J.Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 9 (12): 809 - 816, 2018

Groundwater Quality Assessment for Irrigation Purposes in the West of Minia, Governorate, South Egypt [b]

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ABSTRACT

This investigation has been conducted to assess the suitability of ground waters in west Minia governorate for irrigation purposes. Thirty-three groundwater samples were collected from different sites, along Assiut the West Desert Road. These samples were analyzed for water quality criteria, namely electrical conductivity (EC), soluble cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), anions (HCO_3^-, CO_3^{2-}, Cl^- and SO_4^{2-}). The chemical parameters that control water quality such as sodium adsorption ratio (SAR), soluble sodium percent (SSP%), residual sodium carbonated (RSC), Kelley's ratio (KR), potential salinity (PS), permeability index (PI), total alkalinity, total hardness, magnesium ratio were also calculated using standard equations. Results revealed that anions contents in the studied ground waters followed the sequence: SO_4^{2-}>Cl^-> HCO_3^- whereas CO^{-3}ion was not detected. On the other hand, the cations contents of the water samples followed the sequence: Na^+> Mg^{2+}> Ca^{2+}> K^+. In addition, the pH values of the studied water samples ranged between 6.9 and 7. 9. The analytical results indicated that 94 % of the groundwater samples can be classified as good for irrigation on bases of EC, SAR, RSC and SSP%. Both SAR and RSC values indicated no liability for sodicity hazard. However, groundwater samples had high salinity levels and low sodicity (C3–S1). Some other parameters, which were generally used for assessing water quality e.g. Irrigation Water Quality Index (IWQI) and Relative Crop Yield Potential (RCYP), were calculated. GIS was used to create a water quality database including spatial distribution map for each parameter. The results obtained herein showed that about 21 % of the groundwater samples belong to No Restriction category (NR) while about 79 % from the total samples belong to the Low Restriction (LR) category. According to the RYPC values calculated for some crops that can be cultivated using the investigated waters, the following sequence is obtained: sugar beet (94) > wheat (74) > corn (33) > bean (13). Thus, it can be concluded that the studied groundwater can successfully be used for irrigation with special salinity control management i.e. leaching requirements and salt tolerant plants.

Keywords: Groundwater, Chemical characters, Irrigation water quality, assessment, relative yield and GIS maps.

INTRODUCTION

Water is a critical natural resource for human life sustainability on the earth. In Egypt, intensive agricultural activities have increased the demand for irrigation water. Therefore, groundwater resources are considered the third water resource for irrigation purpose, after the River Nile and drainage water. Physicochemical quality of water is necessary to evaluate its suitability for different usages. Quality of ground water depends on natural processes i.e. dissolution and precipitation of minerals, as well as recharge of water and its interaction with other water types (Andrade *et al.*, 2008). The natural chemical quality of groundwater depends on the concentrations of a number of constituents which may cause problems for soil or plant on the long term. Hydrogeochemical processes of groundwater are influenced by various factors, such as rock-water interaction and human activities (Hounslow, 1995). Many factors decide the rate of suitability of water for irrigation, e.g. water quality, soil type, salt tolerance characteristics of plants, climate and drainage (Appelo and Postma 2005 and Jafar*et al*., 2013). Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) are the most important factors of quality criteria, which have high influence on water suitability for irrigation (USSL, 1954).

The integration of the geographic information system (GIS) platform to the assessment procedure not only allows the decision maker to create parameter maps for easy visual interpretation but also makes the overall analysis more sound, objective and simple (Waqed 2014). Water Quality Index (WQI) is a very useful and efficient method to evaluate the suitability of water quality and for communicating the information on overall quality of water (Asadi*et al*., 2007). The determination of WQI helps in deciding the suitability of groundwater sources for its intended purpose. From the early 1960s, different WQI methods have been developed (Horton 1965; Harkins 1974).

This work aims at assessing the suitability of some groundwaters in west Minia governorate for irrigation purpose. It will also employ the WQI proposed by Tiwari and Mishra (1985) in assessing the quality of the studied groundwater samples to identify its suitability for agricultural purpose and to produce maps of the groundwater quality as well as relative yield maps for some crops.

MATERIALS AND METHODS

Samples of groundwater were taken from 33 dug wells during March 2017 in different sites of the study area which represent about 28 km2 (Fig. 1). Water samples were collected in polyethylene bottles prewashed with 1:1 HCl and rinsed several times with the same groundwater samples. The bottles were tightly closed, labeled and transported to the laboratory and filtered through 0.45-μm cellulose membranes on the same day and then stored at 4C◦. Acidity number (pH) and electrical conductivity (EC) were measured in site immediately after collecting the samples using portable field meters. The chemical analyses of the different samples were carried out using the standard methods described by APHA (1995). Total hardness and calcium were determined by ethylene-diamine-tetra-acetic acid titrimetric method. Magnesium was estimated by difference between total hardness and calcium. Total alkalinity, carbonate, bicarbonate, and chloride were estimated using titrimetric methods. Sodium and potassium were estimated by flame photometer. Sulphate was determined by gravimetrically method. Total dissolved solids, RSC, % soluble sodium, SAR, Kelley's ratio (KR), permeability index (PI), total alkalinity and magnesium ratio were calculated using standard equations. Thirty-three surface soil samples were taken from the same sites of groundwater and analyzed for soil acidity (pH), electrical conductivity (ECe), saturation percent (SP) and particle size distribution and results are presented in Table 3. The analytical data were then used to assess the suitability of ground water samples for irrigation.

Calculation of Irrigation Water Quality index IWQI

Values of EC, Na^+, Cl^-, HCO_3^- and Sodium Absorption Ratio (SAR) parameters have been selected tocalculate the water quality index (IWQI) model developed by Meireles*et al.* (2010) according to the following equation:

$$IWQI = \sum_{i=1}^{n} qiwi \ldots\ldots\ldots \quad \textbf{Equation 1}$$

Where: IWQI is irrigation water quality index, (q_i) is the quality of the parameter and (w_i) values are the weights of the considered parameters. The criteria of parameters are recognized by Ayers and Westcot (1985) (Table 1). $q_i$was calculated using the next equation depending on the tolerance limits according to Meireles*et al*. (2010)

$$qi = qimax - \{(Xij - Xinf) * qiamp\} / X\,amp \quad \textbf{Equation 2}$$

Where: *qimax*is the maximal value of qi for the category, *xij*is the parameter spotted value, *xinf*is the value corresponding to the minimal limit of the category to each parameter, *qiamp*is the category amplitude, *xamp*is the category ampleness of each parameter.

