Health Environ, 2021, 2(1): 118-140
DOI: 10.25082/HE.2021.01.006

RESEARCH ARTICLE

Quality assessment of the surface and underground water in the region of Al Jabal Al Akhdar, Libya

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Received: August 20, 2021;
Accepted: October 15, 2021;
Published: October 19, 2021.

Citation: Megahed K, El-Gammal M and Ibrahim M. Quality assessment of the surface and underground water in the region of Al Jabal Al Akhdar, Libya. *Health Environ*, 2021, **2**(1): 118-140. https://doi.org/10.25082/HE.2021.01.006

Abstract: Surface and groundwater are the main sources of water supply in Libya. This study aims to assess the water quality index for drinking and irrigation purposes. 15 surfaces and 47 groundwater samples are collected in an area where lies in Al Jabal Al Akhdar region, northeast Libya. Water quality parameters such as temperature (T), pH levels, EC, TDS, TH, TAK, major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and NH_4^{+}) and major anions (Cl^{-}, PO_4^{3-}, HCO_3^{-}, NO_3^{-}, SO_4^{2-} and NO_2^{-}) were measured. Water quality indices including SAR, % Na, RSC, PI, MH, Kelly's Ratio and PS were also computed. Main water types were classified based on Piper trilinear diagram. The results revealed a basic pH level for surface water with a maximum level of 7.88. In addition, it is also exhibited a basic pH level for groundwater in the wet season and changed from acidic to basic in the dry season with a maximum level of 8.1. This indicates high-level concentrations of bicarbonate in water samples as measured. It observed that the ratio between TDS and EC increased with the decrease of pH levels, which indicates more releasing inorganic matter. Calcium and sodium are the dominant cations while Bicarbonate and sulfate are the dominant anions in water samples. Based on the U.S salinity, the Wilcox, and the Doneen classifications, the obtained results revealed that the surface water is suitable for drinking and irrigation purposes. Meanwhile, the groundwater is classified between excellent and doubtful except for some samples that were classified as unfit for irrigation purposes. Furthermore and based on the Piper diagram, the water types are classified as calcium sulfate, sodium chloride and as calcium bicarbonate. The water statuses categorization, based on the computational method of water quality index for drinking and irrigation agree with that concluded by US salinity, the Wilcox, and the Doneen diagram.

Keywords: Al Jabal Al Akhdar North-East Libya, drinking and irrigation water quality index, water types, the U.S salinity, Wilcox, Doneen classifications

1 Introduction

Water plays an important role in socio-economic development, healthy ecosystems, and human survival itself [1,2]. Freshwater, as a part of the Earth's water, resources are globally very limited in the world [3,4]. Approximately 3% of the Earth's water (≈ 71%) is fresh and predominated as surface water in icecaps and glaciers (≈ 69%) and groundwater (≈ 30%). In addition, surface water also originates from lakes, rivers, and swamps [5,6] and combined only account for a small fraction (≈ 0.3%) of the Earth's total freshwater reserves [3,4,7–10] and see also https://en.wikipedia.org/wiki/Water_resources).

Furthermore, over 66% of freshwater resources for the Arab countries originate outside national borders [11,12]. It is estimated that more than 100 million people, including rural people throughout sub-Saharan Africa, utilize groundwater for domestic supplies and livestock rearing [13,14]. Based on these criteria, the Libyan groundwater, on one hand, is part of two transboundary aquifers, the Nubian Sandstone Aquifer System (NSAS) and the North-Western Sahara Aquifer System (NWSAS). The first aquifer covers an area of more than two million square kilometers of Northeast Africa, of which 220,000 km^2 in Chad (≈ 11%), 760,000 km^2in Egypt (≈ 38%), 680,000 km^2in Libya (≈ 34%), and 340 km^2in Sudan (≈ 17%) [15,16]. The amount of groundwater withdrawal is annually estimated at a flow rate of 1500 Mm^3/yr. Meanwhile, the second aquifer covers a total area of over one million km^2, of which 700,000 km^2 in Algeria (≈ 69.96 %), 80,000 km^2 in Tunisia (≈ 7.77%), and 250,000 km^2 in Libya (≈ 22.27%). Moreover, it is also estimated the groundwater withdrawal from the North-Western Sahara Aquifer System (NWSAS) at a flow rate of 500 Mm^3/yr [17,18]. On the other hand, about 93% of Libyan land surface receiving less than 100 mm/year rainfall [19, 20], while the total amount of surface water is estimated annually with a rate of 60 × 10^6 m^3 [21]. Therefore, Libyan's water resources are limited and confined between the atmospheric rainfall and groundwater.

Besides the limitation of Libyan's water resources, UNECA AU and AFDB [22] reported that groundwater is the source of drinking water for 75% of the continent's population. This proportion is higher in some arid and semi-arid countries reaching 95% in the case of Libya [23]. In terms of water quantity, 75% of groundwater is mainly used for irrigation and 20% for domestic water purposes. Although a high heterogeneity exists, groundwater use in rural areas and is very important for domestic uses [24]. In addition, there has been a tremendous increase in the demand for freshwater in the last few decades due to the rapid growth of population and the accelerated rate of agriculture and industrialization [25, 26].

For these reasons, the water may become contaminated either by natural or by human influences and may be harmful to human usages and the environment. Based on these issues, the World Health Organization (WHO) set a standard level for each contaminated parameter that was used in different mathematical models to reduce the measured contaminated parameter to one value namely a Water Quality Index for drinking (WQI) and irrigation (IWQI) purposes [27–33]. Unfortunately, there are insufficient field experiments of quality assessment of the surface and groundwater in Libya with its impact on human health.

The present study aims to assess surface and groundwater quality in the region of Al Jabal Al Akhdar – Libya. This was done by collecting surfaces and groundwater samples during the wet and dry seasons of 2017-2018. The physicochemical parameters of water samples were measured to assess several water quality indices including Sodium Adsorption Ratio (SAR), Percent Sodium (%Na), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Hazard (MH), Kelly's Ratio (Kr) and Potential Salinity (PS). Furthermore, main water types were classified based on Piper Trilinear diagram whereas the water quality status was also classified for drinking and irrigation purposes [34–36].

2 Materials and methods

2.1 Study area

The study area lay in Al Jabal Al Akhdar region northeast Libya (Figure 1(a)). It is characterized by complex terrain (Figure 1(b)) and its geomorphology (Figure 1(d)) with geographical coordinates between latitudes 32.293^o and 32.430^o north, and longitudes 21.241^o and 22.422^o east. It occupies an area of ≈ 3632.76 km^2. The altitudes of the study area vary from 0 to 876 m from the mean sea level (Figure 1(b)). The climate in Al Jabal Al Akhdar region is classified as the subtropical Mediterranean. In addition, the average annual temperature is ≈ 20.2°C (Figure 1(c)) and fluctuated between 1^{o}C [37] and 41^{o}C [38]. The climate is also characterized by heavy rainfall in the cold winter and drought in the dry summer with large quantities of rain estimated annually between 250 mm and 650 mm. The highest rainfall intensity is observed in the middle part of the study area and becomes lowers as one moves northerly, southerly, and easterly as shown in Figure 1(e) [39,40]. High evaporation rates varied in a range of 1530 - 1710 mm/year in the northern regions and rise whenever the one moves a headed to the south [40, 42]. Finally, and as shown in Figure 1(f) the relative humidity varied in a range of 66–72% in the northern regions and rise whenever the one moves from the southwest to the northeast of the study area.

2.2 Geological setting

This section describes generally the topographical division of Al Jabal Al Akhdar region with its soil characteristics focusing on the study area. It is generally divided into three main plateaus on the Mediterranean shore of East-Libya and appeared as concentric unregular annuluses in their shapes with different altitudes (Figure 1(b)). The outer annulus refers to the lower plateau and follows by the middle and the upper plateau respectively, as one moves inside the mountain to its center. The altitudes of the lower plateau vary between 350 m and 400 m a.s.l and lay directly on the Mediterranean shore of the study area with a length of 100 km. It seems like an inverted crescent shape on the Mediterranean shore and belts the other plateaus in its centerFigure 1(b) and 1(d)). In addition, the lower plateau occupied different zones that vary in their width and the slope of the soil with its geomorphology. As shown in Figure 1(b), the first zone lay east of the study area and varies from a wide to a narrow area as one moves in a circular path from the south-southwest to the north-northwest. Further one moving to the west on a crooked line parallel to the Mediterranean shore, the width of the narrow area varies from some tenth meters to 3 km. In addition, a sharp edge mountain appears on the left hand. Meanwhile, the slope of the soil increased gradually as one moves southerly. One notice that the plateau's width decreases as one moves westerly reaching the middle part of the study area and observed that the sharp edge of the mountain becomes very close to the Mediterranean shore in a few hundred meters. As one moves as far away to the west of the study area, the lower plateau becomes widely to the south and revolves around the middle plateau while, the slope of the soil increase gradually as one also moves southerly inside the plateau [43, 44]. The lower plateau soil types are classified according to Figure 1(d) as follows: (a) Brown Carbonate Lithosois in the south part east the study area; (b) Rendzinas covers the most area of the plateau; (c) Red ferrosiallitic soils and; (d) a few spots of Hydromorphic solonchaks and coastal sands.

In addition, the topography of the middle plateau follows the same behavior as for the first one but with altitudes vary between 400 m and 600 m a.s.l. The slope of the soil increased gradually in a wide area from the east to the west in the east zone of the study area and from the west to the east in the west zone of the study area. Meanwhile, the slope of the soil increased sharply in a narrow zone as one moves southerly along the middle part of the study area. The middle plateau belts the upper plateau in the west and the south of the study area as shown in Figure 1(d). The middle plateau soil types are classified as follows: (a) Brown Carbonate Lithosois in the south part east the study area; (b) Rendzinas covers the most area of the plateau with spread spots of red ferrisiallitic soils [44–46].

Finally, the topography of the upper plateau is covered a large area lay in the middle part of the study area and extended to the southwest with altitudes varying between 600 m and 876 m a.s.l at a place close to the Omar Al-Mukhtar region as shown in Figure 1(d). The upper plateau soil types are classified as follows: (a) Brown Carbonate Lithosois in the south part of the plateau; (b) Rendzinas covers the most area of the plateau; (c) Red ferrosiallitic soils and a few spots settlements [44, 47].

