of Sci., El Minia University.

Tiwari, T.N. and Mishra, M., 1985.A preliminary assignment of water quality index of major Indian rivers. *IndianJournal of Environment Protection*, 5(4):276-279

Todd D.K. and Mays L.W., 2005. Groundwater Hydrology, John Wiley & Sons, New York, 535p.

Vega M., Pardo R., Barrado E. and Deban L., 1998. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Water Research 32: 3581-3592.

World Health Organization (WHO), 2011. Guidelines for drinking water quality, 4th ed. Geneva, pp. 978-924.

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