Groundwater Quality Assessment Based on Water Quality Index in Northern Cyprus

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Abstract—The largest coastal aquifer in northwestern Cyprus is the Morphou aquifer. The objective of the current study was to evaluate the quality of the groundwater and its suitability for drinking purposes in the Morphou (Güzelyurt) region, Cyprus. To realize this aim, 118 groundwater samples were collected during wet and dry seasons over a period of 11 years. Major physicochemical characteristics (electrical conductivity, pH, bicarbonate, calcium, magnesium, chloride, and total and carbonate hardness) were measured and analyzed. The assessment of groundwater quality was evaluated with the help of the Water Quality Index (WQI). The results demonstrated that 56% and 50% of the groundwater samples during dry and wet seasons respectively were unsatisfactory according to the Cl^- limits of the WHO standard. In addition, approximately 10% of the groundwater samples come under class 2 (good water), 30% of the samples come under class 3 (fairwater), 13% come under classes 4 and 5, and the rest under class 6 (unsuitable for drinking).

Keywords-Morphou; water quality; groundwater level changes; groundwater; physicochemical parameters; water quality index

I. INTRODUCTION

Groundwater is the main source of water used for multiple purposes in arid and semi-arid regions [1-4]. Additionally, due to the pollution of surface water bodies, groundwater has become an important source to secure the safety of water supply [5]. The growth of populations and increasing climate variations reduced the groundwater level due to the imbalance between groundwater recharge and extraction. This is especially true for Cyprus. The island suffers from periodic drought due to the general decrease in precipitation [6-8]. Since they represent the main source for drinking and irrigation water supplies, groundwater resources in Cyprus are of major concern about the quality and water supplier's sustainability. In Northern Cyprus, the water resources are categorized into groundwater, surface water (dam), and the Turkey-North Cyprus water pipeline project [9, 10]. Furthermore, river basins and dams are the main surface water resources [11]. As mentioned above, groundwater is the main water source in the island. Due to the over-pumping rate, the level of the groundwater declined and reached 45-50m below sea level [12-15] and its quality has been reduced due to the saltwater intrusion and bedrock contamination [14]. According to [16-18], the chloride concentration has reached 7000ppm in several coastal locations. The Kyrenia mountain aquifer, Morphou (Güzelyurt) aquifer, and Gazimağusa aquifer are considered the main aquifers of Northern Cyprus. Morphou aquifer is the largest coastal aquifer, which provides water for irrigation and municipal purposes. Additionally, according to [9, 19-21], overexploitation is the main drive for the decline in the groundwater level below sea level in some sites in the region [9, 19]. In general, the agriculture sector is important in the selected region [22-24]. In Northern Cyprus, the total agricultural area and the total irrigated area are about 187069 ha and 9714 ha respectively [9]. Moreover, agricultural production has decreased and crop yield has been reduced due to the poor water quality and changes in rainfalls. Thus, the study area is currently facing significant water challenges.

Determining the status of groundwater for drinking purposes using the Water Quality Index (WQI) in Morphou aquifer is the main aim of the current paper. In this study, 118 groundwater samples were collected and their physicochemical characteristics were analyzed. The results are compared with the WHO water quality standard. Figure 1 illustrates the flowchart of the current study.

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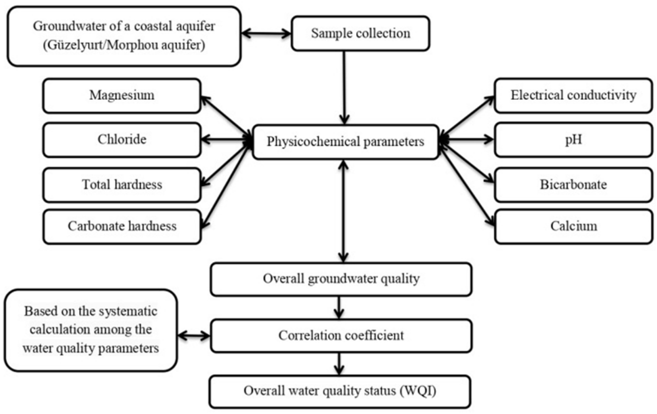

Fig. 1. Flowchart of the procedure followed in the current study.

II. MATERIALS AND METHODS

A. Study Area and Sample Collection

Figure 2 shows the location of the Morphou region, which covers an area of 381km^2 and has average altitude of 45m above sea level.

