18

Egypt. J. Soil Sci. **Vol. 62,** No. 3, pp. 267 - 291 (2022)

Egyptian Journal of Soil Science

http://ejss.journals.ekb.eg/

Classification Approaches to Assess Groundwater Quality in Wadi El-Natron, Egypt

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Environmental management of the groundwater is based on three axes; (1) safe water use that grantee the equilibrium between water consummation and refeed of well groundwater (2) elaboration of chemical and magnetic water to improve water quality, and (3) characterization and classification of water types to achieve the most efficient water use. The third axe of environmental management groundwater is the core of the current research that classified the groundwater (Wadi El-Natron, Egypt) by multiple approaches (1) water quality indices (2) Wilcox and Riverside plotting classification, and (3) groundwater hydrochemical classification. EC index classification, of wadi El-Natron groundwater, indicated that 90.90% of shallow wells samples (SW) were good and permissible class, 90.90 % of moderate deep wells samples (MDW) and 68.75 % of deep wells samples (DW) located in permissible salinity class. The averaged pH values of the groundwater related to their moderate alkalinity. The assessed grade quality of water irrigation varied according to the used sodicity indices. The averaged values of sodium percentage (SP), sodium adsorption ratio (SAR), and permeability index (PI), residual sodium carbonate (RSC) designated the majority of wadi El-Natron groundwater as permissible category. Contrary, most of studied water samples located in not recommended class according to Kelly's ratio (KR) and chloro-alkaline index (CAI1). All studied groundwater samples are situated in the acceptable class according to magnesium hazard (MH) and total hardness (TH). Plotting of EC-Na% analytical data on Wilcox diagram indicated that generally, groundwater of (SW) and (DW) had higher quality waters than (MDW).

EC- Na% Wilcox Diagram: Plotting of EC- Na% analytical data on Wilcox diagram indicated that waters of the shallow wells were distributed excellent (45.46%), good (18.2%), permissible (27.3%) and doubtful (9.09%) water quality. According to EC- SAR Riverside diagram, groundwater in the study area falls within the medium EC-low SAR, high EC–low SAR, and high EC–medium SAR. For groundwater wells, the hydrogeochemical classification indicated the abundance of Na and K cationic facies, while the waters of (MDW) and (DW) were characterized by high contribution of strong acidic anionic (SO_4^{2-}). Generally, NaCl water type was dominant in wadi El-Natron groundwater.

Keywords: Groundwater; Sodicity Indices; Magnesium Hazard; Total Hardness; EC-Na% Wilcox and Riverside Diagrams; Hydrogeochemical Classification.

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Received: 21/7/2022; Accepted: 30/8/2022
DOI: 10.21608/EJSS.2022.151744.1520

Introduction

Egypt is facing an annual water deficit of around seven billion cubic meters and the country could suffer deeply from water scarcity by 2025, so, water availability in Egypt puts it below the World Bank's water scarcity limit of renewable water available (1000 m³/capita/year) (FAOSTAT 2013). Water scarcity is worldwide problem, where more than 40% of the world's population is suffering from water shortages and a serious deterioration of water quality. This problem worsens the economics and social development as a well as human health. Environmental management groundwater could be the solution of the worldwide problem of water scarcity (Nepomilueva 2017; Rosa et al. 2018; D'Odorico et al. 2020) whereas it makes up about one-third of the world's total freshwater and it can used in drinking and agriculture purposes (Giordano 2009). This requires water characterization and classification for achieving the most proficient water use.

Many global researchers focused on study of groundwater quality for instance: Kumar et al. (2014) and Singh et al. (2015) plotted Piper diagrams to assess the hydrochemistry and groundwater quality in the coastal area of South Chennai and area of Tripura, India, correspondingly. In Eastern Niger Delta (Nigeria) six hydrochemical facies: Na-Cl, Ca-Mg-HCO_3, Na-Ca-SO_4, Ca-Mg-Cl, Na-Fe-Cl and Na-Fe-Cl-NO_3 were located on the area (Amadi et al. 2014). Singh et al. (2015) found that the analytical data, of Agartala (Tripura State, India), showed that Na-K-HCO_3 and Ca^{2+}, Mg^{2+}, HCO_3^- are the dominant anionic and cationic facies. Mester et al. (2017) studied the changes of groundwater quality following the establishment of a sewage network in Hungary using contamination index. Feng et al. (2020) showed cations in the groundwater are mainly Na^+, Ca^{2+}, and Mg^{2+}, whereas the anions are mainly HCO_3^-, SO_4^{2-}, and Cl^-. Water-rock interaction and cation exchange were identified as the main factors affecting hydrogeochemical properties (Baojixia area, China).

Water quality is a vital issue in Egypt, so, numerous studies were carried out to evaluate the water quality on the local scale, for instance, Rashed (2014) assessed water quality of irrigation and drainage waters in Southern part of El-Kalubia, and the results found that drainage water in general could be suitable for irrigation by mixing with canal water. Abdel-Fattah and Helmy (2015) evaluated water quality and suitability for irrigation purpose in the drains of Bahr El-Baqar, Bilbies and El-Qalyubia, and their results indicated that water of the three drains are suitable for most crops. Tantawy et al. (2015) evaluated the groundwater quality and Its suitability for agriculture use in Minufiya governorate, and their results showed that groundwater is chemically suitable for agricultural uses in the study area. Hedia(2015) assessed drainage water quality in Siwa oasis and its suitability for reuse in agricultural irrigation in the oasis. Abdelaty (2018) used high resolution images for monitoring the Nile water quality for agriculture purposes. Abdelaziz et al (2020) used Principal Component Analysis for create groundwater quality index in Wadi El-Natrun.

The study's target is to assess groundwater suitability for irrigation by elaborating multiple approaches; indexing, plotting and hydrogeochemical classifications. In addition, some other aims were used such as: 1.Compare between the five indices of soil sodicity: (a) Sodium percentage (SP), (b) Sodium absorption ration (SAR), (c) Residual sodium carbonate, (d) permeability index, and (e) Kelly's ratio (KR)

2.Assess the contrast (similarity and dissimilarity) between the outputs of both of EC-Na % (Wilcox diagram) (Wilcox 1948) and EC-SAR (Riverside diagram) (Richards 1954)

3.Predicate water potential to change soils to sodic ones by determining the dominant exchange reaction between soil solution and exchangeable cations, that was fixed by chloroalkaline index (CAI1)

Materials and Methods

Area of Studied Groundwater Wells:

The area of studied groundwater wells is located in Wadi El-Natron depression, Egypt. It is located on the north-eastern part of the Egyptian Western Desert between latitudes of 30° 14' - 30° 37' North and longitudes of 29° 56' - 30° 34' East (Figure 1). It is roughly halfway through the desert road linking Cairo and Alexandria; 110 km northwest of Cairo and 90 km south of Alexandria (Mashaal et al. 2020).

Water Sampling and Analysis:

Thirty-eight groundwater samples were collected from the wells (sample/well) of Wadi El-Natron, Egypt (Figure 1 and Table 1) to (1) characterize the water chemically (2) elaborate a chemical indexing for plotting classifications of the groundwater and (3) run hydrogeochemical classifications (determination water facies and types). The water samples were collected in polyethylene bottles of 250 mL capacity, for chemically analyze according to (Estefan et al. 2013). The studied groundwater wells were categorized, basing on the groundwater depth (m), into three categories: shallow ≥ 100 (SW), moderately deep (≥101 – ≤ 200) (MDW) and deep (DW) wells ≥ 200 m (DW) (Table 1). The primary statistics of analytical data were graphically described by box-Whisker plot (Flowingdata 2008).

