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ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION USE IN THE M'SILA REGION (ALGERIA)

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Abstract

In this study, the physical and chemical characteristics of groundwater quality parameters of 16 wells within the M'Sila region were used for calculations such as sodium adsorption ratio (SAR), Kelly's ratio (KR), sodium percentage (Na %), permeability index (PI) and magnesium hazard (MH), which are used in irrigation water quality ratings. Also, the irrigation water quality index (IWQI) was calculated for all ground water sources within the study area. The correlations between the irrigation water quality parameters were determined using Pearson correlation analysis. The SAR, KR, and NA % values in the study area show that the groundwater in the study area is excellent and good as such suitable for irrigation purposes. Evaluation of the suitability of the groundwater in the study area for irrigation based on MH and WQI also suggests that 31.25 % and 37.5 % respectively of the samples are suitable and excellent or good for irrigation. The PI values show that the ground waterfalls under Class III, making the groundwater 'unsuitable' for irrigation. The groundwater in the study area is acceptable for irrigation except for a few instances which require a special careful application.

Key words: Groundwater, irrigation water quality index, semiarid region, Algeria

INTRODUCTION

Water resources and water quality are very important for urban development and the ecological environment, especially in the serious water shortage area (Xiao et al., 2019), which plays a massive role in different vital and structural activities (Ferahtia et al., 2021).

Groundwater is the most valuable natural resource, for human health, ecosystems, and socioeconomic growth (Umamageswari et al., 2019).

The existence of groundwater is beneficial for a variety of uses for example, agriculture, industry, urbanization, and the increase in the population demographic. Natural processes and anthropogenic activities influence water quality, thus deteriorating surface and groundwater sources and impairing their potential use for human and animal consumption, agriculture, recreation, and industry (Simeonov et al., 2003).

Groundwater suitability for irrigation purposes is based on the evaluation of the geochemical aspects of ground water. Each groundwater system has a diverse chemical composition, and its change depends on several parameters such as temperature, mineral dissolution, rock-water interaction, soil-water interaction, time-interaction, and anthropogenic factors (Ravi et al., 2020).

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The water indexes are the most effective tools for conveying information about water quality to communities of users, those responsible for the management, decision-making authorities, and the public (Salcedo-Sánchez et al., 2016).

Availability of water for irrigation involves both quantitative and qualitative issues. Additionally, the quality aspect of irrigation is generally ignored (Karakuş and Yıldız, 2020).

The quality of irrigation water is defined as total dissolved solids, major anions, and cations. In general, these cations and anions include Mg^{2+}, Na^{+}, K^{+}, Ca^{2+} and HCO_3^{-}.

The water quality index (WQI) can tell us whether the overall quality of water bodies possesses a potential threat to various uses of water, such as habitat for aquatic life, irrigation water for agriculture and livestock, recreation, esthetics, and drinking water supplies (Kankal et al., 2012).

WQI is expected to be quite helpful in monitoring, evaluation, and control of irrigation water by irrigation managers, site engineers, and decision-makers (Singh et al., 2018).

The suitability of water for irrigation is being determined in several ways, including the degree of acidity or alkalinity (pH), Electrical Conductivity, Sodium Adsorption Ratio (SAR), Kelly's ratio (KR), Percent sodium (Na %), Permeability index (PI) and magnesium hazard (MH).

Algeria is one of the countries of the Mediterranean basin, which suffers from water shortage. In the Algerian arid zone, the Hodna area is marked by a wide-open depression of 8500 km² surrounded by mountains where the saltwater lake "Chott El Hodna" ('saltwater lake' in the local language) 1100 km² wide is located in the center (Amroune et al., 2020).

In the region of M'Sila (Hodna area), all irrigation water and an important portion of drinking and industrial water supplies come from underground water reservoirs.

The primary aim of this research was to determine the suitability of the groundwater quality within the research area for agricultural use. In this context, the objectives of the study involve: (i) determination of the hydro-chemical properties of groundwater; (ii) evaluation of irrigation water quality parameters and IWQI.

In this context, the physical and chemical characteristics of groundwater quality parameters of 16 wells within the provincial boundaries of M'Sila Department (Wilaya) were used for calculations such as SAR, KR, Na %, PI and MH, which are used in irrigation water quality ratings. Also, IWQI was calculated for all groundwater sources.

