Quality Assessment and Spatial Variability Mapping of Water Sources of Sohag Area, Egypt

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ABSTRACT: This study aimed to assess the quality and suitability of water sources for irrigation in Sohag area. A total number of 61 different water samples were collected from various sources which were representative of the study area. The water samples were analyzed in terms of properties pH, EC_w, soluble cations, and anions. Water samples were alkaline (pH above 7.00), EC_w ranged between very low (0.21 $dS.m^{-1}$) and very high (5.62 $dS.m^{-1}$). Soluble sodium was the dominant cation followed by calcium, magnesium, and potassium, respectively. Regarding soluble anions, chloride was dominant and followed by sulphates and bicarbonates. The data of water analysis have been put into several indices for assessing water suitability for irrigation such as electrical conductivity (EC_w), total dissolved salts (TDS), residual sodium carbonates (RSC), sodium adsorption ratio (SAR), sodium percentage (SP), permeability index (PI), Kelly ratio (KR), and magnesium hazard (MH). The most prominent results was that the water used for irrigation in sites of Elmonshah, Sohag, Akhmim, and El-Maraghah were not suitable for irrigation, while the water from other sources was of sufficient quality and suitability for irrigation. Water quality maps were produced using GIS. The results of this study along with spatial maps can be used as a guide for decision-makers in achieving better planning for water management and optimal utilization.

Keywords: water quality, water suitability, Sohag, residual sodium carbonate, sodium adsorption ratio, mapping.

INTRODUCTION

There is no doubt that water is the basis of life, without it no living creature can exist. Water is very necessary to irrigate crops and provide food for people. Conservation of the water resource is very important to the continuation of living on the planet. Therefore, world governments are striving to focus on the good management of water resources. Moreover, reducing the degradation of water resources is a concern of all human beings **(Adimalla *et al.*, 2020).** Recently, the problems of deteriorating water resources, which are pollution, salinization, depletion, and others, have increased. With the increasing climatic changes that negatively affect water resources, it has become necessary to move quickly towards finding innovative solutions to address the matter. Egypt suffers from a severe water problem, as the population increases and its needs in water consumption, and on the other hand, Egypt's share of the Nile water has decreased due to the construction of the Grand Ethiopian Renaissance Dam. However, the Egyptian government is focusing on finding quick solutions that are innovative and economical at the same time to save water consumption. More than 80% of Egypt's share of water falls under the category of agricultural consumption, and 20% is consumed in industry and other activities **(Amer *et al.*, 2017).**

There are two main sources of water in Egypt, the Nile River, and groundwater. The Egyptian government has resorted to establishing several agricultural reclamation projects in the new desert lands, east, and west, to meet the population's food needs. Therefore, water is provided for agricultural activities in those new areas from groundwater that is less in quantity and quality than from the waters of the Nile River **(Ibrahim and Elhaddad 2021).** Therefore, during this period, the focus should be on evaluating the quality and suitability of water, whether from the Nile River or groundwater for irrigating different crops **(Bahadir *et al.*, 2016).** One of the methods used to assess the quality and suitability of water is chemical laboratory methods. Therefore, many water analyses are performed and the results are included in many water quality and suitability assessment models. These models used are intended to classify water samples according to their quality and suitability for irrigating crops. Many studies were carried out to assess water quality and suitability using water chemical parameters **(Adimalla and Qian, 2019; Adimalla and Taloor, 2020; Aravinthasamy *et al.*, 2020; Balamurugan *et al.*, 2020; Haque *et al.*, 2020; Karuppannan and Serre Kawo, 2020; Khan *et al.*, 2020; Panneerselvam *et al.*, 2020; Yetis *et***

***al*., 2021).** The suitability classification data can then be used to produce spatial maps using the Geographic Information System (GIS) that can be utilized as a guide for decision-makers to reach the best use of water and to better manage those resources. Based on what was previously mentioned, this study aims to assess the quality and suitability of water sources in Sohag area and also to produce spatial distribution maps of water suitability.

MATERIALS AND METHODS

Study area

The study area is a part of Sohag Governorate that extend from Tahta city in the area lies between 26°10'21.28", 26°50'30.95"N latitudes and 31°20'51.45", 32° 9'49.11"E longitudes with elevation ranged between 61 and 73 m.a.s.l. The map of the study area was demonstrated in figure (1). The study area belongs to the arid region of North Africa which is generally characterized by hot summer and mild winter with low rainfall. Air temperature ranges between36.5°C (summer) and 15.5°C (winter), relative humidity ranges between 51% and 61% (winter), 33%, and 41% (spring), and 35% and 42% (summer). Old agricultural soils are mainly irrigated by the Nile River and some parts of the newly reclaimed soils are irrigated by the groundwater.

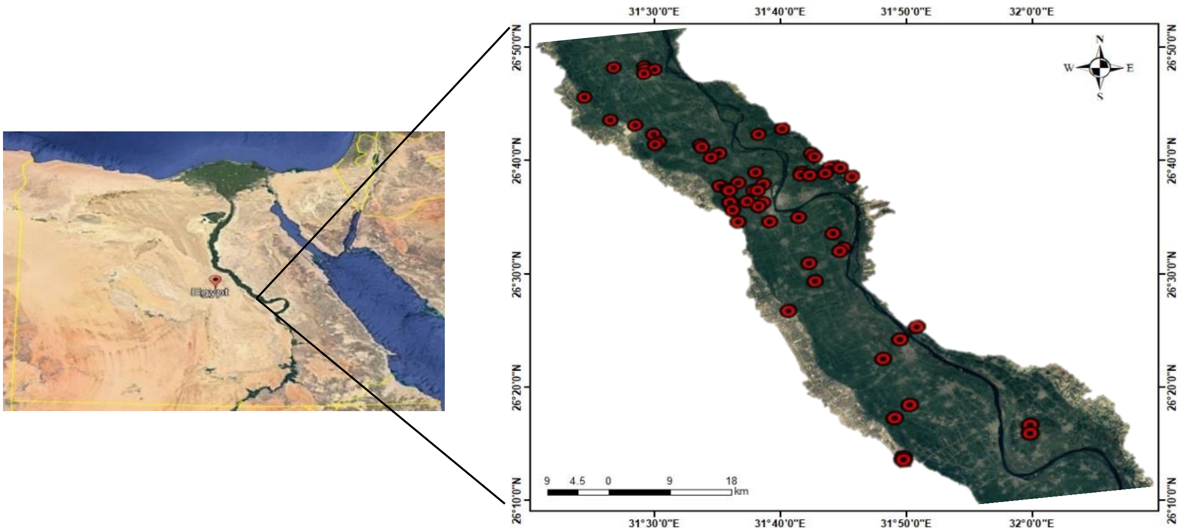

Figure (1) The study area and water sampling location map.

Water sampling

Water samples were collected from different locations in the study area whereas different water sources (Nile River and groundwater). A total number of 61 water samples were collected and shifted immediately to the water testing laboratory to be analyzed for their elemental content. The geo-coordinates of latitudes and longitudes of each water sampling location were recorded using GPS in the sampling sites. Table (1) showed the geo-coordinates of the water sampling locations.

Table (1) Water sampling locations.