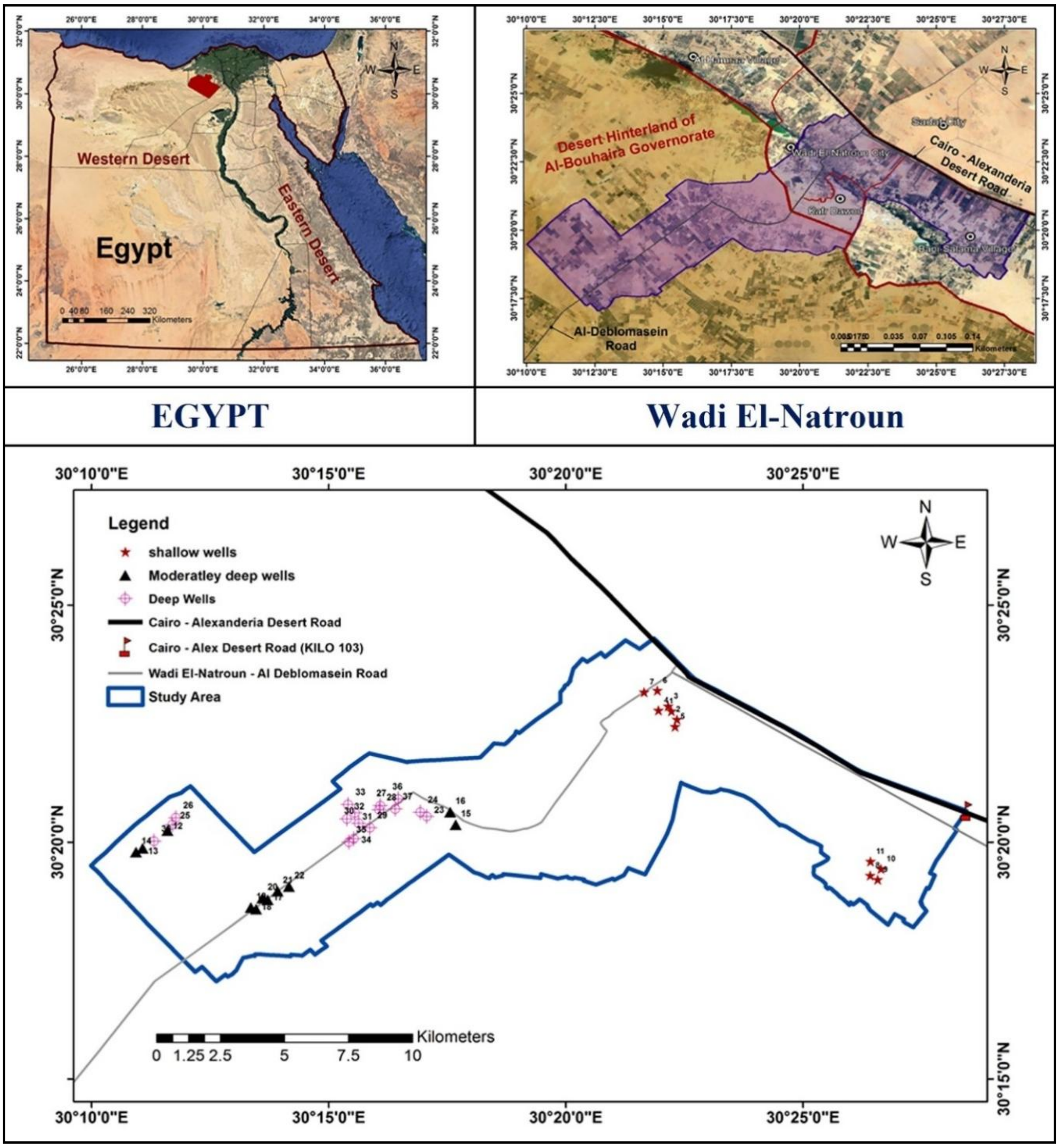

Fig. 1. Location of studied groundwater wells, Wadi El- El-Natron (Egypt)

TABLE 1. Categories of groundwater well based in their depths

Well No.	Well Depth (m)	UTM Coordinates E	UTM Coordinates N	Depth Categories	Well No.	Well Depth (m)	UTM Coordinates E	UTM Coordinates N	Depth Categories
1	85	247209	3363952	Shallow Wells	23	220	229707	229707	Deep Wells
2	90	246879	3363795		24	240	229320	229320	
3	95	247315	3363760		25	240	229092	229092	
4	100	247494	3363427		26	240	230354	230354	
5	100	247420	3363151		27	250	230466	230466	
6	100	246856	3364574		28	250	238949	238949	
7	100	246412	3364516		29	250	233500	233500	
8	100	239919	3359494		30	250	233097	233097	
9	100	239744	3359992		31	250	232922	232922	
10	100	238738	3360010		32	250	233320	233320	
11	100	238005	3360545		33	250	233839	233839	
12	150	237895	3360158	Moderately Deep Wells	34	250	234228	234228	
13	170	237388	3360300		35	250	253882	253882	
14	170	237348	3360143		36	270	254133	254133	
15	180	237018	3359453		37	270	254257	254257	
16	180	236644	3359625		38	285	253904	253904	
17	180	236527	3360038						
18	180	236251	3359817						
19	180	236304	3360372						
20	180	236464	236464						
21	180	236297	236297						
22	180	230174	230174						

Measurements of the guidelines (Indices) of Water Quality

Indices of the groundwater quality parameterswere measured; EC, pH, Sodicity hazards (sodium percentage (SP) (Todd 1995), sodium absorption ration (SAR) (Raghunath 1987), residual sodium carbonate (RSC) (Eaton 1950), permeability index (PI) (Doneen 1964), Kelly's ratio (KR) (Kelly 1963), Chloroalkalinity index (CAI1) (Schoeller 1977), magnesium hazard (MH) (Raghunath 1987), and total hardness (TH) (Todd 1980; Rawat 2018) (Table 2). The results were interpreted by basing on categoriztion thresholds of groundwater quality (Y ıld ı z and Karaku ş 2020) (Table 3).

Plotting Groundwater Classification (Plotting Assessment of Groundwater Suitability for Irrigation)

This classification was elaborated by logiciel (software) d'hydrochimie, (Simler and vignon 2020) to draw EC- Na% - Wilcox Diagram (Wilcox 1948), and EC-SAR- Riverside Diagram (Richards 1954). The output plots were interpreted in the light of information of Zaman et al. (2018).

Elaboration of Hydrogeochemical Classifications of the Groundwater (Determination Water Facies and Types):

Hydrochemical cationic and ionic facies, and water type of groundwater of shallow, moderately, and deep wells were determined by Piper's Trilinear diagram that was drawn by GW Software (USGS 2000). The dominance of certain cations and anions in water located on the two triangles, the water samples to identify, the hydrochemical facies (cationic and ionic facies) (Tank and Chandel 2010). The hydrochemical facies located on to determine the dominant, the groundwater type. The interpretation of resulted diagrams was based on the standard diagram (Hatarilabs 2018).

Results

The current research classified the groundwater (Wadi El-Natron) using several approaches (I) indexing classification based on water quality guidelines (II) Wilcox and Wilcox plotting classification, and (III) groundwater hydrochemical characterization to determine water facies and types. All approaches attempted to assess groundwater suitability for irrigation.

(I) Indexing Groundwater Classification

It is not quite enough to base only on EC to evaluate water suitability for irrigation. Subsequently other parameters were considered to have a clear sight for chose the suitable crops water irrigation. Then, the analytical values of the groundwater samples were input to excel sheet to calculate the water quality referenced indices; EC and pH, sodicity hazards (SP, SAR, RSC, PI, KR, and CAI1 (Schoeller 1977)), magnesium hazard, and total hardness, (Todd 1980; Rawat et al. 2018) (Table 4).

1- EC – Indexing Groundwater Classification: The results found that salinity and alkalinity of groundwater in the shallow wells (SW) were low, and it suitable for long-term irrigation (Table 5). EC index mainly distributed studied water into two classes: good (0.25 – 0.75 dS/m) and permissible (0.75 – 2.00 dS/m). Also, the results indicated that 45.46 %, 90.90 %, and 68.75 % of shallow, moderately deep, and deep wells, respectively, located in permissible salinity class (0.75 – 2.00 dS/m) (Table 6). Groundwater salinity and alkalinity of moderately deep and deep wells ranged from moderate to high, consequently it is not recommended for long-term irrigation.

2- pH - Indexing Groundwater Classification: The averaged pH values of the groundwater samples were 7.78, 7.67, and 7.79 for (SW), (MDW) and (DW), respectively, So, the water is considered as a moderate alkalinity. pH values were generally, moderately fluctuated to reflect the medium internal variation of Std dev values; with 0.35, 0.29, and 0.22 for (SW), (MDW) and (DW), respectively, (Table 5). Some water samples had higher pH 8; 8 – 9 -10 (SW) 21 (MDW), and 31 – 34 -35 (DW) (Table 4). These alkaline waters may contain high concentrations of bicarbonate to precipitate calcium and magnesium from the soil (Hussein 2018).

3- Sodicity Hazards-Indexing Groundwater Classification

Sodicity of irrigation water alters the chemical and physical soil properties by (a) degrading soil structure and reducing water permeability and aeration, and (b) causing K+ and Ca2+ deficiencies that may arise if the soil or irrigation water has a high concentration of Na+. Therefore, evaluation of the sodicity hazards of irrigation water is important, Groundwater sodicity hazards was expressed by five parameters: sodium percent (Na %), sodium absorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI), and Kelly's ratio (KR).

