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ORIGINAL ARTICLE

# Water Quality Index variations in a Mediterranean reservoir: a multivariate statistical analysis relating it to different variables over 8 years

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**Abstract**
Evaluating the status of the water quality of freshwater bodies is crucial for safe use. In this work, the water quality of an understudied Mediterranean reservoir was investigated, using Water Quality Index (WQI) and principle component analysis (PCA) during an 8-year study period, between 2009 and 2016. The WQI was analyzed based on weighted sum aggregation function, considering the following variables: temperature, salinity, pH, conductivity, dissolved oxygen, nitrate, nitrite, ammonia, phosphate, sulfate, and total dissolved solids. After describing the evolution of these variables, WQI was evaluated. It was mostly moderate and showed a deteriorating trend between 2009 and 2016. This deterioration was due to the previously weakened water infrastructure that was furthermore impacted by the sudden increase in the habitants of the basin following Syrian refugees influx after 2011 Syrian crisis. In a new approach, WQI results were also compared to river inflow, reservoir water depth and precipitation. WQI increased with the increased water depth and water volume of the reservoir showing better water quality. Monthly precipitation above 250 mm showed better water quality and increased WQI. No clear relation was found between the WQI and the river flow. PCA analysis indicated that water quality in the reservoir was affected by erosion and fertilizers. WQI results agreed with Carlson Trophic State Index previously applied to the reservoir. These innovative results linking WQI to hydrological variables, urbanization, and trophic index together with the incorporation of PCA with WQI provide a multidimensional nature of water quality evaluation concept.

**Keywords** WQI · PCA · Water quality · Hydrology · Pollution

## Introduction

The increase in population and subsequent expansion of the economic and urban sector has increased the demand on water throughout many countries around the world. To overcome these issues, reservoirs were constructed. They are considered as essential freshwater resource that can serve different human needs from hydropower generation to irrigation during dry season (Fadel 2014). However, climate change, land degradation, unregulated withdrawal of surface and groundwater, effluents of agricultural, urban and industrial pollution, have led to their shortage and degradation (Darwish et al. 2018; Guidigan et al. 2019). Degradation in water quality impairs the use of freshwater bodies for different purposes. It can also impact the ecosystem of these water bodies through hypoxia, algal blooms, reduced biodiversity, and bioaccumulation of heavy metals and toxins (Ghoussein et al. 2019; Pinardi et al. 2018; Sharip et al. 2020).

The assessment of the water quality in freshwater bodies can enhance understanding of the hydrochemical system and the effective management of water resources (Alexakis 2011). It is a prerequisite for environmental regulatory agencies policies around the world, as it is necessary for achieving many millennium development goals (MDGs) (UNESCO-WWAP and UNSD 2011). Traditional approaches to assess water quality are based on the comparison of experimentally determined parameter values with the existing local normal. However, it doesn't readily give a global vision of overall water quality in a basin (Debels et al. 2005).

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Water Quality Index (WQI) is widely used as a practical method for observing and representing the pollution problems in surface water bodies (Akkoyunlu and Akiner 2012) and groundwater (Alexakis 2020; Stamatis et al. 2011). Evaluation of a WQI plays a role in water quality control and management, as it is highly dependent on the number and type of parameters (physical, chemical and biological) under study (Abbasi and Abbasi 2012a; Cude 2001; Debels et al. 2005). WQI permits assessing changes as well as identifying water trends. It gives a quality value, after selected parameters are transformed into different units and dimensions to a common scale, where these parameters are assigned weights, and finally aggregated to produce a final index score (Abbasi and Abbasi 2012b; Sahoo et al. 2015). The main idea in developing a WQI consists in encompassing a wide range of variables into a single numeric value.

Even though analysis including several common features-grouped parameters can provide partial information about the overall water quality, the incorporation of different parameters makes interpretation through traditional approaches even more difficult. Principal component analysis (PCA), is an analytical tool developed to summarize and make interpretation easier of multivariate data sets (Kanj and Fadel 2020; Kempton and Gauch 1984). PCA is often coupled with WQI in order to characterize water quality using a smaller data set (principal components), extracted from the larger original data set, to identify the factor responsible for deteriorating the water quality (Boyacioglu 2006; Fathy et al. 2012; Kazi et al. 2009; Sahoo et al. 2015; Sheykhi et al. 2015).

WQI method was widely applied for water quality assessments and has played an increasingly important role in water resource management (Alobaidy et al. 2010; Ravikumar et al. 2013). Studies that apply it often focus on determining the evolution and the status of the water bodies coming up with interesting findings. However, WQI was never linked to hydrological variables like water depth, river inflow and precipitation in the watershed.

Water resources in the Middle East region are usually understudied. Karaoun Reservoir, is the largest reservoir in Lebanon, it is located in an anthropogenic watershed and is characterized by high variations in its water level, up to 25 m (Fadel et al. 2015), presenting an interesting case study. In this study, we assess the evolution of water quality in Karaoun Reservoir, based on a set of monthly collected physio-chemical variables between 2009 and 2016, to: (1) report and evaluate the evolution of water quality on a monthly and yearly basis, (2) apply PCA analysis and assess the changes of factors along time between 2009 and 2016, and (3) understand the relation between WQI and the urbanization, trophic index and hydrological variables like inflow, precipitation, and changes in water level.

## Materials and methods

### Study area

Karaoun Reservoir (Fig. 1), constructed in 1965, is the largest reservoir in Lebanon, with a surface area of 12 $km^2$, a maximum depth of 60 m and a total capacity of $224 \times 10^6$ $m^3$ (Fadel et al. 2019). It is used for power generation, irrigation, fishing and touristic activities (Slim et al. 2014). It is located on the Litani River in the Bekaa Valley, at an elevation of 800 m. The climate in the watershed of Karaoun Reservoir is semi-arid. The average annual precipitation in the reservoir catchment is about 700 mm (Amery 2000), with the heaviest rainfall period occurring from approximately November to April, with little to no precipitation between June and August (Fadel et al. 2017). Lowest monthly evaporation rates occur in wet season, with almost negligible rates of 0.63 mm/day while highest evaporation rates occur in dry season with an average of 8.04 mm/day (Fadel et al. 2020). Harmful algal blooms of toxic cyanobacterial species were reported annually, since 2009 (Fadel et al. 2014; Sharaf et al. 2019). The reservoir has experienced a continuous rise in nutrient level due to regular polluting activities on the catchment of the upper Litani River (Fadel and Slim 2018).

### Methodology

#### Water quality data

Measurements were performed monthly between January 2009 and November 2016. Temperature ($T$, °C), pH, salinity (Sal, mg/L), total dissolved solids (TDS, mg/L), conductivity (EC, µS/cm), dissolved oxygen (DO, mg/L), were measured on field using "La Motte" in situ probes. Water samples were taken to perform laboratory analysis to obtain concentrations of ammonia ($NH_3$, mg/L) using ammonia ionic strength adjuster, and of nitrate ($NO_3^-$, mg/L), nitrite ($NO_2^-$, mg/L), phosphate ([$PO_4$], mg/L), sulfate ([$SO_4$], mg/L) using spectrophotometry (Table 1). Water depth data (D, m) and daily flow data of Litani River (Q, $m^3$/s) were provided by the Litani River authority. The water level was monitored using a graduated spillway that depicts water volume in the waterbody. Daily precipitation data (PRCP, mm) of Tal-Ammara station were provided by the Lebanese Agricultural Research Institute.

