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Assessment of water quality using Canadian Water Quality Index and GIS in Himreen Dam Lake, Iraq

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Abstract - The Canadian versions of Water Quality Index (WQI) and Geographical Information Systems (GIS) were applied in this study to assess the water quality of Himreen Dam Lake. Water samples were taken seasonally during the period from summer 2014 to spring 2015. A total of 10 parameters were measured in this work, and were considered in calculating the water quality index (WQI), namely: potential hydrogen ion (pH), electrical conductivity (EC), total dissolved solid (TDS), sodium (Na^{+}), calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^{-}), sulphate (SO_4^{-2}), nitrate (NO_3) and sodium adsorption ratio (SAR). The results showed that the pH was ranged from 7.1-7.9, EC was varied from 558-864 µS/cm and TDS was ranged between 322-522 mg/l. The ranges of sodium, calcium, magnesium, chloride, sulphate, nitrate and sodium adsorption ratio were 13-34 mg/l, 32.27-86.34 mg/l, 35.0-67.8 mg/l, 29-88 mg/l, 129-254 mg/l, 0.9-3.6 µg $N\text{-}NO_3$/l and 1.62-4.99 meq/l respectively. The values for the water quality index (WQI) were varied from 72.14 to 72.36 that categorized within category three (fair). The lowest value was recorded at station 2 while the highest was encountered from station 1. The results revealed that the quality of Himreen Lake water was suitable for irrigation.

Keywords: WQI, GIS, PCA and Himreen Dam Lake.

Introduction

Dams are considered as the major threats to aquatic ecosystems and have been shown to change the flow regime and water quality, habitat conditions and aquatic biota of the rivers (Nilsson *et al.*, 2005). So, reservoirs are of high ecological, economic and recreational importance. Water quality index (WQI) was found to be one of the most effective tools, used as a tool for assessing the quality of water (Raychaudhuri *et al.*, 2014). The assessment of water quality in reservoirs was essential because they are often one of the main sources of water for human consumption and irrigation (Carol *et al.*, 2006). Therefore, good quality irrigation water was needed for high agricultural production and crop diversity (Charest *et al.*, 2015).

Moreover, almost all irrigation schemes in those areas are directly linked to large reservoirs. Mohammed (2011) mentioned that the quality of the irrigation water has to be evaluated to avoid or at least, to minimize the negative impacts on agriculture. Concurrent with decreasing water availability in the region, water demands are fast increasing due to population growth and the increase of irrigated agriculture.

Irrigation water quality mapping was considered to be an important means for the spatially distributed evaluations of individual quality parameters. As needs is, GIS gives an essential platform to imagining such maps and making relative assessments (Al-Mussawi, 2014). However, GIS can be a powerful instrument for promoting solutions for water resources problems, evaluate water quality, determining water availability, preventing flooding, conception the natural environment and for managing resources on a local or regional scale (ESRI, 2014)

Numerous studies was applied on WQI (some of them integrate with GIS) to evaluate the irrigation water quality in Iraq, for instance in the study of Abdulrazzaq and Kamil (2010), Alhashimi and Mustafa (2012), Hamza (2012), Mahmood *et al*. (2013), Kadhem (2013), Khalaf and Hassan (2013), Sammen (2013), Al-Mussawi (2014), Hussain *et al*. (2014), Al-Bahrani (2014) and Mohammed and Hassan (2015). Thus, the major goal of the present study was to calculate the Water quality index (WQI) of the Himreen Dam Lake so that to evaluate the water suitability for irrigation, to determine the spatial distribution of water quality parameters and to generate the irrigation water quality map.

Materials and Methods

Three stations were chosen from Himreen Lake to execute this study (Fig. 1). Station 1 (495459 E, 3795485 N meters), station 2 (501870 E, 3781684 N meters) and station 3 (508469 E, 3770162 N meters).

