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Assessment of Groundwater Salinity and Sodicity for Irrigation in Sabratha, Libya.

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AB STR ACT

In the management of water resources, quality of water is just as important as its quantity. The main aim of this research study was to assess the variability of groundwater parameters to develop water quality in Sabratha city and its suitability for irrigation purpose. Ten samples from different sites of selected study area were collected and analyzed for major cations and anions. The suitability of the groundwater for irrigation was evaluated based on electrical conductivity (EC), Sodium Percentage (Na%), Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Permeability Index (PI), and Potential Salinity (PS). The obtained results show that the majority of the groundwater samples were categorized as doubtful to unsuitable for irrigation purposes. The USSLS chart indicating water of high to very high salinity, and low to medium sodium and water with good to moderate quality. The Na% and the resulting Wilcox diagram classify the groundwater as doubtful to unsuitable category. On the Wilcox diagram, the water samples fell into three categories, about 50% of the water samples were good to doubtful category for irrigation, and the other samples fell in the category unsuitable for irrigation. The Doneen diagram showed that more than 50% of the groundwater samples are distributed in class III and are unsuitable for irrigation uses. Generally, the majority of groundwater samples in the study area were categorized as doubtful to unsuitable for irrigation purposes.

تقييم ملوحة المياه الجوفية والصوديوم للري في صبراتة، ليبيا

وفاء الهادي الذيب

في إدارة الموارد المائية، لا تقل أهمية جودة المياه عن كميتها. كان الهدف الرئيسي من هذه الدراسة البحثية هو تقييم تنوع معايير المياه الجوفية لتطوير جودة المياه في مدينة صبراتة ومدى ملاءمتها لأغراض الري. تم جمع وتحليل عشر عينات من مواقع مختلفة من منطقة الدراسة المختارة للكاتيونات والانيونات الرئيسية. تم تقييم ملاءمة المياه الجوفية للري بناءً على التوصيل الكهربائي، نسبة الصوديوم، نسبة امتصاص الصوديوم، ونسبة الصوديوم الذائبة، مؤشر النفاذية والملوحة المحتملة. أظهرت النتائج المتحصل عليها أن غالبية عينات المياه الجوفية صنفت على أنها مشكوك فيها إلى غير صالحة لأغراض الري. وفقًا لتصنيف مختبر الملوحة الأمريكية، فان المياه ذات ملوحة عالية إلى عالية جدًا ، والصوديوم منخفض إلى متوسط والماء بجودة معتدلة. على مخطط ويلكوكس، تم تقسيم عينات المياه إلى ثلاث فئات، حوالي 50٪ من عينات المياه كانت جيدة إلى فئة مشكوك فيها للري، والعينات الأخرى وقعت في فئة غير صالحة للري. أظهر مخطط دونين أن أكثر من 50٪ من عينات المياه الجوفية موزعة في الصنف الثالث وهي غير صالحة لأغراض الري. بشكل عام، تم تصنيف غالبية عينات المياه الجوفية في منطقة الدراسة على أنها في حالة مشكوك بيها الى غير مناسبة لأغراض الري.

INTRODUCTION:

Ground water is the primary source of water for domestic, agricultural and industrial uses in many countries and hence its use needs appropriate planning, development and management. Geochemistry and quality evaluation of water depends upon various physicochemical factors, mobility of elements, and climate (Bashir *et al.*, 2013). The groundwater chemically evolves by the interaction with aquifer minerals or by the inter mixing among the different groundwater reservoirs along flow path in the subsurface (Wallick and Toth, 1976). The natural chemistry of the groundwater is largely controlled by the dissolution of the geologic materials through which the water flows. Contaminants enter groundwater from sources at the ground surface through chemical weathering soil leaching, decaying vegetation, etc. These dominant processes depend on the geological and geochemical conditions, as well as the chemical and biological characteristics of the contaminant. Variations in the major ion chemistry of groundwater lead to identification of geochemical processes that control the groundwater quality (Ravikumar *et al.*, 2011; Ahmida *et al.*, 2013; Srinivas *et al.*, 2013; Nagaraju *et al.*, 2014; Balaji *et al*., 2016; Rawat *et al*., 2018; Aldeeb and Algeidi, 2021). Ion exchange involves the replacement of ions adsorbed on the surface of fine grained materials in aquifers by ions in solution. Groundwater quality depends on the nature of rock formation, topography, soils, atmospheric precipitation, environment, quality of recharged water, and on subsurface geochemical processes. Salinity and sodicity are major problems in irrigation waters, where in the arid areas, rainfall does not adequately leach salts from the soil, an accumulation of salts will occur in the crop's root-zone. Thus, periodic testing of soils and waters is required to monitor any change in salt content (Zaman *et al.*, 2018). Sodicity, the presence of excess sodium, will result in a deterioration of the soil structure, thereby reducing water penetration into and through the soil. A soil permeability problem occurs with a high sodium content in the irrigation water. Sodium has a larger concentration than any other Cation in saline water, its salts being very soluble. Positively charged, it is attracted by negatively charged soil particles, replacing the dominant calcium and magnesium cations. The replacement of the calcium ions with sodium ions causes the dispersion of the soil aggregates and the deterioration of its structure, thus rendering the soil impermeable to water and air.

