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Assessing suitability of surface water from Oued El Gourzi for irrigation east of Alger

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Abstract: The study was conducted to determine the suitability of surface water from Oued El Gourzi for irrigation in the Fesdis area, Algeria, during irrigation season of July 2022. The suitability was assessed by analysing eight water samples collected from various sites along the Oued. A range of physicochemical parameters were examined, including *EC*, pH, Mg^{2+}, Na^{+}, Ca^{2+}, K^{+}, HCO_3^{-} and Cl^{-}, alongside other indices such as sodium absorption ratio (*SAR*), soluble sodium percentage (*SSP*), residual sodium carbonate (*RSC*), permeability index (*PI*) and magnesium adsorption ratio (*MAR*) using standard procedures. The Richards classification shows that these waters are characterised by high salinity and low alkalinity hazard (C3–S1). According to the Wilcox classification, the majority of these waters are of doubtful quality, with only 25% exhibiting good quality for irrigation. Based on the *RSC* and *MAR*, all water samples are deemed safe and suitable for irrigation. However, *PI* values suggest that all sampling sites are of marginal quality for irrigation (class II). In terms of sodium and chloride concentration, all water samples were deemed unsuitable for irrigation. Based on these results, the waters pose risks for irrigation, particularly due to salinity, necessitating the implementation of special management practices and the selection of salt-tolerant crops.

Keywords: Fesdis area, irrigation, Oued El Gourzi, suitability, surface water

INTRODUCTION

Water is a precious and indispensable natural resource vital for sustaining life. It is imperative to study its quality and chemical composition to ascertain its suitability for various applications, including industry, irrigation, and domestic use (Mohammad, 2011). While evaluating the quality of water for irrigation has often been neglected, it is crucial as its availability, given the water quality, directly impacts agricultural production (Islam *et al*., 2007). Utilising unsuitable water for irrigation can diminish soil productivity, alters its structure and chemical properties, and result in reduced crop yields (Ayers and Westcot, 1994; Kiy and Arslan, 2021). The surface water of Oued El Gourzi has been applied as the main irrigation source in the Fesdis area, yet its quality has received little attention. In this context, a study was conducted to evaluate the quality of the surface water from Oued El Gourzi used for irrigation in this region, with the emphasis on the range of parameters such as electrical conductivity (*EC*), sodium adsorption ratio (*SAR*), residual sodium carbonate (*RSC*), sodium percentage (*SP*), permeability index (*PI*), and magnesium absorption ratio (*MAR*).

MATERIALS AND METHODS

STUDY AREA

The study area is located in the Fesdis region, eastern Algeria (Fig. 1). The Fesdis Plain, situated at N 35°37′04′′, E 6°14′51′′, has an average altitude of 960 m and it is surrounded by reliefs ranging between 1080 m and 1744 m. During the dry period, the main river crossing the plain, Oued El Gourzi, carries primarily domestic and industrial waste from the town of Batna. In rainy periods, precipitation helps to dilute the pollutants in this watercourse, whereby replenishing the superficial aquifer located in the region (Khelif and Boudoukha, 2018). The region is characterised by a semi-arid climate, with an annual average temperature of 15.7°C and an annual average rainfall of approximately 350 mm (Belouanas, 2012). This semi-arid character is particularly due to the scarcity and irregularity of precipitation, which exposes the region to high temperatures and increased evapotranspiration.

