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Applications of geographic information systems in studying changes in groundwater quality and soil salinity in Sohag Governorate

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Abstract

Sohag governorate is a narrow long strip of a cultivated valley located in upper Egypt. Groundwater and soil samples were collected along the Nile river, starting form the southern border to the northern border of Sohag governorate to assess the groundwater quality and soil salinity between 1991 and 2006. The obtained data reveal that the electrical conductivity of well waters (EC_w) was classified to four classes (250-750, 750-2250, 2250-5000 and greater than 5000 µS/cm). The results showed an increase in the groundwater salinity within 15 years, especially in the first class where it increased from 9% in 1991 to 14% in 2006 but it raised from 17% in 1991 to 37% in 2006 for the third class. The surface and subsurface soil layers showed an increase trend in the soil salinity from 1991 to 2006. The soil salinity increased with depth from 1991 to 2006. The groundwater pH values changed due to the changes in their salt content from 1991 to 2006. The pH values of the surface and subsurface soil samples also changed from 1991 to 2006 that may be due to the changes in salt content of well waters. Cations and anions of the groundwater increased from 1991 to 2006. The groundwater SAR decreased for the first class (0-10) from 89 % in 1991 to 83 % in 2006 but increased for the second class (>10) from 11% in 1991 to 17% in 2006. The groundwater RSC for the first and third classes changed from 91 and 3 %, respectively, in 1991 to 83 and 11%, respectively, in 2006. The increase in the high class of RSC may limit the use of these waters in irrigation. Thus, the irrigation with such water might affect the permeability of soil and cause infiltration problems.

Keywords: Groundwater quality, soil salinity, geographic information systems.

Introduction

Egypt lies in the arid region. Most of agricultural expansion areas are sandy soils which have poor physical and chemical properties, especially low water retention. One of the ways to overcome the increase of population in Egypt is to cultivate these soils. The expansion in the new areas needs more enough water to irrigate these soils. Saline soils are mostly located in arid and semi-arid regions. One of the conditions for the presence or formation of saline soils is the high evaporation, which greatly exceeds the precipitation. Soil salinity caused by natural or human-induced processes is a major environmental hazard. Crop growth reduction due to soil salinity is generally related to the soil solution osmotic potential of the root zone. As the soil salinity level increases, the plant must spend more energy to take up water from the same soil water content (Al-Khaier 2003; Bakeer 2008; Sayed, 2013). Salinization is of a great danger for arid and semi-arid irrigated agriculture. Without taking care, the salinity will have a negative impact on soil productivity and crop yields and lead to ecological degradation of land and water resources (Hillel, 2000).

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Groundwater is considered the second major source of irrigation water in upper Egypt after the Nile water. The newly cultivated desert areas depend mainly up on the groundwater for irrigation. The groundwater in some cases has a poor quality and contains enough salts to significantly alter the physical and chemical properties of soils and even to make growing crops rather difficult.

Use of poor-quality groundwater has become inevitable for irrigation to compensate the rapid increase of water demands in many arid and semiarid regions. Salinity and sodicity are the principal soil and water quality concerns in such areas. Many saline–sodic and sodic soils have saline or saline–sodic subsurface drainage waters (Qadir et. al., 2001)

Monitoring the groundwater quality, soil salinity and the efficiency of remedial efforts is very much needed in upper Egypt. Geographic information system (GIS), as a new technique, is widely used nowadays as a rapid method for delineating soil boundaries and characterization of soil units. GIS is used an important tool in monitoring and mapping of water quality and land evaluation (Yunus et al., 2003; Bakeer, 2008; Albaji et al., 2010 Ismail and Yacoub, 2012). The combination between remote sensing and GIS creates possible monitoring the soil salinity and waterlogging (Ghabour and Daels, 1993).

This study aims to evaluate the changes in the groundwater quality and soil salinity of Sohag governorate between 1991 and 2006, to help building the future strategic plans of agriculture in upper Egypt. GIS is used an important tool in monitoring and mapping these concerns.

Material and Methods

Sohag governorate lies in Upper Egypt. It is a narrow long strip of a cultivated valley and the total maximum length is about 96 Km, with a maximum width of about 25 km. It is located between 26°, 10', & 26º, 50' N and 31º, 15' & 32º, 50' E and consists of 11 counties. Groundwater and soil surface and subsurface samples were collected from transects along the Nile river, starting form the southern border to the northern border of Sohag governorate, covering a distance of about 96 km to identify the changes in the groundwater quality and soil salinity between 1991 (the results reported by Ghallab, 1995) and 2006 (the results of this study). It is very important to reassess the groundwater and surrounding soils quality after 15 years. One water sample was taken from each well water and two soil samples were collected from the surface (0-25cm) and the subsurface layers (25-50 cm) from the area that the well covered. Groundwater and soil samples were collected from 35 locations in this governorate (Figure 1). Table 1 shows the particle size distribution of these soils. The collected groundwater and soil samples were analyzed for the major constituents using the standard methods of Jackson (1967, 1969), McLean (1982), Nelson (1982), Rhoades (1982), and Page et. al. (1986). This study is exploiting GIS for monitoring and mapping groundwater and salinity soils of Sohag governorate using Arcview, 9.1. The percentage of each class of soil or groundwater property in each figure was calculated based on the total number of groundwater or soil samples and was present in the key of each figure.

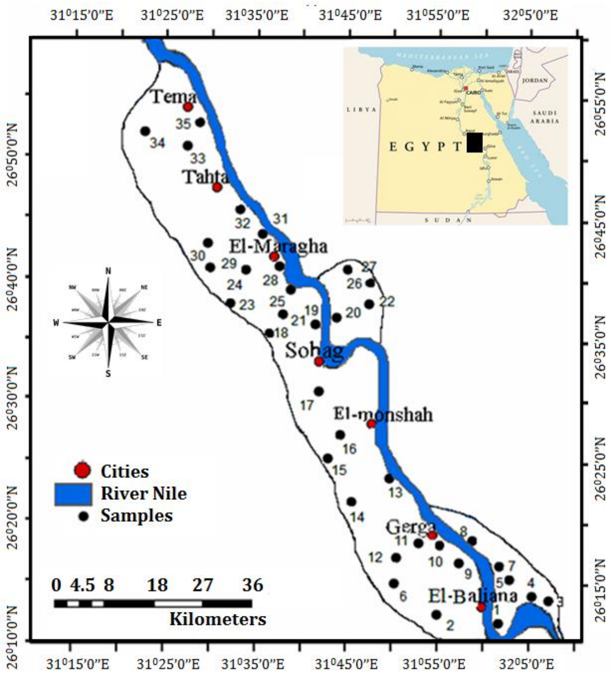

Figure 1. Locations of the colleted groundwater and soil samples.

