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Salinity Status of Groundwater in El-Dakhla Oasis, New Valley Governorate, Egypt

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Abstract

This investigation aims to evaluate the groundwater quality of El-Dakhla oasis, New Valley governorate, Egypt and assess its suitability for irrigation. About 144 groundwater samples were collected from wells distributed in eleven transects that represent the study area. The obtained results indicated that 63 samples were under the C_1S_1 indicating category low sodium and low salinity hazards. Meanwhile, 72 samples in the C_2S_1 category showing low sodium and medium salinity hazards and 9 samples exhibited a C_3S_1 type resulting in low sodium and high salinity hazards.

According to Wilcox diagram, 93.75% of the water samples had an excellent quality for irrigation and 4.86% of them were considered as a permissible class.

The results also revealed that 49.31% of these samples gave positive chloro-alkaline index (CAI) values. However, the remaining samples (50.69%) showed negative CAI.

With respect of the corrosivity ratio (CR), 140 groundwater samples (97.22%) were safe to transport in mineral pipes whereas only 4 samples (2.78%) were corrosive in nature and need non-corrosive pipe to transport and lift these groundwaters.

***Keywords**: El-Dakhla oasis, groundwater, salinity (EC_w), sodium adsorption ration (SAR)*

Introduction

The groundwater is the only renewable water resource in El-Dakhla Oasis, New Valley, Egypt. Therefore, groundwater resource assessment and sustainability considerations are most important in this region where water is common of critical economical and social significance. About 85% of these waters are used in agriculture (MWRI, 2014).

The quality of groundwater is considered as important as its quantity. So, the chemical analysis of water is very important. Groundwater quality is affected by the seasonal and spatial variations of its chemistry (Soltan, 1999; Kumar *et al.* 2006) flow and salt content as well as human activities (Karanth, 1997; Al-Shaibani, 2008).

Therefore, the aim of this study is to evaluate the groundwater quality of El-Dakhla oasis and assess its suitability for irrigation.

Materials and Methods

This study was conducted on El-Dakhla Oasis, New Valley Governorate, Egypt, which bounded by longitudes of 28° 30` to 29° 30` E and latitudes of 25° 11` to 26° 00` N. It covers an area of about 100 km^2.

About 144 groundwater samples were collected from wells distributed in eleven transects representing the study area (Fig., 1) to assess their quality and suitability for irrigation. Each sample was situated using the Global Position System (GPS). The distance between each two consequent transects was 4.5 to 6 km.

The electrical conductivity of each water samples (EC_W) was measured in-situ using a portable EC meter. The chemical analyses for major ions were carried out in the Laboratory of Agricultural Research Station, El-Kharga, New Valley, Egypt. Sodium and potassium concentrations were determined using a flame photometer while calcium and magnesium concentrations were determined by EDTA titration. Chloride was estimated using silver nitrate titration and bicarbonate was measured with acid-base titration. Sulphate was determined using a spectrophotometer (Jackson, 1973).

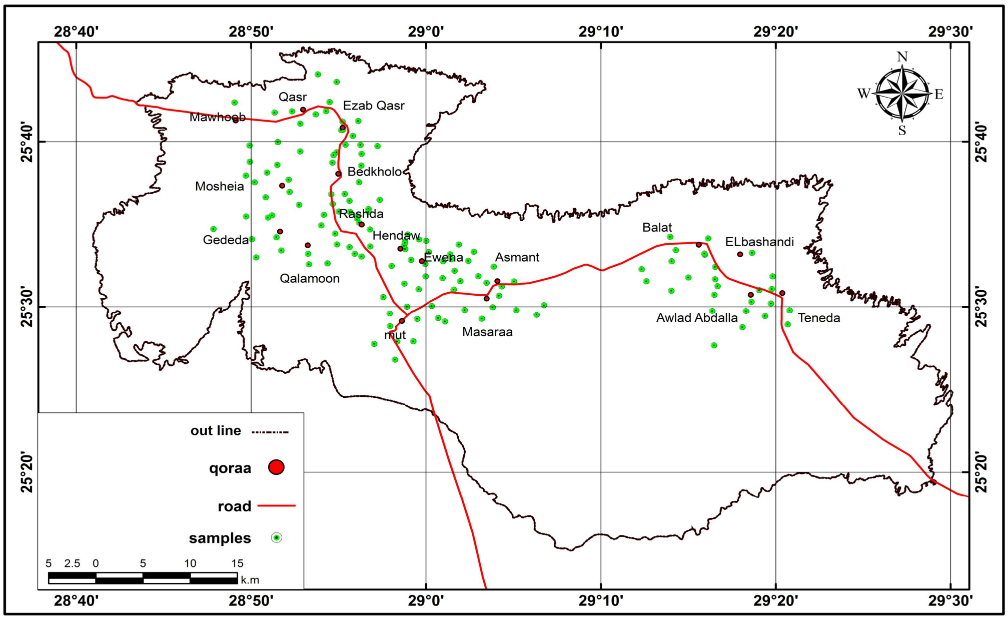


Fig. 1. A location map of groundwater samples

Irrigation water quality parameters such as sodium adsorption ratio (SAR), soluble sodium percentage (SSP), chloro-alkaline indices (CAI) and corrosivity ratio (CR) were calculated using established standard equations as follows:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$$ (U.S. Salinity Laboratory, 1954)

