ISSN 2316-6886
WRIM

Water Resources and Irrigation Management
v.10, n.1-3, p.15-24, 2021
DOI: 10.19149/wrim.v10i1-3.2299

Cruz das Almas, BA – https://www3.ufrb.edu.br/seer/index.php/wrim/index

ORIGINAL PAPER

Demarcation of groundwater quality for irrigation purposes in Sirte, Libya

Demarcação da qualidade da água subterrânea para fins de irrigação em Sirte, Líbia

Hassin Abdelsalam Hassin Makhlof[1]; Ali Widaa Mohammed Elamin[2]; Moftah Ali Mohamed[1]; Adam Bush Adam[3*] & Amir Mustafa Abdeldyim[2]

[1]Department of Soil and Water, Faculty of Agriculture, Sirte University, Sirte, Libya
[2]Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan
[3]Department of Agricultural Engineering, Faculty of Natural Resources and Environmental Studies, Alsalam University, Sudan

Abstract: This study aimed to check the groundwater quality for irrigation in Al-Swawa, Sirte District (Libya), from the dug wells and open ground tanks supplied from the Great Man-Made River. Water samples were collected, and following parameters were analyzed: pH, electrical conductivity (EC), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride ($Cl^–$), and bicarbonate ($HCO_3^–$). Sodium adsorption ratio (SAR), soluble sodium percentage (SSP), ratio of sodium carbonate (RSC), magnesium adsorption ratio (MAR), Kelly's ratio (KR), permeability index (PI), and total hardness (TH) were calculated. The results showed wide variations in water quality parameters for both sources of water. Mean values for pH of 7.7 and 8.4, EC of 8.0 and 0.7 dS m^{-1}, and SAR of 12.0 and 4.8 mg L^{-1} were recorded at wells water and Great Man-Made River water, respectively. Well waters were classified as a very high salinity, while Great River were classified as a medium hazard. Well waters gave values of $Cl^–$ varies from 13.0 to 51.5 mg L^{-1}, while Great Man-Made River gave values less than 10 mg L^{-1}, which classified as moderately $Cl^–$ hazard. Except a sample of the wells, all analyzed water samples showed values of SSP more than 60%, which exceed Eaton's measure value. It is concluded that, wells water just suitable to irrigate a very salts tolerant crop, while the Great Man-Made River water is suitable for irrigation with moderate leaching if intensive management is adopted and followed.

Keywords: Irrigation water quality, Great Man-Made River, water salinity.

[*] Corresponding author: E-mail: adambush99@gmail.com
Editor: Mairton Gomes da Silva
Received in: 04 April, 2021
Accepted in: 14 July, 2021

Resumo: O estudo teve como objetivo verificar a qualidade da água subterrânea para fins de irrigação em Al-Swawa, distrito de Sirte (Líbia), a partir de poços cavados e tanques abertos com fornecimento pela bacia Great Man-Made. Amostras de água foram coletadas e os seguintes parâmetros foram analisados: pH, condutividade elétrica (CE), sódio (Na^+), potássio (K^+), cálcio (Ca^{2+}), magnésio (Mg^{2+}), cloreto ($Cl^–$) e bicarbonato ($HCO_3^–$). A razão de adsorção de sódio (RAS), a porcentagem de sódio solúvel (PSS), a razão de carbonato de sódio (RCS), a razão de adsorção de magnésio (RAM), a razão de Kelly (RK), o índice de permeabilidade (IP) e a dureza total (DT) foram calculados. Os resultados mostraram grandes variações nos parâmetros de qualidade da água avaliados para ambas as fontes hídricas. Valores médios para o pH de 7,7 e 8,4; CE de 8,0 e 0,7 dS m^{-1} e RAS de 12,0 e 4,8 mg L^{-1} foram registrados nas águas dos poços e da bacia Great Man-Made, respectivamente. As águas de poços foram classificadas com salinidade muito alta, enquanto da bacia Great Man-Made foram classificadas com um perigo médio. Os valores de $Cl^–$ das águas de poços variaram de 13,0 a 51,5 mg L^{-1}, enquanto da bacia Great Man-Made os valores foram menores que 10 mg L^{-1}, sendo classificadas com moderado perigo quanto ao $Cl^–$. Exceto para uma amostra dos poços, todas as demais amostras de água analisadas mostraram valores de PSS maiores que 60%, excedendo o valor de medida de Eaton. Conclui-se que, as águas de poços foram adequadas apenas para irrigar culturas muito tolerantes aos sais, enquanto as águas da bacia Great Man-Made foram adequadas para irrigação com lixiviação moderada, desde que um manejo intensivo seja adotado e seguido.

