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Research Article

# Multiple factor analysis using water quality index scores and parameters as an approach for evaluating the environmental status of polluted lakes along the Black Sea coast of Bulgaria

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## Abstract

The moderately salty and lightly salty lakes and marshes near the Black Sea are specific in terms of their high degree of physical alteration; intensive hydromorphological pressure; and point-source and diffusive enrichment with biogenic, organic and inorganic compounds. Nutrients are among the most regularly measured variables in monitoring programs, providing the most complete information for long-term analysis and assessment. Nonetheless, their results need a final summary score, such as the water quality index, which assesses spatial and temporal conditions very well. In this study, we used all available data for Varna and Burgas Lakes from state monitoring for six years (2016–2021), using the parameters monitored with the greatest frequency. The aims were to trace temporal changes in the water quality parameters to determine which of the biogenic elements had the greatest significance for the variance in water quality while seeking the most contributing elements for the formation of the Canadian Council of Ministers of the Environment water quality index (CCME-WQI). The objectives were achieved via multiple factor analysis (MFA) loaded with the results for the environmental variables and the final scores of the CCME-WQI since this multivariate analysis allows simultaneous consideration of multiple data series while balancing the influence of each set of variables. MFA revealed that CCME-WQI scores were influenced solely by total phosphorus (TP) in Varna Lake, where TP was negatively correlated with total nitrogen. In Burgas Lake, TP had the greatest influence on the CCME-WQI, but in this slightly saline lake, pH and dissolved oxygen were also negatively correlated with the complex assessment scores. The approach developed in this study is simple to implement and provides information for the simultaneous use of both the CCME-WQI and the MFA, which could optimize monitoring programs by directing sampling efforts on fewer parameters that could be analyzed more often or from more sampling sites.

**Key words:** Burgas Lake, hydrochemical assessment, multivariate analysis, nutrients, heavily modified lakes, Varna Lake

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## 1. Introduction

European lakes are still affected mostly by nutrient enrichment, which can interact in a synergistic or antagonistic manner with hydrological alteration, thermal alteration and chemical pollution (Birk et al. 2020; Doychev et al. 2024). Therefore, determining trends of multiple anthropogenic pressures with an increasing number of pressure types (Free et al. 2024) on the environmental components in lakes requires urgent and concerted actions in which politicians, nongovernmental and scientific organizations and interested parties need to be involved. In this sense, the greatest challenge in developing the modern world is balancing its social, economic and environmental aspects.

Water resources such as lakes are of major importance in economic and social prosperity. These water bodies cover only 4% of the land surface not covered by glaciers, and their preservation and restoration are of primary importance for healthy living conditions for humans, ensuring high recreational value (Poikane et al. 2024). Therefore, the conditions of their quantitative and qualitative specifics are vital for lake ecosystems considering the large part of the incoming waste that may remain in the environment for decades or even centuries (Doncheva et al. 2020) and accumulate in filter-feeding organisms (Mihova et al. 2024).

The lakes of Bulgaria are complexly used and are highly important. However, many of these water bodies are contaminated because of their multiple-stressor activity. Some of them are concentrated around the two largest bays, Varna Bay and Burgas Bay, where well-defined economic zones have developed. The leading sectors of the Bulgarian "sea" economy are maritime tourism, aquaculture, maritime transport, port activities, shipbuilding, agriculture, industry, recreation, tourism, fishing, etc. (Ganchev et al. 2023). Therefore, the discharge of wastewater by production accidents or in a regulated manner into receiving water bodies is possible.

Several economic sectors, such as light industry and food production, are among the branches of the secondary (e.g., chemical production) and tertiary sectors and present deterioration risks for the studied water bodies and their quality (Ravnachka and Stoyanova 2022; Stoyanova et al. 2024). These anthropic activities could influence the chemical and salinity compositions of lake waters, which determines their classification and evaluation systems (MOEW 2012).

To conduct an assessment and evaluate the impact on surface water bodies and counteract pressure, it is highly important to collect appropriate quantities of monitoring data. The gathered information should reflect spatial and temporal changes to reveal pollution sources, the main impact parameters and the environmental status (Varol 2020).

The water quality index (WQI) is a useful mathematical instrument that uses data that considers the physical and chemical properties of the water, with defined local normative thresholds. The WQI evaluates the quality of water bodies spatially and temporally by summarizing all the results into a single value, which ensures easier interpretation (Etim et al. 2013; Aydin et al. 2020; Varol 2020; Zhang et al. 2022; Benkov et al. 2023).

The WQI is a globally recognized index developed by Horton (1965), for which many regional specifications have been developed over the years. At the end of the XX century, a new WQI was introduced to Canada by the province of

British Columbia. A few years later, the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment (CCME) modified the original version of the WQI and accepted it as the CCME-WQI in 2001 (CCME 2001; Chidiac et al. 2023). Currently, the CCME-WQI is a widely used assessment system because of its advantages related to the tolerance of missing data and the simple addition of parameters with fixed legislative thresholds (Benkov et al. 2023). Therefore, the WQI can play a crucial role in assessing different types of water objects (Zhang et al. 2022), but when applied separately, it is constrained (Varol 2020).

With the increasing number of emerging pollutants (European Commission 2021), the number of measured parameters has increased, which has led to a growing need to mine valuable information (Zhang et al. 2022). Multivariate data analysis is a powerful set of methods that discover knowledge within large datasets. These include principal component analysis (PCA), correspondence analysis (CA), factor analysis (FA), multiple correspondence analysis (MCA), and multiple factor analysis (MFA) (Kassambara 2017).

FA allows the investigation of correlation coefficients between parameters and can reveal hidden relationships (Sürücü et al. 2024). MFA is a general factor analysis based on PCA, which is probably the oldest, most popular and most commonly used multivariate analysis in all scientific branches (Abdi and Williams 2010) when variables are quantitative and MCA when variables are qualitative. MFA can be very useful in environmental studies considering variables from different characters that generate time series (Kassambara 2017).

The application of both WQI and MFA, PCA or another multivariate method will allow a better understanding and interpretation of the results for surface water monitoring programs (Varol 2020). Many studies have used both multivariate methods and WQI to gain qualitative interpretation, but they did not use WQI scores as a variable within the statistical analysis to find the parameters with the greatest contribution to the final ecological status assessment by the WQI. These methods rely on analyzing the variables separately from the WQI (Simeonov et al. 2003; Shrestha and Kazama 2007; Aydin et al. 2020; Varol 2020; Zhang et al. 2022) or considering solely the exceedances of the parameters (Benkov et al. 2023).

This study aims to assess 1) the temporal changes in the water quality of two heavily impacted lakes by the status of the physicochemical parameters; 2) which of the most measured biogenic elements has the greatest variance and contribution for the dataset and has the greatest influence on the CCME-WQI; and 3) the ability of the MFA to use water quality parameters and final CCME-WQI scores as different groups in a simplified approach for environmental assessments of surface water bodies that need evaluation.

## 2. Materials and methods

### 2.1. Study area

Our study focused on two water bodies on the Black Sea coast of Bulgaria. These lakes include Varna Lake, the largest lake system (Ganchev et al. 2022; Mihova et al. 2024; Georgieva et al. 2024), and Burgas Lake, which is smaller but is the largest natural lake ecosystem (Peycheva et al. 2022).

Varna Lake was separated from Beloslav Lake until 1923, when the first channel was dug (Krastev and Stankova 2008). The lagoon formed at the Provadiyska Reka River mouth (Mihova et al. 2024) is connected by two artificially excavated navigation channels with Varna Bay. The lake's surface area is 15.7 km$^2$, the maximum depth is 21.3 m, and the maximum length and width are 10.5 and 2.5 km, respectively (Lambev et al. 2020).

In accordance with the RBMP (2016), Varna Lake is classified as a Water Framework Directive (WFD) water body with code BG2PR100L001 from the type L9 - Black Sea moderately salty lakes and marshes. The main specifics for this lentic ecosystem include mixed geology with carbonates and silicates, a polymictic regime of the water column, an average depth < 15 m and mesohaline to polyhaline conditions (MOEW 2012).