The correlations between the irrigation water quality parameters, were determined using Pearson correlation analysis.

MATERIAL AND METHOD

Study Area

The Hodna basin is with a drainage area of 26 000 km², and it is the fifth largest basin in Algeria, it is located between 36° 11' and 34° 29' N latitude and between 3° 2' and 6° 11' E longitude. This basin straddles two distinct geological and geomorphological domains. To the north and northeast is the Tellian Atlas and, to the South of the Saharan Atlas. The study area has an elevation ranging between 350 to 1854 m above mean sea level (Fig. 1).

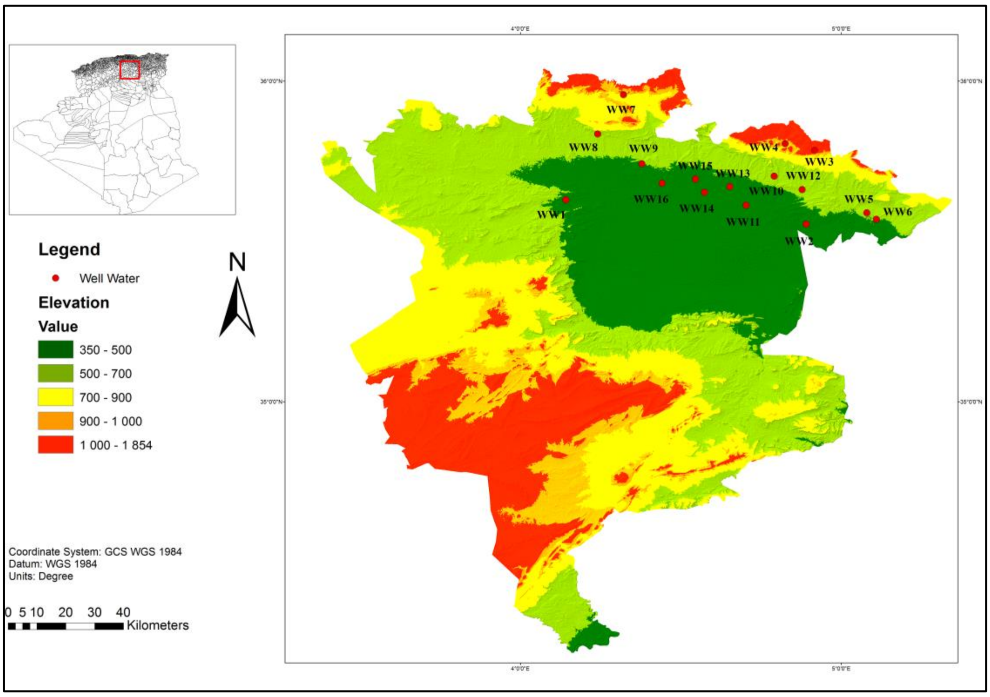

Fig. 1. Geographical location of the study area

The M'Sila region is characterized by a semiarid climate (Mimeche, 2014), with annual mean rainfall less than 200 mm per year and high temperatures in the summer and low in the winter (Ferahtia et al., 2021). The lowest temperature is reached during January with a value of 1.44 °C, while the maximum is 37.92 °C in August (Meteorological station of M'Sila from 1988 to 2014).

Agriculture, which remains the main occupation, especially the production of vegetables and cereals like barley and corn (Amroune et al., 2020) and olive orchard, is being built according to the available water supplies. The arable land area is 50,000 ha, 50 % of which is irrigated

(Abdesselam et al., 2013). Groundwater in the M'Sila region is scarce, and most of them are below 125 m.

Water sampling and analysis

Sixteen ground water samples were used to evaluate the suitability of ground water sources in the M'Sila region for agricultural irrigation. The water samples were collected during March and April 2019. In sampling from boreholes with hand pumps, purging was done for a minimum of 10 min to flush stagnant water retained in the pipes. In the case of hand dug wells, it was properly checked and confirmed that the well was being used daily. This was to ensure that stale and stagnant water was not sampled. All the water samples were collected in 250 ml preconditioned high-density polyethylene bottles. The bottles were conditioned by washing with 5 % nitric acid, and then rinsed several times with distilled water.