The weight values *(wi)* of each chemical parameter used in the quality index of irrigation water have been suggested by Meireles*et al*. (2010). The limitations of the water classes are proposed after computing the total index values are presented in Table 2.

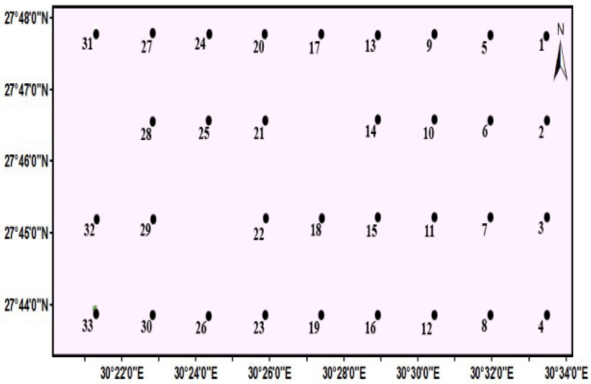

Fig. 1: Sites of groundwater and soil samples of the studied area

Table 1. Critical limits values of parameters and its classes for quality index (qi)

q_i	Ion			SAR	EC (µS/cm)
	HCO_3^-	Cl^-	Na^+		
85-100	$1 \le HCO_3^- < 1.5$	$1 \le Cl^- < 4$	$2 \le Na^+ < 3$	$2 \le$ SAR< 3	$200 \le$ EC < 750
60-85	$1.5 \le HCO_3^- < 4.5$	$4 \le Cl^- < 7$	$3 \le Na^+ < 6$	$3 \le$ SAR< 6	$750 \le$ EC < 1500
35-60	$4.5 \le HCO_3^- < 8.5$	$7 \le Cl^- < 10$	$6 \le Na^+ < 9$	$6 \le$ SAR< 12	$1500 \le$ EC < 3000
0-35	$HCO_3^- < 1$ or $HCO_3^- \ge 8.5$	$1 < Cl^- \ge 4$	$Na^+ < 2$ $Na^+ \ge 9$	$2 \le$ SAR ≥ 12	EC < 200 EC $\ge$ 3000
	Parameters weight by Meireles*et al*. (2010)				
Weight	0.221	0.204	0.202	0.194	0.189

Table 2. Characteristics of Irrigation Water Quality Index (based on Meireles*et al*., 2010)

IWQI	Water use restriction	Recommendation	
		Plant	Soil
85-100	No restriction	No toxicity risk for most plants	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
70-85	Low restriction	Avoid salt sensitive plants	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
55-70	Moderate restriction	Plants with moderate tolerance to salt may be grown	May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts
40-55	High restriction	Should be used for irrigation of plants with moderate to high tolerance , to salts with special salinity control practices expect water with low Na, Cl and HCO_3 values	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µS cm^{-1} and SAR above 7.0
0-40	Severe restriction	Only plants with high salt tolerance except for waters with extremely low values of Na, Cl and HCO_3	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

The values of IWQI of water suitability for irrigation categories have been divided into five categories varying from (0 to 100) and it is dimensional parameter. The categories were divided depending on the proposed groundwater quality index, which was set by the existing groundwater quality indices. They have been defined on bases of salinity hazard problems, soil infiltration, as well as toxicity to plants as noticed in the different classes suggested by Holanda and Amorim (1997).

The Relative Crop Yield Potential (Y)

The equation proposed by Maas and Hoffman (1977) was used to calculate the relative crop yield that can be achieved under salinity threshold value. The yield is presented as percentage of the same crop in absence of salinity stress:

$$Y = 100 - b\,(EC_e - a) \quad \textbf{Equation 3}$$

Where "Y": is the relative crop yield (percent), "EC_e" is salinity of the soil saturation extract in dSm^{-1}, "a" is the salinity threshold value and "b" is the yield loss per unit increase in salinity. The values for (a) and (b) were given by Maas (1990) in his original paper but can also be determined.

The (a) value (the threshold soil salinity) is the EC_e value for 100 percent yield potential. The (b) value can be determined as follows:

$$b = 100 / (EC_e \text{ at zero \% yield} - EC_e \text{ at 100\% yield})$$

RESULTS AND DISCUSSION

1. Groundwater Chemistry

pH values

Results of the physico-chemical analyses of the groundwater samples Table 3 reveal that pH of the ground water samples ranged from neutral to slightly and moderately alkaline and varied from 7.3 to 8.0 with an average of 7.55. These values indicate that the dissolved carbonates are predominant as HCO_3^- form (Adams *et al.* 2001). The lowest pH value (7.3) was recorded for sample No. 1, whereas the highest value was recorded for sample No. 15. All the samples lie within the permissible range of (pH 6.5 - 8.4) according to Ayers and Westcot (1985). Therefore, the groundwater samples are suitable for irrigation purposes without any potential dangerous effect on soil or plant. Sutharsiny*et al.* (2012) mentioned that pH of groundwater typically ranges from about 6.5 to 8.5, depending on soil type and rock that has reacted with the groundwater. These values seem almost be coincide with those reported herein for the studied groundwater samples.

Water salinity

EC values of the groundwater samples varied from 0.77 to 2.49 dSm^{-1} with an average of 1.17 dSm^{-1}. The minimum value is shown for the sample No. 28 while the maximum one is noticed for the sample No. 22 (Table 3). This variation in EC values can be attributed to lithology variation (Zeng*et al*., 2016), rate of evaporation (Aragüés*et al*., 2015), weathering and amount of recharge (Sulieman *et al*., 2016). In other words, groundwater salinity may be affected by salts dissolved from soil and materials of aquifer, and salts leached from irrigation, (Ayers and Westcot, 1985 and Deshpande and Aher, 2012). Bauder *et al*. (2007) has classified the groundwater samples depending on EC to the following classes < 250 µS/cm excellent, 251-750 µS/cm good, 751-2000 µS/cm permissible, 2001-3000 µS/cm doubtful and > 3000 µS/cm unsuitable. According to this classification, 97 % of the water samples belong to the permissible class, while about 3 % belongs to a doubtful group, which is represented by the sample no. 22 only, Table 3. On the other hand, according to Freeze and Cherry (1979) and Liu *et al*. (2017) the groundwater samples are classified according to total dissolved salts into brackish (TDS > 1,000 mgL^{-1}) and fresh (TDS < 1,000 mgL^{-1}). Thus 6 % of the groundwater samples belong to the brackish class and 94 % belongs to the freshwater class, (Table 3).