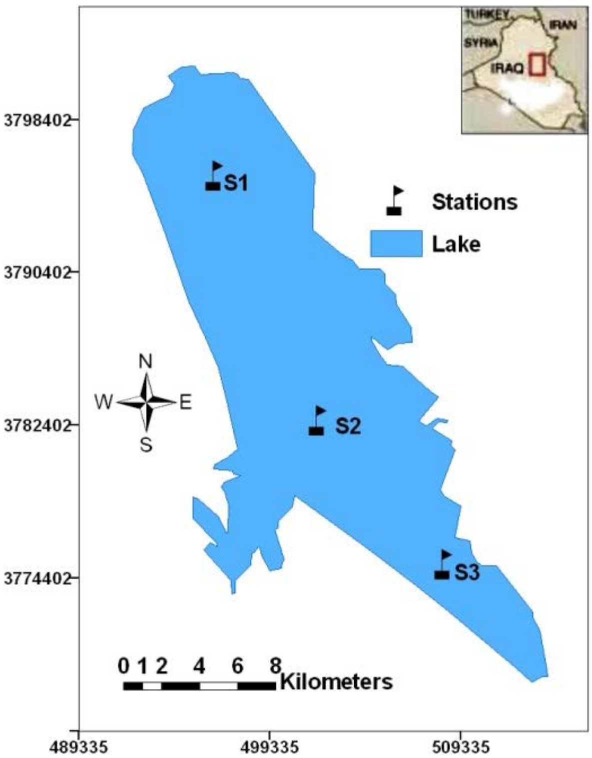

Figure 1. Map of Himreen Dam Lake showing the study sites.

Water samples were regularly collected seasonally from each station from summer 2014 to spring 2015. At each location, the GPS waypoint was collected for spatial reference. Potential hydrogen ion (pH) values were measured by a GTC pH-meter. Electrical Conductivity (EC) values were determined by using a Bischof 117 EC-Meter. Nitrates (NO_3) were measured following the method described in Parsons *et al.* (1984). Analytical methodologies were used in the analysis of the different parameters (total dissolved solid (TDS), sodium (Na^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^-) and sulphate (SO_4^{-2})) were defined by the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). The Sodium Adsorption Ratio (SAR) was calculated according to the equation has given by Richards (1954) as:

$$SAR= Na^+/\sqrt{((Ca^{+2}+Mg^{+2})/2)}$$

Where all the ions are expressed by milliequivalents per liter (meq/l) units.

Water quality index (WQI):

The Canadian Water Quality Index (CCME WQI) was applied in the present study as Irrigation Water Quality Index (IWQI) to indicate the suitability of the Lake for irrigation purpose. A total of 10 parameters were measured in this work, and were considered in calculating the IWQI, namely, potential hydrogen ion (pH), electrical conductivity (EC), total dissolved solid (TDS), sodium (Na^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^-), sulphate (SO_4^{-2}), nitrate (NO_3) and sodium adsorption ratio (SAR).

The system of Ayers and Westcot (1985) which approved by the Food and Agriculture Organization (FAO) was considered as a system for the classification of irrigation water to assess the water quality of Himreen Lake for irrigation. The formulation of the WQI as described in the Canadian Water Quality Index 1.0-technical report (CCME, 2001) was as follows.

1. F_1 (Scope): represents the percentage of variables that do not meet their objectives at least once during the time period under consideration (failed variables), relative to the total number of variables measured:

$$F_1= (\text{Number of failed variables} / \text{Total number of variables}) \times 100$$

2. F_2 (Frequency): represents the percentage of individual tests that do not meet objectives (failed tests):

$$F_2 = (\text{Number of failed tests} / \text{Total number of tests}) \times 100$$

3. F_3 (Amplitude): represents the amount by which failed test values do not meet their objectives. F_3 was calculated in three steps:

   a) The number of times by which an individual concentration was greater than (or less than, when the objective was a minimum) the objective was termed an excursion and was expressed as follows. When the test value must not exceed the objective:

$$\text{Excursion} = (\text{Failed Test Value} / \text{Objective})-1$$

   For the cases in which the test value must not fall below the objective:

$$\text{Excursion} = (\text{Objective} / \text{Failed Test Value})-1$$

b) The collective amount by which individual tests are out of compliance was calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable referred to as the normalized sum of excursions, or nse, was calculated as:

$$nse = \sum_{i=1}^{n} excursion \, / \, \text{Number of tests}$$

c) F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = nse \, / \, (0.01\, nse + 0.01)$$

