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Assessment of water quality in Yapialtin Dam Lake (Sivas, Turkey) during dry and rainy seasons using various parameters and water quality indices

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Abstract: There are many dam lakes in the Şarkışla district of Sivas, where agricultural activities are intense. Yapıaltın Dam Lake, which constitutes our study area, is one of them. The research was conducted at three stations in Yapıaltın Dam Lake during the dry season in August 2023 and the rainy season in May 2024. Eighteen physicochemical variables of lake water were measured. The quality of dam lake water was assessed using indices such as the Eutrophication Index (EI), Organic Pollution Index (OPI), Nutrient Pollution Index (NPI), and Water Quality Index (WQI). The similarity of the stations in terms of physicochemical parameters was determined using Bray-Curtis similarity analysis. Additionally, Pearson and Spearman correlation analyses were employed to examine the relationships among the physicochemical data. The analyses revealed seasonal variations in all water quality indices.In conclusion, the study provides recommendations for the sustainable use of the dam lake.

Keywords: environmental variables; reservoir; multivariate analyses.

INTRODUCTION

Dam lakes provide numerous benefits to people, including sources of drinking water, irrigation, and hydroelectric power generation. They also play a crucial role in managing river water flow and protecting communities from flood hazards. Additionally, dam lakes offer various recreational opportunities, such as birdwatching, hiking, and fishing. Modern dams are strategically important, playing significant roles in energy production, particularly in developing countries.

Eutrophication, acidification, and various changes in hydrology and geomorphology are major pressures affecting the integrity of lakes.[1] The excessive input of plant nutrients, particularly nitrogen (N) and phosphorus (P), into lakes leads to the growth of organic matter, algae, periphyton, and macrophytes,

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resulting in eutrophication. This growth induces changes in aquatic organisms and water quality.[2] Eutrophication can lead to decreased dissolved oxygen levels in the water, which may cause hypoxia and toxic algal blooms.[2] Human activities, including domestic and industrial wastewater discharge and agricultural runoff, contribute to physical, chemical, and biological pollution of freshwater resources, resulting in a deterioration of water quality. This situation also limits the use of freshwater resources for various purposes.[3]

However, intensive and excessive use of these areas can harm both the environment and the living organisms that inhabit them.

This study aimed to calculate the water quality indices, such as the Eutrophication Index (EI), Organic Pollution Index (OPI), Nutrient Pollution Index (NPI), and Water Quality Index (WQI), for Yapıaltın Dam Lake, which is used for irrigation purposes. It also sought to evaluate the relationships between these parameters using various statistical methods, identify the factors contributing to the lake's pollution, and compare the findings with similar studies conducted in Turkey.

EXPERIMENTAL

The study was conducted at three stations (ST1, ST2, and ST3) during both the dry season in 2023 and the rainy season in 2024. ST1 represents the relatively clean part of the lake, ST2 is surrounded by pastures where livestock graze, and ST3 is situated near agricultural fields. During sampling, water temperature (WT) was measured using a thermometer. Electrical conductivity (EC), pH levels, and total dissolved solids (TDS) were measured in the field using a portable Hanna HI 98129 instrument. For other physicochemical parameters, water samples were collected with a Nansen water sampler and stored in dark-colored glass bottles with a 1-liter capacity.

The water samples brought to the laboratory were immediately prepared for analysis. Dissolved oxygen (DO), calcium (Ca), and magnesium (Mg) levels were determined using standard methods.[4] Chloride (Cl), total hardness (TH), and salinity values were measured using conventional titrimetric methods as described in the literature.[5] Nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), sulfate (SO_4), phosphate (PO_4), ammonium nitrogen (NH_4-N), biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD) values were also measured according to standards.[4]

The physicochemical parameters of the sampling stations in Yapıaltın Dam Lake were compared using Bray-Curtis Cluster Analysis in the Biodiversity Pro 2.0 program during both the dry and rainy seasons.[6] The relationship between physicochemical parameters was examined using Spearman and Pearson correlation analyses conducted in IBM SPSS Statistics Version 27.[7]

Water quality indices

The EI is employed to assess the trophic condition of a surface water body. EI values were calculated using the formula below: If the calculated EI value is less than 1, it indicates absence of eutrophication. A value of 1 or greater suggests the presence of eutrophication.[2,8] DIN; dissolved inorganic N (mgL^{-1}), DIP; dissolved inorganic P (mgL^{-1}).[8]

$$E.I = \frac{COD \times DIN \times DIP}{4500} \times 10^6 \quad (1)$$

The OPI is a tool used to evaluate water pollution, specifically focusing on the organic pollution status of surface water resources. OPI values were calculated using the formula below. The value obtained from the OPI formula categorizes water quality as follows:<0: Excellent water quality; 0−1: Good water quality; 1−2: Water starting to be polluted; 2−3: Slightly polluted water; 3−4: Moderately polluted water; >4: Heavily polluted water.[8,9]

COD, DIN, DIP, and DO standard concentration values were used for these calculations.[8,10]

$$OPI = \frac{COD}{COD_S} + \frac{DIN}{DIN_S} + \frac{DIP}{DIP_S} - \frac{DO}{DO_S} \quad (2)$$