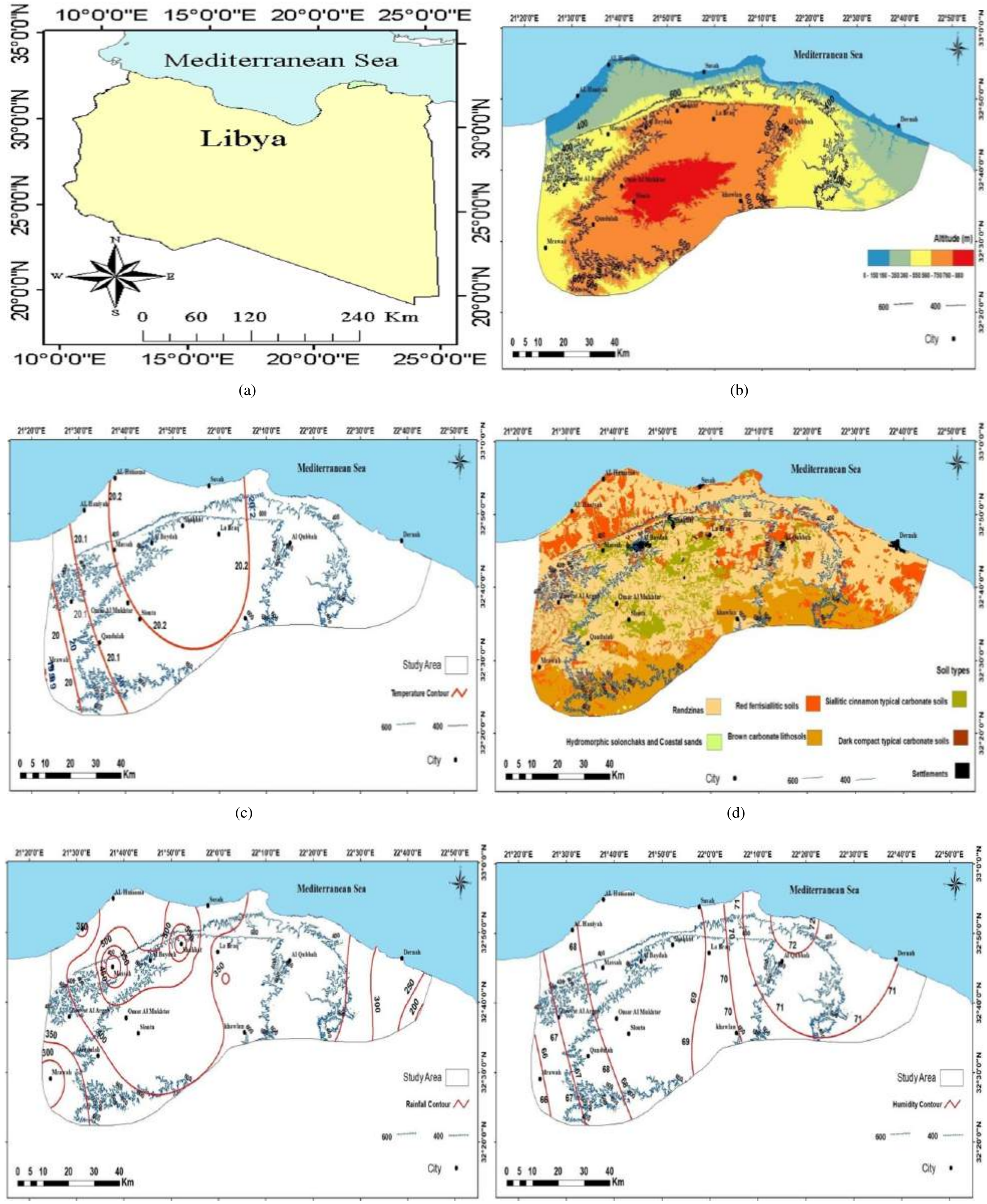
2.3 Sampling and analytical procedure

Water samples were collected from different springs and wells are given in Table 1 in an area of 100 km length and a width of 36 km in Al Jabal Al-Akhdar region, northeast Libya. This was done once during the middle of wet and dry seasons in the year 2017 and monthly from January to April 2018. Firstly, water samples were also collected in clean glass bottles with a capacity not less than 250 ml. The groundwater samples were collected by using a water pump, while the surface water samples were collected manually in glass bottles and at least 20 cm under the surface water. Secondly, all bottles were labeled with the date and the water sample source. After that, the water samples were stored in an icebox at 4 °C to avoid the change in its chemical parameters via photochemical reactions. The physicochemical parameters of water samples were conducted using standard equipment and materials, provided by the well-known international companies, in water analysis laboratories in Man-made River Center (MmRC) (Hawari Region, Benghazi city). Water samples temperature T and pH level were measured as soon as collected from its source using PH meter which Manufacturer and supplied by Hanna Instruments. Electrical conductivity (EC) was also measured using an EC-meter (the Portable device of measurement, Type AR 50 Dual channel pH /Ion/Conductivity Meter.

The following chemical parameters such as TDS, TH, TAK, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^+ Cl^-, PO_4^{3-}, HCO_3^-, NO_3^-, SO_4^{2-} and NO_2^- were analyzed in the laboratory using standard procedures [48]. TH, TAK, SO_4^{2-}, Cl^- and HCO_3^- concentrations are also measured by titrimetric method, while PO_4^{3-}-P, NO_2^--N, NO_3^--N, and NH_4^+-N concentrations were measured by digital spectrophotometer (type 6405 UV/Vis). In addition, Na^+ and K^+ concentrations were measured by using the flame photometer (model, PFP7 flame photometer). Ca^{2+}, Mg^{2+}, and Cl^- were measured by the titrimetric method. Residue Sodium Carbonate (RSC), Sodium Percent (%Na), Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelley's Ratio (Kr) Permeability Index (PI), Potential Salinity (PS), and Soluble Sodium Percentage (SSP) are computed to evaluate the suitability of the water quality for drinking and agricultural purposes.

2.4 Water quality indices

Analysis of the water quality index (WQI) provides us comprehensive details of the quality of surface and groundwater for most different usage. It is computed based on the measured physicochemical parameters for the collected water samples from the study area. The irrigation water quality index (IWQI) for agricultural purposes was also computed based on some different key items that are summarized in Table 2 such as Sodium Adsorption Ratio (SAR), Percent Sodium (%Na), Residual Sodium Carbonate (RSC), Permeability Index(PI), Magnesium Hazard



(a) (b)

(c) (d)

(e) (f)

Figure 1 Location of the study area in Al Jabal Al Libya Akhdar region northeast Libya. (a) The study area; (b) The altitude of the lower, middle, and upper plateau; (c) Temperature contour; (d) Soil types in a different plateau; (e) Rain contour lines; (f) Relative humidity contour lines.

Table 1 Geographical coordinates of surface and groundwater sample points

Spring No.	Well No.	Location	Coordinates		Alt. (m)
			Long.	Lat.	
	1	Hakaash	21.334	32.481	120
	2	Aleiata	21.334	32.500	129
	3	Shkhnu	21.364	32.510	142
	4	Bufuruh	21.371	32.445	504
	5	Almushtal	21.375	32.451	514
	6	Almustawsaf	21.375	32.450	517
	7	Sayidi khalid	22.252	32.463	406
	8	Sarusra	22.231	32.430	403
	9	Almaleab	22.232	32.444	469
	10	Dughush	22.225	32.452	462
	11	Eulwat Alsharif	22.184	32.472	554
	12	Alqiba	22.145	32.453	609
	13	Aleamarat	22.140	32.460	579
	14	Bawawazinih	22.142	32.453	607
	15	Sixteen	22.022	32.470	676
	16	Bualhimria	22.104	32.455	625
	17	Alhasak	22.080	32.471	667
	18	Al Qayqab	22.012	32.433	702
	19	Almueadini	22.011	32.432	718
	20	Altariulat	22.002	32.470	678
	21	Wadi Aleaysh	21.520	32.481	627
	22	Alwahda	21.520	32.484	626
	23	Albaqara	21.504	32.483	628
	24	Qernadah	21.544	32.432	675
	25	Al Faidiyah	21.544	32.411	752
	26	Marawah	21.241	32.293	483
	27	Qandulah	21.343	32.320	625
	28	Suluntah	21.423	32.345	750
	29	Omar Almokhtar	21.411	32.380	746
	30	Antar Sima	21.464	32.455	623
	31	Bo Safah	21.452	32.451	624
	32	Almulk	21.440	32.452	619
	33	’Um Alsafasaf	21.441	32.465	595
	34	Mebirah	21.395	32.523	213
	35	Qasr Alshayabin	21.433	32.500	332
	36	Darnah	22.374	32.453	69
	37	Alkhadamat	22.374	32.453	67
	38	Al Edrah	22.374	32.453	70
	39	Alsharika	22.374	32.453	73
	40	Al wadi 2	22.381	32.451	76
	41	Al wadi 4	22.381	32.452	70
	42	Amwaylah	22.390	32.453	10
	43	Al Tawfiq	22.390	32.451	64
	44	Bo Esmail	22.394	32.450	42
	45	Al Afriqi	22.394	32.450	53
	46	Al Fatayh	22.395	32.440	248
	47	Al Hasadi	22.422	32.430	246
1		Massah	21.619	32.756	472
2		Ayn Mara	22.380	32.750	430
3		Dapposia	22.281	32.833	283
4		Magga	22.268	32.716	517
5		El-Guppa	22.248	32.763	628
6		El-Agdir	22.021	32.726	714
7		El-Gaigab	22.022	32.726	722
8		Stouwa	22.110	32.856	306
9		El-Huffra	21.874	32.828	555
10		Appolo	21.852	32.823	567
11		El-Feltro	21.962	32.865	244
12		Karsaa	22.404	32.822	256
13		El-Belad	22.619	32.728	142
14		Bo-Mansour	22.610	32.702	160
15		El-Bieda	21.751	32.793	583

Table 2 Equations and water status to evaluate water for irrigation purposes

Items	Equations	Water Status	References
SAR	$\mathrm{Na}^{+}/\sqrt{\left(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}\right)/2}$	Excellent, Good, Permissible, Doubtful	[51]
% Na	$100\times\left[\mathrm{Na}^{+}/\left(\mathrm{Na}^{+}+\mathrm{K}^{+}+\mathrm{Mg}^{2+}+\mathrm{Ca}^{2+}\right)\right]$	Excellent, Good, Permissible, Doubtful, Unsuitable	[52]
RSC	$\left(\mathrm{HCO}_3^{-}+\mathrm{CO}_3^{-}\right)-\left(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}\right)$	Good, Medium, Bad	[51]
PI	$100\times\left[\left(\mathrm{Na}^{+}+\sqrt{\mathrm{HCO}_3}\right)/\left(\mathrm{Na}^{+}+\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}\right)\right]$	Excellent, Good, Unsuitable	[53]
MH	$100\times\left(\mathrm{Mg}^{2+}\right)/\left(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}\right)$	Suitable, Unsuitable	[54]
Kelly's Ratio	$\left(\mathrm{Na}^{+}\right)/\left(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}\right)$	Permissible, Non-Permissible	[55]
PS	$\mathrm{Cl}^{-}+1/2\left(\mathrm{SO}_4^{2-}\right)$	Excellent to Good, Good to Injurious, – and Injurious to Unsatisfactory	[53] [56]

(MH), Kelly's Ratio (Kr) and Potential Salinity (PS). The water quality indices were also visualized and classified for irrigation purposes based on the following diagram [49, 50].