SN	Location	Latitudes	Longitudes	SN	Location	Latitudes	Longitudes
		Decimal degrees				Decimal degrees	
1	Awlad Azaz	26.54906	31.64780	**32**	Akhmim	26.60611	31.77058
2	Awlad Azaz	26.54856	31.64807	**33**	El-Maragha	26.62847	31.62189
3	Elshamarna Edfa	26.58022	31.65411	**34**	El-Maragha	26.56981	31.64203
4	Naga Eldier	26.36445	31.90287	**35**	El-Maragha	26.62125	31.61228
5	Edfa	26.57485	31.63094	**36**	Dar Al-Salam	26.22203	32.04497
6	Edfa	26.56769	31.64444	**37**	Dar Al-Salam	26.23269	32.04464
7	Sahel Tahta	26.77863	31.49465	**38**	El Baliana	26.23947	31.88658
8	Markaz Tahta	26.77631	31.45292	**39**	El Baliana	26.25714	31.90283
9	Sahel Tahta	26.77309	31.51074	**40**	El Osairat	26.47453	31.79781
10	Sahel Tahta	26.76563	31.49707	**41**	Elmonshah	26.50136	31.78642
11	Elmonshah Balasfora	26.52607	31.73951	**42**	Elmonshah	26.38542	31.74386
12	Rawafae Elkosair	26.51900	31.70341	**43**	Sohag	26.59753	31.67458

13	Elmonshah Elherizat	26.45602	31.76105	**44**	Sohag	26.57833	31.68742
14	Elmonshah	26.47893	31.80185	**45**	Sohag	26.56842	31.67606
15	Gerga Elgazera	26.34660	31.88392	**46**	Sohag	26.51822	31.66286
16	Gerga Elmashtal	26.31920	31.86614	**47**	Sohag	26.54275	31.68589
17	Gehina Nazat Alheish	26.68368	31.46607	**48**	Sohag	26.54875	31.69100
18	Gehina Nazat Alheish	26.67521	31.50147	**49**	Akhmim	26.62908	31.74392
19	Akhmim Elsalamouna	26.60829	31.77739	**50**	Akhmim	26.59369	31.73422
20	Akhmim Elsalamouna	26.59651	31.76612	**51**	Akhmim	26.59803	31.73431
21	Tahta Elsawalem	26.77299	31.49698	**52**	Akhmim	26.59319	31.74619
22	Tahta Nazlet Ali	26.72334	31.42256	**53**	Akhmim	26.60558	31.78486
23	El Baliana	26.18847	31.90069	**54**	Akhmim	26.59125	31.80142
24	El Baliana	26.18558	31.90125	**55**	Saqulta	26.66047	31.66992
25	Elmonshah	26.42919	31.77172	**56**	Saqulta	26.66997	31.70044
26	Elmonshah	26.42617	31.67189	**57**	El-Maragha	26.64253	31.59442
27	Sohag	26.55031	31.67003	**58**	El-Maragha	26.65967	31.52892
28	Sohag	26.53675	31.65322	**59**	El-Maragha	26.63842	31.59747
29	Sohag	26.56828	31.68133	**60**	Gehina	26.64242	31.53419
30	Saqulta	26.67042	31.70019	**61**	Gehina	26.64642	31.53853
31	Akhmim	26.62361	31.74883				

Water analysis

Water samples were analyzed using the standard methods of analysis. Analyzed water parameters are such as water pH, water Electrical Conductivity (EC_w), water-soluble cations (sodium 'Na^+', potassium 'K^+', calcium 'Ca^{2+}' and magnesium 'Mg^{2+}'), and soluble anions (chloride 'Cl^-', bi-carbonates 'HCO_3^-' and sulphates 'SO_4^{2-}'). Data of EC_w was calculated in $ds.m^{-1}$, while soluble cations and anions were calculated in $meq.l^{-1}$. The methods used for water analysis are presented in table (2).

Table (2) Methods used for estimation of different chemical parameters of water samples in the study area

Parameters	**Methods used**
pH	Glass electrode **(Richards, 1954)**
EC_w (Electrical Conductivity)	Conductivity Bridge method **(Richards, 1954)**
Na^+ (Sodium)	Flame Photometric method **(Osborn and Johns, 1951)**
K^+ (Potassium)	Flame Photometric method **(Osborn and Johns, 1951)**
Ca^{2+} (Calcium) and Mg^{2+} (Magnesium)	EDTA titration method **(Richards, 1954)**
HCO_3^- (Bicarbonate)	Acid titration method **(Richards, 1954)**
Cl^- (Chloride)	Mohr's titration method **(Richards, 1954)**
SO_4^{2-} (Sulphates)	Turbidity method using $CaCl_2$ **(Chesnin and Yien, 1950)**

Criteria of water quality assessment

Different indices were used to assess the quality as well as the suitability of collected water samples. These indices are electrical conductivity (EC_w), total dissolved salts (TDS), residual sodium carbonates (RSC), sodium adsorption ratio (SAR), sodium percentage (SP), permeability index (PI), Kelly ratio (KR), and magnesium hazard (MH). The obtained data from analyzed samples were compared to the reference data of each index to categorize the suitability of each water sample. The calculation of the different water quality indices was expressed in equations (1 to 8). Tables (3 to 10) showed the suitability and quality assessment criteria using different indices.

Table (3) Electrical Conductivity (EC_w) Richards (1954)

$$EC_w\ (ds.m^{-1}) = EC_w\ (\mu s.m^{-1}) / 1000 \qquad \text{equation (1)}$$

Suitability For Irrigation	Salinity Grade	EC_w ($\mu s.m^{-1}$)
Excellent in all conditions	Very Low	Lower than 250
Suitable except for sensitive plants	Low	250 - 750
Moderately suitable	Mid	750 - 2250
Marginally Suitable	High	2250 – 3000
Not Suitable	Very High	Higher than 3000

Table (4) Total Dissolved Salts (TDS) Richards (1954)

$$TDS\ (mg.l^{-1}) = EC_w\ (ds.m^{-1}) \times 640 \qquad \text{equation (2)}$$

Suitability For Irrigation	Grade TDS	TDS ($mg.l^{-1}$)
Excellent in all conditions	Very Low	Lower than 500
Suitable except for sensitive plants	Low	500 - 1000
Moderately suitable	Mid	1000 - 2000
Marginally Suitable	High	2000 - 5000
Not Suitable	Very High	Higher than 5000

Table (5) Sodium Adsorption Ratio (SAR) Ayers and Westcot (1976)

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad \text{equation (3)}$$

Grade	Low	Mid	High	Very high
SAR	Lower than 10	10 - 18	18 - 26	Higher than 26

Table (6) Residual Sodium Carbonates (RSC) Eaton (1950)

$$RSC = \left(CO_3^{2-} + HCO_3^-\right) - \left(Ca^{2+} + Mg^{2+}\right) \qquad \text{equation (4)}$$

Grade	Low	Mid	High
RSC	Lower than 1.25	1.25 – 2.50	Higher than 2.50

Table (7) Sodium Percentage (SP) Wilcox (1955)

$$SP = \frac{Na^+ + K^+}{(Ca^{2+}+Mg^{2+}+K^+ + Na^+)} \times 100 \qquad \text{equation (5)}$$

Suitability For Irrigation	SP Grade	Sodium Percentage
Excellent in all conditions	Very Low	Lower than 20
Suitable except for sensitive plants	Low	20 - 40
Moderately suitable	Mid	40 – 60
Marginally Suitable	High	60 - 80
Not Suitable	Very High	Higher than 80

Table (8) Permeability index (PI) Doneen (1964)

$$PI = \frac{(Na^+ + HCO_3^-)}{(Ca^{2+}+Mg^{2+}+Na^+)} x100 \qquad \text{equation (6)}$$

Grade	Permeability Index
Low	Lower than 35
Mid	35 - 100
High	Higher than 100

Table (9) Kelly Ratio (KR) Kelly (1940)

$$\mathbf{KR} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad \textbf{equation (7)}$$

Table (10) Magnesium Hazard (MH) Szabolcs and Darab (1964)

$$\mathbf{MH} = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times \mathbf{100} \qquad \textbf{equation (8)}$$

Grade	**Magnesium Hazard (%)**
Suitable	Lower than 50
Not Suitable	Higher than 50

Descriptive statistical analysis

A correlation test was done between all water parameters. Mean, maximum, minimum, and other descriptive statistical parameters were done using Microsoft Excel software.