- Sodium percentage (SP) (Todd 1995): Na% values ranged between 16.81 - 65.28 (SW), 45.65 - 74.14 (MDW), and 40 - 84.38% (DW) to indicate the high Na % variations (Table 5). The averaged values were 50.03, 62.54 and 62.16 %, consequently for the three wells groups to generally designate Wadi El-Natron as permissible category (40 – 60 Na%) (Table 6). As indicated by Na% categories, two classes were prevailing: permissible and doubtful with percent of 63.63 and 18.18 (shallow wells) 45.45 and 54.55. (moderately deep wells), and 43.75, and 31.25 Na % (deep wells) (Table 6). The unsuitable Na % water that was only marked in the deep wells no. 24, 27, 28 and 29 (Table 6), might lead to detrimental effects on growth of faba bean (Tavakkoli et al. 2010).

TABLE 2. Indices of the groundwater quality

N	Creteria	Formulas
1	**EC (dSm^{-1})**	
2	**Sodium Hazards**	
	a- Sodium percentage (SP) (Todd 1995)	$Na\% = \frac{(Na^+ + K^+) \div (Ca^{+2} + Mg^{+2} + Na^+ + K^+)}{100}$
	b- Sodium absorption ration (SAR) (Raghunath 1987)	$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{+2}+Mg^{+2})}{2}}}$
	c- Residual sodium carbonate (RSC) (Eaton 1950)	$RSC = [(CO_3^{-2} + HCO_3^-) - (Ca^{+2} + Mg^{+2})]$
	d- Permeability index (PI) (Doneen 1964)	$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{+2} + Mg^{+2} + Na^+} * 100\%$
	e- Kelly's ratio (KR) (Kelly 1963)	$KR = \frac{Na^+}{(Ca^{+2} + Mg^{+2})}$
	f- Chloroalkaline indices (CAI1) (Schoeller 1977)	$\mathrm{CAI1} = \frac{\mathrm{Cl^-} - (\mathrm{Na^+} + \mathrm{K^+})}{\mathrm{Cl^-}}$
3	Magnesium hazard (MH) or magnesium adsorption ratio (MAR) (Raghunath 1987)	$\mathrm{MH} = \frac{\mathrm{Mg^{+2}}}{\mathrm{Ca^{+2}} + \mathrm{Mg^{+2}}}\ \mathrm{X}\ 100$
4	Total hardness (TH) eq/L (Todd 1980, Rawat and Singh 2018)	$\mathrm{TH} = 2.5\ \mathrm{X}\ \mathrm{Ca^{+2}} + 1.4\ \mathrm{X}\ \mathrm{Mg^{+2}}$

All ions are expressed in meq/L.

TABLE 3. Thresholds classification creteria of groundwater quality (Yıldız and Karakuş 2020)

Creteria	Thresholds	Water Class	Water Grade	Creteria	Thresholds	Water Class	Water Grade
EC (dSm^{-1})	<0.25	Excellent	1	PI, %	> 75	Suitable	1
	0.25 – 0.75	Good	2		25–75	Good	2
	0.75 – 2.00	Permissible	3		< 25	Unsuitable	3
	2.00 – 3.00	Doubtful	4	KR	KR ≤ 1	Recommended	1
	> 3.00	Unsuitable	5		KR > 1	Not Recommended	2
pH*	5.5 -7.5	Accetable	1	CAI1	+	Recommended	1
	>7.5	Non Accetable	2				
Na, %	< 20	Excellent	1		-	Not Recommended	2
	20 – 40	Good	2	MH	< 50	Recommended	1
	40 – 60	Permissible	3		MH ≥ 50	Not Recommended	2
	60 – 80	Doubtful	4	TH, mgl^{-1}	0–60	Soft	1
					60–120	Moderately Hard	2
	> 80	Unsuitable	5		120–180	Hard	3
SAR	0 – 6	Good	1		> 180	Very Hard	4
	6 – 9	Doubtful	2				
	> 9	Unsuitable	3				
RSC ($meql^{-1}$)	< 1.25	Good	1				
	1.25 – 2.5	Doubtful	2				
	> 2.5	Unsuitable	3				

* (NSW Government 2022)

TABLE 4. Values of water quality indices

Wells No.	EC (dS/m)	pH	Sodicity Hazards					CAI1	MH	TH
			Na %	SAR	RSC	PI	KR			
Shallow Wells (SW)										
1	1.57	7.07	36.31	2.48	-8	44.79	0.56	-0.43	50	33
2	1.32	7.75	62.12	4.97	-3	72.12	1.57	-1.05	20	14.1
3	1.37	7.73	63.5	5.29	-3	73.16	1.67	-0.74	40	15.7
4	1.55	7.78	54.84	4.4	-5	63.32	1.18	-0.89	28.57	20.7
5	1.67	7.63	46.11	3.41	-7	53.29	0.8	-0.93	44.44	28.9
6	0.35	7.99	16.81	0.46	-0.92	56.73	0.19	0.61	34.25	8.9
7	4.42	7.4	52.49	6.96	-18	55.77	1.07	-0.86	47.62	68.5
8	0.57	8.09	56.14	2.75	-0.5	80.51	1.23	-1.13	40	7.85
9	0.51	8.36	51.37	2.22	-0.48	78.47	1	-0.75	40.32	7.8
10	0.64	8.04	45.31	2.05	-1.5	66.41	0.77	-0.93	42.86	11.15
11	0.72	7.69	65.28	4.09	-0.5	84.64	1.83	-2.13	40	7.85
Moderately Deep Wells (DW)										
12	1.5	7.63	66.67	6.11	-3	75.54	1.93	-1	40	15.7
13	0.99	7.91	54.55	3.5	-2.5	68.35	1.17	-1.16	44.44	14.45
14	1.2	7.8	66.67	5.55	-2	78.18	1.96	-1.29	37.5	12.4
15	1.9	7.58	73.68	8.45	-3	80.47	2.67	-0.65	20	14.1
16	9.92	7.31	59.68	12.65	-35	60.89	1.41	-0.13	50	132
17	0.85	7.43	58.82	3.68	-1.5	75.08	1.39	-1	42.86	11.15
18	0.92	7.56	45.65	2.57	-3	60.47	0.81	-0.68	40	15.7
19	0.85	7.98	64.71	4.38	-1	81.03	1.79	-0.83	33.33	9.1
20	1.69	7.15	64.5	6.17	-4	72.52	1.78	-0.36	33.33	18.2
21	1.16	8.01	74.14	6.85	-1	86.08	2.8	-2.44	33.33	9.1
22	0.85	7.98	58.82	3.61	-1.5	74.78	1.36	-1	42.86	11.15
Deep Wells (DW)										
23	1.16	7.86	56.9	4.04	-3	68.52	1.28	-0.65	40	15.7
24	7.68	7.99	84.38	25.86	-8	86.73	5.28	-0.66	33.33	36.4
25	0.77	7.91	48.05	2.5	-2	65.71	0.89	-0.48	37.5	12.4
26	1.76	7.65	43.18	3.25	-8	50.26	0.73	-0.27	50	33
27	1.65	7.49	81.82	10.75	-1	90.19	4.39	-1.25	33.33	9.1
28	1.76	7.81	77.27	9.33	-2	84.97	3.3	-1.27	25	11.6
29	2.2	7.66	77.27	10.58	-3	83.5	3.35	-0.79	40	15.7
30	1.11	7.51	54.95	3.73	-3	67.07	1.18	-0.53	20	14.1
31	1	8.02	40	2.19	-4	53.16	0.63	-0.14	33.33	18.2
32	1.31	7.98	61.83	4.91	-3	71.9	1.55	-2.24	40	15.7
33	0.96	7.96	68.75	5.22	-1	83.11	2.13	-0.89	33.33	9.1
34	0.62	8.03	51.61	2.54	-1	74.05	1.04	-0.6	33.33	9.1
35	0.72	8.04	44.44	2.17	-2	63.43	0.77	-0.28	37.5	12.4
36	2.22	7.45	77.48	10.43	-2	84.79	3.3	-0.72	40	15.7
37	1.77	7.46	60.45	5.47	-5	67.6	1.46	-0.78	42.86	22.3
38	1.18	7.86	66.1	5.41	-2	77.8	1.91	-0.95	50	13.2

*** can't be calculated (cause $SO_4^{-2} = 0$), RSC is expressed as meq / L

Note: Formulas were cited from (Yıldız and Karakuş 2020, Rawat et al. 2018), and all ions are expressed in meq/L.