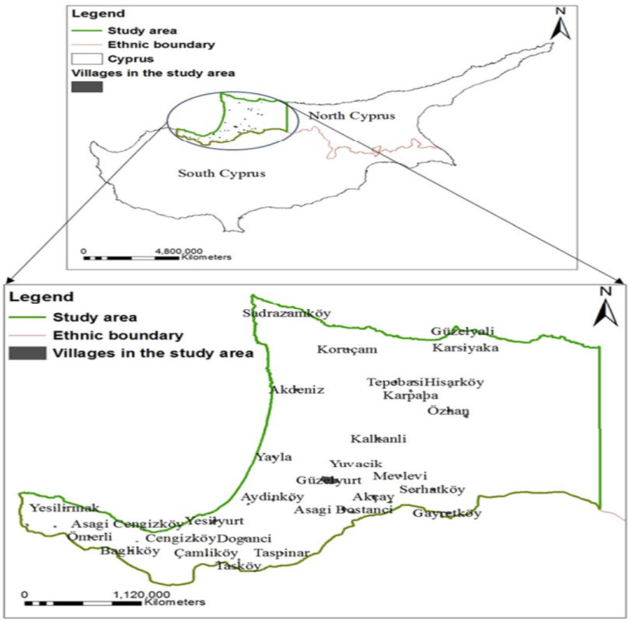

Fig. 2. Cyprus map and location of the Morphou region.

In the present study, the data of 118 wells, distributed over the selected region, have been used to analyze the static groundwater level and quality in the region (Figure 3). The data were measured during two seasons (recharge season, April, May, and June, and charge season, November, December, and January). The study data cover a period from 2006 to 2016. The physicochemical properties (electrical conductivity, pH, bicarbonate, calcium, magnesium, chloride, and hardness in terms of total hardness and carbonate hardness) were analyzed and evaluated. The collected water samples were examined by following the standard methods. Generally, the groundwater samples were collected with 1L polythene bottles and their physicochemical characteristics were analyzed. The sample bottles were washed with distilled water before sample collection. The instrumental and volumetric methods utilized to measure the physicochemical properties are listed in Table I. The temperature of each sample was measured using a common mercury thermometer.

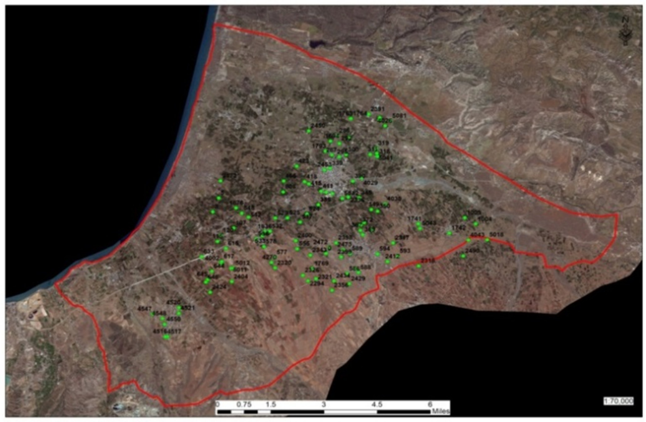

Fig. 3. Map sample locations, prepared with ArcGIS 10.

TABLE I. INSTRUMENTAL AND VOLUMETRIC METHODS USED IN THE CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES

Parameter	Unit	Method/ instrument	Reagents
pH	-	pH meter	pH 4, 7, and 9.2 (buffer solutions)
EC	μS/cm	EC meter	Potassium chloride
HCO_3	mg/l	Volumetric	Hydrosulfuric acid, phenolphthalein, and methyl orange
Ca^{2+}	mg/l	Volumetric	EDTA, sodium hydroxide, and murexide
Mg^{+2}	mg/l	Calculation (TH-Ca^{2+})	-
Cl^-	mg/l	Argentometric	Silver nitrate, potassium chromate

B. Correlations between the Physicochemical Parameters

The interrelationships between physicochemical variables were examined using Pearson product-moment correlation followed by a parametric method for normal distribution. According to [25], Pearson's correlation coefficient (R) can be estimated using (1). Moreover, the data are standardized with (2).

$$R = \sum_i^n (X_i - \bar{X})\,(Y_i - \bar{Y})/(n-1)\,S_x S_y \quad (1)$$

$$Z = \frac{x-\bar{x}}{S} \quad (2)$$

where $\bar{X}$, $\bar{Y}$, S_x, S_y are the sample means and standard deviations of $X_i, Y_i, i = 1, \dots, n, x$ is the initial data value, and $\bar{x}$ and S are the average and standard deviation of data respectively. Correlation coefficients and P-values were calculated with Minitab 17 software.