(1) U.S Salinity Laboratory's diagram based on SAR index and electrical conductivity.

(2) The Wilcox diagram based on %Na and electrical conductivity.

(3) The Doneen diagram based on the Permeability Index (PI) and the total salt concentration in water samples.

(4) Piper Trilinear diagram that was used to classifying water type based on the distribution of cations and anions concentrations in water samples.

All physicochemical parameters were converted to Meq/L before calculations were made.

2.5 Calculation of water quality index for drinking (WQI) and irrigation (IWQI) purposes

The suitability of surface and groundwater for drinking purposes, on one hand, were prepared using the measured concentrations of the physicochemical parameters T, EC, pH, TDS, TAK, TH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+}, Cl^{-}, PO_4^{3-}, NO_3^{-}, NO_2^{-}, SO_4^{2-} and HCO_3^{-}. In addition, the standard values (SI_i) for drinking water that were recommended by the Libyan National Center for Standardization and Meteorology and Ministry of Commerce [57] as shown in Table 3. The method of the computations includes three successive steps [58, 61].

The first step is assigned the parameters relative weight by using successive three sub-steps as follows: -

(1) weighted the 17 physicochemical parameters (W_i) based on its standard values as follows:

$$W_i = 1/\left(SI_i\right) \tag{1}$$

(2) calculate the proportionally constant k_c by using the following equation

$$k_c = 1/\sum_{i=0}^{n} W_i \tag{2}$$

(3) the parameters relative weight were finally assigned using the following equation

$$Rw_i = k_c \times W_i \tag{3}$$

The summation of parameters relative weight must be equal to one.

Meanwhile, the quality rating scale (Q_i) for each parameter, as a second step, is assigned by dividing the parameters measured concentration (Ci) by its respective standard (SI_i) and multiply the result by 100 using the following equation

$$Q_i = 100 \times \frac{\left(c_i - c_0\right)}{\left(s_i - c_0\right)} \tag{4}$$

please note that the concentration of chemical parameters in meq/L. and C_o is equal zero for all parameters except for pH = 7.0 and DO = 14.6.

In the third step, the parameters quality index (Sl_i) is firstly computed by multiply the parameter relative weight times its quality rating scale using the following equation

$$Sl_i = Rw_i \times Q_i \tag{5}$$

Finally, the water quality index (WQI) was computed as a summation of the parameters quality index according to the following equation

$$WQI = \sum_{i=0}^{n} Sl_i \tag{6}$$

Based on the computed values of the water quality index, the water statuses are categorized between ‘excellent, good, poor, very poor, unsuitable and unfit’ as shown in Table 4 [34–36, 61, 63].

Table 3 Standard Values of water quality index (WQI) for drinking purposes

Parameters	Standard Values (SI_i)	Weight (Wi)	Relative Weight (Rw_i)
Temperature	30	0.033333	0.019818
EC	2300	0.000435	0.000258
pH	8	0.125	0.074317
TDS	1000	0.001	0.000595
TAK	200	0.005	0.002973
TH	500	0.002	0.001189
Ca	200	0.005	0.002973
Mg	50	0.02	0.011891
Na	200	0.005	0.002973
K	20	0.05	0.029727
NH4	3	0.333333	0.198178
Cl	250	0.004	0.002378
PO_4	5	0.2	0.118907
NO_3	45	0.022222	0.013212
NO2	3	0.333333	0.198178
SO4	1	0.666667	0.396356
HCO_3	200	0.005	0.002973
		$k_c = 1/\sum_{i=1}^{17} W_i$ $= 0.595$	$Rw = \sum_{i=1}^{17} k_c \times W_i$ $= 1$

Table 4 Categorization of water status based on the values of water quality index [62]

WQI values	Water Status	Recommended usages
0 – 25	Excellent	Drinking, Irrigation and Industrial
26 – 50	Good	Domestic, Irrigation and Industrial
51 – 75	Poor	Irrigation and Industrial
76 - 100	Very poor	Irrigation
100 - 150	Unsuitable	Restricted use for Irrigations
Above 150	Unfit for all	Proper treatment is required before use

Table 5 Standard Values of irrigation water quality index (IWQI)

Parameters	Standard Values (SI_i)	Weight (Wi) $= 1/ SI_i$	Relative Weight $= k_c \times W_i$
EC	2	0.5	0.167311
pH	8.5	0.117647	0.039367
Cl	10	0.1	0.033462
NO_3	2.18	0.458716	0.153496
HCO_3	8.5	0.117647	0.039367
SAR	10	0.1	0.033462
%Na	60	0.016667	0.005577
RSC	2.25	0.444444	0.148721
PI	75	0.013333	0.004462
MH	50	0.02	0.006692
Kr	1	1	0.334621
PS	10	0.1	0.033462
		$k_c = 1/\sum_{i=1}^{12} W_i$ $= 0.335$	$Rw_i = \sum_{i=0}^{i=12} k_c \times SI_i$ $= 1$

On the other hand, the suitability of surface and groundwater for irrigation purposes (IWQI) were also computed using the method for drinking proposes. This was done based on the measured physicochemical parameters for EC, pH, Cl^-, NO_3^- and HCO_3^- with the different key items that are summarized in Table 2 such as Sodium Adsorption Ratio (SAR), Percent Sodium (%Na), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Hazard (MH), Kelly’s Ratio (Kr) and Potential Salinity (PS). The standard values for these items were also recommended by the Libyan National Center for Standardization and Meteorology and Ministry of Commerce [57] as shown in Table 5. The water statuses are also categorized as shown in Table 4 based on the computed values of the irrigation water quality index.

3 Results and discussion

3.1 Physiochemical parameters

The statistical analysis of the physiochemical parameters for surface and groundwater in the region of Al Jabal Al Akhdar – east Libya are given in Table 6 and 7. The trends of seasonal variations are demonstrated by creating a box-Whisker plot in Figure 2 for the surface water and Figure 3 for the groundwater. Temperature is considered the most important factor when assessing water quality leading to alter the physical and chemical properties of water. For surface water, the temperature values varied from 15.5 to 19.9^{o}C and 19.4 to 20.6^{o}C in the wet and dry season of 2017. In addition, the minimum value of the surface water temperature in the wet season of 2018 is approximately equal to that in the wet season of 2017 and less than that for the dry season of 2017. Meanwhile, the maximum value of water temperature in the wet season of 2018 is higher by one degree than that for the wet and dry season of 2017. In addition, the temperature values of groundwater exhibited the same variations for the surface water which varied from 12.8 to 22.9^{o}C in the wet season of 2017 and from 19.9 to 22.1^{o}C in the dry season of 2017. The field measurements exhibited basic pH levels for surface water in all seasons with a maximum level of 7.88. On the contrary with surface water, the field measurements revealed basic pH levels in the wet season of 2017 and changed from acidic to basic in the dry season of 2017 with a maximum level of 8.1. This gives an indication of high-level concentrations of bicarbonate in water as shown in Table 6, 7 and Figure 2, 3.

As known, the TDS concentration is proportional with the measured EC parameter in water samples with a proportional constant that varies between 0.55 and 0.7 [64, 65]. The minimum and maximum values of the TDS concentrations for surface water in the wet and dry seasons of 2017 with the wet season of 2018 are ((312-768 mg/L), (300-780 mg/L) and (462-945 mg/L)) respectively. Meanwhile, the corresponding EC measurements are ((503–1097 μS/cm), (500-1300 μS/cm) and (722-1490 μS/cm)) respectively. In addition, The minimum and maximum values of the TDS concentrations for groundwater in the wet and dry seasons of 2017 are ((261-2300 mg/L) and (295-2501 mg/L)) respectively, while the corresponding EC measurements are ((435–3285 μS/cm), (492-3411 μS/cm) respectively. Generally, the minimum values of the EC measurements and TDS concentrations of the surface water are observed east of the study. Meanwhile, their maximum values are observed west and the middle part of the study area due to urban sewage. In addition, their minimum values of groundwater are observed south of the study area and their maximum values are observed east of the study area due to seawater intrusion which lay directly in the Mediterranean shore of the study area and the lower plateau. The ratio of TDS concentrations and EC measurements of the minimum values for the surface and groundwater are (0.62, 0.6, 0.63, 0.6, and 0.59) and for the maximum values are (0.7, 0.6, 0.64, 0.7, and 0.73). This ratio increased with the decrease of pH levels, which indicates more releasing inorganic matter with the decrease of pH levels as a result of a complex geomorphological constitute of the study area as shown in Figure 1(d).

The measured concentrations of TH in water samples exhibited the same trends of EC and TDS variations. For surface water, it varied within a range of 142–324 mg/L in wet seasons of 2017, and within the range of 199 – 350 mg/ L in the dry season of 2017 and within a range of 197–461 mg/L in the wet season of 2018. Meanwhile, for groundwater, it varied within a range of 106–625 mg/L in the wet season of 2017 and 146–696 mg/L in the dry season of 2017.

For cations concentrations of surface water samples, on one hand, $Ca^{2+}$and K^+ ion concentrations exhibited the same behavior of trends as shown in Figure 2 in each interval between the seasons. Meanwhile, Mg^{2+} and Na^+ ion concentrations exhibited the same behavior of trends as shown in Figure 2 overall season. In addition, $NH_4{}^+$ ion concentration exhibited a negative trend overall seasons. The cations concentrations of groundwater samples, on the other hand, Ca^{2+}, Mg^{2+}, Na^+, K^+ and $NH_4{}^+$ exhibited a slightly positive change in trends as shown in Figure 2 overall the seasons.