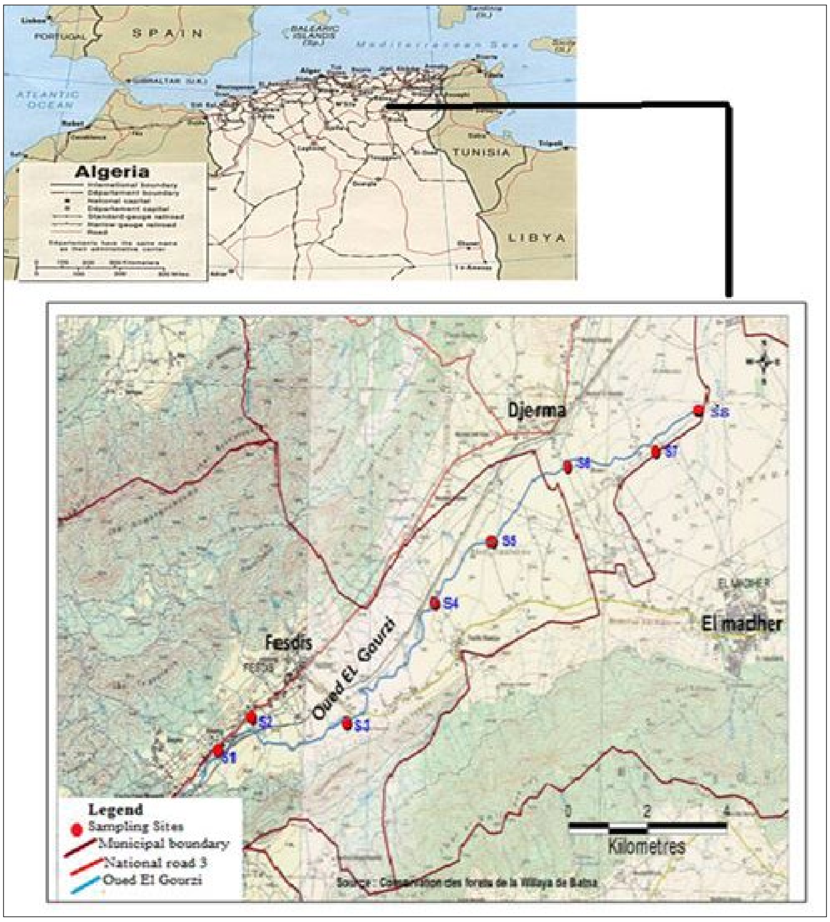

Fig. 1. Location of sampling sites in the study area; source: own elaboration

WATER SAMPLING AND LABORATORY ANALYSIS

Water samples were collected from different sites located in the Oued El Gourzi during the irrigation season of July 2022. The collection was carried out using clean 1.5 dm^3 polyethylene bottles. Precise determination of sampling locations was facilitated by GPS technology. Subsequently, all samples were transported to the laboratory in an ice chest to maintain a temperature <4°C, ensuring the integrity of the samples. Chemical parameter analysis was conducted within 24 h of collection using standard test methods (Rodier *et al.*, 2005; Rodier, Legube and Merlet, 2009). Electrical conductivity (*EC*) and pH were measured onsite using a multi parameter WTW (P3 MultiLine pH/LF-SET). In the laboratory, calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations were determined by the EDTA titration method. Sodium (Na^+) and potassium (K^+) levels were measured using a flame photometer, while bicarbonate (HCO_3^-) and chloride (Cl^-) were determined by titrimetry. The suitability of surface water for irrigation was evaluated based on the main irrigation indices: electrical conductivity (*EC*), sodium adsorption ratio (*SAR*), soluble sodium percentage (%*Na*), permeability index (*PI*), residual sodium carbonate (*RSC*), and magnesium adsorption ratio (*MAR*). The calculations of the water quality indices were made using the equations below.

Sodium adsorption ratio (*SAR*) was calculated using the equation given by Richards (ed.) (1954) as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{1}$$

The soluble sodium percentage was evaluated by Equation (2) (Todd, 1980) as:

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

The residual sodium carbonate was calculated by Equation (3) (Eaton, 1950) as:

$$RSC = \left(HCO_3^- + CO_3^-\right) - (Ca^{2+} + Mg^{2+}) \tag{3}$$

The permeability index was calculated by Equation (4) (Doneen, 1964) as:

$$PI = \frac{Na^{+} \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^{+}} 100 \tag{4}$$

The magnesium adsorption ratio was calculated by Equation (5) (Ayers and Westcot, 1994) as:

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} 100 \tag{5}$$

All the units of indices are in meq·dm^{-3}.

