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QUALITY OF SURFACE WATER IN SAN EL-HAGAR REGION, SHARKIA GOVERNORATE, EGYPT

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ABSTRACT: A total of 36 water samples were collected from 3 irrigation and drainage canals in San El-Hagar (Sharkia Governorate, Egypt); site 1; Bahr-Mouse canal, site 2; Kafr El-Masalamya drainage canal and site 3; Almashraa drainage canal. Measurements included pH, electrical conductivity (EC), soluble ions and heavy metals were carried out during 12 months (one sample each month for each site) from June 2015 to May 2016. The pH values ranged between 7.04 to 7.67 and EC for sites 1, 2 and 3 were averaged 2.14, 2.67 and 2.71 dSm^{-1}, respectively. Respective averages for sodium adsorption ratio (SAR) were 4.92, 5.92 and 4.56. Those for chlorides were 16.15, 20.78 and 22.92 mmole l^{-1}. Others were as follow, HCO_3^-: 3.82, 4.35 and 4.34 mmole l^{-1}, Na^+: 10.79, 14.15 and 12.07 mmole l^{-1}, and Ca^{2+}: 3.65, 3.67 and 6.37 mmole l^{-1}. Water of site 1 was C_3S_1 (high salinity and low sodicity hazards), while waters of sites 2 and 3 were C_4S_1 (very high salinity and low sodicity hazards) and could be used for crops which are tolerant to salinity. Most of the waters contained heavy metals below the permissible limits. The results are important and might be used as a guide to water quality in San El-Hager region.

Key words: Water resources, multi-elements, water quality, irrigation, salinity, trace elements, heavy metals.

INTRODUCTION

Egypt is an arid country facing water shortage that has become a critical factor limiting its food production and economic development. Nile River constitutes a vital water resource serving the population along the Nile including the Egyptian Nile Valley and the Nile Delta. With increasing population in Egypt, the *per capta* shares of farmland and water are reduced considerably. Thus, there is a need to develop alternative water resources **(Mosaad, 2017)**. In addition, there is a great need for additional water resources to meet the agricultural demands of deseart land for the 630 thousand hectares area (1.5 million faddan) which the government intends to reclaim. Such area lies in Toshki, Sinai and the west desert **(Soliman, 1983; Soliman, 2000; Alnaimy *et al.,* 2012; Abd Al-Hamid *et al.,* 2017)**. The current Egyptian water supply is insufficient to meet the increased national demand.

The management of water sources in Egypt, for a long time, was concerned mainly with salinity control and quantitative water management to sustain the production of irrigated-agriculture. Agricultural productivity is limited by soil salinity, water quality and encroachment of urban settlements into cultivated areas **(Van Steenbergen and Dayem, 2007)**. Water is a dynamic system containing living, non-living, organic, inorganic, soluble and insoluble components, all of them are vital to life. Water pollution is a growing problem caused by increasing levels of industrial, agricultural and commercial chemicals discharged in it, causing a significant increase in their amounts in the aquatic system **(Ghazy *et al.,* 2017)**. In the Egyptian Delta, drainage water containing fertilizers and pesticides is reused for irrigation after mixing with Nile water **(Van Steenbergen and Dayem, 2007; Alnaimy *et al.,* 2012; Abd Al-Hamid *et al.,* 2017)**.

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Drainage waters could be available for irrigation. The drainage program in Egypt is unique in its coverage. The area provided by surface and subsurface drainage is 2.9 million and 2.0 million hectares, respectively, and most of old lands have drainage systems **(Van Steenbergen and Dayem, 2007)**. The total annual discharge of drainage water in Egypt is 12 billion m^3/year, wherein most of it is disposed of in the Mediterranean Sea and the Northern lakes of Delta **(FAO, 2002)**. An intensive expansion program for the reuse of drainage water in agriculture requires adequate, proper measures and precautions due to salinity and alkalinity problems of waters. One of the promising projects in Egypt based on the use of drainage water mixed with Nile water is EL-Salam canal to irrigate northern part of Sinai. It carries the drainage water of Eastern Delta mixed with Nile water at a ratio of 1:1 **(Abdel-Hamid *et al.,* 2000; Abd Al-Hamid *et al.,* 2017)**.

In water quality classification, water that has an electrical conductivity (EC) exceeding 3 dSm^{-1} (bout 2000 mg salts l^{-1}) is considered unsatisfactory **(Abd Al-Hamid *et al.,* 2017)**. **Wilcox (1955)** classified irrigation water into three classes. Class II (good water) has an EC of 1.0 to 3.0 dSm^{-1}; 0.5 to 2.0 mg boron l^{-1}; 60 to 75% soluble sodium percent (SSP) and 5 to 10 mmole chloride l^{-1}. Waters having less than such levels are class I (excellent water) and those having higher levels are class III (unsatisfactory water). **Gupta (1984, 1990)** suggested a classification of five classes based in sodic hazards, boron and the salinity hazards and called it the ABC classification.

Soluble ions and heavy metals in surface waters are of major interest because they are bio-accumulative and persistent in nature, and they can cause health risk to humans **(Khan *et al.,* 2009; Wu *et al.,* 2017)**. Water quality has been reported in many countries **(Fordyce *et al.,* 2007; Mukherjee *et al.,* 2008; Kavcar *et al.,* 2009; Muhammad *et al.,* 2011; Wu *et al.,* 2011; Bikundia and Mohan, 2014; Islam *et al.,* 2015)**. Intensification of urban development, industrial, and agricultural activities have worldwide degraded the water resources quality **(Islam *et al.,* 2015)**. Access to high-quality water is decisive for global and local development, especially in arid and semi-arid regions **(Wu *et al.,* 2017)**.

Interactions of different factors affect water quality. This reflects complexity of the ecosystem **(Ghazy *et al.,* 2017)**. Some studies investigated water quality in different areas of Egypt. **Zein *et al.* (2002)** studied the contents of Pb, Mn, Zn, Cd, Ni and Cu heavy metals and obtained averages of 0.03, 0.011, 0.10, 0.004, 0.021 and 0.022 mg l^{-1}, respectively in the Nile water compared with 0.5, 0.19, 0.19, 0.02, 4.95 and 0.08 mg l^{-1} in one season; and 0.73, 0.27, 0.18, 0.030, 3.47 and 0.06 mg l^{-1}, respectively in the following season. **Ibrahim (2004)** reported that non-saline waters exhibited a wide range of heavy metals contents depending on geology, climate and anthropic activity.

In San El-Hagar which is located in the Northeastern Nile Delta of Egypt (Sharkia Governorate), efforts are currently exerted to reclaim salt-affected soils and to use water resources of the area. Determination of soluble ions and salts in surface waters in Egypt is extremely important for hazard assessment.

The aim of the present work was to assess the quality of irrigation water in San Al-Hagar area (Sharkia Governorate, Egypt). The results will help to strengthen understanding of approaches related to sustainable agriculture and rural transformation in the region. In addition, the results will help authorities and smallholder farmers to manage water resources effectively.