#### Water Quality Index

For the determination of WQI, the following empirical equation (weighted sum aggregation function) was used (Eq. 1)

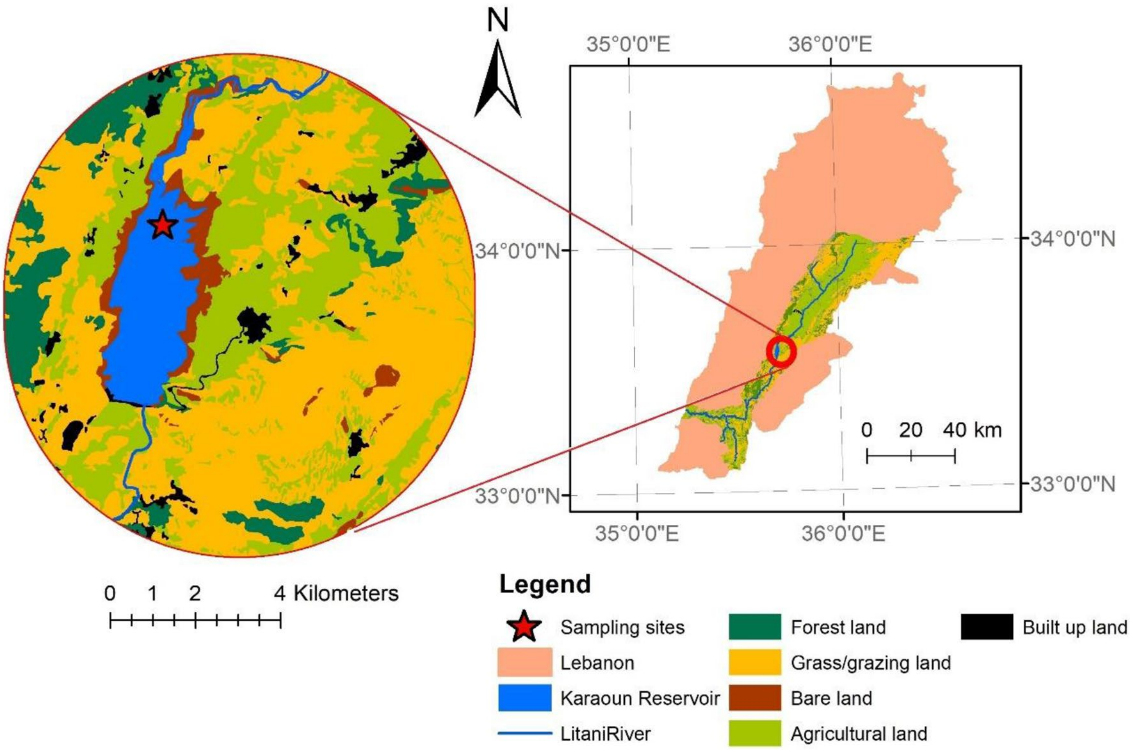


**Fig. 1** Location of Karaoun Reservoir and the sampling site

**Table 1** Used instrumentation, methods, and quality control

| Variable | Used instrumentation and methods/solutions | Accuracy (sensitivity) | Range test |
|---|---|---|---|
| Temperature ($T$, °C) | LaMotte, Salt/TDS/Conductivity/Temp TRACER | ± 1.0 °C | 0–65 °C |
| Salinity (Sal, mg/L) | | ± 2 mg/L | 0–9999 ppm (mg/L) |
| Total dissolved solids (TDS, mg/L) | | ± 2 mg/L | 0–9999 mg/L |
| Conductivity (EC, µS/cm) | | ± 2 µS/cm | 0–1999 µS/cm |
| pH | LaMotte,—pH Meter | ± 0.01 pH | 0–14 pH |
| Dissolved oxygen (DO, mg/L) | LaMotte, DO 6 Plus Dissolved oxygen meter | ± 0.3 mg/L | 0–20 mg/L |
| Ammonia ($NH_3$, mg/L) | Ionic strength adjustor (ISA) for ammonium determinations by ion selective electrode (ISE) method | ± 0.05 mg/L $NH_3$-N | 0.1–10.0 mg/L $NH_3$-N |
| Sulfate ([$SO_4^{2-}$], mg/L) | Spectrophotometry using powder pillows Hach 8051 | ± 0.5 mg/L $SO_4^{2-}$ | 2–70 mg/L $SO_4^{2-}$ |
| Phosphate ($PO_4^-$, mg/L) | Spectrophotometry using USEPA PhosVer 3 ascorbic acid method | ± 0.06 mg/L $PO_4^-$ | 0.06–5.00 mg/L $PO_4^-$ |
| Nitrite ($NO_2^-$, mg/L) | Spectrophotometry using USEPA NitriVer 3 diazotization method | ± 0.002 mg/L $NO_2^-$-N | 0.002–0.300 mg/L $NO_2^-$-N |
| Nitrate ($NO_3^-$, mg/L) | Spectrophotometry using NitraVer 5 cadmium reduction method | ± 0.2 mg/L $NO_3^-$-N | 0.1–10.0 mg/L $NO_3^-$-N |

(Conesa Fernández-Vítora et al. 1997; Pesce and Wunderlin 2000; Sánchez et al. 2007; Tirkey et al. 2013):

$$\mathrm{WQI} = k \times \frac{\sum_i C_i P_i}{\sum_i P_i}, \tag{1}$$

where: $k$ is a subjective constant, representing the visual impression of river contamination, the value of which ranges from 0.25 (for highly contaminated water indicated by blackish color, hard odour, visible fermentation, etc.) to 1 (for water without apparent contamination, clear or with natural suspended solid (Pesce and Wunderlin 2000). $k$ is taken as equal to 1 in all cases, to account for variations caused by parameters only. $C_i$ value is assigned to parameter $i$ after normalization and $P_i$ is the relative weight assigned to each parameter. $P_i$ values range from 1 to 4, with 4 assigned to a parameter that has the most importance for aquatic life preservation (e.g., dissolved oxygen) and value of 1 assigned to the parameter that has a smaller impact (e.g., chloride). The compilation of the variables with their significant scores of normalization and weights collected from different literature, are found in Table 2.

Water quality can be categorized into four classes based on WQI values: excellent, good, medium, bad and very bad if WQI lies in the ranges 0–25, 26–50, 51–70, 71–90 and 91–100, respectively (Tiwari and Mishra 1985). WQI was calculated monthly, taking the mean value of each parameter in a month, as well as it was calculated on a yearly basis, taking the mean value of each parameter along the year.

To study whether change in flow, depth or precipitation play a role in the change in WQI scores, WQI was calculated at different intervals for each of these parameters.