The aims of this study were the sodicity and Salinity assessment of groundwater for irrigation purposes in Sabratha.

MATERIALS AND METHODS:

The study area is in the north western side of Libya in Sabratha city and located between the following latitudes and Longitude:

Table (1): Location of the study area

Well	Latitudes	Longitude
1	32°47'59.41"N	12°26'50.93"E
2	32°44'15.63"N	12°25'52.43"E
3	32°43'20.30"N	12°19'27.00"E
4	32°43'21.50"N	12°19'27.77"E
5	32°44'4.81"N	12°29'15.85"E
6	32°47'13.11"N	12°28'36.04"E
7	32°48'24.84"N	12°25'12.51"E
8	32°46'24.64"N	12°31'26.83"E
9	32°48'7.31"N	12°23'51.76"E
10	32°45'1.62"N	12°28'21.05"E

The present research work is based on 10 ground water samples collected from the study area. The groundwater samples were collected in pre-cleaned polyethylene bottles from bore wells as per the standard procedures, after 5 minutes of run-off water drawn from wells. The water samples were analyzed for various parameters which include electrical conductivity (EC) and cations such as calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}) and potassium (K^{+}). polyethylene bottles from bore wells as per the standard procedures, after 5 minutes of run-off water

Table (2): Groundwater chemical analyses (mg/L).

Well	TDS	Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-
limit	1000	200	200	150	40	200	250	45	250
1	5,094	737	862	149	46	129.3	731.3	13.3	2480
2	8,928	1,291	1511	516	80	227	1,599	23.2	4345
3	1,416	187	259	38	11.6	103	186	3.4	629
4	4,563	422	796	286	23.8	172.7	842.8	7.4	2,122
5	8,243	762	1,438	261	45.2	131.4	1,599	13.4	3,833
6	1,766	163	308	110.6	7.9	128.2	280.9	2.9	821.5
7	6,637	613	1,158	415.7	36	105.8	1275	10.8	3,086
8	1,670	155	291.5	104.6	7.3	126.6	259.3	2.7	776.7
9	1,576	236	173	71.44	8	203.5	560	28.2	296.59
10	835	118	118.5	23.81	7.1	132.3	113	58.8	263.83

polyethylene bottles from bore wells as per the standard procedures, after 5 minutes of run-off water drawn from wells. The water samples were analyzed for various parameters which include electrical conductivity (EC) and cations such as calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+) and potassium (K^+); and anions as Chloride ions (Cl^-), bicarbonate ions (HCO_3^-), Sulfate ions (SO_4^{--}) and nitrate ions (NO_3^-). The groundwater chemical composition were measured to determine the concentrations of sodium ions (Na^+), potassium ions (K^+), the water samples contents of these cations is measured using Flame photometer. The total hardness calcium ions (Ca^{++}), magnesium ions (Mg^{++}) was determined by EDTA titrimetric method. Chloride ions (Cl^-) was determined by silver nitrate titration. Bicarbonate ions (HCO_3^-) were determined by sulfuric acid. Whereas, sulfate ions (SO_4^{--}) and nitrate ions (NO_3^-) were determined using spectro-photometer. The statistical parameters and the major ion-concentrations in capering with the (Libyan standard, 1992), were summarized in Table (2).

RESULTS AND DISCUSSION :

Mathematical computations on the basis of Water quality parameters major cations and anions were used to determine water quality indices such as Sodium Percentage (Na%), Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Permeability Index (PI), and Potential Salinity (PS); in order to evaluate the suitability of groundwater in the study area for irrigation use, Table (3).

Table (3): Groundwater indices for Irrigation.