MATERIALS AND METHODS

Water Sampling

Water samples were collected from 3 sites in San El-Hagar region which is along the Southeastern part of Manzala lake. The climate of the studied area is a Mediterranean one which is hot arid in summer and warm with low rain in winter (*ca.* 73 mm). Water samples were taken monthly from June 2015 to May 2016. Figs. 1 and 2 show the study area and the sampling sites. Information on longitude, and latitude of 3 sites are presented in Table 1.

Samples was collected at a depth of about 60 cm to ensure that the sampled water was representative. The water samples were collected

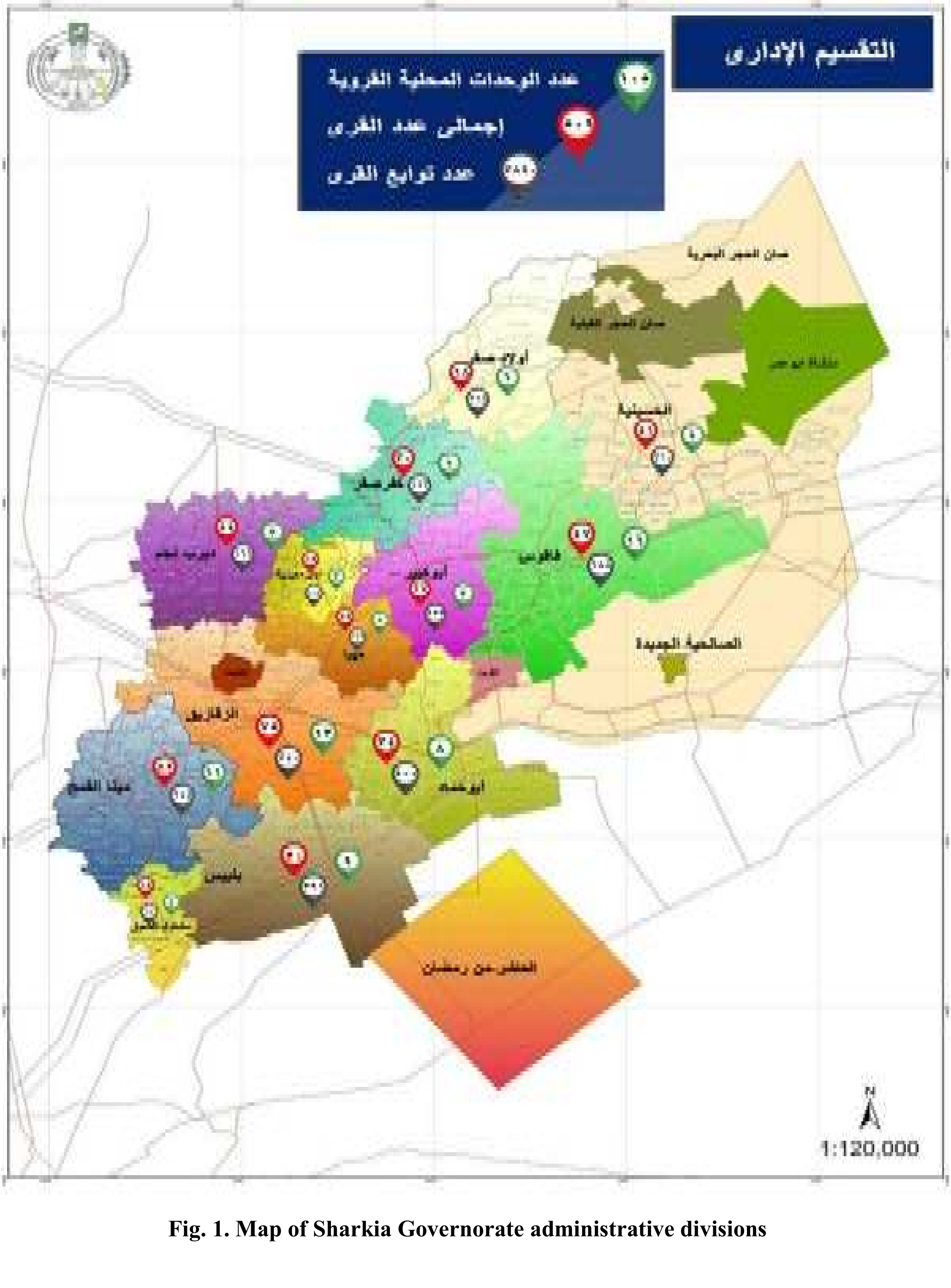


Fig. 1. Map of Sharkia Governorate administrative divisions

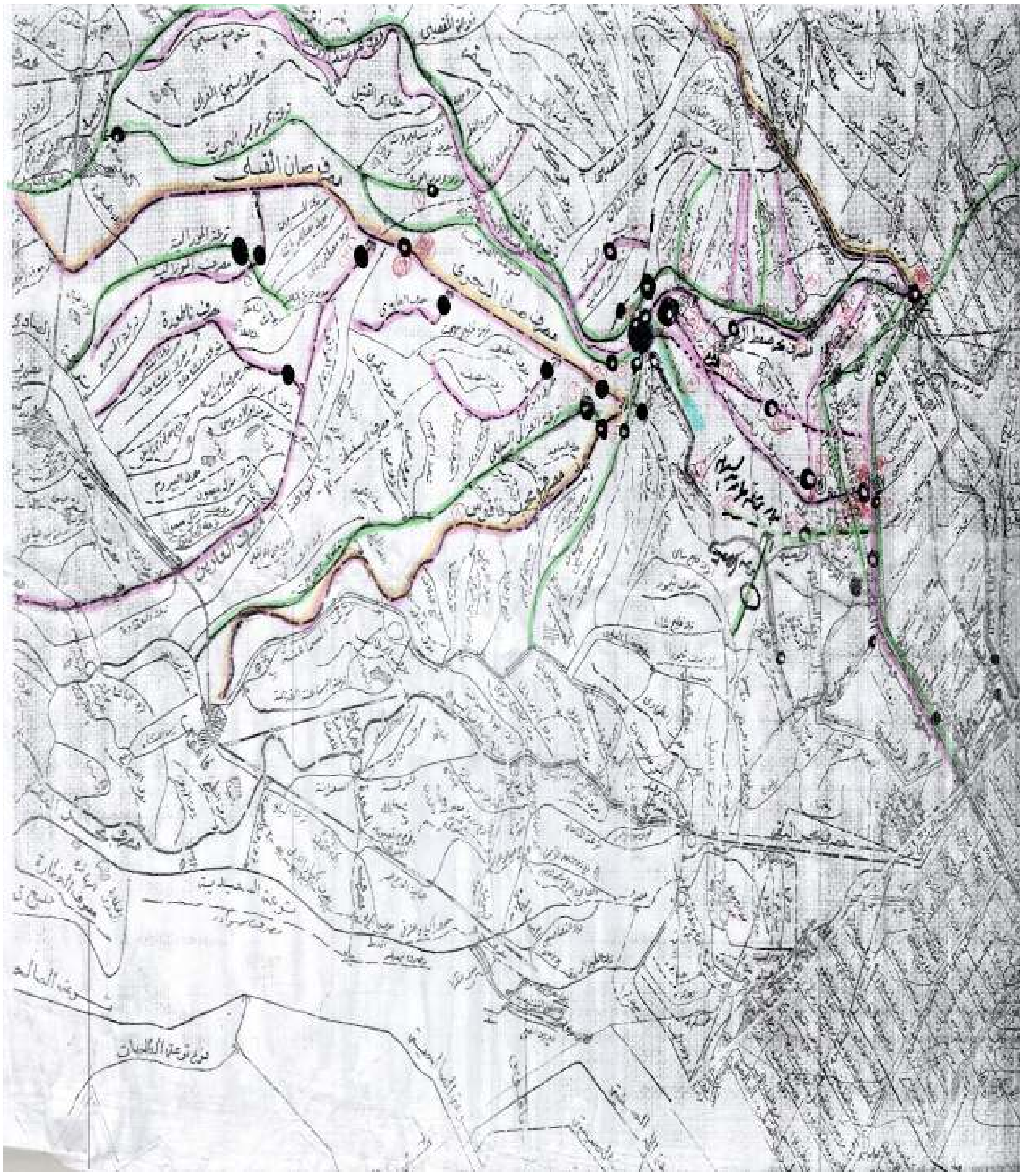


Fig. 2. Map of canals and drainage canals of the study area

Table 1. Geographical locations and description of water sites in the present study

Sample No.	X	Y	Description
1	0337500	3424207	Bahr-Moues canal
2	0388912	3426804	Kafr El-Masalamya drainage canal
3	0392907	3426520	Almashraa drainage canal

in capped polyethylene bottles (1 l × 2 for each sample). Samples for heavy metal analysis were collected in acid-washed polyethylene bottles and preserved by adding nitric acid (pH < 2) at the site. Samples were immediately filtered and subjected to chemical analyses. The pH and EC were measured *in situ* using precision pH meter (PHS 2C) (T-Bota Scietech, Nanjing, China) and EC meter (DDSJ 308A) (Biocotek, Ningbo, China) at 25˚C then kept under refrigerated conditions (cooling boxes). Samples were delivered within 48 hr., to the laboratory and stored in dark at 4˚C until they were analyzed.

Water Analyses

Water samples were analyzed for pH, EC, sodium (Na^+), sulfate (SO_4^{2-}), ammonium (NH_4^+), potassium (K^+), chloride (Cl^-), bicarbonate (HCO_3^-), nitrate (NO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), and heavy metals [cobalt (Co), iron (Fe), lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), manganese (Mn) and Nickel (Ni)]. All samples were analyzed following methods cited in **USDA (1954)** and the sulfate calculated by difference. Boron was determined by the curcumin method **(Jackson, 1958)**. Heavy metals were measured using Atomic Absorption Spectrophotometer (Perkin-Elmer, model 290B, Norwalk, C.T., Perkin Elmer 3300).

Quality Indices