The water quality analysis of 11 parameters pH, electrical conductivity (EC), HCO_3^-, Ca^{+2}, Mg^{+2}, Na^+, K^+, Cl^-, SO_4^{-2}, NO_3^- and NO_2^-. Parameters such as pH and electrical conductivity were measured in situ by using a portable Multiparameter. All samples are labeled properly after that they transported in cooler boxes at a temperature below 4 C° immediately to the laboratory for analysis of other physicochemical parameters. The following chemical elements have been analyzed: bicarbonate (HCO_3^-), calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+), potassium (K^+), chloride (Cl^-), sulphate (SO_4^{-2}), nitrate (NO_3^-) and nitrite (NO_2^-). The samples were analyzed using American Public Health Association methods (APHA, 2005).

The irrigation water quality index parameter

Water quality index (WQI)

The concept of establishing an IWQI is based upon comparison of water quality parameters with specific standards (Sidhu et al., 2015). In this research, the IWQI model developed by Meireles et al., 2010, was used to calculate the WQI. The quality evaluation defined in this method differs from the WQI-based process used by the WHO (Meireles et al., 2010):

$$WQI = \frac{\sum_{i=1}^{n} \mathrm{QiWi}}{\sum_{i=1}^{n} \mathrm{Wi}}$$

where: *Qi* is the sub quality index of the i^{th} parameter (or *Q*i is the quality rating scale of each parameter). *W* is the weight unfit of each parameter and *n* is the number of parameters.

Calculation of Qi :

$$\mathrm{Qi} = 100\left[\left(\mathrm{Vi} - \frac{\mathrm{V0}}{\mathrm{Si}} - \mathrm{V0}\right)\right];$$

where: Vi is the estimated concentration of i^{th} parameter in the analyzed water. Vo is the ideal value of this parameter in pure water. Vo = 0 (except pH = 7.0 and DO = 14.6 mg/l). S_i is the recommended standard value of i^{th} parameter.

Calculation of Wi

Calculation of unfit weight (*Wi*) for water quality parameters is inversely proportional to the recommended standards for the corresponding parameters.

$$\mathrm{Wi} = \mathrm{K/Si};$$

where: K = the proportionality constant and it can also be calculated by using the following equation:

$$\mathrm{K} = \frac{1}{\sum(1/\mathrm{Si})};$$

WQI has been classified into 5 classes; the water quality is rated between excellent, good, poor, very poor and unfit consumption when the value of the index lies between 0 - 25, 26 - 50, 51 - 75, 76 - 100 and > 100 respectively.

The sodium adsorption ratio (SAR) proposed by the Richards, 1954, and defined as:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\mathrm{Ca+Mg}/2}};$$

SAR indicates the level that irrigation water undergoes cation exchange reaction in soil.

Kelly's ratio defined by Kelly, 1963, as:

$$\mathrm{KR} = \frac{\mathrm{Na}}{\mathrm{Ca+Mg}};$$

(All the ion concentrations are expressed in meq/l).

KR > 1 indicates an excess level of Na^+ in waters. Therefore, water with a KR ≤ 1 has been recommended for irrigation, while water with KR ≥ 1 is not recommended for irrigation due to alkali hazards (Rawat et al., 2018).

Percent sodium (%Na) or sodium hazard

Na^+ is important parameter and helps in categorization of any source of water for irrigation uses. The %Na is also used in classifying water for irrigation purposes. Percent Na^+ concentration is a factor to assess its suitability for irrigation purposes (Wilcox, 1948). The %Na values are calculated as:

$$\mathrm{Na\%} = \frac{\mathrm{Na}}{\mathrm{Ca+Mg+Na+K}} \text{ x } 100;$$

(all the ion concentrations are expressed in meq/l).

The classification of water is based on %Na as excellent (< 20 %), good (20 – 40 %), permissible (40 – 60 %), doubtful (60 – 80 %) and unsuitable (> 80 %) (Khodapanah et al., 2009).

