

Salinity of the agricultural soils in some farms due to the long-term sprinkling irrigation, ALDABWAT agricultural project

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ABSTRACT

The quality of irrigation water available to irrigators significantly impacts crops and yields. Therefore, there is a need to understand irrigation water quality better. The present study mainly focuses on assessing the suitability of water in five bore wells of the Aldabwat agriculture project in Alshatti, Libya. The well water samples were evaluated for agricultural uses according to the universal standard classification. Separate bore wells have been analyzed for various water quality indices, including exchangeable sodium percent (SSP or %Na), residual sodium carbonate (RSC or RA), Kelly's ratio, permeability index, potential salinity (PS), magnesium hazard, total dissolved solids, and total hardness. Most of the wells fall under the moderate water category for irrigation purposes. The analysed water was specified as having a low restriction according to the water quality index (IWQ index).

INTRODUCTION

Great efforts are being made by the Libyan state to achieve sustainable development, leading to carbon neutrality in the Libyan economy in 2050 (Ahmed et al., 2023; Nassar et al., 2023; Awad et al., 2023). And ensure a safe and sustainable supply of energy, food, and water to its community, a policy of local industrialization of these basic sources of energy and decentralized self-reliance for each community was adopted, while ensuring support, especially with the presence of a solid infrastructure of electrical power networks, water, oil & NG transportation pipelines and paved roads that connect all regions of Libya despite the great distance that separates Libyan cities from each other. This can be achieved by optimal use of available resources, including solar energy in the production of electrical energy (Alsharif et al., 2023), water desalination, and in industry and agriculture purposes (Hala et al., 2024; Alatrash et al., 2024). Also the agricultural residues can be used to produce organic fertilizer, and Methane gas GH4 which used in cooking and to heat animal pens in the winter (Nassar et al., 2017; Nassar et al., 2018).

Fertile and productive soils are rare and limited in arid and semi-arid areas. Due to the limited freshwater supplies in these regions, using good water quality for agricultural practices is crucial to maintain its productivity (Salem et al., 1995; Hipkin et al., 2004; Gorji et al., 2015; Huda et al., 24). Salinity or sodicity of soils can be due to many factors such as irrigation practices systems, precipitation, ineffective drainage system, irrigation with low quality either groundwater or recycled water, rising of the water table (Minhasa et al., 2018; Salem et al., 2022). Soil salinity is defined as one in which the exchangeable sodium is 15% and has the electrical conductivity of saturation extract of soil (ECe) at 25 °C in the root zone greater than 4dS m⁻¹ or about 40 mM NaCl (Salem and Chirgawi, 2005; Shrivastava and Kumar, 2015). Soil salinization had defined by Kumar and Sharma (2020) as the process of raising the salt content of the soil to a point where it affects agricultural production, environmental health, economics, and quality of life. The mechanisms of evaporation, salt precipitation and dissolution, salt transport, and ion exchange all contribute to soil salinization. The soils affected by salt contain significant concentrations of either soluble salts, exchangeable sodium, or both since there has not been enough base-forming cation leaching. The major soluble mineral salts are composed of the cation's Na⁺, Ca²⁺, Mg²⁺ and K⁺, and the anions Cl⁻, SO₄²⁻, HCO₃⁻, CO₃²⁻ and NO₃⁻ (Salem et al., 2013). Groundwater in arid regions is a crucial source of soil water, which indirectly influences the interaction of dissolved salts and the transfer and redistribution of soil salts (Wang et al., 2019c). Salts can accumulate in the soil over time due



to irrigation causing numerous problems, such as inhibition of plant growth, groundwater contamination and change in soil characteristics; globally, about 25% of the land has been affected by high salt concentrations, altering them unsuitable for agriculture (Bennett et al., 2009). About 50% of the irrigated agricultural areas in semi-arid and arid regions were affected by salinity in one way or another. For example, salinity threatens the irrigated agriculture of semi-arid and desert regions in the Mediterranean basin (Aragues et al., 2011; Salem et al., 2013).

METHOD

Site description

Wadi Alshatii district is situated in the middle of southwest Libya (Fig. 1), between 27° 52' 60" N and 12° 45' 00" E, with 52,342 km² characterized by an arid continental climate with an annual mean temperature of around 45°C in the summer and 20°C in the winter. With an average elevation of about 423 m, about 91% of the land is desert. Although 8.8% is agricultural land, only 1% is arable land. The location of the ALDABWAT agricultural project is between 27° 60' 23" or 27° 36' 8" N and 12.8638° or 12° 51' 50" N. The project was built in 1985 and consisted of 40 farms.