Table 1. Particle size distribution of the studied soils in the areas irrigated by groundwater

No	Location	Surface (0 - 25 cm)				Subsurface (25- 50 cm)			
		Sand, %	Silt, %	Clay, %	Class	Sand, %	Silt, %	Clay, %	Class
1	El -Balabesh Gobly	55.088	24.386	20.526	SCL	55.088	24.386	20.526	SCL
2	El-Ghabat	76.140	17.018	6.842	SL	73.333	18.456	8.211	SL
3	Awlad Salam Bahre	55.088	35.333	9.579	SL	49.818	39.235	10.947	L
4	Naknk	60.702	37.930	1.368	SL	64.913	30.982	4.105	SL
5	Gazert Naknk	74.737	21.158	4.105	SL	71.930	17.123	10.947	SL
6	Beat Alam	77.544	18.351	4.105	LS	76.736	15.053	8.211	SL
7	El-Nosirat	51.877	40.912	7.211	SL	53.685	35.368	10.947	SL
8	Nego Mazen Shark	39.649	48.035	12.316	L	50.877	36.807	12.316	L
9	Gazert Bardes	53.684	39.474	6.842	SL	56.491	33.930	9.579	SL
10	Gazert Bardes	46.667	39.649	13.684	L	48.070	35.509	16.421	L
11	Gerga	31.228	41.404	27.368	L	35.438	33.088	31.474	CL
12	El-Rakakna	48.877	31.965	19.158	L	52.281	27.193	20.526	SCL
13	Awlad Hamza	51.158	42.737	24.632	L	24.210	32.631	24.632	SiL
14	Awlad Salama	60.386	20.772	18.842	SL	53.684	21.684	24.632	SCL
15	El-Zara	42.053	32.947	25.000	L	46.667	30.070	23.263	L
16	Awlad Harwon	45.263	41.053	13.684	L	34.035	46.807	19.158	L
17	Rwafe Eyswaia	59.298	32.491	8.211	SL	48.666	36.702	14.632	L
18	Awlad Azaz	86.717	8.860	4.423	LS	85.860	8.719	5.421	LS
19	Kelfao	57.895	29.789	12.316	SL	52.281	31.298	16.421	SL
20	Arab El Atawla	57.895	21.579	20.526	SCL	59.299	29.754	10.947	SL
21	Gezert Shandawil	43.860	32.877	23.263	L	55.087	20.281	24.632	SCL
22	Bahta	43.859	34.246	21.895	L	55.088	21.649	23.263	SCL
23	El-Ghrizat	56.491	33.930	9.579	SL	52.281	31.298	16.421	SL
24	El-Ghrizat	85.965	10.298	3.737	LS	84.562	8.596	6.842	LS
25	Tunise	55.088	28.491	16.421	SL	56.491	21.614	21.895	SCL
26	Neida	83.158	11.368	5.474	LS	83.158	12.737	4.105	LS
27	Gehina El Sarkia	55.087	36.702	8.211	SL	56.491	31.193	12.316	SL
28	El-Swamia Shark	50.877	43.649	5.474	SL	55.087	23.018	21.895	SCL
29	Neg Hermas	78.948	19.684	1.368	LS	76.141	19.754	4.105	SL
30	El-Sheik Shibl	49.473	38.211	12.316	L	39.649	39.825	20.526	L
31	Nazlt Aly	85.965	12.667	1.368	S	88.772	8.491	2.737	S
32	El-Swamea Gharb	57.894	36.632	5.474	SL	71.930	21.228	6.842	SL
33	Nazlt Imara	46.088	8.526	4.105	LS	81.754	10.035	8.211	LS
34	Bin Harb	57.895	35.263	6.842	SL	59.298	31.123	9.579	SL
35	Um Dona	57.299	33.754	8.947	SL	56.895	30.947	12.158	SL

SL: Sandy loam, LS: Loamy sand, CL: Clay loam, SCL: Sandy clay loam SL: Silty Loam, L: Loamy

Results and Discussion

Studying the changes in the groundwater quality and soil salinity due to the use of this water in irrigation between 1991 (Ghallab, 1995) and 2006 (this study) is very important to reassess the groundwater and surrounding soil quality after 15 years. This comparative study will include the changes in most groundwater properties as well as soil salinity and soil pH.

Groundwater

- Salinity (EC_w)

The results of the groundwater salinity, expressed as electrical conductivity values (EC_w) are present in Table 2. Figure 2 shows the changes in the groundwater Salinity (EC_w) in Sohag governorate between 1995 and 2006. The groundwater salinity was classified to four classes (< 750, 750-2250, 2250-5000 and > 5000 µS/cm) according to the American soil salinity lab (Richards, 1954). The maps of the groundwater salinity in 1991 and 2006 show increase in the EC_w. The first class of groundwater salinity (< 750 µS cm^{-1}) increased from 9% in 1991 to 14% in 2006. However, the second class (750-2250 µS cm^{-1}) decreased from 71% in 1991 to 46% in 2006. The 25% difference of this groundwater salinity class went to the upper salinity class. Therefore, the third class of groundwater salinity (2250-5000 µS cm^{-1}) increased from 17% in 1991 to 37% in 2006. Moreover, the last groundwater salinity class (>5000 µS cm^{-1}) has the same level as in 1991. These results ensure increases in the groundwater salinity within these 15 years. . These results agree with those obtained by Bakeer (2008).

Table **2.** Analysis of the groundwater samples of the areas understudy between 1991 and 2006