In addition, the anion concentrations of surface water samples Cl^-, PO_4^{2-} and HCO_3^- exhibited the same behavior of trends as shown in Figure 3 which increased sharply from the wet to dry season of 2017 and approximately constant from the dry season of 2017 to the wet season of 2018. Meanwhile, the seasonal trends of NO_3^-, NO_2^- and SO_2^- mean concentration is slightly changed. For groundwater, the PO_4^{2-} anion concentration exhibited a sharp positive trend in the wet and the dry season of 2017. Not far away from this, the anion concentrations of Cl^-, NO_3^-, NO_2^-, SO_2^- and HCO_3^- are exhibited a positive slightly trend.

Table 6 Statistical summary of physicochemical parameters for the surface water

Parameters	Winter 2017					Summer 2017					Winter 2018				
	Min	Max	Mean	Med	STD	Min	Max	Mean	Med	STD	Min	Max	Mean	Med	STD
Temp (^{o}C)	15.50	19.90	18.06	18.30	1.23	19.40	20.60	20.12	20.30	0.38	16.10	21.70	19.34	19.60	1.03
pH	7.10	7.86	7.35	7.35	0.23	7.12	7.52	7.28	7.24	0.10	7.01	7.88	7.49	7.50	0.23
EC (μS/ Cm)	503.00	1097.00	724.07	691.00	176.20	500.00	1300.00	773.00	740.00	207.10	722.00	1490.00	960.80	1010.00	183.40
TDS (mg/L)	312.00	768.00	450.79	433.00	122.10	300.00	780.00	469.90	444.00	129.10	462.00	954.00	615.40	646.00	117.80
TH (mg/L)	141.70	323.60	241.70	226.90	57.38	199.20	349.70	274.50	287.70	53.64	196.90	461.30	311.60	323.30	68.80
Ca^{2+} (mg/L)	37.00	96.00	71.14	73.00	19.10	60.00	112.00	84.71	79.00	19.41	43.00	138.00	85.33	78.00	23.60
Mg^{2+}(mg/L)	9.00	21.00	15.57	17.00	4.13	11.00	22.00	15.29	16.00	3.02	6.00	48.00	23.97	24.00	11.44
Na^+ (mg/L)	10.00	34.00	15.79	14.00	6.64	15.00	40.00	26.29	28.00	8.42	47.90	109.90	67.38	68.00	12.77
K^+ (mg/L)	2.60	3.50	3.01	3.10	0.30	1.62	11.35	4.85	4.86	2.53	1.67	10.00	4.20	3.70	2.53
NH_4^+ (mg/L)	0.13	0.90	0.54	0.61	0.24	0.08	0.79	0.45	0.52	0.22	0.27	0.99	0.65	0.69	0.19
Cl^- (mg/L)	21.00	78.00	35.14	29.00	15.21	40.00	100.00	72.36	69.00	18.16	68.00	196.00	105.80	98.00	31.31
PO_4^{2-} (mg/L)	0.20	2.29	0.55	0.45	0.52	1.21	4.52	2.20	1.85	1.10	0.17	2.90	0.57	0.44	0.52
NO_3^- (mg/L)	12.00	42.00	23.79	23.00	7.51	12.00	44.00	23.07	25.00	8.64	3.61	66.18	25.82	17.00	18.14
NO_2^- (mg/L)	0.43	2.32	0.97	0.84	0.49	0.40	2.34	0.95	0.90	0.54	0.88	2.75	1.27	1.15	0.48
SO_4^{2-} (mg/L)	20.00	210.00	54.71	43.00	46.04	10.00	100.00	49.07	50.00	23.58	45.00	265.00	83.69	65.00	58.40
HCO_3^- (mg/L)	162.00	285.00	215.21	220.00	37.70	166.00	288.00	238.40	240.00	36.31	192.00	295.00	246.80	2520.00	29.89

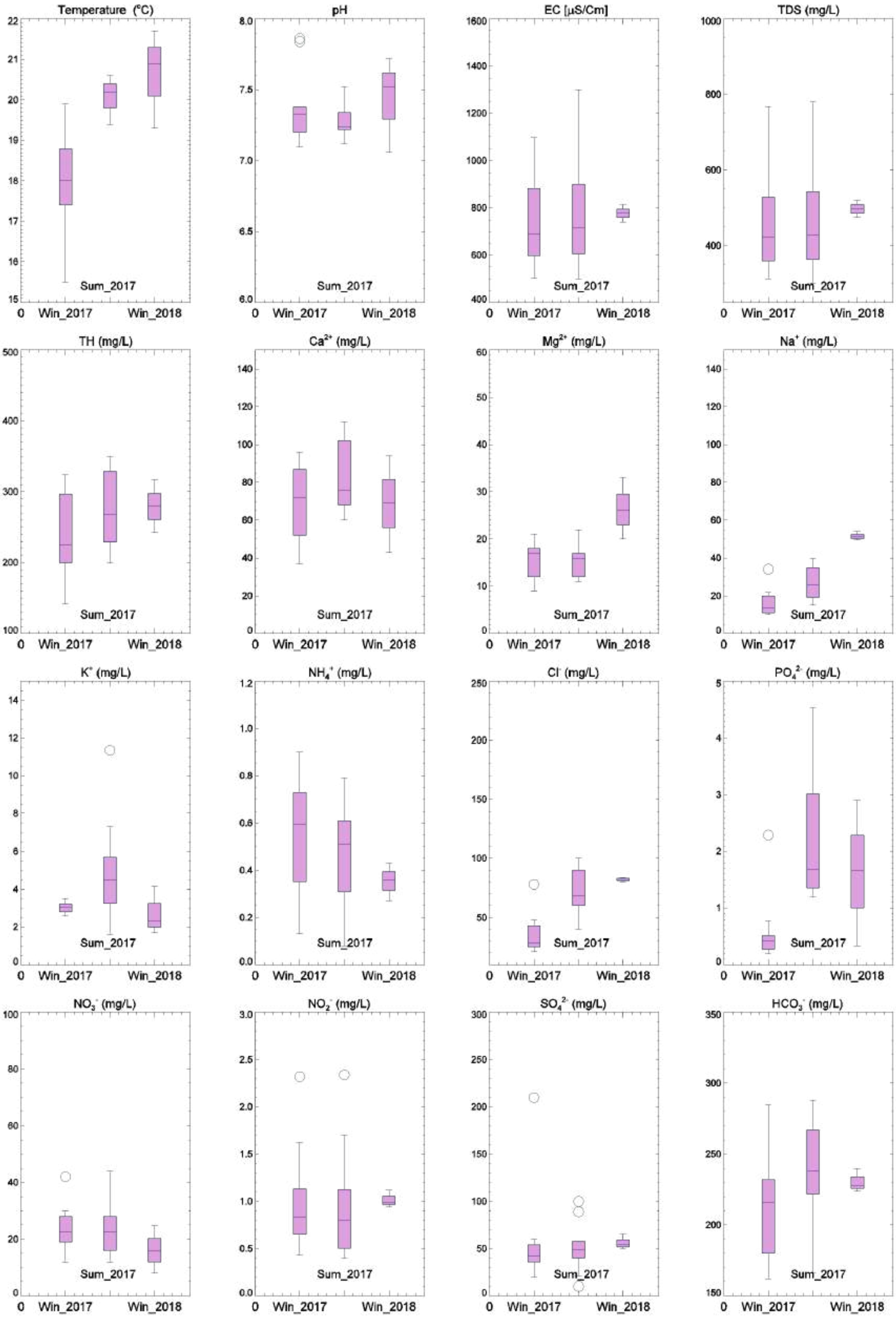


Figure 2 Trend of seasonal variation of surface water quality parameters in the study area

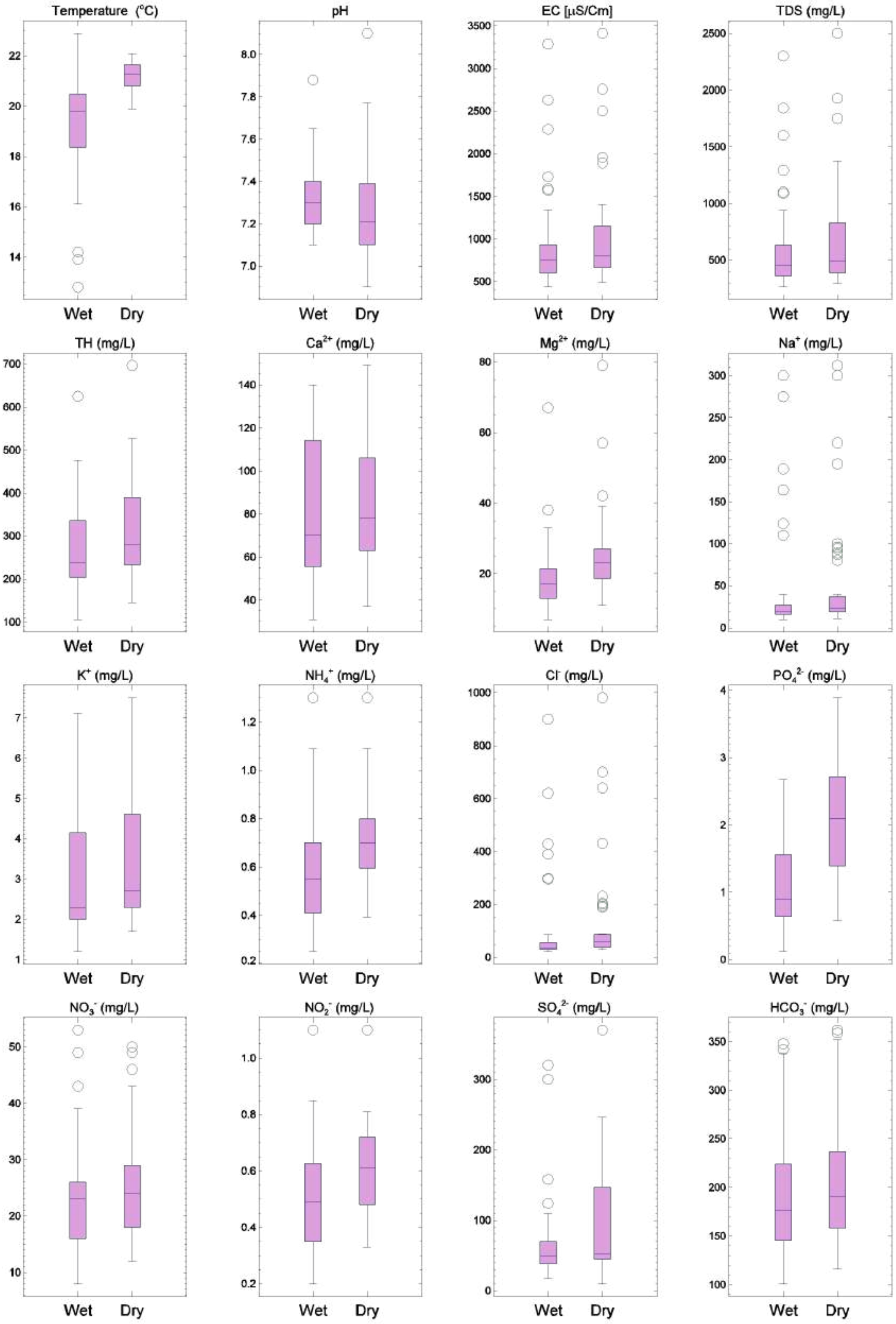


Figure 3 Trend of seasonal variation of groundwater quality parameters in the study area