TABLE 5. Descriptive statistics of water quality indices

Descriptive Statistics	EC (dS/m)	pH	Sodicity Hazards					Chloro-Alkalinity Hazards	Mg Hazard (%)	Total Hardness
			Na%	SAR	RSC	PI	KR	(CAI1)	(MH)	(TH)
Shallow wells (SW)										
Min	0.35	7.07	16.81	0.46	-18	44.79	0.19	-2.13	20	7.8
Max	4.42	8.36	65.28	6.96	-0.48	84.64	1.83	0.61	50	68.5
Mean	1.34	7.78	50.03	3.55	-4.35	66.29	1.08	-0.84	38.91	20.4
Std dev	1.13	0.35	13.99	1.82	5.25	12.69	0.49	0.64	8.58	18.16
Moderately Deep Wells (MDW)										
Min	0.85	7.15	45.65	2.57	-35	60.47	0.81	-2.44	20	9.1
Max	9.92	8.01	74.14	12.65	-1	86.08	2.8	-0.13	50	132
Mean	1.98	7.67	62.54	5.77	-5.23	73.94	1.73	-0.96	37.97	23.91
Std dev	2.66	0.29	8.28	2.87	9.92	8.05	0.6	0.6	7.94	35.96
Deep Wells (DW)										
Min	0.62	7.45	40	2.17	-8	50.26	0.63	-2.24	20	9.1
Max	7.68	8.04	84.38	25.86	-1	90.19	5.28	-0.14	50	36.4
Mean	1.74	7.79	62.16	6.77	-3.13	73.3	2.07	-0.78	36.84	16.48
Std dev	1.66	0.22	14.58	5.95	2.19	11.95	1.42	0.5	7.78	7.94

TABLE 6. Categoriesof groundwater wells

Water Indices	Thresholds	Water Class	Wells					
			Shllow Wells		Moderately Deep Wells		Deep Wells	
			Samples		Samples		Samples	
			No.	(%)	No.	(%)	No.	(%)
EC Index (dS/m)	<0.25	Excellent	No samples	0	No samples	0	No sample	0
	0.25 – 0.75	Good	6 -8 - 9 – 10 - 11	45.5	No sample	0	34 -35	12.5
	0.75 – 2.00	Permissible	1 – 2 – 3 – 4 5	45.5	12 – 13 – 14 - 15 - 16 – 17 – 18- 19 – 20 - 21-22	90.9	23 – 25- 26 -27 -28 -30 -31-32-33-37 -38	68.8
	2.00 – 3.00	Doubtful	7	9.09	16	9.09	24 – 29 -36	18.8
	> 3.00	Unsuitable	7 - 9 – 10	27.3	No samples	0	No samples	0
p^H Index	5.5 -7.5	Acceptable	1-7	18.2	16 – 17 – 20 21 - 22	45.5	24 -27 -28 -29 -33 -36	37.5
	>7.5	Non Acceptable	2 – 3 - 4 - 5- 6 8 - 9- 10 - 11	81.8	12- 13 -14 -15 -18 -19	54.6	23 -25 -26 -30 -31 32 -34 -35 - 37-38	62.5
Na Index (%)	< 20	Excellent	6	9.09	No samples		No samples	0
	20 – 40	Good	1	9.09	No samples	0	No samples	0
	40 – 60	Permissible	3 - 4 - 5 – 7 -8 – 9 -10	63.6	13 -16 – 17- 18 22	45.5	23 – 25 - 26 – 30 – 31- 34- 35	43.8
	60 – 80	Doubtful	02-Nov	18.2	12 – 14 – 15 19 – 2o -21	54.5	32 -33- 36 - 37-38	31.3
	> 80	Unsuitable	No samples		No samples	0	24 -27 -28- 29	25
SAR Index	0 – 6	Good	1 – 2 – 3 – 4 5- 6 – 8 - 9 -10 – 11	90.9	13 -14 -17 -18 19 - 22	54.6	23 -25 -26 – 30 -31 -32 -33 -34 -35 -37 -38	68.8
	6 – 9	Doubtful	7	9.09	12 -15 -16 -20- 21	45.5	24 -27 -28 -29 - 36	31.3
	> 9	Unsuitable	No samples	0	No samples	0	No samples	0
RSC Index (meq/l)	< 1.25	Good	1 – 2 – 3 – 4 – 5 – 6 – 7 –-8 – 9 – 10 – 11	100	12 – 13 – 14 15 – 16 – 17 18 – 19 – 20 21 - 22	100	23 - 24 - 25 - 26 27 - 28 29 - 30 31 - 32 - 33 - 34 35 - 36 - 37 - 38	100
	1.25 – 2.5	Doubtful	No samples	0	No samples	0	No samples	0
	> 2.5	Unsuitable	No samples	0	No samples	0	No samples	0

PI Index (%)	> 75%	Suitable	8 – 9- 11	27.3	12 -14 -15 -17 19 -21	54.6	24 -27 -28 -29 -33 -36	37.5
	25–75%	Good	1 – 2 – 3 – 4 5 – 6 – 7 -10	72.7	13- 16 – 18 - 20 - 22	45.5	23 -25 -26 -30 -31 -32-34- 35 -37 -38	62.5
	< 25%	Unsuitable	No samples	0	No samples	0	No samples	0
KR	< 1	Suitable	1 – 5 – 6 -9-10	45.5	18	9.09	25 -26 -31 -35	25
	> 1	Unsuitable	2- 3 -4 -7- 8- 11	54.5	12- 13 -14-15 - 16 -17 -19- 20- 21-22	90.9	23 -24 -27 -28 -29- 30 -32 - 33-34-38- 37- 38	75
CAI1		Recommended	6	9.09	No samples	0	No samples	0
	-	Not Recommended	1 – 2 – 3 – 4 – 5 – 7- 8 – 9 – 10 – 11	90	12 – 13 – 14 – 15 – 16 – 17 – 18 – 19 – 20 – 21 - 22	100	23 - 24 - 25 - 26 27 - 28 29 - 30 31- 32 - 33 - 34 35 - 36 - 37 - 38	100
MH Index	< 50	Recommended	2 – 3 – 4 – 5 6 7 – 8 –10 11	81.8	12 – 13 – 14 – 15 – 16 – 17 – 18 – 19 – 20 – 21 - 22–	100	24 – 25 –26 28 29 30 - 31– 32 – 33 34 - 35 – 36 37 38	87.5
	≥ 50	Not Recommended	1-9	18.2	No samples	0	23 – 27	12.5
TH Index (mg/l)	0–60	Soft	1 – 2 – 3 – 4 5 – 6 – 8 -10 11 –	81.8	12 – 13 – 14 – 15 – 16 – 17 – 18 – 19 – 20 – 21 - 22 –	100	23 - 24 - 25 26 27 - 28 - 29 - 30 31 - 32 – 33- 34 35 - 36 - 37 - 38	100
	60–120	Moderately Hard	7	9.09	No samples	0	No samples	0
	120–180	Hard	9	9.09	No samples	0	No samples	0
	> 180	Very Hard	No samples	0	No samples	0	No samples	0

- Sodium absorption ration (SAR): Results indicated that the groundwater of Wadi El-Natron generally had low SAR with averaged values of 3.55 (SW), 5.77 (MDW), and 6.77 (DW) (Table 5). The relatively high SAR values were mainly represented by some of (MDW), well no.; 12 -15 -16 -20-21, and (DW), well no. 24 - 27 -28 - 29 – 36 (Table 6). The long run use of these wells may reduce soil permeability, which conducts to poor internal drainage. Consequently, growth plants could be reduced and then give low crop yield (Yıldız and Karakuş 2020).
- Residual sodium carbonate (*RSC*): Hence, the concentration of bicarbonate and carbonate influence the suitability of irrigation water it was calculated (Table 4). All water samples had a negative RSC to indicate the absence of potential risk of sodium accumulation due to offsetting levels of calcium and magnesium. Thus, all water samples were considered safe - RSC for irrigation to be classified as good RSC irrigation water (Table 6).
- Permeability index (PI): Thisaveraged calculated values were 66.29, 73.94 and 73.3 %, for (SW), (MDW), and DW) (Table 5) to be generally located into suitable permeability classes I and II. These Classes were dominant with the percent of 27.27 and 72.72 % (SW) 54.54 and 45.45 % (MDW), and 37.5 and 62.5% (DW), respectively (Table 6). These results conducted to conclude that soil permeability may be affected by long term use of water for irrigation.
- Kelly's ratio (KR): Most water wells had values more than 1 to indicate an excess level of sodium in water. This majority had 54.54 % (SW), 90.90 % (MDW), and 75.00 % (DW) (Table 6).
- Chloroalkalinity index (CAI1) for Classification of the Groundwater or Groundwater Potentiality to change Soils to sodic Ones: The chemical reaction in which ion exchange between the groundwater and the aquifer occurs during the movement and rest condition of water. It can be analyzed through the chloroalkaline index (CAI1) that may be negative or positive depending on the exchange process of Na+ and K+ from the rock with Mg+2 and Ca+2 present in water and vice versa. If a direct exchange process (DEP) happens between Na+ and K+ in water with Mg2+ and Ca2+ in rocks or soils, then CAI ratio will be positive, and the direct cation exchange reaction can be expressed as follows:

$$(Ca_{1-x}Mg_x)\,CO_3 + H^+ + Na_{2\text{-Clays}} \longrightarrow 2Na^+ + HCO_3^- + (Ca_{1-x}Mg_x)_{\text{-Clays}}$$

If a reverse exchange process occurs (Na+ and K+ in water with Mg2+ and Ca2+ in rocks), then CAI ratio will be negative (Schoeller 1977) and reverse cation anion exchange reaction is expressed:

$$2Na^+ + HCO_3^- + (Ca_{1-x}Mg_x)_{\text{-Clays}} \longrightarrow (Ca_{1-x}Mg_x)\,CO_3 + H^+ + Na_{2\text{-Clays}}$$

All studied water samples had negative (CAI1) values to be situated into CAI1- not recommended class. This status refereed to the dominance of the reverse exchange process occurs (Na+ and K+ in water with Mg2+ and Ca2+ in rocks) to indicate high potentiality of transform soils to sodic ones, table (4).