Permeability index (PI)

The permeability index (PI) is an indicator to study the suitability water for irrigation purposes. Water movement capability in soil (permeability) is influenced by the long-term use of irrigation water (with a high concentration of salt) as it is affected by Na^{+}, Ca^{2+}, Mg^{2+} and HCO_3^{-} ions of the soil. PI formula has been developed by Doneen, 1964, to assess water movement capability in the soil as the suitability of any kind of source of water for irrigation, and it is formulated as:

$$\mathrm{PI} = \frac{\mathrm{Na}+\sqrt{\mathrm{HCO}}}{\mathrm{Ca}+\mathrm{Mg}+\mathrm{Na}}\ x\ 100;$$

(all the ion concentrations are expressed in meq/l).

According to Doneen, 1964, PI can be categorized in three classes: class I (> 75 %, suitable), class II (25 – 75 %, good) and class III (< 25 %, unsuitable). Water under class I and class II is recommended for irrigation.

Magnesium hazard (MH) or magnesium adsorption ratio (MAR)

Usually, alkaline earths (Ca^{2+} and Mg^{2+}) are in an equilibrium state in groundwater. Szaboles and Darab, 1964, projected MH values for irrigation water, and it is calculated as:

$$\mathrm{MH} = \frac{\mathrm{Mg}}{\mathrm{Ca}+\mathrm{Mg}}\ x\ 100;$$

(all the ion concentrations are expressed in meq/l). MH > 50 is not recommended for irrigation purposes (Khodapanah et al., 2009).

Statistical Analysis

Statistical summary of the physicochemical parameters was carried. Pearson's correlation coefficient was applied to calculate the relationship between various irrigation water quality index parameter (WQI, SAR, KR, %, Na, PI, and MH). Significance levels of tests were taken as $p < 0.05$ and highly significant as $p < 0.01$. All the statistical analyses were performed with SPSS statistical software, version 18.0, 2012.

RESULTS AND DISCUSSION

Hydrochemical properties of groundwater quality

A statistical summary of the physical and chemical parameters of the 16 water wells is shown in Table 1.

The pH of the groundwater in the study area ranged between 7.03 to 8.26. These values are nearly neutral or alkaline, which characterize the calcareous soils of the M'Sila region. The minimum value of 7.03 was observed in well water 1, and the maximum value of 8.26 was found in well water 7, typical values of shallow aquifers in arid areas (Joshi et al., 2009). This change in pH values is attributable to the low alkalinity of rainwater, agricultural activities, and leakage of dissolved components into the groundwater (Islam et al., 2018). The pH interval recommended for irrigation waters is 6.5-8.0 (WHO, 2007).

Table 1

Statistical summary of the hydrochemical properties of groundwater samples (Mean, SD (standard deviation), min and max)

Wells water	pH	CE (µS /cm)	HCO_3^- (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	NO_2^- (mg/l)
WW1	7.03	2,722.60	234.16	175.54	79.96	23.14	4.13	284.24	11.40	15.83	0.09
WW2	7.90	2,974.75	3.75	37.45	157.30	30.65	3.18	901.55	24.77	5.64	0.07
WW3	8.21	2,075.60	6.48	57.36	181.40	9.46	4.32	218.76	62.18	8.84	0.06
WW4	8.16	2,422.17	9.93	44.71	196.33	20.24	5.43	513.20	58.35	0.67	0.09
WW5	7.40	2,365.50	304.40	168.91	97.29	15.94	6.85	273.80	81.10	11.80	0.10
WW6	7.62	1,820.80	326.32	105.80	63.12	14.52	3.66	183.08	3.38	4.27	0.08
WW7	8.26	2,482.88	624.56	135.98	27.53	1.44	3.61	468.69	69.09	2.82	0.91
WW8	7.64	886.80	530.10	108.08	39.65	0.43	4.64	251.24	127.19	2.67	0.81
WW9	7.78	1,985.71	441.62	172.20	86.61	2.02	3.58	811.41	74.13	6.56	0.86
WW10	7.52	1,814.25	73.22	62.34	123.55	88.23	1.18	78.20	604.65	4.10	0.10
WW11	7.62	1,115.00	67.15	19.38	68.17	4.00	0.31	31.83	49.88	8.92	0.03
WW12	7.43	2,420.83	93.72	40.42	68.01	21.24	1.02	33.18	744.62	7.89	0.14
WW13	7.43	1,784.00	67.87	37.40	68.87	1.16	0.41	24.40	733.93	10.75	0.23
WW14	7.63	2,513.05	107.77	54.85	121.38	12.75	1.74	48.60	1,783.11	6.76	0.28
WW15	7.37	1,846.80	115.07	37.67	45.22	2.38	0.44	28.89	1,631.84	4.99	0.23
WW16	7.42	3,274.00	119.20	43.80	81.64	15.59	2.66	74.85	2,004.51	2.63	0.25
Min	7.03	886.8	3.75	19.38	27.53	0.43	0.31	24.4	3.38	0.67	0.03
Max	8.26	3,274	624.56	175.54	196.33	88.23	7.18	901.55	2,004.51	15.83	0.91
Mean	7.65	2,156.55	195.33	81.37	94.13	16.45	3.32	326.62	504.01	6.57	0.27
Stand. dev	0.34	624.70	195.29	54.63	49.55	21.26	2.33	473.87	697.53	3.98	0.30