No	Location	EC_w, µS cm^{-1}		pH_w		SAR		RSC	
		1991	**2006**	**1991**	**2006**	**1991**	**2006**	**1991**	**2006**
1	El -Balabesh Gobly	0.84	2.84	8.44	8.22	2.08	8.45	0.84	0.00
2	El-Ghabat	1.04	1.30	7.53	8.11	2.13	0.98	0.00	0.00
3	Awlad Salam Bahre	1.33	1.20	7.85	8.54	2.88	3.27	0.00	0.20
4	Naknk	0.94	1.23	8.05	7.93	1.15	3.55	0.00	0.00
5	Gazert Naknk	0.79	1.19	8.24	7.38	0.96	1.16	0.00	0.00
6	Beat Alam	7.04	8.02	7.84	8.40	13.31	13.97	0.00	0.00
7	El-Nosirat	0.94	1.13	8.10	7.92	3.31	3.12	1.92	0.00
8	Nego Mazen Shark	3.37	4.04	8.39	8.59	17.28	18.52	2.94	0.00
9	Gazert Bardes	0.90	1.55	7.92	8.42	1.43	0.77	0.00	0.20
10	Gazert Bardes	1.02	1.58	8.06	8.50	1.72	1.00	0.00	1.00
11	Gerga	1.14	0.70	8.31	8.24	2.85	3.35	0.71	3.97
12	El-Rakakna	1.97	3.20	7.93	8.42	5.39	5.84	0.00	0.00
13	Awlad Hamza	1.49	0.89	8.22	8.76	7.32	7.45	2.28	5.83
14	Awlad Salama	0.68	1.01	7.97	8.83	2.43	1.07	0.00	0.00
15	El-Zara	1.11	0.97	8..47	8.49	2.37	3.77	0.00	0.03
16	Awlad Harwon	2.05	2.94	7.45	8.08	6.51	8.54	0.00	0.00
17	Rwafe Eyswaia	0.89	0.60	8.46	8.34	1.29	1.60	0.77	2.30
18	Awlad Azaz	1.87	0.92	7.88	8.27	5.48	5.17	0.00	4.03
19	Kelfao	0.91	0.62	7.99	8.56	2.08	3.83	0.43	0.97
20	Arab El Atawla	0.84	0.57	8.17	8.23	1.01	0.91	0.00	0.03
21	Gezert Shandawil	1.09	0.95	7.81	8.06	1.49	1.65	0.00	0.23
22	Bahta	1.28	3.19	7.83	8.25	1.53	7.91	0.00	0.10
23	El-Ghrizat	3.16	3.24	7.87	7.96	8.74	13.38	0.00	0.00
24	El-Ghrizat	4.91	4.41	7.97	8.16	10.82	14.32	0.00	0.00
25	Tunise	1.04	0.91	8.34	7.96	2.70	7.90	0.91	5.30
26	Neida	0.94	0.73	8.05	7.48	1.33	1.48	0.00	2.50
27	Gehina El Sarkia	1.18	1.19	7.82	8.63	2.12	0.45	0.00	0.00
28	El-Swamia Shark	2.58	3.20	7.71	8.28	6.31	14.48	0.00	0.00
29	Neg Hermas	3.47	4.12	7.66	8.29	9.63	6.05	0.00	0.00
30	El-Sheik Shibl	2.01	2.50	8.05	8.02	5.69	4.80	0.00	0.00
31	Nazlt Aly	1.77	4.20	8.37	7.85	12.68	3.46	0.15	0.00
32	El-Swamea Gharb	0.73	0.98	8.36	8.10	1.63	0.43	0.02	0.00
33	Nazlt Imara	3.18	4.30	7.27	8.17	7.25	13.12	0.00	0.00
34	Bin Harb	0.87	1.30	8.25	8.36	2.25	1.76	0.00	0.20
35	Um Dona	0.70	2.72	8.08	7.98	1.09	2.57	0.00	0.00

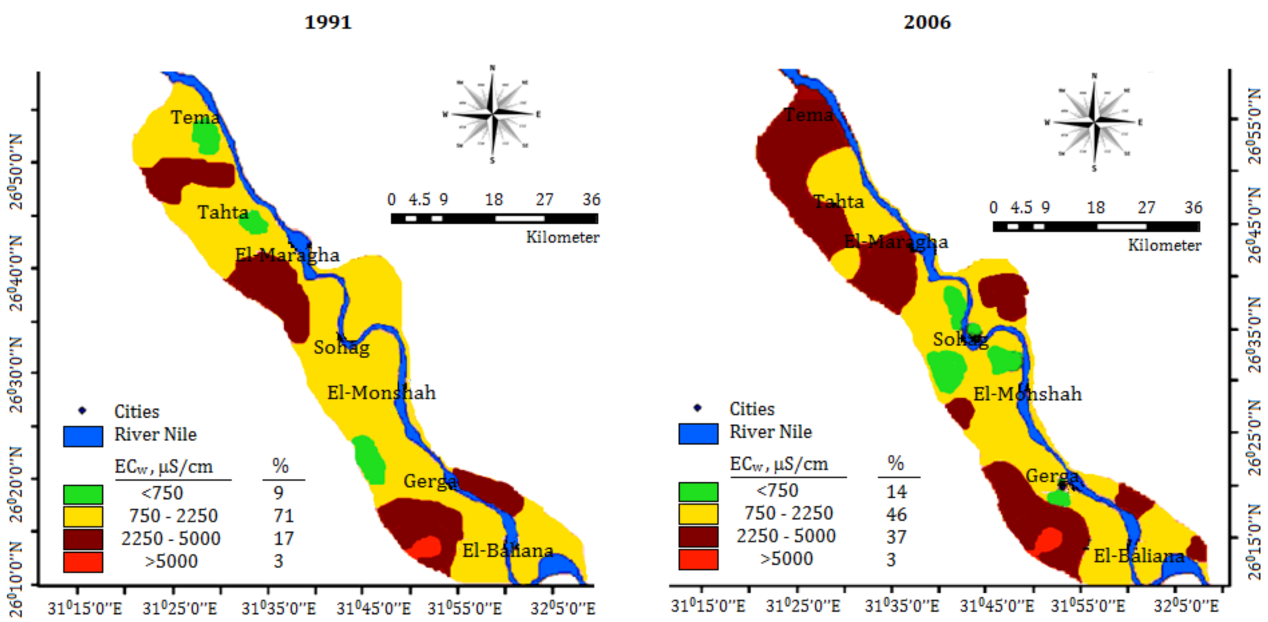

Figure 2. The changes in the electrical conductivity (EC_w) of the groundwater between 1991and 2006.

- pH_w

The data in Table 2 and pH_w map of the groundwater (Figure 3) reveal that groundwater pH has three classes, namely, less than 7.5, 7.5-8.0, and greater than 8.0. The pH of the first groundwater class has the same level (6%) as in 1991 but the pH of the second class (7.5-8.0) decreased from 43% in 1991 to 17 % in 2006. Also, the third class pH (>8.0) increased from 51% in 1991 to 77 % in 2006. These changes in the pH classes may be attributed to the changes in the groundwater salt content which is negatively correlated to the pH (El-Dardiry, 2007).