- Sodicity Indices Comparison:

\- RSC – Na % and SAR: Water samples had negative RSC values to indicate the absence of potential risk of carbonate and bicarbonate ions accumulation due to offsetting levels of calcium and magnesium. Thus, RSC designate all water samples as good and safe - RSC for irrigation. Contrary, the classifications output of Na % and SAR indices located the samples into classes 3, 4 (permissible and doubtful) and classes 1, 2 (good and doubtful), respectively. The values of Na % and SAR indices conducted conclude that that soil permeability may be affected by long term use of irrigation water.

\- PI: PI represented intermediate scale between RSC – Na % and SAR from hand and KR and CAI1from other hand. These findings arranged the sodicity indices in the following descending Na sensitivity order; Na % and SAR, PI, KR and CAI1 and RSC. Na % and SAR, permeability (PI) indices can be applied to assess sodium hazards of irrigation water of fruits and vegetables. While it is advised to use KR and CAI1, and RSC indices to estimate these hazards in the case the field crops.

\- KR and CAI1: Values of KR and CAI1 led to the same classification, where they locatedmost of the water samples into the second class (unsuitable and not recommended). These indices distributed the samples into the classes of KR unsuitable and CAI1 not recommended with the percentage of 54.54 % and 90.01% (SW), 90.90 % and 100% (MDW), and 75.00 % and 100% (DW).

*4- Magnesium hazard (MH)***:** expressed by magnesium adsorption ratio (MAR) as Index for Classification of the Groundwater. Generally, all studied groundwater samples are situated in the class of recommended (Raghunath 1987) with an averaged MH values of; 38.91 (SW) ,37.97 (MDW), and 36.84 (DW) to indicate that MH % has not effect on soil pH (Table 5). Only four groundwater samples had high MH % values to be classified as not recommended; n. 1,9 (SW), and n. 23, 27 (DW) (Table 6). The high value of MH %, in water of these three wells, can increase soil pH to cause soil alkalinity and decreasing soil phosphorus availability. Excess concentration of magnesium in groundwater affects the soil quality by converting it into alkaline and decreases the crop yield (Gautam et al. 2015). In addition, Mg-hazards and low infiltration rate might threaten the suitability of water for irrigation (Abdelhafez, et al 2021)

5- Total hardness (TH) (Todd 1980; Rawat et al. 2018)

The averaged values of groundwater TH in the studied wells were 20.4 (SW), 23.91 (MDW), and 16.48 meq/L (DW) (Table 5) to refer that the water quality was generally soft to provide good control over corrosion and is the usually acceptable grade.

(II) Plotting Groundwater Classifications (Plotting Assessment of Groundwater Suitability for Irrigation)

EC – Na % Wilcox diagram (Wilcox 1948) and EC-SAR Riverside diagram (Richards 1954) software were run to output the classification plotting to determine the grade of irrigation water that has a significant impact on soil and yields crops.

1- EC- Na% Wilcox Diagram

Plotting of EC- Na% analytical data on Wilcox diagram (Figure 2), indicated that waters of the shallow wells were distributed excellent (45.46%), good (18.2%), permissible (27.3%) and doubtful (9.09%) water quality. Waters of wells no (6-8-9-10-11) and (no.1-5) represented the high-water quality, excellent and good classes, respectively. Only, well n. (7) located in the class doubtful to present of bad water quality. Three wells (n. 2-3-4) had marginally suitable water category were deigned as permissible class (Table 7) Generally, groundwater of (DW) and (MDW) were characterized by the dominancy of and good and permissible classes (Figure 3 and Figure 4). Comparison between varied - depth wells showed that (SW) had higher quality waters than those (MDW) and (DW). Excellent water was completely absent from (MDW), the permissible (marigally suitable) class got up to (63.63%) (Table 7).

2- EC-SAR Riverside Diagram

The designation of EC- SAR combined categories classes were based on the individual EC and SAR classes that were determined according to EC and SAR thresholds (Table 8), that thresholds were extracted from riverside diagram. The US salinity diagram (Mashaal 1954) illustrated that most of the groundwater samples, of (SW), fallen in the field of moderate EC –low SAR (C2S1: wells no. 6-8-9-10-11) and relatively high EC –low SAR (C3S1 wells no.1-2 - 3 -4 -5) (Figure 5) and (Table 9). The groundwater of well (7) represented non- suitable irrigation water, where it was classified as very high – high SAR (C4S3). This water is high relatively salinity (0.75 – 2.25 dS/m) that limits the crop selection to obtain the maximum field yield. They are so risky to irrigate vegetables.

The waters of (MDW) had higher EC values than those of shallow ones. Most of these wells located into two classes: high EC – low SAR (wells no. 13-17-18-19-22), and high EC - moderate SAR (12-14-15-20-21) (Figure 6) and (Table 9). Saline water were represented by C4S3 (shallow well no. 7), C5S3 (moderately deep well no. 16). With exception of well no (34), all water sample of (DW) situated in C3S2 (high saline and moderate sodicity) class (Figure 7) and (Table 9). These classes can only be used for well-drained soils and resistant plants with high leaching fraction (Gorine 2019).

3- Comparison water quality categories of Riverside and Wilcox diagrams:

The nonculture of water quality categories, of Riverside and Wilcox diagrams, are so different, so the comparison of their classification outputs was difficult. To overcome this problem, three categories were proposed to contain the Riverside and Wilcox groundwater classes: suitable, marginally suitable, and unsuitable water (Table 10). This simple grouping of diagram water classes indicted that the outputs of Riverside and Wilcox diagrams are like each other, and we can use any of them.

(III) Hydrogeochemical Classification of the Groundwater (Determination of Hydrogeochemical Cationic and Ionic Facies, and Groundwater Types):

Different irrigation water of equal EC has varying effects on the same crops. This may be due to the specific ion detrimental effect on soil properties and plant growth. High Na+ interferes with K+ and Ca2+ nutrition and disturbs efficient stomatal regulation, which results in a depression of photosynthesis and growth (Tavakkoli et al. 2010). Groundwater hydrogeochemical classification studies the balance of Na+ interferes with K+ and Ca2+ cations, in addition, for the point view of geology, it guides to determine the groundwater origin.

Piper’s Trilinear of the groundwater of shallow (SW), moderately (MDW) and deep wells (DW) were plotted to study the variation of water constituents and their spatial distribution. Piper diagram of (SW) referred to the dominancy of Na-K cationic and SO4- ionic facies (Figure 8). All these water wells had Na+ and K+ cationic facies, with exception of well no (10) that had No dominant cationic and ionic facies, and consequently it was located as mixed water type (Table 11).