The following quality indices were studied. Salinity was in terms of EC and measured as dSm^{-1}. Soluble sodium percentage (SSP) was calculated as:

$$SSP=\frac{Na}{\Sigma\ Cations}\times 100$$

Where:

Ions are expressed as mmole l^{-1} (1)

Sodium adsorption ratio (SAR) was calculated as:

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

Where:

Ions are expressed as mmole l^{-1} (2)

Adjusted Sodium Adsorption Ratio (adj. SAR) was calculated according to the following equation **(Ayers and Westcot, 1976)**:

$$Adj.\ SAR = SAR\ [1 + (8.4 - pH_c)] \quad (3)$$

$$pH_c=(PK'_2-PK'_c)+ p(Ca^{2+}+Mg^{2+})+p(Alk) \quad (4)$$

Adjusted sodium hazard (adj.^{R} Na) was calculated as follows:

$$Adj.^R Na=\frac{Na^+}{\sqrt{(Ca_x^{2+}+Mg^{2+})/2}}$$ **(Suarez, 1981)** (5)

Where:

Ca_x value is modified according to the salinity of the water, its HCO_3/Ca ratio and the estimated partial pressure of CO_2 in the surface few millimeters of soil (PCO_2 = 0.0007 atmospheres), and Mg in the water. The Ca_x represents the Ca expected to remain in a solution of soil water at equilibrium. The obtained adj.^{R} Na is used in place of the SAR to evaluate the Na hazard which can cause infiltration problems if the water is used for irrigation.

Estimated exchangeable sodium percent (ESP) expected in the soil using the SAR of water was calculated as follows **(USDA, 1954)**.

$$ESP=\frac{100(-0.0126+0.001745\,SAR)}{1+(-0.0126+0.001745\,SAR)} \quad (6)$$

The Permeability Index (PI) was calculated as follows **(Doneen, 1964)**:

$$PI=\frac{(Na^+ +\sqrt{HCO_3^-})\times 100}{Na^+ +Ca^{2+}+Mg^{2+}} \quad (7)$$

RESULTS AND DISCUSSION

Considering the water chemistry and its suitability for irrigation, water quality was evaluated on basis of salinity, sodicity, residual sodium carbonate, boron, heavy metals and nitrogen contents. Tables 2, 3, 4, 5, 6 and 7 show the chemical analyses of water samples from the 3 sites in San Al-Hagar area taken monthly from June 2015 to May 2016. All locations where water samples were taken are in the eastern part of Nile Delta. Water characteristics of drains are affected by the nature, composition and salinity of soils from

Table 2. Values of pH, EC (dSm^{-1}) and soluble ions (mmole l^{-1}) parameters and indices in water samples collected from Bahr-Moues canal (site 1) during June 2015 to May 2016