The CCME Water Quality Index (CCME WQI):

$$WQI = 100 - \sqrt{(F_1^2+F_2^2+F_3^2)} / 1.732$$

The divisor 1.732 normalizes the resultant values to a range between zero and 100, where zero represents the worst water quality and 100 represent the best water quality. Once the WQI value has been determined, water quality was ranked by relating it to one of the following categories (Table 1).

Table 1. WQI categorization (CCME, 2001).

Category	Index value	Description
Excellent	95-100	Very close to natural or pristine levels.
Good	80-94	Rarely depart from natural or desirable levels.
Fair	65-79	Sometimes depart from natural or desirable levels.
Marginal	45-64	Often depart from natural or desirable levels.
Poor	0-44	Usually depart from natural or desirable levels.

Results of water parameters at all stations were treated by using two statistical programs, SPSS (version 19). Whereas, the multiple linear correlation analysis has carried out on water parameters to verify if there is any significant relationship by applying the multivariate analysis of ecological data using CANOCO program (Version 4.5, Cajo J.F. ter Braak, 2004). Geographic analyses were carried out in ArcGIS 9.3 to produce the spatial distribution (by kriging) of water parameters and water quality over the lake.

Results

Table (2) reveals the seasonal variations of water parameters among stations and the statistical details in Himreen Lake during the study period. Fluctuations in the average of pH values were observed locally (Fig. 2). Values ware ranged from 7.1 in winter in station 3 to 7.9 in spring in station 2. Insignificant differences ($P>0.05$, $F= 0.168$) were found among stations. However, the overall values of pH in the Lake were in the alkaline state and ranged from 7.33 in winter to 7.58 in spring. Spatially changes in the mean values of electrical conductivity are shown in Figure (3). The EC was ranged from 558 µS/cm in winter in station 1 to 864 µS/cm in summer in the same station. Insignificant differences ($P>0.05$, $F= 0.14$) were found among stations. The overall value of EC in the Lake differs from 647.3 µS/cm in winter to 845.67 µS/cm in summer.

Table 2. Seasonal changes in water parameters among stations and statistical summary in Himreen Lake

		pH	EC (μS/cm)	TDS (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (μg/L)	SAR (meq/l)
S1	**Sum**	7.55	864	522	23	62.52	39	47	254	2.2	3.84
	Aut	7.4	746	322	25	42.86	43.8	32	129	1	4.94
	Win	7.7	558	387	17	86.34	36	41	162	0.9	2.23
	Spr	7.8	765	411	13	78.23	35	35	177	1.1	2.68
Average		**7.6125**	**733.25**	**410.5**	**19.5**	**67.49**	**38.45**	**38.8**	**180.5**	**1.3**	**3.423**
S2	**Sum**	7.72	840	512	26	56.92	40.3	48	210	1.1	3.73
	Aut	7.5	732	380	20	48.11	36.5	38	163	1	3.17
	Win	7.2	722	425	13	33.12	63.8	81	143	1	1.62
	Spr	7.9	773	406	18	37.91	61.2	31	185	1.4	2.86
Average		**7.58**	**766.75**	**430.75**	**19.25**	**44.02**	**50.45**	**49.5**	**175.3**	**1.13**	**2.845**
S3	**Sum**	7.33	833	505	34	53.01	39	46	218	1.5	4.99
	Aut	7.8	739	345	18	32.27	37.7	29	143	1	3.27
	Win	7.1	662	391	19	55.2	54.5	88	171	1	2.12
	Spr	7.77	782	419	15	36.32	67.8	37	180	3.6	2.51
Average		**7.5**	**754**	**415**	**21.5**	**44.2**	**49.75**	**50**	**178**	**1.78**	**3.223**
Min		7.1	558	322	13	32.27	35	29	129	0.9	1.62
Max		7.9	864	522	34	86.34	67.8	88	254	3.6	4.99
Total mean		**7.56**	**751.33**	**418.75**	**20.08**	**51.9**	**46.22**	**46.1**	**177.9**	**1.4**	**3.16**
Standard Deviation		**0.26**	**82.9**	**64.06**	**6.08**	**17.33**	**12.1**	**19.1**	**35.46**	**0.78**	**1.07**