Palavras-chave: Qualidade da água de irrigação, Great Man-Made River, salinidade da água.

Introduction

Most of the arid and semi-arid regions are increasingly suffering from water shortage. Therefore, water might be used economically and effectively to promote further agricultural development. Moreover, the impact of climate change on water resources and the increase in the world population at a high rate puts more pressure on securing food production (Islam, 2019).

Groundwater is of great importance for agricultural activities, as about 45% of the total irrigation needs are provided from this type of water (Singh et al., 2014). Most of the water requirements for domestic activities and irrigation in arid and semi-arid regions are met from groundwater resources, and around 1.5 billion people depend on groundwater across the world (Bian et al., 2018).

Some countries such as Libya depend mainly on groundwater sources to enhance their agricultural development, as groundwater consumption exceeds 98% of the total water consumption (Shahin, 2003). But groundwater resources need quantitative and qualitative assessment. Therefore, groundwater it must be subjected to water quality test before it is used, to overcome problems related to water shortages and negative environmental impacts.

Groundwater is vital for different uses (Hema et al., 2010), and testing the groundwater quality is necessary to determine its suitability for different purposes (Vennila et al., 2008). Assessing the suitability of groundwater for irrigation is critical for crop production and poverty reduction (Shahid et al., 2006). Water quality refers to the characteristics of water supply that will influence its suitability for specific use. Quality is defined by certain physical, chemical and biological characteristics (Ayers and Wescot, 1989).

The water quality for irrigation purposes is determined by its salts content (Scherer et al., 1996), and is usually expressed as electrical conductivity (EC). The analysis of water for irrigation should include the cations: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and the anions: chloride ($Cl^–$), sulfate ($SO_4^{2–}$), bicarbonate ($HCO_3^–$), and carbonate ($CO_3^{2–}$). Irrigation water may also contain boron (B), which can be toxic to plants (Kaledhonkar et al., 2007).

Basic criteria for evaluating water quality for irrigation purposes are described, including EC, permeability hazard in relation to sodium (sodium adsorption ratio – SAR), and ion toxicity (Ayers and Wescot, 1989). Furthermore, Arulkirithas et al. (2019) stated that water quality for irrigation affected growth rate, yield of crops and adversely affected soil fertility. Therefore, this research aims to assess the quality of groundwater and its suitability for irrigation in Al-Swawa, Sirte District, Libya. Then, a comparison was made between the groundwater sources, which are dug wells and the Great Man-made River, based on irrigation water quality, where different international standards were used.

Material and Methods

Study site

The study was carried out in Al-Swawa, 20 km distance east Sirte city, Libya, at 32.2 N, 16.58 E and 13 m above mean sea level. The soil texture is sandy, from the types Entisols and Aridsols. The study covered an area of 3500 hectares, divided into 124 farms, all of them irrigated from groundwater (dug-wells) and Great Man-Made River.

Water samples collection

Total of eight composite water samples were taken, as follows: four from wells (W_1, W_2, W_3, and W_4) and others four from ground tanks (GT_1, GT_2, GT_3, and GT_4) supplied from Great Man-made River, which both of them were selected randomly to represent the study area. Water samples were collected using 0.5 L well-sealed plastic containers. The used bottles were cleaned with hot water and suitable detergents, rinsed with hot water to remove all traces of detergent used and finally were sterilized in an autoclave. Then the samples were transferred to water quality laboratory of the Faculty of Agriculture, University of Tripoli, Libya.

Water quality parameters

The analyses were done for the following irrigation water quality parameters using standard procedures: pH, electrical conductivity – EC (in dS m^{-1}), sodium – Na^+ (in mg L^{-1}), potassium – K^+ (in mg L^{-1}), calcium – Ca^{2+} (in mg L^{-1}), magnesium – Mg^{2+} (in mg L^{-1}), chloride – $Cl^–$ (in mg L^{-1}), and bicarbonate – $HCO_3^–$ (in mg L^{-1}).