Table 3. Chemical properties of the ground water and soil samples

WS	Coordinates (m)		Groundwater samples										B mgL^{-1}	Soil			
						Cations $mmolcL^{-1}$				Anions $mmolcL^{-1}$							
	North	East	pH	EC dSm^{-1}	TDS mgL^{-1}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}		pH	ECe	SP	Text
1	259602	3077876	7.3	0.92	588	2.11	2.46	3.91	0.09	2.08	2.13	4.37	n.d.	7.7	3.5	28	SL
2	238403	3075489	7.4	0.94	601	2.64	2.06	3.83	0.09	1.98	2.38	4.26	n.d.	7.8	4.4	27	SL
3	257935	3077660	7.5	0.99	633	2.7	2.95	4.09	0.09	1.89	2.25	5.69	n.d.	8.1	3.7	23	LS
4	240422	3075772	7.5	1.15	736	2.49	2.36	5.13	0.09	1.7	3	5.37	n.d.	8.0	12.7	30	SL
5	239741	3075674	7.4	1.21	774	2.72	2.54	5.39	0.09	1.6	3.44	5.7	n.d.	8.0	12.3	23	LS
6	244291	3076351	7.5	1.44	921	3.34	2.75	6.8	0.11	1.51	4.06	7.42	n.d.	7.9	5.8	24	LS
7	245017	3076430	7.6	1.41	902	3.11	3.11	6.2	0.09	1.32	3.88	7.31	n.d.	7.8	6.6	25	LS
8	245685	3076516	7.6	1.13	723	2.62	2.27	5.13	0.09	1.32	3.13	5.67	n.d.	7.9	7.7	25	LS
9	247680	3076785	7.7	1.18	755	3.15	1.89	5.3	0.11	1.79	3.38	5.29	n.d.	8.1	5.9	26	SL
10	248395	3076923	7.5	1.35	864	3.51	1.97	6	0.11	1.6	4	5.98	n.d.	8.0	4.1	23	LS
11	254445	3077092	7.6	1.12	716	2.72	2.15	5.3	0.11	2.17	3.13	4.99	n.d.	8.2	21.2	30	SL
12	253768	3076970	7.5	1.67	1068	4.36	2.81	7.6	0.13	1.32	5	8.58	n.d.	7.8	4.6	25	LS
13	247795	3076113	7.7	1.23	787	3.3	2.12	5.48	0.12	1.6	3.5	5.91	n.d.	8.0	10.7	30	SL
14	245807	3075887	7.6	1.43	915	3.62	2.93	6.6	0.11	1.42	4	7.84	n.d.	8.0	38.7	22	LS
15	242486	3075375	8	1.43	915	3.94	2.15	7	0.11	1.7	4	7.5	n.d.	7.9	10.3	25	LS
16	241228	3075211	7.7	1.23	787	3.28	1.79	5.83	0.09	1.7	3.25	6.03	n.d.	8.0	10.3	24	LS
17	240520	3075081	7.8	1.11	710	2.77	1.8	5.3	0.09	1.79	2.88	5.29	n.d.	7.9	6.9	27	SL
18	239158	3074953	7.5	1.26	806	3.17	2.24	5.57	0.11	1.6	3.25	6.23	n.d.	8.5	17.4	26	SL
19	238508	3074860	7.7	0.97	620	2.45	1.53	4.7	0.1	1.79	2.5	4.48	n.d.	8.0	5.1	27	SL
20	238559	3074129	7.5	0.9	576	2.66	1.19	4.52	0.09	1.75	2.25	4.47	n.d.	8.2	22.6	22	LS
21	239334	3074194	7.7	0.98	627	2.98	1.33	4.78	0.09	1.89	2.5	4.79	n.d.	8.0	3.7	20	S
22	240245	3074235	7.6	2.49	1593	2.49	1.49	4.87	0.11	1.89	2.5	4.57	n.d.	8.0	5.4	23	LS
23	240196	3073578	7.6	1.08	691	2.55	2.29	5.13	0.07	1.6	2.88	5.57	n.d.	7.9	5.8	25	LS
24	239523	3073477	7.4	0.89	569	2.04	1.57	4.61	0.07	1.65	2.25	4.39	n.d.	8.0	3.2	22	LS
25	237996	3073235	7.4	0.88	563	2.21	0.83	4.87	0.07	1.32	2	4.67	n.d.	8.1	3.8	26	SL
26	238131	3072447	7.5	0.9	601	2.3	2.01	4.43	0.13	1.51	2	5.4	n.d.	8.4	6.8	33	SCL
27	238131	3072447	7.5	0.89	569	1.57	2.01	4.52	0.13	1.42	1.88	4.94	n.d.	8.4	6.8	33	SCL
28	238177	3071816	7.4	0.77	492	2.21	2.14	3.48	0.12	1.51	1.75	4.68	0.06	8.4	13.4	28	SL
29	238177	3071816	7.5	0.92	588	2.55	2.88	3.91	0.13	1.42	1.88	6.18	n.d.	8.4	13.4	28	SL
30	240422	3071094	7.6	1.27	812	2.26	3.33	5.65	0.14	1.6	3.13	5.65	n.d.	7.9	10.7	34	SCL
31	240422	3071094	7.5	0.78	499	1.7	2.56	3.74	0.1	1.51	2	4.59	n.d.	7.9	10.7	25	LS
32	239199	3070402	7.5	1.28	819	3.15	3.22	5.39	0.14	1.6	3.13	7.17	n.d.	8.0	36.4	31	SCL
33	238213	3070218	7.5	1.36	870	2.49	3.03	6.6	0.14	1.32	3.5	7.44	n.d.	8.0	6.0	25	LS

WS=Water samples; EC=Electrical conductivity; TDS=Total dissolved salts; SP=Saturation percent; Text=Texture class; LS=Loamy sand; SL=Sandy loam; SCL=Sandy clay loam

Soluble Ions

Table 3 shows that the concentrations of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} ions ranged from 1.57 to 4.36, 0.83 to 33.3, 3.48 to 7.6, and 0.07 to 0.14 $mmol_cL^{-1}$ with average values of 2.67, 2.24, 5.2, and 0.1 $mmol_cL^{-1}$, respectively. About 75.7 % of the soluble cations of the water samples could be arranged in the following descending order Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}, while in 24.3 % of the water samples, the soluble cations followed the sequence: Na^{+}> Mg^{2+}> Ca^{2+}> K^{+}. The dissolved anions HCO_3^-, Cl^- and SO_4^{2-} ranged between 1.32 to 2.17, 1.75 to 5.0 and 4.26 to 8.58 $mmol_cL^{-1}$ with average values of 1.63, 2.93 and 5.71 $mmol_cL^{-1}$, respectively. All anions of the groundwater samples could be arranged in the following descending order: SO_4^{2-} >$Cl^{-\,>}$ HCO_3^-. Carbonate ions are not found in any detectable concentration in the investigated water samples.

