Groundwater Assessment by using Water Quality Index in Some Agricultural Expansion Areas in Sohag Governorate, Egypt

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ABSTRACT

The present study aims to assess groundwater quality for agriculture purposes using water quality index (WQI) in some agricultural Expansion areas at Sohag Governorate in Egypt. Forty seven (47) water samples were collected from different wells and analyzed. The parameters that define the water quality were recognized using Principal Component Analysis and Factor Analysis (PCA/FA). Hence electrical conductivity (EC), soluble sodium (Na^+), soluble chloride (Cl^-), and sodium adsorption ratio (SAR) were determined. Based on the obtained results, the WQI values ranged between 10.36 and 97.19. About 53.2% of the samples were unsuitable for irrigation. However, 12.8% of samples may be suitable for the irrigation of soils without salinization problems. The remaining samples (34%) showed an average of WQI values were 8.51, 6.38 and 19.15 within the low, moderate, and high restriction classes, respectively. WQI may be successfully used as a guideline for the decision-makers.

Keywords: Groundwater Assessment, Water Quality Index, Agricultural Expansion Areas

INTRODUCTION

Groundwater that lies beneath the surface is one of the most important resources available to humanity, and it is an essential part of the hydrologic cycle. As the rapidly increasing population, several environmental problems are created, including groundwater quality deterioration (Christophoridis et al., 2009; Masoud et al., 2016). Therefore, it is more than necessary to provide a system that can assess its quantity and quality over space.

In groundwater studies, GIS and RS are ordinarily used for studies of different objectives related to groundwater. These include groundwater quality classification, and spatial analysis of groundwater quality (Asadi et al., 2007; Yammani, 2007).

Doneen (1964) and Christiansen et al. (1977) proposed different numbers of guidelines for irrigation water quality classifications. The broadest accepted criteria applied in many countries were adopted according to US Salinity Laboratory (Staff, 1954) proposed guidelines that deal with four criteria, i.e., toxicity, permeability, salinity, and others. Consequently, the proposed guidelines were adjusted by Ayers and Westcot (1985) and widely used to assess irrigation water quality. Although all the guidelines above came in handy, none was satisfied under variable field conditions. To overcome this problem, scientists employed a mathematical index by combining water quality parameters to generate arithmetic tool called water quality index (WQI).

Water Quality Index (WQI) is a technique for assessing the suitability of groundwater for alternative purposes. WQI highlighted water quality issues by the decision-makers (Katyal, 2011). Ten widely applied and accepted water quality variables water used for calculating WQI, (Horton, 1965). According to Water Quality, National and International Agencies, there are many indexes specific to each area region (Dao et al., 2020; Tyagi et al., 2020).

The present study was proposed to assess groundwater suitability for irrigation in the new reclaimed area in Sohag Governorate using WQI and map the groundwater quality throughout the study area. This is very useful for increasing the interaction between decision-makers and end-users, and agricultural investors by facilitating the data of whole groundwater quality.

MATERIALS AND METHODS

1. The study location

Sohag governorate (Fig. 1) covers a part of the Nile Valley, Egypt and extends from the northern side of Qena governorate at latitude 26°07′N to the southern side of Assiut governorate at latitude 26°57′N. It is bounded between longitudes 31°20′ and 32°14′E.

As stated by the Census estimation in 2018, the total population in Sohag city Governorate reached 5 $(10)^6$ people (Sayed, 2018). They represent about five percent of the Egyptian population. The area's economy depends chiefly on crop production, like, wheat, cotton, sugar cane, corn, sorghum, and others. The study area is generally characterized by hot summer and mild winter (Fig. 2 and 3)with low rainfall and high evaporation rate (Liu et al., 2015).