	Month	pH	EC (dSm^{-1})	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^-	SO_4^{-2}	Cations	Anions	SAR	SSP	RSC	RSBC	ESP	pHc	Adj.SAR	Adj.^{R}Na	SCAR[1]	SAR/ SCAR	RSC/ RSBC	ICAR[2]	USDA[3]
2015	June	7.25	2.23	10.90	0.45	3.13	6.76	17.65	3.00	0.00	0.59	21.24	21.24	4.90	51.32	6.89	-0.13	6.03	7.60	8.82	5.56	6.16	0.80	53.00	C2 S0	C3 S1
	July	7.22	2.08	10.02	0.50	4.32	5.38	15.50	3.80	0.00	0.91	20.21	20.21	4.55	49.55	5.90	-0.52	5.50	7.60	8.19	5.63	4.82	0.94	11.45	C2 S0	C3 S1
	August	7.10	2.29	11.84	0.44	3.62	6.38	15.75	5.35	0.00	1.17	22.27	22.27	5.30	53.17	4.65	1.74	6.62	7.60	9.53	6.19	6.23	0.85	-2.68	C2 S0	C4 S1
	September	7.17	2.04	10.19	0.44	3.32	6.38	15.90	3.50	0.00	0.92	20.32	20.32	4.63	50.15	6.20	0.19	5.62	7.60	8.33	5.33	5.60	0.83	-33.49	C2 S0	C3 S1
	October	7.12	2.02	10.79	0.45	2.97	6.18	15.50	3.85	0.00	1.03	20.38	20.38	5.05	52.94	5.30	0.89	6.24	7.60	9.08	5.72	6.27	0.81	-5.98	C2 S0	C3 S1
	November	7.18	2.14	10.59	0.50	3.13	6.76	16.33	3.75	0.00	0.91	20.98	20.98	4.76	50.48	6.14	0.62	5.82	7.60	8.57	5.40	5.99	0.80	-9.90	C2 S0	C3 S1
	December	7.29	2.18	10.33	0.45	4.32	5.38	16.83	3.05	0.00	0.60	20.47	20.47	4.69	50.44	6.65	-1.27	5.71	7.60	8.44	5.81	4.97	0.94	5.25	C2 S0	C3 S1
2016	January	7.10	2.04	10.28	0.55	3.13	6.76	15.00	4.50	0.00	1.22	20.72	20.72	4.62	49.61	5.39	1.37	5.61	7.60	8.32	5.24	5.81	0.80	-3.93	C2 S0	C3 S1
	February	7.33	2.12	9.75	0.45	5.50	4.00	16.00	3.10	0.00	0.60	19.70	19.70	4.47	49.49	6.40	-2.40	5.39	7.60	8.05	6.20	4.16	1.08	2.67	C2 S0	C3 S1
	March	7.09	2.54	13.40	0.32	4.10	6.00	16.50	6.20	0.00	1.12	23.82	23.82	5.96	56.26	3.90	2.10	7.61	7.60	10.73	7.19	6.62	0.90	-1.86	C2 S0	C4 S1
	April	7.24	2.04	10.10	0.32	3.50	6.00	16.80	2.50	0.00	0.62	19.92	19.92	4.63	50.70	7.00	-1.00	5.63	7.60	8.34	5.42	5.40	0.86	7.00	C2 S0	C3 S1
	May	7.14	1.99	11.30	0.34	2.80	5.60	16.00	3.20	0.00	0.84	20.04	20.04	5.51	56.39	5.20	0.40	6.94	7.60	9.92	6.25	6.75	0.82	-13.00	C2 S0	C3 S1
	Average		2.14	10.79	0.43	3.65	5.97	16.15	3.82	0.00	0.88	20.84	20.84	4.92	51.71	5.80	0.17	6.06	7.60	8.86	5.83	5.73	0.87	0.71	C2 S0	C3 S1

[1] SCAR: sodium, calcium activity ratio= Na/√Ca in mmole l^{-1} **(Gupta, 1984)**.

[2] ICAR water quality class according to **Gupta (1979 a, b)**; C0, C1, C2, C3, C4, C5 are non, normal, low, medium, high and very high salinity; S0, S1, S2, S3, S4, S5 are non, normal, low, medium, high and very high sodicity, respectively.

[3] Water quality class according to **USDA (1954)**; C_1, C_2, C_3, C_4 are low, medium, high and very high salinity; S_1, S_2, S_3, S_4 are low, medium, high and very high sodicity, respectively.

-ESP: Exchangeable sodium percentage; **RSC**: Residual sodium carbonate (mmole l^{-1}); **RSB**: Residual sodium bicarbonate (mmole l^{-1}); and **-SAR**: sodium: adsorption ratio.

Table 3. Values of pH, EC (dSm^{-1}) and soluble ions (mmole l^{-1}) parameters and indices in water samples collected from Kafr El-Masalamya drainage canal (site 2) during June 2015 to May 2016

Year	Month	pH	EC (dSm^{-1})	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^-	SO_4^{-2}	Cations	Anions	SAR	SSP	RSC	RSBC	ESP	pHc	Adj.SAR	Adj.^{R}Na	SCAR[1]	SAR/ SCAR	RSC/ RSBC	ICAR[2]	USDA[3]
2015	June	7.67	2.81	13.70	0.60	3.57	9.33	22.50	3.97	0.00	1.00	27.20	27.47	5.39	50.37	8.93	0.40	6.76	7.60	9.71	6.05	7.25	0.74	22.33	C2 S0	C4 S1
	July	7.12	2.85	15.03	0.70	4.00	8.40	20.95	5.25	0.00	1.93	28.13	28.13	6.03	53.42	7.15	1.25	7.72	7.60	10.86	6.95	7.51	0.80	-5.72	C2 S0	C4 S1
	August	7.10	2.34	12.79	0.70	3.85	6.00	18.50	3.75	0.00	1.09	23.34	23.34	5.76	54.81	6.10	-0.10	7.31	7.60	10.37	6.87	6.52	0.88	61.00	C2 S0	C4 S1
	September	7.11	2.58	13.89	0.65	3.00	8.25	20.25	4.55	0.00	0.99	25.79	25.79	5.86	53.86	6.70	1.55	7.45	7.60	10.54	6.48	8.02	0.73	-4.32	C2 S0	C4 S1
	October	7.06	2.76	15.04	0.69	3.60	8.75	21.95	5.05	0.00	1.08	28.08	28.08	6.05	53.56	7.30	1.45	7.74	7.60	10.89	6.83	7.93	0.76	-5.03	C2 S0	C4 S1
	November	7.38	2.74	13.99	0.67	3.54	9.17	21.50	4.60	0.00	1.26	27.36	27.36	5.55	51.13	8.10	1.07	7.00	7.60	9.99	6.22	7.44	0.75	-7.61	C2 S0	C4 S1
	December	7.41	2.92	14.74	0.63	4.04	8.57	21.95	4.35	0.00	1.67	27.97	27.97	5.87	52.69	8.25	0.32	7.47	7.60	10.57	6.76	7.34	0.80	26.19	C2 S0	C4 S1
2016	January	7.08	2.67	14.28	0.74	3.50	9.00	20.50	5.50	0.00	1.52	27.52	27.52	5.71	51.89	7.00	2.00	7.24	7.60	10.28	6.41	7.63	0.75	-3.50	C2 S0	C4 S1
	February	7.15	3.02	15.77	0.66	4.50	7.80	21.40	5.00	0.00	2.33	28.73	28.73	6.36	54.89	7.30	0.50	8.20	7.60	11.45	7.54	7.43	0.86	14.60	C2 S0	C4 S1
	March	7.12	2.00	11.30	0.65	4.20	3.00	16.50	2.00	0.00	0.65	19.15	19.15	5.96	59.01	5.20	-2.20	7.60	7.60	10.72	8.05	5.51	1.08	2.36	C2 S0	C3 S1
	April	7.13	2.49	13.50	0.56	2.50	7.50	20.00	3.60	0.00	0.46	24.06	24.06	6.04	56.11	6.40	1.10	7.72	7.60	10.87	6.57	8.54	0.71	-5.82	C2 S0	C4 S1
	May	7.04	2.84	15.80	0.64	3.70	8.50	23.40	4.60	0.00	0.64	28.64	28.64	6.40	55.17	7.60	0.90	8.26	7.60	11.52	7.27	8.21	0.78	-8.44	C2 S0	C4 S1
	Average		2.67	14.15	0.66	3.67	7.86	20.78	4.35	0.00	1.22	26.33	26.35	5.92	53.91	7.17	0.69	7.54	7.60	10.65	6.83	7.44	0.80	-3.35	C2 S0	C4 S1

[1] SCAR: sodium, calcium activity ratio= Na/√Ca in mmole l^{-1} **(Gupta, 1984)**.

