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Irrigation suitability of the surface and ground water in Qus City, Upper Egypt, using hydrochemical parameters

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Abstract: *The surface water and groundwater hydrochemistry at 45 locations in Qus City, where farming activities are considerably intensive, was investigated to evaluate their irrigation suitability. The irrigation suitability of the collected water samples was evaluated based on the water salinity (EC), effective salinity (ES), sodium percentage (%Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP) and magnesium adsorption ratio (MAR). The results showed that most of the water samples classified under the first class (ES < 3 epm) of water are suitable for irrigation. Based on the SAR classification, it was found that almost all the water samples in the study area are classified under the S1 water class; it is excellent and suitable for irrigation with no harmful effects from sodium. Furthermore, the US salinity laboratory (USSL) classification revealed that most of the water samples fall within the C2–S1 (medium salinity with low sodium hazard) and C3–C1 (high salinity with low sodium hazard) classes. The Wilcox diagram and %Na also classify the water samples as excellent, doubtful, or unsuitable, individually. SSP showed that the majority of the water in the study area range from permissible to doubtful. The overall results showed that the water in the study area is suitable for irrigation, with the exception of few locations that require careful application in irrigation methods.*

Keywords: *hydrochemistry, irrigation, groundwater, salinity, sodium adsorption ratio, residual sodium carbonate*

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I. Introduction

Water naturally contains different dissolved inorganic constituents in the form of cations, mainly Na^+, Ca^{2+}, K^+, and Mg^{2+}, and anions, mainly SO_4, Cl, and HCO_3. These constituents reflect chemical, biological, and physical characteristics. The suitability of irrigation waters depends on their chemical constituents as well as the soil and plant type (Ebong et al. 2017; Ravikumar and Somashekar 2012; Ghazaryan and Chen 2016). Therefore, it is considered acceptable for irrigation purposes if its dissolved mineral constituents do not have detrimental effects on both the soil and plant. To avoid damage to sensitive crops and to maintain soil structural stability from excess salts and other trace metals, irrigation water should be of good quality and low sodicity (Kurdi et al. 2013; Little et al. 2010). Irrigation water with high salinity may be toxic to most plants and pose a salinity hazard that causes crop yield reductions, where salt accumulation in the root zone makes the crop incapable of extracting sufficient water from the salty soil solution (Fipps 2003; Salifu et al. 2017). The effect of the mineral constituents of water on both plants and soil mainly controls their irrigation suitability, where salts adversely affect soils by altering their structure, permeability, and aeration, consequently affecting plant growth. In an agriculture-dependent and developing country, such as Egypt, an abundant water supply is of utmost importance. A study of water use in Egypt in 1990 found that out of 59.2 million cm^3 of groundwater used, 84% was used for agriculture, 8% for industries, 5% for municipal use, and 3% for navigational purposes. According to El-Rawy et al. (2020), the total irrigated area in Egypt as of 2011 was 3.612 million ha, with a water demand of 60.9 of MCM/y. The study objective is to evaluate the irrigation water quality based on different indices, including salinity (EC), effective salinity (ES), sodium percentage (%Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), and magnesium adsorption ratio (MAR).

Site Description

Egypt is a very arid country, receiving negligible amounts of rainfall during the winter months from November through March. The Nile River supplies 95% of their present water requirements. The Nile River, which originates from the Ethiopian Highlands and contributes 85% of the water in the river, flows north through Sudan and Egypt, forming a fertile delta north of Cairo and eventually draining into the Mediterranean (El-Rawy et al. 2020). The study area is situated in Upper parts of Egypt along the Nile, between Qena and

Luxor, at latitudes of 25°50′–25° 57′ N and longitudes of 32°45′–32°48′ E. The region is characterized by the cultivated land of the Nile flood plain, where the Nile valley occupies the alluvial tract of the River Nile and is approximately 10 km wide at Qena (Abdalla and Khalil 2018; El Alfy et al. 2019).