Burgas Lake is a brackish estuary connected to the sea by a channel. The stagnant water body is also filled by the Aytoska Reka, Sunderdere and Chukarska Reka Rivers, which flow into its western part. The lake's surface area is 28 km$^2$. The length is 9.6 km, and the width is between 2.5 and 5.0 km (Gartsiyanova 2016).

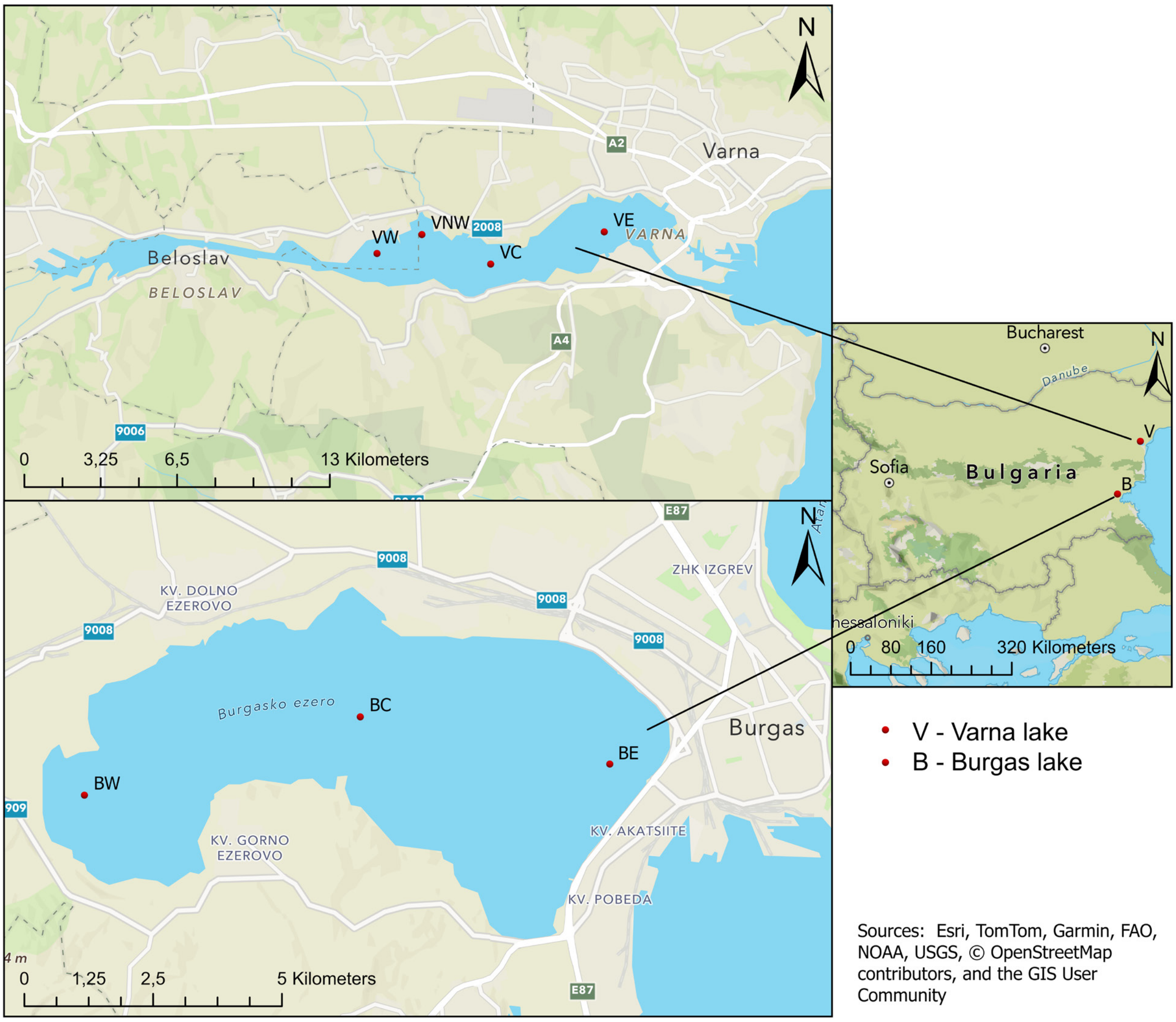


**Figure 1.** Map of the study areas.

**Table 1.** Basic information for the sampling sites.

| Sampling sites | Codes of the sampling sites | Waterbody type | Coordinates | |
|---|---|---|---|---|
| | | | N | E |
| Varna Lake–west (VW) | BG2PR00155MS013 | L 9 | 43.19237 | 27.77643 |
| Varna Lake–northwest (VNW) | BG2PR00155MS014 | L 9 | 43.19762 | 27.79362 |
| Varna Lake–center (VC) | BG2PR00155MS015 | L 9 | 43.18939 | 27.81992 |
| Varna Lake–east (VE) | BG2PR00155MS016 | L 9 | 43.19837 | 27.86333 |
| Burgas Lake–west (BW) | BG2SE90000MS022 | L 8 | 42.49106 | 27.35119 |
| Burgas Lake–center (BC) | BG2SE90000MS023 | L 8 | 42.50111 | 27.39928 |
| Burgas–east (BE) | BG2SE90000MS024 | L 8 | 42.49511 | 27.44272 |

According to the RBMP (2016), Burgas Lake is classified as a WFD water body with code BG2SE900L037 from the type L8 - Black Sea lightly salted lakes and marshes. This ecosystem's main specifics include mixed geology with silicates, a polymictic regime of the water column, an average depth of less than 3 m and oligohaline conditions (MOEW 2012).

By Order No. RD-405/4.12.1997, Burgas Lake was declared a protected area. Even earlier in 1989, it was defined as an Ornithologically Important Site by BirdLife International. According to the Ramsar Convention in 2003 it was determined as a Wetland Area of International Importance. Therefore, the water body has conservational importance and serves as the natural habitat of aquatic organisms of national and international significance (Gartsiyanova 2016; Midyurova 2021; Syulekchieva and Midyurova 2024).

The national monitoring program related to water sampling was conducted at four sampling sites in Varna Lake and three in Burgas Lake (Fig. 1; Table 1). Their locations are selected as representative by the responsible authorities based on the hydromorphological characteristics, the length of the lakes and the specific types of pressure in the individual areas.

## 2.2. Physicochemical parameters

The regular state monitoring at Varna and Burgas Lakes is the data source for the physicochemical parameters. Water samples were collected and analyzed by an accredited regional laboratory under the control of the Executive Environmental Agency (EEA) following Bulgarian national standards.

We used officially published data on surface water quality provided by the EEA to the Ministry of the Environment and Waters for the period 2016–2021. The indicators, or the so-called physicochemical quality elements (PCQEs), used in this research are pH, dissolved oxygen (DO), ammonium nitrogen ($NH_4$-N), nitrate nitrogen ($NO_3$-N), nitrite nitrogen ($NO_2$-N), orthophosphates such as phosphorus ($PO_4$-P), total nitrogen (TN), total phosphorous (TP) and biological oxygen demand for five days ($BOD_5$). We have used only the mentioned nutrients and general physicochemical indicators since the other monitored parameters were not examined regularly at all monitoring sites. Some aren't even surveyed annually, much less seasonally.

The obtained data sets are based on monitoring programs for every sampling site with six repetitions per year—from March, May or June, July, August, September and November (Fig. 1; Table 1). In 2020, only four water samples were taken in July, August, September and November. In total, 136 samples from Varna Lake and 105 samples from Burgas Lake were analyzed during the second RBMP.

In situ, and laboratory-analyzed PCQEs are defined as supporting data for ecological status assessment. The results are separated into three groups: high ecological status, good ecological status (GES) and moderate ecological status (European Commission 2005; MOEW 2012).