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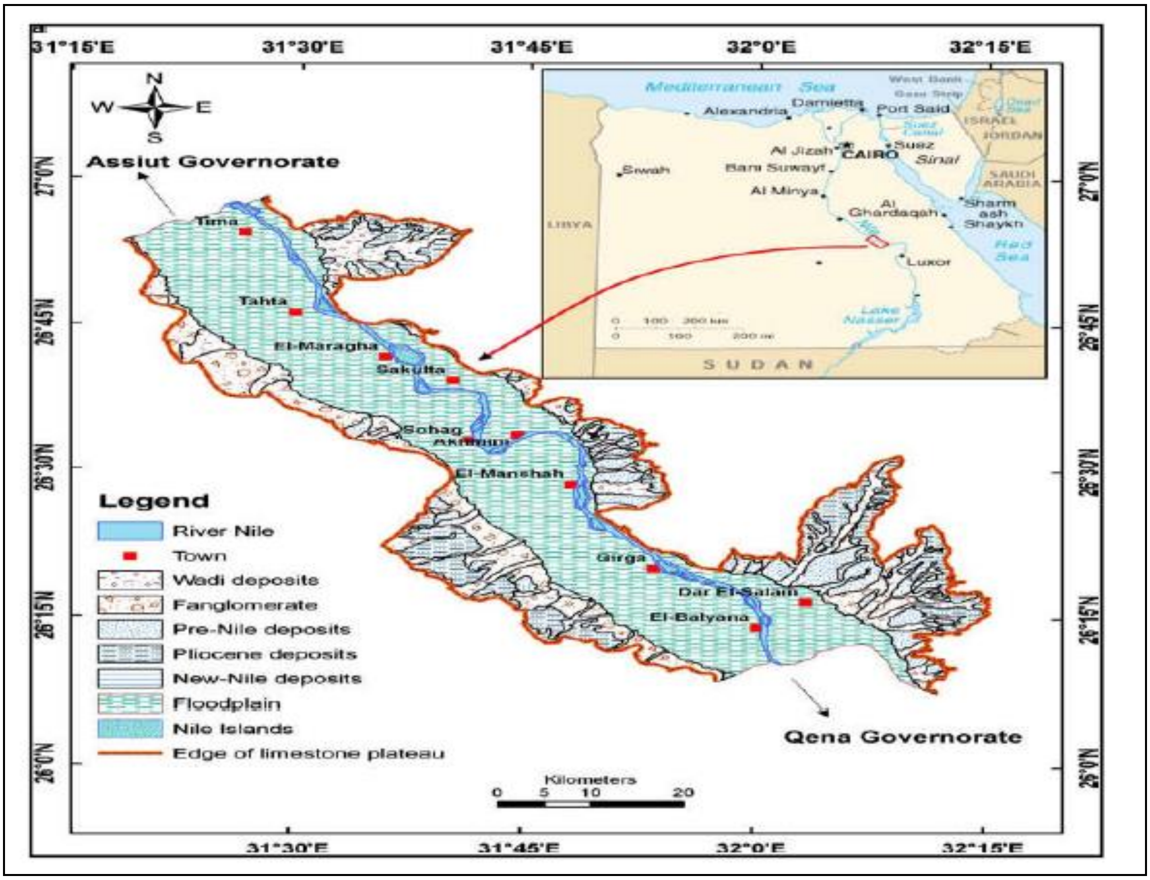

Fig. 1. The location map of the studied area.

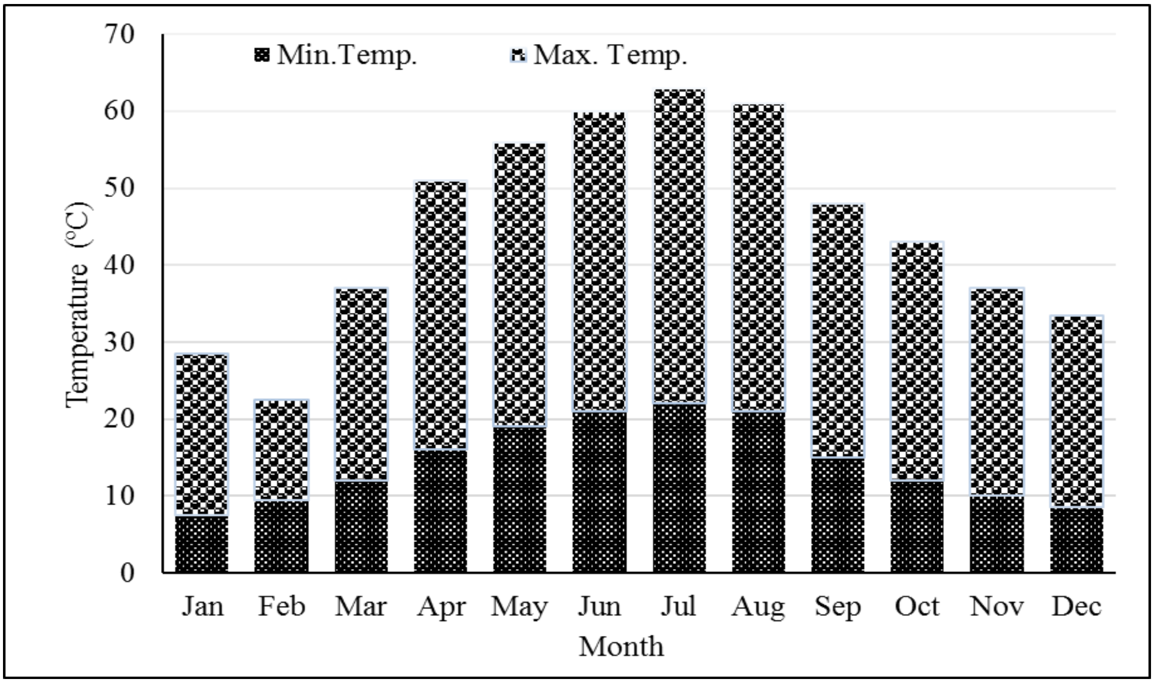

Fig. 2. The mean temperature of the study area.