$$SSP = \frac{Na^{+}+K^{+}}{\left(Ca^{+2}+Mg^{+2}+Na^{+}+K^{+}\right)}\times 100$$ (Doneen, 1962)

$$CAI = \frac{Cl^- - (Na^+ + K^+)}{Cl^-}$$ (Todd and Mays, 2003)

$$CR = \frac{\left(\frac{Cl^-}{35.5}\right) + \left(\frac{2 \times SO_4^{-2}}{96}\right)}{\left(\frac{HCO_3^- + CO_3^{-2}}{100}\right)}$$ (Ryner, 1944; Raman, 1985)

All ion concentrations are expressed in meq l^{-1}

Results and Discussion

Salinity hazard

The results indicated that the groundwater of the El-Dakhla oasis has low salinity. There is no a clear trend for water salinity in study area. However, great differences in the water salinity vary from one place to another. The EC_w values range from 164 to 1840 µS cm^{-1}. The lowest values (164 and 169 µS cm^{-1}) were recoded in wells No. 50 and 52 of El Hindaw village, respectively. The highest EC_w values (1840 and 1330 µS cm^{-1}) were found in the groundwaters of wells No. 93 and 11 that were located in El-Kalamon and Balat villages, respectively. Dahab (1998) and Soltan (1999) revealed that the EC of the groundwater extended from 133 to 1260 µS cm^{-1} in El-Dakhla oasis. They also indicated that the water salinity increased westward until it reached its maximum values in Mut, Hindaw, and Rashda with an average value of 3125 µS cm^{-1}. Moreover, Safelnasr, (2007) concluded that the water in the eastern part of the oasis is marked by low salinity, where its average EC_w value was 578 µS cm^{-1} in Tenieda and Balat.

The United States Salinity Laboratory classified the irrigation water quality based on its EC (U.S. Salinity Laboratory, 1954) into four groups. These classes include low salinity (<250 µS cm^{-1}), medium salinity (250-750 µS cm^{-1}), high salinity (750-2250 µS cm^{-1}) and very high salinity (>2250 µS cm^{-1}).

According to U.S. Salinity Laboratory classification (1954), the results indicated that the EC_w of the groundwater in the study area ranges from 164 to 1840 µS cm^{-1} (Table, 1). Moreover, 42.36% of the collected groundwater samples were recoded in the first class of the low salinity hazard. Meanwhile, 51.39% of these samples showed a medium salinity hazard. However, 6.25% of the samples had a high salinity hazard. It means that 42.36% of these groundwaters can be used in irrigation for most crops grown on most soils without developing soil salinity problems. Under normal irrigation practices some leaching is required, except in soils of extremely low permeability. In addition, 51.39% of irrigation water can be used if a moderate amount of water is applied for salt leaching. Plants with this water class can be grown in most cases without special practices for salinity control. The remaining water samples (6.25%) cannot be used on soils with restricted drainage due to their high salinity content. Special management for salinity control may be required and plants with good salt tolerance should be selected such as barley, wheat, sorghum, sugar beet, date palm etc.

Table 1. Classification of groundwater samples of El-Dakhla oasis based on their salinity (ECw) according toUSDA Salinity Laboratory (1954)

EC (µS cm^{-1}) at 25° C	Salinity Class	Water samples well No.	Remarks
<250	Low (C_1) or excellent for use	2,8,12,13,14,15,16,17,19,20,21, 22,25,27,28,29,30,32,34,35,37, 38,41,42,45,47,48,49,50,52,53, 57,59,61,62,65,68,72,74,82,84, 87,95,96,98,99,107,108,110,112, 114,116,120,122,123,124,136,137, 140,141,143	42.36% of the total samples
250-750	Medium (C_2) or good for use	1,4,5,6,10,18,23,24,26,36,39,40, 43,44,46,51,54,55,56,58,60,63,64, 66,67,69,70,71,73,75,76,78,79,80, 83,85,86,88,89,90,91,92,94,97,100, 101,102,103,104,105,106,109,111, 113,115,117,118,119,121,125, 126,127,128,129,130,131,132, 133,134,135,138,139,142,144	51.39% of the total samples
750-2250	High (C_3) or permissible for use	3,7,9,11,31,33,77,81,93	6.25% of the total samples