The electrical conductivity (EC) shows wide variations, ranging between 886.8 to 3274 µS/cm, with a mean concentration of 2156.55 µS/cm. The higher EC recorded in the majority of ground waters in the study area indicates the enrichment of some salts in the groundwater. The EC acceptable permissible limit recommended by FAO for water irrigation is 3000 µS/cm (Ayers and Westcot, 1994).

The HCO^-_3 values range from 3.75 and 624.56 mg/l. All but one sample has its HCO_3^-concentrations exceeding the 610 mg/l standards set by the FAO (Ayers and Westcot, 1994).

Ca^{2+} values vary between 19.38 and 175.54 mg/l with an average value of 81.37 mg/l. Mg^{2+} concentrations also range from 27.53 to 196.33 mg/l. Ca^{2+} and Mg^{2+} have all their concentrations within the FAO (Ayers and

Westcot, 1994), acceptable limits of 400 and 250 mg/l, respectively. The presence of Ca^{2+} in the water, which is dissolved from earth and rocks leading to the hardness of water, originates from geological units and agricultural and industrial waste (Deshpande and Aher, 2011; Kumaravel et al., 2014). Crops grown on soils having an imbalance of calcium and magnesium may exhibit toxic symptoms (Salifu et al., 2017).

Na^+ concentration in groundwater of the study area ranges from 0.43 to 88.23 mg/l. The mean value is 16.45 mg/l. K^+ values also range between 0.31 and 7.18 mg/l. The Na^+ concentration is within acceptable limits. Evaluation of groundwater suitability for irrigation is, primarily based upon the evaluation of Na^+ content with respect to total cations within the system (Varol and Davraz, 2015). The K^+ acceptable permissible limit recommended by FAO for water irrigation is 2 mg/l (Ayers and Westcot, 1994). High concentrations of K^+ may introduce a magnesium deficiency and iron chlorosis (Salifu et al., 2017).

The chloride values range between 24.4 and 901.55 mg/l. All samples have their HCO_3^-concentrations not exceeding the 1063 mg/l standards set by the FAO (Ayers and Westcot, 1994).

The sulphate concentration in the present investigation varied from 3.38 to 2004.51 mg/l. The mean value is 504.01 mg/l. All but three samples have their SO_4^{--} concentrations exceeding the 960 mg/l standards set by the FAO (Ayers and Westcot, 1994). These high levels of sulphates are due to the fertilizers containing relatively large amounts of organic and inorganic sulfur compounds. SO_4^{2-} ions in water under natural conditions (Sharma et al., 2017).

The NO_3^- concentration ranges from 0.67 to 15.83 mg/l, with an average of 6.57 mg/l. The mean concentration of NO_2^- is 0.27 mg/l, with a maximum of 0.91 mg/l. The FAO (Ayers and Westcot, 1994) irrigation water quality standards set the acceptable limit of NO_3^- for irrigation purposes as 10 mg/l.

Irrigational water quality

The SAR parameter represents the tendency of Na ions to adsorb on soil (Karakuş and Yıldız, 2020). The SAR value obtained in the present study ranged from 0.05 meq/l (WW11) to 0.44 meq/l (WW8) with an average value of 0.25 ± 0.13 meq/l for the study area (Table 2). According to the standard presented by Ayers and Westcot (1985) and Richards (1954), all the ground waters could be classified as excellent and would be suitable for irrigation (Table 2).