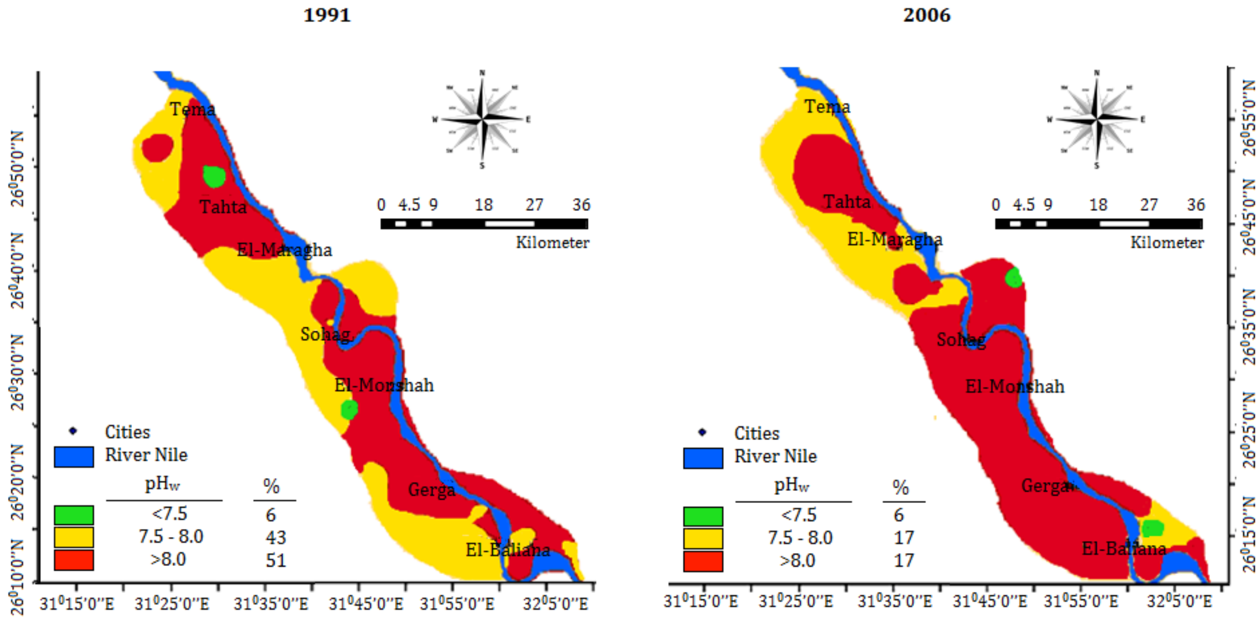

Figure 3. The changes in the groundwater pH between 1991 and 2006.

- Sodium Adsorption Ratio (SAR_w)

Groundwater SAR of the studied area were classified into two classes namely, 0 to10 and > 10 (Table 2 and Figure 4). The groundwater SAR of the first class (0-10) decreased from 89 % in 1991 to 83 % in 2006 but it's the second class (> 10) increased from 11% in 1991 to 17% in 2006 (Labeeb, 2002).

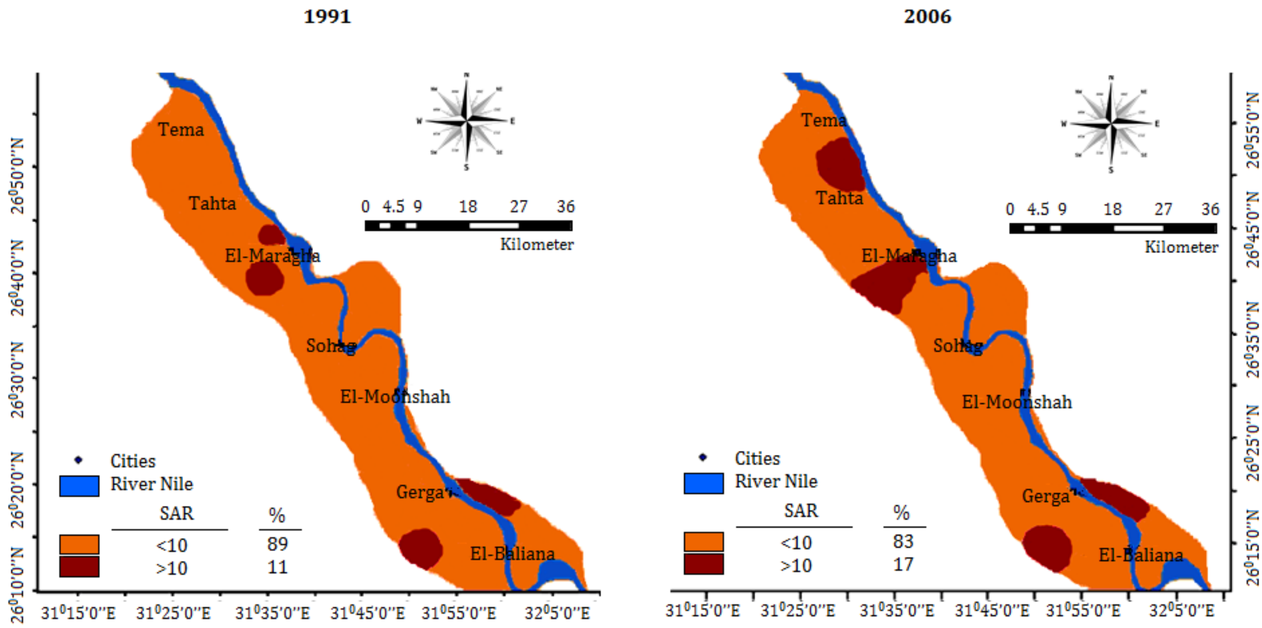

Figure 4. The changes in the sodium adsorption ratio (SAR) of the groundwater between 1991 and 2006.

- Residual Sodium Carbonate (RSC_w)

RSC of groundwater samples were classified into three classes, namely, less than 1.25, 1.25 to 2.50, and greater than 2.50 meq/l (Table 2 and Figure 5). The maps showed that the first and third classes of RSC_w changed from 91 and 3 %, respectively, in 1991 to 83 and 11%, respectively, in 2006. The second class (1.25

-2.5 meq/l) showed the same level of 6 %in 1991 and 2006. The increase in the high groundwater class of RSC may limit the use of this water in irrigation. If the RSC is greater than 2.5 meq/l, the water will not be appropriate for irrigation. High sodium ions in water affect the permeability of soil and cause infiltration problems. This is because the exchangeable sodium on soil clays can replace the adsorbed calcium and magnesium on these clays and cause the dispersion of soil particles. The increase in the RSC of irrigation water is attributed to the increases in salinity (EC_e) and SAR of the soil.