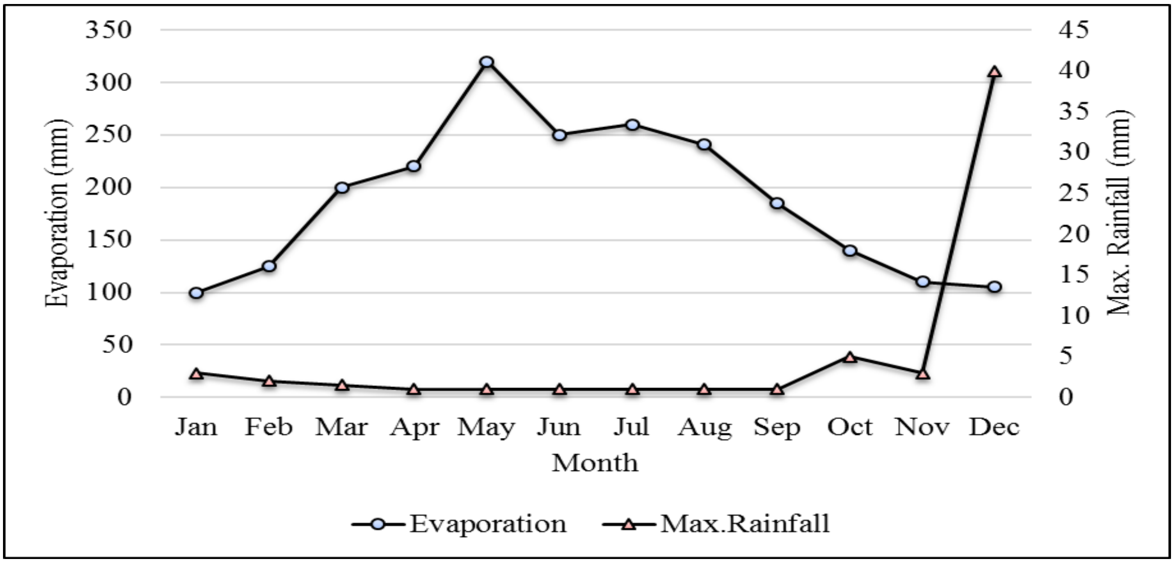

Fig. 3. The mean evaporation and rainfall of the study area.

2. Satellite and ancillary data

In the current study, the Landsat TIRS satellite data were used. The study area is covered by three images viz., (175 Path /42 Row, 176 Path /42 Row, and 176 Path /41 Row). The digital data of geo-coded cloud free of three images were downloaded from (http://glcf.umd.edu/data/landsat/). Using ENVI 4.8 software (Research Systems Inc., Boulder, CO, US), the Sohag Governorate image was extracted and masked from the whole image. The digital elevation model (DEM) and slope maps (Figs. 4 & 5) of the study area were generated following the standard methodology of Mustafa and Moursy, (2020). The land use/ land cover map (Fig. 6) was also generated by El Sayed, (2016).

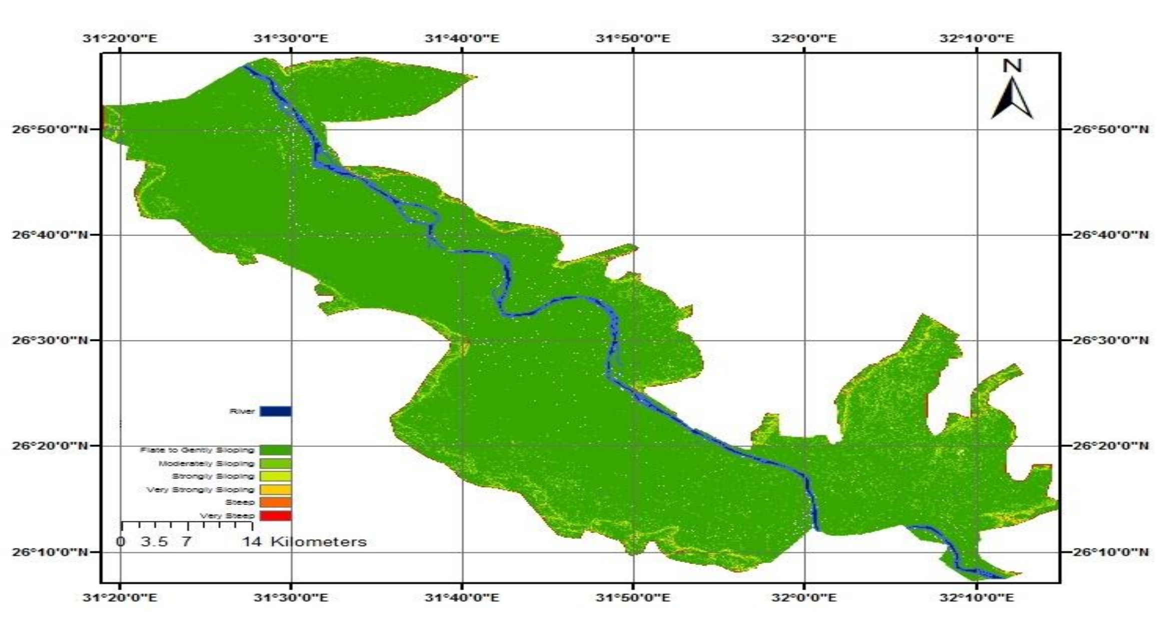

Fig. 4. The slope map of the study area.