Mapping of spatial variability

Depending on laboratory data of water parameters and corresponding geographic information, Arc-GIS 10.4 was used for mapping the spatial variability of different water parameters as well as water quality and suitability indices.

RESULTS AND DISCUSSION

Water samples characterization

The data of water samples' analysis were shown in table (11). The descriptive statistical parameters of the studied water samples were shown in table (12). The obtained results demonstrated that all water samples are alkaline (pH is more than 7.00). Water pH ranged between 7.10 and 8.90 with an average of 8.06. This alkaline pH is not preferable for agricultural purposes as using this water for irrigating the grown crops in the study area because it affects the availability of macro and micronutrients in the soil **(Mohiuddin *et al.*, 2022).** However, the pH is not significantly affecting water quality because of the buffering capacity of the soil and also the majority of the crops are pH tolerant **(Bresler *et al.* 1982).** Regarding EC_w results, minimum and maximum values of total soluble salts were 0.21 ds.m^{-1} and 5.62 ds.m^{-1}, respectively with the mean value of 1.05 ds.m^{-1}. According to **Richards (1954),** this water ranged between low saline (EC_w is between 0.25 and 0.75 dS.m^{-1}) and very high saline water (EC_w is more than 3.00 dS.m^{-1}). The low saline water is suitable for irrigating all plants except sensitive kinds, while very high saline water is not-suitable for irrigation **Richards (1954)**. Soluble sodium data showed a wide range of water content of this cation whereas the minimum value was 0.91 meq.l^{-1} while the maximum value was 42.82 meq.l^{-1}. The high concentrations of soluble sodium lead to increasing the sodium adsorption by the soil, and affects soil properties **(Hailu and Mehari 2021).** High sodium and chloride levels in water, affect the plant and the soil physically and chemically which lead to productivity decrease **(Jang and Chen 2009).** Furthermore, sodium hazard is resulted from the high concentration of water sodium, which can reduce the soil permeability as well as inhibit crop water absorption **(Tahmasebi *et al.*, 2018).** Soluble potassium varied between 0.08 and 0.36 meq.l^{-1} in all studied water samples. These concentrations are non-hazardous, while a problem of low infiltration of irrigation water may cause by the high levels of potassium in the applied water **(Rengasamy and Marchuk, 2011).** Regarding the soluble calcium, minimum and maximum values were 0.40 and 8.43 meq.l^{-1}, respectively. The soluble magnesium content in the water samples ranged between 0.10 and 6.11 meq.l^{-1} with an average of 1.57 meq.l^{-1}. The magnesium hazard is caused when high concentration of magnesium in water, which lead to alkalinity of soil and also declining crop yields **(Ravikumar *et al.*, 2011).** According to soluble bicarbonates were ranged between 0.50 and 7.66 meq.l^{-1}, soluble chloride varied between 0.38 and 22.92 meq.l^{-1}, while soluble sulphates ranged between 0.01 and 23.83 meq.l^{-1}. However, sulfate is not taken in a consideration when calculating water quality indices and currently not assigned in water quality assessment **(Zaman *et al.*, 2018).**

Table (11) Water samples characterization.

SN	pH	EC	Na^+	K^+	Ca^{+2}	Mg^{+2}	HCO_3^-	Cl^-	SO_4^{-2}
		$dS.m^{-1}$	$meq.l^{-1}$						
1	7.96	0.28	1.48	0.23	0.70	0.40	0.50	2.30	0.01
2	7.83	0.21	0.91	0.18	0.60	0.40	0.50	1.40	0.20
3	7.72	0.33	2.22	0.13	0.40	0.20	0.50	2.30	0.52
4	8.03	0.65	3.09	0.28	0.50	0.30	0.75	5.20	0.56
5	8.08	0.54	1.13	0.18	0.50	0.30	0.75	2.30	2.31
6	8.15	0.46	1.09	0.15	0.40	0.10	0.50	3.60	0.47
7	7.84	0.32	2.13	0.18	0.40	0.50	0.50	2.10	0.63
8	7.64	1.79	4.22	0.23	2.40	0.90	1.00	11.50	5.40
9	7.72	0.55	1.83	0.18	0.80	0.50	0.75	3.00	1.75
10	7.54	1.63	4.70	0.28	1.90	1.00	1.00	9.50	5.77
11	7.8	0.52	2.61	0.18	0.70	0.40	0.75	3.20	1.22
12	7.72	0.93	3.65	0.26	1.40	1.00	1.00	5.00	3.29
13	8.9	0.52	1.74	0.18	0.90	0.60	0.50	2.10	2.64
14	8.63	0.55	1.57	0.21	0.80	0.50	0.50	1.70	3.26
15	8.36	0.56	1.83	0.21	0.90	0.60	0.75	3.60	1.20
16	8.06	1.40	3.91	0.26	1.90	0.90	1.00	9.50	3.51
17	8.1	0.52	1.57	0.21	0.90	0.50	0.50	2.70	2.00
18	8.33	2.07	5.35	0.31	1.80	1.10	1.25	11.60	7.85
19	7.84	0.66	2.17	0.21	0.80	0.50	0.50	4.00	2.10
20	8.33	2.64	5.61	0.36	2.80	1.50	1.25	11.00	14.15
21	7.1	0.48	2.13	0.18	0.40	0.30	0.50	4.30	0.04
22	8.27	0.49	1.87	0.15	0.60	0.30	0.75	4.00	0.15
23	8.56	3.44	21.77	0.11	8.43	3.50	3.02	11.20	18.44
24	7.98	1.12	3.59	0.13	6.17	1.23	1.15	3.74	6.25
25	8.02	0.88	2.24	0.28	3.89	2.45	2.23	1.08	4.16
26	8.34	1.24	4.38	0.13	3.44	3.66	3.55	2.46	5.50
27	8.21	1.09	2.90	0.14	3.40	5.80	4.53	0.38	7.18
28	7.88	0.79	2.61	0.14	1.86	2.81	3.24	2.83	1.79
29	7.47	3.08	15.22	0.29	7.72	6.11	7.66	5.45	16.89
30	7.64	1.74	8.26	0.13	6.33	3.02	5.14	4.55	6.52
31	7.52	1.28	4.08	0.11	4.82	2.50	3.18	1.88	6.66
32	8.08	4.02	25.50	0.12	7.02	5.92	5.29	18.02	15.95
33	8.03	0.86	4.07	0.11	2.03	1.68	1.11	2.44	4.13
34	8.54	5.62	42.82	0.08	6.04	4.98	5.50	22.92	20.32
35	7.86	3.37	22.48	0.11	6.15	4.26	4.79	4.54	23.83
36	7.82	0.76	2.58	0.14	2.33	1.60	1.68	1.35	3.88
37	7.78	0.88	2.04	0.15	3.78	1.22	1.22	2.08	4.15
38	8.11	0.67	2.11	0.14	2.48	1.35	1.02	1.11	3.89
39	7.74	0.78	3.15	0.13	3.44	1.25	1.14	1.02	6.04
40	8.08	0.58	2.22	0.15	1.72	1.04	2.58	0.96	1.42
41	8.33	0.77	2.96	0.14	1.90	1.55	2.16	1.06	2.25
42	7.98	0.51	2.68	0.15	1.43	0.72	2.06	1.05	1.34
43	8.65	0.55	2.14	0.17	1.52	0.61	2.44	1.44	1.31
44	8.18	0.85	3.23	0.16	3.13	1.68	3.07	2.38	3.09
45	8.31	0.65	2.22	0.17	1.54	1.21	2.43	1.33	2.44
46	7.82	0.74	3.50	0.13	2.60	1.11	2.65	1.03	3.56
47	8.13	0.68	2.49	0.17	1.88	1.43	2.09	1.43	2.19
48	8.14	0.58	1.86	0.17	1.56	1.33	2.39	1.18	1.87
49	8.03	0.52	1.98	0.17	1.25	1.28	2.02	1.25	1.65
50	8.11	0.66	1.55	0.15	1.93	1.43	1.89	1.67	2.11
51	8.27	0.56	1.76	0.18	1.52	1.45	2.32	1.06	2.90
52	8.21	0.62	1.89	0.15	1.44	1.65	0.96	1.76	3.63
53	8.32	0.64	2.99	0.18	1.72	1.02	2.07	2.14	2.26
54	8.39	0.75	2.15	0.19	3.88	1.30	2.08	2.56	2.14
55	8.16	1.12	3.60	0.18	3.80	2.90	2.45	3.41	4.91
56	7.78	0.61	2.30	0.19	1.63	1.76	1.86	1.56	3.10
57	8.12	0.53	2.50	0.19	0.90	1.14	2.05	1.17	1.94
58	8.19	0.52	2.45	0.19	0.80	1.18	2.25	1.48	1.42