Soluble Sodium Percentage (SSP)

Arshid*et al.* (2011) mentioned the high amount of sodium in irrigation water is considered undesirable because it can be potentially adsorbed on the exchange sites causing dispersion of soil aggregates, thereby lower soil permeability. The sodium in irrigation waters may be also expressed as soluble sodium percentage (SSP) and it is calculated using the formula proposed by Wilcox (1955) and Bunani *et al*. (2005), where all ionic concentrations are expressed in $mmol_cL^{-1}$.

$$\boldsymbol{Na}\,\% = \frac{(\boldsymbol{Na}+\boldsymbol{K})}{(\boldsymbol{Ca}+\boldsymbol{Mg}+\boldsymbol{Na}+\boldsymbol{K})} * \mathbf{100} \qquad \textbf{Equation 4}$$

According to Wilcox (1955), the water samples are grouped depending on SSP into: Excellent (< 20 %), good (20-40 %), permissible (40-60 %), doubtful (60-80 %) and unsuitable (> 80 %). Data in Table 4 reveal that, the highest SSP value (61.9%) was recorded for the sample number 25, while the lowest (42.5%) was recorded for the sample number 2. About 97 % of the ground water samples are classified as permissible according to their SSP values, while 3 % of the groundwater samples are doubtful for irrigation. SSP are taken against electrical conductivity values and are designated as Wilcox diagram in Fig. (2). The soils irrigated with water sample no. 22 must receive leaching requirement and cultivated with salt tolerant plants like beet, sorghum and others according to Sutharsiny*et al*. (2012).

Table 4. The parameters used for evaluating water quality

WS	SAR	RSC	SSP	KR	Ca/Mg molar	Ca/Mg ratio	PS	PI	Adj SAR
1	2.59	0.46	46.70	0.86	0.86	46.20	4.32	62.50	4.30
2	2.50	0.42	45.50	0.81	1.28	56.20	4.51	60.80	4.20
3	2.43	0.33	42.50	0.72	0.92	47.80	5.10	55.60	4.00
4	3.30	0.35	51.80	0.97	1.06	51.30	5.69	63.90	5.10
5	3.32	0.30	51.00	0.96	1.07	51.70	6.29	62.00	5.30
6	3.90	0.25	53.20	1.12	1.21	54.80	7.77	61.80	5.90
7	3.52	0.21	50.30	0.98	1.00	50.00	7.54	58.70	5.30
8	3.28	0.27	51.60	0.97	1.15	53.60	5.97	62.10	5.00
9	3.34	0.36	51.80	0.96	1.67	62.50	6.03	63.50	5.70
10	3.63	0.29	52.70	0.97	1.78	64.10	6.99	62.70	5.70
11	3.40	0.45	52.60	0.99	1.27	55.90	5.625	65.90	5.70
12	4.01	0.18	51.90	0.98	1.55	60.80	9.29	58.70	6.80
13	3.33	0.30	50.80	0.96	1.56	60.90	6.455	61.20	5.30
14	3.65	0.22	50.60	0.97	1.24	55.30	7.92	58.80	5.80
15	4.01	0.28	53.90	1.15	1.83	64.70	7.75	62.90	6.66
16	3.66	0.34	53.90	1.15	1.83	64.70	6.27	64.90	5.90
17	3.51	0.39	54.10	1.16	1.54	60.60	5.53	66.60	5.50
18	3.38	0.30	51.20	0.97	1.42	58.60	6.37	61.60	5.60
19	3.33	0.45	54.70	1.18	1.60	61.60	4.74	68.80	5.10
20	3.26	0.45	54.50	1.17	2.24	69.10	4.485	69.10	5.00
21	3.26	0.44	53.10	1.11	2.24	69.10	4.90	67.00	4.90
22	3.45	0.47	55.60	1.22	1.67	62.60	4.785	69.70	5.20
23	3.30	0.33	51.80	0.98	1.11	52.70	5.67	63.70	5.20
24	3.43	0.46	56.50	1.28	1.30	56.50	4.45	71.10	5.30
25	3.95	0.43	61.90	1.60	2.66	72.70	4.34	75.40	5.10
26	3.01	0.35	51.20	0.96	1.16	53.80	4.7	63.50	4.50
27	3.38	0.40	56.50	1.26	0.78	43.90	4.35	69.40	4.90
28	2.36	0.35	45.30	0.80	1.03	50.80	4.09	59.20	3.56
29	2.37	0.26	42.70	0.72	0.89	47.00	4.97	53.90	3.90
30	3.38	0.29	50.90	0.96	0.68	40.40	5.96	60.80	6.20
31	2.56	0.35	47.40	0.88	0.66	39.90	4.30	61.30	3.80
32	3.02	0.25	46.50	0.85	0.98	49.50	6.72	55.90	4.90
33	3.97	0.24	55.00	1.20	0.82	45.10	7.22	63.20	5.60

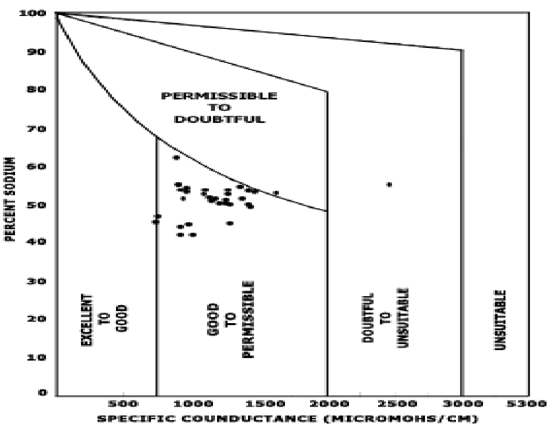

Fig. 2. Groundwater samples rating to salinity and percent of soluble sodium percent(SSP)

Sodium Adsorption Ration (SAR)

Sodium adsorption ratio (SAR) is a more reliable approach for determining the effect of relative cation concentrations to sodium accumulation in the soil than sodium percentage. The groundwater samples are classified according to SAR value as follows: < 10 excellent, 10-18 good, 18-26 doubtful and > 26 unsuitable (USSL, 1954). (SAR) is calculated with the following formula, where all ionic concentrations are expressed in $mmol_cL^{-1}$.

$$SAR = \frac{Na}{\sqrt{Ca + Mg/2}}$$ **Equation 5**

Values of SAR are shown in Table 4 and the minimum and maximum values of SAR are 2.36 and 4.01, respectively, Table (4). All the studied water samples (100%) are classified, therefore, as excellent water, where these groundwater samples have SAR values less than 10. These water samples are suitable for irrigation without any dangers of exchangeable sodium on either soil or plant (USSL 1954).