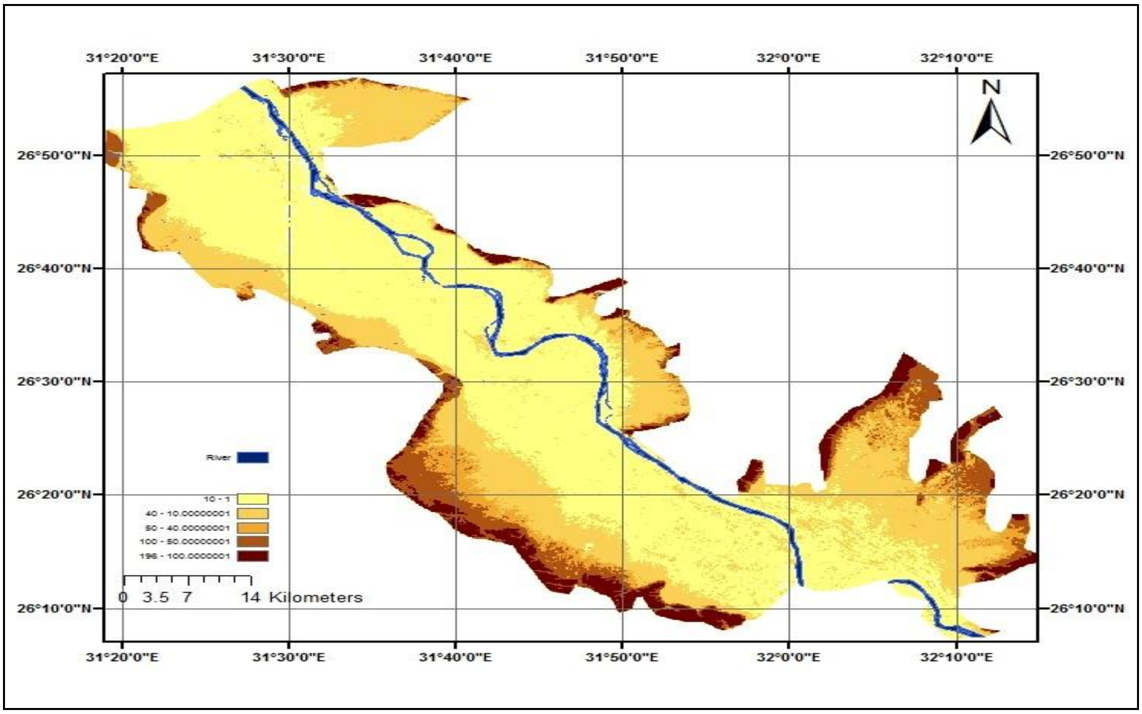

Fig. 5. The digital elevation model (DEM) map of the study area.