RESULTS AND DISCUSSION

STATISTICAL ANALYSIS (STUDENT'S TEST)

The comparison of the analysis results against the irrigation water quality standards, using the Student's *t*-test at the 5% significance threshold (Tab. 1), revealed a significant difference for such parameters as pH, *SAR*, %Na^+, *RSC,* and *MAR*. However, no significant difference was observed for such parameters as *EC*, Na^+, Cl^-, and *PI*. It is important to note that the latter parameters exceed the prescribed irrigation standards.

Table 1. Results of irrigation water quality statistical analysis (Student's *t*-test)

Parameter	*t*-value		*p*-value (unilateral)
	observed	critical	
pH	–19.455	–1.895	<0.0001***
EC	38.617	–1.895	1.000 ns
Na^+	17.186	–1.895	1.000 ns
Cl^-	9.732	–1.895	1.000 ns
SAR	–117.334	–1.895	<0.0001***
$\%Na^+$	–27.891	–1.895	<0.0001***
PI	–18.079	1.895	1.000 ns
RSC	–7.051	–1.895	0.0001***
MAR	–14.608	–1.895	<0.0001***

Explanations: threshold of significance α = 5%, ns = not significant, *** significant at 1‰, *EC* = electrical conductivity, *SAR* = sodium adsorption ratio, $\%Na^+$ = soluble sodium percentage, *PI* = permeability index, *RSC* = residual sodium carbonate, *MAR* = magnesium adsorption ratio.
Source: own study.

The surface water quality parameters for Oued El Gourzi and their statistical summary are presented in Table 2.

POTENTIAL OF HYDROGEN (pH)

The physicochemical balance of water is greatly influenced by pH, which depends on multiple factors such as temperature and water source. pH serves as a crucial indicator of water aggressiveness, reflecting its capacity to dissolve limescale (Aboubakar, Abdoul and Bouba, 2017).

The pH values for the surface water samples varied from 7.17 to 7.58, indicating a very slight alkaline tendency (Tab. 2). These results indicate that the pH of all surface water samples falls within the normal range (6.5–8.5) proposed for irrigation water (Ayers and Westcot, 1994). Dinka (2016) reported that irrigation with water characterised by high pH and HCO_3^- can lead to a reduction in crop production, precipitation of salts, and clogging of soil porosity.

SALINITY

The salinity hazard was evaluated based on electrical conductivity values, which reflect the overall mineralisation of the water (Ayers and Westcot, 1994). Electrical conductivity values for surface water samples ranged from 1920 to 2230 μS·cm^{-1}, indicating high salinity classes (C3) (Richard, 1954) – Table 3. This salinity level can cause significant yield reduction. The use of this water for irrigation is possible but requires the adoption of special management practices, including appropriate drainage, intense leaching, and the selection of salt-tolerant crops. High salt levels in irrigation water can alter physical properties of the soil, significantly reducing crop growth and yield, especially in sodium-saturated soils ((Peñaharo *et al.* (2010) as cited in Boubguira *et al.* (2021), p. 96). Tak *et al.* (2012), reported that irrigation with high *EC* waters affects the physiological growth of plants due to osmotic stress (osmotic effect) and toxic effect of ions.