The lowest EC_w values (100-300 µS cm^{-1}) were recoded in the middle and northern parts of El-Dakhla oasis (Fig., 2). The EC_w of groundwater ranged from 300 to 600 µS cm^{-1} in most part of oasis, especially in the eastern, western and southern parts of oasis. Meanwhile, the EC_w values varied from 600 to 900 µS cm^{-1} at the southern boundary, except some areas that are characterized by EC_w values (900 µS cm^{-1}).

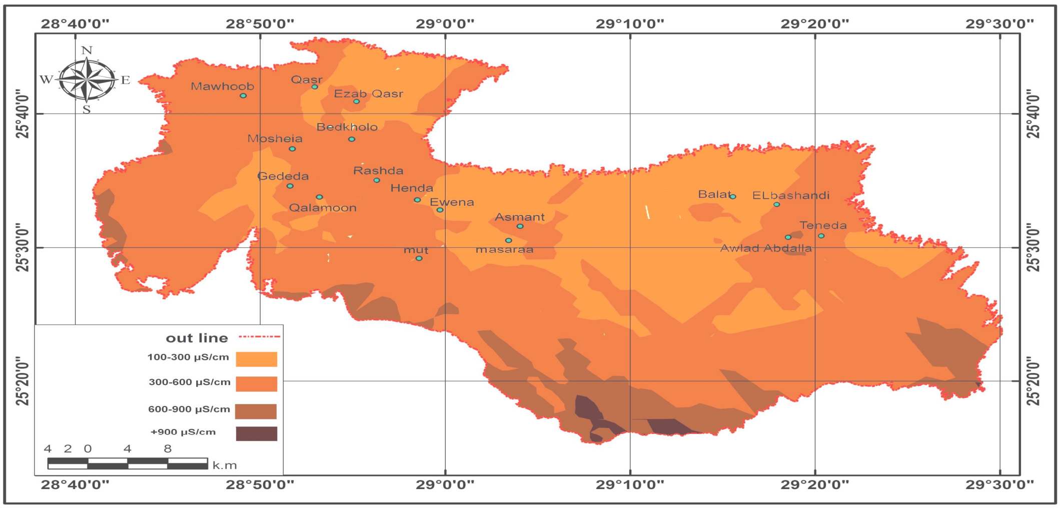


Fig. 2. Distribution of groundwater electrical conductivity (EC_w) in El-Dakhla oasis

Sodium hazard

High concentrations of sodium in irrigation water have harmful effects on plants and soils. On plants, the excess sodium can cause toxicity problems for some crops, especially when sprinkler irrigation is applied (Maas, 1986; Ayers and Westcot, 1994). On soils, irrigation water with high sodicity hazard implies the replacement of the exchangeable calcium and magnesium of the soil by sodium through the cation exchange process when it is used for irrigation eventually damaging soil permeability and structure (Matthess, 1982; Gupta, 2005; Nata *et al.*, 2009; Attibu, 2014). The sodium adsorption ratio (SAR) values of the groundwater samples in the study area varied from 0.26 to 5.06. The minimum and maximum SAR values were recoded in well Nos. 50 and 11, respectively in El Hindaw and El-Kalamon villages (Table, 2). The low SAR value results from the dominant levels of calcium in the water samples.

According to USDA Salinity Laboratory (1954) the irrigation water quality was classified based on SAR value into four classes. They include class I (SAR<10), class II (SAR 10-18), class III (SAR 18-26) and class IV (SAR>26). Therefore, according to this classification, the SAR values for studied water samples are within the first class. This means that these waters can be used for irrigation without significant harmful effects of the exchangeable sodium on the soils. Moreover, the results indicate that the SAR values of groundwater samples increase to wards the east reaching maximum values in the south eastern part (Fig., 3). The SAR value of the studied groundwater samples is classified in to 7 classes including 0.4-0.6, 0.6-0.8, 0.8-1.0, 1.0-1.2, 1.2-1.4, 1.4-2 and 2 (Fig., 4). The SAR class of 1.0-1.2 occupies a large area of the oasis followed by 0.8-1.0 and 0.6-0.8 classes.