C. Water Quality Index (WQI)

Several studies have classified groundwater with the help of WQI [26, 27] as shown in Table II. The WQI calculation was carried out using a weighted arithmetic index as shown below [29].

Water quality rating is calculated as:

$$q_n = \left(\frac{V_n - V_i}{S_n - V_i}\right) \times 100 \quad (3)$$

where q_n is the water quality rating for the n^{th} parameter, V_n is the observed value of the n^{th} parameter, S_n is the standard permissible value of the n^{th} parameter, and V_i is its ideal value.

The unit weight (W_n) for each water quality parameter is determined by:

$$W_n = \frac{K}{s_n} \quad (4)$$

where W_n is the unit weight of the n^{th} parameter, s_n is its standard value, and K is constant proportionality, which is calculated using the below equation:

$$K = \frac{1}{\sum 1/\, s_n} \quad (5)$$

The overall WQI is estimated by:

$$\text{WQI} = \frac{\sum q_n W_n}{\sum W_n} \quad (6)$$

TABLE II. CLASSES PROPOSED FOR WQI FOR DRINKING (WQID) [28]

Class	Range	Type of groundwater
1	<25	Excellent water
2	25-50	Good water
3	50-75	Fairwater
4	75-100	Poor water
5	100-150	Very poor water
6	>150	Unsuitable for drinking/irrigation

III. RESULTS

A. Physicochemical Parameters of the Selected Wells

Table III summarizes the descriptive statistics of the analyzed variables of the collected samples. The groundwater temperature is within the range of 20-25°C for both wet and dry seasons.

1) pH

Generally, pH is an essential indicator that can be utilized for evaluating water quality and contamination degree in water bodies [30]. As shown in Table III, the pH value of most groundwater samples varied from 6.4 to 8.3 with an average value of 7.7 for the dry season. Regarding the wet season, the pH value of groundwater samples ranged from 7.1 to 8.3 with an average value of 7.7. Based on the findings, the groundwater in the selected region is slightly acidic to alkaline in nature.

2) Electrical Conductivity (EC)

EC is another important property that measures the ions present in the water. There is a strong relationship between EC and Total Dissolved Solids (TDS) [30, 31] and a relationship with salinity [32]. In the present study, EC ranges from 604.0 to 8690.0µS/cm for both seasons (see Table III). Table IV presents the classification of EC ranges and types. Thus, for the dry season, 55% of the total groundwater samples come under type I, 24% under type II, and 21% under type III, as shown in Figure 4. During the wet season, 54% of the groundwater samples come under type I, 23% under type II, and 23% under type III.

TABLE III. PHYSICOCHEMICAL PARAMETER STATISTICS RESULTS

Variable	Dry season				WHO standard
	Mean	SD	Minimum	Maximum	
EC [µS/cm]	2132.0	1769.0	606.0	8690.0	500
pH [-]	7.7	0.2	7.1	8.3	6.5-8.5
Temperature [°C]	24.6	0.4	22.5	25.0	-
CO_3 [mg/l]	5.8	21.6	0.0	233.0	-
HCO_3 [mg/l]	281.2	95.5	137.3	621.5	500
TH [mg/l]	685.0	1089.0	84.0	9371.0	-
CH [mg/l]	240.9	92.5	126.7	761.4	-
Ca^{2+} [mg/l]	131.3	204.1	15.5	1620.0	75
Mg^{+2}[mg/l]	86.7	139.2	10.8	1252.7	50
Cl^- [mg/l]	593.9	940.8	65.9	8317.1	250
Variable	**Wet season**				**WHO standard**
	Mean	**SD**	**Minimum**	**Maximum**	
EC [µS/cm]	2088.0	1650.0	604.0	7873.0	500
pH [-]	7.7	0.2	7.1	8.3	6.5-8.5
Temperature [°C]	25.0	0.1	24.2	25.7	-
CO_3 [mg/l]	4.0	4.9	0.0	39.1	-
HCO_3 [mg/l]	270.0	83.9	127.0	562.8	500
TH [mg/l]	654.0	1089.0	74.0	9650.0	-
CH [mg/l]	228.5	78.1	132.5	632.1	-
Ca^{2+} [mg/l]	133.3	207.7	15.5	1622.8	75
Mg^{+2}[mg/l]	84.2	150.4	6.4	1317.9	50
Cl^- [mg/l]	579.3	912.9	64.4	8200.6	250