59	8.28	0.71	2.44	0.18	3.41	1.32	2.10	1.86	3.13
60	8.41	0.55	2.50	0.18	1.50	1.20	2.31	1.71	2.05
61	8.23	0.62	2.34	0.17	1.61	1.32	2.01	1.32	2.24

Table (12) Descriptive Statistical Analysis.

Statistical parameter	pH	EC	Na^+	K^+	Ca^{+2}	Mg^{+2}	HCO_3^-	Cl^-	SO_4^{-2}
		$dS.m^{-1}$	$meq.l^{-1}$						
Mean	8.06	1.05	4.60	0.18	2.37	1.57	1.96	3.73	4.39
Standard Error	0.04	0.13	0.89	0.01	0.25	0.18	0.19	0.54	0.65
Median	8.08	0.66	2.49	0.17	1.72	1.22	1.89	2.30	2.64
Mode	7.72	0.55	2.22	0.18	0.40	0.50	0.50	2.30	1.42
Standard Deviation	0.32	1.00	6.96	0.05	1.95	1.41	1.47	4.20	5.08
Sample Variance	0.10	1.00	48.50	0.00	3.81	1.99	2.17	17.65	25.77
Kurtosis	0.73	7.99	16.66	1.53	1.54	3.23	3.17	8.31	5.20
Skewness	-0.18	2.71	3.89	1.15	1.45	1.88	1.61	2.72	2.34
Range	1.80	5.41	41.91	0.28	8.03	6.01	7.16	22.54	23.82
Minimum	7.10	0.21	0.91	0.08	0.40	0.10	0.50	0.38	0.01
Maximum	8.90	5.62	42.82	0.36	8.43	6.11	7.66	22.92	23.83

The correlation test

Correlation coefficient values of all studied water parameters were shown in table (13). From the obtained data, a high correlation was observed between EC_w and all studied parameters except soluble potassium. The highest correlation was recorded between EC_w and soluble sodium (r=0.94) while the minimum correlation was for soluble potassium (r=-0.06). A very low correlation was observed between water pH and all other water parameters. Similar observation was for soluble potassium which performed poorly against all water parameters. Soluble calcium and magnesium showed reasonable correlation coefficient values for all other parameters. However, soluble chloride was highly correlated with EC_w and soluble sodium, and showed low correlation with other water parameters. Regarding soluble sulphates, it was highly correlated with all parameters except pH and soluble potassium.

Table (13) Correlation between water parameters.

Water parameter		pH	EC_w	Na^+	K^+	Ca^{+2}	Mg^{+2}	HCO_3^-	Cl^-	SO_4^{-2}
			$dS.m^{-1}$				$meq.l^{-1}$			
pH		1.00								
EC_w	**$dS.m^{-1}$**	0.06	1.00							
Na^+		0.10	0.94	1.00						
K^+		-0.06	-0.06	-0.26	1.00					
Ca^{+2}		-0.03	0.76	0.70	-0.25	1.00				
Mg^{+2}	**$meq.l^{-1}$**	0.01	0.74	0.70	-0.24	0.80	1.00			
HCO_3^-		0.00	0.65	0.64	-0.26	0.76	0.90	1.00		
Cl^-		0.06	0.86	0.79	0.14	0.45	0.40	0.29	1.00	
SO_4^{-2}		0.04	0.93	0.86	-0.09	0.82	0.77	0.67	0.66	1.00