### Principle component analysis (PCA)

PCA was applied to the 11 water quality variables used for WQI analysis using IBM SPSS Statistics 23. To examine the suitability of these data for factor analysis, Kaiser–Meyer–Olkin (KMO) and Bartlett's tests were performed. KMO is a measure of sampling adequacy that indicates the proportion of variance, which is common variance, i.e., which might be caused by underlying factors. High value (close to 1) generally indicates that factor analysis may be useful; if the test value is less than 0.5 then the factor analysis will not be useful. Bartlett's test of sphericity indicates whether correlation matrix is an identity matrix, which would indicate unrelated variables. In addition, it provides results of the Pearson correlation ($r$) test, which identifies the association between pairs of variables along the study period.

## Results

### Trend analysis

Water temperature maximum average of 27 °C was observed in July while the minimum average of 10 °C was observed in January (Table 3; Fig. 2). As for variations on a yearly basis, maximum average temperature was recorded in 2016, while the minimum was recorded in 2015 (Table 3; Fig. 3). Salinity, electric conductivity, and total dissolved solids showed minimum and maximum average monthly values during dry season (Table 3, Fig. 2). Maximum values were observed during 2015 for these three variables while lowest values were recorded in 2013 for salinity and TDS and 2014 for EC (Table 3; Fig. 3).

Minimum monthly averages of ammonia were observed during dry season (August), whereas maximum average monthly values were observed in wet season (February) (Table 3, Fig. 2). As for its average yearly variations, the lowest observed value was in 2013, while the maximum observed value was in 2014 (Table 3; Fig. 3). Dissolved oxygen maximum and minimum average monthly values were observed during dry season (Table 3, Fig. 2). Yearly variations showed a maximum in 2009 and a minimum in 2014 (Table 3; Fig. 3).

Both nitrates and nitrites, showed minimum and maximum average monthly values during wet season (Table 3, Fig. 2). As for yearly variations, the maximum recorded values were in 2011 and 2009 while the lowest values in 2014 and 2016 (Table 3; Fig. 3).

Minimum monthly averages of pH were observed during wet season (January), whereas maximum average

**Table 2** Variables used in the Water Quality Index calculation, scores of normalization ($C_i$) and relative weights ($P_i$). $C_i$ and $P_i$ adopted from: [a](Debels et al. 2005), [b](Pesce and Wunderlin 2000), [c](Kannel et al. 2007), [d](Shekha and Al-Abaychi 2010), [e](Cude 2001)

| Variable | $P_i$ | $C_i$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0 | |
| $T$ | 1 | < 20 | < 21.0 | < 22.0 | < 24.0 | < 26.0 | < 28.0 | < 30.0 | < 32.0 | < 36.0 | ≤ 40.0 | > 40.0 | [a] |
| Sal | 1 | < 25 | < 50 | < 100 | < 150 | < 200 | < 300 | < 500 | < 700 | < 1000 | ≤ 1500 | > 1500 | [b, c] |
| $NH_3$ | 3 | < 0.01 | < 0.05 | < 0.1 | < 0.2 | < 0.3 | < 0.4 | < 0.5 | < 0.75 | < 1 | ≤ 1.25 | > 1.25 | [b, c, d] |
| EC | 1 | < 750 | < 1000 | < 1250 | < 1500 | < 2000 | < 2500 | < 3000 | < 5000 | < 8000 | ≤ 12,000 | > 12,000 | [b, c, d] |
| DO | 4 | ≥ 7.5 | > 7.0 | > 6.5 | > 6.0 | > 5.0 | > 4.0 | > 3.5 | > 3.0 | > 2.0 | ≥ 1.0 | < 1.0 | [a, b, c, d] |
| $NO_3^-$ | 2 | < 0.5 | < 2.0 | < 4.0 | < 6.0 | < 8.0 | < 10.0 | < 15.0 | < 20.0 | < 50.0 | ≤ 100.0 | > 100.0 | [a, b, c, d] |
| $NO_2^-$ | 2 | < 0.005 | < 0.01 | < 0.03 | < 0.05 | < 0.10 | < 0.15 | < 0.20 | < 0.25 | < 0.50 | ≤ 1.00 | > 1.00 | [b, c, d] |
| pH | 1 | 7 ≤ pH ≤ 8 | $4 \le pH < 7$: $C_i = 2.628 \times e^{(pH \times 0.52)}$<br>$8 < pH \le 11$: $C_i = 100e^{(pH-8)-0.5188}$ | | | | | | | | | pH < 4<br>pH > 11 | [e] |
| [PO4] | 1 | < 0.025 | < 0.05 | < 0.1 | < 0.2 | < 0.3 | < 0.5 | < 0.75 | < 1 | < 1.5 | ≤ 2 | > 2 | [c] |
| [SO4] | 2 | < 25 | < 50 | < 75 | < 100 | < 150 | < 250 | < 400 | < 600 | < 1000 | ≤ 1500 | > 1500 | [b, c] |
| TDS | 2 | < 100 | < 500 | < 750 | < 1000 | < 1500 | < 2000 | < 3000 | < 5000 | < 10,000 | ≤ 20,000 | > 20,000 | [b, c] |

**Table 3** Descriptive statistics showing parameters, units, number of samples, average mean standard deviation, minimum and maximum values, as well as minimum and maximum values in months and year

| Parameter | Units | *n* | Average | | | | Monthly average | | Yearly average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SD | Min | Max | Min | Max | Min | Max |
| *T* | °C | 95 | 19.27 | 3.19 | 10 | 27 | Jan | Jul | 2015 | 2016 |
| Sal | mg/L | 95 | 208.76 | 40.62 | 137 | 338 | Aug | Mar | 2013 | 2015 |
| $NH_3$ | mg/L | 95 | 0.87 | 0.69 | 0 | 3 | Aug | Feb | 2013 | 2014 |
| EC | µS/cm | 95 | 413.09 | 75.28 | 265 | 617 | Aug | Mar | 2014 | 2015 |
| DO | mg/L | 93 | 6.12 | 1.85 | 3 | 13 | Jul | Mar | 2014 | 2009 |
| $NO_3^-$ | mg/L | 95 | 11.09 | 6.87 | 0 | 44 | Oct | Feb | 2014 | 2011 |
| $NO_2^-$ | mg/L | 91 | 0.54 | 0.33 | 0.03 | 3.2 | Sep | Jan | 2016 | 2009 |
| pH | unitless | 95 | 8.14 | 0.5 | 6.9 | 9.3 | Jan | Aug | 2012 | 2011 |
| $[PO_4]$ | mg/L | 95 | 0.64 | 0.74 | 0 | 3.5 | Jun | Dec | 2014 | 2016 |
| $[SO_4]$ | mg/L | 95 | 28.63 | 7.4 | 0 | 48 | Nov | Mar | 2011 | 2015 |
| TDS | mg/L | 95 | 291.69 | 52.26 | 189 | 407 | Aug | Mar | 2013 | 2015 |
| D | m | 78 | 847.41 | 7.19 | 831.7 | 858.1 | Dec | Apr | 2016 | 2013 |
| Q | $m^3/s$ | 78 | 7.84 | 9.86 | 0 | 39 | Aug | Feb | 2016 | 2013 |
| PRCP | mm | 94 | 46.33 | 65 | 0 | 267 | Jun-Jul | Jan | 2014 | 2012 |

monthly values were recorded during dry season (August) (Table 3, Fig. 2). As for yearly variations, the maximum recorded values were in 2011 and lowest values in 2012 (Table 3; Fig. 3).