TABLE IV. EC CLASSIFICATION [33]

Range	Type
<1500µS/cm	Type I (the enrichments of salt are low)
1500-3000µS/cm	Type II (the enrichments of salt are medium)
> 3000µS/cm	Type III (the enrichments of salt are high)

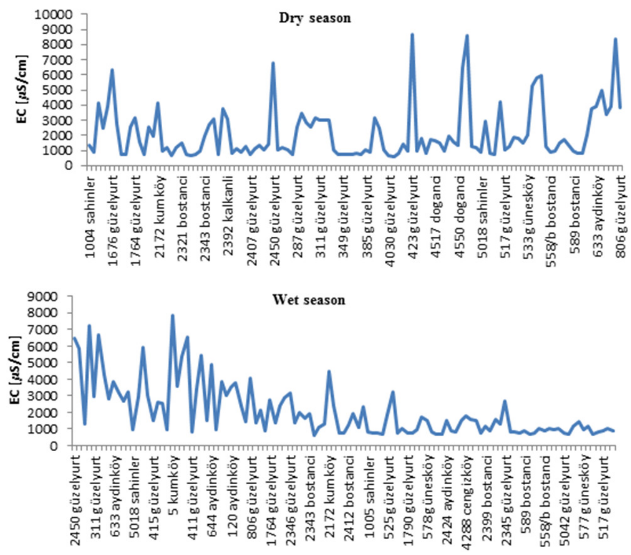

Fig. 4. EC values of the groundwater samples during wet and dry season.

3) Chloride (Cl^-)

It is commonly found in nature as sodium, potassium, and calcium salts. Both natural and human factors contribute to the presence of chloride in groundwater [34]. The results show that the Cl^- concentration in the collected samples varied from 64.4 to 8317.1mg/l as shown in Table III. In general, Cl^- concentrations above about 250mg/l can give a detectable taste in water. Cl^- is mainly derived from non-lithological sources and its solubility is generally high.

4) Calcium (Ca^{2+}) and Magnesium (Mg^{+2})

They are important parameters for evaluating water quality. Ca^{2+} and Mg^{+2} have a direct relationship with hardness [35]. The results showed that the Ca^{2+} and Mg^{+2} in groundwater samples are within the range of 15.5-1622.8mg/l and 6.4-1317.9mg/l respectively. Additionally, it was found that the majority of the samples have a higher concentration of Ca^{2+} and Mg^{+2} compared to the safety limits of the WHO standard.

5) Total Hardness and Carbonate Hardness

Ca^{2+} and Mg^{+2} are the principal ions responsible for Total Hardness (TH). The observed value of TH in the samples lies between 84.0 and 9371.0mg/L as shown in Table III. Table V shows the classification of TH values. According to this, during the dry season, approximately 52% of the groundwater samples come under the very hard category, 34% fall in the hard category, and 14% fall under the moderate category, with no samples belonging to the soft category (Figure 5). Similarly, for the wet season, 49% of the samples come under the very hard category, 36% under the hard category, 15% under the moderate category, and 1% under the soft category. Carbonate Hardness (CH) is a measure of the water hardness caused by the presence of carbonate (CO_3^{-2}) and bicarbonate (HCO_3^-) anions. The observed value of CH ranges from 10 to 3120mg/l.

6) Standard Deviations in the Geochemistry of Groundwater

The Standard Deviations (SDs) of the chemical parameters are shown in Table III. EC and TH have the highest SDs, followed by Cl^-.

B. Interrelations of Physicochemical Parameters

To show the relationship between the physicochemical parameters, the correlation coefficient (r) model was used (Table VI). For the dry season, it was found that EC shows strong positive correlation with pH (-0.551), HCO_3 (0.708), TH (0.847), CH (0.728), Ca^{2+} (0.866), Mg^{+2} (0.814), and Cl^- (0.847). For the wet season, EC has a strong positive correlation with pH, CO_3, HCO_3, TH, CH, Ca^{2+}, Mg^{+2}, and Cl^-. This indicates that the groundwater is mainly controlled by Ca^{2+}, Mg^{+2}, and Cl^-, which depend on anthropogenic activities and mineral solubility, water flow path conditions, and topographical features. The T (sample temperature) has a good correlation with CO_3 (-0.335) and HCO_3 (0.259) for the dry season. It is noticed that there is no relationship between the chemical parameters and temperature samples for the wet season. In addition, it is found that the TH is in good positive correlation with CH, Ca^{2+}, Mg^{+2}, and Cl^-. Also, the Ca^{2+} has a good positive correlation with Cl^- and Mg^{+2}, while Mg^{+2} has a significant positive correlation with Cl^-, reflecting the influences of Ca^{2+} and Mg^{+2} bearing minerals, in addition to the sources of anthropogenic and marine origin.