Table 7 Statistical summary of physicochemical parameters for the groundwater

Parameters	Winter 2017					Summer 2017				
	Min	Max	Mean	Med	STD	Min	Max	Mean	Med	STD
Temp (°C)	12.8	22.9	19.25	19.8	2.171	19.9	22.1	21.17	21.3	0.632
pH	7.1	7.88	7.324	7.3	0.158	6.9	8.1	7.265	7.21	0.228
EC (μS/ Cm)	435	3285	917.74	755	571.89	492	3411	1013.5	808	606.09
TDS (mg/ L)	261	2300	597.27	455	422.49	295	2501	649.87	488	452.62
TH (mg/ L)	106.2	624.7	273.95	237.9	105.12	145.8	696.4	312.49	280.4	105.90
Ca^{2+} (mg/ L)	31	140	78.106	70	30.65	37	149	84.277	78	27.845
Mg^{2+}(mg/ L)	7	67	19.191	17	9.57	11	79	24.83	23	12.112
Na^{+} (mg/ L)	10	300	42.489	20	64.194	11	312	52.085	24	69.01
K^{+} (mg/ L)	1.2	7.1	3.187	2.3	1.678	1.7	7.5	3.577	2.7	1.683
NH_4^{+} (mg/ L)	0.25	1.3	0.581	0.55	0.211	0.39	1.3	0.693	0.7	0.179
Cl^{-} (mg/ L)	22	900	96.468	38	170.75	29	981	126.04	58	190.88
PO_4^{2-} (mg/ L)	0.12	2.67	1.08	0.9	0.611	0.58	3.89	2.09	2.1	0.887
NO_3^{-} (mg/ L)	8	53	22.787	23	9.659	12	50	25.213	24	9.706
NO_2^{-} (mg/ L)	0.2	1.1	0.501	0.49	0.18	0.33	1.1	0.599	0.61	0.16
SO_4^{2-} (mg/ L)	18	320	67.255	50	59.326	10	370	91.83	53	77.541
HCO_3^{-} (mg/ L)	101	348	195.76	176	69.393	116	362	209.53	191	68.925

3.2 Major anions

The seasonal distributions of physiochemical parameters are summarized statistically in Table 6 and 7. Generally, on one hand, the decreasing order of magnitude of cations in the study area of surface water in all seasons was the same with the following order Ca^{2+}> Na^{+}> Mg^{2+}>K^{+}> $NH_4{}^{+}$. Calcium with Sodium was the dominant cation with concentrations up to 93.35 and 72.25 mg/L. Meanwhile, the magnesium and potassium concentrations were measured up to 21.75 and 6.45 mg/L respectively. In addition, the decreasing order of magnitude of cations in the study area of groundwater was the same with the following order $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+} > NH_4{}^{+}$. As expected, sodium and calcium were the dominant cations with concentrations up to 161.5, 93 mg/L. Meanwhile, the magnesium with potassium concentrations was measured up to 45 and 4.6 mg/L respectively.

On the other hand, the decreasing order of magnitude of anions in the study area of surface water in the wet and dry seasons of 2017 and 2018 was the same with the following order $HCO_3^{-} > SO_4^{2-} > Cl^{-} > NO_3^{-} > PO_4^{3-} > NO_2^{-}$. Bicarbonate and sulfate were the dominant anions with high concentrations up to 233 and 146.5 mg/L. Meanwhile, chloride concentration was 128 mg/L. In addition, the decreasing order of magnitude of anions in the study area for surface water in the wet season of 2017 were the following order $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-} > PO_4^{3-} > NO_2^{-}$. Bicarbonate and chloride were the dominant anions with high concentrations of up to 233 and 76 mg/L. Meanwhile, sulfate concentration was 55 mg/L. in addition, the decreasing order of magnitude of anions in the study area for the groundwater in winter and summer of 2017 was the same with the following order $Cl^{-} > HCO_3^{-} > SO_4^{2-} > NO_3^{-} > PO_4^{3-} > NO_2^{-}$. As expected, chloride with bicarbonate was the dominant anion with concentrations up to 506.5 and 289 mg/L respectively. Meanwhile, sulfate concentration was 190 mg/L.

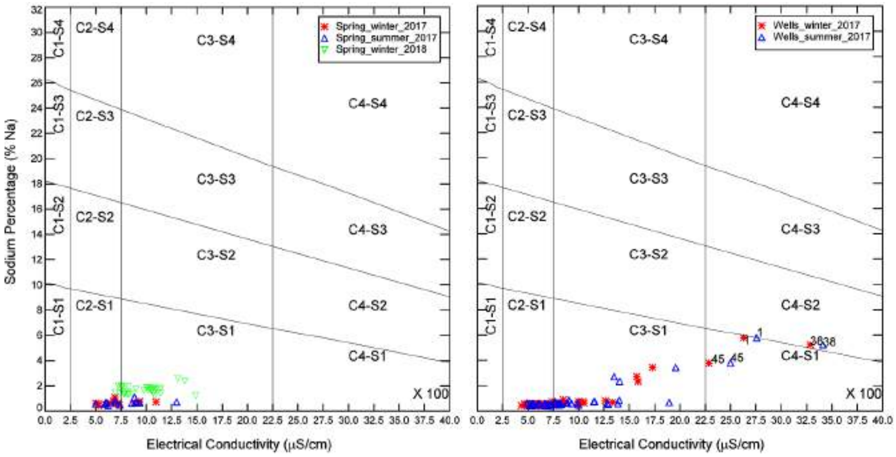
3.3 Water quality Indices

3.3.1 Salinity hazard and alkali hazard

Richards (1968) [66] is classified the quality of water for irrigations purposes based on the obtained EC values in the water sample vs the calculated Sodium Adsorption Ratio (SAR) (Table 2) and as shown in Figure 4(a) and 4(b). The computed index was projected on the US salinity diagram, in which the EC is taken as a salinity hazard and SAR as an alkalinity hazard. The results revealed that the surface water Figure 4(a), on one hand, was categorized as (Good/ Excellent) with 71.43 % in winter 2017, 57.14 % in summer 2017, and 11.11% in winter 2018. In addition, it was also classified as (Doubtful/ Excellent) with 28.57 % in winter of 2017, 42.86% in summer of 2017 and 88.89 % in winter of 2018, which give an indicator into the suitability of water for irrigation purposes.

Furthermore, the groundwater, on the other hand, Figure 4(b) were categorized as (Good/ Excellent) with 48.94 % in winter of 2017 and 38.3 % in summer of 2017, as (Doubtful/ Excellent) with 44.68 % in winter of 2017 and 55.34 % in summer of 2017. This leads us to its suitability for irrigation purposes. In addition, some samples for the groundwater were classified as unsuitable during the winter and summer of 2017 with the same percentage of 4.25 % and

2.13 % respectively. This leads us to its unsuitability for irrigation purposes. All results were visualized as shown in Figure 4(b).

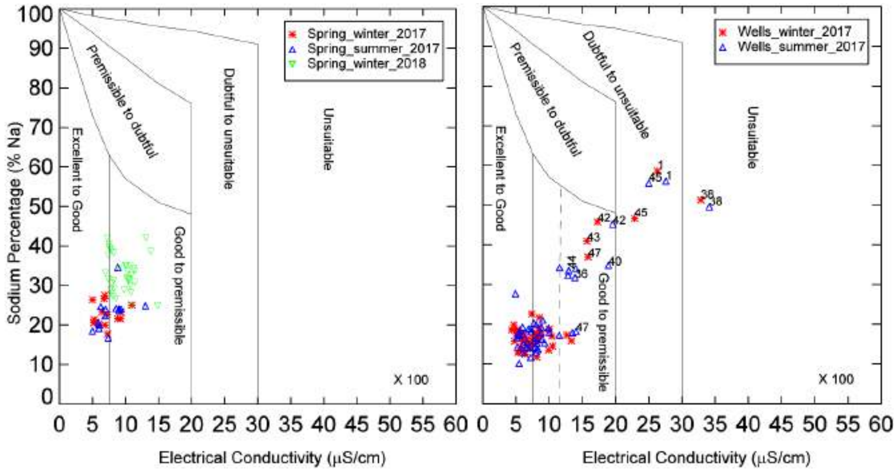


(a) (b)

Figure 4 Rating of surface and groundwater samples concerning salinity and alkali hazards. (a) Surface water; (b) Groundwater.

3.3.2 Wilcox diagram

Wilcox diagram [50, 52] used % sodium, as an indicator of sodium hazard, and specific conductance in evaluating the suitability of groundwater for irrigation usage [49, 50] as well as the U.S. Salinity Laboratory's diagram. A high %Na in the soil can have devastating impacts on the soil structure, aeration, and infiltration [67]. Sodium percentage determines as shown in Table 2. All the concentration values are expressed in (meq/L). Evaluation based on the Wilcox diagram was categorized as "Excellent to good", good to permissible", "Permissible to doubtful", "Doubtful to Unsuitable" and "Unsuitable". Visualizations of the analytical data for the surface and groundwater were done by projecting them on the US salinity diagram as shown in Figure 5(a) and 5(b).