## 2.3. Water Quality Index

To fulfill the goal set in the present study and consider the Bulgarian legislative framework, the quality state of the waters in the studied lakes has been assessed by applying the water quality index developed by the Canadian Council of Ministers of the Environment (Neary et al. 2001). In 2006, the CCME-WQI was recommended for water quality evaluation procedures by the United Nations Environment Programme and is defined as one of the fundamental complex assessments, on the basis of which several other models have been developed (Benkov et al. 2023).

Mathematically, the model combines three variables that characterize the impact on water quality: range (F1), frequency (F2), and amplitude (F3). F1 represents "failed variables" in percentages that do not achieve GES. F2 shows "failed tests" in percentages from the total number of all samples that did not reach the range of GES, and F3 demonstrates the extent of the amplitude of the "failed tests" values concerning threshold legislation (Table 2) (MOEW 2012).

**Table 2.** GES thresholds for the PCQEs for L8 and L9 lakes (MOEW 2012).

| Lake type | DO (mg/l) | pH | $NH_4$-N (mg/l) | $NO_3$-N (mg/l) | $NO_2$-N (mg/l) | TN (mg/l) | $PO_4$ -P (mg/l) | TP (mg/l) | $BOD_5$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| L9 | 6–7 | 6.5–8.7 | 0.1–0.3 | 0.8–2 | 0.03–0.06 | 0.7–2.5 | 0.025–0.06 | 0.025–0.075 | 2–4 |
| L8 | 6–7 | 6.5–8.7 | 0.1–0.3 | 0.8–2 | 0.03–0.06 | 0.7–2.5 | 0.025–0.06 | 0.025–0.075 | 2–4 |

The following equation (eq. 1) generates a value between 0 and 100. Zero indicates the "worst" case scenario, and 100 indicates the "best" possible result.

$$WQI = 100 - \left(\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right) \quad (1)$$

Unlike PCQEs, the original CCME-WQI scale divides water quality into five categories: poor, marginal, fair, good, and excellent (Table 3) (Neary et al. 2001).

**Table 3.** CCME-WQI scores represented in the color code following the WFD. Legend: The color code follows the ecological status classification. Blue–high ecological status. Green–GES. Yellow–moderate ecological status. Orange–poor ecological status. Red–bad ecological status.

| Categories | CCME-WQI | Water Quality Condition |
|---|---|---|
| Excellent | 95–100 | Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. |
| Good | 80–94 | Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels. |
| Fair | 65–79 | Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels. |
| Marginal | 45–64 | Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels. |
| Poor | 0–44 | Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels. |

### 2.4. Data analysis

MFA was conducted in an R environment with RStudio (R 4.2.3, R Core Team 2023). We used the “factoextra” and “FactoMineR” packages. The statistical significance ($P<0.05$) of the parameters for principal components 1 (Dim 1) and 2 (Dim 2) was determined with the “dimdesc” function in “FactoMineR”.

MFA, such as PCA, is capable of extracting the most important information from a group of variables and visualizing the results better. Nevertheless, the choice of MFA as a multivariate data analysis method is quite logical because of its ability to consider multiple data series simultaneously while balancing the influence of each set of variables. This is accomplished by considering all groups as active, while each group is normalized with varying weighting values between groups. Therefore, participating in the determination of principal components is ensured for all datasets (Kassambara 2017).

In the present research, the data are organized into two groups. PCQE is the larger group with nine variables, and the other group consisting of only one variable is represented by the scores of the CCME-WQI. With MFA, we were able to investigate the influence of PCQEs on the results of the CCME-WQI and to demonstrate interrelations between physicochemical parameters in Dim 1 and Dim 2.

To achieve a better understanding of the significance of every physicochemical variable in determining principal components and revealing hidden relationships within PCQEs, we considered the whole dataset for water quality. This approach differs from the one applied in Benkov et al. (2023), where only calculated excursions of PCQEs were included in the PCA.

## 3. Results and discussion

### 3.1. Varna Lake

Instead of interpreting the results for every sampling site on a seasonal or yearly basis as in Falah et al. (2019), we used a summary of the results for the entire study period. All the data considering the PCQE results from all the sampling events and all the sampling sites in a water body were used for the physicochemical status interpretation following Regulation No. H-4 (MOEW 2012) for six years.

The maximum values for all the studied parameters from all the sampling sites in Varna Lake were in the range of “moderate” ecological status. Mean, median, mode and minimum scores of the PCQEs that achieved GES were pH, $NH_4$-N, $NO_3$-N, $NO_2$-N, TN and $BOD_5$. All measurements for phosphor-containing variables were out of the range of GES, excluding the minimum registered results (Table 4) (MOEW 2012).

During the studied period, the TP concentrations were between 10 and 25 times and often more than 25 times above the set norm for GES (0.06 mg/l) (Table 2). The extreme maximum value of 6.1 mg/l (Table 4) was registered on 10.08.2021 at VNW. According to the analyzed indicators, those that reacted least often and to the lowest extent to the applied anthropogenic load were nitrogen-containing parameters. In practice, their values register episodic or one-time deviations from the standards set ($NH_4$-N—0.1–0.3 mg/l; $NO_3$-N—0.8–2 mg/l; $NO_2$-N—0.03–0.06 mg/l; TN—0.7–2.5 mg/l) (Table 2). Such an exceeding was registered in March 2017 and November 2019 at VW. In 2017, the maximum values were for $NO_3$-N and TN, whereas in 2019, the maximum was for $NO_2$-N (Table 4).

**Table 4.** Descriptive statistics for Varna Lake, considering all sites. Legend: The color code follows the ecological status classification. Blue–high ecological status. Green–GES. Yellow–moderate ecological status.

| Lake type | DO (mg/l) | pH | $NH_4$-N (mg/l) | $NO_3$-N (mg/l) | $NO_2$-N (mg/l) | TN (mg/l) | $PO_4$-P (mg/l) | TP (mg/l) | $BOD_5$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| n | 136 | 136 | 136 | 136 | 136 | 136 | 49 | 73 | 112 |
| mean | 8.05 | 8.29 | 0.19 | 0.38 | 0.04 | 1.10 | 0.11 | 1.00 | 3.05 |
| median | 7.31 | 8.33 | 0.13 | 0.20 | 0.03 | 1.13 | 0.11 | 0.22 | 2.65 |
| mode | 10.2 | 8.43 | 0.10 | 0.13 | 0.01 | 1.13 | 0.13 | 2.5 | 3.1 |
| standard deviation | 2.96 | 0.34 | 0.20 | 0.44 | 0.07 | 0.36 | 0.09 | 1.35 | 2.54 |
| minimum | 1.78 | 7.11 | 0 | 0.05 | 0.003 | 0.58 | 0.022 | 0.008 | 0.57 |
| maximum | 17.16 | 9.18 | 1.27 | 2.74 | 0.49 | 2.79 | 0.62 | 6.1 | 23 |

The hydrochemical characteristics of Varna Lake are determined by its connection with Beloslav Lake, which receives polluted industrial and domestic wastewater containing diverse pollutants, and by its hydraulic connection with the Black Sea.

Because of the large number of pollution sources at Varna Lake, the negative direct or indirect impact on the water quality is a consequence of multiple anthropogenic pressures. The ascertained deviations of the investigated quality parameters from the normatively defined ones give reason to define the lake’s water area as a “hot spot”. This is confirmed by another previous research (Gartsiyanova 2016; Toneva and Dimova 2019; Ganchev et al. 2023).

The values obtained from the application of the CCME-WQI demonstrated that in most of the cases (Fig. 2), the water quality in Varna Lake was defined as “marginal” and frequently threatened or impaired (Table 3). In addition, conditions often are within the range of "fair" status (Fig. 2), departing from natural or desirable levels and nearly always being threatened or impaired (Table 3). The worst water quality was recorded at VC, where in 4 out of the 6 years, the calculated values for the CCME-WQI placed the lake basin in the "marginal" and "poor" categories. The years in which the values of the obtained comprehensive quality assessment at all the sampling sites did not meet the conditions for "fair" status were 2016 and 2021 (Fig. 2).