Water quality assessment

SN	TDS mg.L^{-1}	RSC	SAR	MH	SP (%)	PI	KR
1	179.84	0.60	2.00	36.36	60.85	76.74	1.35
2	134.40	0.50	1.29	40.00	52.15	73.82	0.91
3	212.48	0.10	4.05	33.33	79.66	96.45	3.70
4	416.64	0.05	4.89	37.50	80.82	98.71	3.86
5	343.04	0.05	1.79	37.50	62.09	97.41	1.41
6	292.48	0.00	2.18	20.00	71.26	100.00	2.18
7	206.72	0.40	3.18	55.56	71.96	86.80	2.37
8	1145.60	2.30	3.29	27.27	57.42	69.41	1.28
9	352.00	0.55	2.27	38.46	60.73	82.43	1.41
10	1041.28	1.90	3.90	34.48	63.20	75.00	1.62
11	330.88	0.35	3.52	36.36	71.72	90.57	2.37
12	594.56	1.40	3.33	41.67	61.97	76.86	1.52
13	335.36	1.00	2.01	40.00	56.14	69.14	1.16
14	349.44	0.80	1.95	38.46	57.79	72.13	1.21
15	355.20	0.75	2.11	40.00	57.63	77.48	1.22
16	896.64	1.80	3.30	32.14	59.83	73.17	1.40
17	332.80	0.90	1.88	35.71	55.97	69.70	1.12
18	1324.80	1.65	4.44	37.93	66.12	80.00	1.84
19	422.40	0.80	2.69	38.46	64.67	76.95	1.67
20	1689.60	3.05	3.83	34.88	58.13	69.22	1.30
21	309.76	0.20	3.60	42.86	76.74	92.93	3.04
22	313.60	0.15	2.79	33.33	69.18	94.58	2.08
23	2201.60	8.91	8.91	29.34	64.71	73.56	1.82
24	716.80	6.25	1.87	16.62	33.45	43.13	0.49
25	563.20	4.11	1.26	38.64	28.44	52.10	0.35
26	793.60	3.55	2.32	51.55	38.85	69.08	0.62
27	697.60	4.67	1.35	63.04	24.84	61.40	0.32
28	505.60	1.43	1.71	60.17	37.06	80.36	0.56
29	1971.20	6.17	5.79	44.18	52.86	78.76	1.10
30	1113.60	4.21	3.82	32.30	47.29	76.09	0.88
31	819.20	4.14	2.13	34.15	36.40	63.68	0.56
32	2572.80	7.65	10.03	45.75	66.44	80.10	1.97
33	550.40	2.60	2.99	45.28	52.98	66.58	1.10
34	3596.80	5.52	18.24	45.19	79.56	89.75	3.89
35	2156.80	5.62	9.85	40.92	68.45	82.91	2.16
36	486.40	2.25	1.84	40.71	40.90	65.44	0.66
37	563.20	3.78	1.29	24.40	30.46	46.31	0.41
38	428.80	2.81	1.52	35.25	37.01	52.69	0.55
39	499.20	3.55	2.06	26.65	41.15	54.72	0.67
40	371.20	0.18	1.89	37.68	46.20	96.39	0.80
41	492.80	1.29	2.25	44.93	47.33	79.88	0.86
42	326.40	0.09	2.58	33.49	56.83	98.14	1.25
43	352.00	0.31	2.07	28.64	52.03	107.26	1.00
44	544.00	1.74	2.08	34.93	41.34	78.36	0.67
45	416.00	0.32	1.89	44.00	46.50	93.56	0.81
46	473.60	1.06	2.57	29.92	49.46	85.30	0.94
47	435.20	1.22	1.94	43.20	44.56	78.97	0.75
48	371.20	0.50	1.55	46.02	41.26	89.47	0.64
49	332.80	0.51	1.76	50.59	45.94	88.69	0.78
50	422.40	1.47	1.20	42.56	33.60	70.06	0.46
51	358.40	0.65	1.44	48.82	39.51	86.26	0.59
52	396.80	2.13	1.52	53.40	39.77	57.23	0.61
53	409.60	0.67	2.55	37.23	53.64	88.31	1.09
54	480.00	3.10	1.34	25.10	31.12	57.71	0.42
55	716.80	4.25	1.97	43.28	36.07	58.74	0.54
56	390.40	1.53	1.77	51.92	42.35	73.11	0.68
57	339.20	0.01	2.48	55.88	56.87	100.22	1.23
58	332.80	0.27	2.46	59.60	57.14	106.09	1.24

59	454.40	2.63	1.59	27.91	35.65	63.32	0.52
60	352.00	0.39	2.15	44.44	49.81	92.50	0.93
61	396.80	0.92	1.93	45.05	46.14	82.54	0.80

Table (15) Descriptive statistical analysis of water quality indices.

Statistical parameters	RSC	SAR	TDS	MH	KR	SP	PI
Mean	2.00	3.02	671.82	39.59	1.24	52.30	78.17
Standard Error	0.26	0.35	81.91	1.22	0.11	1.78	1.90
Median	1.29	2.13	422.40	38.46	1.09	52.86	78.36
Standard Deviation	2.06	2.70	639.72	9.52	0.83	13.89	14.86
Sample Variance	4.23	7.28	….	90.60	0.69	192.95	220.68
Kurtosis	1.63	17.56	7.99	0.28	2.91	-0.72	-0.40
Skewness	1.41	3.81	2.71	0.21	1.69	0.14	-0.21
Range	8.91	17.05	3462.40	46.42	3.57	55.98	64.13
Minimum	0.00	1.20	134.40	16.62	0.32	24.84	43.13
Maximum	8.91	18.24	3596.80	63.04	3.89	80.82	107.26

Table (16) showed the classes of water quality and suitability based on applied indices. Starting with the data of EC_w, the majority of water samples were under low class whereas electrical conductivity values of those samples were below 0.25 ds.m^{-1}. This water is suitable for irrigating all crops except for sensitive plants. Some sites in the study area were found to be having mid water quality whereas EC_w values were between 0.25 ds.m^{-1} and 0.75 ds.m^{-1}, which is moderately suitable for irrigation. Few sites such as El-Baliana, Sohag, Akhmim and El-Maragha were having very high EC_w values (more than 3.00 ds.m^{-1}). This water is not suitable for irrigating any kind of crop. Regarding the total dissolved salts (TDS) index, all studied water samples varied between very low and low classes of suitability whereas TDS values of these samples ranged from less than 500 to 1000 mg.L^{-1}. This water varied from excellent in all conditions to suitable for irrigating all crops except for sensitive plants. Mid water suitability was observed in some sites in the study area such as Markaz Tahta, Sahel Tahta, Gehiena Nazet Elheish, Akhmim Elsalamouna, Sohag, and Saqulta. The TDS values of these samples ranged between 1000 mg.L^{-1} and 2000 mg.L^{-1} whereas this water is moderately suitable for irrigation. El-baliana, akhmim and El-Maragha sites were high in TDS which values ranged between 2000 mg.L^{-1} and 3000 mg.L^{-1}. This water is marginally suitable for irrigation. The obtained data of residual sodium carbonates (RSC) revealed that about a half of the total number of water samples were categorized to be low (RSC is lower than 1.25) whereas this water was excellent for irrigation. Other half of water samples ranged between mid to high for their RSC values (ranged from 1.25 to more than 2.5). According to sodium adsorption ratio (SAR) values, all water samples were classified as low SAR samples whereas their values were less than 10, while one site of Akhmim was under mid SAR class (SAR is between 10 and 18), other one site of El-Maragha was high (SAR is more than 18). All water samples were suitable for irrigation regarding their results of magnesium hazard index (MH), whereas values were less than 50%. Sites of Sahel Tahta, Elmonshah, Sohag, Akhmim, Saqulta, and El-Maragha were found to be under not suitable class where their MH values were more than 50%. Regarding Kelly ratio index (KR), approximately half of the studied water samples were suitable for irrigation (having KR values less than 1) while the other half of water samples are not suitable (having KR values more than 1). Low sodium percentage (SP) values were recorded for sites of El-Baliana, Elmonshah, Sohag, Akhmim, and Saqulta whereas SP values were between 20 and 40 %. This water was suitable for irrigating all crops except for sensitive plants. Moderate suitability was found in many water samples whereas SP values ranged between 40 and 60%, while the rest water samples were classified to be marginally suitable for irrigation and with high SP values (between 60 and 80%). Regarding permeability index (PI), all water samples were under mid class whereas PI values were lower than 35%, except a few sites of Sohag and El-Maragha were having PI values higher than 100%.

From the previous discussion of water suitability indices' results, it was clear that sites (26, 27. 29, 32, 34 and 35) of Elmonshah, Sohag, Sohag, Akhmim, El-Maraghah and El-Maraghah, respectively were not suitable for using in irrigating crops. Other water samples ranged from moderately suitable to highly suitable for irrigation.

Table (16) classification of water quality.