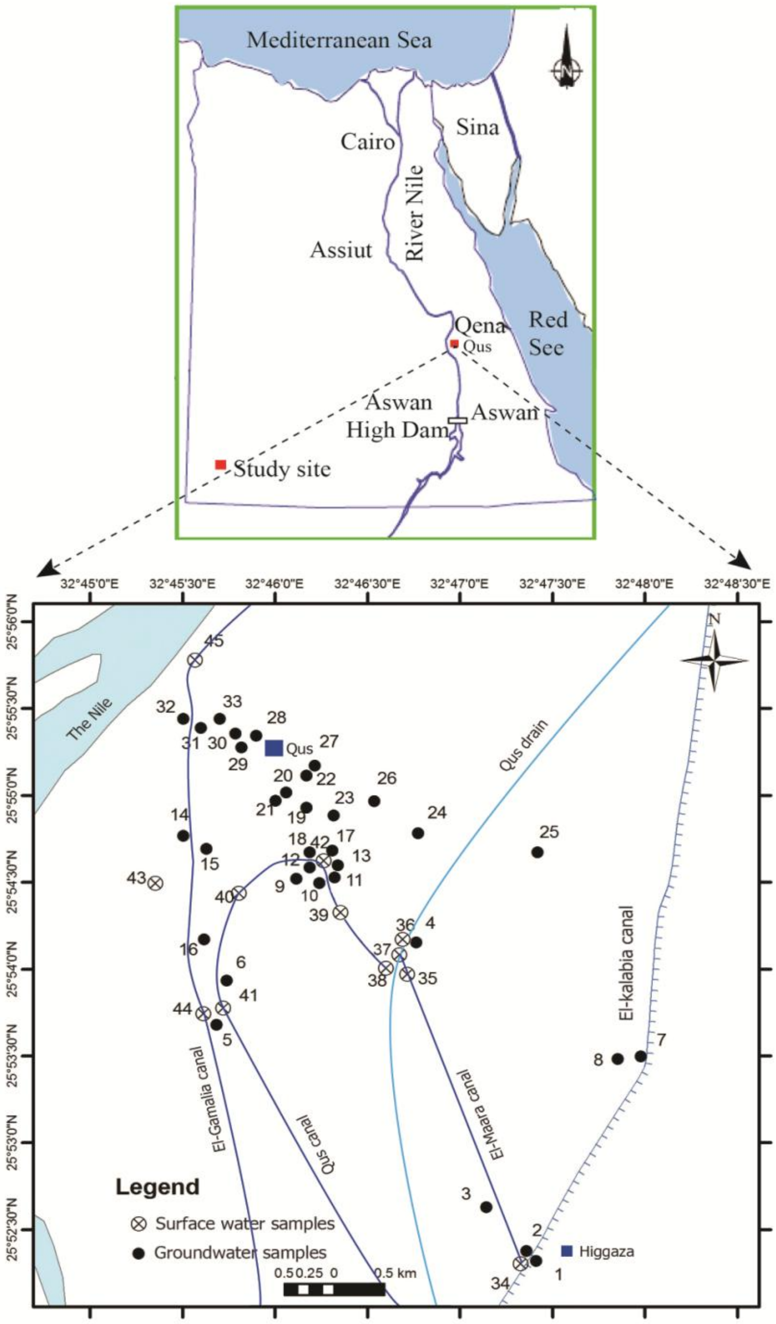

Fig. 1 Location map of the study area (Abdalla and Khalil 2018)

A complex system of irrigation and drainage canals dissect the area, supplying the much-required water to the surrounding farms (Fig. 1). Outside the reach of the irrigation system, water is supplied from individual wells close to each farm. Previous investigations suggest that two main aquifers are present in this area: a shallow unconfined aquifer up to 50 m in depth and a relatively deep confined to semi-confined aquifer along the Nile flood plain and surrounding desert fringes (Abdalla, Shamrukh; Abdalla et a. 2016). Water for irrigation and domestic purposes comes from wells emplaced in the shallow aquifer.

Sampling and analytical procedures

A total of 45 water samples were obtained for major ion analyses, 12 of which were from irrigation canals and drains crossing the area and 33 of which were from groundwater (Table 1). All the water samples were sealed carefully and stored at 4 °C until they were sent out to the laboratory. The reliability of the chemical analysis results was checked against the anion–cation balance, and the results showed that the percentage balance error was reliable < ±5%.