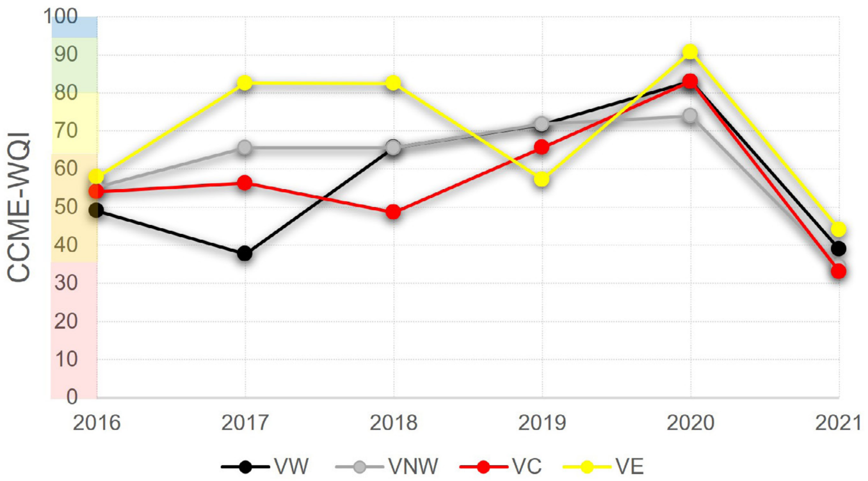


**Figure 2.** Annual dynamics of CCME-WQI scores for Varna Lake. The color code on the ordination axis is as follows: blue–excellent; green–good; yellow–fair; orange–marginal; red–poor.

The MFA results demonstrate that Dim 1 and Dim 2 are responsible for 22.8% and 19.1% of the variation, respectively (Fig. 3). In the first principal component, only two variables had contributions above the average contribution (Fig. 4). These parameters are the TP and WQI. They demonstrate a strong negative correlation (Table 5), which is well illustrated and on the correlation circle (Fig. 3), where the TP and WQI are located far from the origin, in opposite quadrants and near the axis of Dim 1.

Phosphates and $BOD_5$ are important for CCME-WQI score formation since they are statistically significant, but their role is less significant since they correlate weakly (Table 5, Fig. 4) with the index.

**Table 5.** Statistically significant variables in Varna Lake within Dim 1.

| Dim 1 | Correlation | P-value |
|---|---|---|
| WQI | **0.9346308** | 4.994965e-62 |
| TN | 0.2899983 | 6.156747e-04 |
| $BOD_5$ | 0.3047085 | 3.099441e-04 |
| $PO_4$-P | -0.3598877 | 1.682500e-05 |
| TP | **-0.5892777** | 4.462373e-14 |

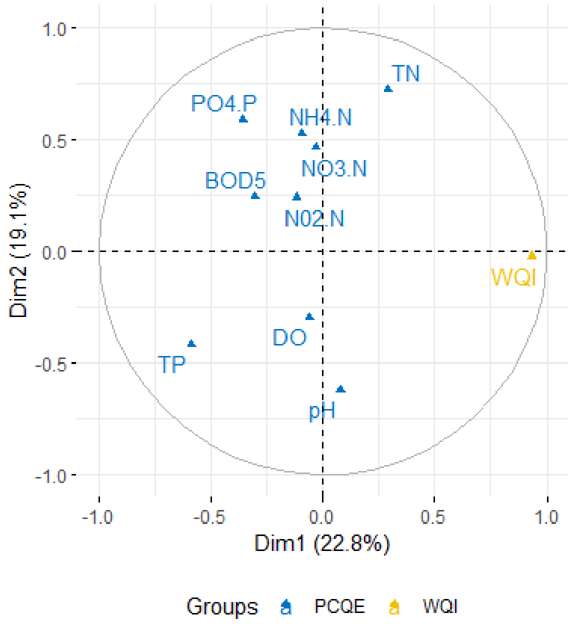


**Figure 3.** MFA correlation circle for all parameters from Varna Lake sampling sites. Blue triangles–Physicochemical quality element “PCQE”. Yellow triangles–Water quality index scores “WQI”.

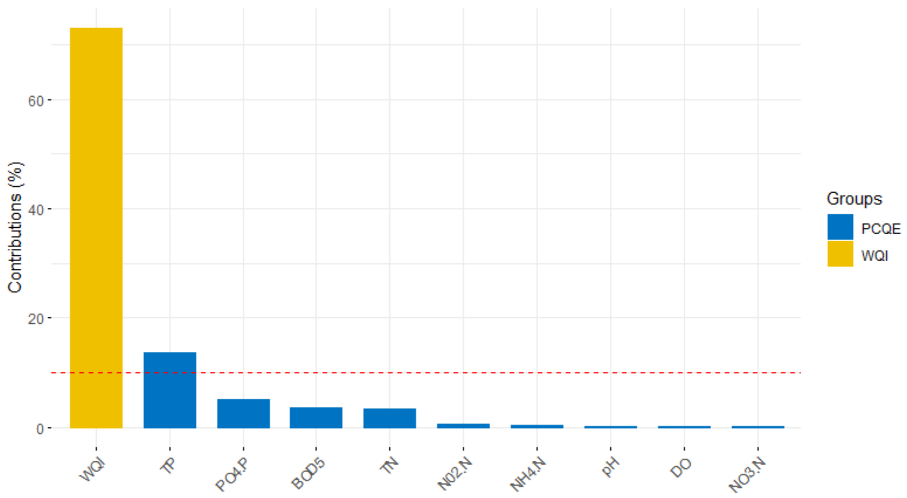


**Figure 4.** Bar plot demonstrating the contributions of the variables in Varna Lake. The red dotted line shows the average contribution for a parameter within Dim 1.

The majority of the PCQEs are important for Dim 2 since they are located near the ordinal axis. TN is the most distant from the origin and has the strongest negative correlation with pH and DO (Fig. 3). In addition, TN was the most significant parameter, with an almost 25% contribution (Fig. 5).

All 9 PCQEs are statistically significant for Dim 2 (Table 6), but only five have contributions above the average and are therefore important for Dim 2 (Kassambara 2017). They have a total contribution of approximately 82% (Fig. 5).

TN had the strongest negative correlation with pH and TP (Table 6). These correlation coefficients suggest that the increase in TN may be related to acidification and TP enrichment, and vice versa.

All these results could serve as a proposal for decision-makers to direct more observation efforts around the analysis of phosphor-containing parameters in terms of sites or monitoring frequency. This could be due to the reduced expenses for seasonal analysis of nitrates, dissolved oxygen, pH, ammonia and nitrites, which are located near Dim 2 (Fig. 3) and make the lowest contribution to Dim 1.

The artificially formed Varna Lake complex has great social and economic significance for the surrounding area. This naturally corresponds to the increasing anthropogenic influence on the ecosystem with the acceleration of urbanization and industrialization in the coastal areas of Varna Bay. Specifically, industrial development, marine transport and urbanization have been identified as major sources of heavy inorganic and organic pollution (Ganchev et al. 2023). The abovementioned findings suggest that Varna Lake is subjected

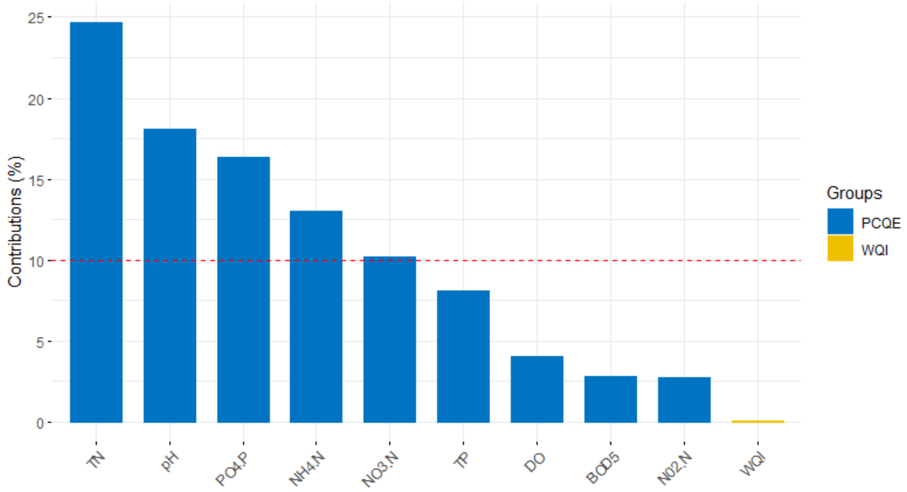


**Figure 5.** Bar plot demonstrating the contributions of the variables in Varna Lake. The red dotted line shows the average contribution for a parameter within Dim 2.