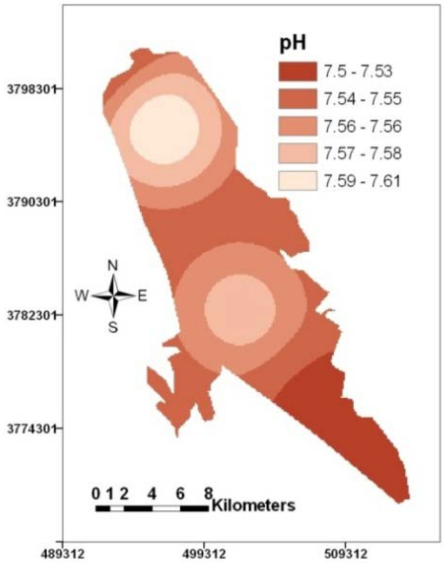

Figure 2. A pattern of the average of pH values in the Himreen Lake.

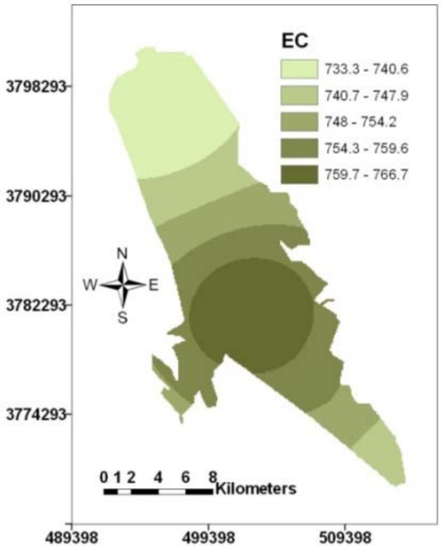

Figure 3. A pattern of the average of EC values in the Himreen Lake.

Figure (4) illustrates the spatially changes in the average values of the total dissolved solids. TDS were ranged as 322 mg/l in autumn in station 1 to 522 mg/l in summer in the same station. Insignificant differences ($P>0.05$, $F= 0.092$) were detected in TDS values among stations. The overall values of TDS in the Lake ranged from 349 mg/l in autumn to 513 mg/l in summer. Locally variations in the mean of sodium values are presented in Figure (5). Values of sodium were ranged from 13 mg/l (in winter) in station 2 to 34 mg/l (in summer) in station 3. Insignificant differences ($P>0.05$, $F= 0.139$) were detected in sodium values among stations. The overall value of sodium in the Lake was varied from 15.33 mg/l in spring to 27.67 mg/l in summer. The Figure (6) illustrates the spatial changes in the average of calcium values. It was varied from 32.27 mg/l in autumn in station 3 to 86.34 mg/l in winter in station 1. The Ca^{+2} values in the station 1 was found to differ significantly ($p<0.05$, $F= 3.56$) with other stations. The overall value in the Lake was varied from 41.08 mg/l in autumn to 58.22 mg/l in winter. Local fluctuations in the mean values of magnesium are shown in Figure (7). The lowest value of Mg^{+2} was encountered during the spring season (35 mg/l) in station 1 whereas the highest Mg^{+2} value was 67.8 mg/l in the same season in station 3. Insignificant differences ($p>0.05$, $F= 1.31$) were detected in Mg^{+2} values among stations. The overall values were differ from 39.3 mg/l in autumn to 54.67 mg/l in spring. The Figure (8) revealed the local changes in the average of chloride values. It was ranged from 29 mg/l in autumn at station 3 to 88 mg/l in winter in the same station. Insignificant variations ($P>0.05$, $F= 0.396$) were detected among stations. The overall value varies from 33 mg/l in autumn into 70 mg/l in winter. Figure (9) illustrates the spatial variations in the mean of SO_4^{-2} values. It was ranged from 129 mg/l in autumn at station 1 to 254 mg/l in summer in the same station. Variations among stations were insignificant differences ($P>0.05$, $F= 0.018$).