From these parameters determined above, the following were calculated: sodium adsorption ratio – SAR, according to Richards (1954) (Equation 1); soluble sodium percentage – SSP, according to Todh (1980) (Equation 2); magnesium adsorption ratio – MAR, according to Raghunath (1987) (Equation 3); Kelly's ratio – KR, according to Kelly (1963) (Equation 4); permeability index – PI, according to Raghunath (1987) (Equation 5); total hardness – TH expressed as equivalent of calcium carbonate ($CaCO_3$), according to Raghunath (1987) and Pal et al. (2018) (Equation 6); and ratio of sodium carbonate – RSC, according to Eaton (1950), Raghunath (1987) and Subramani et al. (2005) (Equation 7).

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

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \quad (2)$$

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (3)$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (4)$$

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \quad (5)$$

$$TH\ (CaCO_3) = 2.5(Ca^{2+}) + 4.1(Mg^{2+}) \quad (6)$$

$$RSC = \left(CO_3^{2-} + HCO_3^{-}\right) - (Ca^{2+} + Mg^{2+}) \quad (7)$$

Results and Discussion

Overall assessment

The results of water quality analysis of groundwater (dug-wells) and Great Man-Made River, showed wide variation in the values of evaluated parameters. The different degrees of restriction of the parameters of water quality with regard to salinity (electrical conductivity – ECw, in dS m^{-1}), infiltration (sodium adsorption ratio – SAR, in mg L^{-1}), ions toxicity and miscellaneous effects are shown in Table 1. The pH values of groundwater samples ranged from 7.6 to 7.8, while the Great Man-made River samples showed values range of 8.3 to 8.5, with mean values of 7.7 and 8.4, respectively (Table 2).

The obtained results of pH are considered within the normal range of irrigation water quality according to FAO standard (Ayers and Westcott, 1985). On the other hand, these values indicate that Great Man-Made River's water is more alkaline than Al-Swawa groundwater, and this agrees with finding of Palanisamy et al. (2021).

The EC values of dug-wells water range from 2.33 to 16.9 dS m^{-1}, with an average value of 8.0 dS m^{-1}, and values of the Great Man-Made River range from 0.53 to 1.05 dS m^{-1}, with an average value of 0.7 dS m^{-1} (Table 2). The results of salinity indicated that the water of dug-wells classified as a water of high salinity and under severe level based on the FAO standard for irrigation water, where Great Man-Made River's water showed less salinity, and classified under slight to moderate level of salinity (Ayers and Westcott, 1985).

Moreover, the SAR average values that obtained with dug-wells and Great Man-Made River were 12.0 and 4.8, respectively (Table 2). Therefore, wells water can be classified as none infiltration problem causes due to its high level of salinity, while Great River water can cause slight to moderate problem. The contents of Cl^{-}, K^{+}, Ca^{2+}, Mg^{2+}, Na^{+}, and HCO_3 varies from 13-147, 0.42-2.1, 5.68-38.5, 2.2-36.5, 14.6-94.3, and 3.9-18.5 mg L^{-1} with dug-wells water, and 4.2-4.4, 0.77-1.54, 1.4-1.8, 1.1-1.56, 5.5-5.9, and 3.6-3.8 mg L^{-1} with Great Man-Made River, respectively. According to classification FAO, most of these parameters were found within slight to moderate problems.

Suitability of Al-Swawa groundwater and Great Man-Made River for agricultural activities

According to the classification of Richards (1954), who classified the irrigation water into four categories based on the salinity level, as shown in Table 3. The dug-wells (W_1, W_2, W_3, and W_4) are classified under very high salinity, but Great Man-Made River (GT_1, GT_3, and GT_4) are classified under medium hazard and GT_2 under high hazard. Therefore, the groundwater of Al-Swawa is unsuitable for irrigation purposes, except for very salts tolerant crops, with frequent leaching and intensive management, according to Malash et al. (2008), who stated that effective management of saline irrigation water highly decrease the hazard of salinity, because water with high salinity adversely affect the crops (Saleh et al., 1999; Subramani et al., 2005). While the water delivered from the Great Man-Made River is suitable for irrigation purposes with moderate leaching and good drainage, according to the FAO standard (Ayers and Westcott, 1985).

Based on the classification of the US Salinity Laboratory (USSL) (1954), the EC and SAR values were used to categorize the dug-well and Great Man-Made River water in terms of sodium and salinity hazards, as shown in Table 4.