[2] ICAR water quality class according to **Gupta (1979 a, b)**; C0, C1, C2, C3, C4, C5 are non, normal, low, medium, high and very high salinity; S0, S1, S2, S3, S4, S5 are non, normal, low, medium, high and very high sodicity, respectively.

[3] Water quality class according to **USDA (1954)**; C_1, C_2, C_3, C_4 are low, medium, high and very high salinity; S_1, S_2, S_3, S_4 are low, medium, high and very high sodicity, respectively.

-**ESP**: Exchangeable sodium percentage; **RSC**: Residual sodium carbonate (mmole l^{-1}); **RSB**: Residual sodium bicarbonate (mmole l^{-1}); and -**SAR**: sodium: adsorption ratio.

Table 4. Values of pH, EC (dSm^{-1}) and soluble ions parameters and indices in water samples collected from Almashraa drainage canal (site 3) during June 2015 to May 2016

	Month	pH	EC (dSm^{-1})	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^-	SO_4^{-2}	Cations	Anions	SAR	SSP	RSC	RSBC	ESP	pHc	Adj.SAR	Adj.^{R}Na	SCAR[1]	SAR/ SCAR	RSC/ RSBC	ICAR[2]	USDA[3]
2015	**June**	7.42	2.89	11.70	0.65	6.55	8.53	23.40	3.70	0.00	0.33	27.43	27.43	4.26	42.65	11.38	-2.85	5.08	7.60	7.67	5.38	4.57	0.93	3.99	C2 S0	C4 S1
	July	7.23	2.65	11.50	0.58	6.50	7.45	22.00	4.00	0.00	0.03	26.03	26.03	4.35	44.18	-9.95	-2.50	5.21	7.60	7.84	5.61	4.51	0.97	3.98	C2 S0	C4 S1
	August	7.16	2.73	12.60	0.46	6.75	8.05	23.75	3.25	0.00	0.87	27.86	27.86	4.63	45.23	11.56	-3.51	5.63	7.60	8.34	5.94	4.85	0.96	3.30	C2 S0	C4 S1
	September	7.15	2.72	11.75	0.65	5.95	8.05	21.95	3.90	0.00	0.55	26.40	26.40	4.44	44.51	10.10	-2.05	5.34	7.60	7.99	5.54	4.82	0.92	4.93	C2 S0	C4 S1
	October	7.14	2.61	11.80	0.58	6.25	7.60	23.05	2.90	0.00	0.28	26.23	26.23	4.48	45.00	10.95	-3.35	5.41	7.60	8.07	5.71	4.72	0.95	3.27	C2 S0	C4 S1
	November	7.26	2.78	11.35	0.63	6.53	8.52	22.70	4.10	0.00	0.22	27.02	27.02	4.14	42.01	10.94	-2.43	4.89	7.60	7.45	5.22	4.44	0.93	4.51	C2 S0	C4 S1
	December	7.39	2.77	11.85	0.61	6.53	7.47	22.70	3.60	0.00	0.15	26.45	26.45	4.48	44.81	10.39	-2.93	5.40	7.60	8.06	5.78	4.64	0.97	3.55	C2 S0	C4 S1
2016	**January**	7.10	2.66	11.00	0.60	6.50	8.50	22.00	4.50	0.00	0.10	26.60	26.60	4.02	41.35	10.50	-2.00	4.71	7.60	7.23	5.06	4.31	0.93	5.25	C2 S0	C4 S1
	February	7.35	2.64	12.00	0.56	6.50	6.40	22.00	3.50	0.00	0.04	25.46	25.46	4.72	47.13	-9.40	-3.00	5.77	7.60	8.50	6.26	4.71	1.00	3.13	C2 S0	C4 S1
	March	7.21	2.79	14.20	0.32	7.00	7.60	25.50	1.99	0.00	1.63	29.12	29.12	5.26	48.76	12.61	-5.01	6.56	7.60	9.46	6.87	5.37	0.98	2.52	C2 S0	C4 S1
	April	7.20	2.78	12.50	0.70	5.40	7.60	21.90	3.30	0.00	1.00	26.20	26.20	4.90	47.71	-9.70	-2.10	6.03	7.60	8.83	6.05	5.38	0.91	4.62	C2 S0	C4 S1
	May	7.18	2.56	12.60	0.55	6.00	6.70	24.10	1.30	0.00	0.45	25.85	25.85	5.00	48.74	11.40	-4.70	6.18	7.60	9.00	6.45	5.14	0.97	2.43	**C2 S0**	**C4 S1**
	Average		2.71	12.07	0.57	6.37	7.71	22.92	3.34	0.00	0.46	26.72	26.72	4.56	45.17	10.74	-3.03	5.52	7.60	8.20	5.82	4.79	0.95	3.79	**C2 S0**	**C4 S1**

[1] SCAR: sodium, calcium activity ratio= Na/√Ca in mmole l^{-1} **(Gupta, 1984)**.

[2] ICAR water quality class according to **Gupta (1979 a, b)**; C0, C1, C2, C3, C4, C5 are non, normal, low, medium, high and very high salinity; S0, S1, S2, S3, S4, S5 are non, normal, low, medium, high and very high sodicity, respectively.

[3] Water quality class according to **USDA (1954)**; C_1, C_2, C_3, C_4 are low, medium, high and very high salinity; S_1, S_2, S_3, S_4 are low, medium, high and very high sodicity, respectively.

-ESP: Exchangeable sodium percentage; **RSC**: Residual sodium carbonate (mmole l^{-1}); **RSB**: Residual sodium bicarbonate (mmole l^{-1}); and **-SAR**: sodium: adsorption ratio.

Table 5. Heavy metal contents (mean values in mg l^{-1}) in water samples collected from Bahr-Moues canal (site 1)

	Month	Co	Zn	Pb	Cd	Fe	Mn	Ni	Cu
2015	June	0.014	0.083	0.136	0.136	0.059	0.038	0.147	0.011
	July	0.015	0.084	0.122	0.129	0.052	0.024	0.138	0.004
	August	0.019	0.083	0.132	0.137	0.059	0.030	0.119	0.005
	September	0.020	0.082	0.127	0.077	0.051	0.030	0.142	0.004
	October	0.014	0.089	0.127	0.137	0.055	0.033	0.143	0.004
	November	0.014	0.083	0.129	0.134	0.055	0.033	0.145	0.007
	December	0.015	0.085	0.129	0.131	0.056	0.029	0.140	0.008
2016	January	0.014	0.082	0.122	0.132	0.051	0.028	0.142	0.003
	February	0.015	0.086	0.121	0.125	0.052	0.020	0.133	0.005
	March	0.023	0.083	0.141	0.141	0.066	0.031	0.096	0.007
	April	0.025	0.082	0.131	0.021	0.051	0.031	0.141	0.005
	May	0.013	0.095	0.131	0.141	0.058	0.037	0.143	0.004
	Average	**0.017**	**0.085**	**0.129**	**0.120**	**0.055**	**0.030**	**0.136**	**0.006**

Table 6. Heavy metal contents (mean values in mg l^{-1}) in water samples collected from Kafr El-Masalamya drainage (site 2)