Salinity and Alkalinity Classes

According to USSL (1954) salinity and alkalinity classes, water samples are highly saline with low sodicity (C3–S1), except the sample, no. 22 that has very high salinity and low SAR (C4-S1) Fig., (3). This means that the groundwater samples cannot be used as a source for irrigation without special conditions for salinity control such as application of the water-leaching requirement, adequate drainage and selected salt tolerant plants. La¨uchli and Epstein (1990) pointed out that water salinity has undesirable effect on plant growth by different ways, such as osmotic pressure, specific ion toxicity and nutritional disorders.

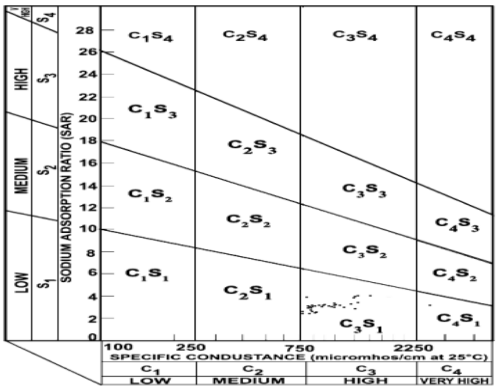

Fig. 3. Groundwater samples rating to electrical conductivity and sodicity hazard

Residual Sodium Carbonate (RSC)

Residual sodium carbonate (RSC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on water quality. It is determined by the following equation according to Prasad *et al.* (2001) $RSC = (CO3 + HCO3) - (Ca + Mg)$, where ions concentrations are expressed in $mmol_cL^{-1}$.Generally, when water has excess concentration of bicarbonate there will be tendency for calcium and magnesium to precipitate as carbonates. Table 4 shows that the values of RSC ranged from 0.184 to 0.475 $mmol_cL^{-1}$with an average of 0.34 $mmol_cL^{-1}$. Based on RSC values, the studied groundwater samples are less than 1.25 $mmol_cL^{-1}$ and can be considered good for irrigation purposes.

Kelly's Ratio

Kelly (1940) has determined the hazardous effect of sodium on water quality for irrigation usage in terms of Kelly's ratio (KR). It means the ratio of sodium to calcium and magnesium ions computed as:

$$KR = \frac{Na}{Ca + Mg}$$ **Equation 6**

KR varied from 0.72 to 1.6 with an average value of 0.98. A Kelley's ratio (KR) of more than one indicates an excess of sodium level in waters and unsuitable for irrigation, while the value of a Kelley's ratio less than one is suitable for irrigation. The results obtained herein indicate that 63.6% of Kelley's ratio (KR) values for the groundwater samples under study area are equal or less than 1 which means that 63.6 of the investigated groundwater samples are of good quality for irrigation purpose, while 36.4 % recorded KR values more than 1 which indicates that they are of unsuitable quality for irrigation (Table 4). Generally the mean KR value of water samples is (0.98) indicating that most of the ground water samples are suitable for irrigation purpose as their average KR values is less than 1.

The permeability Index (PI)

The soil permeability is influenced by several soil cations such as sodium, calcium and magnesium as well as bicarbonate anions. Raghunath (1987) and Aghazadeh and Mogaddam (2014) suggested a criterion for assessing suitability of water quality for irrigation based on permeability index (PI) and classified it into three classes: I and II are categorized as good and suitable classes for irrigation with 75% or more maximum permeability. Class III is unsuitable with 25% maximum permeability.

$$PI = \frac{Na + \sqrt{HCO3}}{Ca + Mg + Na} * 100 \qquad \textbf{Equation 7}$$

The concentrations of ions are in $mmol_cL^{-1}$. The PI values range from 53.9 (sample No. 29) to 75.4 (sample No. 25) with an average value of 63.2, (Table 4). Data revealed that about 58 % and 42 % of the studied water samples are subjected to the first and second classification, respectively, and they are good and suitable for irrigation.

Magnesium hazard

In most waters, there is an equilibrium status between calcium and magnesium but when dolomites prevail and/or in some case of soils of marine origin, magnesium prevails resulting in adverse effects on both soil and crop yields, Arveti*et al*. (2016). The excessive amounts of dissolved magnesium in irrigation water are thought to be coupled with soil permeability problems, Kushal*et al*., (2015). Magnesium hazard is assessed by following equations, firstly magnesium ratio {(Ca/(Ca+Mg))*100} and secondly calcium to magnesium molar (Ca/Mg).

Data presented in Table 4, show that the magnesium ratio varied from 39.9 to 72.7 % with an average value of 55.6 %. About 75.7 % of total samples, relatively, have Mg ratio values more than 50 %, which may adversely affect the crop yield according to Paliwal (1972). Ca:Mg molar values ranged from 0.66 to 2.66 with an average of 1.34. About 75 % of total samples showed Ca:Mg molar ratio > 1and are considered as good water class according to Jalali (2008) and Kushal et al., (2015) who pointed out that water with a Ca:Mg molar ratio <1, resulted in increases of SAR values, which adversely affect soil structure and crop yield.

Chloride (Cl)

Chloride is a good indicator of groundwater quality and it is also considered an essential element for plant growth. The minimum and maximum contents of Cl^- in the studied samples are 1.75 and 5 $mmol_cL^{-1}$, respectively (Table 3). According to Ayers and Westcot (1985), the groundwater samples can be classified into three groups, according to their contents of chloride, as follows: suitable (Cl< 4 $mmol_cL^{-1}$), marginally (4-10 $mmol_cL^{-1}$) and unsuitable (Cl> 10 $mmol_cL^{-1}$), thus about 85% of water samples which have Cl^- contents of less than 4 $mmol_cL^{-1}$ being belong to the suitable group. Moreover, and according to Mass (1990) who reported that levels of chloride between 140 and 350 mgL^{-1} are injurious to even moderately tolerant plants and those of 350 mgL^{-1} may cause severe damage to plant life, consequently about 82 % of the investigated samples are suitable for irrigation since their chloride concentrations are less than 140 mgL^{-1}.

Boron (B)

Boron content in water is considered an important indicator for evaluating its suitability for irrigation. According to the guidelines suggested by Ayers and Westcot (1985), slight to moderate degree of restriction occurs only if B content in the irrigation water exceeds 0.7 mg B L^{-1}. The results obtained herein presented very low concentrations of B in the water samples i.e. ≤0.06 mg B L^{-1} and therefore no problems with boron can be deduced in such waters. Moreover, these waters can be used safely for irrigating very sensitive crops (<0.5mg B L^{-1}) according to Ayers and Westcot (1985).