SN	EC	RSC	SAR	TDS	MH	KR	SP	PI
1	low	low	low	very low	suitable	not-suitable	high	mid
2	very low	low	low	very low	suitable	suitable	mid	mid
3	low	low	low	very low	suitable	not-suitable	high	mid
4	low	low	low	very low	suitable	not-suitable	very high	mid
5	low	low	low	very low	suitable	not-suitable	high	mid
6	low	low	low	very low	suitable	not-suitable	high	mid
7	low	low	low	very low	not-suitable	not-suitable	high	mid
8	mid	mid	low	mid	suitable	not-suitable	mid	mid
9	low	low	low	very low	suitable	not-suitable	high	mid
10	mid	mid	low	mid	suitable	not-suitable	high	mid
11	low	low	low	very low	suitable	not-suitable	high	mid
12	mid	mid	low	low	suitable	not-suitable	high	mid
13	low	low	low	very low	suitable	not-suitable	mid	mid
14	low	low	low	very low	suitable	not-suitable	mid	mid
15	low	low	low	very low	suitable	not-suitable	mid	mid
16	mid	mid	low	low	suitable	not-suitable	mid	mid
17	low	low	low	very low	suitable	not-suitable	mid	mid
18	mid	mid	low	mid	suitable	not-suitable	high	mid
19	low	low	low	very low	suitable	not-suitable	high	mid
20	high	high	low	mid	suitable	not-suitable	mid	mid
21	low	low	low	very low	suitable	not-suitable	high	mid
22	low	low	low	very low	suitable	not-suitable	high	mid
23	very high	high	low	high	suitable	not-suitable	high	mid
24	mid	high	low	low	suitable	suitable	low	mid
25	mid	high	low	low	suitable	suitable	low	mid
26	mid	high	low	low	not-suitable	suitable	low	mid
27	mid	high	low	low	not-suitable	suitable	low	mid
28	mid	mid	low	low	not-suitable	suitable	low	mid
29	very high	high	low	mid	suitable	not-suitable	mid	mid
30	mid	high	low	mid	suitable	suitable	mid	mid
31	mid	high	low	low	suitable	suitable	low	mid
32	very high	high	mid	high	suitable	not-suitable	high	mid
33	mid	high	low	low	suitable	not-suitable	mid	mid
34	very high	high	high	high	suitable	not-suitable	high	mid
35	very high	high	low	high	suitable	not-suitable	high	mid
36	mid	mid	low	very low	suitable	suitable	mid	mid
37	mid	high	low	low	suitable	suitable	low	mid
38	low	high	low	very low	suitable	suitable	low	mid
39	mid	high	low	very low	suitable	suitable	mid	mid
40	low	low	low	very low	suitable	suitable	mid	mid
41	mid	mid	low	very low	suitable	suitable	mid	mid
42	low	low	low	very low	suitable	not-suitable	mid	mid
43	low	low	low	very low	suitable	not-suitable	mid	high
44	mid	mid	low	low	suitable	suitable	mid	mid
45	low	low	low	very low	suitable	suitable	mid	mid
46	low	low	low	very low	suitable	suitable	mid	mid
47	low	low	low	very low	suitable	suitable	mid	mid
48	low	low	low	very low	suitable	suitable	mid	mid
49	low	low	low	very low	not-suitable	suitable	mid	mid
50	low	mid	low	very low	suitable	suitable	low	mid
51	low	low	low	very low	suitable	suitable	low	mid
52	low	mid	low	very low	suitable	suitable	low	mid
53	low	low	low	very low	suitable	not-suitable	mid	mid
54	low	high	low	very low	suitable	suitable	low	mid
55	mid	high	low	low	suitable	suitable	low	mid
56	low	mid	low	very low	not-suitable	suitable	mid	mid
57	low	low	low	very low	not-suitable	not-suitable	mid	high
58	low	low	low	very low	not-suitable	not-suitable	mid	high
59	low	high	low	very low	suitable	suitable	low	mid

60	low	low	low	very low	suitable	suitable	mid	mid
61	low	low	low	very low	suitable	suitable	mid	mid

Mapping of spatial variability

Spatial variability distribution maps of water parameters and water suitability indices were generated and shown in figures (2 to 17). Each map was classified into different colors in five classes ranged ascending from blue color (lowest values) to red color (highest values) based on values of water parameters or suitability indices.

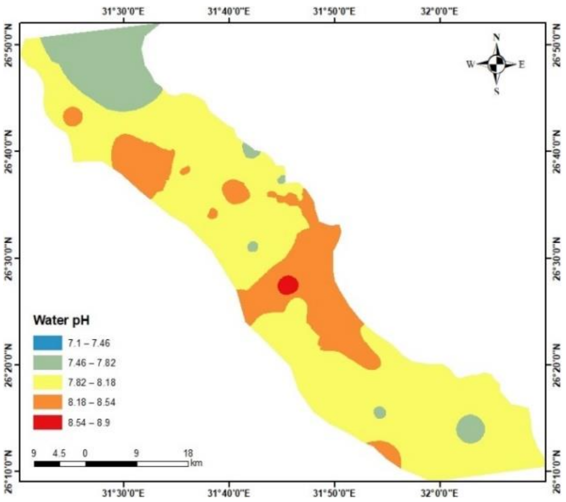

Figure (2) Map of Water pH.

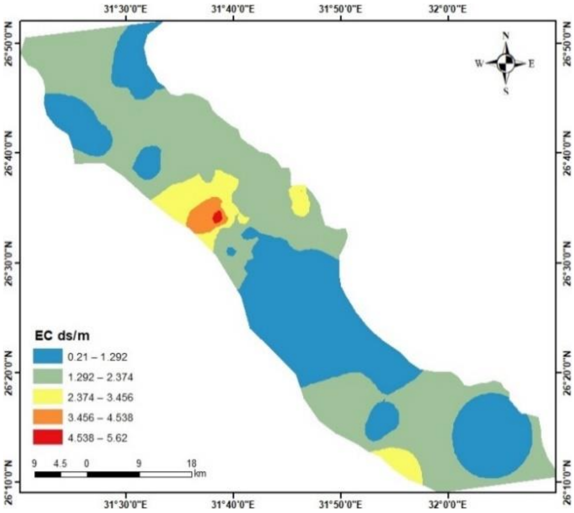

Figure (3) Map of Water EC_w.

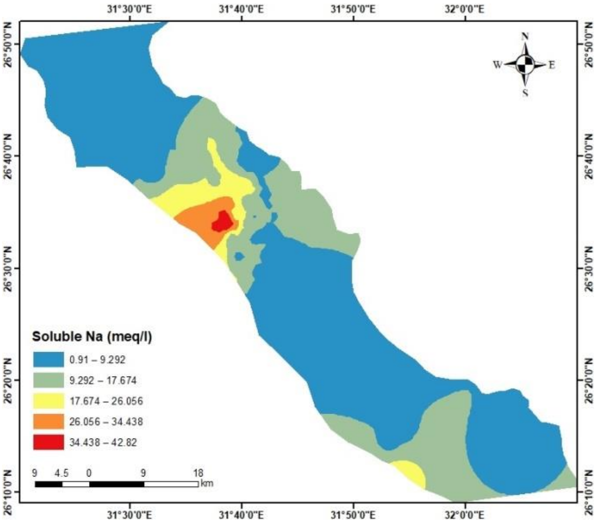

Figure (4) Map of soluble Na.