Minimum monthly average value of phosphate was observed during dry season (June), whereas maximum average monthly value was observed during wet season (December) (Table 3, Fig. 2). Highest and lowest average yearly values were observed in 2016 and 2014, respectively (Table 3; Fig. 3). Sulfate had minimum monthly and yearly values during wet season (November) and 2011, and maximum values for average monthly and yearly values during dry season (March) and in 2015 (Table 3, Figs. 2, 3).

Depth of the reservoir changed both monthly and yearly. Lowest depths were observed in December while highest depths were observed in April.

Both flow and precipitation had lowest monthly values during dry season (August and June–July) and highest values during wet season (February and January) (Table 3, Fig. 2). As for their variation on a yearly basis, both had highest values in 2013 and 2012, respectively; and lowest values in 2014 (Table 3; Fig. 3).

## Water Quality Index (WQI)

The mean and range values of WQI score, in the whole studied period are shown in Table 4. WQI scores was less than 80 on a scale of 0 to 100 (Table 4). Average monthly WQI in the Karaoun Reservoir, ranged between 56.7 and 66.04 while the mean annual WQI ranged between 55.23 and 69.64. April 2016 had the lowest WQI score and August 2013 had the highest. WQI scores lower than 60, occurred mostly in wet season as shown in Table 4. A decreasing annual trend of WQI is shown between 2009 and 2016. The average monthly and annual variation of WQI scores is shown in Fig. 4a, b, respectively.

Out of all dates, 13 sample dates had a WQI between 71 and 90 while 78 dates had a WQI between 51 and 70 and 4 had a WQI between 26 and 50, Table 5.

The four dates with “Bad” WQI were for Apr-2016, Feb-2014, Sep-2011 and Jan-2014 with a WQI of 48.25, 48.35, 48.5 and 50.5, respectively (Tables 4, 5). When checking the variables affecting the variation in the water quality against the average of the variables, we could see that ammonia, dissolved oxygen, nitrite, and phosphate affect this variation. As such, when running the analysis again for the WQI removing one variable at a time, the variables affecting causing a shift in WQI from 61.75 to 67.15 (removing ammonia from analysis), to 60.76 (removing dissolved oxygen from analysis), 66.94 (removing nitrite from analysis) and 61.99 (removing phosphate from analysis). As such, when removing all three major changing variables from analysis of WQI, the new WQI was 75.31 for Karaoun Reservoir, indicating a good quality. As such, these three variables—ammonia, nitrite, and phosphate—alter the WQI in this study.

Figure 5 shows the changes of WQI with respect to the flow of the Litani River, depth of the reservoir and precipitation for the study period 2009–2016. WQI scores varied in each interval when compared with the flow. WQI had two high peaks at 5–10 and 30–35 m3/sec flow (Table 6, Fig. 5a). As for depth, WQI increased with depth (Table 6, Fig. 5b). With precipitation between 0 and 250 mm, WQI was between 57 and 59; however, it increased to 71.82 when precipitation was between 250 and 300 mm (Table 6, Fig. 5c).

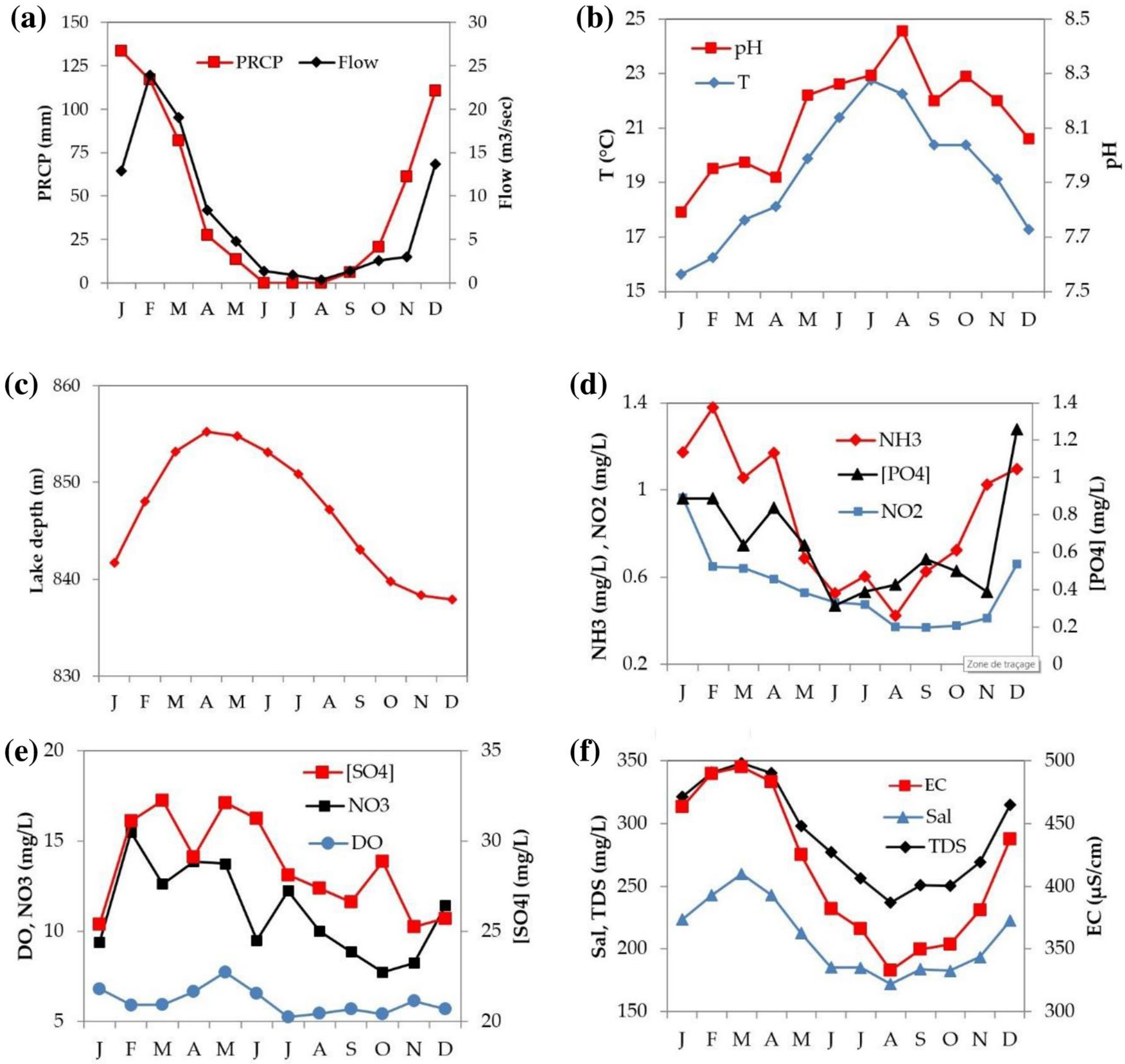


**Fig. 2** Average monthly variation for variables under study in Karaoun Reservoir: **a** flow of Litani river and precipitation **b** temperature and pH **c** lake depth **d** nitrite, ammonia, and phosphate concentrations electric conductivity, **e** dissolved oxygen, nitrate, and sulfate concentration **f** salinity, dissolved solids, and conductivity during the period of 2009 till 2016

## Principal component analysis (PCA)

The application of KMO (Table 7) to the measurements used in this study gave a value of 0.703, showing the analysis useful. Bartlett's Test of Sphericity also showed a significance level of 0 (less than 0.05), indicating a significant relationship among variables.