Table 2. Irrigation water quality parameters for Oued El Gourzi

Sample site	pH (–)	*EC* (μS·cm^{-1})	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	*SAR*	*%Na*	*PI*	*RSC*	*MAR*
			meq·dm^{-3}										
1	7.50	2031	10.34	3.85	5.66	0.55	7.33	6.92	2.13	30.44	42.11	–6.86	27.13
2	7.17	2021	7.22	3.32	5.77	0.54	7.17	5.35	2.52	37.44	51.74	–3.37	31.50
3	7.38	2010	6.31	3.60	5.49	0.54	10.17	5.68	2.47	37.83	56.29	0.26	36.32
4	7.55	2230	8.82	4.13	5.54	0.49	10.42	5.34	2.18	31.77	47.37	–2.53	31.89
5	7.48	2220	7.62	3.92	5.15	0.49	7.74	5.52	2.14	32.83	47.51	–3.8	33.96
6	7.41	2042	7.66	3.77	5.41	0.51	5.82	5.32	2.26	34.12	46.43	–5.61	32.98
7	7.58	1991	7.34	4.12	4.84	0.56	7.58	7.37	2.02	32.02	46.56	–3.88	35.95
8	7.17	2017	6.84	4.00	4.72	0.57	6.58	7.13	2.03	32.79	46.78	–4.26	36.90
Max.	7.58	2230	10.34	4.13	5.77	0.57	10.42	7.37	2.52	37.38	56.29	0.26	36.90
Min.	7.17	1920	6.31	3.32	4.72	0.49	5.82	5.32	2.02	30.44	42.11	–6.86	27.13
Mean	7.40	2002	7.77	3.84	5.32	0.53	7.85	6.20	2.22	33.66	48.10	–3.76	33.33
Standard deviation	0.16	37.89	1.27	0.27	0.38	0.03	1.63	0.90	0.19	2.67	4.21	2.11	3.23

Explanations: *EC*, *SAR*, $\%Na^+$, *RSC*, *PI*, *MAR* as in Tab. 1.
Source: own study.

Table 3. Suitability of Oued El Gourzi waters for irrigation

Parameter	Range	Water classification	Reference	Samples site
EC (µS·cm^{-1})	<250	excellent	Richard (1954)	–
	250–750	good		–
	750–2000	doubtful		7
	2000–3000	unsuitable		1, 2, 3, 4, 5, 6, 8
SAR (meq·dm^{-3})	<10	excellent	Richard (1954)	all
	10–18	good		–
	18–26	doubtful		–
	>26	note suitable		–
%Na (meq·dm^{-3})	<20	very good	Wilcox (1948)	–
	20–40	good		all
	40–60	permissible		–
	60–80	doubtful		–
	>80	unpermissible		–
RSC (meq·dm^{-3})	<1.25	safe	Eaton (1950)	all
	1.25–2.5	marginal		–
	>2.5	unsafe		–
PI (meq·dm^{-3})	>75	suitable	Doneen (1964)	–
	25–75	marginal		all
	<25	unsuitable		–
MAR (meq·dm^{-3})	<50	suitable	Ayers and Westcot (1994)	all
	>50	unsuitable		–

Explanations: *EC*, *SAR*, %Na^+, *RSC*, *PI* and *MAR* as in Tab 1.
Source: own study.

SODIUM ABSORPTION RATIO (*SAR*) AND SOLUBLE SODIUM PERCENTAGE (*%Na*)

Dinka (2016) reported that the assessment of sodium risk (sodicity) is based on the value of the *SAR* or the %*Na*. The *SAR* quantifies the excess sodium content relative to calcium and magnesium cations.Aragaw and Gnanachandrasamy (2021) reported that high sodium content in irrigation water, compared to calcium and magnesium, significantly decreases the infiltration capacity of the soil due to the dispersion of clay particles. It also affects crop yields and irrigation systems (Couture, 2004). In this study, all water samples (100%) met permissible values of *SAR* and %Na^+ for irrigation ($SAR \le 10$, and %$Na < 60$) (Wilcox, 1948; Khodapanah, Sulaiman, and Khodapanah, 2009). The *SAR* values varied from 2.02 to 2.52 meq·dm^{-3}, and %*Na* values ranged from 30.44 to 37.38 (Tab. 2). Therefore, these water types are suitable for irrigation purposes (Alsubih *et al*., 2022).