Data treatment and classification

The main parameters used globally for evaluating water suitability, i.e., EC, ES, SAR, RSC, SSP, and MAR, were evaluated to determine the irrigation suitability of the water. All concentrations were expressed in meq/L. Furthermore, the results of the analyses were interpreted using graphical representations, such as the US salinity laboratory (USSL) and the Wilcox diagram (Tatawat et al. 2007; Ravikumar and Somashekar 2012; Ghazaryan and Chen 2016) (Table 1).

II. Results and Discussion

The measured and calculated irrigation indices of the collected surface and groundwater samples in this study area are presented in Table 1 and Figs. 2 and 3.

Table 1 Measured and calculated irrigation quality indices of the water samples from the study area.

	Sample No.	pH (-)	EC (µS/cm)	SSP %	RSC (meq/L)	Na (%)	SAR (meq/L)	RSBC (meq/L)	MAR (meq/L)	ES (meq/L)
Groundwater samples	1	7.8	385	50.42	4.28	50.42	1.91	7.07	50.00	0.84
	2	7.1	1101	42.89	2.65	42.89	1.44	5.64	53.89	1.06
	3	7.9	872	48.90	5.09	48.90	1.81	9.16	54.16	1.68
	4	8.2	2560	41.08	-0.29	41.08	1.24	1.84	57.80	1.65
	5	7.8	883	30.61	1.27	30.61	0.81	5.33	59.42	1.14
	6	8.1	678	51.82	0.76	51.82	2.03	2.33	57.15	1.49
	7	7.7	1392	49.00	5.31	49.00	1.86	11.05	58.07	2.59
	8	7.5	1010	50.28	5.10	50.28	1.95	9.94	59.02	1.93
	9	7.8	1406	57.12	3.17	57.12	2.59	6.52	56.59	2.60
	10	7.7	1417	53.87	2.78	53.87	2.22	6.33	55.37	2.83
	11	7.9	1446	53.92	4.28	53.92	2.24	8.38	56.09	2.84
	12	8.1	1291	55.95	3.67	55.95	2.40	6.37	43.83	2.88
	13	7.8	1778	61.25	5.37	61.25	2.98	9.14	56.11	3.73
	14	7.2	1780	66.17	12.52	66.17	3.86	16.48	53.03	0.78
	15	7.8	3120	77.40	7.65	77.40	6.58	10.34	46.03	6.77
	16	7.8	692	59.10	4.32	59.10	2.76	6.90	45.38	1.39
	17	7.5	1980	63.96	5.02	63.96	3.36	8.95	53.28	3.97
	18	7.4	1960	76.52	6.38	76.52	6.33	9.79	51.55	9.59
	19	7.3	1819	71.42	6.06	71.42	4.84	8.65	41.43	6.22
	20	7.5	4000	72.51	4.62	72.51	5.16	7.13	41.18	7.61
	21	7.2	1970	72.36	7.60	72.36	5.05	11.12	45.65	8.13
	22	7.4	1608	68.54	4.67	68.54	4.26	7.06	37.81	5.14
	23	7.4	1785	70.42	4.13	70.42	4.43	7.72	50.74	8.08
	24	7.5	2536	65.87	4.11	65.87	3.74	8.21	48.30	7.04
	25	8	562	72.69	8.31	72.69	5.22	10.32	51.79	1.73
	26	7.9	2920	69.29	5.47	69.29	4.30	8.70	40.87	6.01
	27	7.5	2828	69.53	7.31	69.53	4.46	9.64	49.71	2.14
	28	7.3	2020	70.62	7.54	70.62	4.63	10.11	53.95	1.97
	29	7.4	1520	61.17	6.92	61.17	3.02	9.91	54.65	1.52
	30	7.5	1141	59.91	5.60	59.91	2.90	8.47	55.20	1.74
	31	7.5	1114	69.13	6.22	69.13	4.35	8.46	56.31	1.78
	32	7.1	1448	68.23	8.85	68.23	4.20	11.53	56.49	1.12
	33	7.3	1512	65.93	7.29	65.93	3.76	9.74	48.92	1.93
	Min	7.1	385	47.32	0.66	47.32	1.67	2.23	51.63	0.66
	Max	8.2	4000	68.00	9.59	68.00	4.03	15.33	57.15	11.23
	Avg.	7.6	1718.8	63.87	5.27	63.87	3.40	8.45	55.17	3.54
Surface water samples	34	8.5	272	54.04	1.56	54.04	2.20	2.99	56.26	0.90
	35	8.5	347	49.30	0.83	49.30	1.76	2.74	68.78	0.81
	36	7.9	812	53.53	4.57	53.53	2.04	8.46	59.68	1.90
	37	8.1	1075	51.81	4.71	51.81	1.93	8.82	57.98	1.73
	38	9.2	401	54.63	0.26	54.63	2.10	2.14	58.11	1.70
	39	9.2	287	35.83	0.84	35.83	1.02	5.77	63.49	2.04
	40	8.4	299	49.56	0.63	49.56	1.67	3.10	62.34	2.03
	41	7.9	281	49.90	0.85	49.90	1.73	2.84	59.25	1.54
	42	7.8	1285	55.68	5.59	55.68	2.21	9.14	55.35	0.69