Table 1: The overall assessment of the wells and Great Man-Made River water with FAO (1985) standard for irrigation water

Water parameters	Units	Degree of restriction			Well waters	Ground tank
		None	Slight - moderate	Severe		
Electrical conductivity	dS m^{-1}	<0.7	0.7-3.0	>3.0	8.00	0.7
Infiltration					SAR	
SAR 0-3 and ECw		>0.7	0.7-0.2	<0.2		
3-6		>1.2	1.2-0.3	<0.3		4.8
6-2		>1.9	1.9-0.5	<0.5		
12-20		>2.9	2.9-1.3	<1.3	12	
20-40		>5.0	5.0-2.9	<2.9		
Ion toxicity						
Sodium – Na^+	SAR	<3	3-9	>9	12	4.8
Chloride – Cl^-	mg L^{-1}	<4	4-10	>10	65	4.35
Boron – B	mg L^{-1}	<0.7	0.7-3.0	>3.0	-	-
Miscellaneous effects						
Nitrogen – NO_3-N	mg L^{-1}	<5	5-30	>30	-	-
Bicarbonate – HCO_3	mg L^{-1}	<1.5	1.5-8.5	>8.5	8.2	3.7
pH		Normal range 6.5-8.5			7.7	8.4

Table 2: The checked physiochemical parameters of the wells and Great Man-Made River water

Parameters	Units	W_1	W_2	W_3	W_4	GT_1	GT_2	GT_3	GT_4
ECw	dS m^{-1}	6.6	7.0	16.9	2.33	0.6	1.05	0.53	0.58
SAR	-	11.3	13.4	15.4	7.4	4.4	5.3	4.7	4.5
Cl^-	mg L^{-1}	48.5	51.5	147	13	4.4	4.4	4.4	4.2
K^+	mg L^{-1}	0.7	0.75	2.1	0.42	1.03	1.54	1.03	0.77
Ca^{2+}	mg L^{-1}	12.8	10.1	38.5	5.68	1.8	1.4	1.6	1.6
Mg^{2+}	mg L^{-1}	9.0	9.4	36.5	2.2	1.56	1.1	1.5	1.4
Na^+	mg L^{-1}	37.3	41.8	94.3	14.6	5.7	5.9	5.8	5.5
HCO_3	mg L^{-1}	3.9	4.7	18.5	5.7	3.6	3.8	3.7	3.6
pH	-	7.8	7.6	7.7	7.7	8.3	8.5	8.4	8.4

Table 3: The salinity hazards of the checked waters based on Richards (1954) measured

Richards (1954)		Dug-wells				Great Man-Made River			
EC (dS m^{-1})	Water category	W_1	W_2	W_3	W_4	GT_1	GT_2	GT_3	GT_4
<0.25	Low								
0.25-0.75	Medium					0.60		0.53	0.58
0.75-2.25	High						1.05		
2.25-5.0	Very high	6.60	7.04	16.88	2.33				

Table 4: The salinity and sodium hazards of the checked waters based on the US Salinity Laboratory classification

Types of water	Water category	Spatial distribution	Remark
C_2S_1	Medium saline with low sodium	GT_1, GT_3, and GT_4	Low salinity hazard, with detrimental effects on sensitive crops. Low sodium hazard.
C_3S_1	High saline with low sodium	W_4 and GT_2	Medium hazard. Salinity may adversely affect crops.
C_4S_2	Very high saline with medium sodium	W_1, W_2, and W_3	Medium-high hazard, which can be used for salt tolerant crops. Appreciable sodium hazard, need careful management.

Whereas, the GT_1, GT_3 and GT_4 categorized under C_2S_1, which indicate low sodium and salinity hazards, but may show detrimental effects on sensitive crops. The W_4 and GT_2 classified under C_3S_1 category, that characterized with high saline and low sodium hazard, this category adversely affect crops when used for irrigation, but may be used for irrigation purposes when strict management program followed as stated by Arshad and Shakoor (2017), while the dug-well water, W_1, W_2 and W_3 located under C_4S_2 classified as a very high saline with medium sodium, which can be used for salt tolerant crops with careful management according to finding of Mass (1990).

When using SAR to indicating the permeability problem according to the Richards (1954), which increased when sodium concentration in soil increased as stated by Subramani et al. (2005). As shown in Table 5, the types of water mentioned above, W_4, GT_1, GT_2, GT_3, and GT_4 are shown low sodium hazard. Therefore, they are considered under excellent level as mentioned by Palanisamy et al. (2021), while W_1, W_2, and W_3 revealed medium sodium hazard, and classified under good level as stated by Palanisamy et al. (2021).