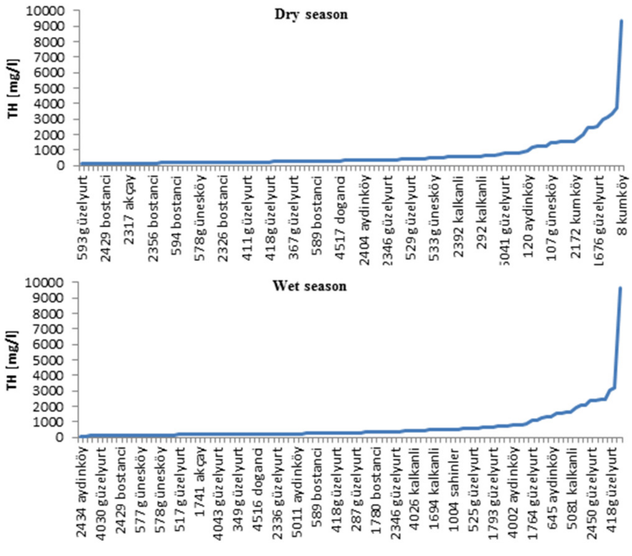

Fig. 5. TH values of the groundwater samples.

TABLE V. TH CLASSIFICATION [36]

Range	Type
<75mg/l	Soft
75-150 mg/l	Moderate
150-300 mg/l	Hard
< 300 mg/l	Very hard

C. Suitability of Groundwater Quality for Drinking

In general, it is observed that the groundwater is free of color, odor and turbidity in the field. The physicochemical characteristics of the collected samples regarding its drinking suitability are shown in Table VII. Based on the previous sections, the pH value, which ranges between 6.4 and 8.3 with an average of 7.7 for both seasons, indicates that all the collected samples are within the safe limit specified by the WHO standard. As shown in Table VIII, 78% and 68% of the samples are above the TH specification during dry and wet seasons respectively. According to [37], hardness is an essential factor for estimating the water usability for drinking and other domestic purposes. Moreover, the Ca^{2+} concentrations indicate that about 40% of the samples are above the Ca^{2+} specification of the WHO standard. The concentration of Mg^{+2} indicated that 60% of the samples were below the safe water limit of 30mg/l. Mortality rates for cardiovascular diseases are associated with a deficit of Ca^{2+} and Mg^{+2} in drinking water [37-39]. Furthermore, bicarbonate is a major element in groundwater chemistry and the human body and may result from the weathering of silicate minerals [40]. It is observed that the HCO_3 concentration of about 32% of the samples was more than 300mg/l. Generally, the high concentration of HCO_3 can lead to the emergence of kidney stones in the presence of a higher concentration of Ca^{2+} [33]. The results demonstrated that 56% and 50% of the groundwater samples during dry and wet seasons were unsatisfactory according to the Cl^- specifications of WHO.