RESIDUAL SODIUM CARBONATE (*RSC*)

The *RSC* is an index used to estimate alkalinity hazards in irrigation water. It is measures the water capacity to neutralise acids (Eaton, 1995) and it is defined as the effect of $HCO_3^- + CO_3^{2-}$ ions relative to $Ca^{2+} + Mg^{2+}$ ions (Simeneh *et al*., 2023). The *RSC* values of the surface water samples studied are well below the recommended values of 1.5 meq·dm^{-3} for fine-textured soils and 2.5 meq·dm^{-3} for other soil types (Tab. 2), indicating that these waters are safe for irrigating crops (Bendida, Kendouci and Tidjani, 2021) – Table 3. While an increase in alkalinity level in irrigation water reduces the risk of salinity, it increases the risk of sodium buildup in the soil (Ayers and Westcot, 1994; Silva, 2004).

PERMEABILITY INDEX (*PI*)

The *PI* is a key parameter in classifying water for irrigation purposes. It assesses the potential for water infiltration problems (Singh, Tewari and Kumar, 2020). In this study, *PI* values in the water samples ranged between 42.11 and 56.29 (Tab. 2). The study show that the waters have marginal quality for irrigation (class II) (*PI* between 25 and 75) (Doneen, 1964) – Table 3. Waters of marginal quality may or may not cause significant water infiltration issues. However, for waters with unsuitable quality, it is essential to implement special management practices to avoid the degradation of the soil structure (Ayers and Westcot, 1994).

MAGNESIUM ADSORPTION RATIO (*MAR*)

The *MAR* is crucial in determining the suitability of water for irrigation purposes (Vasan and Raju, 2007). Using water with high magnesium content for irrigation can lead to increased soil salinity and alteration of its structure (Shyamala *et al*., 2021). The results of the surface water study show that all samples have *MAR* values below 50 (Tab. 2), with values ranging from 27.13 to 36.90. These results suggest that the water is suitable for agricultural irrigation (Tab. 3). In their studies, Gupta and Gupta (1987) have noted that MAR values exceeding 50 meq·dm^{-3} in irrigation water can have a detrimental effect on soil properties.

SODIUM AND CHLORIDE

Sodium and chloride levels in water samples from Oued El Gourzi exceed 3 meq·dm^{-3} (Tab. 2), surpassing the tolerable threshold for irrigation by sprinkling (Ayers and Westcot, 1994). Spray irrigation with water containing relatively high levels of sodium or chloride ions can damage foliage of sensitive crops, especially under climatic conditions that promote evaporation, such as high temperatures and low humidity (Ayers and Westcot, 1994).

CLASSIFICATION BASED ON RICHARD AND WILCOX DIAGRAMS

In the study, the overall suitability of Oued El Gourzi waters for irrigation was assessed using the Richards diagram (Richards (ed.), 1954) – Figure 2 and the Wilcox diagram (Wilcox, 1948) – Figure 3. These diagrams, which assess the combined effects of salinity and sodicity, are widely used to evaluate irrigation water quality (Dinka, 2016; Singh, Tewari and Kumar, 2020; Aragaw and Gnanachandrasamy, 2021; Boubguira *et al*., 2021).

The relationship of *SAR* values and *EC* on the Richards diagram (Richards (ed.), 1954) shows that all water samples belong to class C3–S1 (Fig. 2), characterised by high salinity and moderate sodicity. Such water conditions can lead to the accumulation of soluble salts in the soil, reducing the yield of plants sensitive to salt, like citrus and beans. Effective management strategies, such as intense leaching, adequate drainage, and special salt management, are necessary (Ayers and Westcot, 1994; Dinka, 2016; Pivić *et al*., 2022). Similar results were reported by Azhari *et al*. (2023) for waters from Oued Laou, Morocco.

The Wilcox diagram, which plots electrical conductivity against the percentage of sodium, reveals that the majority of these waters (75%) are of doubtful quality, with only 25% exhibiting good irrigation quality (Fig. 3).