43	7.8	2311	65.74	5.06	65.74	3.61	9.84	52.32	7.05
44	8.3	284	54.22	0.89	54.22	2.18	2.26	52.36	1.20
45	8.2	280	77.81	1.40	77.81	6.58	1.99	49.80	1.76
Min	7.8	272	57.11	1.40	65.38	2.43	1.99	49.80	0.69
Max	9.2	2311	68.88	4.92	68.88	4.09	9.84	57.28	7.05
Avg.	8.3	751	65.38	2.39	57.11	3.56	5.14	53.07	2.22

Evaluation of water according to water salinity (EC)

The presence of excess salt in irrigation water induces salinity hazards and increases the osmotic pressure of soils. Consequently, the crop roots are unable to absorb water with high salt concentrations. As described in the College of Agricultural Sciences 2002, irrigation water with EC values < 250 µS/cm is considered to be low hazard; 250–750 µS/cm EC values could show stress for sensitive plants, 750–2250 µS/cm EC values will adversely affect most plants, and EC values > 2250 µS/cm are unsuitable for irrigation use, except for very salt-tolerant plants. The irrigation water with EC values < 250 µS/cm, 250–750 µS/cm EC values, 750–2250 µS/cm EC values, and EC values > 2250 µS/cm are classified as C1, C2, C3, and C4, respectively. The measured EC value for groundwater in the study area varied from 385 to 4000 µS/cm with an average of 1719 µS/cm. For surface water, it ranges between 272 µS/cm and 2311 µS/cm with an average of 751 µS/cm. Based on the salinity value (Table 1), 7 samples representing 58% of the surface water samples are classified under C2 water type, 3 samples representing 25% are classified under C3, 1 sample representing 8% is classified under C4, and another 1 sample is classified under C1. Most of the groundwater samples are classified under the C3 water type with 22 samples representing 67%; 4 samples representing 12% are classified under C2, while the remaining 7 samples representing 21% are classified under C4, which are unacceptable for irrigation, and this may be due to the household water disposal and solid waste accumulation.

Evaluation of water according to effective salinity (ES)

The total salinity is not sufficient to measure the water suitability for irrigation (Elewa 2004) due to the possible accumulation of some carbonate and sulfate salts in the soil. A high concentration of $CaCO_3$ or $MgCO_3$ in the water will result in the precipitation of lime or dolomite within the soil material to form a soil matrix. The ES value is calculated from the following formula:

$$ES = Cl + \frac{1}{2} SO_4$$

The calculated ES values for all the surface water samples are in the first class (ES < 3 epm), which were utilized for low permeability soils. Regarding the groundwater samples, 21 samples (47%) were classified under the first class (ES < 3 epm), 2 samples under the second class (ES between 3 and 5 epm), and 8 samples (17%) under the third class (ES > 5 epm), which are utilized for low permeability soils. The remaining 2 samples are in the second class (ES from 5–10 epm) and are suitable for medium permeability soils.