**Table 6.** Statistically significant variables in Varna Lake within Dim 2.

| Dim 2 | Correlation | P-value |
|---|---|---|
| TN | **0.7229288** | 2.878346e-23 |
| $PO_4$-P | 0.5886575 | 4.814540e-14 |
| $NH_4$-N | 0.5255916 | 5.029231e-11 |
| $NO_3$-N | 0.4641038 | 1.263956e-08 |
| $BOD_5$ | 0.2429604 | 4.371075e-03 |
| NO2-N | 0.2409204 | 4.722199e-03 |
| DO | -0.2931571 | 5.329292e-04 |
| TP | **-0.4142794** | 5.335227e-07 |
| pH | **-0.6194358** | 9.049700e-16 |

to four out of five principal impacts at the European level, such as chemical pollution, nutrient and organic enrichment and morphological alteration, which affect 38%, 26%, 16% and 31%, respectively, of all surface water bodies in Europe (Free et al. 2024).

The calculation of the CCME-WQI for the studied period, which is based on the PCQEs included in Bulgarian legislation for the characterization of surface waters with MFA addition, is a simplified approach seeking low-cost complex assessment. In the case of Varna Lake, this approach defined the nutrient TP as the most important parameter for CCME-WQI scores. In addition, MFA demonstrated that the TP concentration was negatively correlated with the TN content at a moderate scale. Bearing in mind the necessity of reducing the pressure of nutrients in the context of climate change (Free et al. 2024), those results must be taken into consideration, and some restrictive or restorative measures should be initiated.

### 3.2. Burgas Lake

The maximum values for all the studied parameters from all the sampling sites in Burgas Lake did not achieve the GES. The minimum scores of all the PCQEs, excluding DO and pH, were better than those of the GES conditions during the study period. The scores for the mean, median and mode values related to nitrogen-containing parameters such as $NH_4$-N, $NO_3$-N and $NO_2$-N were in the high and good physicochemical status ranges. For TN, only the mode value was better than that for GES, whereas the mean and median scores did not achieve GES. Only the mean value for phosphates was moderate, whereas the mean and mode were GES or better than GES. The TP results outperformed the GES condition for the minimum and mode values, while the rest of the results presented for this parameter were in moderate condition (Table 7). $BOD_5$ and pH were the parameters with the worst results and were always moderate, excluding the minimum scores. DO showed great amplitude, and only the mean and median values were in GES (Table 7) (MOEW 2012).

The differentiated analysis of the water quality reveals a constant exceedance. Up to ten times the normative values were registered for all the studied parameters without nitrates (Table 2). At all three sampling sites, the most sig-

**Table 7.** Descriptive statistics for Burgas Lake, considering all sites. Legend: The color code follows the ecological status classification. Blue–high ecological status. Green–GES. Yellow–moderate ecological status.

| Lake type | DO (mg/l) | pH | $NH_4$-N (mg/l) | $NO_3$-N (mg/l) | $NO_2$-N (mg/l) | TN (mg/l) | $PO_4$-P (mg/l) | TP (mg/l) | $BOD_5$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| n | 102 | 102 | 105 | 105 | 105 | 105 | 105 | 105 | 105 |
| mean | 7.34 | 8.97 | 0.27 | 0.23 | 0.044 | 3.92 | 0.073 | 0.29 | 11.52 |
| median | 7.44 | 9 | 0.15 | 0.078 | 0.023 | 2.93 | 0.038 | 0.23 | 9.02 |
| mode | 1.57 | 9.2 | 0.004 | 0.02 | 0.003 | 0.2 | 0.006 | 0.008 | 11.1 |
| standard deviation | 2.56 | 0.58 | 0.34 | 0.42 | 0.088 | 3.35 | 0.107 | 0.29 | 7.23 |
| minimum | 1.57 | 7.16 | 0.004 | 0.005 | 0.001 | 0.2 | 0.003 | 0.008 | 1.86 |
| maximum | 16.6 | 10.26 | 1.52 | 3.21 | 0.775 | 13.4 | 0.693 | 1.41 | 35.8 |

nificant excess of the standards was registered for TP. The detected deviations were in the range of 10–25 times over the permissible normative content (0.06 mg/l). In 2021, all the measurements of TP exceeded the standards for GES at L8 lakes (Table 2).

The greatly deteriorated values of the PCQEs analyzed in Burgas Lake during the second RBMP are explained by the significant anthropogenic pressure to which it was subjected. The industrial area of the city is built on the sandbar that separates the lake from the sea, and two of the larger residential districts of Burgas (Upper and Lower Ezerovo) are in the northwestern and southwestern parts of the water body (Fig. 1). In city districts, several industrial, commercial, transport and tourist activities generate significant amounts of wastewater, and industrial zones worsen the water quality even more by emitting complex substances with different compositions and properties (Gartsiyanova 2016).

Following the requirements of Regulation No. H-4 and the obtained ranking for the quality status of Burgas Lake for the studied period, the lentic ecosystem was defined as having “marginal” or “poor” conditions (Table 3). According to the values of the applied complex quality index (CCME-WQI) at all investigated sites, the requirements for “good” physicochemical conditions were never met, and from 18 cases, only five reached a “marginal” score, whereas the remaining cases presented “poor” results (Fig. 6).

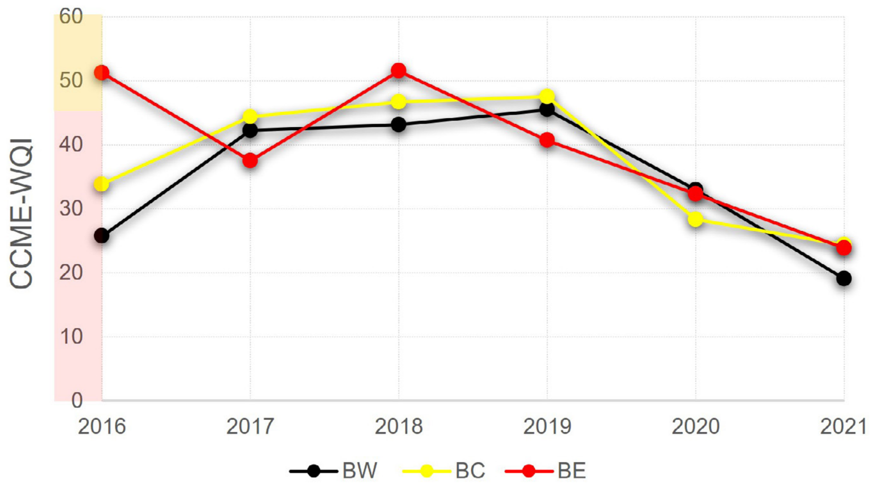


**Figure 6.** Annual dynamics of CCME-WQI scores for Burgas Lake. The color code on the ordination axis is as follows: orange–marginal; red–poor.

The MFA correlation circle reveals that Dim 1 and Dim 2 are responsible for 29.9% and 15.4%, of the variation respectively (Fig. 7), which is better for differentiating the principal component significance than the data from Varna Lake. In Dim 1, the same two variables (TP and WQI) as those in the other lake systems had contributions above the average value (Fig. 8). These parameters demonstrate a very strong negative correlation (Table 8), which is also visible from the correlation circle (Fig. 7). Other statistically significant parameters for the first principal component, such as ammonium, phosphates and TN, also correlated negatively with the CCME-WQI but moderately (Table 8; Fig. 7). Nevertheless, these parameters are not as important as the PCQE with an above average contribution within Dim 1 (Fig. 8).