TABLE VI. THE CORRELATION COEFFICIENT OF THE ANALYZED PHYSICOCHEMICAL GROUNDWATER PARAMETERS FOR BOTH SEASONS

			EC	pH	T	CO_3	HCO_3	TH	CH	Ca^{2+}	Mg^{+2}	Cl-
Dry Season	EC	Pearson Correlation	1	-0.551**	0.082	0.03	0.708**	0.847**	0.728**	0.866**	0.814**	0.847**
		Sig. (2-tailed)		0	0.379	0.75	0	0	0	0	0	0
	pH	Pearson Correlation		1	-0.222*	-0.05	-0.618**	-0.436**	-0.584**	-0.448**	-0.424**	-0.449**
		Sig. (2-tailed)			0.017	0.611	0	0	0	0	0	0
	T	Pearson Correlation			1	-0.335**	.0259**	0.021	0.167	0.072	0.001	0.01
		Sig. (2-tailed)					0.005	0.825	0.074	0.44	0.993	0.916
	CO_3	Pearson Correlation					0.011	0.004	-0.01	-0.01	0.016	0.023
		Sig. (2-tailed)					0.908	0.963	0.954	0.955	0.865	0.805
	HCO_3	Pearson Correlation					1	0.504**	0.866**	0.523**	0.473**	0.511**
		Sig. (2-tailed)						0	0	0	0	0
	TH	Pearson Correlation						1	0.733**	0.982**	0.990**	0.983**
		Sig. (2-tailed)							0	0	0	0
	CH	Pearson Correlation							1	0.719**	0.724**	0.750**
		Sig. (2-tailed)								0	0	0
	Ca^{2+}	Pearson Correlation								1	0.954**	0.968**
		Sig. (2-tailed)									0	0
	Mg^{+2}	Pearson Correlation									1	0.976**
		Sig. (2-tailed)										0
	Cl-	Pearson Correlation										1
		Sig. (2-tailed)										
Wet Season	EC	Pearson Correlation	1.0	-0.673**	0.0	-0.321**	0.717**	0.788**	0.747**	0.844**	0.765**	0.805**
		Sig. (2-tailed)		0	1.0	0.001	0.0	0	0	0	0	0
	pH	Pearson Correlation		1	-0.1	0.523**	-0.637**	-0.503**	-0.625**	-0.539**	-0.471**	-0.527**
		Sig. (2-tailed)			0.5	0	0.0	0	0	0	0	0
	T	Pearson Correlation			1	-0.133	0.0	-0.145	-0.13	-0.105	-0.149	-0.138
		Sig. (2-tailed)				0.164	0.6	0.129	0.175	0.271	0.118	0.148
	CO_3	Pearson Correlation				1	-0.206*	-0.249**	-0.138	-0.274**	-0.236*	-0.258**
		Sig. (2-tailed)					0.0	0.008	0.147	0.004	0.013	0.006
	HCO_3	Pearson Correlation					1.	0.548**	0.939**	0.566**	0.529**	0.598**
		Sig. (2-tailed)						0	0	0	0	0
	TH	Pearson Correlation						1	0.709**	0.982**	0.985**	0.982**
		Sig. (2-tailed)							0	0	0	0
	CH	Pearson Correlation							1	0.703**	0.689**	0.752**
		Sig. (2-tailed)								0	0	0
	Ca^{2+}	Pearson Correlation								1	0.966**	0.956**
		Sig. (2-tailed)									0	0
	Mg^{+2}	Pearson Correlation									1	0.962**
		Sig. (2-tailed)										0
	Cl-	Pearson Correlation										1
		Sig. (2-tailed)										
**. Correlation is significant at the 0.01 level (2-tailed).												
*. Correlation is significant at the 0.05 level (2-tailed).												

TABLE VII. GROUNDWATER QUALITY CRITERIA FOR DRINKING

Variable	WHO (2011)	% of samples exceeding the safe limit	
		Dry season	Wet season
EC [µS/cm]	1000	68%	66%
pH [-]	6.5-8.5	0%	0%
HCO_3 [mg/l]	120	100%	100%
TH [mg/l]	200	78%	68%
Ca^{2+} [mg/l]	75	41%	40%
Mg^{+2}[mg/l]	50	42%	41%
Cl^- [mg/l]	250	56%	50%

D. Water Quality Index

Groundwater quality and its suitability for drinking were assessed with the WQI method. Five parameters (pH, TH, Ca^{2+}, Mg^{+2}, and Cl^-) were taken into account for the calculation of the WQI and the WHO drinking water standards were considered.

TABLE VIII. RELATIVE WEIGHTS OF CHEMICAL PARAMETERS

Parameters	WHO standard (2011)	Weight	Relative weight
EC [µS/cm]	1000	4.00	0.235
HCO_3 [mg/l]	120	1.00	0.059
TH [mg/l]	200	3.00	0.176
Ca^{2+} [mg/l]	75	3.00	0.176
Mg^{+2}[mg/l]	50	3.00	0.176
Cl- [mg/l]	250	3.00	0.176
Sum		24.00	1.000

Weighted values were set according to the relative importance of groundwater parameters in drinking water quality. Chloride was given the maximum weight of 5, as it plays the most significant role in water quality assessment. The other parameters were assigned weights between 1 and 5 depending on their importance in water quality determination. The computed W_i values for groundwater parameters are presented in Table VIII. WQI values were computed and the water quality types for each sample location are given in Table IX. It is found that approximately 10% of the groundwater samples come under class 2 (good water), 30% of the samples come under class 3 (fairwater), 13% of groundwater samples come under class 4 and 5, and the rest of the groundwater samples under the class 6 (unsuitable for drinking).