Meanwhile, Ayers and Westcot (1994) and Bara (2008) classified the irrigation water quality based on the SAR value into three classes which include class I (SAR<3), class II (SAR 3-9) and class III (SAR>9). As it is shown in Table (2), most of groundwater samples have SAR values that are less than 3 including no restriction in using this water on soils and plants. The groundwaters of wells Nos. 7, 9, 11, 93 and 109, which have SAR values more than 3 can be also used in irrigation for most plants without problems according to this classification system. In addition, this classification suggested that the irrigation water of a SAR value ranging from 6 to 9 would exhibit soil permeability problem. For values that are greater than 9 a severe problem will be displayed on most plants that use this water. According to the EC_w and SAR values, Abdel Ghaffar *et al.* (2013) reported that most of the groundwater samples of these wells had high and moderate suitability classes for irrigation uses. However, few samples showed marginally suitable class due to their relatively shallow wells which had an increased groundwater abstraction. Recently, Ismael (2015) indicated that the lowest SAR value of the groundwater in El-Dakhla oasis was 7.20.

Table 2. Sodium adsorption ratio (SAR) values of the studied groundwater samples.

Well No	SAR	Well No	SAR	Well No	SAR	Well No	SAR
1	0.61	37	0.64	73	1.98	109	3.81
2	0.54	38	0.76	74	1.12	110	0.32
3	2.36	39	1.57	75	1.47	111	1.03
4	1.46	40	1.38	76	1.36	112	0.54
5	1.01	41	0.91	77	1.59	113	0.91
6	1.21	42	0.40	78	0.86	114	0.96
7	3.35	43	0.95	79	1.62	115	1.38
8	0.86	44	1.38	80	0.52	116	1.16
9	4.26	45	0.43	81	0.31	117	1.28
10	0.96	46	1.03	82	0.46	118	1.58
11	5.06	47	1.07	83	0.82	119	1.23
12	0.55	48	0.37	84	0.71	120	0.48
13	0.59	49	0.77	85	1.70	121	1.08
14	0.63	50	0.26	86	1.05	122	1.08
15	0.81	51	1.01	87	0.42	123	1.31
16	0.49	52	0.73	88	0.92	124	0.70
17	0.51	53	0.72	89	1.44	125	0.99
18	0.63	54	1.06	90	1.98	126	0.98
19	0.70	55	1.34	91	1.40	127	0.81
20	0.72	56	1.31	92	0.75	128	2.15
21	0.96	57	0.67	93	3.34	129	1.03
22	1.31	58	1.29	94	1.00	130	1.52
23	1.19	59	0.73	95	0.41	131	1.52
24	1.28	60	0.99	96	0.28	132	0.64
25	0.94	61	0.61	97	1.11	133	0.77
26	1.28	62	0.69	98	0.90	134	0.71
27	0.92	63	1.42	99	0.62	135	0.84
28	0.88	64	1.12	100	1.04	136	0.49
29	0.74	65	1.38	101	0.78	137	0.57
30	0.50	66	1.24	102	2.35	138	0.64
31	2.57	67	1.28	103	1.03	139	0.81
32	0.80	68	0.50	104	0.81	140	0.55
33	1.42	69	0.38	105	0.95	141	0.60
34	0.67	70	2.80	106	1.77	142	0.86
35	0.60	71	1.36	107	0.43	143	0.66
36	0.92	72	0.68	108	0.49	144	0.59

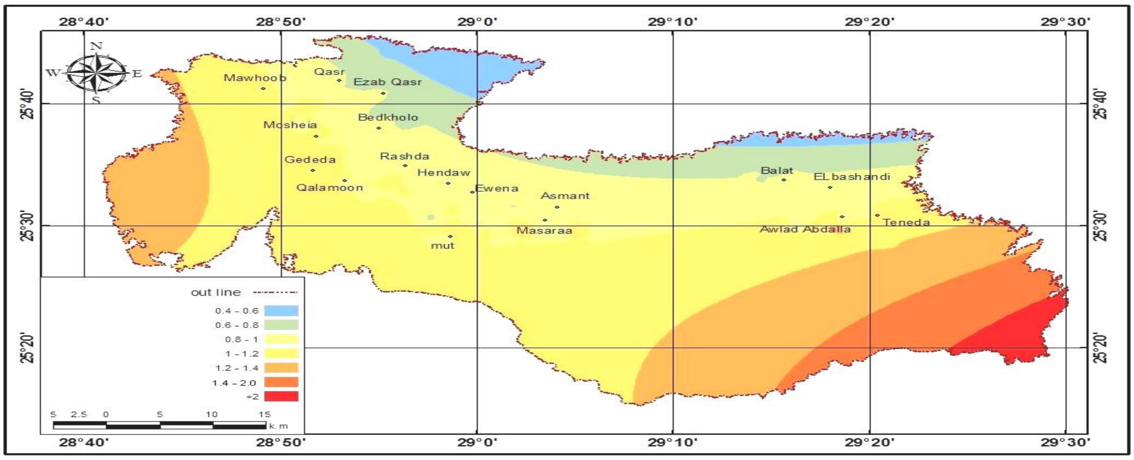


Fig. 3. Distribution of the sodium adsorption ratio (SAR) of the groundwater in El-Dakhla oasis