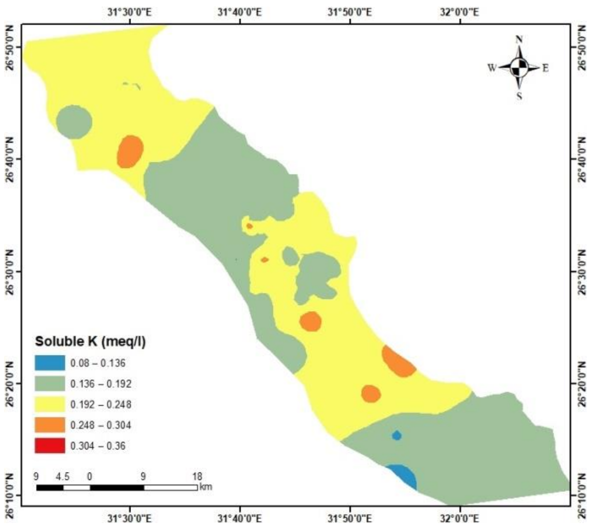

Figure (5) Map of Soluble K.

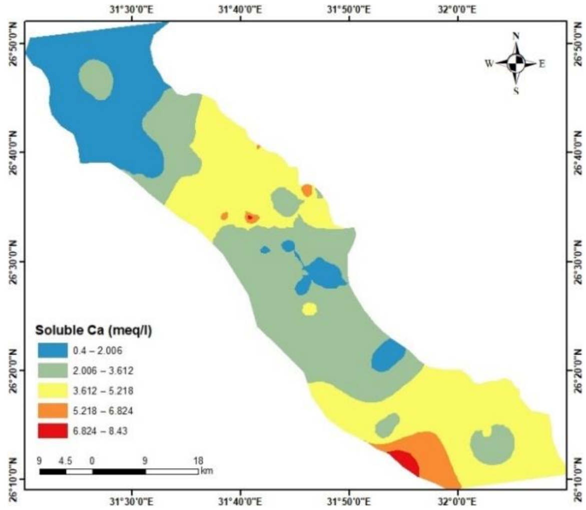

Figure (6) Map of soluble Ca.

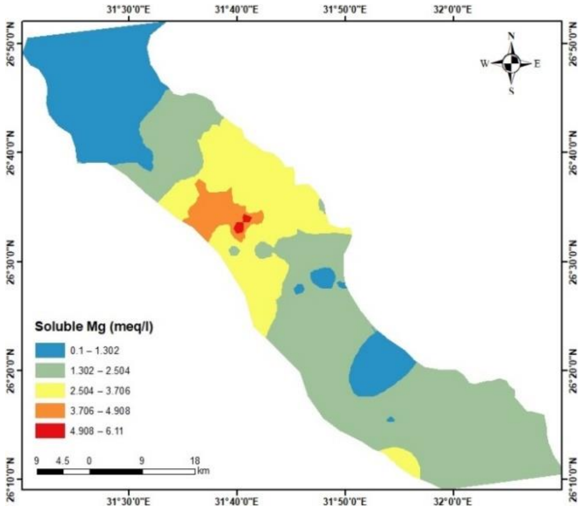

Figure (7) Map of Soluble Mg.

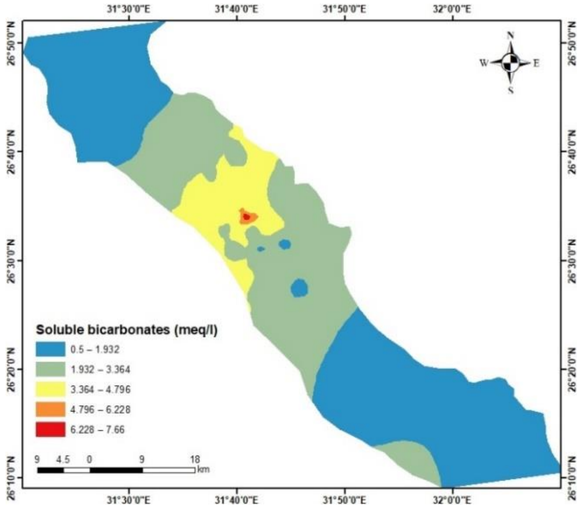

Figure (8) Map of soluble HCO_3.

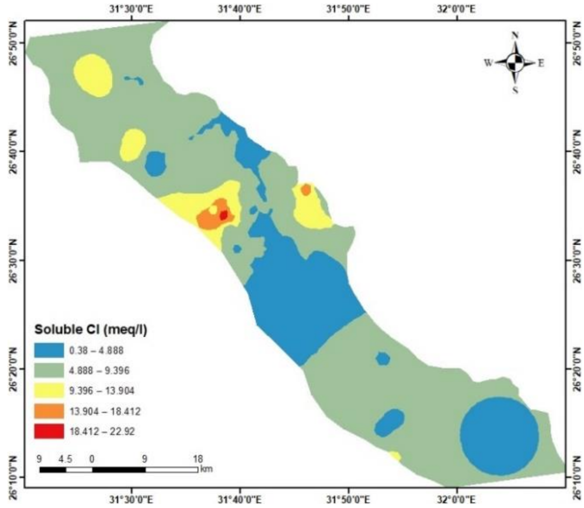

Figure (9) Map of Soluble Cl.

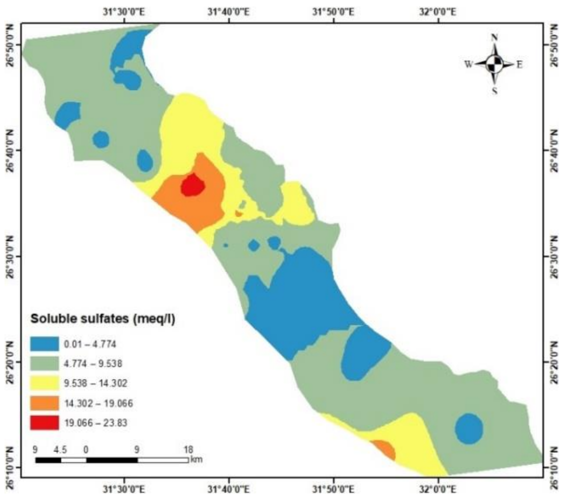

Figure (10) Map of soluble SO_4.

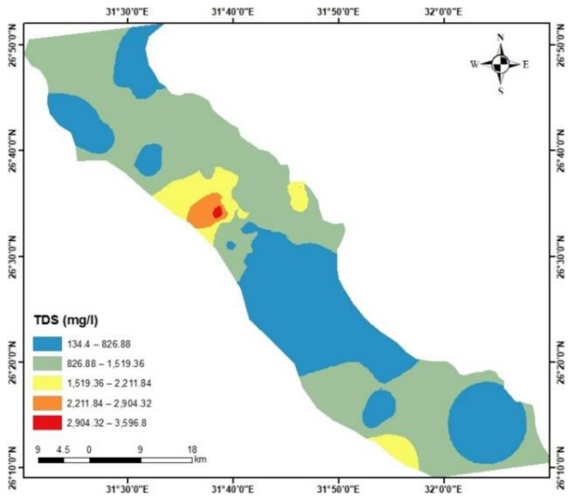

Figure (11) Map of TDS.