	Month	Co	Zn	Pb	Cd	Fe	Mn	Ni	Cu
2015	June	0.024	0.086	0.043	0.047	0.371	0.053	0.105	0.008
	July	0.023	0.077	0.035	0.045	0.318	0.046	0.117	0.006
	August	0.024	0.079	0.045	0.050	0.376	0.050	0.102	0.002
	September	0.028	0.080	0.041	0.037	0.370	0.049	0.101	0.003
	October	0.022	0.083	0.039	0.049	0.371	0.050	0.101	0.002
	November	0.023	0.082	0.039	0.045	0.369	0.049	0.103	0.005
	December	0.024	0.081	0.040	0.047	0.320	0.050	0.119	0.010
2016	January	0.022	0.077	0.034	0.043	0.367	0.045	0.100	0.001
	February	0.024	0.076	0.036	0.047	0.269	0.047	0.133	0.011
	March	0.026	0.080	0.056	0.056	0.384	0.054	0.103	0.003
	April	0.033	0.082	0.047	0.031	0.372	0.052	0.101	0.004
	May	0.021	0.088	0.043	0.055	0.374	0.054	0.101	0.002
	Average	**0.024**	**0.081**	**0.041**	**0.046**	**0.355**	**0.050**	**0.107**	**0.005**

Table 7. Heavy metal contents (mean values in mg l^{-1}) in water samples collected from Almashraa drainage outlet (site 3)

	Month	Co	Zn	Pb	Cd	Fe	Mn	Ni	Cu
2015	**June**	0.110	0.190	0.013	0.011	0.028	0.052	0.507	0.011
	July	0.103	0.192	0.006	0.008	0.021	0.043	0.429	0.007
	August	0.110	0.154	0.016	0.014	0.027	0.045	0.504	0.005
	September	0.103	0.188	0.012	0.052	0.023	0.046	0.503	0.005
	October	0.106	0.190	0.010	0.012	0.024	0.047	0.503	0.005
	November	0.108	0.187	0.009	0.009	0.024	0.047	0.505	0.008
	December	0.105	0.195	0.010	0.010	0.025	0.048	0.432	0.010
2016	**January**	0.106	0.184	0.005	0.007	0.020	0.042	0.502	0.004
	February	0.099	0.200	0.006	0.009	0.021	0.044	0.356	0.009
	March	0.113	0.123	0.027	0.020	0.033	0.047	0.505	0.006
	April	0.099	0.191	0.018	0.097	0.025	0.049	0.503	0.005
	May	0.105	0.195	0.014	0.016	0.027	0.051	0.503	0.005
	Average	**0.105**	**0.182**	**0.012**	**0.022**	**0.025**	**0.047**	**0.479**	**0.007**

which the water was drained. In addition, lakes, sea and human activities would affect the properties of drainage water of the area.

pH

Water samples were slightly alkaline and ranged between 7.04 to 7.67 (Tables 2, 3 and 4). The pH values of water of locations 1, 2 and 3 were 7.18, 7.20 and 7.23, respectively. Water samples from drainage sites 2 and 3 is characterized by slightly high pH. In general, such values are within the normal range of the FAO guidelines for water quality **(Ayers and Westcot, 1976)**. The pH tends to be buffered in soil and most crops can tolerate a slightly alkaline pH.

Ayers and Westcot (1976) presented guidelines for evaluating water quality based on concepts introduced by US salinity Laboratories (USSL) such as pH and adjusted sodium adsorption ratio (SAR). **Gupta (1979a)** suggested five classes based on salinity and sodicity hazard as well as boron. **FAO (2002)** reported that pH of some wastewaters in Egypt did not vary widely from that of the Nile water, and ranged from 7.29 to 7.40. **El-Sherbieny *et al.* (1998)** showed that 50% of the agricultural drainage water had pH ranging from 7.6 to 8.4. **Shaban (1998)** stated that the pH of irrigation water varied between 8.22 and 9.00, and that the most prevalent values of pH of Nile water, drainage water and sewage water were 8.33, 8.34 and 8.46, respectively.

Salinity

Electrical conductivity (EC) is related directly to the levels of ions dissolved in water **(Wu *et al.,* 2017)**. Classification of irrigation water with respect to salinity hazard, is primarily based on the development of salinity in the soil to the extent that yields are adversely affected. Water analysis (Tables 2, 3 and 4) shows that during 12 months, water had an EC below 3.02 dSm^{-1}. The mean values for the three water sites (1, 2 and 3) were 2.14, 2.67 and 2.71 dSm^{-1}, respectively (Tables 2, 3 and 4). Based on the classification of the USSL Staff **(USDA, 1954)**, the water in site 1 could be classified as class C_3 (high salinity water with EC between 0.75 and 2.25 dSm^{-1} (App. 1), whereas water from sites 2 and 3 could be classified as class 4 (very high salinity water with EC between 2.25 and

App. 1. USDA classification of irrigation water

Salinity hazard	Class	EC (dSm^{-1})	Sodicity hazard	Class	SAR
Low	**C1**	0.1-0.25	**Low**	**S1**	10<
Medium	**C2**	0.25-0.75	**Medium**	**S2**	10-18
High	**C3**	0.75-2.25	**High**	**S3**	18-26
Very high	**C4**	2.25-5.00	**Very high**	**S4**	>26

5.00 dSm^{-1}). Based on the FAO guidelines **(Ayers and Westcot, 1976)** water of the three sites could be classified as a class with 0.75-3.0 dSm^{-1}, which indicates increasing problems (App. 2). According to Gupta's ABC classification (App. 3) of water (**Gupta, 1979b**), water from the sampling sites 1 and 2 could be classified as C_2 (1.5 -3 dSm^{-1}), whereas water from site 3 could be classified as C_3 (3-5 dSm^{-1})

Sodicity

Tables 2, 3 and 4 present the results of sodium adsorption ratio (SAR) in water samples. The average SAR values of water from sites 1, 2 and 3 were 4.92, 5.92 and 4.56, respectively. The waters are of no or low sodicity hazards, and mean SAR values were between 4.56 and 5.92. The SAR value was, relativity greater in winter than during the summer. According to USDA classification of irrigation water (App.1), all water samples could be classified as low sodicity hazard class S1 (<10).

Regarding the parameter of Adjusted sodium hazard (adj.^{R} Na) proposed by **Gupta (1979a)**, water samples under study ranged between 5.82 and 6.83 indicating low to high sodium hazards.

Anions

Values of anions during 12 months in sites 1, 2 and 3 averaged 16.15, 20.78 and 22.92 mmole l^{-1}, respectively. Water with high chloride levels is usually considered a tracer for water contamination and taken as a pollution index **(Bikundia and Mohan, 2014)**. Chloride could be released into rivers through ion exchange processes **(Drever, 1997)**. Chlorides ranged between 4 and 10 mmole l^{-1} indicating classes ranging from no problem to increasing problems according to the FAO guidelines **(Ayers and Westcot, 1976)**.