The soluble sodium percentage (SSP) is another sodium hazard indicator of the irrigation water. It is computed to evaluate the suitability of water quality for irrigation (Wilcox 1948). In the studied water samples, it ranges from 29.59 to 66.15%. Todd (1980) grouped the groundwater based on its soluble sodium percentage into five classes (Table, 3). About 23.61, 72.22 and 4.17% of the investigated groundwater samples have good, permissible and doubtful irrigation water qualities, respectively. It means that 95.83% of the studied water samples are suitable for irrigation purposes, while 4.17% of these samples are doubtful to be unsuitable for irrigation.

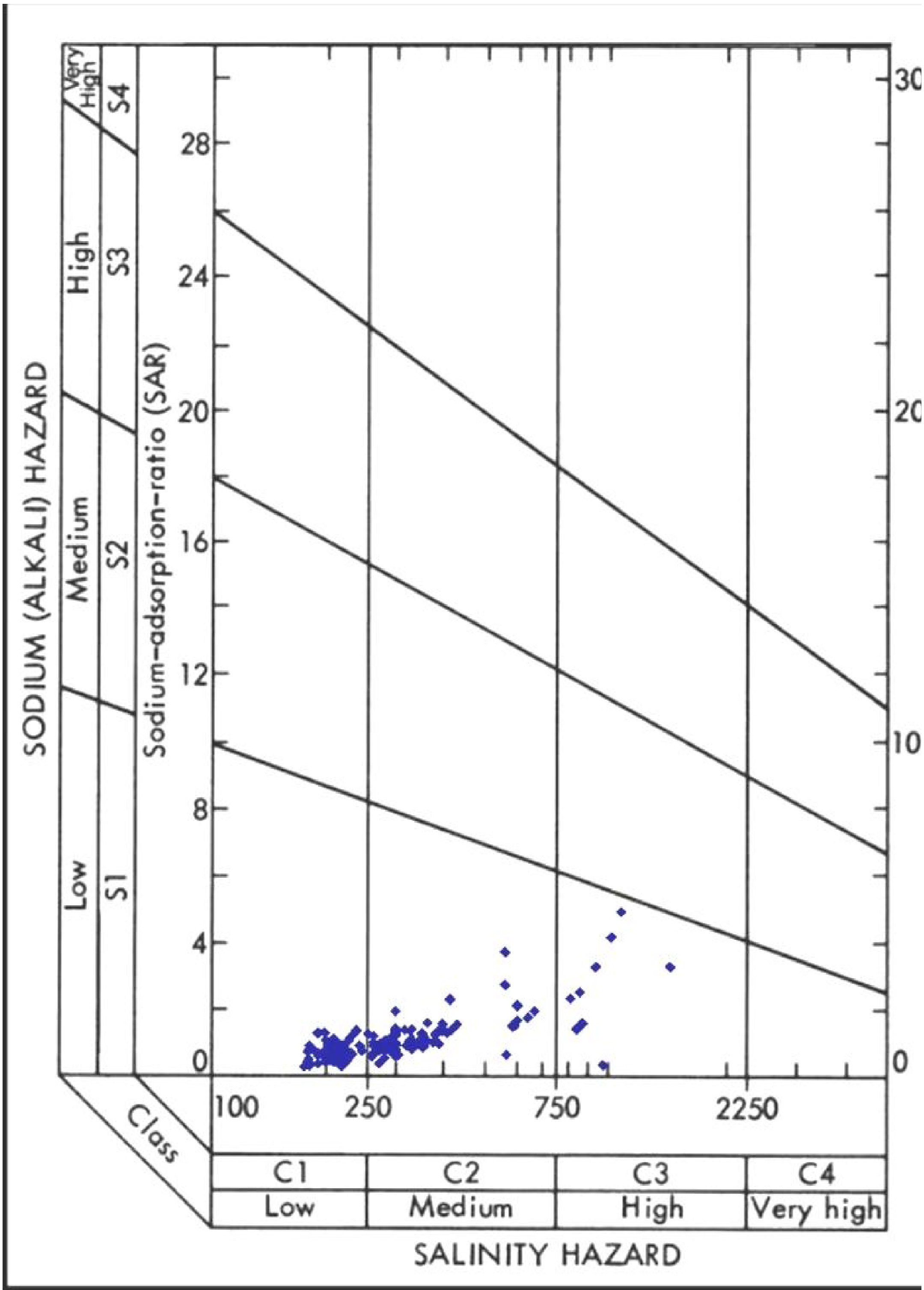
Table 3. Classification of the groundwater samples quality of El-Dakhla oasis based on the soluble sodium percentage (SSP).