The correlation matrix resulting from the PCA is presented in Table 8. It showed that salinity had a negative correlation with temperature (− 0.52). Conductivity had high positive correlation with salinity (0.91) and a negative correlation with temperature (− 0.56). Ammonia had negative correlation with dissolved oxygen (− 0.52) and TDS had negative correlation with temperature and pH (− 0.57 and − 0.51), and high positive correlation with salinity and conductivity (0.92 and 0.97). No correlation was found between the following pairs: temperature and dissolved oxygen; temperature and sulfate; ammonia and nitrite; electric conductivity and dissolved oxygen, dissolved oxygen and phosphate, dissolved oxygen and total dissolved solids, nitrate and sulfate, nitrite and phosphate, nitrite and sulfate and pH and sulfate.

According to the eigenvalues, variance is explained by 3 principal components (PC) (Fig. 6). These 3 PC explain 65.98% of total variation in the original dataset. PC1, PC2 and PC3 explain 38.62, 16.87 and 10.48% of total variation as calculated by loadings for a cumulative percentage of variance by SPSS (Table 9).

To make interpretation easier, to find responsible factors, these three PC were rotated according to Varimax rotation

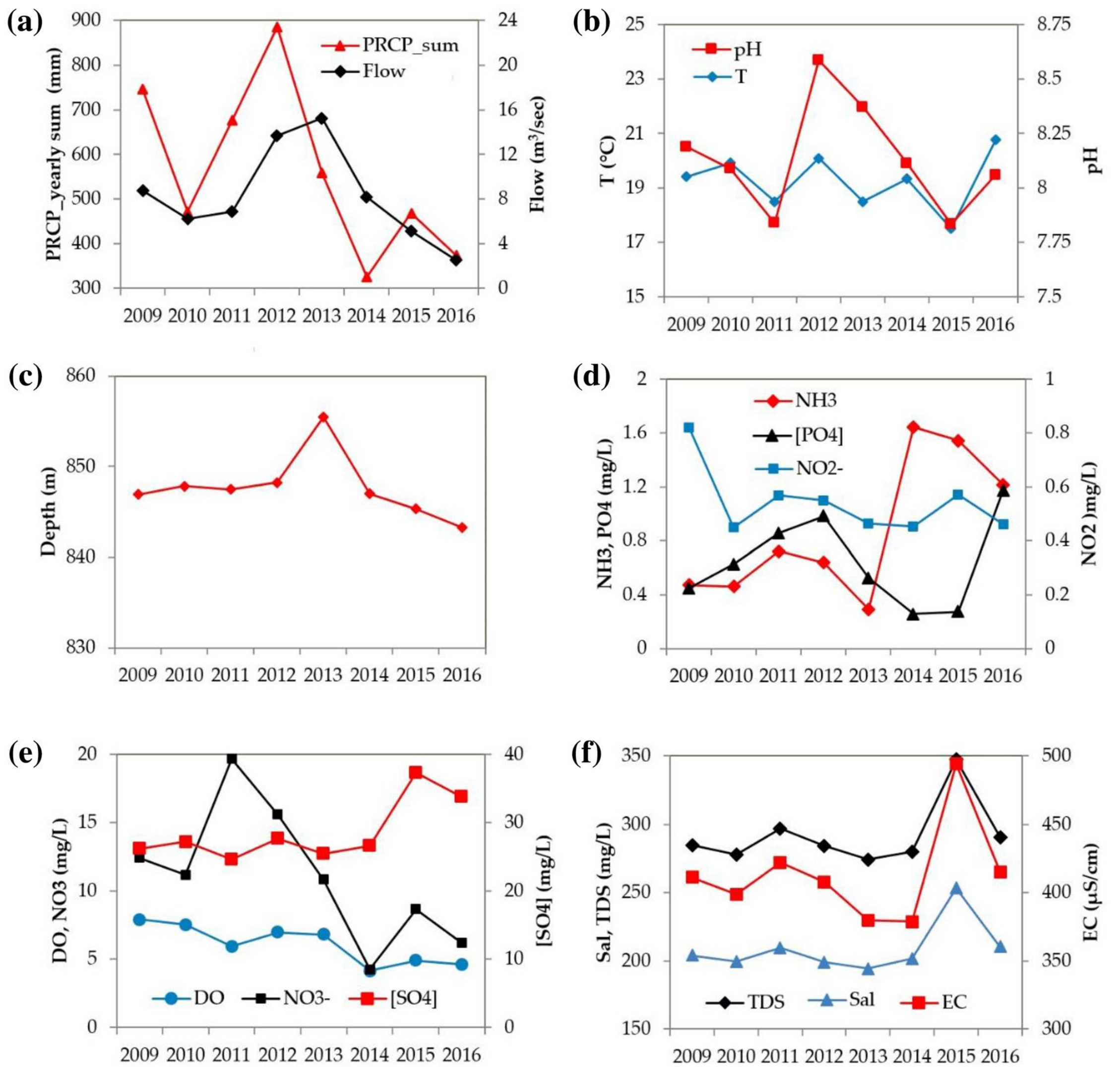


**Fig. 3** Average annual variation for variables under study in Karaoun Reservoir: average monthly variation for variables under study in Karaoun Reservoir: **a** flow of Litani river and precipitation **b** temperature and pH **c** lake depth **d** nitrite, ammonia, and phosphate concentrations electric conductivity, **e** dissolved oxygen, nitrate, and sulfate concentration **f** salinity, dissolved solids, and conductivity during the time period of 2009 till 2016