Fig 1. Map of Libya with Alshatii district.
[Source: https://en.wikipedia.org/wiki/Wadi_al_Shatii_District]

Sample collection and analysis of physio-chemical parameters

Water samples were collected three times in 2022 from the five wells in prewashed polyethene bottles with narrow mouth and rinsed three times with the same water to be sampled, using the standard method of sampling technique as mentioned by APHA (2005). pH and EC had been analyzed in situ using a portable multi-parameter water probe (JANEWAY 3540). TDS was measured by evaporating a pre-filtered sample to dryness. Calcium and total hardness were determined by the volumetric titration method. There was 0.01M of ethylene diamine tetraacetic acid (EDTA) titrated with Eriochrome Black T and Murexide indicators, respectively. Magnesium was calculated by subtracting calcium from the total concentration of calcium and magnesium. Sodium and potassium levels have been measured using flame photometry with a Janeway PFP7 flame photometer. Bicarbonate and carbonate concentrations were measured titrimetrically against a hydrochloric acid solution (0.01N). The chloride content was determined by argentometric titration using a standard silver reagent. Sulphate was measured as described by Sharma and Kaur (2016).

Assessment of water quality indices (WQI)

Water quality indices for irrigation were calculated using the equations and water quality criteria below, (El-Amier et al., 2021).

Table 1. Indices of irrigation water quality, their values, classes, and their calculation equations.

Indices	Value	Class	Calculation Formula
Residual Sodium Carbonate (RSC) meq. l ⁻¹	RSC < 1.25	Good	$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$
	RSC = 1.25 - 2.50	Medium	
	RSC > 2.50	Unsuitable	



Sodium Percentage (Na%)	Na% < 20 Na% = 20 - 40 Na% = 40 - 60 Na% = 60 - 80 Na% > 80	Excellent/Safe Good/Safe Permissible/Safe Doubtful/Unsafe Unsuitable/Unsafe	$\text{Na\%} = \frac{\text{Na}^+ + \text{K}^+}{\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+} + \text{Mg}^{2+}} \times 100$
Permeability Index (PI%)	PI > 75% PI = 25 - 75% PI < 25%	Suitable Moderate Unsuitable	$\text{PI} = \frac{\text{Na} + \sqrt{\text{HCO}_3}}{\text{Ca} + \text{Na} + \text{Mg}} \times 100$
Kelly's Ratio (KR)	KI < 1 KI > 1	Suitable Unsuitable	$\text{KI} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}}$
Potential Salinity (PS) meq. l ⁻¹	PS < 3.0 PS = 3.0 – 5.0 PS > 5.0	Excellent to good Good to injurious Injurious to unsatisfactory	$\text{PS} = \text{Cl} + \frac{1}{2}\text{SO}_4^{2-}$
Magnesium Hazard (MH)	MH < 50% MH > 50%	Suitable Unsuitable	$\text{MH\%} = \frac{\text{Mg}^{2+}}{\text{Ca}^{++} + \text{Mg}^{2+}} * 100$
Total Hardness (TH) meq. l ⁻¹	0 – 60 61 – 120 121 – 180 > 181	Soft Moderate Hard Very hard	$\text{TH} = 2.5\text{Ca}^{2+} + 4.1\text{Mg}^{2+}$
TDS (mg. l-1)	< 450 450 – 2000 >2000	Best Mode Hazard	$\text{TDS} = \text{EC} * f$ In this study, f = 0.640
Irrigation Water Quality Index (IWQI)	85 – 100 70 – 85 55 – 70 40 – 55 0.0 - 40	No Restriction (NR) low Restriction (LR) Moderate Restriction (MR) High Restriction (HR) Severe Restriction (SR)	$\text{IWQI} = \sum_{i=1}^n q_i w_i$ $q_i = q_{\text{max}} - [(x_{ij} - x_{\text{inf}}) * q_{\text{iamp}}/x_{\text{amp}}]$

RESULTS AND DISCUSSION

Physicochemical analysis

The descriptive analysis of the water quality characteristics of the wells used for the sprinkler irrigation shown in Table 2. The pH ranged between 6.39 and 6.75 with an average of 6.52 ± 0.14 . These values are within the permissible limit set by WHO (2011) for irrigation. The EC value ranged between 1.06 and 1.24 dS m⁻¹, with an average of 1.16 ± 0.08 . The wells showed a little variation among those properties, which we attributed to the fact that the wells had all stemmed from the same source and area. These results are similar to those reported by Matereche (2011). The concentration of total dissolved solids ranges between 680.96 and 775.04 mg.⁻¹ with a mean of 739 ± 38.67 .