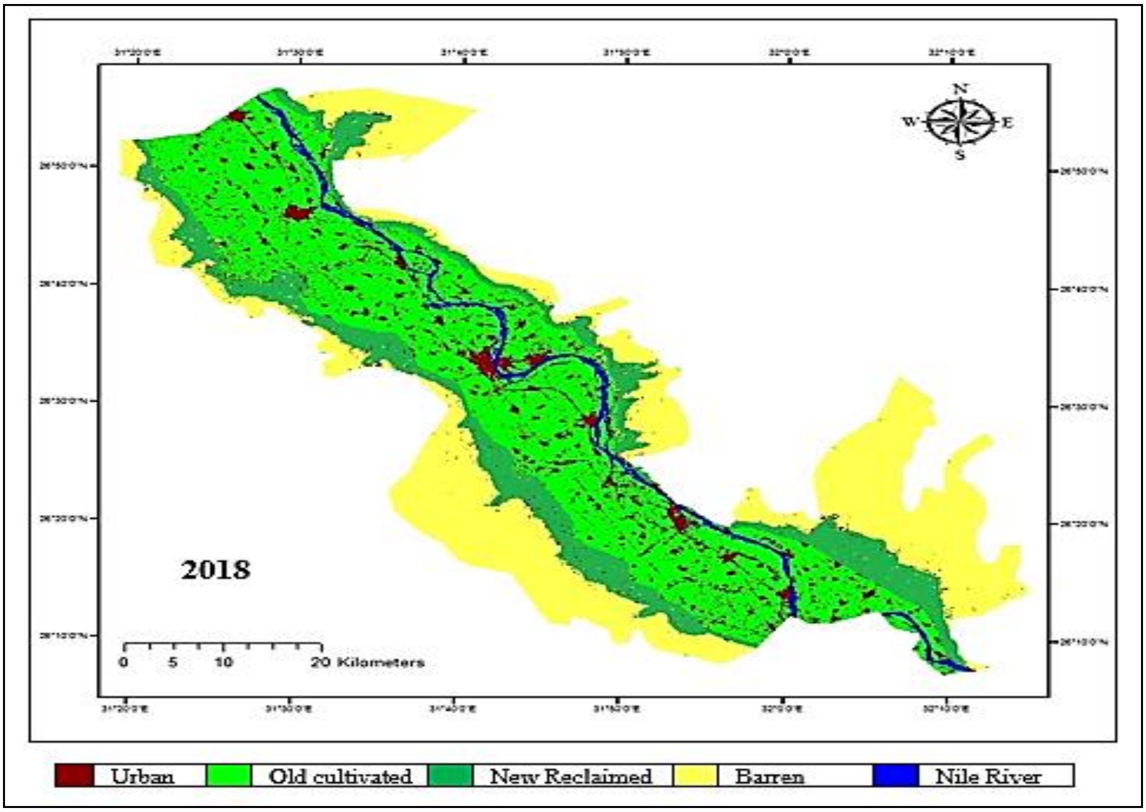

Fig. 6. Land use and land cover map of the study area.

Available research papers, dissertations, and reports were a useful guide in the present study. Corresponding maps on a scale of 1:250,000 were used as secondary data to recognize the different features of the area under study.

3. Methodology

3.1. Extraction of agricultural extension areas

Using visual interpretation and unsupervised classification of ENVI 4.8 software (Research Systems Inc., Boulder, CO, US), the agricultural extension areas in the present study were extracted and masked out from the whole image. The extracted image was saved as a shapefile and used under Arc GIS 10.1 environment for the spatial data analysis.

3.2 Field study and sample collection

Forty seven water samples (Fig. 7) were collected to assess groundwater quality from the different wells located in agricultural extension areas according of the standard procedures proposed by Association et al., (1915).

3.4 Water analysis

The samples were filtered and stored for further analysis. All methods used in this study were done following standard methods of water chemical analysis elaborated (Association et al., 1915).

4. Proposed water quality evaluation model

The water quality index (WQI) proposed in this study was developed in two steps (Cude, 2001). Firstly, parameters that caused variability in irrigation water quality were recognized using (PCA/FA) as given in STATISTICA 10 Computer Program distributed by StatSoft Inc. Secondly, quality values (qi) and weights (Wi) were generated. Values of (qi) were estimated based on each parameter value, according to irrigation water quality parameters proposed by UCCC and by the criteria elaborated by Ayers and Westcot (1995). Each parameter weight used in the WQI was obtained from the PCA/FA, by the sum of all factors multiplied by each parameter's explainability. Then wi values were normalized such that their sum equals one. The water quality index was calculated, as shown in the following equation (Kawo and Karuppannan, 2018):

$$WQI = \sum_{i=1}^{n}(q_i W_i) \qquad (1)$$

Rating the classes based on the threat of salinity for soil and plants (Bernardo, 1995).

5. Generation of thematic maps

Inverse distance weight (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. Thematic maps were generated for each of the determined parameters using IDW interpolation in Arc GIS 10.1 software.