The average values of HCO_3^- in water samples from sites 1, 2 and 3 were 3.82, 4.35 and 4.34 mmole l^{-1}, respectively. According to FAO guidelines (Appendix 2), values of HCO_3 were between 1.5-8.5 indicating an increasing problem. The pH of the water sources ranged between 7.04 and 7.67, indicating the ability to precipitate soluble calcium. Bicarbonate dissolved in surface water is derived from mineral and biogenic sources. In biogenic formation, CO_2 released in soil atmosphere, and therefore in the water draining through the soil, both directly by the microbial degradation of organic matter and from plant roots, dissolves in water to form carbonic acid which release Mg^{2+} and Ca^{2+} to the solution yielding HCO_3^- **(Maddock, 2008; Wu *et al.,* 2017)**.

In all type of water bodies, sulfate is a naturally occurring ion **(Wu *et al.,* 2017)**. The average values of SO_4^- in water samples from sites 1, 2 and 3 were 0.88, 1.22 and 0.46 mmole l^{-1}, respectively. Sulfate might cause gastro-intestinal irritation at higher levels in the drinking water **(Marghade *et al.,* 2012)**.

Cations

The results in Tables 2, 3 and 4 present the values of cations in water samples. The average values of Na^+ in water samples from sites 1, 2 and 3 were 10.79, 14.15 and 12.07 mmole l^{-1}, respectively. The high sodium value may be related to pollutant discharge **(Wu *et al.,* 2017)**. The average values of K^+ in sites 1, 2 and 3 were 0.43, 0.66 and 0.57 mmole l^{-1}, respectively. The water K^+ sources might include rain-water, application of potash fertilizer and weathering of potash silicate minerals **(Bikundia and Mohan, 2014)**. The average values of Ca^{2+} in water samples from sites 1, 2 and 3 were 3.65, 3.67 and 6.37 mmole l^{-1}, respectively. Some water

App. 2. The FAO guidelines for interpretation of water quality for irrigation (Ayers and Westcot, 1976)

Irrigation problem	Degree of problem		
	No. problem	Increasing problem	Severe problem
Salinity (affects crops water availability) EC_W (dSm^{-1})	<0.75	0.75-3.0	>3.0
Permeability (affects infiltration rate into soil) ECW (dSm^{-1}) Adj.SAR	>0.5	0.5-0.2	<0.2
Montmorillonite (2:1 crystal lattice)	>6	6-9	>9
Illite-Vermicultic (2:1 crystal lattice)	<8	8-16	>16
Kaolinite-sesquioxides (1:1 crystal lattice)	<16	16-22	>22
Specific ion toxicity (affects sensitive crops) Sodium/ (adj.SAR)	<3	3-9	>9
Chloride (meq l^{-1})	<4	4-10	>10
Boron (mg l^{-1})	<0.75	0.75-2.0	>2.0
Miscellaneous effects (affects susceptible crops) NO_3-N or NH_4-N (mel^{-1})	<5	5-30	>30
HCO_3 (meq l^{-1})(overhead sprinkling)	<1.5	1.5-8.5	<8.5
pH	Normal range (6.8-8.4)		

App. 3. Gupta's classification of water regarding salinity and sodicity (Gupta, 1979b)

Class	Adj. SAR	Class	EC dSm^{-1}
A_1	<10	C_1	<1.5
A_2	10-20	C_2	1.5-3
A_3	20-30	C_3	3-5
A_4	30-40	C_4	5-10
A_5	<40	C_5	>10

App. 4. Maximum concentrations of trace elements in irrigation waters, recommended by the US committee on water quality[1]

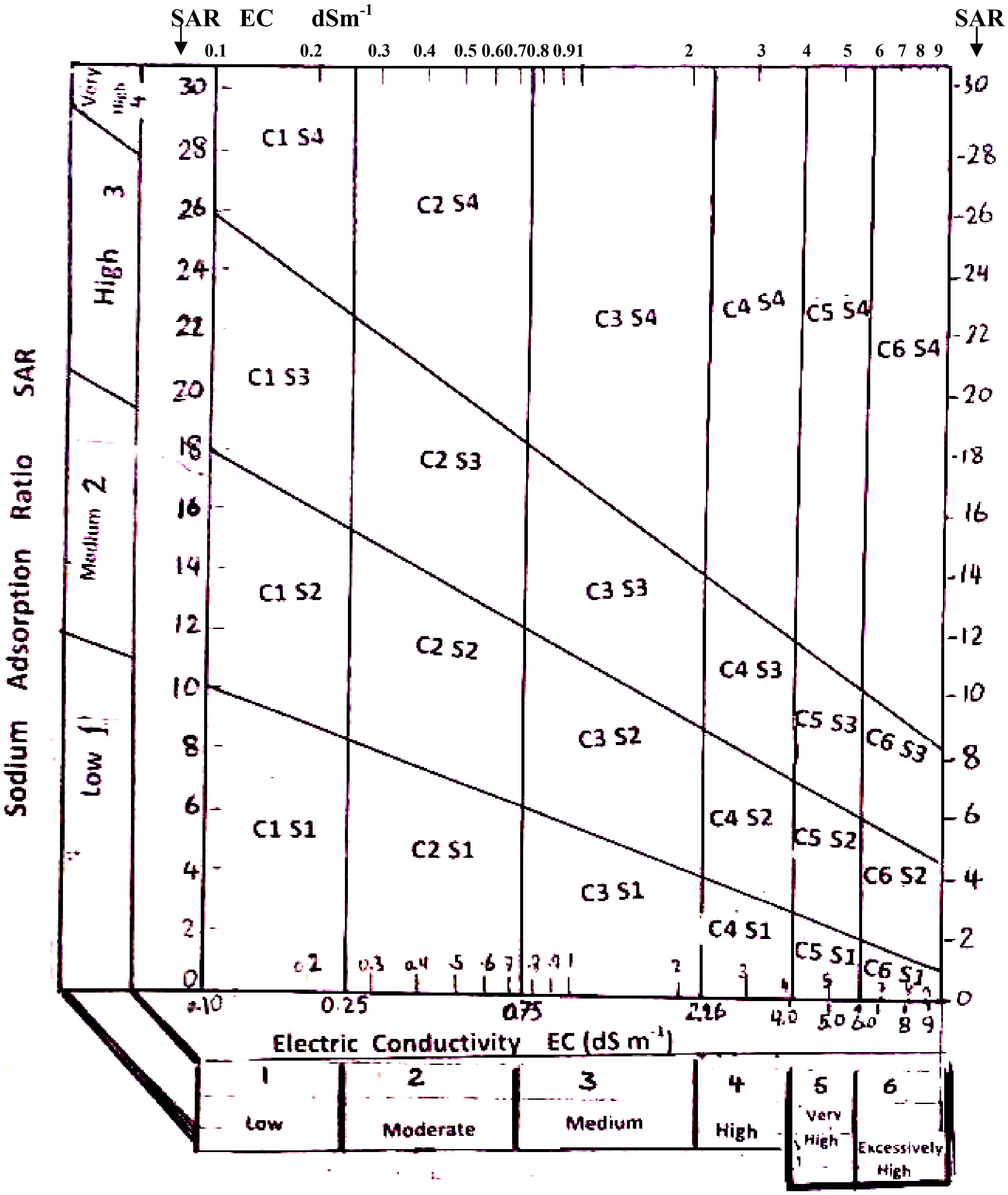
Element	For waters used continuously on all soils	For use up to 20 years on fine-textured soils of pH 6.0 to 8.5
	mg l^{-1}	mg l^{-1}
Aluminum (AI)	5.00	20.0
Arsenic (AS)	0.10	2.0
Beryllium (Be)	0.10	0.5
Boron (B)	0.75	2.0
Cadmium (Cd)	0.01	0.05
Chromium (Cr)	0.10	1.0
Cobalt (Co)	0.05	5.0
Copper (Cu)	0.20	5.0
Fluoride (F)	1.00	15.0
Iron (Fe)	5.00	20.0
Lead (Pb)	5.00	10.0
Lithium (Li) [2]	2.50	2.50
Manganese (Mn)	0.20	2.0
Molybdenum (Mo)	0.01	0.05 [3]
Nickel (Ni)	0.20	2.0
Selenium (Se)	0.02	0.02
Vanadium (V)	0.10	1.0
Zinc (Zn)	2.00	10.0

[1] The levels will normally not adversely affect plants or soils.