**Table 4** WQI scores of the Karaoun Reservoir monthly the study period

| WQI | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | 74.85 | 62.5 | 68.06 | 65.15 | 72.39 | 73.13 | 52.95 | 72.21 | 68.96 | 68.5 | 67.10 | 58.5 | 67.02 | 6.44 |
| 2010 | 68.5 | 64.5 | 67.5 | 73.5 | 70.57 | 71.75 | 69.57 | 66.48 | 65.5 | 64 | 72.94 | 56 | 67.57 | 4.83 |
| 2011 | 65.5 | 53.5 | 51 | 61.5 | 60 | 69.5 | 60 | 59.80 | 48.5 | 51.26 | 60.53 | 56.4 | 58.12 | 6.22 |
| 2012 | 59.87 | 58.32 | 58.13 | 62.62 | 66.62 | 67.12 | 60.52 | 64.78 | 70.5 | 69.75 | 57.81 | 57.28 | 62.78 | 4.82 |
| 2013 | 71.82 | 61.05 | 58.46 | 76.13 | 76.13 | 77.44 | 73.5 | 77.92 | 60.58 | 73.48 | 73.48 | 55.66 | 69.64 | 8.2 |
| 2014 | 50.5 | 48.36 | 57.61 | 56.5 | 59.96 | 59.16 | 60.28 | 60.28 | 54 | 56.01 | 58.5 | 57.5 | 56.55 | 3.84 |
| 2015 | 60.5 | 53.5 | 52.5 | 54.96 | 55.56 | 55.25 | 57 | 55.5 | 63 | 58 | 57 | 55.5 | 56.52 | 2.9 |
| 2016 | 54.5 | 53.5 | 52 | 48.25 | 51 | 54.98 | 53.98 | 59.05 | 64.23 | 59.80 | 56.22 | 55.2 | 55.23 | 4.47 |
| Mean | 63.25 | 56.9 | 58.16 | 62.33 | 64.03 | 66.04 | 60.97 | 64.50 | 61.91 | 62.60 | 62.95 | 56.70 | | |
| SD | 8.44 | 5.56 | 6.62 | 9.34 | 8.78 | 8.55 | 7.19 | 7.5 | 7.44 | 7.63 | 7.18 | 1.1 | | |

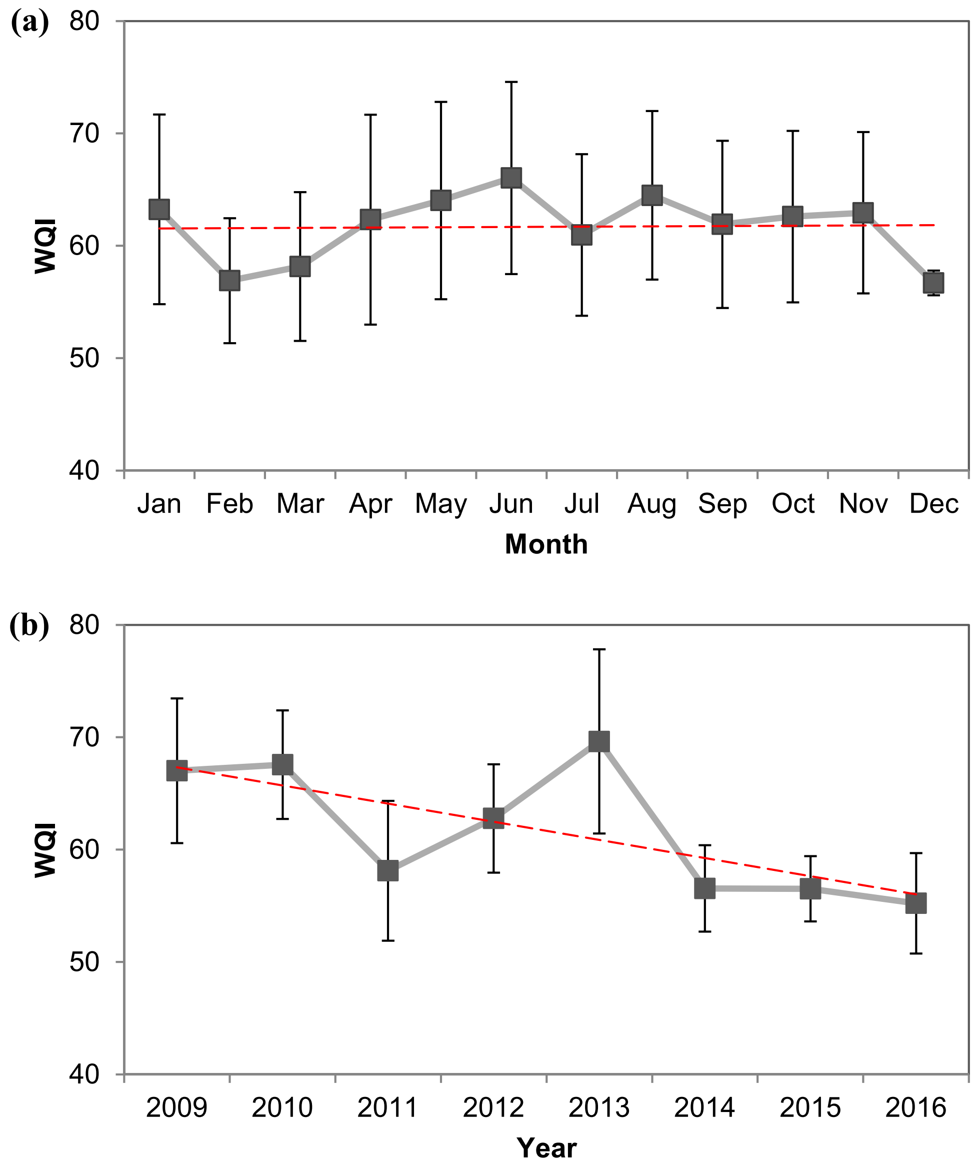


**Fig. 4** Temporal variation of mean WQI scores in the Karaoun Reservoir from 2009 to 2016 along: **a** monthly basis, **b** yearly basis. The bar denotes ± SD

**Table 5** Description of water quality across all sampling dates

| Number of samples | WQI range | Quality description |
|---|---|---|
| 13 | 71–90 | Good |
| 78 | 51–70 | Medium |
| 4 | 26–50 | Bad |

with Kaiser Normalization (Table 8). For a given factor, high loadings become higher, low loadings become lower, and intermediate loadings become either lower or higher. Following the criteria of Kowalkowski et al. (2006), parameters whose components loadings is higher than 0.6 may be taken into consideration for the interpretation of the PC analysis. As such, in the first PC, temperature and pH are significant parameters with a negative relation, while salinity and conductivity show a positive relation (Table 8). In the second PC, the significant parameters were: ammonia and dissolved oxygen with positive relation, while nitrate showed a negative relation. The final PC shows a negative relation with phosphates; whereas a positive one with sulfates. The distribution of the water quality parameters on rotated loadings PC1 and PC2 can also be found scattered in Fig. 7.