Well	SAR	Na%	SSP	PS	EC	PI	∑con.
W1	2.53	30.46	29.89	3.29	2463	37.66	49.18
W2	2.6	40.49	39.66	5.09	1305	51.67	26.08
W3	7.57	44.09	43.33	54.74	7960	45.75	175.19
W4	8.99	38.8	38.07	89.29	13950	39.9	334.54
W5	4.51	48.13	47.48	13.87	2213	53.54	47.37
W6	7.33	44.13	43.7	42.31	7130	46.24	160.15
W7	11.46	51.7	51.24	74.85	12880	52.89	266.94
W8	4.56	44.1	43.73	17.33	2760	48.8	61.99
W9	8.85	44.18	43.73	60.52	10370	45.31	231.55
W10	4.44	44.08	43.72	16.51	2610	49.02	58.60

Sodium Absorption Ratio (SAR)

The Sodium adsorption ratio (SAR) is an irrigation water quality parameter used in the management of sodium-affected soils. It is an indicator of the suitability of water for use in agricultural irrigation, as determined from the concentrations of the main alkaline and earth alkaline cations present in the water. Salinity and sodium are two issues that occur in terms of SAR. Measurements like total dissolved solids (TDS) and electric conductivity (EC) help indicate the hazardous issues that contribute to an increased sodium absorption ratio (SAR). Total dissolved solids (TDS) measures the amount of particles, contaminants, and salts in the water. When TDS levels are high, it is indicative of an elevated number of salts which is associated with the level of SAR. As far as electrical conductivity, when the EC is low, the SAR is relatively low. When the EC levels are high (whether there are elevated amounts of sodium or not), the SAR level will be high. The issue with having high SAR levels is plant growth and survival. SAR also influences percolation time of water in the soil. Therefore, the low value of SAR of irrigation water is desirable. The sodium adsorption ratio is an indicator of the relative proportion of sodium ions in a water sample to those of calcium and magnesium. It is formulated as:

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

Water having SAR values <10 is considered excellent, 10-18 is good, 18-26 is fair and above 26 is unsuitable for irrigation use (Kelly, 1946). The SAR values varied from 2.53 to 11.46 and the majority of the samples were rated as excellent and suitable for irrigation (Table 3).

Sodium Percentage (Na%)

The Sodium Percentage (Na%) is also used in classifying water for irrigation purpose. Sodium (Na^+) is important parameter and helps in categorization of any source of water for irrigation uses. Na^+ makes chemical bounding with soil to reduce water movement capacity of the soil (Ayers and Westcot 1985). Na^+ reacts with carbonate and forms alkaline soils, while Na^+ reacts with chloride and forms saline soils. Sodium-affected soil (alkaline/saline) retards crop growth (Todd, 1980). If concentration of Na+ in irrigation water is high, then the ions tend toward the clay particles, by removing Ca^{2+} and Mg^{2+} ions through a base-exchange reaction. This exchange process in soil reduces water movement capacity. In this condition, air and water cannot move freely or restricted during wet conditions, and such soils have become hard when dry (Singh *et al.*, 2015).

To assess the suitability of water quality for irrigation, the percentage of sodium in water is calculated by the following equation (Wilcox, 1955):

$$Na\% = \frac{Na^+ + K^+}{(Ca^+ + Mg^{2+}Na^+ + K^+)} \cdot 100 \dots\dots (2)$$

Na%	excellent	0 - 20
	good	20 - 40
	permissible	40 - 60
	doubtful	60 - 80
	Unsuitable	>80

The obtained values of the sodium percentage Na% in the groundwater of the study area ranged from 30.46 %

to 51.70%. 80 % of the samples from the study area were in the permissible category.

Soluble Sodium Percentage (SSP)

Wilcox has proposed a classification for rating irrigation waters on the basis of Soluble Sodium Percentage (SSP). The SSP was calculated using the following formula (Wilcox, 1955):

$$SSP = \frac{Na}{Ca + Mg + Na} \times 100 \;\ldots\ldots\ldots\ldots(3)$$

The values of SSP < 50 indicate good quality of water, and higher values >50 show that the water is unsafe for irrigation (Magesh Kumar *et al.*, 2016). In Table (3), 94% of groundwater samples show SSP values < 50, that indicates good quality for irrigation.