2. Assessment of Irrigation Water Quality Index (IWQI)

Quality Index (qi)

Quality index of the used parameter is calculated according to "California University Committee of Consultant (UCCC)" by Ayers and westcot (1985) as follows:

$$qi = qimax - \{(xij - xinf) * qiamp\}/xamp \qquad \textbf{Equation 8}$$

According to Meireles*et al*. (2010), the qi value was classified to four classes as follow; class 1 has value of qi from 100 to 85, class 2 from 85 to 60, class 3 (60 to 35) and class 4 (less than 35).

The quality index q_i calculated for the EC parameter, The quality index qi calculated for the EC parameter, as presented in Table 5, varied between 43.5 and 84.3 (belong to the second and third classes 6 and 94 %, respectively). Quality index values of SAR, SSP, Cl, and HCO3- are ranged between 76.6 to 93.6, 51.7 to 81, 76.3 to 93.6, and 79.4 to 90.4, respectively. These indicated that qi values for SAR, Cl, and HCO3 representing the first and second classes and, thus these samples are considered suitable for irrigation from this point of view. While the qi values of SSP belong to the second and third classes, therefore, more attention is needed for soil leaching requirements.

Irrigation Water Quality Index (IWQI)

Irrigation Water Quality Index (IWQI) is an important parameter for assessing groundwater quality (Avvannavar and Shrihari, 2008).

According to Meireles*et al*. (2010), the IWQI is classified to 5 classes as follows: IWQI which has values from 85 to 100 is considered of no restriction, while that which has values ranging from 70 to 85 is of low restriction, and IWQI of values ranging from 55 to 70 is considered of moderate restriction while that of values ranging from 40 to 55 is considered of high restriction whereas that of values ranging from 0 to 40 is considered of severe restriction, Table (2). According to the IWQI values of the groundwater samples, obtained values ranged from 73.1 to 85.7 (Fig and Table, 5). The water samples are belonged either to the first category or to the second ones, and they are either of no restriction or at least of low restriction class. The water of the first category is safe and suitable irrigating most plants; while of the second category, (low restriction) may cause problems for salt sensitive plants and therefore be used in irrigation on light textured and moderately permeable soils with salt leaching.

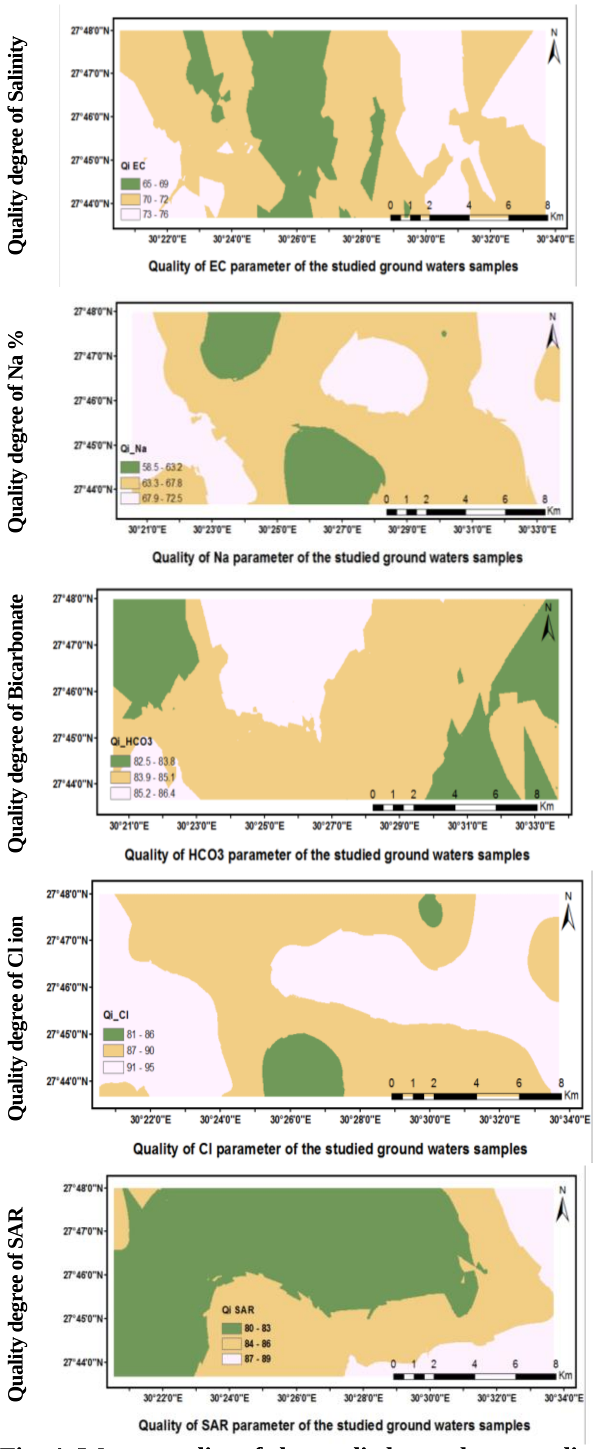

Fig. 4. Water quality of the studied samples according to different water parameters

Fig. 6 represents the relative yield potential maps of selected crops such as bean, corn, and sugarbeet as well as wheat crops based on Hoffman equation. The values of relative yield potential for bean ranged from 0.0 to 58 % with an average of 13 %, Table (6). According to the calculated values of (RYPC) for bean crop, about 58 % of the investigated groundwater samples have zero value, i.e., will not give any bean yield when used for irrigation. About 36 % of these water samples may result in relative yield potential for bean less than 50 %, whereas two samples (1 & 24) may give RYPC from 50 to 60 % (Table 6 and Fig. 6).

Table 5. Quality index q_i and total IWQI for different parameters of the groundwater's