Soluble Na (%)	Salinity Class	Water sample No.	Remarks
20-40	Good	1,5,13,42,46,51,52,54,64,78,82,83,86,96,99,101,104,108,111 112,119,120,124,125,126,127,133,134,135,138,139,140,142,144	23.67 of the total samples
40-60	Permissible	2,3,4,6,7,8,9,10,12,14,15,16,17,19,20,21,23,24,25,26,27,28,29, 31,32,33,34,35,36,37,38,39,40,41,43,44,45,47,48,49,50,53,55, 57,58,58,60,61,62,63,65,66,67,69,71,72,73,75,77,79,80,84,85,88, 89,90,91,92,93,95,97,98,103,105,106,107,110,113,114,115,116, 117,118,121,122,128,129,130,131,132,136,137,141,143	72.22 of the total samples
60-80	Doubtful	22,11,102,123,70,109	4.17% of the total samples

The EC_w and SAR diagram of the studied water samples

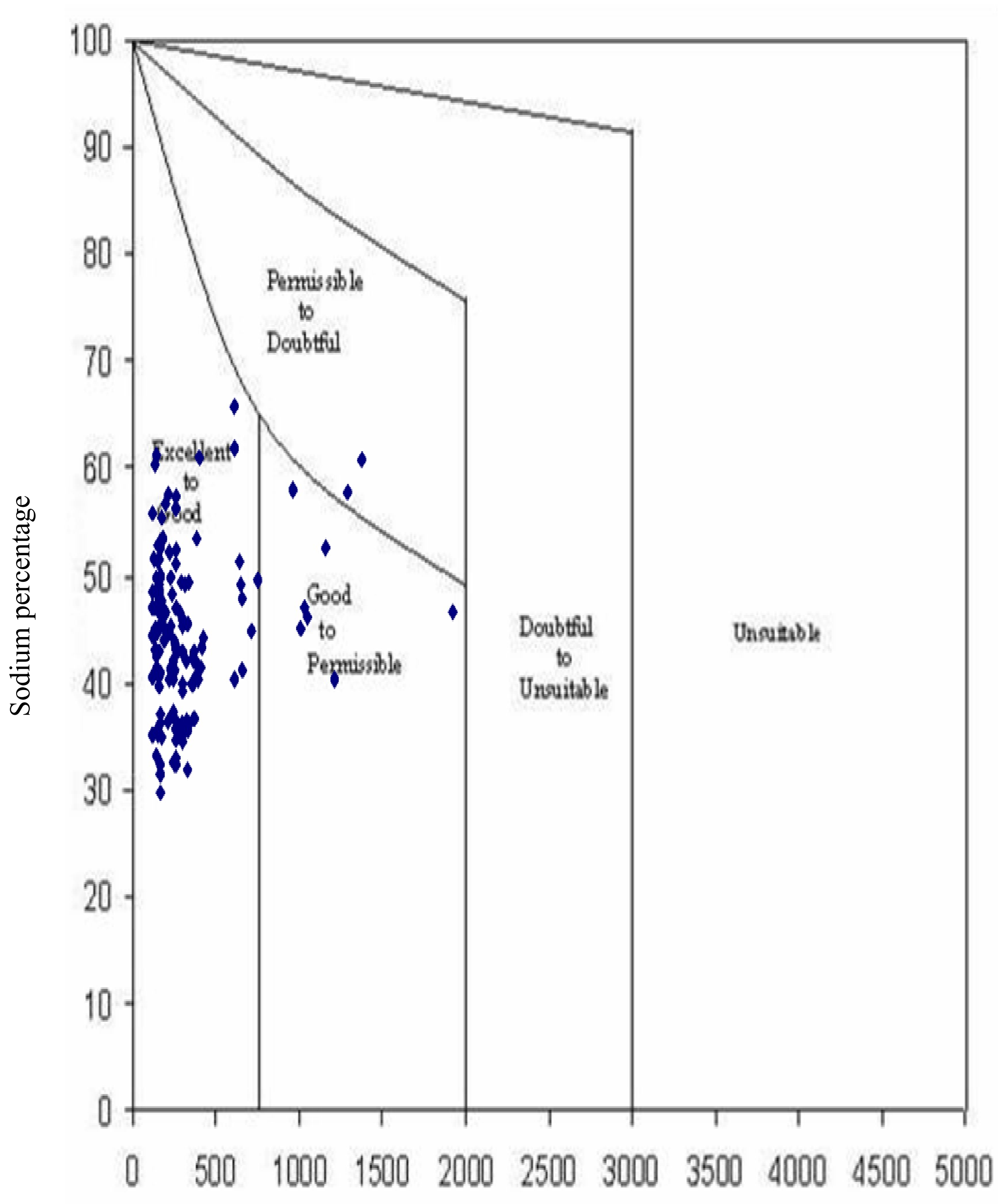
The EC_w and SAR values of the investigated groundwater samples were plotted on the widely used diagram suggested by the U.S. Salinity Laboratory (1954) to evaluate their suitability for irrigation purposes (Fig., 5). In this diagram, the water samples of the study area are classified into C_1, C_2 and C_3 types on the basis of salinity hazard and S1 type on the basis of sodium hazard. It is clear that 63 water samples (43.75%) fall under C_1S_1 category suggesting low sodium and low salinity hazards conditions. Moreover, 72 samples (50%) occurs in the C_2S_1 category indicating low sodium and medium salinity hazards and only 9 samples (6.25%) take place in the C_3S_1 type suggesting low sodium and high salinity hazards. Al Temamy *et al.* (2010) reported that based on the relationship between EC_w and SAR, their groundwater samples of El-Dakhla oasis were located in C_3-S_1 class suitable for irrigating most plants, except for those that are sensitive to salts. They also showed that the groundwater of Taref sandstone had a high quality and can be used for the different development objectives in El-Dakhla Oasis.