TABLE 7. Water quality classes, based on EC – Na % (Wilcox 1948)

EC –SAR Class	Wells	
	No.	**(%)**
Shallow Wells (SW)		
Excellent	6-8-9-10-11	45.46
Good	1-5	18.18
Permissble	2-3-4	27.27
Doubtful	7	9.09
Moderately Deep Wells (MDW)		
Good	13-18-22	27.27
Permissble	12-14-15-17-19-20-21	63.63
Unsuitable	16	9.09
Deep Wells (DW)		
Excellent	34-35	18.75
Good	23-25-26-30-31-32	37.5
Permissble	27-28-33-37-38	31.25
Doubtful	29-36	12.5
Unsuitable	24	6.25

TABLE 8. EC and SAR thresholds and classes of riverside diagram (Richards 1954)

EC		SAR		EC-SAR Category
Thresholds EC Index (dS/m)	**Class**	**Thresholds**	**Class**	
0.10 -0.25	C1	≤ 10	S1: Low	C1S1: Low EC –Low SAR
		10-18	S2: Medium	C1S2: Low EC – Medium SAR
		≥ 18	S3: High	C1S3: Low EC – High SAR
0.25 –0.75	C2	≤ 8	S1: Low	C2S1: Medium EC –Low SAR
		8 – 15	S2: Medium	C2S2: Medium EC – Medium SAR
		≥ 15	S3: High	C2S3: Medium EC – High SAR
0.75 – 2.25	C3	≤ 6	S1: Low	C3S1: High EC –Low SAR
		6 – 12	S2: Medium	C3S2: High EC – Medium SAR
		≥ 12	S3: High	C3S3: High EC – High SAR
2.25- 5.00	C4	≤ 4	S1: Low	C4S1: Very high EC –Low SAR
		4-9	S2: Medium	C4S2: Very high EC – Medium SAR
		≥ 9	S3: High	C4S3: Very high EC – High SAR
5.00 -10.00	C5	≤ 2	S1: Low	C5S1: Extremely high EC – Low SAR
		2-6	S2: Medium	C5S2: Extremely high EC – Medium SAR
		≥6	S3: High	C5S3: Extremely high EC – High SAR

TABLE 9. Water quality classes (%), based on EC –SAR (Riverside diagram)

EC –SAR Class	Wells	
	N.	(%)
Shallow Wells (SW)		
C2S1	6-8-9-10-11	45.46
C3S1	1-2-3-4-5	45.46
C4S3	7	9.09
Moderately Deep Wells (MDW)		
C3S1	13-17-18-19-22	45.46
C3S2	12-14-15-20-21	45.46
C5S3	16	9.09
Deep Wells (DW)		
C2S1	34	6.25
C3S2	23-24-25-26-27-28-29-30-31-32-33-35-36-37-38	93.75

TABLE 10. Integration of Riverside and Wilcox water classes

Simple Classes	Diagrams Classes	
	Riverside	Wilcox
Suitable	C2S1	Excellent , Good
Marginally Suitable	C3S1, C3S2	Permissble , Doubtful
Unsuitable	C3S3 , C4S3 , C5S3	Unsuitable

TABLE 11. Ionic facies and groundwater types of the study wells

Well No.	Facies		Water Type	Well No.	Facies		Water Type
	Cationic Facies	Anionic Facies			Cationic Facies	Anionic Facies	
	Shallow Wells (SW)				**Deep Wells (DW)**		
1	No**	SO_4^-	CaCl2	23	Na-K	No**	NaCl
2	Na-K	SO_4^-	NaCl	24	Na-K	Cl	NaCl
3	Na-K	No**	NaCl	25	No**	No**	Mixed
4	Na-K	SO_4^-	NaCl	26	No**	SO_4^-	Mixed
5	No**	SO_4^-	Mixed	27	Na-K	SO_4^-	NaCl
6	Ca	HCO_3	Mg $(HCO_3)_2$	28	Na-K	SO_4^-	NaCl
7	Na-K	SO_4^-	NaCl	29	Na-K	No**	NaCl
8	Na-K	No**	NaCl	30	Na-K	No**	NaCl
9	Na-K	No**	NaCl	31	No**	No**	Mixed
10	No**	No**	Mixed	32	Na-K	SO_4^-	NaCl
11	Na-K	SO_4^-	NaCl	33	Na-K	No**	NaCl
	Moderately Deep Wells (MDW)			34	Na-K	No**	NaCl
12	Na-K	SO_4^-	NaCl	35	No**	No**	Mixed
13	Na-K	SO_4^-	NaCl	36	Na-K	No**	NaCl
14	Na-K	SO_4^-	NaCl	37	Na-K	SO_4^-	NaCl
15	Na-K	No**	NaCl	38	Na-K	No**	NaCl
16	Na-K	Cl	NaCl				
17	Na-K	No**	NaCl				
18	No**	SO_4^-	Mixed				
19	Na-K	No**	NaCl				
20	Na-K	No**	NaCl				
21	Na-K	SO_4^-	NaCl				
22	Na-K	No**	NaCl				

No**: No dominant
- Alkalis cationic facie (Na^+, K^+) exceed alkaline earth cationic facie (Ca^{+2}, Mg^{+2}) This may lead to sodic soils
- High contribution of strong anion SO^4 in the composing of anionic facies
- We have to locate water well (no.6) because of the absence of Ca $(HCO_3)_2$ water type. So, the rhombus, in the diamond, representing Mg (HCO_3)2 water type must be referred as Ca $(HCO_3)_2$ – Mg $(HCO_3)_2$ water type