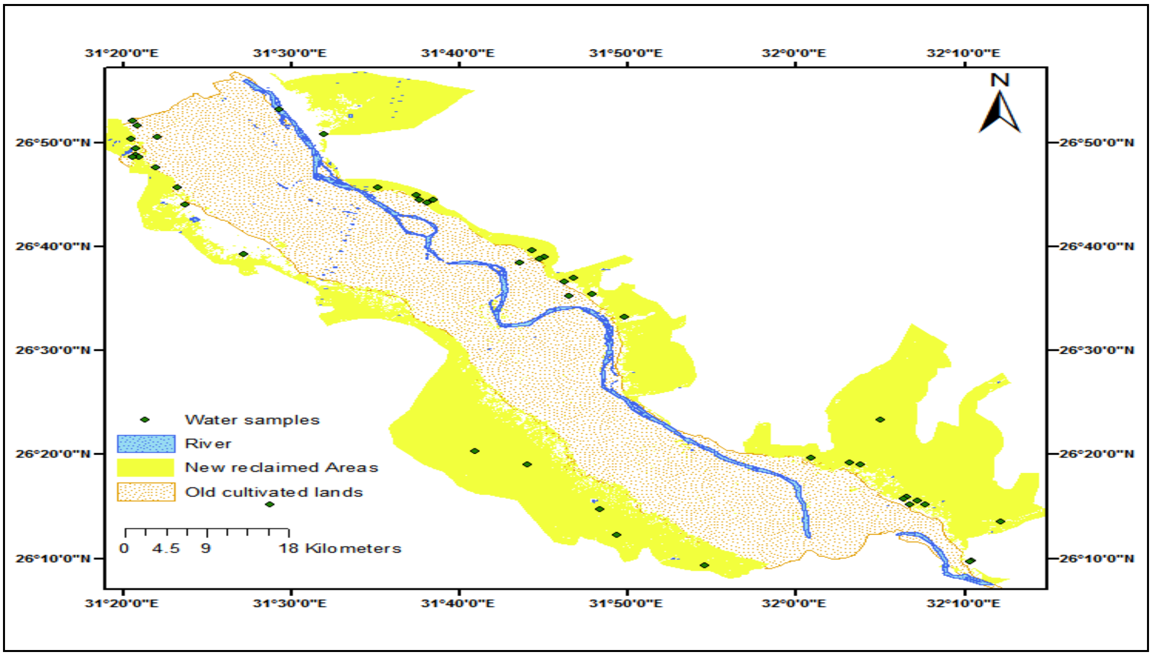

Fig. 7. Water samples locations map.

RESULTS AND DISCUSSION

1. Hydrochemical characteristics of groundwater samples:

1.1 Total dissolved solids

The quality of irrigation water can vary depending on the type and quantity of dissolved salts. This salt accumulates in the root zone, and hence occurs the salinity problems cause a loss in yield. Irrigation water with TDS less than 500 mg/L is considered acceptable, whereas TDS greater than 2000 mg/L is harmful and unsuitable for irrigation (Sappa et al., 2014). In the current study, the lowest value of total dissolved solids was 476.3 mg/L, while the highest value was 6094.2 mg/L, with an average value of 2129.91 mg/L (Table 1). More than 44% of samples are unfit for irrigation, and about 34% may adversely affect plant growth and hence requiring careful management practices.

1.2 Hydrogen–ion activity

The pH value represents the degree of acidity or alkalinity. It ranges from 7.9 and 8.5. This indicates that the groundwater is slightly alkaline to alkaline.

1.3 Electrical conductivity

In the present study, the electrical conductivity (EC) values ranged between 0.66 to 9.9 dSm^{-1} with an average of 3.38 dSm^{-1} (Table 2). The EC up to 0.7 dSm^{-1} has no effects; whereas, an EC of 0.7 dSm^{-1} to 3 dS/m has a slightly moderate effect on crops. EC values of more than 3 dSm^{-1} will damage the crop (Al-Kharabsheh, 1999; Ayers and Westcot, 1985). Water with high salinity is toxic to most plants and poses a salinity hazard. According to the EC values, the waters have been classified as excellent, suitable, permissible, doubtful, unsuitable (Table 2). 53.19% of the studied when samples are unsuitable for irrigation. and 31.91% of samples exhibit permissible salinity levels these are suitable for irrigation and may leaching is required.

Table 1. Summary of descriptive statistics of determining chemical investigation of the groundwater samples.

Property	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Skewness	Kurtosis
Ec	3.38	3.07	0.66	9.90	1.76	4.55	9.24	2.10	0.93
Na^+	20.69	19.87	4.34	67.69	8.73	28.26	63.34	13.18	1.26
K^+	0.13	0.12	0.02	0.51	0.07	0.15	0.48	0.10	1.74
Ca^{2+}	6.95	5.85	0.65	20.60	3.70	10.30	19.95	4.80	0.99
Mg^{2+}	6.70	4.91	0.25	16.41	3.08	10.00	16.16	5.05	0.77
HCO_3^-	4.41	4.32	1.80	9.67	3.73	4.91	7.86	1.30	1.31
Cl^-	17.75	13.49	1.15	59.26	7.97	24.39	58.11	13.48	1.11
SO_4^{2-}	10.941	10.18	0.27	30.58	3.68	17.08	30.31	7.76	0.44
SAR	8.01	7.89	2.61	16.51	5.75	9.78	13.90	3.05	0.57
TDS	2129.9	1941.56	476.28	6094.20	1145.08	2841.40	5617.92	1279.15	0.93
pH	8.30	8.00	7.9	8.50	7.90	8.10	0.50	0.10	-0.19

Table 2. Classification of Irrigation water according to EC value.