The suitability of the investigated groundwater samples for irrigation use was identified according Wilcox diagram (Fig., 5), based on the EC_w and sodium percentage (Willcox, 1955). About 93.75% of these water samples had excellent to good quality for irrigation and 4.86% exhibited a good to permissible. Meanwhile, the rest samples (1.39%) showed a low quality (permissible to doubtful).



Electrical conductivity (µS cm^{-1})

Fig. 4. US salinity lab classification of the groundwater samples of El-Dakhla oasis based on their EC_w and SAR values.



Electrical conductivity (µS cm^{-1})

Fig. 5. The Wilcox diagram of the investigated groundwater samples based on their EC_w and SAR values.

Chloro-alkaline Index (CAI)

Chloro-alkaline index (CAI) is an indicator of the ion-exchange between the groundwater and its host environment (Aghazadeh and Mogaddam, 2010). It is obvious that 49.31% of samples gave positive values of CAI. Meanwhile, the remaining samples (50.69%) displayed negative values. The negative CAI values mean that releasing Na^+ and K^+ ions release from the host rock to the groundwater. On the other hand, the positive CAI values point out that there is a reverse ion exchange between water and the host rock.

Table 4. Chloro-alkaline indices (CAI) and corrosivity ratio (CR) values of the groundwater samples of El-Dakhla oasis.