For the second principal component, the most important parameters are the WQI and 3 PCQEs since they have contributions above the mean. The CCME-WQI has the greatest contribution, followed by nitrates, pH and DO (Fig. 9). Nitrates, which are the PCQE with the smallest exceedance of all biogenic elements, are positively correlated with the CCME-WQI and negatively correlated with the physical parameters pH and DO (Table 9; Fig. 7). The latter is highly important for denitrification processes, and its reduction could induce internal loading of inorganic nitrogen from the sediment (Doychev and Taneva 2025).

Eight PCQEs and the CCME-WQI are statistically significant for Dim 2 (Table 9). Nevertheless, only four had contributions above the average one in the principal component and therefore were important (Kassambara 2017). They have

**Table 8.** Statistically significant variables in Burgas Lake within Dim 1.

| Dim 1 | Correlation | P-value |
|---|---|---|
| TP | **0.8175196** | 1.975842e-26 |
| $NH_4$-N | 0.5502362 | 1.199635e-09 |
| TN | 0.5286791 | 6.749792e-09 |
| $PO_4$-P | 0.4718512 | 3.751318e-07 |
| $NO_2$-N | 0.3065150 | 1.471935e-03 |
| pH | -0.2581040 | 7.853098e-03 |
| WQI | **-0.8509696** | 1.437847e-30 |

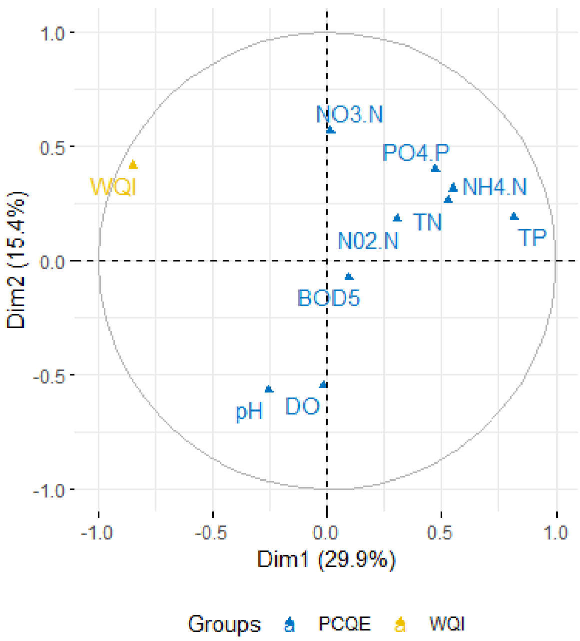


**Figure 7.** MFA correlation circle for all parameters from Burgas Lake sampling sites. Blue triangles–Physicochemical quality element "PCQE". Yellow triangles–Water quality index scores "WQI".

a total contribution of approximately 77% (Fig. 9). The WQI and nitrate content had the strongest negative correlations with pH and DO (Table 9).

Burgas Lake has different results than L9 Lake since the WQI has the greatest contribution in both visualized dimensions (Figs 8, 9).

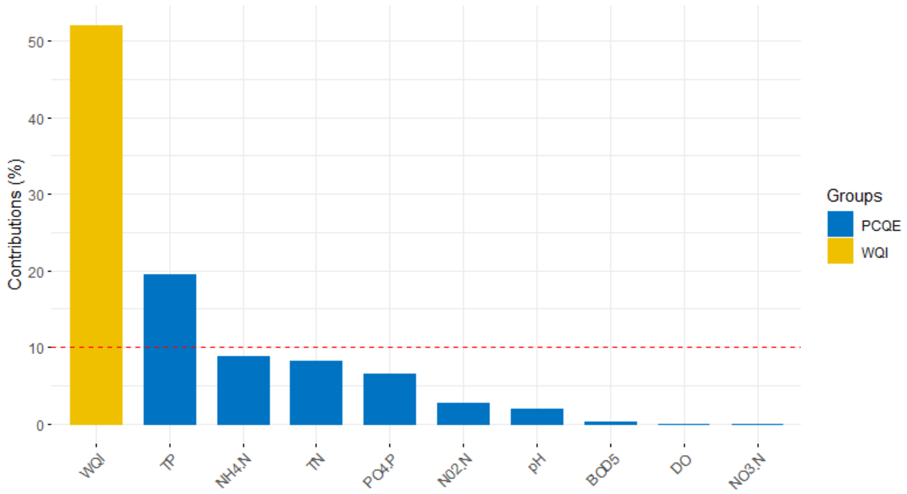


**Figure 8.** Bar plot demonstrating the contributions of the variables in Burgas Lake. The red dotted line shows the average contribution for a parameter within Dim 1.

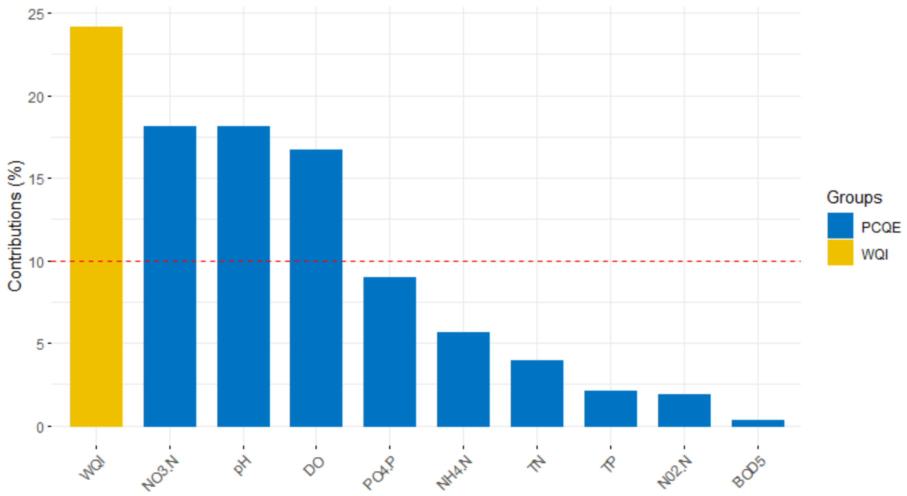


**Figure 9.** Bar plot demonstrating the contributions of the variables in Burgas Lake. The red dotted line shows the average contribution for a parameter within Dim 2.

The Burgas Lakes complex is one of Europe's most significant sites for bird conservation, as it provides permanent and transient shelter for many birds, such as waterfowl and pygmy cormorants. The latter, *Microcarbo pygmeus*, roosted in high numbers in 2011 and 2012, representing approximately 25% of the total European population of the species (Mladenov et al. 2015). This avian species, which is numerous in Burgas Lake, uses the fish resources of lentic water body basins for population maintenance. Unfortunately, constantly deteriorating conditions could result in a decline in the fish population and therefore in a reduction in wintering or roosting birds.

**Table 9.** Statistically significant variables in Burgas Lake within Dim 2.

| Dim 2 | Correlation | P-value |
|---|---|---|
| $NO_3$-N | **0.5651911** | 3.360851e-10 |
| WQI | **0.4161680** | 1.008135e-05 |
| $PO_4$-P | 0.3982779 | 2.579388e-05 |
| $NH_4$-N | 0.3150554 | 1.062254e-03 |
| TN | 0.2626421 | 6.794385e-03 |
| TP | 0.1921956 | 4.950728e-02 |
| DO | **-0.5430264** | 2.167075e-09 |
| pH | **-0.5648387** | 3.465674e-10 |

In addition to higher trophic levels, such as fishes and birds, lower trophic levels could also be affected by pollution (Fig. 6). Macroinvertebrates, planktonic communities, microorganisms and macrophytes could alter their assemblages and lower the self-purification capacity of the lake. This vital capability is dependent on filtration and biological accumulation from the abovementioned organism groups (European Commission 2019).