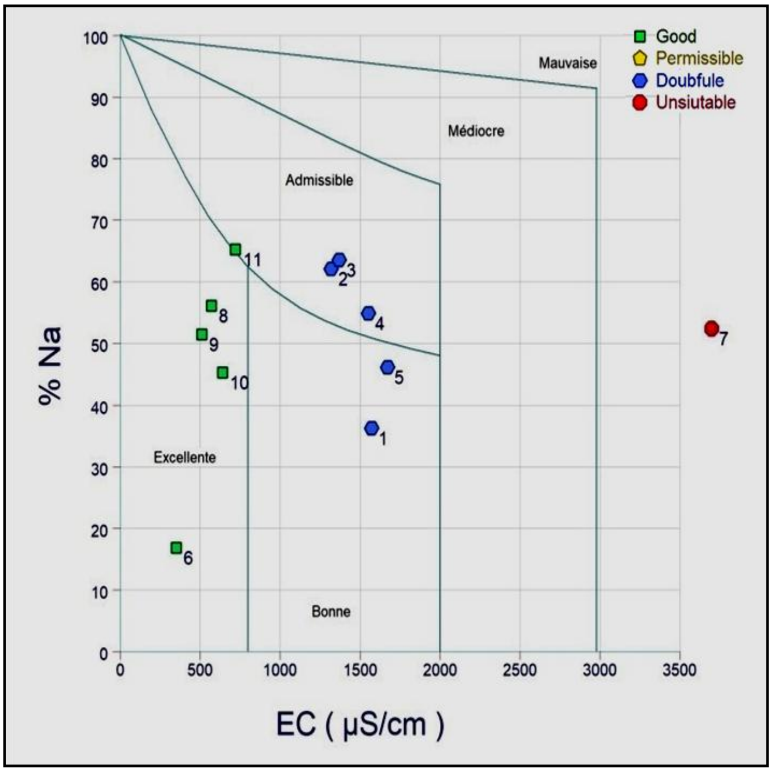

Fig. 2. EC –Na % classes (SW), Wilcox diagram

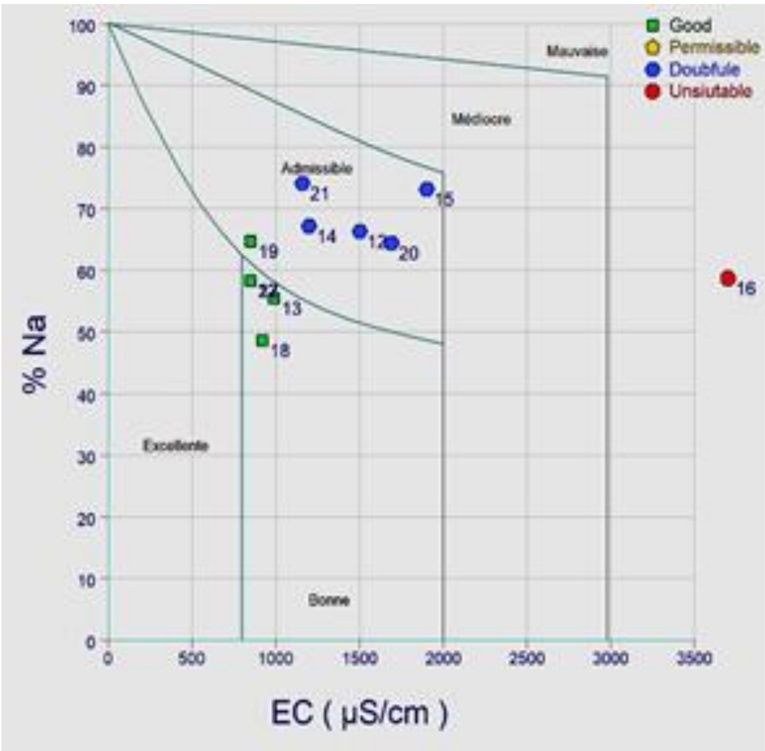

Fig. 3. EC –Na % classes (MDW), Wilcox diagram

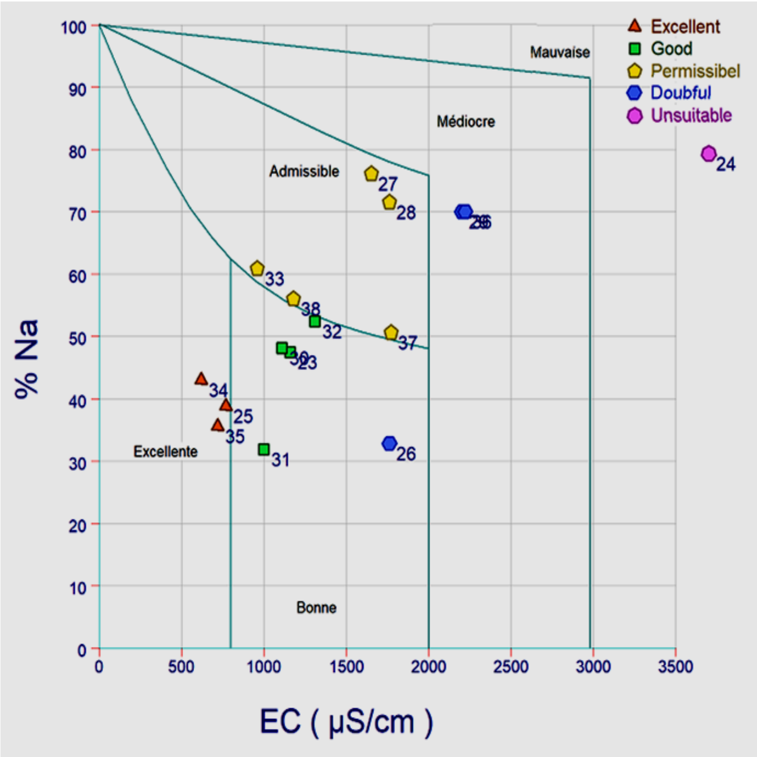

Fig. 4. EC –Na % classes (DW), Wilcox diagram

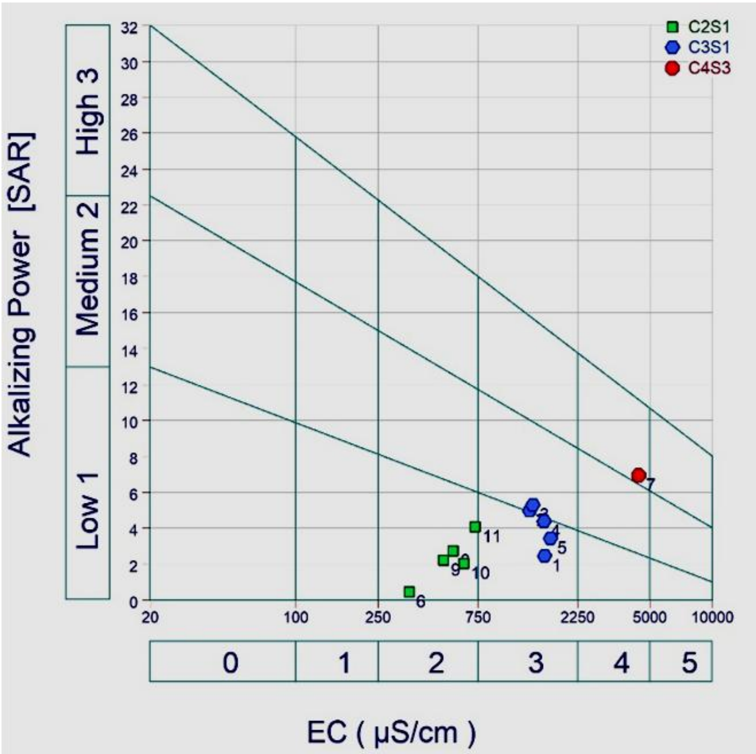

Fig. 5. EC –SAR classes of shallow wells (Riverside diagram)

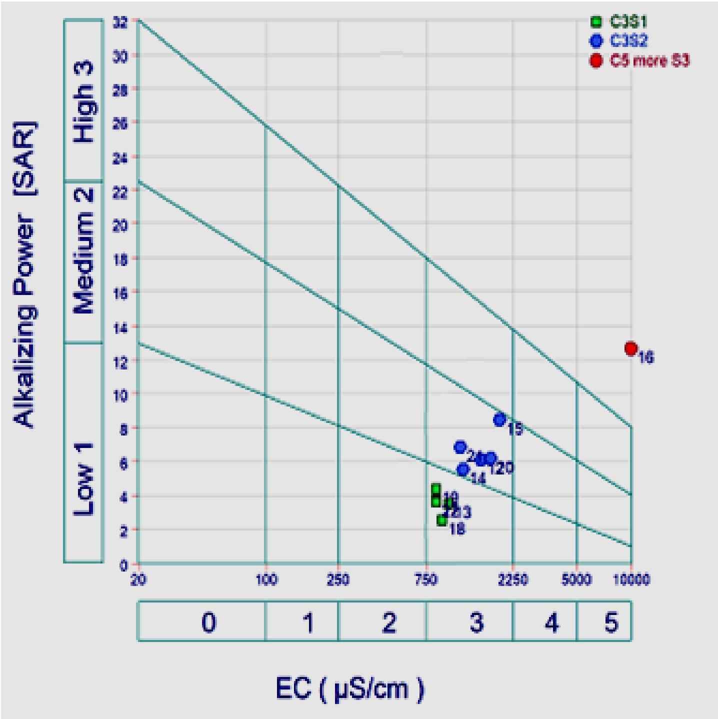

Fig. 6. EC –SAR classes of moderately deep wells (Riverside diagram)

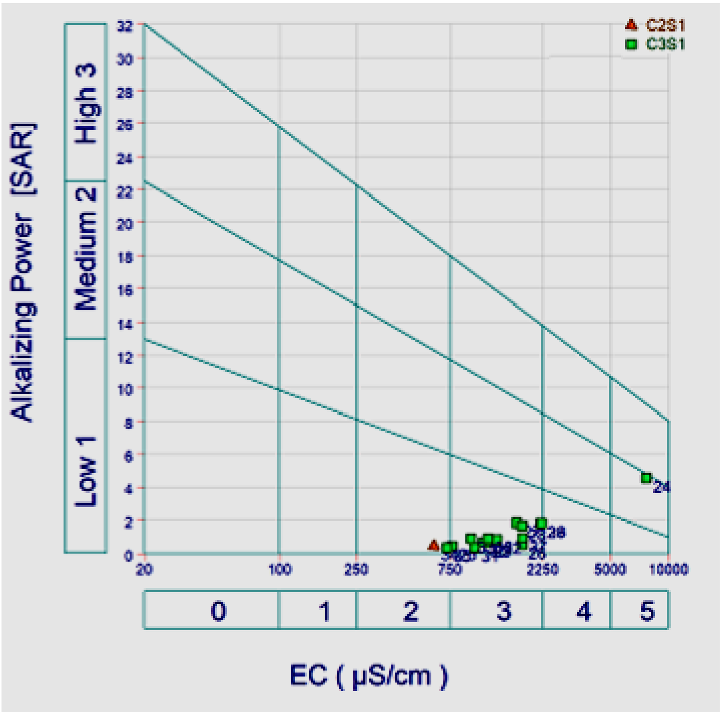

Fig. 7. EC –SAR classes of deep wells (Riverside diagram)