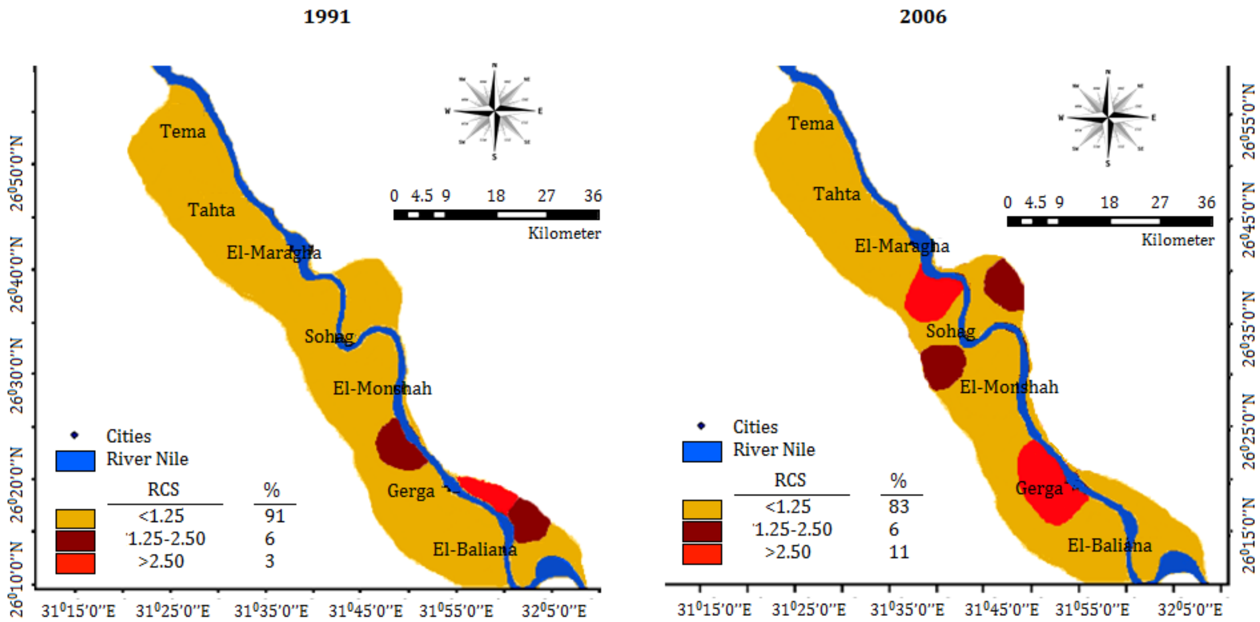

Figure 5. The changes in the residual sodium carbonate (RSC) of the groundwater between 1991 and 2006.

- **Soluble Cation Changes**

Table 3 reveals that the major ions in groundwater samples are sodium, calcium and magnesium. The mean value of the sodium in the groundwater increased from 8.18 meq/l in 1991 to 11.95 meq/l in 2006. The increase in sodium concentration matches the changes in the EC_w. The mean calcium ions in the groundwater increased from 1.57 meq/l in 1991 to 4.65 in 2006. The mean groundwater magnesium also increased from 4.41 meq/l in 1991 to 4.74 meq/l in 2006.

- **Soluble Anion Changes**

Chloride, sulfate, carbonate and bicarbonate ions are the main anions in groundwater (Table 3). The average groundwater chloride generally increased from 6.59 meq/l in 1991 to 7.23 meq/l in 2006. The increase in the groundwater chloride was consistent with that of the EC_w and Na. The mean sulphate ions in the groundwater were doubled from 3.94 meq/l in 1991 to 7.07 meq/l in 2006. However, average concentrations of $CO_3^{=}$ + HCO_3^{-} ions in the groundwater increased from 3.69 meq/l in 1991 to 6.12 meq/l in 2006.

Soils

- **Soil Salinity**

Various analyses in Table 4 indicate that the soil salinity increased from 1991 to 2006. The salinity maps of surface and subsurface soils (Figures 6 and 7, respectively) show an increase trend in the soil salinity from 1991 to 2006. The salinity class of < 0.05% for the surface soils increased from 69 % in 1991 to 77 % in 2006. However, the salinity class of 0.05-0.10 % salts approximately appears to have the same level (17 %) in 1991 and 2006. Also, the class of 0.10- 0.15% salts decreased from 11% in 1991 to 3% in 2006. The worse soil salinity class of > 0.15% has been the same percentage (3 %) in 1991 and 2006. The results reveal that the salinity of the surface soils decreased from 1991 to 2006 in some classes. This may indicate that the salts were leached from surface layer to subsurface one. The percentage of the 0.05-0.10% salinity class of subsurface layers decreased from 37 % in 1991 to 28 % in 2006. Also, the class containing 0.10 -0.15% salts decreased from 23 % in 1991 to 15 % in 2006. However, the class of 0.15 -0.20 % salts increased from 11 % in 1991 to 14 % in 2006. The worse soil salinity class of > 0.20 salts ascended from 29 % in 1991 to 43 % in 2006. These results reveal that the soil salinity increased with depth from 1991 to 2006. This may be due to the leaching processes.

Table 3. Some chemical properties of the groundwater of the studied areas between 1991 and 2006