Another possible path for inhibiting the self-purification capacity of Burgas Lake is the induction of dissimilative reduction. This process is characteristic of the transformation of nitrates to ammonium ions because of organic matter enrichment (Jiang et al. 2023) from the surroundings, wastewater treatment plants, industry, etc. (Falah et al. 2019). As a result, reducing the share of processes related to nitrification and denitrification will occur, and worsening of the ecosystem services will follow. The quality of the irreplaceable dividend provided free of charge by aquatic ecosystems is dependent on the proportion of water bodies at GES and better than that under GES conditions (Grizzetti et al. 2019), which is not accomplished in the studied period, considering surface water quality (Fig. 6).

## 4. Conclusions

This research confirms the ability of the CCME-WQI to reflect temporal changes in surface water bodies, including those that are heavily influenced and physically altered. In addition, we demonstrated the already proven ability of multivariate analysis methods to interpret and visualize the variance and significance of the monitoring data, especially for MFA.

The approach developed in this study provides information for the simultaneous use of both tools since the MFA discloses which PCQEs have the strongest correlation coefficients for the so-called complex assessment by the CCME-WQI. Moreover, the approach chosen here is simple to implement and could be combined with additional groups of variables, as in Doychev (2023), where biological and hydrological metrics were used and analyzed successfully via the MFA.

Separately assessed PCQEs used in the Bulgarian legislation for surface water characterization do not achieve good environmental conditions to fulfill the normative requirements, considering the studied period in both lakes. In Varna Lake, at least two parameters did not achieve GES for any of the averaged values (Table 4), and in Burgas Lake, the results are even worse (Table 7). The yellow-colored parameter results in the mentioned tables activating the rule "one out–all out", and the assessment cannot reach GES, concerning PCQEs. This rule has its exceptions and should not be applied if oxygen parameters are present in the dataset for stagnant water bodies with slow turnover but remain extremely important when acidification is evaluated (European Commission 2024).

Unlike the separate assessment, the complex assessment by the CCME-WQI was capable of differentiating the "moderate" condition established for both water bodies into several categories, predominantly "marginal" and "poor" (Figs 2, 6). The values of almost all the studied indicators in the two lakes exhibited constant excesses, most often up to ten times the regulated norms. The water quality of Varna Lake shows significant temporal dynamics, whereas Burgas Lake registered minor fluctuations during the whole period and was always heavily polluted.

The sources of water pollution for the two WFD water bodies are complex and could be generated from technogenic, agricultural and domestic sources. The overall policy on monitoring and management programs for water resources that receive such a diverse set of pollutants requires the monitoring of numerous variables. Our MFA results related to the CCME-WQI scores and parameters could be used to optimize monitoring programs by directing sampling efforts to fewer parameters that could be analyzed more often or from more sampling sites.

## References

Abdi H, Williams LJ (2010) Principal component analysis. WIREs Computational Statistics 2: 433–459. https://doi.org/10.1002/wics.101

Aydin H, Ustaoğlu F, Tepe Y, Soylu EN (2020) Assessment of water quality of streams in northeast Turkey by water quality index and multiple statistical methods. Environmental Forensics 22: 270–287. https://doi.org/10.1080/15275922.2020.1836074

Benkov I, Varbanov M, Venelinov T, Tsakovski S (2023) Principal Component Analysis and the Water Quality Index—A Powerful Tool for Surface Water Quality Assessment: A Case Study on Struma River Catchment, Bulgaria. Water 15: 1961. https://doi.org/10.3390/w15101961

Birk S, Chapman D, Carvalho L, Spears BM, Andersen HE, Argillier C, Auer S, Baattrup-Pedersen A, Banin L, Beklioğlu M, Bondar-Kunze E, Borja A, Branco P, Bucak T, Buijse AD, Cardoso AC, Couture RM, Cremona F, Zwart D, Feld CK, Ferreira MT, Feuchtmayr H, Gessner MO, Gieswein A, Globevnik L, Graeber D, Graf W, Gutiérrez-Cánovas C, Hanganu J, Işkın U, Järvinen M, Jeppesen E, Kotamäki N, Kuijper M, Lemm JU, Lu S, Lyche Solheim A, Mischke U, Moe SJ, Nõges P, Nõges T, Ormerod SJ, Panagopoulos Y, Phillips G, Posthuma L, Pouso S, Prudhomme C, Rankinen K, Rasmussen JJ, Richardson J, Sagouis A, Santos JM, Schäfer RB, Schinegger R, Schmutz S, Schneider SC, Schülting L, Segurado P, Stefanidis K, Sures B, Thackeray SJ, Turunen J, Uyarra MC, Venohr M, Ohe PC, Willby N, Hering D (2020) Impacts of multiple stressors on freshwater biota across spatial scales and ecosystems. Nature Ecology & Evolution 4:1060–1068. https://doi.org/10.1038/s41559-020-1216-4

Canadian Council of Ministers of the Environment (CCME) (2001) Canadian water quality guidelines for the protection of aquatic life. Canadian Water Quality Index 1.0 Technical Report, Canadian Council of Ministers of the Environment, Excerpt from

Publication No 1299. https://unstats.un.org/unsd/envaccounting/ceea/archive/Water/CCME_Canada.PDF [Accessed on 21.08.2024]

Chidiac S, El Najjar P, Ouaini N, El Rayess Y, El Azzi D (2023) A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives. Reviews in Environmental Science and Bio/Technology 22: 349–395. https://doi.org/10.1007/s11157-023-09650-7

Doncheva V, Mihova S, Stefanova K, Popov D (2020) Microplastic Pollution of Pomorie Lake, Bulgarian Black Sea Coast. In: Rumen Kishev (Ed.) Fifteenth international conference on marine sciences and technologies "Black Sea 2020", Varna (Bulgaria), October 2020. Varna Scientific and Technical Unions, 34–39.

Doychev DD (2023) Longitudinal recovery gradient of macroinvertebrates during different hydrological scenarios in a downstream river reach. Journal of Limnology 82 (1). https://doi.org/10.4081/jlimnol.2023.2125

Doychev D, Gartsiyanova K, Taneva L (2024) Environmental Variables Significance for Ecological Status Assessment in the Bulgarian Eastern Continental Shallow Lakes. Journal of Ecological Engineering 25(10): 16–30. https://doi.org/10.12911/22998993/191540

Doychev DD, Taneva LR (2025) An unpolluted regulated stream and its recovery gradient dependency from environmental variables. Limnetica 44: 1. https://doi.org/10.23818/limn.44.11

Etim EE, Odoh R, Itodo AU, Umoh SD, Lawal U (2013) Water Quality Index for the Assessment of Water Quality from Different Sources in the Niger Delta Region of Nigeria. Frontiers in Science 3(3): 89–95. https://doi.org/10.5923/j.fs.20130303.02

European Commission (2005) Common implementation strategy for the Water Framework Directive (2000/60/EU). Guidance Document No. 13. Overall approach to the classification of ecological status and ecological potential.

European Commission (2019) Commission staff working document. Fitness Check of the Water Framework Directive, Groundwater Directive, Environmental Quality Standards, Directive and Floods Directive. Brussels, 10.12.2019, SWD, 439 final. https://commission.europa.eu/publications/fitness-check-water-framework-directive-and-floods-directive_en#details [Accessed on 12.08.2024]

European Commission (2021) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Pathway to a Healthy Planet for All. EU Action Plan: 'Toward Zero Pollution for Air, Water and Soil'. Brussels, 12.5.2021, COM, 400 final. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0400 [Accessed on 01.09.2024]

European Commission. Joint Research Centre (2024) Physico-chemical criteria to support good ecological status in Europe. Publications Office, LU. https://data.europa.eu/doi/10.2760/355815 [Accessed on 05.09.2024]

Falah A, Peneva G, Koleva R, Yemendzhiev H, Nenov V (2019) Monitoring and Water Quality Assessment of Burgas Lake (Vaya Lake) in the Black Sea Region of Republic of Bulgaria. International Journal of Life Sciences Research 7(3): 130–140.