(a) (b)

Figure 5 Rating for the surface and groundwaters to percentage sodium (% Na) and the electrical conductivity [52]

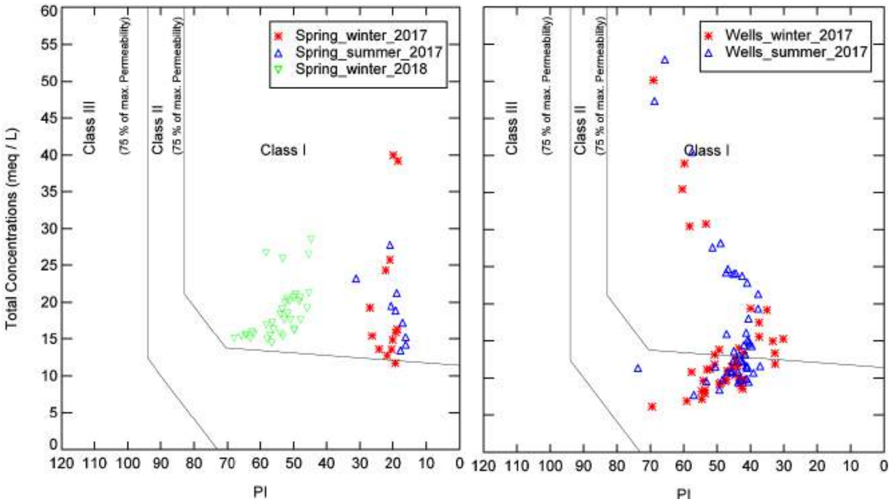
The results revealed that the surface water, on one hand, was categorized as (Excellent to Good) with 71.43 % in winter of 2017, 57.14 % in summer of 2017, and 11.11% in winter 2018. In addition, it was also categorized as (Good to Permissible) with 28.57 % in winter of 2017, 42.86% in summer of 2017 and 88.89 % in winter of 2018 as shown in Figure 5(a) , which give an indicator into the suitability of water for irrigation purposes. In addition, the groundwater, on the other hand, were categorized as (Excellent/ Good) with 48.94 % in winter of 2017 and 38.3 % in summer of 2017, as (Good to Permissible) with 44.68 % in winter of 2017 and 55.32 % in summer of 2017, as (Doubtful to Unsuitable) with the same percentage of 4.25 % in winter and summer of 2017. Finally, it was exhibited as (Unsuitable) with the same percentage of 2.13 % in winter and summer of 2017 as shown in Figure 5(b). It seems to us that the groundwater samples have approximately the same percentage that shown in the previous section (3.3.1). In addition, the results suggested that good groundwater suitability for irrigation purposes except for a small number of the wells samples that were labeled in Figure 5(b) and with the revealed results in Figure 4(b).

3.3.3 The permeability index (PI)

The Permeability Index (PI) is an important parameter to assess the quality of irrigation water concerning the soil for agriculture improvement [68, 69]. The long-term use of irrigation water can affect the soil permeability, influenced by the content of Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- in the soil. Permeability index is calculated by using the PI formula in Table 2 with all unit parameters in (meq/L) [53, 70, 71]. Thus, a diagram was developed using the total concentration of salts in water samples and the PI index. Based on the PI values, the irrigated water is classified as Class I ($>$ 75%), Class II (25-75%) and Class III ($<$ 25%). In Class (I and II). The waters are categorized as good for irrigation with 75% or more of the maximum permeability. In addition, Class III is characteristic of what water is not suitable for irrigation purposes with 25% of the maximum permeability [61].

The PI values for the surface water in winter of 2017 were classified into Class I and Class II with a percentage of 35.71% and 64.29% from the total samples respectively. In addition, water categorizations indicate that the water is changed from moderate to good and is suitable for irrigation purposes. Categorizations of surface water in the summer of 2017 altered inversely with that exhibited for a winter season of 2017 to be 64.29% of the samples fall under Class I and 35.71% of the total samples belong to Class II. Unlike the previous results, 100% of the surface water in winter of 2018 were classified into Class I indicating that the surface water is as good for irrigation purpose.

In addition, the PI values for the groundwater in the winter of 2017 were classified into Class I and Class II with a percentage of 36.17% and 63.82% from the total samples respectively. In addition, water categorizations indicate that the groundwater is changed from moderate to good and is suitable for irrigation purposes. Meanwhile, the PI values for the groundwater in the summer of 2017 were classified into Class I and Class II with a percentage of 53.19% and 46.81% respectively. The obtained results revealed that the groundwater is changed from moderate to good and is suitable for irrigation purposes.



(a) (b)

Figure 6 Doneen classification for irrigation purposes based on the permeability index (PI) [53]. (a) Surface water; (b) Groundwater.

3.3.4 Piper diagram

The Piper diagram [72] is a representative method for classifying groundwater by producing a diagram based on the distribution of cations and anions in the water sample. This was done by a combination of anions and cations triangles that lie on a common baseline and a central diamond shape between them. In the two triangular fields, the values of major cations and anions are in meq/L and plotted separately. After that, they projected onto the central field for the representation of the overall characteristics of water. This visualization reveals useful properties and relationships for large sample groups [73]. The Piper diagram can separate into hydrochemical faces as shown in Figure 7. In addition, the diamond diagram tells us different things depending on what one plotting. For example, the top quadrant is calcium sulfate waters (gypsum groundwater and mine drainage), the left quadrant is calcium bicarbonate waters (shallow fresh groundwater), the right quadrant is sodium chloride waters (marine and deep ancient groundwater), while the bottom quadrant is sodium bicarbonate waters (deep groundwater influenced by ion exchange). For these reasons, the author used a Piper diagram to classify the types of collected water samples. Due to a large number of groundwater samples, it is divided into 4 groups; each group contains 12 samples. This allowed us to classify the water type more accurately for further interpretations. Classifications of water samples were projected on a map using the GIS software as shown in Figure 10.

The obtained data for groundwater in the winter of 2017 is shown in Figure 7 and 8, and revealed that east and west the study area especially in *Derna* and *Massah* districts, the groundwater is characterized as calcium sulfate waters (gypsum groundwater and mine drainage). Most of all groundwater closed to the Mediterranean coast of the study area revealed that the groundwater is characterized by sodium chloride waters (marine and deep ancient groundwater) due to seawater intrusion. In addition, the other groundwater samples are characterized as calcium bicarbonate waters (shallow fresh groundwater). These results exhibited a complex characteristic for groundwater that derived mainly from the dissolution of minerals in the soil and the rocks with which it is or has been in contact.

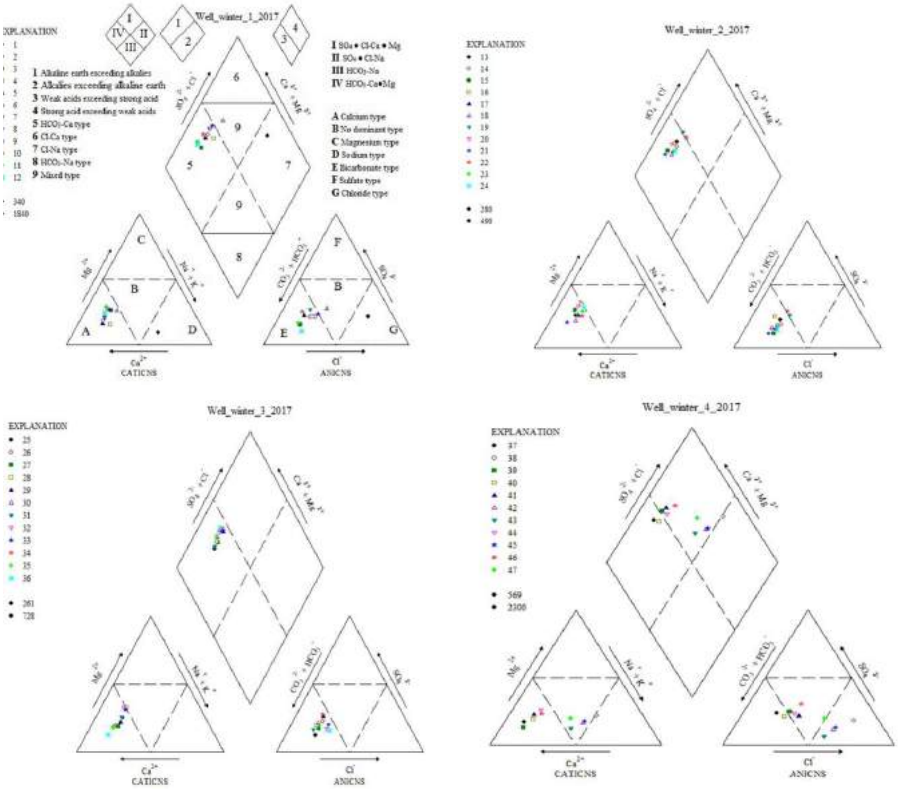


Figure 7 Piper diagram for assessing the irrigation water quality of groundwater in the winter of 2017. The water samples were divided into four groups; each group contains only 12 samples to clarify the plot for further interpretations. The upper left diagram contains a different legend clarification for the first 12 samples.

Not far away from all the results in the winter season, the obtained results for the groundwater samples in the summer of 2017 revealed that all water samples are also characterized by calcium bicarbonate waters (shallow fresh groundwater). In addition, collected groundwater samples closed to the Mediterranean coast of the study area characterized as sodium chloride waters (marine and deep ancient groundwater) especially, in the east and the west parts of the study area and calcium sulfate water due to seawater intrusion as shown in Figure 8. Furthermore, a piper diagram was also used to classify the surface water samples in the winter of 2017.