No	Location	Na^+		Ca^{2+}		Mg^{2+}		Cl^-		SO_4^{2-}		$CO_3^{2-} + HCO_3^-$	
		(meq/l)											
		1991	2006	1991	2006	1991	2006	1991	2006	1991	2006	1991	2006
1	El -Balabesh Gobly	2.83	28.14	0.82	8.00	2.88	14.20	1.79	22.00	2.08	8.36	4.54	4.20
2	El-Ghabat	3.36	2.00	1.03	4.20	3.91	4.20	3.58	5.00	3.02	4.77	3.31	6.80
3	Awlad Salam Bahre	4.34	5.26	0.82	3.60	3.71	1.60	3.23	2.00	6.25	4.21	4.27	5.40
4	Naknk	1.85	10.69	1.24	8.20	3.91	10.00	1.79	4.20	1.77	5.14	2.75	7.40
5	Gazert Naknk	1.51	3.29	0.62	8.00	4.33	8.20	2.33	4.20	1.15	5.87	2.26	8.20
6	Beat Alam	26.05	28.50	6.39	7.00	1.27	1.40	29.03	3.20	13.54	6.20	1.24	5.20
7	El-Nosirat	3.99	6.53	0.62	6.20	2.28	2.60	2.50	2.40	4.06	6.04	4.82	4.40
8	Nego Mazen Shark	24.29	41.66	0.32	3.00	3.63	7.20	17.56	30.00	7.40	14.82	6.89	6.80
9	Gazert Bardes	2.19	1.41	0.82	3.60	3.90	3.00	1.97	3.60	1.04	2.98	3.86	6.80
10	Gazert Bardes	2.78	1.58	2.68	2.80	2.57	2.20	2.69	3.00	1.88	2.69	4.54	6.00
11	Gerga	4.09	4.42	0.82	1.07	3.29	2.43	2.51	1.87	2.19	4.52	4.82	7.47
12	El-Rakakna	10.54	11.50	2.88	3.40	4.74	4.40	9.68	1.40	5.10	3.67	2.75	5.20
13	Awlad Hamza	10.24	7.98	0.41	1.28	3.50	1.02	3.40	1.87	4.17	4.89	6.19	8.13
14	Awlad Salama	2.59	3.13	1.03	6.20	2.06	10.80	1.79	3.60	1.25	8.81	3.03	6.20
15	El-Zara	3.80	6.34	0.82	3.42	4.33	2.28	2.69	6.94	3.96	4.93	4.41	5.73
16	Awlad Harwon	12.88	23.91	1.85	6.21	5.97	9.49	9.14	20.23	4.90	11.78	3.30	5.53
17	Rwafe Eyswaia	2.92	2.29	0.41	1.93	4.33	2.17	1.43	1.02	2.08	2.53	5.51	6.40
18	Awlad Azaz	9.95	7.90	0.82	2.14	5.77	2.56	3.76	1.53	4.48	1.61	3.72	8.73
19	Kelfao	2.83	4.45	0.82	1.93	2.88	0.77	1.79	1.19	1.04	1.34	4.54	3.67
20	Arab El Atawla	1.66	1.51	0.82	2.57	4.53	2.93	1.79	1.02	1.04	8.36	4.13	5.53
21	Gezert Shandawil	2.29	2.77	0.62	2.57	4.12	3.13	2.15	1.36	1.04	3.95	4.41	5.93
22	Bahta	3.61	14.47	1.24	2.57	9.89	4.13	2.23	3.06	2.81	7.09	2.75	6.80
23	El-Ghrizat	19.02	32.24	2.68	7.28	6.79	4.42	21.86	18.87	5.21	28.03	2.07	3.93
24	El-Ghrizat	31.92	43.11	4.94	10.49	12.45	8.81	26.52	30.94	9.38	7.09	1.93	2.93
25	Tunise	3.67	8.45	1.65	1.28	2.67	1.02	1.79	1.53	1.56	6.73	5.23	7.60
26	Neida	1.95	2.22	0.82	3.21	3.50	1.29	1.43	1.36	1.04	3.23	3.72	7.00
27	Gehina El Sarkia	2.97	0.98	0.82	4.20	3.09	5.40	1.79	6.40	4.06	2.42	3.72	5.80
28	El-Swamia Shark	14.31	29.25	4.12	4.80	6.18	3.40	13.98	11.60	6.98	10.89	2.62	7.80
29	Neg Hermas	20.49	14.65	4.12	6.20	4.94	5.60	22.67	11.80	5.73	9.89	2.07	4.20
30	El-Sheik Shibl	11.41	10.56	1.65	3.21	6.37	6.50	7.53	4.93	6.25	7.30	4.68	7.47
31	Nazlt Aly	15.22	9.51	0.82	7.80	2.06	7.40	3.94	4.40	6.35	11.74	3.03	4.40
32	El-Swamea Gharb	2.34	0.95	0.82	5.60	3.29	4.20	1.08	3.20	1.35	3.99	4.13	4.20
33	Nazlt Imara	17.56	33.33	3.09	5.60	8.65	7.40	15.41	17.40	10.42	13.69	2.34	7.40
34	Bin Harb	3.31	3.56	0.82	5.00	3.50	3.20	1.97	3.80	1.56	3.33	3.59	8.40
35	Um Dona	1.61	6.99	1.24	8.20	3.09	6.60	1.97	12.20	1.88	14.59	2.07	6.60
	Mean	8.18	11.87	1.58	4.65	4.41	4.74	6.59	7.23	3.94	7.07	3.69	6.12

Table **4.** Analysis of the soil samples of the area understudy between 1991 and 2006

No	Location	Salts, %				pHe			
		1991		2006		1991		2006	
		Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
1	El -Balabesh Gobly	0.04	0.08	0.03	0.31	7.69	8.21	7.95	8.60
2	El-Ghabat	0.04	0.06	0.03	0.06	7.96	8.70	7.85	8.75
3	Awlad Salam Bahre	0.04	0.07	0.04	0.09	7.94	8.60	7.84	8.50
4	Naknk	0.03	0.18	0.02	0.27	7.75	8.15	7.75	8.35
5	Gazert Naknk	0.06	0.27	0.04	0.32	7.94	8.18	7.72	8.10
6	Beat Alam	0.04	0.07	0.03	0.08	8.20	8.60	8.50	8.30
7	El-Nosirat	0.06	0.07	0.03	0.13	7.74	7.82	7.95	8.26
8	Nego Mazen Shark	0.12	0.29	0.08	0.31	7.90	8.60	8.15	8.60
9	Gazert Bardes	0.02	0.10	0.03	0.09	7.80	8.50	7.74	8.45
10	Gazert Bardes	0.02	0.07	0.02	0.09	7.75	8.44	7.84	8.30
11	Gerga	0.04	0.10	0.03	0.71	8.10	8.70	8.00	8.00
12	El-Rakakna	0.04	0.12	0.03	0.17	7.83	8.71	7.75	8.50
13	Awlad Hamza	0.11	0.14	0.13	0.14	7.95	9.30	8.16	9.60
14	Awlad Salama	0.03	0.09	0.02	0.09	7.95	8.86	7.77	8.71
15	El-Zara	0.04	0.14	0.04	0.37	8.05	8.90	8.00	8.20
16	Awlad Harwon	0.04	0.60	0.05	0.16	7.90	8.44	7.75	9.20
17	Rwafe Eyswaia	0.04	0.66	0.02	0.45	7.74	8.20	7.82	8.10
18	Awlad Azaz	0.15	0.08	0.27	0.21	8.01	8.99	8.95	9.25
19	Kelfao	0.02	0.19	0.02	0.20	8.06	8.35	7.75	8.30
20	Arab El Atawla	0.02	0.15	0.02	0.22	7.85	9.50	7.69	9.10
21	Gezert Shandawil	0.02	0.25	0.02	0.50	7.75	8.16	7.70	7.98
22	Bahta	0.05	0.34	0.06	0.40	7.95	8.20	7.91	8.25
23	El-Ghrizat	0.03	0.12	0.04	0.16	7.82	8.52	8.06	8.75
24	El-Ghrizat	0.02	0.05	0.01	0.12	8.50	8.55	8.50	8.72
25	Tunise	0.02	0.25	0.02	0.45	7.65	8.22	8.10	7.95
26	Neida	0.02	0.10	0.02	0.10	7.91	8.33	8.15	8.50
27	Gehina El Sarkia	0.03	0.09	0.04	0.07	7.80	8.41	8.54	8.70
28	El-Swamia Shark	0.03	0.09	0.02	0.09	7.74	8.38	8.00	8.35
29	Neg Hermas	0.16	0.14	0.07	0.13	7.75	8.75	7.90	8.82
30	El-Sheik Shibl	0.05	0.21	0.07	0.27	7.65	8.10	7.75	8.19
31	Nazlt Aly	0.05	0.30	0.04	0.36	8.10	8.05	8.30	8.00
32	El-Swamea Gharb	0.02	0.08	0.06	0.07	7.82	8.45	7.63	8.35
33	Nazlt Imara	0.02	0.30	0.02	0.07	8.12	8.10	8.35	8.10
34	Bin Harb	0.05	0.08	0.04	0.23	7.82	8.58	7.90	8.19
35	Um Dona	0.14	0.19	0.04	0.17	7.78	8.64	7.78	8.16