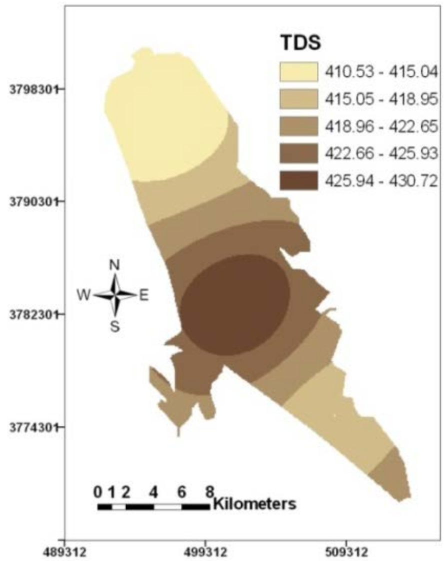

Figure 4. A pattern of the average of TDS values in the Himreen Lake.

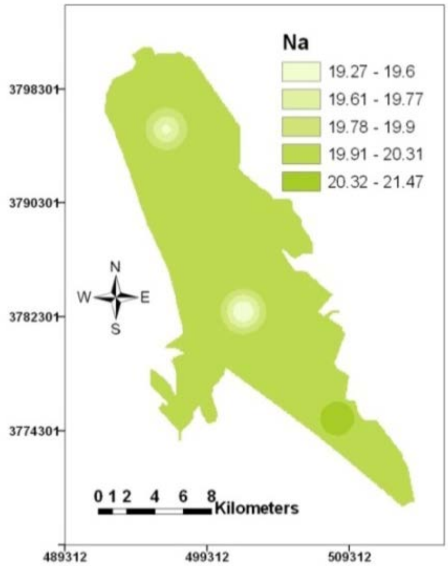

Figure 5. A pattern of the average of Na^{+2} values in the Himreen Lake.

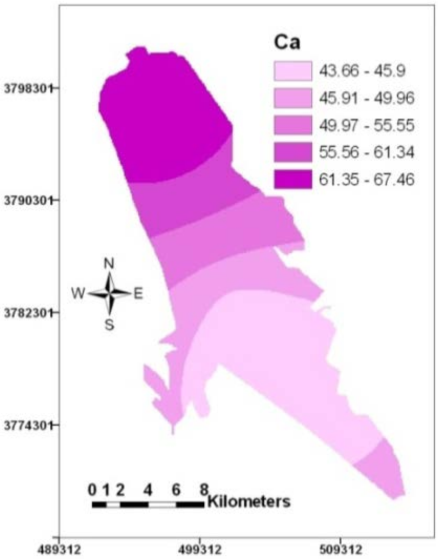

Figure 6. A pattern of the average of Ca^{+2} values in the Himreen Lake.

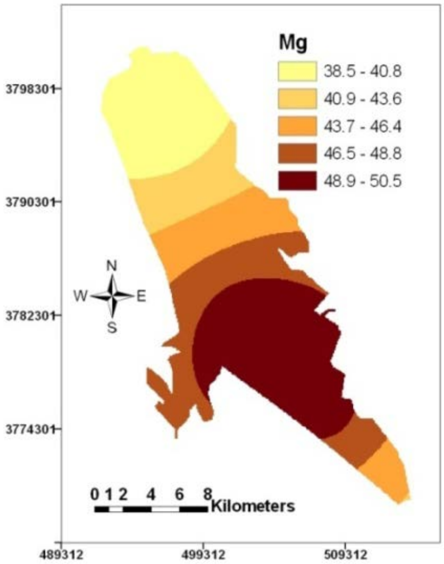

Figure 7. A pattern of the average of Mg^{+2} values in the Himreen Lake.