Evaluation of water according to percentage sodium (%Na)

The %Na in water is also considered to be an important parameter for controlling its irrigation suitability. It indicates the soluble sodium content of water and is also used to evaluate sodium hazard. Irrigation water with a %Na > 60% may result in sodium accumulations that will cause a breakdown in the soil's physical properties and eventually restrict the circulation of air and water. The results revealed that the %Na of the groundwater samples in the study area ranges from 47.32 to 68.00% with an average of 63.37%, while it ranges from 57.11 to 78.88% with an average of 65.38% for the surface water samples.

Evaluation of water according to sodium adsorption ratio (SAR)

The SAR value is considered a key parameter for controlling the water suitability for irrigation use, where it reflects the alkali/sodium hazard to crops and the relative activity of sodium ion in the exchange reaction in the soil. It is calculated using the following formula:

$$SAR = \frac{Na}{\sqrt{\frac{1}{2}(Ca + Mg)}} .$$

The continued use of water with a high SAR results in the breakdown in the soil's physical structure, where sodium replaces calcium and magnesium adsorbed on the clay minerals and causes the dispersion of irrigation water. This dispersion results in the breakdown of soil aggregates and causes cementation of the soil under dry conditions as well as prevents infiltration of rainwater. This problem is also related to several factors, such as salinity rate and soil type. For example, sandy soils may not become as easily damaged as other heavier soils when irrigated with high SAR water.

As defined in the USSL (Fig. 2) (Tatawat et al. 2007), water with SAR values < 10 is considered to be excellent; a SAR value within the range of 10–18 is good, a SAR value within the range of 18–26 is fair, and

SAR values > 26 is unsuitable for irrigation use. The calculated SAR for the groundwater samples ranges between 1.67 and 4.01 with an average of 3.40. For surface water, it ranges between 2.43 and 4.09 with an average of 3.56. Based on the SAR classification, it is observed that almost all the water samples in the study area are classified under the S1 water type, indicating that they are excellent and suitable for irrigation with no harmful effects from sodium.

The SARs (S1, S2, and S3), described by 3 intervals, were plotted against EC (C1, C2, and C3) (Fig. 2). All the samples from the study area are classified under the S1–S2 (low-medium sodium hazard) water type, which is suitable for irrigation with no harmful effects from sodium. Water with high salinity cannot be used on soils with restricted drainage. According to the USSL classification, out of 45 water samples, 12 samples show the properties of the C2–S1 water class (medium salinity and low sodium content), 25 samples have high salinity and low sodium content (C3–S1), 5 samples have high salinity and low sodium content (C4–S1), and only 2 samples have very high salinity and medium sodium content(C4–S2).