Free G, Poikane S, Lyche Solheim A, Bussettini M, Bradley C, Smith J, Caroni R, Bresciani M, Pinardi M, Giardino C, van de Bund W (2024) Climate change and ecological assessment in Europe under the WFD – Hitting moving targets with shifting baselines? Journal of Environmental Management 370: 122884. https://doi.org/10.1016/j.jenvman.2024.122884

Ganchev T, Markova V, Valcheva-Georgieva I, Dobrev I (2022) Assessment of pollution with heavy metals and petroleum products in the sediments of Varna Lake. Review of the Bulgarian Geological Society 83(2): 3–9. https://doi.org/10.52215/rev.bgs.2022.83.2.3

Ganchev T, Markova V, Valcheva-Georgieva I, Dobrev I (2023) Pollution of Varna Lake and possibilities of using the pollutants as resources. In: Iliev T, Stoyanov I, Mihaylov G, Fantidis J (Eds). E3S Web of Conferences 404: 03002. https://doi.org/10.1051/e3sconf/202340403002

Gartsiyanova K (2016) Water quality in lakes of Varna and Bourgas (in Bulgarian). Journal of the Union of Scientists, Section "Marine Sciences", 20–28.

Georgieva I, Ganchev T, Markova V, Vachinska S (2024) Importance of Handbook „Good Practices for the Management of the Aquatic Ecosystem in Lake Varna". In: Stankova S, Kabaкchieva D (Eds). Conference Proceedings VI Scientific conference with international participation "Geography, Regional Development and Tourism", Shumen (Bulgaria), November 2024. University Press "Bishop Constantine of Preslav", 149–155.

Grizzetti B, Liquete C, Pistocchi A, Vigiak O, Zulian G, Bouraoui F, De Roo A, Cardoso AC (2019) Relationship between ecological condition and ecosystem services in European rivers, lakes and coastal waters. Science of The Total Environment 671: 452–465. https://doi.org/10.1016/j.scitotenv.2019.03.155

Horton RK (1965) An index-number system for rating water quality. Journal of Water Pollution Control Fed. 37: 292–315.

Jiang X, Liu C, Cai J, Hu Y, Shao K, Tang X, Gong Y, Yao X, Xu Q, Gao G (2023) Relationships between environmental factors and N-cycling microbes reveal the indirect effect of further eutrophication on denitrification and DNRA in shallow lakes. Water Research 245: 120572. https://doi.org/10.1016/j.watres.2023.120572

Kassambara A (2017) Practical Guide to Principal Component Methods in R. Edition 1. STHDA, 264 pp.

Krastev T, Stankova S (2008) Physical geography of Bulgaria and the Black Sea. Part I - General characteristics of the national geographical space. "Konstantin Preslavsky" University Publishing House, Shumen, 240 pp.

Lambev T, Prodanov B, Dimitrov L, Kotsev I (2020) Digital terrain model of the Varna and Beloslav Lakes, North Bulgarian Black Sea Coast. In: Themistocleous K, Michaelides S, Ambrosia V, Hadjimitsis DG, Papadavid G (Eds), Eighth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2020). SPIE, Paphos, Cyprus, 52. https://doi.org/10.1117/12.2571104

Midyurova B (2021) Assessment and observed Trophic Index (TRIX) values for the waters of Burgas Lake. Journal of Environmental Protection and Ecology 22(4): 1386–1394

Mihova SH, Alexandrova AV, Doncheva VG, Stefanova KB, Chipev NH, Ivanov PP (2024) Microplastic Uptake by *Mya arenaria* Linnaeus, 1758, *Mytilus galloprovincialis* Lamarck, 1819 and *Cerastoderma glaucum* (Bruguière, 1789) (Bivalvia) from Varna Lake, Bulgaria*. Acta Zoologica Bulgarica 76(3): 367–374.

Ministry of Environment and Water (MOEW) (2012) Regulation No. H-4 of 14.09.2012 on characterization of surface water. https://www.moew.government.bg/bg/vodi/zakonodatelstvo/naredbi/ [Accessed on 26.07.2024]

Mladenov VR, Kovacheva DM, Georgieva RG, Rusev DZ, Kornilev YV (2015) Burgas Wetlands, Bulgaria: a Conservation Area of European Priority for Roosting of the Pygmy Cormorant, *Microcarbo pygmeus* (Pallas, 1773). Acta Zoologica Bulgarica 67(3): 435–442.

Neary B, Cash K, Hébert S, Khan H, Saffran K, Swain L, Williamson D, Wright R (2001) Canadian Water Quality Guidelines for the Protection of Aquatic Life. CCME Water Quality Index 1.0 Technical Report. Canadian Council of Ministers of the Environment, Winnipeg, MB, Canada.

Peycheva K, Panayotova V, Stancheva R, Makedonski L, Merdzhanova A, Parrino V, Nava V, Cicero N, Fazio F (2022) Risk Assessment of Essential and Toxic Elements in Freshwater Fish Species from Lakes near Black Sea, Bulgaria. Toxics 10: 675. https://doi.org/10.3390/toxics10110675

Poikane S, Kelly MG, Free G, Carvalho L, Hamilton DP, Katsanou K, Lürling M, Warner S, Spears BM, Irvine K (2024) A global assessment of lake restoration in practice: New insights and future perspectives. Ecological Indicators 158: 111330. https://doi.org/10.1016/j.ecolind.2023.111330

R Core Team (2023) R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/

Ravnachka A, Stoyanova V (2022) Clustering analysis of the light industry in Bulgaria. Journal of the Bulgarian Geographical Society 46: 31–42. https://doi.org/10.3897/jbgs.e89215

River Basin Management Plan (RBMP) (2016) River basin management plan of the Black Sea Basin Directorate (2016-2021). Decision 1107/29.12.2016 of the Council of Ministers. https://www.bsbd.org/bg/index_bg_5493788.html Accessed on 27/07/2024

Shrestha S, Kazama F (2007) Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environmental Modelling & Software 22: 464–475. https://doi.org/10.1016/j.envsoft.2006.02.001

Simeonov V, Stratis JA, Samara C, Zachariadis G, Voutsa D, Anthemidis A, Sofoniou M, Kouimtzis Th (2003) Assessment of the surface water quality in Northern Greece. Water Research 37: 4119–4124. https://doi.org/10.1016/S0043-1354(03)00398-1

Stoyanova V, Ravnachka A, Genchev S (2024) Applying cluster analysis in Bulgarian chemical industry for the period 2010-2020. Journal of the Geographical Institute Jovan Cvijic, SASA 74: 165–180. https://doi.org/10.2298/IJGI240312011S

Syulekchieva D, Midyurova B (2024) Evaluating the ecological status of Aytoska River and Burgas Lake using the water quality index. Journal of Environmental Protection and Ecology 25(7): 2190–2202

Sürücü L, Yıkılmaz İ, Maşlakçı A (2024) Exploratory Factor Analysis (EFA) in Quantitative Researches and Practical Considerations. Gümüşhane Üniversitesi Sağlık Bilimleri Dergisi 13: 947–965. https://doi.org/10.37989/gumussagbil.1183271

Toneva D, Dimova D (2019) Study on the state of Varna Lake by physical and chemical indicators (June-August 2019). Sustainable development 3(9): 12–17.

Varol M (2020) Use of water quality index and multivariate statistical methods for the evaluation of water quality of a stream affected by multiple stressors: A case study. Environmental Pollution 266: 115417. https://doi.org/10.1016/j.envpol.2020.115417

Zhang Z-M, Zhang F, Du J-L, Chen D-C (2022) Surface Water Quality Assessment and Contamination Source Identification Using Multivariate Statistical Techniques: A Case Study of the Nanxi River in the Taihu Watershed, China. Water 14: 778. https://doi.org/10.3390/w14050778

## Additional information

### Conflict of interest

No conflict of interest was declared.

## Ethical statement

No ethical statement was reported.

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## Author contributions

Conceptualization: DD. Data curation: GSY, KG. Formal analysis: DD, LT, KG, GSY. Investigation: LT. Methodology: GSY, DD, KG. Resources: KG. Software: DD, LT. Supervision: DD. Validation: DD. Visualization: LT. Writing - original draft: DD, KG. Writing - review and editing: DD, LT.

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## Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.