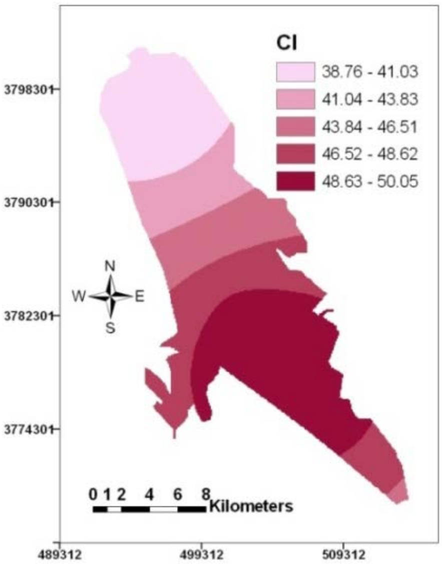

Figure 8. A pattern of the average of Cl^{-} values in the Himreen Lake.

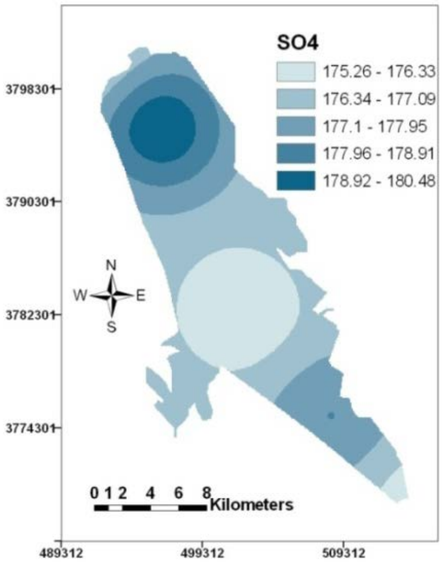

Figure 9. A pattern of the average of SO_4^{-2} values in the Himreen Lake.

However, the overall values differ from 145 mg/l in autumn to 227.3 mg/l in summer. Figure (10) illustrate the spatial changes in the average of nitrate values. This parameter was varied and fluctuated from 0.9 in winter in station 1 to3.6 µg atom N-NO_3/l in spring at station 3. Insignificant differences ($p>0.05$, F= 0.7) in NO_3 values were detected among stations. The overall value varies from 0.97 µg in winter to 2.3 µg in spring. Local variations in the mean of SAR values are shown in Figure (11). Values are ranged from 1.62 meq/l in winter at station 2 to 4.99 meq/l in summer at station 3. Insignificant differences ($P>0.05$, F= 0.265) in SAR values were detected among stations. The overall value of SAR in the Lake was varied from 1.99 meq/l in winter to 4.19 meq/l in summer.

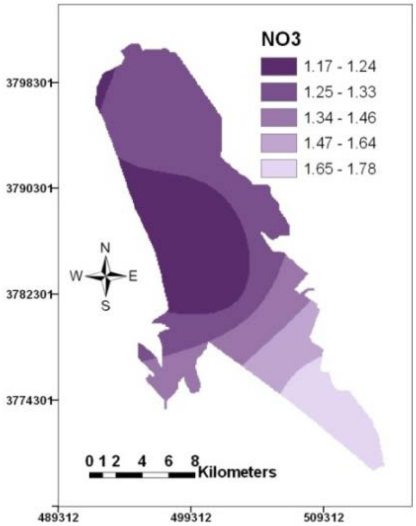

Figure 10. A pattern of the average of NO_3 values in the Himreen Lake.

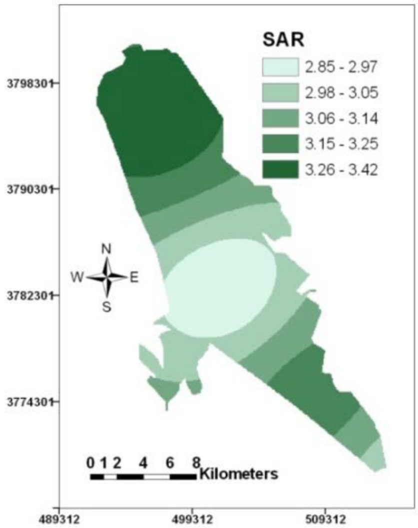

Figure 11. A pattern of the average of SAR values in the Himreen Lake.