TABLE IX. GROUNDWATER QUALITY INDEX CLASSIFICATION OF THE SAMPLES BASED ON WQI FOR BOTH SEASONS

Site name	WQI	Water quality category	Site name	WQI	Water quality category
4043 Morphou	42.69	Good	555 Bostanci	80.16	Poor
2318 Akçay	44.76	Good	2472 Morphou	83.94	Poor
4030 Morphou	44.90	Good	5011 Aydinköy	85.52	Poor
345 Morphou	45.65	Good	2434 Aydinköy	85.67	Poor
2328 Morphou	47.70	Good	2404 Aydinköy	86.81	Poor
1790 Morphou	47.82	Good	588 Bostanci	89.79	Poor
349 Morphou	48.05	Good	2424 Aydinköy	92.13	Poor
350 Morphou	48.43	Good	578 Günesköy	93.19	Poor
5043 Akçay	48.79	Good	4550 Doganci	93.40	Poor
2356 Bostanci	49.14	Good	415 Morphou	94.82	Poor
593 Morphou	49.38	Good	1004 Sahinler	94.87	Poor
2407 Morphou	49.71	Good	2321 Bostanci	98.94	Poor
1741 Akçay	50.74	Fair	532 Morphou	100.84	Very poor
2326 Bostanci	50.76	Fair	1780 Bostanci	102.77	Very poor
2490 Zümrütköy	50.98	Fair	4548 Doganci	106.48	Very poor
1742 Akçay	51.14	Fair	4517 Doganci	106.64	Very poor
2336 Morphou	51.37	Fair	4520 Doganci	110.05	Very poor
372 Morphou	52.52	Fair	4516 Doganci	110.12	Very poor
4310 Morphou	52.81	Fair	586 Bostanci	111.35	Very poor
594 Bostanci	53.04	Fair	529 Morphou	120.26	Very poor
367 Morphou	53.52	Fair	4288 Cengizköy	130.44	Very poor
2400 Morphou	53.99	Fair	525 Morphou	133.71	Very poor
369 Morphou	54.32	Fair	1836 Morphou	134.23	Very poor
5042 Morphou	55.33	Fair	615 Aydinköy	135.80	Very poor
411 Morphou	55.98	Fair	2343 Bostanci	137.36	Very poor
2398 Morphou	56.77	Fair	533 Güneskoy	138.53	Very poor
558/b Bostanci	57.03	Fair	4547 Doganci	141.69	Very poor
4270 Güneskoy	57.22	Fair	4026 Kalkanli	158.11	Unsuitable for drinking
390 Morphou	59.09	Fair	287 Morphou	159.05	Unsuitable for drinking
1005 Sahinler	59.16	Fair	1763 Kalkanli	160.97	Unsuitable for drinking
577 Güneskoy	60.85	Fair	295 Morphou	162.89	Unsuitable for drinking
5018 Sahinler	61.55	Fair	115 Aydinköy	168.81	Unsuitable for drinking
2473 Morphou	61.56	Fair	2345 Morphou	172.51	Unsuitable for drinking
2294 Bostanci	62.80	Fair	1793 Morphou	178.14	Unsuitable for drinking
589 Bostanci	62.97	Fair	1694 Kalkanli	183.99	Unsuitable for drinking
418 Morphou	63.47	Fair	292 Kalkanli	189.83	Unsuitable for drinking
339 Morphou	63.72	Fair	2346 Morphou	195.88	Unsuitable for drinking
2429 Bostanci	64.08	Fair	318 Morphou	201.06	Unsuitable for drinking
2453 Morphou	66.78	Fair	5041 Morphou	201.79	Unsuitable for drinking
2338 Morphou	67.84	Fair	2392 Kalkanli	202.35	Unsuitable for drinking
517 Morphou	68.26	Fair	311 Morphou	207.47	Unsuitable for drinking
2412 Bostanci	69.79	Fair	319 Morphou	207.47	Unsuitable for drinking
4029 Morphou	70.21	Fair	300 Kalkanli	211.82	Unsuitable for drinking
2399 Bostanci	70.32	Fair	4002 Aydinköy	221.72	Unsuitable for drinking
385 Morphou	70.45	Fair	288 Kalkanli	230.76	Unsuitable for drinking
4521 Doganci	71.14	Fair	1764 Morphou	241.35	Unsuitable for drinking
2317 Akçay	73.48	Fair	2391 Kalkanli	267.67	Unsuitable for drinking
524 Morphou	75.96	Poor	645 Aydinköy	269.11	Unsuitable for drinking
2320 Güneskoy	77.90	Poor	120 Aydinköy	271.97	Unsuitable for drinking
5012 Aydinköy	79.20	Poor	617 Aydinköy	282.65	Unsuitable for drinking
633 Aydinköy	286.50	Unsuitable for drinking	542 Morphou	454.55	Unsuitable for drinking
806 Morphou	296.12	Unsuitable for drinking	548 Morphou	471.40	Unsuitable for drinking
646 Aydinköy	305.99	Unsuitable for drinking	1676 Morphou	495.66	Unsuitable for drinking
5081 Kalkanli	314.14	Unsuitable for drinking	466 Morphou	509.60	Unsuitable for drinking
107 Güneskoy	316.60	Unsuitable for drinking	2450 Morphou	532.79	Unsuitable for drinking
2172 Kumköy	329.49	Unsuitable for drinking	5 Kumköy	672.73	Unsuitable for drinking
644 Aydinköy	370.90	Unsuitable for drinking	423 Morphou	708.33	Unsuitable for drinking
536 Güneskoy	409.99	Unsuitable for drinking	8 Kumköy	1828.98	Unsuitable for drinking