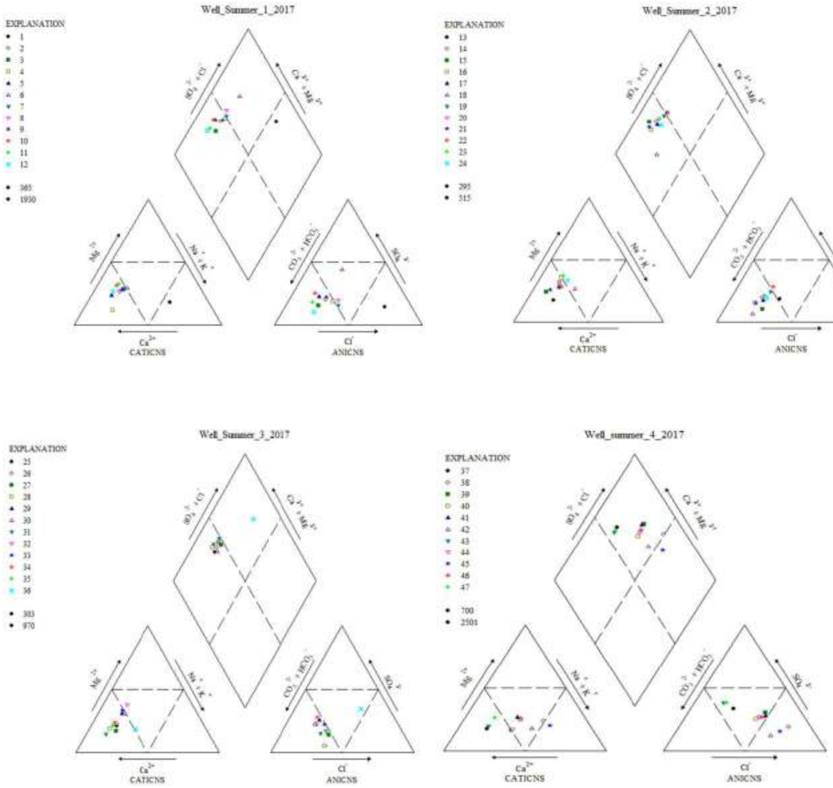


Figure 8 As in Figure 7 but for the groundwater in the summer of 2017

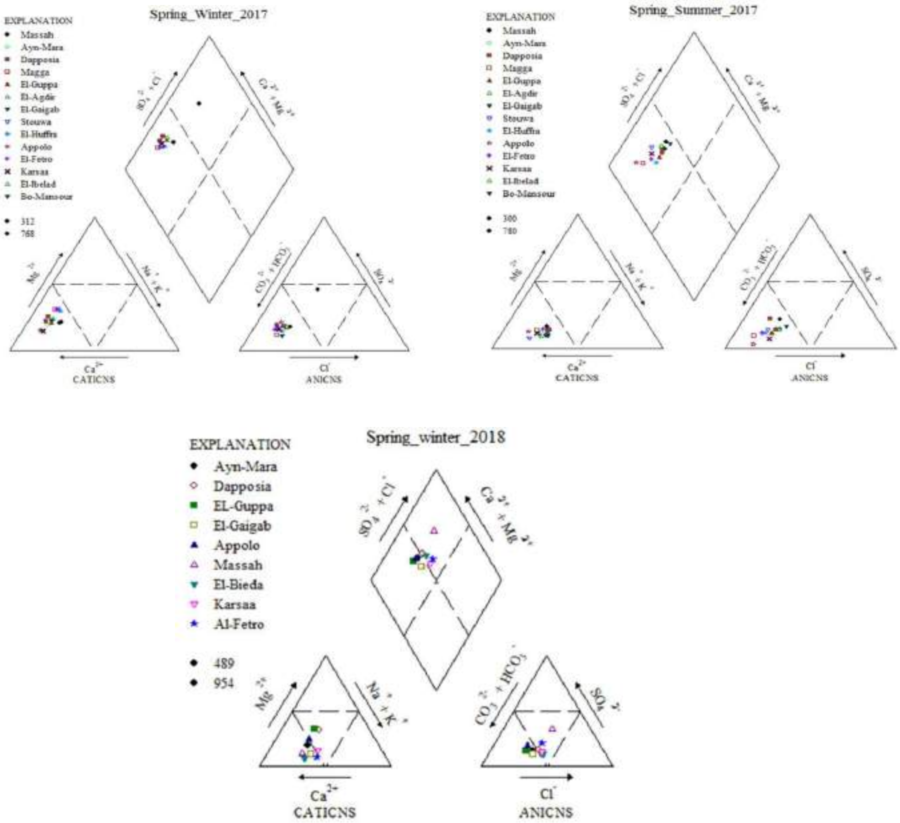
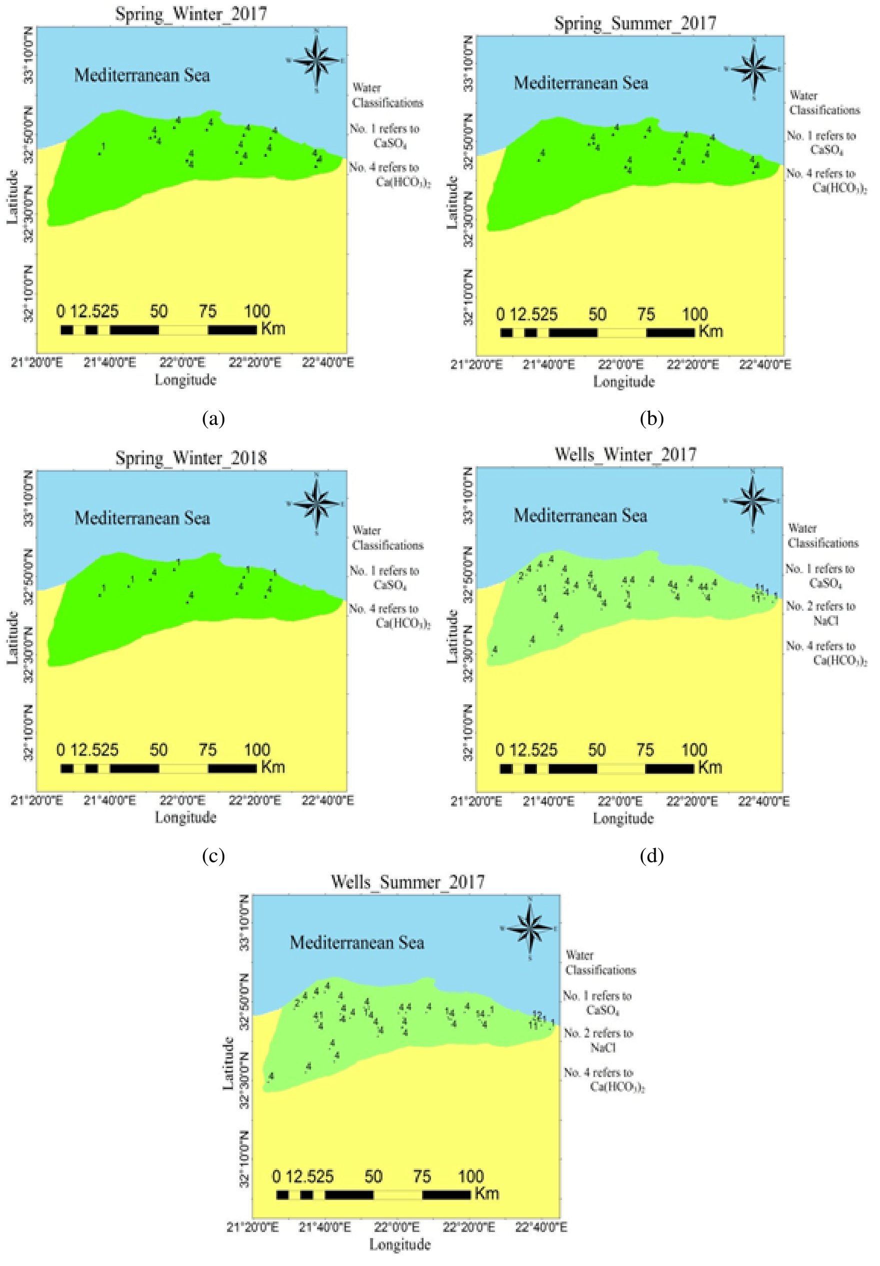


Figure 9 As in Figure 81 but for the surface water in winter and summer of 2017 with winter of 2018

It was observed that calcium bicarbonate waters characterize all the water samples. It was also observed the same result for the collected surface water samples in the summer of 2017 except for *Massah* spring that characterized as calcium sulfate waters. In addition, the surface water samples in the winter of 2018 are characterized as calcium bicarbonate waters, except for *El-Bieda*, *Massah*, *El-Fetro*, *Dapposia* and *Karsaa* Districts that are characterized by calcium sulfate waters as shown in Figure 9.



(a) (b)

(c) (d)

(e)

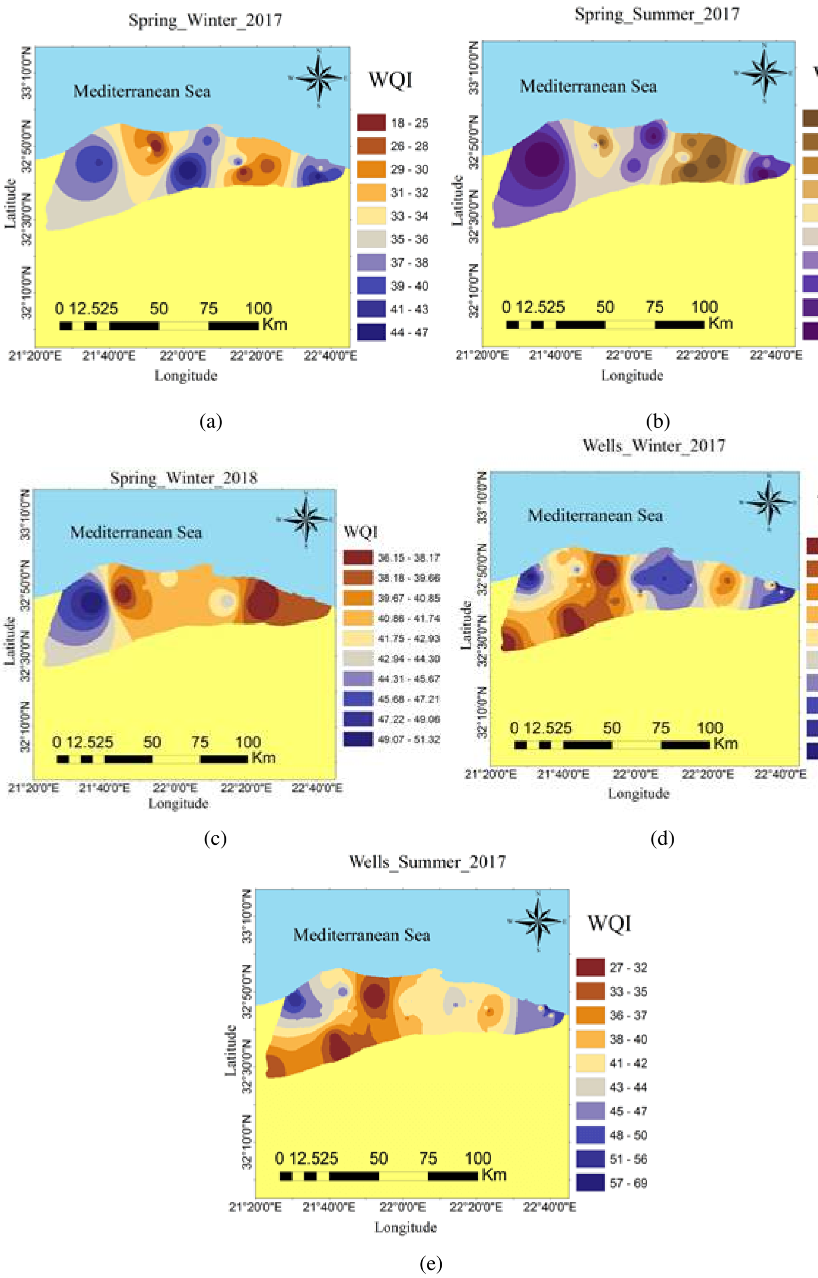
Figure 10 Water Classifications for the study area by projecting the results from a piper diagram in a map using GIS software. (a, b, c): The upper and the middle panel for the surface water in winter & summer of 2017 and winter of 2018. (d, e): The lower panel for the groundwater in winter and summer of 2017.