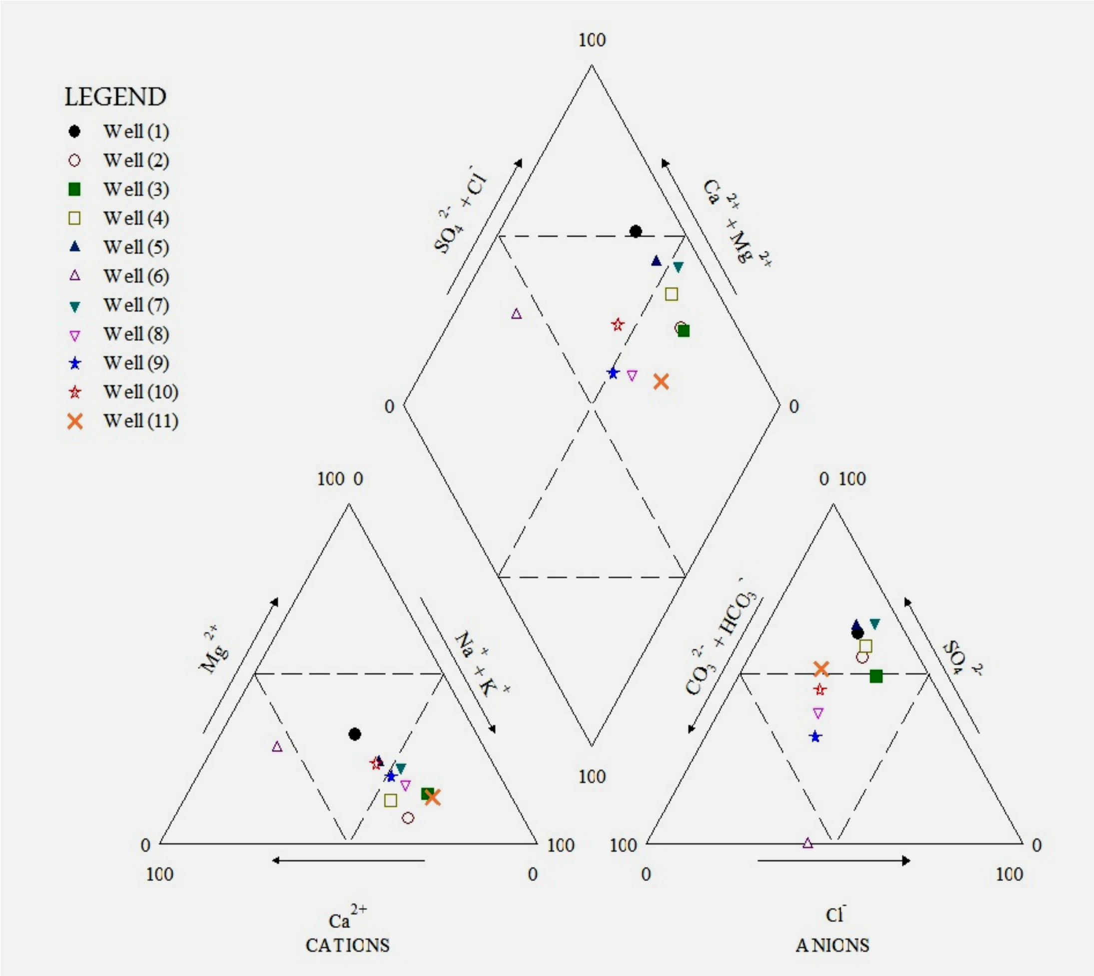

Fig. 8. Piper's Trilinear of groundwater hydrochemical classification for the shallow wells (SW)

The dominancy of Na+ and K+ cationic facies enhances the opportunities of replacement of soluble and exchangeable soil Ca2+ by water Na+, to push soils to arrive finally to sodic state. Therefore, water of (SW) had high potential to transform soil to sodic one. As for water of well (6) it had Ca2+ cationic and HCO3- ionic facies and located at the diamond as Mg (HCO3)2 water type. This was due the absence of the Ca (HCO3)2 water type. So, the rhombus, in the diamond representing Mg (HCO3)2 water type must be referred as Ca (HCO3)2 - Mg (HCO3)2 water type. Dominance of the alkaline earth cationic Ca+2 facie and the weak acids anionic facie HCO3- conducts to precipitate CaCO3 to raise the pH.

The waters of (MDW) were characterized by high contribution of strong and minor of strong acidic anions SO42-, and Cl-, consequently, and no dominant ionic facies (wells, 17, 18, 20, 21, 22) (Figure 9). The abundance of these ionic facies was more notably in the case of (DW); wells: 25, 29, 33, 34, 35, 36 and 38. Like (SW) and (MDW), (DW) were characterized by the abundance of Na+ and K+ cationic facies (Figure 10). This similarity of anionic facies of (MDW) and (DW), and the abundance of NaCl water type supported the proposal that they came from unique aquifer layer that may differ from that of (SW).

Conclusion

Salinity and alkalinity of (SW) groundwater were low, and therefore suitable for long-term irrigation. Opposing, majority of (MDW) and (DW) water are permissible salinity class, therefore it is not recommended for long-term irrigation. The research led to conclude that assessment of sodium hazards of irrigation water depends on the applied sodicity index. The comparison of sodicity indices that arrange them in the descending Na sensitivity - order; Na % and SAR, PI, KR and CAI1, and RSC. Consequently, Na % and SAR, PI indices are reliable assess sodium troubles irrigation water of fruits and vegetables While, it is advised to apply KR and CAI1, and RSC indices for evaluation of irrigation of the field crops.

Wadi El-Natron groundwater has generally the following features:

- Having the situation of Na % - classes 3, 4 (permissible and doubtful) and SAR- classes 1, 2 (good and doubtful)

- The dominancy of the reverse exchange process occurs (Na+ and K+ in water with Mg+2 and Ca+2 in soils to designate water high potentiality to transform soils to sodic ones

- Having magnesium content that has had no effect on soil pH to cause soil alkalinity and decreasing soil phosphorus availability.

- It is soft to provide good control over corrosion and is the usually acceptable grade.

The compiling of the different nonculture of Wilcox and Riverside and diagrams led to compare their outputs. These the outputs were similar one to each other to prove that any of them guide to the same irrigation water categories. Most of wadi El-Natron wells high sodic potentiality of due to the dominancy of Na-K cationic facie and NaCl water type. Waters of (MDW) and (DW) came from have the same aquifer layer that may differ from that of (SW).

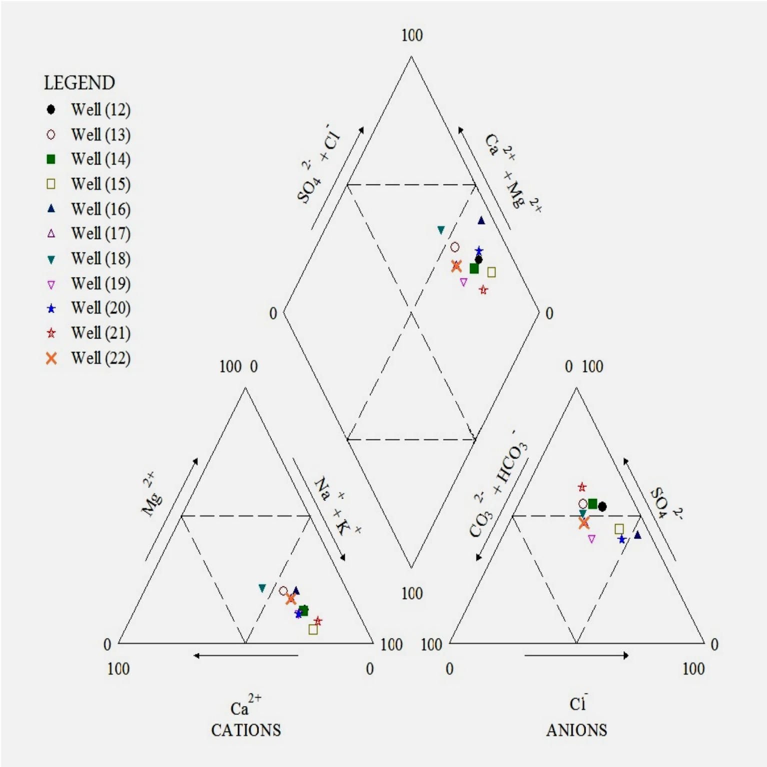

Fig. 9. Piper's Trilinear of groundwater hydrochemical classification for the moderately deep wells (MDW)

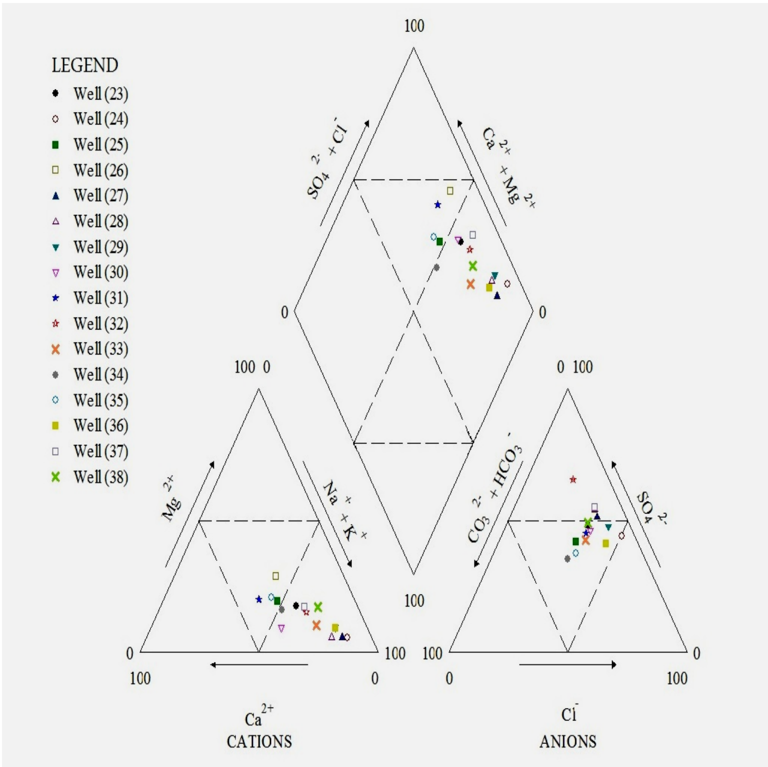

Fig. 10. Piper's Trilinear of groundwater hydrochemical classification for the deep wells (DW)

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