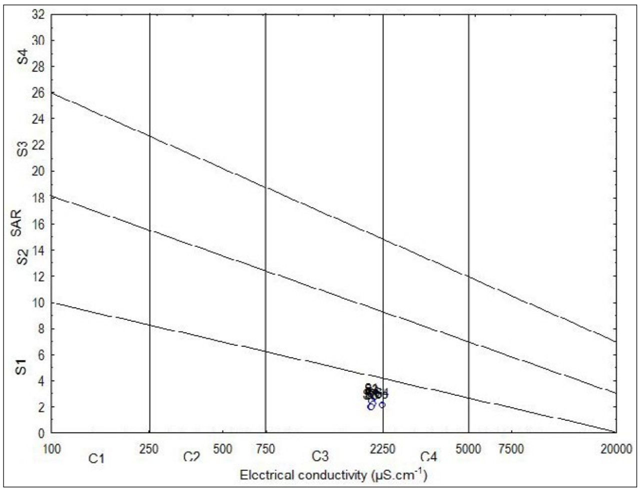

Fig. 2. Classification of surface waters of Oued El Gourzi on the Richards diagram; source: own study

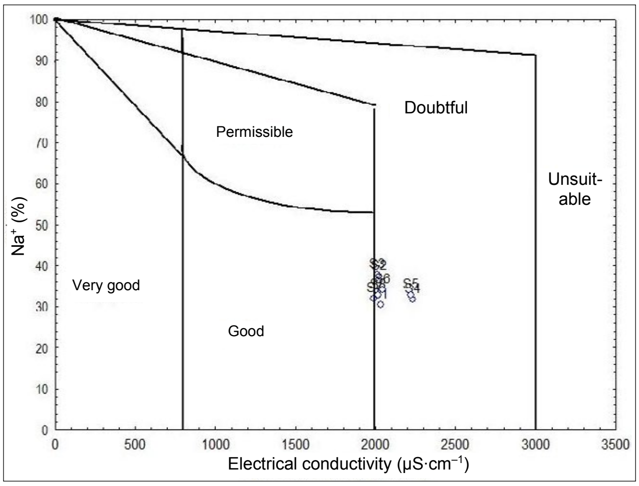

Fig. 3. Classification of surface waters of Oued El Gourzi on the Wilcox diagram; source: own elaboration

CONCLUSIONS

This study assessed the suitability of surface water from Oued El Gourzi for irrigation purposes. The results indicate that the pH values of all samples fall within the normal range (6.5–8.5) recommended for irrigation water. Values of residual sodium carbonate are well below the recommended thresholds of 1.5 meq·dm^{-3} for fine-textured soils and 2.5 meq·dm^{-3} for other soil types, indicating that these waters are suitable for irrigation. Additionally, all water samples showed magnesium adsorption ratio below the permitted limit of 50%, categorising them as suitable for irrigation. However, the calculated permeability index values (42.11–56.29) suggest that these waters are of marginal quality (class II). Despite these favourable indicators, all surface water samples show sodium and chloride values exceeding 3 meq·dm^{-3}, which make them unsuitable for irrigation by sprinkling. According to the Richards classification, which assesses the relationship between sodium adsorption ratio and electrical conductivity, these waters exhibit high salinity with low alkalinity hazard (C3–S1). Additionally, the Wilcox classification, based on electrical conductivity and the percentage of sodium, reveals that the majority of these waters are of doubtful quality, with only 25% showing good quality for irrigation.

These results indicate that the waters pose irrigation risks, particularly due to their high salinity. To mitigate these risks, the implementation of special management practices and adoption of salt-tolerant crops will be crucial. Additionally, we recommend adopting treatment measures for liquid effluents before they are discharged into Oued El Gourzi. Such treatments would help reduce the pollutant load of both organic and mineral matter, thereby decreasing the water salinity levels.