## Discussion

The water quality in the Karaoun Reservoir was found as medium based on the WQI. According to Meireles et al. (2010), having a WQI between 55 ≤ 70, necessitating moderate restriction of water usage. It may be used in soils with high to moderate permeability, and to irrigate plants with

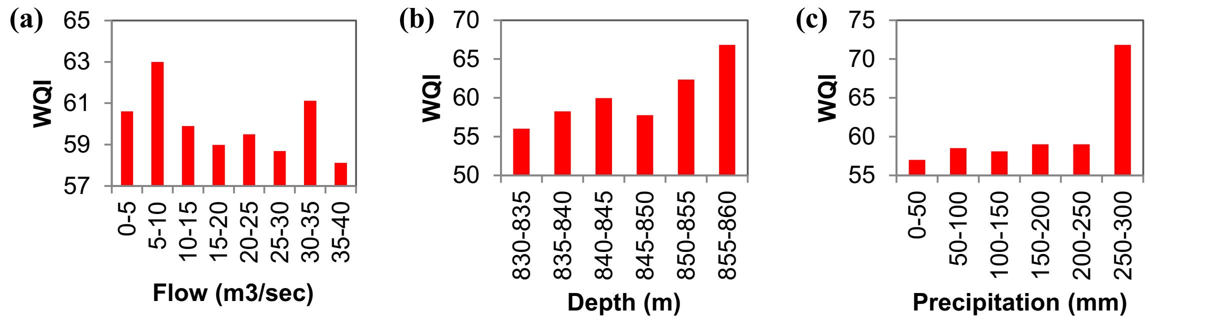


**Fig. 5** Variation of mean WQI scores in the Karaoun Reservoir along study period with changes in: **a** flow of Litani river ($m^3/s$), **b** depth (m) and **c** precipitation (mm)

**Table 6** WQI statistical analysis with respect to flow of Litani, depth and precipitation

| WQI | Mean ± SD | Min Interval | Max Interval |
|---|---|---|---|
| *Q* | 59.99 ± 1.57 | 58.13 (35–40 $m^3/s$) | 63 (5–10 $m^3/s$) |
| *D* | 60.2 ± 3.9 | 56 (830–835 m) | 66.84 (855–860 m) |
| PRCP | 60.57 ± 5.56 | 57.01 (0–50 mm) | 71.82 (250–300 mm) |

**Table 7** KMO and Bartlett's test results

| KMO and Bartlett's test | | |
|---|---|---|
| Kaiser–Meyer–Olkin | Measure of sampling adequacy | 0.703 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 665.517 |
| | *df* | 91 |
| | Sig. | 0.000 |

moderate tolerance to salts (Abbasi and Abbasi 2012c). WQI ranging between 60 and 70 requires necessary treatment if used as public water supply and recreational purposes. However, for agricultural and industrial purposes, no treatment would be needed (Dinius 1987).

WQI was previously applied to other water bodies throughout the world. In Loktak Lake located in India, WQI showed that the water quality of the lake was good throughout the year with slight deterioration during wet season (Roy and Majumder 2019). In Lake Taihu Basin located in China, the water quality presented distinct seasonal variation, with the lowest WQI values during wet season (Wu et al. 2018). Like these studies, Karaoun Reservoir also showed slighter deterioration during wet season.

WQI showed a decreasing trend between 2009 and 2016. Sudden increase in the number of habitants has occurred in the basin of Litani might have resulted in the decrease of annual WQI and deterioration of water quality. Due to

**Table 8** Correlation matrix

| | *T* | Sal | $NH_3$ | EC | DO | $NO_3$ | $NO_2$ | pH | $PO_4$ | $SO_4$ | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *T* | 1 | | | | | | | | | | |
| Sal | **− 0.52**** | 1 | | | | | | | | | |
| $NH_3$ | − 0.28** | 0.48** | 1 | | | | | | | | |
| EC | **− 0.56**** | **0.91**** | 0.47** | 1 | | | | | | | |
| DO | − 0.04 | − 0.11 | **− 0.52**** | − 0.017 | 1 | | | | | | |
| $NO_3$ | − 0.17 | 0.14 | − 0.28** | 0.20* | 0.29** | 1 | | | | | |
| $NO_2$ | − 0.43** | 0.29** | − 0.00 | 0.34** | 0.20 | 0.15 | 1 | | | | |
| pH | 0.44** | − 0.46** | − 0.37** | − 0.47** | 0.17 | − 0.11 | − 0.11 | 1 | | | |
| $PO_4$ | − 0.12 | 0.13 | 0.16 | 0.23* | 0.05 | 0.18 | 0.04 | − 0.14 | 1 | | |
| $SO_4$ | − 0.09 | 0.34** | 0.17 | 0.30** | − 0.20* | 0.00 | 0.07 | − 0.08 | − 0.12 | 1 | |
| TDS | **− 0.57**** | **0.92**** | 0.47** | **0.97**** | − 0.06 | 0.20* | 0.29** | **− 0.51**** | 0.18 | 0.29** | 1 |

Bold values indicate high correlation

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

**Table 9** Rotated component matrix: by Varimax with Kaiser Normalization

| | Variances explained by rotated components | | |
|---|---|---|---|
| | PC1 | PC2 | PC3 |
| Eigenvalues | 4.24 | 1.85 | 1.15 |
| Percent variance | 38.62 | 16.87 | 10.48 |
| Cumulative variance | 38.62 | 55.50 | 65.98 |
| | Rotated loadings | | |
| | PC1 | PC2 | PC3 |
| *T* | − 0.70 | − 0.19 | 0.04 |
| Sal | 0.91 | − 0.02 | 0.13 |
| $NH_3$ | 0.21 | 0.63 | − 0.17 |
| EC | 0.94 | 0.06 | 0.04 |
| DO | − 0.11 | 0.81 | − 0.10 |
| $NO_3$ | 0.56 | − 0.67 | − 0.08 |
| $NO_2$ | 0.39 | 0.47 | 0.17 |
| pH | − 0.63 | 0.15 | 0.21 |
| [$PO_4$] | 0.26 | 0.02 | − 0.75 |
| [$SO_4$] | 0.33 | − 0.12 | 0.67 |
| TDS | 0.94 | 0.02 | 0.05 |