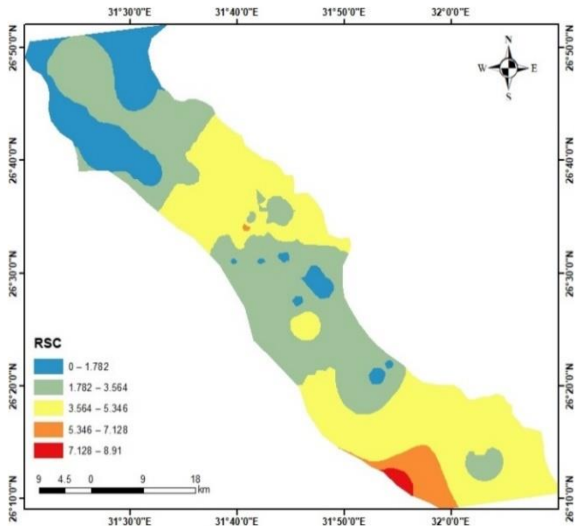

Figure (12) Map of RSC.

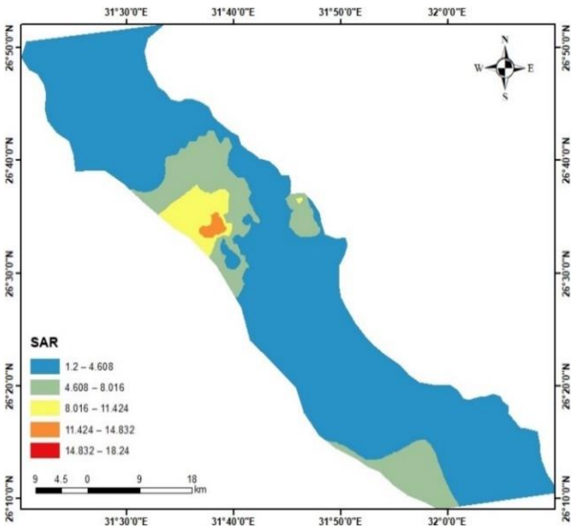

Figure (13) Map of SAR.

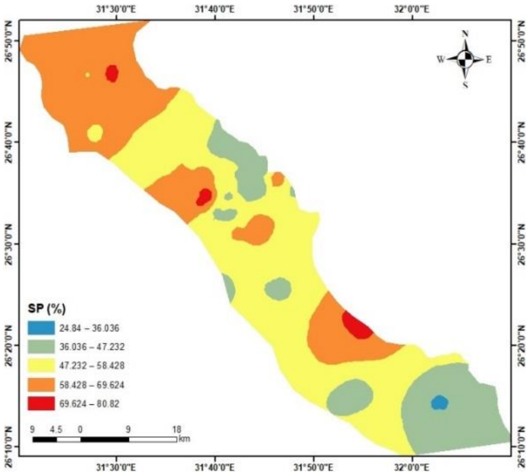

Figure (14) Map of SP.

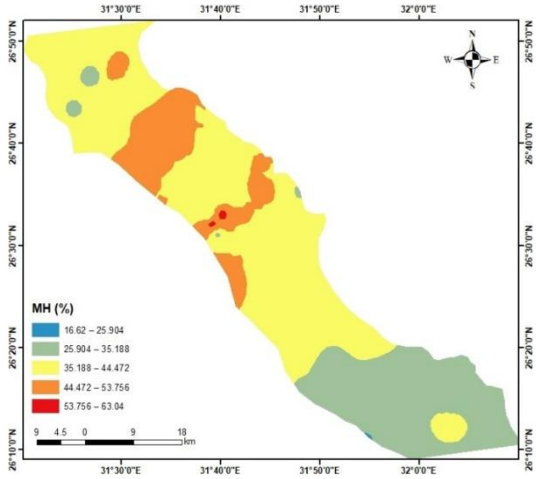

Figure (15) Map of MH.

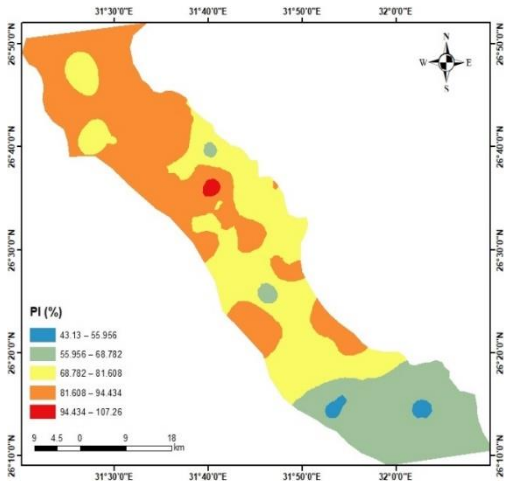

Figure (16) Map of PI.

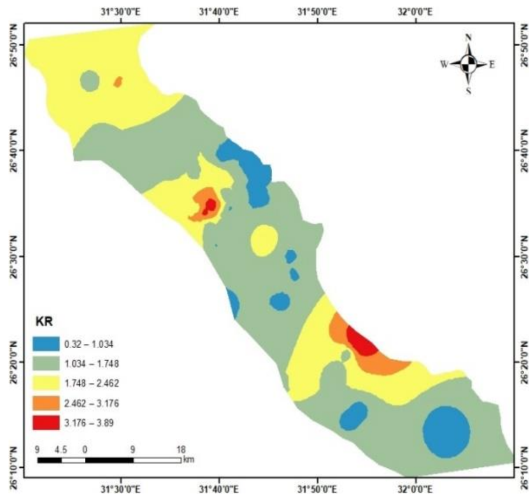

Figure (17) Map of KR.

CONCLUSION

Water quality and suitability of Sohag area were assessed using different indices (EC_w, TDS, SAR, RSC, PI, KR, SP and MH) based on water properties. The studied water samples of sites (Elmonshah, Sohag, Akhmim, and El-Maraghah) were not suitable for irrigating crops, while the rest water samples were suitable for irrigation. It should be recommended that these water sources shall not be used for agricultural purposes without treatment for enhancing their quality. These results as well as the generated maps can be used as a guide for decision-makers and help in better water management planning.

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الملخص العربي

تقييم الجودة وانتاج خرائط التباين المكاني لمصادر المياه في منطقة سوهاج ، مصر

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هدفت هذه الدراسة إلى تقييم جودة وصلاحية مصادر المياه لغرض الري بمنطقة سوهاج. تم جمع ٦١ عينة مياه من مصادر مختلفة لتمثل منطقة الدراسة. تم تحليل عينات المياه من حيث خصائص pH، الأملاح الكلية الذائبة، الكاتيونات والآنيونات الذائبة. كانت عينات المياه قلوية (pH أعلى من ٧.٠٠)، وتراوحت الأملاح الكلية الذائبة بين المنخفضة جدًا (٠.٢١ ديسيسيمنز/م) وعالية جدًا (٥.٦٢ ديسيسيمنز/م)، وكان الصوديوم الذائب هو السائد، يليه الكالسيوم والمغنيسيوم والبوتاسيوم على التوالي. فيما يتعلق بالأنيونات الذائبة، كان الكلوريد هو السائد تلاه الكبريتات والبيكربونات. تم وضع بيانات تحليل المياه في عدة مؤشرات لتقييم جودة وصلاحية المياه للري مثل التوصيل الكهربي (EC_w)، الأملاح الذائبة الكلية (TDS)، كربونات الصوديوم