Well No	CAI	CR	Well No	CAI	CR	Well No	CAI	CR	Well No	CAI	CR
1	0.22	0.14	37	-0.36	0.26	73	0.24	0.47	109	-0.13	0.54
2	-0.68	0.16	38	-0.57	0.18	74	0.16	0.32	110	-0.19	0.13
3	-0.02	1.16	39	0.05	0.90	75	0.01	0.43	111	0.37	0.58
4	-0.48	0.17	40	0.25	0.53	76	0.13	0.39	112	0.19	0.15
5	0.12	0.43	41	-0.42	0.21	77	-0.23	0.20	113	-0.06	0.28
6	-0.19	0.34	42	-0.10	0.16	78	0.27	0.24	114	0.25	0.40
7	0.26	0.77	43	0.03	0.41	79	-0.17	0.43	115	-0.05	0.40
8	0.01	0.18	44	-0.04	0.26	80	0.02	0.24	116	-0.10	0.24
9	0.08	1.92	45	-0.04	0.21	81	-0.08	0.13	117	0.11	0.56
10	-0.27	0.36	46	0.34	0.45	82	0.25	0.15	118	-0.06	0.24
11	-0.19	2.00	47	-0.71	0.20	83	0.37	0.45	119	0.16	0.59
12	-0.14	0.19	48	-0.02	0.16	84	-0.42	0.21	120	0.00	0.15
13	0.22	0.11	49	-0.20	0.29	85	-0.12	0.27	121	-0.12	0.29
14	-0.29	0.17	50	-0.02	0.17	86	0.26	0.50	122	0.00	0.28
15	0.13	0.23	51	0.38	0.50	87	-0.03	0.16	123	-0.69	0.15
16	-0.24	0.14	52	0.13	0.40	88	0.22	0.40	124	-0.01	0.14
17	-0.71	0.11	53	-0.07	0.23	89	0.14	0.56	125	0.09	0.15
18	0.78	0.95	54	0.36	0.56	90	-0.13	0.33	126	0.16	0.50
19	0.12	0.27	55	0.04	0.44	91	-0.58	0.29	127	0.05	0.33
20	-0.25	0.15	56	0.09	0.63	92	-0.18	0.34	128	0.08	0.28
21	0.16	1.67	57	-0.27	0.20	93	-0.54	0.29	129	-0.37	0.21
22	0.12	0.95	58	0.15	0.55	94	0.00	0.36	130	-0.16	0.17
23	0.18	0.17	59	-0.20	0.16	95	-0.18	0.21	131	-0.19	0.16
24	0.07	0.32	60	-0.20	0.18	96	0.00	0.18	132	-0.06	0.21
25	-0.41	0.12	61	-0.09	0.20	97	0.02	0.34	133	0.31	0.35
26	0.00	0.31	62	-0.38	0.23	98	-0.12	0.33	134	0.36	0.36
27	0.01	0.14	63	0.22	0.51	99	0.14	0.21	135	0.32	0.40
28	0.03	0.54	64	0.38	0.50	100	0.01	0.36	136	-0.16	0.19
29	-0.31	0.13	65	-0.03	0.32	101	-0.05	0.32	137	-0.35	0.15
30	0.22	0.17	66	0.02	0.43	102	-0.35	0.33	138	0.11	0.17
31	0.27	0.54	67	0.15	0.36	103	0.09	0.37	139	-0.10	0.28
32	-0.24	0.10	68	-0.21	0.13	104	-0.16	0.34	140	0.20	0.16
33	-0.20	0.14	69	-0.28	0.14	105	0.04	0.21	141	-0.48	0.26
34	-0.33	0.14	70	-1.00	0.13	106	-0.12	0.33	142	0.25	0.26
35	-0.20	0.14	71	0.11	0.57	107	-0.43	0.21	143	0.06	0.29
36	-0.29	0.27	72	-0.25	0.20	108	0.20	0.15	144	0.16	0.19

Corrosivity Ratio (CR)

The groundwater with corrosivity ratio (CR) of < 1 is considered to be safe for the water transport in any type of pipes, whereas that of CR value of >1 indicates a corrosive nature and hence it does not transport through metal pipes (Ryner, 1944; Raman, 1985). The calculated CR values of the investigated groundwater samples are present in Table (4). So, 140 samples (97.22%) are considered safe whereas 4 samples (2.78%) are corrosive in nature and need non-corrosive pipes for groundwater transporting and lifting groundwater.

Conclusion

The chemical analysis and the calculated irrigation water quality indices show that the groundwater in the studied area is generally safe and suitable for long term irrigation uses. Overall, 93.75% of the investigated water samples have excellent to good quality for irrigation and 4.86% display a good to permissible class (4.86%). Meanwhile the rest samples (1.39%) show low quality (permissible to doubtful).

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حالة ملحية المياه الجوفية في واحة الداخلة بالوادي الجديد، مصر

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الملخص

أجريت هذه الدراسة في واحة الداخلة بالوادي الجديد، مصر وتهدف إلى تقييم المياه الجوفية في واحة الداخلة وتحديد مدى ملائمتها للري. حيث تم جمع ١٤٤ عينة من آبار المياه الجوفية المنتشرة بالمنطقة.

أوضحت النتائج المتحصل عليها أن ٦٣ عينة مياه بما يعادل ٤٣,٧٥% من العدد الكلي للعينات تعتبر مياه قليلة الأملاح وقليلة الصوديوم وتقع في القسم (C_1S_1). في حين ان ٧٢ عينة (٥٠%) تقع في القسم C_2S_1 أما باقي العينات وهى تمثل ٦,٢٥% تقع في C_3S_1 على مخطط معمل الملوحة الأمريكي.

كما أظهرت النتائج أن ٤٩,٣١% من تلك العينات ذات قيما موجبة لمعامل الكلوريد والقلوية (CAI) مما يدل على انتقال كل من ايونات الصوديوم والبوتاسيوم من المياه إلى الصخور الحاملة للماء. في حين أن ٥٠,٦٩% من العينات أعطت قيما سالبة. وهذا يدل على انطلاق كل من ايونات الصوديوم والبوتاسيوم من الصخور إلى المياه.

اظهر معامل التآكل أن ١٤٠ عينة يمكن استخدامها بأمان مع المواسير والمواد المعدنية الناقلة للماء، في حين أن ٤ عينات فقط ربما قد تؤدي لحدوث تآكل في المواد المعدنية الناقلة للماء لذا يفضل استخدام مواد غير قابلة للتآكل مع تلك المياه.