Permeability Index (PI):

The PI in a groundwater sample measures the total concentration of Na and HCO_3 to the total cations. Permeability Index (Doneen, 1964) is calculated by using the following formula:

$$PI = \frac{Na + K + \sqrt{HCO_3}}{(Ca + Mg + Na + K)} \cdot 100 \;\ldots\ldots\ldots\ldots(4)$$

Potential Salinity (PS)

(Doneen, 1954) pointed out that the suitability of water for irrigation is not dependent on the concentrations of soluble salts. Potential salinity is defined as follows:

$$PS = Cl^{-} + \sqrt{(SO_4^{--})^2} \;\ldots\ldots\ldots(5)$$

Water quality was categorized into excellent if PS < 5, good, when PS 5-10, unsuitable, if PS >10. The value of PS in the groundwater samples of the study area ranges from 3.29 to 89.29. 80% of the groundwater samples have been classified as unsuitable for irrigation purposes (Table 5).

Electrical conductivity (EC)

EC is a good measure of salinity hazard to crops as it reflects the TDS in ground water. The total concentration of soluble salts in irrigation water termed as low (C1, EC < 250 µS/cm), medium (C2, 250-750 µS/cm), high (C3, 750-2,250 µS/cm) and very high (C4, >2,250 µS/cm). The electrical conductivity (EC) of the groundwater in the study area varies from 1,305 to 13,950 µS/cm. 80% of the samples show very high salinity.

Standard diagrams such as USSLS and Wilcox diagram were determined for the suitability of groundwater for irrigation.

USSLS diagram

Irrigation water can also be classified according to the US salinity laboratory's diagram (Richards, US Salinity Laboratory, 1954) where SAR is an index of sodium hazard and EC is an index of salinity hazard. In order to accommodate higher water salinity levels, Shahid and Mahmoudi (2014) have modified the USSL Staff water classification diagram by extending water salinity up to 30,000 µS/cm. USSLS diagram Figure (1) classifies the water quality into 16 zones to assess irrigation suitability of water according to Table (4).

Table (4): USSLS classification

Zone	EC	SAR	Water quality
C1-S1	Low	Low	Good
C1-S2	Low	Medium	Moderate
C1-S3	Low	High	Poor
C1-S4	Low	Very high	Very poor
C2-S1	Moderate	Low	Good
C2-S2	Moderate	Medium	Moderate
C2-S3	Moderate	High	Poor
C2-S4	Moderate	Very high	Very poor
C3-S1	High	Low	Good
C3-S2	High	Medium	Moderate
C3-S3	High	High	Poor
C3-S4	High	Very high	Very poor
C4-S1	Very high	Low	Good
C4-S2	Very high	Medium	Moderate
C4-S3	Very high	High	Poor
C4-S4	Very high	Very high	Very poor

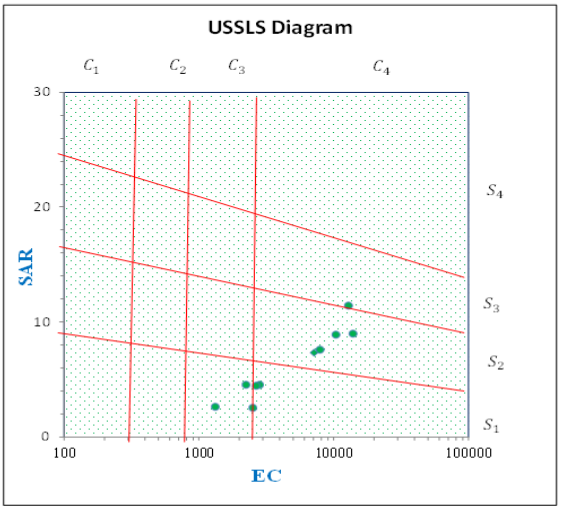

Figure (1): USSLS classification of groundwater.

It was observed that the samples were grouped into two zones, namely (C3-S1) and (C4-S2). Samples fall in the zone (C3-S1), indicating water of high salinity and low sodium and water with good quality. This kind of water can be used for irrigation in almost all types of soil. Samples fall in the zone (C4-S2), indicating water of very high salinity and medium sodium and water with moderate quality.

Wilcox diagram

The plot of analytical data on the (Wilcox, 1955) diagram relating EC and Na% show that water samples fall in three classes, Figure (2). About 50% of the water samples are good to doubtful category for irrigation, and the other 50% fall under unsuitable for irrigation purposes.