The concentrations of Cl^- are presented in Table 6. The obtained results revealed that all the groundwater samples recorded values more than 10, where, it can cause severe problems when used for irrigation according to Mass (1990) and Bauder et al. (2011). On the other hand, the samples of Great Man-Made River showed the values less than 10, and based on these values, water as moderately tolerant and may show slight injury for crops. Therefore, restrict management should be followed to use this water without causing serious problem.

All the tested samples showed values of SSP more than 60%, as shown in Tables 7 and 8. According to Eaton (1950), these results may cause slight injurious. Fipps (2003) and Khodapanah et al. (2009) indicated that when values of SSP be more than 60% this leads to sodium accumulation and deterioration of soil physical properties.

As shown in Table 8, the RSC values were found under safe level according to the Eaton (1950) and Wilcox et al. (1954), except GT_2, which was found under marginal level. Therefore, the Al-Swawa groundwater and Great Man-Made River water can be used safely for irrigation without negative effect of carbonate and bicarbonate on the crop yield as mentioned by Zaki et al. (2019).

The obtained values MAR, KR, PI, and TH are shown in Table 8. The MAR values of all analyzed samples were found less the 50. Therefore, no magnesium hazard detected with using Al-Swawa groundwater and great river water hence are suitable for irrigation as found by Keesari et al. (2016) and Palanisamy et al. (2021). KR is a measure stated by Kelly (1963), which indicated that any irrigation water has KR > 1 is indicated an excess level of Na^+, while it be suitable for irrigation when KR < 1, and unsuitable for irrigation when KR > 3. Consequently, all the samples showed values more than 1. Based on Kelly's ratio the groundwater and the Great Man-Made River water showed excess of Na^+. Therefore, strict management is highly needed to minimize the hazard of Na^+.

Table 5: Classification of dug-wells and Great Man-Made River based on SAR according to Richards (1954) measured

Richards (1954)		Wells water				Man-Made River water			
Water class in relation to sodium hazard	SAR value	W_1	W_2	W_3	W_4	GT_1	GT_2	GT_3	GT_4
Low	0-10				7.4	4.4	5.3	4.7	4.5
Medium	10-18	11.3	13.4	15.4					
High	18-26								
Very high	>26								

Table 6: Chloride (Cl^-) concentration in irrigation water and its suitability for irrigation

Cl^- (mg L^{-1})	Effect on crops	Spatial distribution
<2	Generally safe for all plants.	
2-4	Sensitive plants usually show slight to moderate injury.	
4-10	Moderately tolerant plants usually show slight to substantial injury.	GT_1, GT_2, GT_3, and GT_4
>10	Can cause severe problems.	W_1, W_2, W_3, and W_4

Table 7: Classification of dug-wells and Great Man-Made River based on soluble sodium percentage – SSP (%) according to Richards (1954) measured

Eaton (1950)		Wells water				Man-Made River water			
Suitability of water for irrigation	SSP	W_1	W_2	W_3	W_4	GT_1	GT_2	GT_3	GT_4
Good	<40								
Slightly injurious	40-70	64.3	68.8	56.2	65	67.4	75.8	69.4	68
Unsatisfactory	>70								

Table 8: Values different measures in dug-wells and Great Man-Made River water

Parameters	Well waters				Man-Made River water			
	W_1	W_2	W_3	W_4	GT_1	GT_2	GT_3	GT_4
RSC	-18.1	-14.7	-56.5	-2.3	0.2	1.4	0.6	0.6
MAR	41	48	48	25	47	41	48	46
KR	1.8	2.2	1.2	1.9	1.8	2.5	1.9	1.9
PI%	70	76	66	90	100	100	100	100
TH mg L^{-1}	1092	976	396	3755	168	125	155	150

RSC – residual sodium carbonate (mg L^{-1}); MAR – magnesium adsorption ratio (mg L^{-1}); KR – Kelly's ratio (mg L^{-1}); PI – permeability index (%); TH – total hardness (mg L^{-1}), and RSC – ratio of sodium carbonate (mg L^{-1}).