CONFLICT OF INTERESTS

The author declares no competing interests.

REFERENCES

Aboubakar, Abdoul, W. and Bouba, L. (2017) "Caracterisation des eaux de surface aux alentours d'une societe agro-industrielle de Maroua-Cameroun [Characterization of surface water around a agro-industrial company in Maroua-Cameroon]," *Larhyss Journal*, 29, pp. 209–225. Available at: http://larhyss.net/ojs/index.php/larhyss/article/view/491/480 (Accessed: March 01, 2017).

Alsubih, M. *et al.* (2022) "Assessing surface water quality for irrigation purposes in some dams of Asir Region, Saudi Arabia using multi-statistical modeling approaches," *Water*, 14(9), 1439. Available at: https://doi.org/10.3390/w14091439.

Aragaw, T.T. and Gnanachandrasamy, G. (2021) "Evaluation of groundwater quality for drinking and irrigation purposes using GIS-based water quality index in urban area of Abaya-Chemo sub-basin of Great Rift Valley, Ethiopia," *Applied Water Science*, 11, 148. Available at: https://doi.org/10.1007/s13201-021-01482-6.

Ayers, R.S. and Westcot, D.W. (1994) "Water quality for agriculture," *FAO Irrigation and Drainage Paper*, 29. Rome. FAO. Available at: https://www.fao.org/4/t0234e/t0234e00.htm (Accessed: October 12, 2021).

Azhari, H.E. *et al.* (2023) "Assessment of surface water quality using the Water Quality Index (IWQ), Multivariate Statistical Analysis (MSA) and Geographic Information System (GIS) in Oued Laou Mediterranean Watershed, Morocco," *Water*, 15(1), 130. Available at: https://doi.org/10.3390/w15010130.

Belouanas, H. (2012) *Influence du comportement des argiles sur les écoulements souterrains au sein des formations du recouvrement de la zone de Fesdis–El Madher (Nord-Est Algérien) [Influence of the behavior of clays on the underground flows within the recovery formations of the zone of Fesdis–El Madher (North-East Algeria)]*. MSc Thesis. Batna: University of Batna 2.

Bendida, A., Kendouci, M.A. and Tidjani, A.E.-B (2021) "Characterization of Algerian Sahara groundwater for irrigation and water supply: Adrar region study case," *Journal of Water and Land Development*, 49, pp. 235–243. Available at: https://doi.org/10.24425/jwld.2021.137117.

Boubguira, S. *et al.* (2021) "Suitability of surface water for irrigation in the Maffragh basin, North-East of Algeria," *Journal of Water Land Development*, 48, pp. 94–98. Available at: https://doi.org/10.24425/jwld.2021.136151.

Couture, C. (2004) "Analyse d'eau pour fin d'irrigation [Water analysis for irrigation]," *AGRI-VISION 2003–2004*. Available at: https://www.agrireseau.net/petitsfruits/documents/analyse%20eau.pdf (Accessed: May 18, 2004).

Dinka, M.O. (2016) "Quality composition and irrigation suitability of various surface water and groundwater sources at Matahara Plain," *Water Resources*, 43(4), pp. 677–689. Available at: https://doi.org/10.1134/S0097807816040114.

Doneen, L.D. (1964) "Notes on water quality in agriculture," *Water Science and Engineering Papers*, 4001. Davis: University of California, Department of Water Sciences and Engineering.

Eaton, F.M. (1950) "Significance of carbonates in irrigation waters," *Soil Science*, 69, pp. 123–134. Available at: https://doi.org/10.1097/00010694-195002000-00004.

Gupta, S.K. and Gupta, I.C. (1987) *Management of saline soils and waters*. New Delhi: Oxford & IBH Publishing Company.

Islam, D. *et al*. (2007) "Irrigation suitability of surface water within the polder area of Bhola Sadar Thana," *International Journal of Biological Research*, 3(5), pp. 42–49. Available at: https://www.researchgate.net/publication/282574961 (Accessed: November 15, 2007).