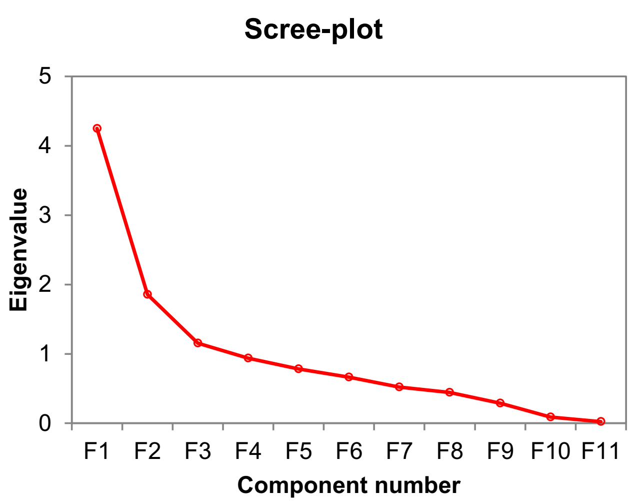


**Fig. 6** Scree-plot for the PCA of the water quality parameters in Karaoun Reservoir

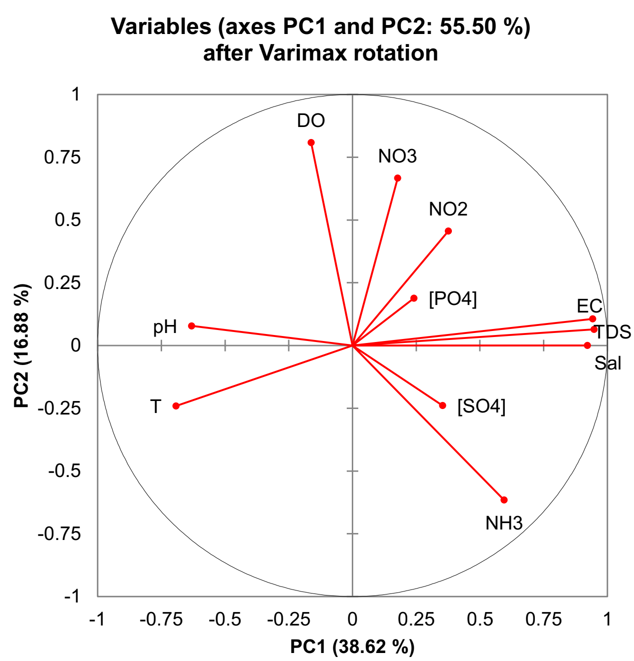


**Fig. 7** Principal component analysis (PCA) with Varimax rotation of 11 environmental parameters for the whole study period in the Karaoun Reservoir, Lebanon

the Syrian crisis that started in 2011, Lebanon hosted up to 1,500,000 Syrian refugees (Hussein et al. 2020). Many of those displaced refugees have settled in the Upper Litani River Basin, the watershed of the Karaoun Reservoir, almost doubling its inhabitants. The negatively impacted the quantity and the quality of water resources in the basin that was already suffering from a weak water infrastructure and mismanagement of water treatment plants.

PCA analysis showed that PC1 explained 38% of total variance, where it was negatively related to temperature and pH and positively related to salinity and conductivity. This implies a saline soil weathering and run-off along a freshwater body, offset of enrichment of the basin by these minerals (Merian et al. 2004). Also, conductivity levels show the presence of dissolved ions beyond natural background levels (Debels et al. 2005; Massoud 2012). As for pH and temperature, they alter the functions of aquatic ecosystem and influences growth and distribution of flora and fauna (Rameshkumar et al. 2019). Therefore, PC1 can be interpreted as the seasonality of salinity, where erosion leads to higher input of salts.

The second component contributing to 16% of total variance relating positively to ammonia and dissolved oxygen, and negatively with nitrate. Nitrogen, an essential nutrient for crop production, is also the most common fertilizer used worldwide. Excess nitrogen not taken up by plants result in its subsequent influx into water bodies (Merian et al. 2004; Sheykhi et al. 2015). As for dissolved oxygen, it's determination is fundamental to water quality assessment, since oxygen is involved in nearly all chemical and biological processes within water bodies (Sheykhi et al. 2015). It is an indication of the degree of pollution by organic matter and the ability of the self-purification process in water to function normally (Massoud 2012; Shrestha and Kazama 2007). Therefore, PC2 represent organic pollution and its impact on dissolved oxygen.

The third component explains 10.48% of total explained variance relating negatively to phosphates and positively with sulfates. Phosphates are a limiting nutrient in the eutrophication in lakes (Parinet et al. 2004; Simeonov et al. 2003). Their surplus may cause the eutrophication that enhances the production of bio-mass in ecosystems that in surface waters can result in a limitation of oxygen availability that ultimately proves fatal to water-borne life systems (Merian et al. 2004). As for sulfate, it may enter waters through waste discharges and household wastes industrial effluents (Merian et al. 2004). Thus, this factor represents the effect of fertilizers into the freshwater system.

When statistical tools like PCA is incorporated with WQI, it provides a multidimensional nature of water quality concept, where the former points out the importance of certain environmental parameters for water quality trends and the latter, integrates the results of the environmental parameters into a single score in time and space. This allows water quality to be viewed in terms of a numerical value that qualifies possible water uses.

However, WQI may not carry enough information about the real situation of water, as it does not include all threats to water quality including but not limited to, pesticides, heavy metals, endocrine disruptive compounds (Massoud 2012). As well, the different usage of water quality (i.e., irrigation, recreation, drinking, etc.) cannot all be met with a single unbiased index. In addition, other quantifiable parameters, may not be included in the index, or may not have a weight assigned to it, due to the changes in topography and geographical position from one study site to another (Kachroud et al. 2019). As for the weights, there is bias in assigning weights were each weight may eclipse or over-emphasize a parameter value negatively (Tyagi and Sharma 2013). For that, meta-evaluation approach of WQIs is recommended (Alexakis 2020).

Precipitation and reservoir water level appear to be adversely impacting WQI in Karaoun Reservoir. Rainfall is a significant factor that can affect water quality via storm water runoff (Coulliette and Noble 2008). Seasonal rains can increase the water flow in freshwater bodies and, can consequently silt more particles and other dissolved material (Sipaúba-Tavares et al. 2007).

The relation between water level and water quality is not easily and adequately assessed. For that, hydrodynamic model has been used to predict the impact of water-level change on the water quality. Simulation results from calibrated models showed that at low water-level pollutants dispersal ability decreased and increased at higher water-level. At low water-level, the contents of TN and TP were higher, compared with higher water-level condition, in water body of the reservoir (Wang et al. 2016).

Carlson Trophic State Index (CTSI) is another important index used to evaluate the ecological status of lakes and reservoirs. It was previously applied to Karaoun Reservoir classifying it as eutrophic between 2004 and 2013. The CTSI increased in 2015, classifying the reservoir as hypereutrophic and showing that the reservoir's trophic state has not improved in the last ten years (Fadel et al. 2016). The high trophic state of the reservoir has resulted in a dramatic change in the phytoplankton community with reduced biodiversity and dominance of toxic cyanobacterial blooms since 2010. The evaluation provided by CTSI, classifying the reservoir as eutrophic agrees with the WQI findings in this study that classifies the quality of the reservoir as medium.

Untreated industrial wastes, agricultural fertilizers, and municipal sewages are dumped directly to Litani River that inputs in Karaoun Reservoir without any treatment resulting in the deterioration of its water quality. An effective management of the water quality produced in the catchment area of Karaoun Reservoir is necessary to improve its quality. This can be achieved by the treatment of wastewater effluents from municipalities and industries through operational water treatment plants, raising awareness among the Litani River basin inhabitants, and the strengthening of basin managers' capacities.

## Conclusion

In this study, WQI method was applied to assess the water quality in Karaoun Reservoir. It showed that the quality of the reservoir deteriorated over the 8-year study period, mainly due to sudden urbanization resulting from Syrian Refugees crisis. Factors directly causing a change in WQI when removing one variable at a time were ammonia, nitrate, and phosphate. Application of PCA helped identifying the indicator parameters affecting water quality. It showed that deterioration of water quality is attributed to erosion factors, municipal sewages, and pollution by fertilizers. No clear relation was found between WQI and river flow. However, precipitation higher than 250 mm and higher water depth increased WQI. An integrated approach based on WQI and PCA is an effective way in assessing the pollution levels as well as establishing the most important sites and variables where attention must be focused on. This study concludes that the managers of Karaoun Reservoir should take some mitigation measures to maintain and improve water quality for the different water usage purposes that it provides.

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