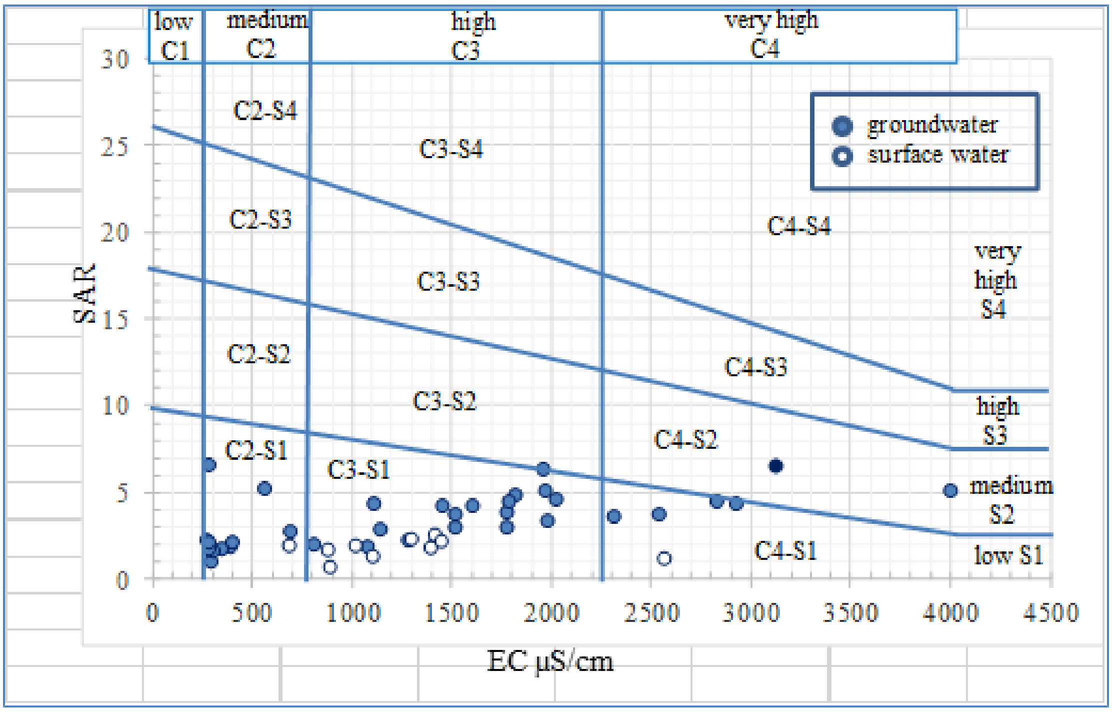

Fig. 2 USSL diagram for the classification of irrigation quality, with respect to salinity hazard and sodium hazard

The Wilcox diagram relating the %Na and total concentration of the analyzed samples (Tatawat et al. 2007) (Fig. 3) has revealed that out of the 45 water samples, 11 are of excellent quality, 12 samples, mostly surface water, fall under the good to permissible quality range, 14 samples fall under permissible to doubtful, 6 samples fall under doubtful to unsuitable, and 2 samples fall under unsuitable and hazard for irrigation use.

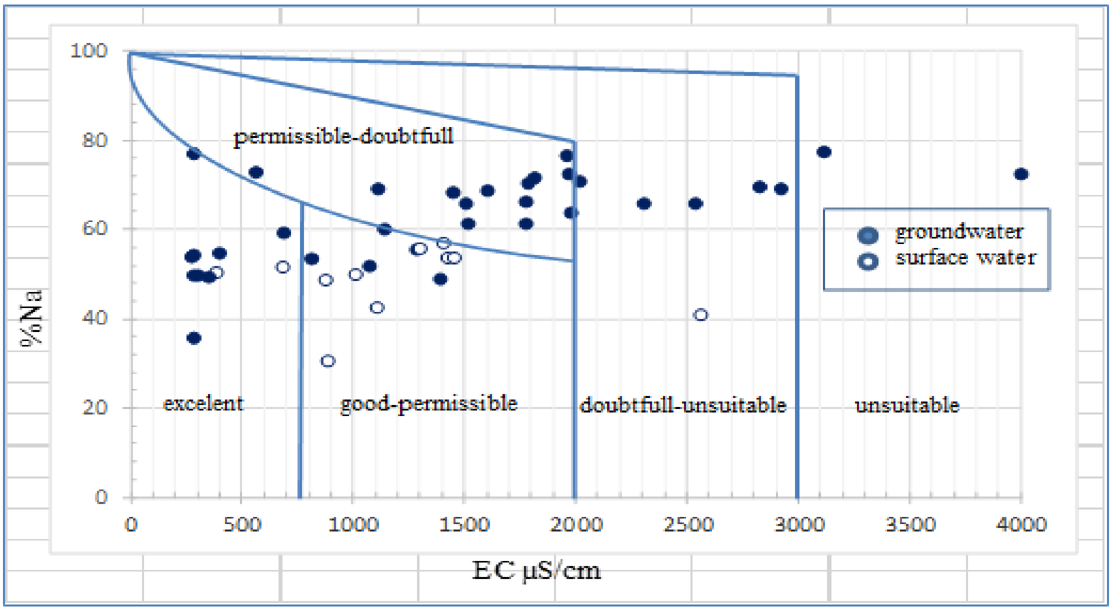

Fig. 3 Wilcox classification for irrigation water in the study area

Residual Sodium Carbonate (RSC)