IV. DISCUSSION

Groundwater is the main water source for drinking and agricultural and domestic purposes in the selected region. The quality of water was evaluated using WQI. To the best of our knowledge, no study has been conducted on the groundwater of the region with the use of WQI. Based on the groundwater analysis, it has been possible to understand the geochemical groundwater quality in Morphou and to evaluate its suitability for drinking purposes. The groundwater quality was evaluated along with the coastal aquifers of the Morphou region. Agricultural activities in Northern Cyprus are carried out mainly in the selected area. The results indicated that the groundwater in the selected region is slightly acidic to alkaline in nature. Similar results have been reported in previous studies [41, 42].

Additionally, the results demonstrated that the concentration of Cl^- in groundwater is above the minimum limit of the WHO standard, due to the agricultural activities that take place in the area [43]. Based on this finding, the majority of groundwater samples demonstrated that the concentration of Ca^{2+} and Mg^{+2} above the chloride indicated seawater intrusion into coastal aquifers [44]. According to [9, 16, 21], the groundwater level reached the mean level of the sea in some sites due to over-pumping. In addition, the amount of salt contamination is within the range of 1000-5000mg/g [9]. Moreover, the concentration of Ca^{2+} and Mg^{+2} in the majority of the groundwater samples did not meet the acceptable limits for drinking water. According to [45-47], the high amount of Ca^{2+} in the groundwater is attributed to cation exchange between minerals. Besides, the higher amount of Mg^{+2} than that of Ca^{2+} is attributable to the effects of ferromagnesium minerals present in the rocks of the region [48]. Moreover, it is found that the values of TH and CH are within the range of 84.0-9371.0mg/l and 10-3120 mg/l respectively. According to [49], the groundwater's suitability is dependent on the result of an increase in the concentration of carbonate and bicarbonate more than the sum of the calcium and magnesium content of the water. In the end, the results demonstrated that the majority of the groundwater samples are not suitable for drinking.

V. CONCLUSIONS

Periodic assessment of the quality of drinking water sources is necessary to ensure the quality and security of the water supply. Consequently, the present study evaluated the groundwater quality for drinking water supply in the Morphou region based on the WQI. To achieve this, 118 samples of groundwater were collected seasonally during the period from 2006 to 2016 and the main physical and chemical properties were analyzed. It was found that the pH value of most of the groundwater samples varied from 6.4 to 8.3 and from 7.1 to 8.3 during dry and wet seasons respectively. Additionally, based on EC classification, the results indicate that 55% of the majority of groundwater samples come under type I, 24% under type II, and 22% under type III during both seasons. Moreover, the results indicated that the TH values varied from 84.0 to 9371.0mg/L and approximately 50% of the groundwater samples come under the very hard category. Thus, the groundwater is characterized by higher concentrations of TH, HCO_3, and Cl^- and is not safe. Furthermore, it is found that approximately 10% of the groundwater samples come under class 2 (good water), 30% of the samples come under class 3 (fairwater), 13% of groundwater samples come under class 4 and 5 and the rest of the groundwater samples are unsuitable for drinking.

In the current study, there was no consideration of groundwater level and climate parameters, particularly rainfall. Thus future research should focus on the investigation of the relationship between groundwater level, groundwater quality, and climate parameters using machine learning models and GIS.

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