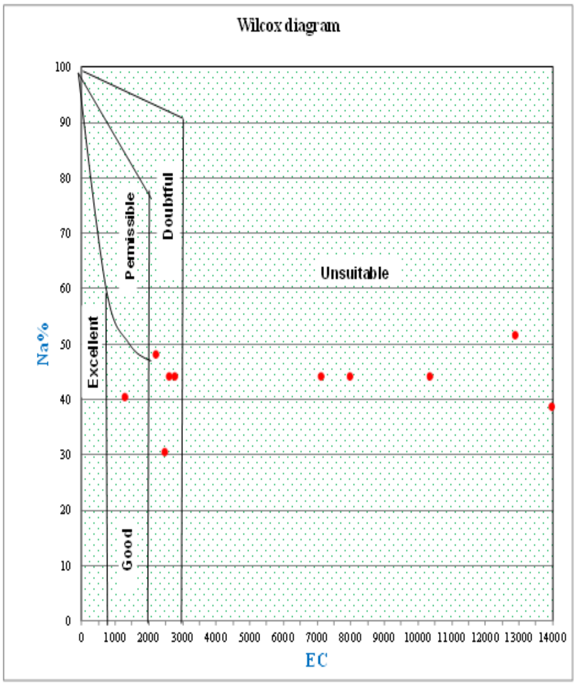

Figure (2): Wilcox diagram relating Na% and EC.

Doneen Diagram

(Doneen, 1964) proposed a categorization system for irrigation water based on PI and the total amount of the cations (Na^+, Ca^{2+}, Mg^{2+}, K^+) and anions (HCO_3^-, SO_4^{2-}, NO_3^-, Cl^-) in (meq/L). The Permeability Index (PI) in a groundwater sample measures the total concentration of Na and HCO_3 to the total cations. Permeability Index is calculated by using the following formula:

$$PI = \frac{Na + K + \sqrt{HCO_3}}{(Ca + Mg + Na + K)} \cdot 100 \quad \dots\dots\dots\dots (6)$$

Doneen classified irrigation waters into three classes, Class I (>75%, excellent), Class II (25-75 %, good) and Class III (<25 %, unsuitable). The representation of the permeability index values on the Doneen diagram, based on the total ionic concentration (TDS) and the permeability index (PI) (Figure 3), showed that more than 50% of the groundwater samples are distributed in class III and are unsuitable.

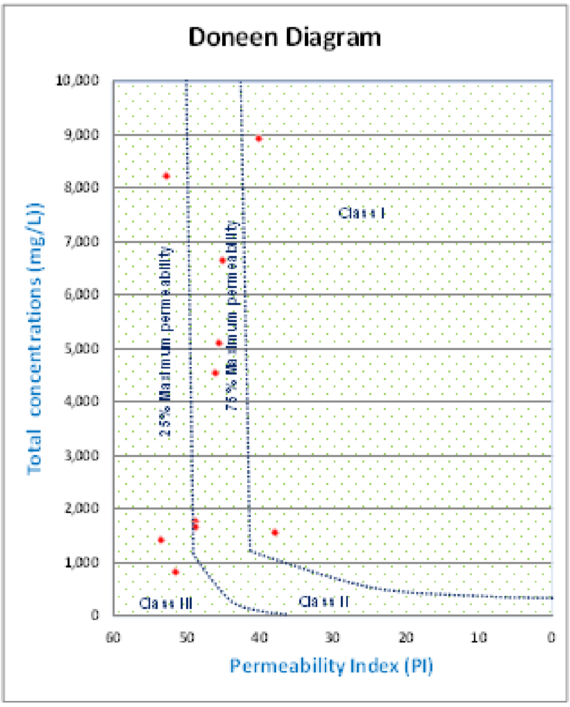

Figure (3): Doneen diagram relating TDS and PI.

CONCLUSION :

The aim of this study was to assessment the quality of groundwater in Sabratha for irrigation purposes according to sodicity and Salinity. Groundwater quality indices were used such as Sodium Percentage (Na%), Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Permeability Index (PI) and Potential Salinity (PS) and diagrams such as USSLS, Wilcox and Doneen. The irrigation water quality parameters indicated that the majority of the water samples are in permissible to unsuitable category for irrigation purposes. According to the USSLS classification, 50% of the samples were located in the zone (C3-S1), with high salinity and low sodium, and were classified as water of good quality, while the rest of the samples were located in the zone (C4-S2), with very high salinity and medium sodium, and were classified as water with moderate quality. The Na% and the resulting Wilcox diagram classify the groundwater as doubtful to unsuitable category. The Doneen diagram showed that more than 50% of the groundwater samples are distributed in class III and are unsuitable.

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