To calculate KR (Kelly's ratio) parameter, Na is measured against Ca and Mg, as Ca and Mg preserve their steady state in most waters (Kelly, 1963). KR values ranged between 0.0035 at WW11 and 0.04 at WW2 (Table

2). According to Kelly's ratio classification (Kelly, 1963) groundwater with a KR value less than one (KR < 1) is suitable for irrigation (Table 3). From this study, all groundwater samples have values less than 1.

Table 2

Calculated irrigation water quality parameters of groundwater samples in the study area (Mean, SD (standard deviation), min and max)

Sample ID	SAR	Kr	Na%	PI	MH	WQI
WW1	0.25	0.02	3.37	7.00	31.30	91.01
WW2	0.32	0.04	5.05	2.58	80.77	35.82
WW3	0.30	0.02	3.10	2.42	75.98	20.37
WW4	0.31	0.02	3.55	2.69	81.45	34.88
WW5	0.42	0.03	4.21	8.23	36.55	23.29
WW6	0.38	0.02	4.06	12.51	37.37	52.65
WW7	0.40	0.02	4.23	17.12	16.84	18.30
WW8	0.44	0.03	5.41	17.70	26.84	68.99
WW9	0.31	0.01	2.69	9.37	33.47	81.40
WW10	0.12	0.01	1.25	5.20	66.46	87.02
WW11	0.05	0.0035	0.70	9.68	77.87	96.36
WW12	0.14	0.01	1.85	9.78	62.72	90.49
WW13	0.06	0.00	0.77	8.11	64.81	87.38
WW14	0.19	0.01	1.94	6.81	68.88	99.63
WW15	0.07	0.01	1.06	13.40	54.56	97.32
WW16	0.34	0.02	4.06	10.60	65.08	96.96
Min	0.05	0.0035	0.7	2.42	16.84	18.3
Max	0.44	0.04	5.41	17.79	81.45	99.63
Mean	0.25	0.016	2.96	8.95	55.06	67.62
Stand. dev	0.133	0.010	1.53	4.66	21.34	31.155

In all natural waters, Na% is a common parameter to assess its suitability for irrigation purposes since sodium reacts with the soil to reduce permeability (Wilcox, 1948). The Na% of the ground waters in the study area ranges from 0.7 to 5.41 %. The Wilcox, 1948, classification relates sodium percent and EC. It shows that all of the groundwater, could be classified as excellent and would be suitable for irrigation (Table 3).

Doneen, 1964, developed a PI-based criterion to evaluate the suitability of water for irrigation. The PI values obtained in the present study ranged from 4.15 % (WW2) and 18.99 % (WW8), with an average value of 10.12 ± 4.54 % for the study area (Table 2). PI values show that all of the groundwater could be classified as unsuitable for irrigation (Table 3).

Table 3

Classification of ground water sample for irrigation use on the basic SAR, KR, Na%, PI, MH and WQI

Index	Range	Class	Sample ID
SAR	< 10	Exc.	All samples
	10 – 18	Go.	
	18 – 26	Dou.	
	> 26	UnSu.	
KR	< 1	Su.	All samples
	> 1	UnSu.	
Na%	< 20	Exc.	All samples
	20 – 40	Go.	
	40 – 60	Perm.	
	60 – 80	Dou.	
	> 80	UnSu.	
PI (%)	> 75 %	Su.	
	25 – 75 %	Go.	
	< 25 %	UnSu.	All samples
MH (%)	< 50	Su.	WW1, WW5, WW6, WW7, WW8, WW9,
	> 50	UnSu.	WW2, WW3, WW4, WW10, WW11, WW12, WW13, WW14, WW15, WW16
WQI	< 25	Exc.	WW3, WW5, WW7
	26 - 50	Go.	WW2, WW4
	51 - 75	Po.	WW6, WW8,
	76 - 100	UnSu.	WW1, WW9, WW10, WW11, WW12, WW13, WW14, WW15, WW16

Exc. - excellent, Go. - good, Po. - Poor, Dou. - doubtful, Su. - suitable, UnSu. - unsuitable, Perm. - permissible.