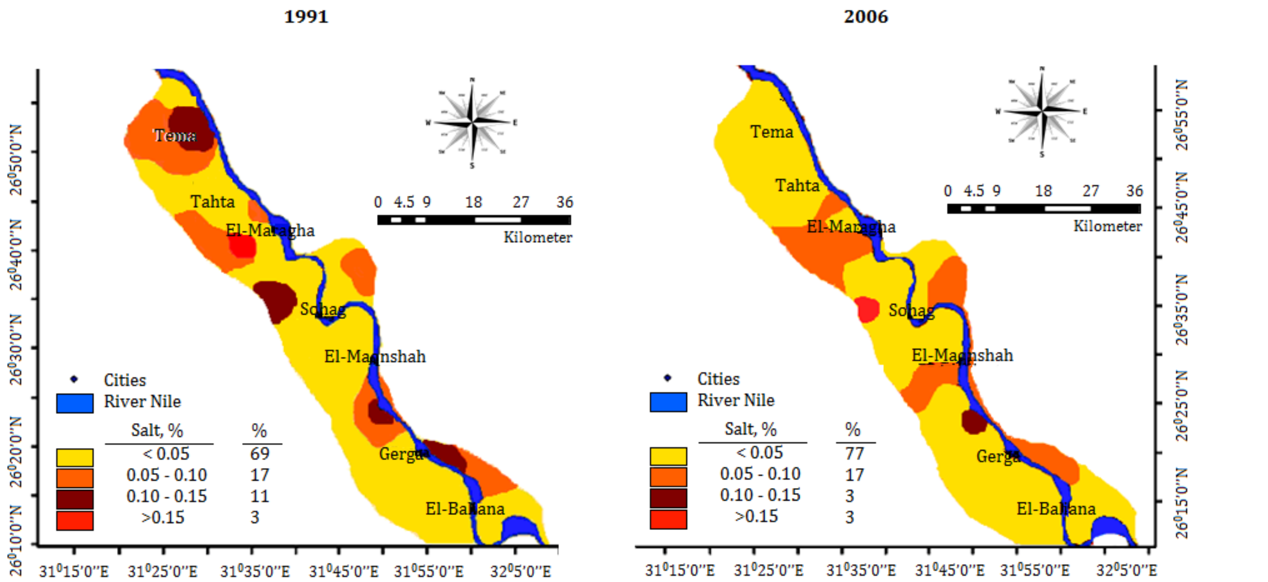

Figure 6. The changes in salt concentration of surface soil samples (0-25cm) irrigated by groundwater between 1991 and 2006.

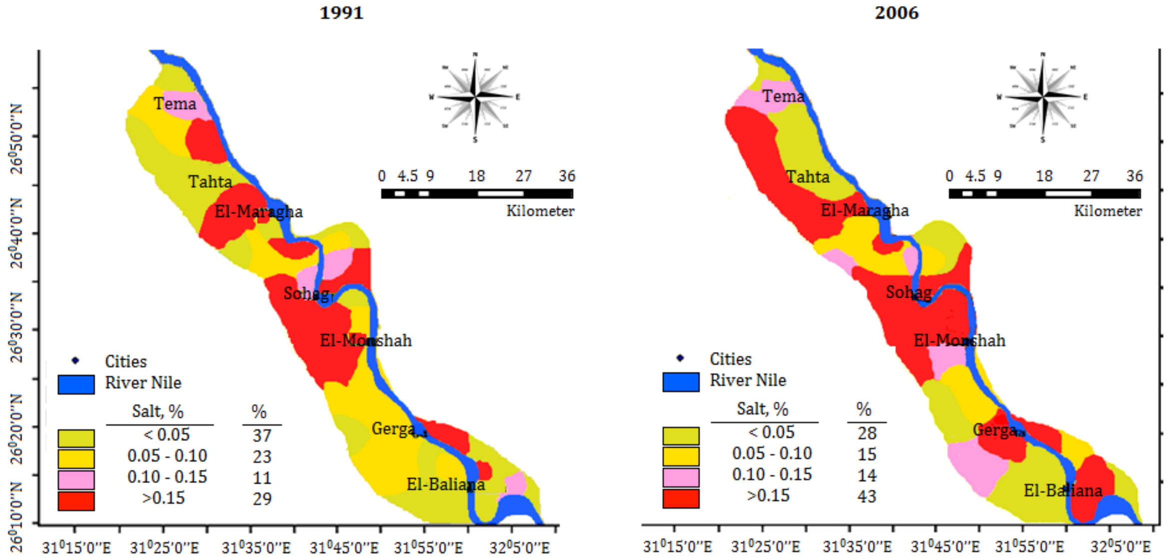

Figure 7. The changes in salt concentration of subsurface soil samples (25-50 cm) irrigated by groundwater between1991 and 2006.

It is clear that the future of Sohag soils irrigated with groundwater is of a great danger at most measures. The overall view of the salinity indicates a shift toward the salinization of the groundwater and soils irrigated with these waters. The excess of salt content is one of the major concerns with water used for irrigation. A high salt concentration in the water and soil negatively affects the crop yields, degrade the land and pollute the groundwater. These results agree with those obtained by Ghallab and Ali (2000).

- **Soil pH**

The pH of the soil samples (Table 4, Figures 8, 9) was classified into two classes, namely less than 8.0 and greater than 8.0 according to Ghallab (1995). The percentage of surface soil samples of the first class (pH < 8.0) decreased from 77 % in 1991 to 60 % in 2006. However, the second pH class (> 8) increased from 23 % in 1991 to 40 % in 2006. The first pH class (< 8) of the subsurface layers increased from 3 % in 1991 to 6 % in 2006. However, the percentage of subsurface soil samples having pH range between 8.0 and 8.5 increased from 51 % in 1991 to 60 % in 2006. However, subsurface soil pH having > 8 decreased from 46 % in 1991 to 34 % in 2006. These changes in the soil pH may be related to the changes in the salt content.