Table 2. Statistical summary of measured cations and anions of groundwater of the studied wells

	pH	EC μS/cm	TH	Na	K	Ca	Mg	Cl	SO ₄ ²⁻	HCO ₃ ⁻	CO ₃ ²⁻	TDS
W1	6.45	1.235	120.6	130.13	85.59	38.13	8.88	180.61	17.36	199.58	N. D	745.94
W2	6.55	1.206	144.9	122.08	90.32	37.07	12.76	209.51	20.65	219.67	N. D	771.84
W3	6.47	1.077	133.8	133.57	84.25	36.65	11.42	215.44	17.66	187.64	N. D	725.16
W4	6.39	1.221	140.1	138.17	78.98	39.28	10.21	159.52	16.81	164.75	N. D	775.04
W5	6.75	1.064	113.1	135.64	76.64	34.47	6.65	248.50	16.85	201.37	N. D	680.96
Min.	6.39	1.06	113.10	122.08	76.64	34.47	6.65	159.52	16.81	164.75	N. D	680.96
Max.	6.75	1.24	144.90	138.17	90.32	39.28	12.76	248.50	20.65	219.67	N. D	775.04
Mean	6.52	1.16	130.50	131.92	83.16	37.12	9.98	202.72	17.87	194.60	N. D	739.79
S. D	0.14	0.08	13.33	6.24	5.44	1.80	2.35	34.13	1.60	20.24	N. D	38.67
WHO	6.5–8.5	1.500	500	200	12	75	50	250	250	500	-	-
FAO	6.5 - 8.5	0.7 <3	0 - 2000	0-20	0 - 2	0 - 400	9.4-13.5	70	575	-	-	>450 - <2000

(*) Permissible limits (mg. l⁻¹) set by (Meireles et al., 2010; Simeonov et al., 2003), N. D = Not Detected. (-) = not mentioned. W1 -W5, irrigation wells.

Irrigation water quality indices

Groundwater had defined by many indices for its suitability for irrigation. In this study, nine indices have been chosen, including RSC, Na%, PI, KI, PS, MH%, TH, and IWQI, to assess the quality of the water produced by these wells for irrigating the farms of the Aldabwat agricultural project. The results indicate that the irrigation water is classified as excellent, according to Ayers & Westcot, 1985; Wilcox, 1955.

Residual sodium carbonate (RSC)

Residual sodium carbonate (RSC) is used to assess the impact of CO₃ and HCO₃ on water quality for agricultural uses. According to Ramesh and Elango (2012), RSC may be classified into three classes: 1.25 = safe, 1.25-2.5 = moderate, and > 2.5 = inappropriate, with its concentration represented in meq. l⁻¹ and computed as follows: $RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{++} + Mg^{++})$. The RSC of the irrigation water collected from the research wells ranged from -0.10 to 1.0 meq. l⁻¹, (table 3), which may be regarded as safe and appropriate for irrigation purposes according to USPEA 1999.

Sodium percentage (Na%)

The groundwater with high sodium content reacts with soil and reduce its permeability as well as it had devastating impacts on soil structure, aeration and infiltration (Hipkin et al., 199; Vasanthavigar et al., 2012; Makhzom et al., 2023). The soluble sodium percentage in the water of the investigated wells were 72.43%, 74.15%, 77.67%, 73.42% and 74.56%. Water with a sodium percentage content of more than 60% might cause sodium accumulation and, as a result, the breakdown of physical soil characteristics (Fipps, 2003; Narsimha et al., 2012; Yasser et al., 2023). From the results table 3, sodium percentage of the irrigation water is ranged between 72.43 – 77.67%. According to classification indicated by (El-Amier et al., 2021; Yasser et al., 2021; Salem et al., 2022) we can conclude that the groundwater of the studied wells is doubtful/unsafe for irrigation.

Permeability index (PI)

Irrigation with groundwater rich with minerals of calcium, magnesium, sodium, chloride and bicarbonate for long-term can cause aeration reduction of the soil and consequentially to the obstacle of seedlings growth (Alam, 2014; Khalid, 2019). The permeability index of the irrigation water of the wells were 87.79%, 94.57%, 86.87%, 85.58% and 88.17% (Table 3) Based on the PI values and the classification suggested by (Doneen, 1964), this groundwater is suitable for irrigation (Xu, et al., 2019; Salem et al., 2020) had reported that high values of PI are related to high levels of HCO₃⁻ and Na⁺, which may be a result of the dissolution of calcite and dolomite and high cation exchange.

Kelly's index (KI)



Kelly's index, also called Kelly's ratio (KR), has been proposed by Kelly (1940). It expresses the relationship of sodium against calcium and magnesium (table 2). Water with KI >1 means it has a high concentration of sodium and deemed unfit for agricultural use, whereas water with KI <1 is considered suitable for irrigation. (Sundaray et al., 2009; Vasanthavigar et al., 2012; Salem et al., 2019; Makhzom). The KI of the irrigation water of the studied wells 1.83, 2.15, 2.61, 2.03 and 2.33, from the results this water was considered unsuitable for irrigation. These results consisted to the results obtained for Na% which exhibited high concentration of sodium of the groundwater of the studied wells.