3.4 The suitability of water for drinking and irrigation purposes

3.4.1 Suitability of surface and groundwater for drinking purposes

According to the computational method of water quality index (WQI) for drinking purposes and categorization of their water statuses as explained in section 2.5; it was found that the surface water statuses in the winter of 2017 were categorized between excellent (14.28%) and good (85.72%) with water quality ratings varied between 17.41 and 46.58 as shown in Figure

11(a). In addition, the surface water statuses in the summer of 2017 were categorized between excellent (7.14%) and good (92.86%) with water quality ratings ranged between 23.10and 47.51 as shown in Figure 11(b). Furthermore, the surface water statuses in the winter of 2018 were categorized between good (88.89%) and poor(11.11%) with water quality ratings ranged between 36.10and 51.3 as shown in Figure 11(c). It was found that the groundwater statuses in the winter of 2017 were categorized between excellent (8.51%), good (85.11%) and poor(6.38%) with water quality ratings varied between 17.41 and 46.58 as shown in Figure 11(d). In addition, the groundwater statuses in the summer of 2017 were categorized between good (91.49%) and poor (8.51%) with water quality ratings ranged between 23.10and 47.51 as shown in Figure 11(e).



(a) (b)

(c) (d)

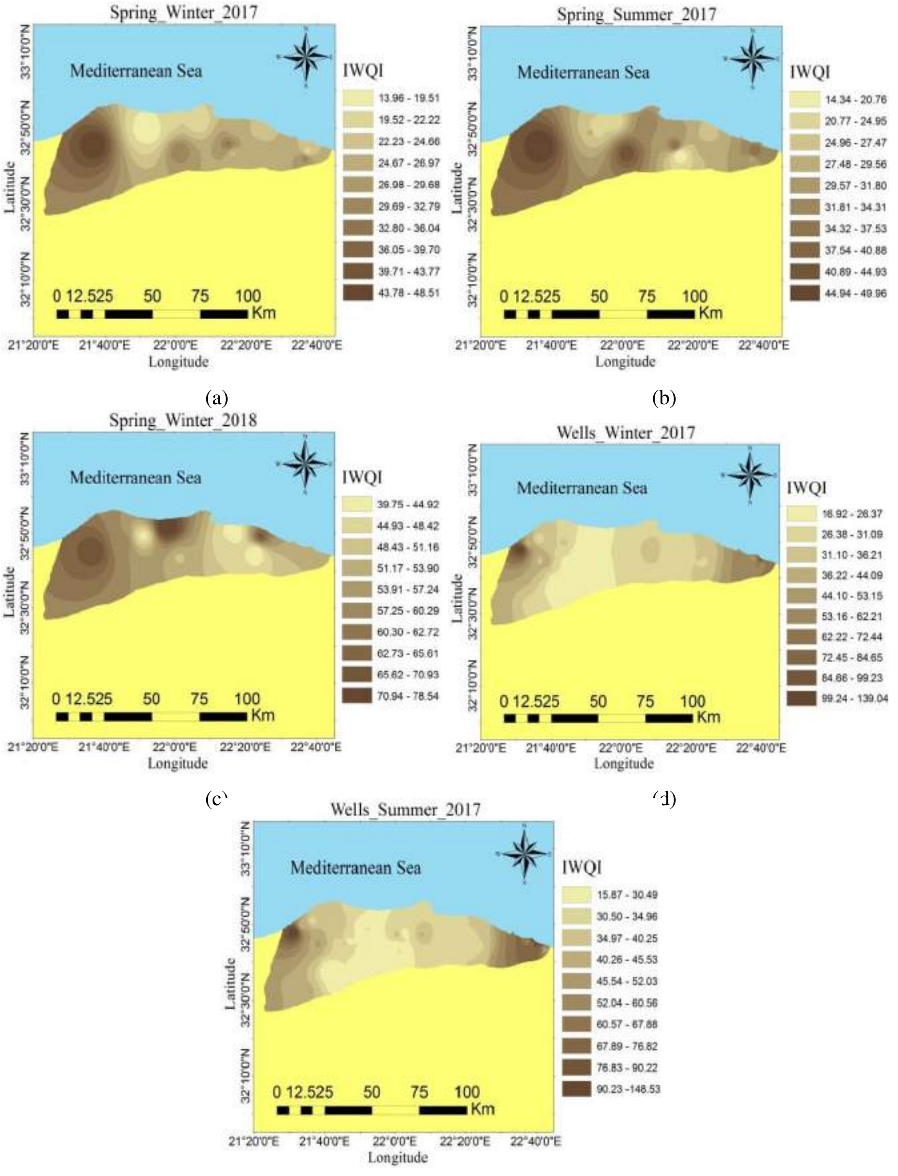
(e)

Figure 11 Classification of water status for drinking purposes of surface water in: (a) Winter 2017; (b) Summer 2017; (c) Winter 2018; and of groundwater in: (e) Winter 2017; (f) Summer 2017.

3.4.2 Suitability of surface and groundwater for irrigation purposes

According to the calculation method of water quality index (WQI) for irrigation purposes and categorization of their water statuses as explained in section 2.5; It was found that the surface water statuses in the winter of 2017 were categorized between excellent (49.99%) and good(50.01%) with water quality ratings varied between 13.95 and 48.51 as shown in

Figure 12(a). In addition, the surface water statuses in the summer of 2017 were categorized between excellent (21.42%) and good (78.58%) with water quality ratings ranged between 14.32and 49.95 as shown in Figure 12(b). Furthermore, the surface water statuses in the winter of 2018 were categorized between good(44.44%), poor(44.44), and very poor(11.12%) with water quality ratings ranged between 39.95and 78.45 as shown in Figure 12(c). It was found that the groundwater statuses in the winter of 2017 were categorized between excellent (21.28 %), good(61.7%), poor(8.51%), very poor (4.25%) and unsuitable(4.26%) with water quality ratings varied between 16.92 and 139.04 as shown in Figure 12(d). In addition, the groundwater statuses in the summer of 2017 were categorized between excellent (6.38%) good(70.22%), poor(12.77%), very poor (4.26%), and unsuitable(6.38%) with water quality ratings ranged between 15.69and 148.53 as shown in Figure 12(e).



(a) (b)

(c) (d)

(e)

Figure 12 Classification of water status for irrigation purposes of surface water in: (a) Winter 2017; (b) Summer 2017; (c) Winter 2018; and of groundwater in: (e) Winter 2017; (f) Summer 2017.

4 Conclusion

The present study is aimed to investigate the water quality index of the surface and underground water for drinking (WQI) and irrigation (IWQI) purposes in the Al Jabal al Akhdar region of Libya. Based on the physicochemical parameters the results revealed a basic pH level for surface water in all seasons and the wet season of groundwater ($7.01 < pH < 7.88$). In addition, it altered from acidic to basic in the dry season of 2017 with a maximum level of 8.1

due to a high-level concentration of bicarbonate in water samples as measured. It was observed that the ratio between TDS and EC increased with the decrease of pH levels, which indicates more releasing inorganic matter due to different content of rocks, minerals and metals in the study area. Generally, calcium with sodium was dominant cations of surface water and while sodium and calcium were dominated cations for the groundwater. Furthermore, bicarbonate and sulfate were the dominant anions of the surface and groundwater. Meanwhile, bicarbonate and chloride were the dominant anions in the wet season of 2017.

It was observed that the surface water is suitable for irrigation purposes based on the U.S salinity, the Wilcox, and the Doneen classifications. Meanwhile, the groundwater is classified between excellent and doubtful except for some samples that were classified as unfit for irrigation purposes in east and west the study area especially in Derna and Massa city respectively. Furthermore and based on the Piper diagram, the types of surface and groundwater were classified as calcium sulfate (gypsum groundwater and mine drainage) and sodium chloride due to seawater intrusion east, along the Mediterranean shore and the west part of the study area. Meanwhile, the surface and groundwater types are classified as calcium bicarbonate (water passes through limestone or other calcium carbonate-containing minerals) in the middle part of the study area. The water types reflected the zones soil types as shown in Figure 1(d).

The computed water quality index for irrigation (IWQI) purposes in the wet and dry seasons of 2017 with a wet season of 2018 were categorized between excellent (49.99, 21.42 and 0%), good (50.01, 78.58 and 44.44%), poor (0, 0, 4.44%) and very poor (0, 0, 11.12%). In addition, It was found that the groundwater statuses were categorized between excellent (21.28 and 6.38%), good (61.7 and 70.22%), poor (8.51 and 12.77%), very poor (4.25 and 4.25%), and unsuitable (4.26 and 6.38%) respectively. Finally, the water quality index (WQI) of surface water for drinking purposes was categorized as excellent (14.28 and 7.14%) and good (85.72 and 92.86%) in the wet and dry seasons of 2017. In addition, the surface water statuses in the winter of 2018 were categorized between good (88.89%) and poor (11.11%). Meanwhile, the groundwater statuses were categorized between excellent (8.51 and 0%), good (85.11 and 91.49%), and poor (6.38 and 8.51%). The revealed results of the water quality index for drinking and irrigation purposes agree with that concluded by US salinity, the Wilcox, and the Doneen diagram.

Acknowledgments

The author is highly appreciated and gratefully of Prof. Dr. Maie El-Gammal at Environmental Sciences Department, Faculty of Science, Damietta University, Egypt for her excellent support with vital comments and improving the quality of this article. In addition, my thanks to staff members at the Man-made River Laboratory in Benghazi city in Libya for their offerts for water samples analysis and support us with more detailed information for analysis methods and instrumentations.

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