WS	EC qi	EC IWQI	SAR qi	SAR IWQI	Na^+ qi	Na^+ IWQI	Cl^- qi	Cl^- IWQI	HCO_3^- qi	HCO_3^- IWQI	Total IWQI	R
1	79.3	16.7	91.2	17.2	77.4	15.8	94.4	18.3	80.2	16.2	84.3	NR
2	77.0	16.2	93.6	17.7	75.9	15.5	93.8	18.2	81.8	16.5	84.1	NR
3	78.7	16.6	92.5	17.5	78.1	15.9	93.1	18.1	81.0	16.4	84.4	NR
4	71.7	15.1	82.5	15.6	67.3	13.7	90.0	17.5	83.3	16.8	78.7	LR
5	69.7	14.7	82.3	15.6	65.1	13.3	87.8	17.0	84.2	17.0	77.6	LR
6	62.0	13.1	81.3	15.4	58.3	11.9	84.5	16.4	84.9	17.2	73.9	LR
7	63.0	13.3	82.5	15.6	63.3	12.9	85.6	16.6	90.4	18.3	76.7	LR
8	72.3	15.3	77.5	14.6	67.3	13.7	89.4	17.3	90.4	18.3	79.2	LR
9	70.7	14.9	80.7	15.2	65.8	13.4	88.1	17.1	82.6	16.7	77.4	LR
10	65.0	13.7	82.7	15.6	60.0	12.2	85.0	16.5	84.2	17.0	75.1	LR
11	72.7	15.3	82.2	15.5	65.8	13.4	89.4	17.3	79.4	16.0	77.7	LR
12	57.2	12.1	81.4	15.4	51.7	10.5	76.7	14.9	90.4	18.3	71.1	LR
13	69.0	14.6	79.8	15.1	64.3	13.1	87.5	17.0	84.2	17.0	76.7	LR
14	62.3	13.2	77.1	14.6	60.0	12.2	85.0	16.5	87.4	17.7	74.1	LR
15	62.3	13.2	84.9	16.0	56.7	11.6	85.0	16.5	83.3	16.8	74.1	LR
16	69.0	14.6	81.7	15.4	61.4	12.5	88.8	17.2	83.3	16.8	76.6	LR
17	73.0	15.4	76.6	14.5	65.8	13.4	90.6	17.6	82.6	16.7	77.6	LR
18	68.0	14.3	82.3	15.5	63.6	13.0	88.8	17.2	84.2	17.0	77.1	LR
19	77.7	16.4	79.6	15.0	70.8	14.5	92.5	17.9	82.6	16.7	80.5	NR
20	80.0	16.9	76.6	14.5	72.3	14.8	93.8	18.2	82.9	16.7	81.0	NR
21	77.3	16.3	79.5	15.0	70.2	14.3	92.5	17.9	81.8	16.5	80.1	NR
22	43.5	9.2	80.8	15.3	69.4	14.2	92.5	17.9	81.8	16.5	73.1	LR
23	74.0	15.6	81.8	15.5	67.3	13.7	90.6	17.6	84.2	17.0	79.4	LR
24	80.3	17.0	82.3	15.5	71.6	14.6	93.8	18.2	83.8	16.9	82.2	NR
25	80.7	17.0	82.8	15.7	69.4	14.2	95.0	18.4	90.4	18.3	83.5	NR
26	78.7	16.6	82.8	15.7	73.1	14.9	95.0	18.4	84.9	17.2	82.7	NR
27	80.3	17.0	81.3	15.4	72.3	14.8	95.6	18.5	87.4	17.7	83.3	NR
28	84.3	17.8	82.5	15.6	81.0	16.5	96.3	18.7	84.9	17.2	85.7	NR
29	79.3	16.7	81.4	15.4	77.4	15.8	95.6	18.5	87.4	17.7	84.1	NR
30	67.7	14.3	77.1	14.6	62.9	12.8	89.4	17.3	84.2	17.0	76.0	LR
31	84.0	17.7	84.9	16.0	78.8	16.1	95.0	18.4	84.9	17.2	85.4	NR
32	67.3	14.2	81.8	15.5	65.1	13.3	89.4	17.3	84.2	17.0	77.3	LR
33	64.7	13.6	81.8	15.5	60.0	12.2	87.5	17.0	90.4	18.3	76.6	LR
Aver	71.6	15.1	82.1	15.5	67.6	13.8	90.2	17.5	84.7	17.1	79.0	

WS=Water samples, IWQI=Irrigation water quality, qi=Quality of parameter, R= Restriction, NR=No restriction. LR=Low restriction;

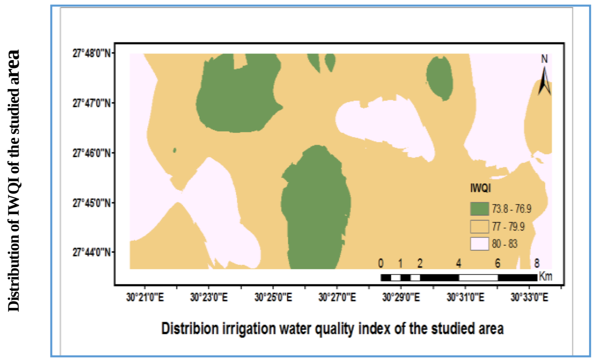

Fig. 5. IWQI for the studied groundwater samples

Relative Yield Potential for Crop (RYPC)

For corn crop, data presented in Table 6 reveal that the values of relative yield potential ranged between 0.0 to 81 % with an average of 33 %. The (RYPC) values of about 12 % (exceed 75%, while 42 % of groundwater samples are of zero (RYPC) values. The best result are those of sugar beet crop, since 94 % of the investigated groundwater samples may result in 100 % of relative yield potential, whereas groundwater samples Nos. 14 and 32 will give zero (RYPC) values.

The values of relative yield potential for wheat ranged from 0.0 to 100 % with an average of 73.5 %, Table 6. According to the (RYPC) values of wheat crop, 12.1 %, representing 4 groundwater samples have zero RYPC value i.e. will not give any yield when used for irrigation and about 9.0 % will result in relative yield potential for wheat less than 50 %, whereas eight samples will give RCYP from 52 to 88 % whereas eighteen water samples will give 100% of RYPC.