Water Quality Index:

Figure (12) revealed the geographic analyses pattern of IWQI values. The index provides a minor difference in IWQI values between stations. However, values were varied from 72.14 to 72.36 and categorized within category three (fair) during the study period. The lowest value of IWQI was 72.14 recorded at station 2 and the highest was 72.36 encountered from station 1. The overall value of IWQI in Himreen Lake was 72.34 (Fig. 13). The environmental habitat vectors on the principal components analysis (PCA) ordination plot represent the relationships between the distributions of the environment variables in the Himreen Lake are given in Figure (14). Electrical conductivity was a greater impact factor on the IWQI compared with others. Red-solid rows are describing the parameters that affected WQI in the Lake (variables that do not meet their objectives).

Discussion

Most reservoirs were built for a single purpose, storage of a certain quantity of water. With increasing environmental degeneration and multiple uses of reservoirs, water quality has become an issue of great concern.

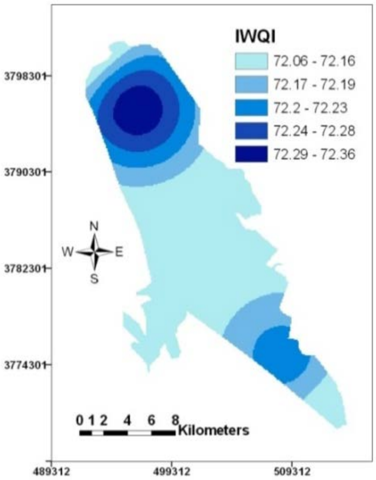

Figure 12. A pattern of the average of IWQI values in the Himreen Lake.

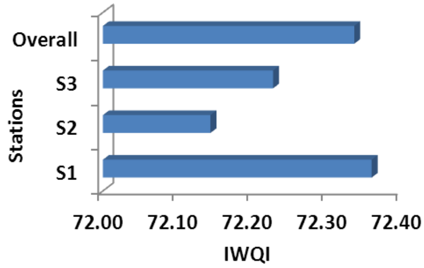

Figure 13. IWQI values in Himreen Lake.

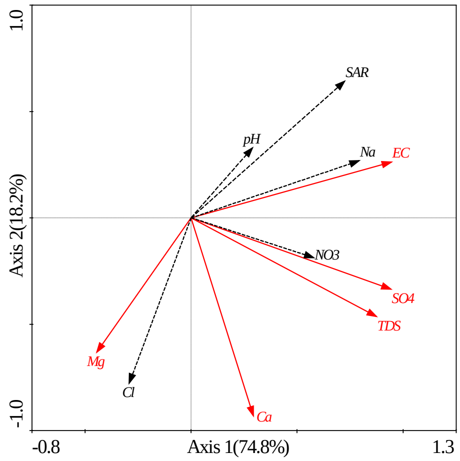

Figure 14. PCA ordination plots showing the relationship among various ecological factors in the Himreen Lake.

So, water quality was neither a static state of a system nor could it be characterised by the estimation of an only single parameter. Moreover, it was changed in both time and space and needs routine control to reveal spatial and temporal patterns. The study was undertaken to assess the impacts of 10 water quality parameters. However, the results showed that five of them were within normal range, except EC, TDS, Ca^{+2}, Mg^{+2} and SO_4^{-2} which exceed the criterion were considered in the present study. Insignificant differences ($p>0.05$) were detected in all parameters values among stations, except one Significant difference ($p<0.05$, $F=3.557$) in calcium values were recorded between station 1 and the other stations.

Whether electrical conductivity estimates the amount of total dissolved salts, or the total amount of dissolved ions in the water, at all the seasons, the electrical conductivity of the main reservoir exhibited the values more than those assigned by the standard of the system for the classification of irrigation.