Class	EC (dSm^{-1})	Samples within the limits	
		Count	%
1	<0.25	--	--
2	0.25- 0.75	2	4.26
3	0.75- 2.25	15	31.91
4	2.25-3.00	5	10.64
5	>3.00	25	53.19

1.4 Sodium adsorption ratio

Sodium adsorption ratio (SAR) is an essential measure of alkali/sodium hazard to crops and damages the soil structure, making it compact and impervious (Subramani et al., 2005 Raju, 2006). The SAR is the relative proportion of sodium ions in a water sample to calcium and magnesium ions. The SAR values are classified into four classes (Table 3). In the present study, the water samples have low SAR values within 10 and hence less likely to cause any soil structure determination. This crucial result revealed that the grand water in the newly reclaimed area is most suitable for irrigation.

The chloride concentration of the groundwater samples was within a wide range of 1.15 – 59.26 me/L. The range of HCO_3 values in the water samples was 1.8 - 9.67 me/L.

1.5 Principal component and factorial model

The correlation matrix for the measured parameters is presented in Table 4. The highest correlation above 0.9 was obtained between EC, Na, Ca, Mg, Cl, SAR, and TDS. According to the Kaiser-Meyer-Olkin (KMO) adequacy test, the value of 0.82 indicates that the model may be applied with any restrictions. These results are close to those reported previously (Parinet et al., 2004).

The result of many studies indicated that the two to four first generated components explain a high part of the variations of the original data (60 to 90%), thus allowing the use of such components to describe the data completely (Helena, 2000; Inácio et al., 2002; Omran et al., 2014; Simeonov et al., 2003). According to Table 5, about 65.5% of the whole variance explained by the first Factor, whereas 11.4, 10.8, and 9.1% were described by the second, third, and fourth factors, respectively. The EC, Na^{+}, Mg^{2+}, $Ca^{2+,}$ SO^{2-} and Cl^{-} parameters present a load above 0.70, whereas SAR presents a load of 0.63 in the first component.

2. Water quality index characteristics

The normalized weights wi were found to be 0.2961, 0.2671, 0.2982, and 0.1386 for EC, Na, Cl, SAR, respectively. Classes were defined according to the risk of toxicity to plants, salinity, and infiltration rate reduction (Holanda et al., 1997). Based on the results observed (Table 6), the WQI varied from 10.36 to 97.19. About 53.19% of samples unsuitable for irrigation and should be avoided for use under normal conditions. However, 12.77% and 8.51% of samples were very high and highly suitable for irrigation and may be used for a great extent of soils. The remaining samples showed an average of WQI within the moderate and margined suitable classes, with a percent of 6.38 and 19.15, respectively. The spatial variability of WQI map is presented in Fig. 8.

Table 3. Classification of Irrigation water according to SAR value.

Class	SAR	samples within the limits	
		Count	%
1	<10	36	78.26
2	10 – 18	10	21.74
3	18 – 26	--	--
4	>26	--	--

Table 4. Correlation coefficients of determining chemical investigation of the groundwater samples.

Property	EC	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	SAR	TDS
EC	1.00									
Na^{+}	0.97	1.00								
K^{+}	0.33	0.24	1.00							
Ca^{2+}	0.90	0.79	0.37	1.00						
Mg^{2+}	0.90	0.80	0.43	0.86	1.00					
HCO_3^{-}	-0.21	-0.13	0.04	-0.30	-0.24	1.00				
Cl^{-}	0.97	0.91	0.28	0.92	0.92	-0.30	1.00			
SO_4^{2-}	0.93	0.93	0.34	0.79	0.78	-0.15	0.82	1.00		
SAR	0.67	0.81	0.00	0.37	0.39	0.14	0.55	0.74	1.00	
TDS	1.00	0.97	0.33	0.90	0.90	-0.21	0.97	0.93	0.67	1.00

Table 5. Factors loads and communalities for the measured properties.

Property	Factor 1	Factor 2	Factor 3	Factor 4	Communality
EC	0.995	0.021	0.034	-0.078	0.997
Na^+	0.949	-0.040	-0.039	-0.284	0.985
K^+	0.300	-0.057	0.948	0.069	0.996
Ca^{2+}	0.922	0.117	0.085	0.240	0.928
Mg^{2+}	0.923	0.037	0.147	0.230	0.928
HCO_3^-	-0.197	-0.975	0.054	-0.084	0.999
Cl^-	0.978	0.093	-0.032	0.085	0.973
SO_4^{2-}	0.906	0.013	0.115	-0.306	0.929
SAR	0.630	-0.219	-0.166	-0.715	0.984
Variance	5.8958	1.0273	0.9739	0.8206	8.7177
% variance	65.5	11.4	10.8	9.1	96.9

Table 6. Classification of water samples according to WQI.