The RSC equals the sum of the bicarbonate concentrations minus the sum of the calcium and magnesium ion concentrations. As the RSC value increases, a large amount of calcium and some magnesium are precipitated from the solution. When water is applied to the soil, an increase in the %Na and rate of sorption of sodium on the soil particles will increase the potential of sodium hazard. RSC is calculated using the following equation (Acharya et al. 2008):

$$RSC = \{(HCO_3 + CO_3) - (Ca + Mg)\}$$

Irrigation waters with RSC values < 0 show no hazard; RSC values of 0–1.25 is considered low hazard, 1.25–2.50 medium hazard, and RSC values > 2.50 show high hazard. The calculated RSC values for the groundwater samples range between 0.66 and 9.59 with an average of 5.27. For surface water, they range between 1.40 and 4.92 with an average of 2.39. Based on the RSC values of the irrigation water type (Table 1), 91% of the groundwater samples are described as high hazard, while the remaining 9% are described as low hazard. Around 50% of the surface water samples in the study area can be described as low hazard, while 2 samples representing 17% can be described as medium hazard, and the remaining 4 samples can be described as high hazard. Sulfuric acid and/or gypsum can be added to the soil to dissociate the bicarbonate ions and to neutralize the excess carbonates and bicarbonates in the irrigation water. It allows the calcium and magnesium to remain in the solution in relation to the sodium content.

Sodium Soluble Percentage (SSP)

The SSP was calculated in meq/L using the following equation:

$$SSP \frac{(Na + K)100}{Ca + Mg + Na + K}$$

Based on the Wilcox diagram (Tatawat et al. 2007), an irrigation water body with a SSP value ranging between 0 and 20 is considered excellent, 20 and 40 is good, 40 and 60 is permissible, 60 and 80 is doubtful, and > 80 is unsuitable for irrigation use.

The calculated SSP values for the groundwater samples range between 47.32 and 68.00 with an average of 63.87. For surface water, the SSP values range between 57.11 and 68.88 with an average of 65.38. In the study area, the results revealed that 3% of the groundwater samples are classified as good, 39% are permissible, and the remaining 58% are doubtful. Concerning the surface water samples, 1 sample out of 12 samples is good, 9 samples are permissible, and the remaining 2 samples are doubtful.

Magnesium Adsorption Ratio (MAR)

Magnesium may be harmful to plants when the calcium value in water is low; calcium reduces the plant's injury. Magnesium has several functions in the metabolism of plants (James and Martin 2003). The magnesium hazard (MAH) can be calculated by the following formula:

$$MAR = \frac{Mgx100}{Ca + Mg}$$

When the MAR value is more than 50, it is considered to be harmful for irrigation purposes.

In the study area, the calculated MAR values (Table 1) range from 51.63 to 57.15 with an average value of 55.17 for groundwater, while they range from 49.80 to 57.28 with an average value of 53.07 for surface water. It was found that 60% of the water samples have MAR values > 50, indicating that the water should not be used for irrigation without treatment, while the remaining 40% have MAR values < 50, indicating that the water is suitable for irrigation. For the surface water samples, 92% have MAR values > 50; thus, they have an adverse effect on the crop yield as the soil alkalinity increases.

III. Conclusion

In the present study, the water quality was monitored to assess the sustainability effects with respect to irrigation purposes. According to the Wilcox diagram relating %Na and EC, 51% of the samples fall under the excellent–permissible range, 31% fall under the permissible– doubtful range, while the remaining 18% fall under the doubtful–unsuitable range. According to the USSL classification all water samples fall under the C2–C4 water class (medium-very high-salinity water), while the classification based on the SAR values indicates that all samples in the study area fall under the S1–S2 water class (low-medium sodium hazard), which is suitable for irrigation with no harmful effects from sodium. According to the USSL classification, all samples in the study area are classified under the S1–S2 water class (low-medium sodium hazard), which are suitable for irrigation with no harmful effects from sodium, and C2–C4 water class (medium-very high-salinity water). The SSP values of the water samples ranged from 5.7 to 75.3%. The data further revealed that about 65% of the water samples have high values (> 60) of SSP, while the RSC values varied from 333 to 1853, which are very high from the usable level. As a conclusion, the water in the study area was suitable for irrigation purposes with some restrictions at most sites using the %Na, SAR, SSP, and RSC approaches. However, the water bodies in few locations are doubtful and unsuitable for irrigation without prior treatment, due to their high salinity.

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