However, EC in the lake controlled by and increased due to Climate change, increase of temperature, evaporation of water from the surface, geology (rock types), some of pollutants (point and non-point source pollutants), diminished freshwater contributions and Bacterial metabolism in the hypolimnion (Hayashi, 2004; Miyamoto *et al.*, 2007; Tanny *et al.*, 2008 and Pal *et al.*, 2015).

EC values were raised within the study period (especially in spring and summer) perhaps due to the decrease of water levels and increase the proportion of evaporation, or maybe caused by an anthropogenic source. This coincides with the findings of Sammen (2013). However, EC values in the currents investigation never exceed 864 µS/cm. Potasznik and Szymczyk (2015) deduce that magnesium and calcium are found naturally in surface water, and their concentrations are determined mainly by the carbonate balance (Galczynska *et al.*, 2013). Mg values exceed the criterion in the research period during the winter and spring (in stations 2 and 3) maybe due to the influence by organic compounds supplied with the wastewater (Bhat *et al.*, 2014). While, Ca values overstep the standard during the winter and spring in station 1 perhaps caused by the chemical denudation due to dilution from rains coupled with the reservoir circulation and weathering from rock, and runoffs from surrounding area might have participate to the availability of calcium and magnesium ions (Mustapha, 2008).

However, the lower values of the calcium were recorded during summer and autumn perhaps attributed to the uptake of the calcium by the phyto and microorganisms (McLaughlin and Wimmer, 1999). Sulphate values in the present study never exceed criterion excepted in the summer. However, the higher Sulphate concentration in summer was maybe due to an activity of biodegradation. Whereas, dilution and utilization by aquatic plants gradually brought down the concentrations (Munawar, 1970). Lonkar *et al.* (2015) deduced the same conclusion.

In spite of the decrease in water levels in the lake and slightly increases in the values of EC, TDS, Mg, Ca and SO4, water quality at all stations categorised as Fair during the whole study period. So, the geographic analysis did not derive a clear spatial change in values of irrigation water quality (IWQI). Therefore, the water quality of Himreen Lake was suitable for irrigation and this agrees with most findings, namely Salah (2013) and Sammen (2013).

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تقييم نوعية المياه باستخدام دليل نوعية المياه (النموذج الكندي) ونظم المعلومات الجغرافية في بحيرة سد حمرين، العراق

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قسم العلوم، فرع علوم الحياة، الكلية التربوية المفتوحة في البصرة، العراق

المستخلص - طبق في الدراسة الحالية دليل نوعية المياه (النموذج الكندي) ونظم المعلومات الجغرافية (GIS) لتقييم نوعية مياه بحيرة سد حمرين. جمعت عينات المياه فصليا للمدة من صيف 2014 الى ربيع 2015. قيست 10 عوامل بيئية لتقييم نوعية المياه وهي الاس الهيدروجيني، التوصيلة الكهربائية، المواد الصلبة الذائبة، الصوديوم، الكالسيوم، المغنسيوم، الكلوريد، الكبريتات، النترات ونسبة امتزاز الصوديوم (SAR). أظهرت النتائج أن قيمة الاس الهيدروجيني تراوحت بين 7.1-7.9، وتباينت التوصيلية الكهربائية من 558- 864 مايكرو سيمنز/سم وتراوحت قيم TDS بين 322-522 ملغم/لتر. وتراوحت قيم كل من الصوديوم، الكالسيوم، المغنيسيوم، الكلوريد، الكبريتات ،النترات ونسبة امتزازالصوديوم من 13-34 ملغم/لتر، 32.27-86.34 ملغم/لتر، 35-67.8 ملغم/لتر، 29-88 ملغم/لتر، 129-254 ملغم/لتر، 0.9-3.6 مايكروغرام ذرة نترات/لتر و1.62-4.99 ملي مكافئ/لتر على التوالي. أختلفت قيم دليل نوعية المياه (WQI) بين 72.14-72.36 والتي صنفت ضمن الفئة الثالثة (مقبول). سجلت أدنى قيمة في المحطة الثانية بينما سجلت أعلى القيم في المحطة الأولى. أظهرت النتائج أن نوعية مياه بحيرة حمرين ملائمة للأحياء المائية والري.