Water Quality Class	WQI	samples within the limits		Suitability
		Count	%	
Excellent	$85 \leq 100$	6	12.77	Very high
Good	$70 \leq 85$	4	8.51	highly
Poor	$55 \leq 70$	3	6.38	Moderately
Very Poor	$40 \leq 55$	9	19.15	Marginally
Unsuitable	$0 \leq 40$	25	53.19	Unsuitable

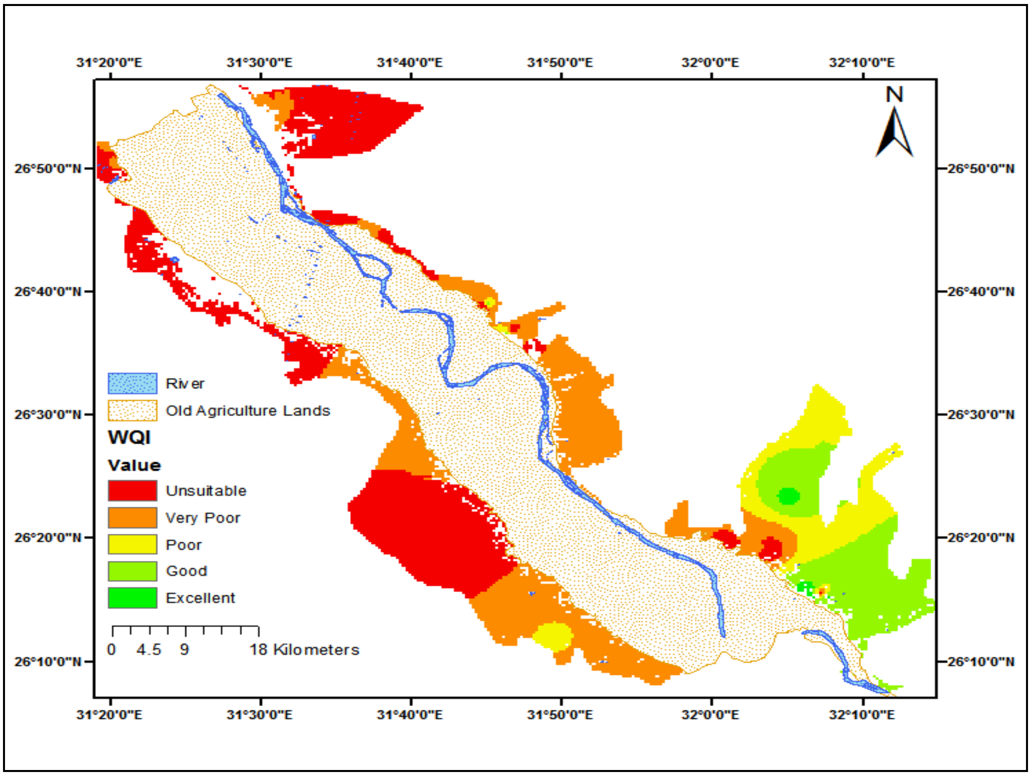

Fig. 8. The IDW of WQI values throughout the study area.

CONCLUSIONS

The water quality index (WQI) considers as a tool for understanding ground water quality and management. It was calculated based on various important parameters in the studied area to dissect irrigation water's suitability for agricultural purposes. The observed data indicated that the WQI ranged between 10.36 and 97.19. About 53.19% of samples unsuitable for irrigation and should be avoided use under normal conditions. However, 12.77 and 8.51% of samples were very high and highly suitable for irrigation and may be used for a great extent of soils. The remaining samples showed an average of WQI within the moderate and margined suitable classes, with a percent of 6.38 and 19.15, respectively. WQI can be successfully used to transform the complex water quality data into easy and understandable guidelines appropriated by the decision-makers.

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الملخص العربي

تقييم جودة المياه الجوفية باستخدام مؤشر جودة المياه في بعض مناطق التوسع الزراعي في محافظة سوهاح، مصر

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تهدف الدراسة الحالية إلى تقييم جودة المياه الجوفية للأغراض الزراعية باستخدام مؤشر جودة المياه (WQI) في بعض مناطق التوسع الزراعي في محافظة سوهاج، مصر. حيث تم جمع سبعة واربعون (٤٧) عينة مياه من آبار جوفية مختلفة وتم تحليلها. أيضاً تم التعرف على القياسات التي تحدد جودة المياه باستخدام تحليل المكونات الرئيسية وتحليل العوامل (PCA / FA). وتم قياس التوصيل الكهربائي (EC) والصوديوم الذائب (Na) والكلوريد الذائب (Cl) ونسبة ادمصاص الصوديوم (SAR). بناءً على النتائج التي تم الحصول عليها، تراوحت قيم WQI بين ١٠.٣٦ و٩٧.١٩. حوالي ٥٣.٢٪ من العينات كانت غير صالحة للري. ومع ذلك، فإن ١٢.٨٪ من العينات قد تكون مناسبة لري التربة دون مشاكل تمليحها. وأظهرت العينات المتبقية (٣٤٪) أن متوسط قيم WQI كان ٨.٥١ و٦.٣٨ و١٩.١٥ ضمن فئات الحصر المنخفضة والمتوسطة والعالية على التوالي. لذا يمكن استخدام WQI بنجاح كدليل لصانعي القرار.