Potential salinity (PS)

Doneen (1964) suggested that the potential salinity of the water be defined as the sum of the chloride concentration and half of the sulfate concentration (table 2). It represents the summation of salts precipitated and accumulated in the soil due to irrigation with low solubility salts or waters with high salt concentration for long-term irrigation (Gholami and Srikantaswamy, 2009; Awiadat et al., 2013; Nagaraju et al., 2014; Al-Ethawi et al., 2019). Water samples from the had a potential salinity of 6.13, 4.68, 7.18, 5.88 and 6.27. The result indicates that the water of the wells was injury/unsatisfactory. We attributed the high potential salinity of water from some wells to their content of high concentrations of chloride.

Magnesium hazards (MH)

The magnesium content of irrigation water is one of the most crucial qualitative criteria in determining its quality (Joshi et al., 2009). However, the ratio of the concentration of calcium and magnesium ensures a state of equilibrium in the groundwater. However, water with high magnesium levels, adversely affects the soil quality, rendering it alkaline and resulting in a decline in the crop yield (Kumar et al., 2007; Nagaraju et al., 2014; Awiadat et al., 2013). The magnesium hazard ratio (MR) has been suggested by (Paliwal 1972; Salem et al., 2018) and calculated as shown in table 2. MR has classified the water as MH > 50%, which indicates the water is harmful and unsuitable for irrigation. MH < 50%, which means the water is suitable for irrigation. The MH of the groundwater samples collected were, 36.21%, 30.0%, 23.89%, 33.25% and 28.19 (table 3). The results indicate the water is suitable for irrigation.

Total hardness (TH)

The total hardness of water is a significant property to be evaluated to determine its suitability for irrigation purposes. Water hardness had defined as the natural accumulation process of calcium, magnesium ions, and some salts (Salem et al., 2014; Sreedevi et al., 2018; El-Amier et al., 2021). Calcium carbonate (CaCO₃), dolomite (CaMg (CO₃)₂), and calcium sulfate (CaSO₄) are usually the primary sources of calcium in the water (Nagaraju et al., 2014; Salem et al 2018). The total hardness has been categorized into five classes (table 1). The hardness values of the studied wells were 2.90, 2.80, 2.26, 2.11 and 2.50 (Table 3). The results indicate the groundwater samples from these wells are soft and suitable for irrigation.

Table 3. Irrigation water quality evaluation indices for the groundwater of the study wells.

Parameter (meq.l ⁻¹)	Well No.					Category
	W1	W2	W3	W4	W5	
Residual Sodium carbonate (RSC) meq. l ⁻¹	0.70	-0.10	1.04	0.42	1.02	Good
Sodium soluble percent (Na%)	72.43%	74.15%	77.67%	73.42%	74.56%	Doubtful/unsafe
Permeability Index (PI)	87.79%	86.87%	94.57%	85.58%	88.17%	Suitable
Kelly's Index (KI)	1.83	2.15	2.61	2.03	2.33	Unsuitable
Potential Salinity (PS)	6.13	4.68	7.18	5.88	6.27	All wells are injuries/ unsatisfactory.
Magnesium hazard (MH%)	36.21%	30.0%	23.89%	33.25%	28.19%	Suitable for irrigation
Total Hardness (TH) meq. l ⁻¹	2.90	2.80	2.26	2.11	2.50	soft
TDS (mg-l)	745.94	771.84	725.16	775.04	680.96	moderate
Irrigation Water Quality Index (IWQI)	60.10	67.40	58.30	61.98	62.35	Moderate restriction.

Irrigation water quality index (IWQI)

The irrigation water quality index is a tool utilized to evaluate the suitability of water for agricultural purposes and relies mainly on the water quality parameters that harm soil quality and crop yield. It exhibits a clear description of the water quality because it accurately computes the wide range of complex indicators into one value (Salem et al., 2012; Spandana et al., 2013). IWQI has been classified into five categories, as suggested by Meireles et al. (2010) in table 1. The IWQI of the studied wells (table 3) were, 60.10, 67.40, 58.30, 61.98 and 62.35. These results indicate that



the water quality of these wells is under the moderate restriction category and can be used to irrigate the soils with moderate-high permeability and conduct medium salt leaching processes (Meireles et al., 2010; Awiadat and Abuhadara, 2010; Al-Saffawi et al., 2020).

CONCLUSION

From the results obtained we can conclude that the groundwater of the studied wells of Aldabwat agriculture project is suitable for irrigation.

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