No data available for Mercury (Hg), Silver (Ag), Tin (Sn), Titanium (Ti), Tungsten (W).

[2] Recommended maximum concentration for citrus is 0.75 mg l^{-1}.

[3] Only for acid fine-textured soils or acid soils with relatively high iron oxids contents **(Branson *et al.,* 1975)**.



App. 5. Modified six-class Salinity-Sodicity USDA Classification of irrigation water (USDA, 1954)

samples from rivers might exceed the Ca^{2+} permissible limit of 200 mg l^{-1} **(Bikundia and Mohan, 2014**). Average magnesium values in sites 1, 2 and 3 were 5.97, 7.86 and 7.71 mmole l^{-1}, respectively.

Micronutrients and Heavy Metals

Results in Tables 5, 6 and 7 show contents of micro-nutrients and heavy metals in water samples during the study period. Average contents (mg l^{-1}) of Co, Zn, Pb, Cd, Fe, Mn, Ni, and Cu in site 1 were 0.017, 0.085, 0.129, 0.120, 0.055, 0.030, 0.136, and 0.006, respectively. Comparable values in site 2 were 0.024, 0.081, 0.041, 0.046, 0.355, 0.050, 0.107, and 0.005, respectively. Those of site 3 were 0.105, 0.182, 0.012, 0.022, 0.025, 0.047, 0.479, and 0.007 mg l^{-1}, respectively. **Ramadan (1995)** and **Mohamed *et al.* (1999)** reported values rather similar to the present study. Heavy metals might contaminate surface water resulting in deterioration of water quality **(Krishna *et al.*, 2009)**. The heavy metals are severe pollutants owing to their toxic effects, persistence and bio-accumulative nature in the environment **(Pekey *et al.*, 2004)**. Accumulation of heavy metals in soil, leads to their adsorption or complexation by soil colloids, and other soil component and can be leached into the groundwater either in ionic forms or soluble complexes **(Willems *et al.*, 1981; Abdel-Aal *et al.*, 1988)**. **Ramadan (1995)** reported that Manzala lake water near Bahr El Bakar drain showed average contents of 8.90, 0.63, 1.98, 0.59, 0.44, 0.77, 0.10 and 5.90 mg l^{-1} for Fe, Zn, Mn, Cu, Co, Ni, Cd, Pb, respectively.

On basis of US committee on water quality **(Branson *et al.*, 1975)** presented in Appendix 4, waters of the three sources may be within the maximum permissible limits whether used continuously or used for of up to 20 years on heavy soils. Appendix 5 presents the modified six-class salinity-sodicity as USDA classification of irrigation water.

Suitability of Waters Concerning Salinity/ Sodicity

According to the **USDA (1954)**, water of site 1 was class C_3S_1 (high salinity/low sodicity). High salinity hazard (C_3) damage plants with low tolerance to salinity. Plant growth could be increased with excess irrigation for leaching or periodic use of low salinity water with providing good drainage. CAs for sites 2 and 3, the class was C_4S_1 (very high salinity/low sodicity). Very high salinity hazard (C_4) damage plants with high tolerance to salinity. Successful use as an irrigation source requires salt tolerance plants, good soil drainage, and excess irrigation for leaching and periodic utilization of low salinity water. Waters of sites 2 and 3 can be used for irrigation of crops grown on coarse-textured light soils with fewer hazards than those grown on fine-textured ones.

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جــودة الميـــاه السطحية في منطقة صـــان الحجـــر بمحافـظـة الشـــرقيـة

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إن الإنتاج الزراعي في مصر يتأثر بدرجة كبيرة بمصادر المياه والتي تعتبر من أهم التحديات الحالية والمستقبلية في مصر، إن الهدف من هذه الدراسة هو جودة المياه لأغراض الري في منطقة صان الحجر بمحافظة الشرقية، في هذه الدراسة تم تجميع ٣٦ عينة مياه من ثلاث مواقع (الموقع الأول بحر مويس- الموقع الثانى مصرف كفر المسلمية - الموقع الثالث مخرج مصرف المشرع) خلال ١٢ شهر من شهر يونيو ٢٠١٥ إلى مايو ٢٠١٦ (عينة واحدة كل شهر من كل موقع)، تم تقدير كل من العناصر الثقيلة و الكاتيونات والانيونات وكذلك pH, EC، تراوحت قيم درجة الحموضة pH في عينات المياه ما بين ٧,٠٤ و ٧,٦٧ مما يشير ان المياه تعتبر منخفضة القلوية، كان متوسط قيم ال EC للعينات ١ و ٢ و ٣ هي ٢,١٤ و ٢,٦٧ و ٢,٧١ dSm^{-1}. كان متوسط قيم الكلوريد للعينات ١ و ٢ و ٣ هي ١٦,١٥ و ٢٠,٧٨ و ٢٢,٩٢ ملليمول/لتر، كان متوسط قيم HCO_3^- للعينات ١ و ٢ و ٣ هي 3.82 و 4.35 و4.34 ملليمول/لتر، كان متوسط قيم الصوديوم Na^+ للعينات ١ و ٢ و ٣ هي ١٠,٧٩ و ١٤,١٥ و ١٢,٠٧ ملليمول/لتر. كان متوسط قيم الكالسيوم Ca^{2+} للعينات ١ و ٢ و ٣ هي ٣,٦٥، ٣,٦٧ و ٦,٣٧ ملليمول/لتر، تم تقييم جودة المياه من الموقع الأول على أنه C_3S_1 وهو يشير إلى ارتفاع الملوحة وانخفاض الصودية، من ناحية أخرى فان جودة المياه من الموقع الثانى والثالث تم تقييمة على أنه C_4S_1 وهو يشير إلى ارتفاع الملوحة بدرجة كبيرة وانخفاض الصودية، وبالتالي فان المياه من المصارف ٢ و٣ يمكن استخدامها في رى المحاصيل المقاومة للملوحة مع اخذ الاحتياطات الأزمة في الاعتبار للتربة من حيث عمليات الغسيل وجودة الصرف بها، تعتبر النتائج هامة للاسترشاد بها في السياسات الزراعية لمنطقة صان الحجر.

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