Szaboles and Darab, 1964, developed a parameter called MH to evaluate the suitability of water for irrigation purposes. Calcium and magnesium in most waters maintain a state of equilibrium. High Mg_2^+ levels in the soil are expected to result in alkalization, which impairs both soil structure and crop yield (Rao et al., 2012). MH values varied between 16.84 and 81.45%, with an average value of 55.06 ± 21.34 % for the study area (Table 2). MH values showed that 37.5 % of the ground water samples were in the 'suitable' category and 62.5% in the 'unsuitable' category (Table 3).

WQI was applied to get a more comprehensive understanding of well water quality for irrigation purposes in the M'Sila region (Table 2). The WQI score for irrigation water was calculated using the guidelines of FAO (Ayers and Westcot, 1994). Only 10 variables were used for the calculation of WQI according to irrigation criteria. The selected parameters for irrigation water are pH, EC, HCO_3^-, Cl^-, SO_4^{-2}, Ca^{+2}, Mg^{+2}, NO_3^- and K^+. The WQI values in the M’Sila region ranged from 8.3 to 99.63 in well waters, with an average of 67.62 ± 31.155 (Table 3).

In well waters, 18.75 % of the samples belonged to “excellent”, 12.5 % were “good”, 12.5 % were “poor” and 56.25 % were “very poor”. Our study indicates that the fluctuation of the water quality index varied from excellent to very poor for water irrigation utilizations. The high potassium values increase the calculated WQI values, where potassium standards should not exceed 2 mg/l (Ayers and Westcot, 1994). The water quality was generally poor in the M’Sila region.

Pearson correlation analysis

In this study, Pearson correlation analysis was performed to determine the effect of the WQI, SAR, KR, Na %, PI and MH parameters on the irrigation water quality index parameter and to determine the relationships between these parameters (Table 4). The negative correlation between WQI parameter and SAR ($r = -0.665$; $P < 0.01$), KR ($r = -0.637$; $P < 0.01$) and NA% ($r = -0.615$; $P < 0.05$) respectively. The negative correlations were found between the MH parameter and SAR ($r = -0,514$; $P < 0.05$) and PI ($r = -0,723$; $P < 0.05$).

Table 4

Pearson’s correlation matrix (r) and sig. (2-tailed) (P values in the M’Sila region

	WQI	SAR	KR	NA%	PI	MH
WQI	1					
SAR	**-0,665****	1				
KR	**-0,637****	**0,801****	1			
NA%	**-0,615***	**0,943****	**0,918****	1		
PI	0,149	0,213	-0,0570	0,160	1	
MH	0,137	**-0,514***	-0,206	-0,397	**-0,723***	1

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

The SAR values were positively correlated with KR ($r = 0,801$; $P < 0.01$) and NA% ($r = 0,943$; $P < 0.01$). The positive correlations were found between the KR parameter and NA% ($r = 0,918$; $P < 0.01$). These results were statistically significant.

CONCLUSIONS

In this study, groundwater resources in the M’Sila region were evaluated in terms of irrigation water quality parameters. Sixteen ground water samples were used to evaluate the suitability of ground water sources in the M’Sila region for agricultural irrigation. Parameters such as SAR, KR, Na%, PI, MH, and WQI were estimated based on the hydrochemical properties of these samples. These parameters were evaluated in line with irrigation water quality standards and literature information, and the suitability of ground water samples for irrigation was determined following the FAO guideline.

Cation concentrations in ground water samples were ranked as Mg_2^+ > Ca_2^+ > Na^+ > K^+, while anion concentrations were ranked as SO_4^{2-} > Cl^- > HCO_3^- > NO_3^- > NO_2^-.

The irrigation water quality parameters (WQI, SAR, KR, Na% and PI) calculated for the research area indicated that the majority of the ground water sources within the research area are varied between 'suitable' and 'unsuitable' water categories in terms of irrigation water quality.

The SAR, KR, and NA% values in the study area show that the groundwater in the study area is excellent and good which is suitable for irrigation purposes. Evaluation of the suitability of the groundwater in the study area for irrigation based on MH and WQI also suggests that 31.25 % and 37.5 % respectively are suitable and excellent or good for irrigation. The PI values based on Doneen's chart show that the groundwater falls under Class III, making the groundwater 'unsuitable' for irrigation.

This groundwater could therefore be used limitedly and carefully to irrigate only semi-tolerant crops. Generally, ground water in the study area is acceptable for irrigation except for a few instances which require a special careful application.

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