According to the PI as stated by Doneen (1964), who divided irrigation water into three groups: PI of 100% is appropriate for irrigation, PI of 75% is slightly appropriate, and PI of 25% is unsuitable for irrigation. Based in this classification the Great Man-Made River water showed high quality under the first group, while the ground water classified under the second group slight appropriate (Table 8).

The checked water samples showed different levels of hardness (Table 8).

Therefore, Al-Swawa groundwater classified as very hard water, while Great Man-Made water classified moderate to hard, based on the classification of Sawyer and McCarty (1967), who categorized water into four groups: soft, when TH less than 50 mg L^{-1}, moderately hard, in the range of 50-150 mg L^{-1}, hard within the range of 150-300 mg L^{-1}, and very hard when TH more than 300 mg L^{-1}.

Conclusions

Based on salinity level, the groundwater of Al-Swawa unsuitable for irrigation purposes, except for very salts tolerant crops, when frequent leaching and intensive management are followed, while the Great Man-Made River will be suitable for irrigation purposes with moderate leaching and good drainage.

The groundwater shows none infiltration problem; however, Great Man-Made River water can cause slight to moderate infiltration problem. On the other hand, the contents of chloride, sodium, calcium, magnesium and bicarbonate indicated slight to moderate problems. Therefore, restrict management should be followed, when planning to use this water without causing serious problem.

References

Arshad, M.; Shakoor, A. Irrigation water quality. Pakistan Journal of Agricultural Research, v. 31, n. 2, p. 102-123, 2017.

Arulkirithas, N.; Sugirtharan, M.; Irfeey, A. M. M. Suitability of groundwater for irrigation in Manmunai West Divisional secretariat area of Batticaloa District. AGRIEAST: Journal of Agricultural Sciences, v. 13, n. 2, p. 17-26, 2019. http://doi.org/10.4038/agrieast.v13i2.71

Ayers, R. S.; Westcot, D. W. Water quality for agriculture. Rome: FAO – Irrigation and Drainage, Paper 29, 1985. 97p.

Ayers, R. S.; Westcott, D. W. Water quality for Agriculture. Rome: FAO – Irrigation and Drainage, Paper 29 rev. 1, 1989. 174p.

Bauder, T. A.; Waskom, R. M.; Sutherland, P. L.; Davis, J. G. Irrigation water quality criteria. Fort Collins: Colorado State University Extension Publication, 2011. 4p. (Crop Series/Irrigation - Fact Sheet No. 0.506).

Bian, J.; Nie, S.; Wang, R.; Wan, H.; Liu, C. Hydrochemical characteristics and quality assessment of groundwater for irrigation use in central and eastern Songnen Plain, Northeast China. Environmental Monitoring and Assessment, v. 190, n. 7, 382, 2018. https://doi.org/10.1007/s10661-018-6774-4

Doneen, L. D. Notes on water quality in agriculture. Published as a water science and engineering, Paper 4001. Davis: Department of Water Sciences and Engineering, University of California, 1964.

Eaton, F. M. Significance of carbonate in irrigation water. Soil Science, v. 69, n. 2, p. 123-134, 1950.

Fipps, G. Irrigation water quality standards and salinity management strategies. Texas: Texas Agricultural Extension Service, Texas A&M University System, College Station, 2003. p. 1-19.

Hema, S.; Subramani, T.; Elango, L. GIS study on vulnerability assessment of water quality in a part of Cauvery River. International Journal of Environmental Sciences, v. 1, n. 1, p. 1-17, 2010. http://dx.doi.org/10.6088/ijes.00101010001

Kaledhonkar, M. J.; Gupta, S. K.; Bundela, D. S.; Singh, G. On-farm land and water management. Karnal: Central Soil Salinity Research Institute, 2007. 178p.

Keesari, T.; Ramakumar, K. L.; Chidambaram, S.; Pethperumal, S. Understanding the hydrochemical behavior of groundwater and its suitability for drinking and agricultural purposes in Pondicherry area, South India – A step towards sustainable development. Groundwater for Sustainable Development, v. 2/3, p. 143-153, 2016. https://doi.org/10.1016/j.gsd.2016.08.001

Kelly, W. P. Use of saline irrigation water. Soil Science, v. 95, n. 6, p. 385-391, 1963.

Khodapanah, L.; Sulaiman, W. N. A.; Khodapanah, N. Groundwater quality assessment for different purposes in Eshtehard district, Tehran, Iran. European Journal of Scientific Research, v. 36, n. 4, p. 543-553, 2009.