Khelif, S. and Boudoukha, A. (2018) "Multivariate statistical characterization of groundwater quality in Fesdis, East of Algeria," *Journal of Water and Land Development*, 37, pp. 65–74. Available at: https://doi.org/10.2478/jwld-2018-0026.

Khodapanah, L., Sulaiman, W.N.A. and Khodapanah, N. (2009) "Groundwater quality assessment for different purposes in Eshtehard District, Tehran, Iran," *European Journal of Scientific Research*, 36(4), pp. 543–553.

Kiy, M.Ş. and Arslan, H. (2021) "Assessment of groundwater quality for irrigation and drinking using different quality indices and geostatistical methods in Çorum province (Turkey)," *Journal of Irrigation and Drainage*, 70(4), pp. 871–886. Available at: https://doi.org/10.1002/ird.2593.

Mohammad, N.I. (2011) *Assessment of ionic toxicity of water sources in Rajbari district in Bangladesh*. MSc Thesis. Dhaka: Sher-e-Bangla Agricultural University.

Pivić, R. *et al*. (2022) "Hydrochemical assessment of water used for agricultural soil irrigation in the water area of the three Morava Rivers in the Republic of Serbia," *Agronomy*, 12(5), 1177. Available at: https://doi.org/10.3390/agronomy12051177.

Richards, L.A. (ed.) (1954) "Diagnosis and improvement of saline and alkali soils," *Agricultural Handbook*, 60. Washington, DC: USDA. Available at: https://www.ars.usda.gov/ARSUserFiles/20360500/hb60_pdf/hb60complete.pdf (Accessed: October 14, 2021).

Rodier, J. *et al*. (2005) *L'analyse de l'eau, eaux naturelles, eaux résiduaires, eau de mer: chimie, physicochimie, microbiologie, biologie, interprétation des résultats [Analysis of water, natural waters, wastewater, seawater: Chemistry, physico-chemistry, microbiology, biology, interpretation of results]*. 8th edn. Paris: Dunod.

Rodier, J., Legube, B. and Merlet, N. (2009) *L'analyse de l'eau [The water analysis]*. 9th edn. Paris: Dunod.

Shyamala, G. *et al*. (2021) "Suitability evaluation of groundwater quality for the intent of irrigation," *Nature Environment and Pollution Technology*, 20(2), pp. 793–799. Available at: https://doi.org/10.46488/NEPT.2021.v20i02.041.

Silva, E.L.L. (2004) "Quality of irrigation water in Sri Lanka – Status and trends," *Asian Journal of Water and Environment Pollution*, 1(1–2), pp. 5–12.

Simeneh, S. *et al*. (2023) "Evaluation of shallow groundwater suitability for irrigation purposes: A case study from Doornfontein area, South Africa," *Journal of Water and Land Development*, 58, pp. 189–197. Available at: https://doi.org/10.24425/jwld.2023.146611.

Singh, K.K., Tewari, G. and Kumar, S. (2020) "Evaluation of groundwater quality for suitability of irrigation purposes: A case study in the Udham Singh Nagar, Uttarakhand," *Journal of Chemistry*, 2020, 6924026. Available at: https://doi.org/10.1155/2020/6924026.

Tak, H.I. *et al*. (2012) "Effluent quality parameters for safe use in agriculture," in T.S. Lee (ed.) *Water quality, soil and managing irrigation of crops*. London: InTech. Available at: http://dx.doi.org/10.5772/31557.

Vasan, A. and Raju, K.S. (2007) "Application of differential evolution for irrigation planning: An Indian case study". *Water Resources Management*, 21(8), pp. 1393–1407. Available at: https://doi.org/10.1007/s11269-006-9090-7.

Wilcox, L.V. (1948) "The quality of water for irrigation use," *Technical Bulletin*, 962. Washington, D.C.: Department of Agriculture.