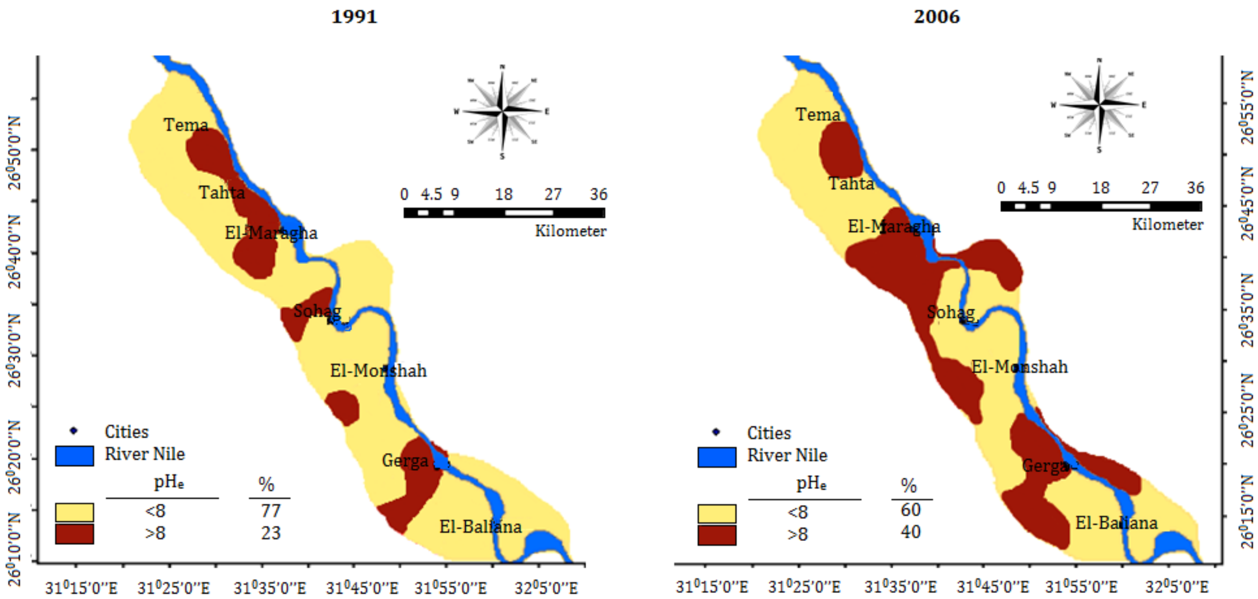

Figure 8. The changes in the pH of surface soil samples (0-25 cm) irrigated by groundwater between 1991 and 2006.

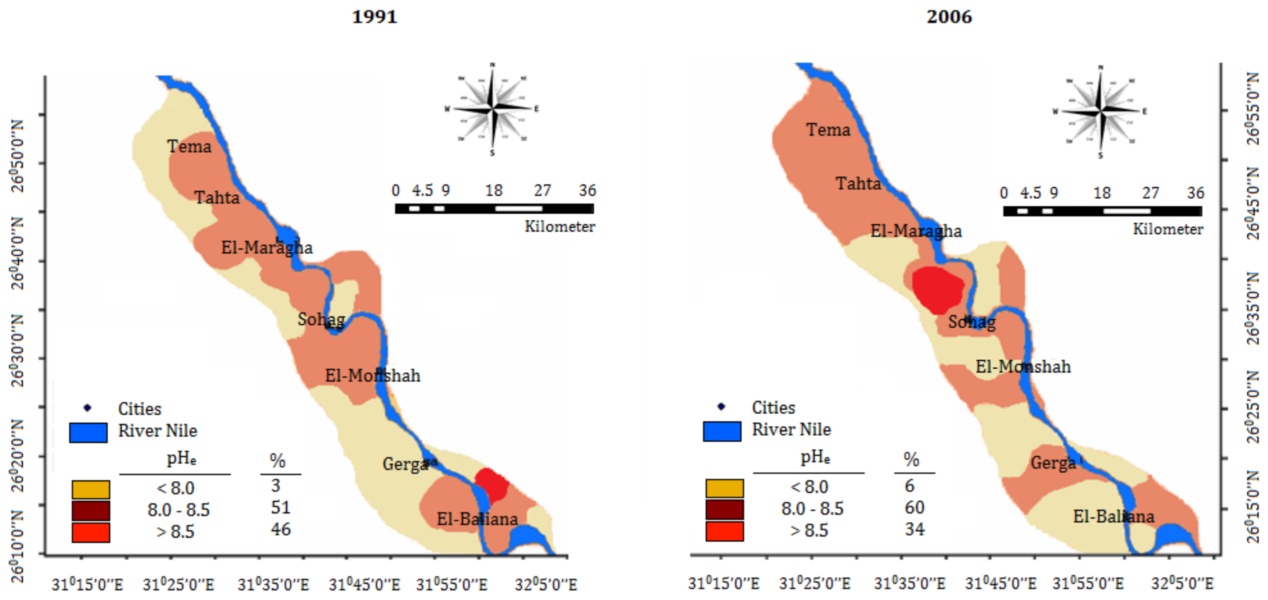

Figure 9. The changes in the pH of subsurface soil samples (25-50 cm) irrigated by groundwater between 1991 and 2006.

Conclusion

The increase of salinity in the groundwater and soil from 1991 to 2006 is certain. Soils with a moderate content of salts can be used if a moderate leaching occurs. Water with high salinity and sodium (SAR) should not be used for water irrigation. However, in some places with water shortage, water with high salinity can be used as a supplement for other sources and with a good management and a control of salinity. If water with a very high salinity is used, a drainage system must be installed to overcome the soil salinity problem that is caused by using saline groundwater in irrigation. Moreover, drainage must be adequate and water must be applied in excess to provide considerable leaching. Amelioration of these soils needs a source of calcium (Ca^{2+}) that can replace the excess exchangeable sodium (Na^{+}). Additions of gypsum may help to ameliorate such soils to supply adequate Ca^{2+} and growing of certain crops that are tolerant to ambient soil salinity and sodicity. Further research will be carried out to determine the change in soil and groundwater properties over the next 15 years. Monitoring soil salinity, as well as, periodic analysis of soils and groundwater wells to determine the changes taking place in the salinity and other properties is recommended.

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