Malash, N. M.; Flowers, T. J.; Ragab, R. Effect of irrigation methods, management and salinity of irrigation water on tomato yield, soil moisture and salinity distribution. Irrigation Science, v. 26, n. 4, p. 313-323, 2008. https://doi.org/10.1007/s00271-007-0095-7

Mass, E. V. Crop salt tolerance. In: Tanji, K. K. (ed.). Agricultural salinity and assessment management manual. New York: ASCE, Manuals and Reports on Engineering No. 71, 1990. p. 262-304.

Palanisamy, A.; Karunanidhi, D.; Subramani, T.; Roy, P. D. Demarcation of groundwater quality domains using GIS for best agricultural practices in the drought-prone Shanmuganadhi River basin of South India. Environmental Science and Pollution Research, v. 28, n. 15, p. 18423-18435, 2021. https://doi.org/10.1007/s11356-020-08518-5

Pal, A.; Pal, M.; Mukherjee, P.; Bagchi, A.; Raha, A. Determination of the hardness of drinking packaged water of Kalyani area, West Bengal. Asian Journal of Pharmacy and Pharmacology, v. 4, n. 2, p. 203-206, 2018. https://doi.org/10.31024/ajpp.2018.4.2.17

Islam, S. M. F.; Karim, Z. World's demand for food and water: The consequences of climate change. In: Farahani, M. H. D. A.; Vatanpour, V.; Taheri, A. (ed.). Desalination - Challenges and opportunities. London: IntechOpen, 2019. p. 1-27. http://dx.doi.org/10.5772/intechopen.85919

Raghunath, I. I. M. Groundwater. 2nd ed. New Delhi: Wiley Eastern Ltd., 1987. 563p.

Richards, L. A. Diagnosis and improvement of saline and alkali soils. Washington: United States Department of Agriculture, 1954. 160p. (Agriculture Handbook No. 60).

Saleh, A.; Al-Ruwaih, F.; Shehata, M. Hydrogeochemical processes operating within the main aquifers of Kuwait. Journal of Arid Environments, v. 42, n. 3, p. 195-209, 1999. https://doi.org/10.1006/jare.1999.0511

Scherer, T. F.; Seelig, B.; Franzen, D. Soil, water and plant characteristics important to irrigation. Fargo: North Dakota State University - Extension Circular, 1996.

Shahid, S.; Chen, X.; Hazarika, M. K. Evaluation of groundwater quality for irrigation in Bangladesh using geographic information system. Journal of Hydrology and Hydromechanics, v. 54, n. 1, p. 3-14, 2006.

Shahin, M. Groundwater resources of Africa. In: Shahin, M. (ed.). Hydrology and water resources of Africa. Dordrecht: Kluwer Academic Publishers, 2003. p. 509-563. https://doi.org/10.1007/0-306-48065-4_12

Singh, A. Conjunctive use of water resources for sustainable irrigated agriculture. Journal of Hydrology, v. 519, p. 1688-1697, 2014. https://doi.org/10.1016/j.jhydrol.2014.09.049

Subramani, T.; Elango, L.; Damodarasamy, S. R. Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India. Environmental Geology, v. 47, v. 8, p. 1099-1110, 2005. https://doi.org/10.1007/s00254-005-1243-0

Sawyer, C. N.; McCarty, P. L. Chemistry for sanitary engineers. 2nd ed. New York: McGraw-Hill, 1967. 518p.

Todh, D. K. Groundwater hydrology. 2nd ed. New York: John Wiley and Sons, Inc., 1980. 535p.

Vennila, G.; Subramani, T.; Elango L. GIS based groundwater quality assessment of Vattamalaikarai Basin, Tamil Nadu, India. Nature Environment and Pollution Technology, v. 4, n. 7, p. 585-592, 2008.

Wilcox, L. V.; Blair, G. Y; Bower, C. A. Effect of bicarbonate on suitability of water for irrigation. Soil Science, v. 77, n. 4, p. 259-266, 1954.

Zaki, S. R.; Redwan, M.; Masoud, A. M.; Moneim, A. A. A. Chemical characteristics and assessment of groundwater quality in Halayieb area, southeastern part of the Eastern Desert, Egypt. Geosciences Journal, v. 23, n. 1, p. 149-164, 2019. https://doi.org/10.1007/s12303-018-0020-5