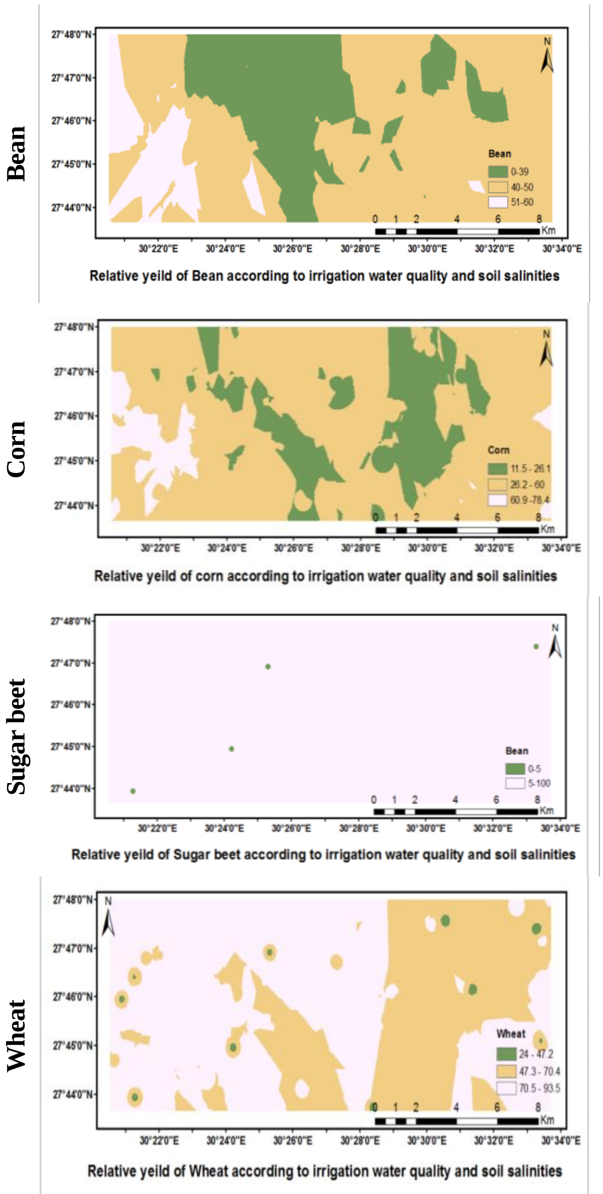

Fig. 6. Relative yield for selected crops based on Hoffman equation

Table 6. The relative yield potential for selected crops

No.	Bean	Corn	Sugar beet	Wheat	No.	Bean	Corn	Sugar beet	Wheat
1	52.4	78.0	100.0	100.0	18	0.0	0.0	100.0	18.7
2	35.8	67.5	100.0	100.0	19	23.2	59.4	100.0	100.0
3	49.8	76.4	100.0	100.0	20	0.0	0.0	100.0	0.0
4	0.0	0.0	100.0	52.1	21	48.4	75.5	100.0	100.0
5	0.0	0.0	100.0	55.2	22	17.1	55.5	100.0	100.0
6	9.4	50.6	100.0	100.0	23	9.9	50.9	100.0	100.0
7	0.0	41.6	100.0	96.1	24	58.0	81.6	100.0	100.0
8	0.0	27.7	100.0	87.9	25	47.4	74.8	100.0	100.0
9	7.5	49.4	100.0	100.0	26	0.0	38.9	100.0	94.5
10	42.0	71.4	100.0	100.0	27	0.0	38.9	100.0	94.5
11	0.0	0.0	100.0	0.0	28	0.0	0.0	100.0	47.3
12	31.6	64.8	100.0	100.0	29	0.0	0.0	100.0	47.3
13	0.0	0.0	100.0	66.6	30	0.0	0.0	100.0	66.5
14	0.0	0.0	0.0	0.0	31	0.0	0.0	100.0	66.5
15	0.0	0.0	100.0	69.3	32	0.0	0.0	0.0	0.0
16	0.0	0.0	100.0	69.5	33	5.9	48.3	100.0	100.0
17	0.0	37.2	100.0	93.5					

The aforementioned selected crops can be arranged according to the calculated RYPC values in the following descending order: sugar beet, wheat, corn and bean.

CONCLUSION

Groundwater is the only resource for irrigation in the study area. The quality of the studied ground waters samples indicated that 100% of groundwater samples are permissible for irrigation purposes based on EC, SAR and RSC. On the other hand, 94 %, 85%, 63% of ground water samples classified as good order based on Na %, Cl and KR parameters, respectively. As for multi index (IWQI) the results showed that about 21 % of the groundwater samples belong to No Restriction (NR) while about 79 % from the total samples belong to the Low Restriction (LR) category. All samples in multi index are suitable for irrigation, but some of the studied groundwater samples belong to the Low Restriction (LR) can be used successfully for irrigation, but they are in need for special salinity control management involving the addition of leaching requirements and selecting salt tolerant plants. The relative yield percent according to the RYPC values is: (94%), (74%), (33%) and (13 %) for sugar beet, wheat, corn and bean respectively.

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تقييم جودة المياه الجوفية لأغراض الري بمنطقة غرب المنيا

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تم جمع 33عينة مياه جوفية من آبار منطقة الدراسة التي تقع غرب طريق أسيوط الصحراوي الغربي لتقييم مدي مناسبة استخدام المياه الجوفية للري في أراضي غرب محافظة المنيا، والتي تبعد 300كم جنوب محافظة الجيزة, قد تم تحليل العينات المأخوذة طبقاً لمعايير الجودة مثل التوصيل الكهربائي (EC) والكاتيونات الذائبة (Ca^{2+}, Mg^{2+}, Na^+, K^+) والأيونات الذائبة (Cl^-, HCO_3^-, SO_4^{--}) بالإضافة إلي حساب كل من نسبة الصوديوم القابلة للادمصاص (SAR)، والنسبة المئوية للصوديوم الذائب (SSP)، والكربونات المتبقية (RSC) ، وكانت أهم النتائج المتحصل عليها أن حوالي 94% من عينات المياه صالحة للاستخدام الزراعي ، وأن 70% من عينات المياه الجوفية تصنف علي أنها متوسطة الملوحة – قليلة الصودية (C2-S1) ، بينما حوالي 30% منها عالية الملوحة - قليلة الصودية (C3-S1)، و بجانب التقييم الفردي السابق (Individual Index)لعينات المياه، فإنه تم تقييم المياه بواسطة مجموعة عوامل مجتمعة (Multi Index) أو ما يسمي بمعايير جودة مياه الري (IWQI) وهي عبارة عن مجموعة من القياسات والتقديرات تشمل (EC, SAR, Na %, Cl and HCO_3)، وفيها وجد أن كل عيناتت منطقة الدراسة مناسبة للري حيث كانت حوالي21 % من جملة عينات المياه جيدة وصالحة للاستخدام وليس بها أي ممانعة حال استخدامها (No Restriction)، وحوالي79 % بها ممانعات قليلة (Low Restriction) وتحتاج إلي إدارة جيدة عند استخدامها، بالإضافة إلي ما سبق، فإنه تم حساب المحصول النسبي (RYPC) لبعض المحاصيل المختارة عند زراعتها وريها باستخدام هذه النوعية من المياه الجوفية وتحت ظروف أراضي منطقة الدراسة، وقد أظهرت التقديرات أن الأفضلية المحاصيل المختارة كانت لمحصول بنجر السكر (94 %) يليه محصول القمح (74 %) ثم الذرة (33%) ثم الفول (13%).وبالتالي فإن المياه الجوفية المدروسة يمكن أن تستخدم بنجاح في الاستخدامات الزراعية، وبعضها يحتاج إلى إدارة خاصة للتحكم في الملوحة مثل إضافة معدلات الغسيل اللازمة لمنع تراكم الأملاح وإبعادها خارج منطقة انتشار الجذور واختيار النباتات التي تتحمل الملوحة.