The NPI is derived from concentrations of NO_3 and PO_4 in surface water sources. It is calculated using the following formula: The resulting NPI value categorizes pollution levels as follows: <1 no pollution, 1-3 moderately polluted, 3-6 significantly polluted, >6 very high pollution.[8,11] NO_3-N maximum limit (mgL^{-1}) is named as MAC_N, PO_4-P maximum limit (mgL^{-1}) is named as MAC_P, values were taken.[8,10]

$$NPI = \frac{C_N}{MAC_N} + \frac{C_P}{MAC_P} \quad (3)$$

The WQI is a crucial metric for assessing the overall quality of surface water resources. It integrates multiple water quality parameters into a single value.[8,12] In this study, 10 parameters including EC, pH, DO, BOD_5, COD, Cl, NO_3-N, NO_2-N, NH_4-N, and SO_4 were used to calculate WQI values. It is calculated using the following formula; n: total number of selected parameters, C_i the value assigned to i parameter; P_i: The relative weight of parameter (1-4). [8] The values are classified as follows: 0-25 indicates very poor water quality, 26-50 indicates poor water quality, 51-70 indicates moderate water quality, 71-90 indicates good water quality, and 91-100 indicates excellent water quality. [8,12]

$$WQI = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \quad (4)$$

RESULTS AND DISCUSSION

About the study area are given in Supplementary material to this manuscript in details.

The station codes, coordinates and information on stations are presented in Supplementary material (Table S- I).

Physicochemical parameters, units, average values, and quality classes of the dam lake water according to[13] and Turkey surface water quality regulation[14] protocols are presented in Supplementary material (Table S-II).

The lowest WT measured in the lake was 18 °C (rainy season, ST3), with the highest recorded at 35 °C (dry season, ST2), and an average of 26.4 °C. The lowest EC value was 307 µScm^{-1} (rainy season, ST3), the highest was 584 µScm^{-1} (rainy season, ST2), and the average was 424 µScm^{-1}. The lowest pH value observed was 7.91 (rainy season, ST1), the highest was 8.20 (dry season, ST1), and the average was 8.05. BOD_5 ranged from a minimum of 9.6 mgL^{-1} (rainy season, ST2) to a maximum of 30.3 mgL^{-1} (dry season, ST3), with an average of 18.15 mgL^{-1}. COD values ranged from a minimum of 18 mgL^{-1} (rainy season, ST3) to a maximum of 64.6 mgL^{-1} (dry season, ST3), with an average of 35.66 mgL^{-1}. TDS ranged from a minimum of 176 ppm (dry season, ST3) to a maximum of 307 ppm (rainy season, ST3), with an average of 238 ppm. TSS ranged from a minimum of 85 mgL^{-1} (rainy season, ST3) to a maximum of 150 mgL^{-1} (dry season, ST1), with an average of 113 mgL^{-1}. The lowest Cl measured in the lake was 15.99 mgL^{-1} (dry season, ST3), with the highest observed 20.99 mgL^{-1} (dry season, ST1), and the an average 18.49 mgL^{-1}. Salinity ranged from a minimum of 0.01 ‰ (dry season, ST2) to a maximum of 0.05 ‰ (rainy season, ST2 and ST3), with an average of 0.03 ‰. Ca levels ranged from a minimum of 18.84 mgL^{-1} (dry season, ST3) to a maximum of 44.88 mgL^{-1} (rainy season, ST3), with an average of 29.72 mgL^{-1}. Mg levels ranged from a minimum of 0.58 mgL^{-1} (rainy season, ST2) to a maximum of 3.80 mgL^{-1} (dry season, ST2), with an average of 1.88 mgL^{-1}.

TH ranged from a minimum of 1 FS° (rainy season, ST3) to a maximum of 11.6 FS° (dry season, ST2), with an average of 6.26 FS°. NO_3-N ranged from a minimum of 3.13 mgL^{-1} (dry season, ST3) to a maximum of 20.31 mgL^{-1} (rainy season, ST2), with a mean value of 7.50 mgL^{-1}. NO_2-N was not detected in all three stations during the dry season, and the highest concentration found was 0.021 mgL^{-1} (rainy season, ST1), with an average of 0.0065 mgL^{-1}. The lowest NH_4-N measured in the lake 0.010 mgL^{-1} (rainy season, ST3), with the highest recorded 0.034 mgL^{-1} (rainy season, ST1), and an average was 0.021 mgL^{-1}. PO_4 ranged from a minimum of 0.79 mgL^{-1} (dry season, ST1) to a maximum of 1.80 mgL^{-1} (dry season, ST3), with an average of 1.22 mgL^{-1}. SO_4 ranged from a minimum of 9.89 mgL^{-1} (rainy season, ST1) to a maximum of 17.51 mgL^{-1} (dry season, ST1), with an average of 13.53 mgL^{-1}.

When evaluating the dam lake in terms of water quality indices, the highest EI was found at ST3 during the rainy season as 32, and the lowest was at ST1 during the dry season as 8. The OPI was also highest at ST3 during the rainy season as 15.09 and lowest at ST1 during the dry season as 5.97. The NPI was lowest at ST1 during the dry season as 6.53 and highest at ST3 during the rainy season as 15.8. The WQI was lowest at ST2 during the dry season as 10.19 and highest at ST3 during the rainy season as 48.83. The change in water quality index values across the stations for dry and rainy seasons is illustrated in Fig. 1.

Fig 1. Variation Graph of Water Quality Indices

Pearson correlation analysis was applied to normally distributed variables among the physicochemical parameters of lake water. According to this analysis, strong positive correlations were found between WT and SO_4, TDS and NO_3-N. Strong negative correlations were found between WT and TDS, NO_3-N and TDS, WT and NO_3-N, TDS and SO_4, and NO_3-N and TDS. The table showing the results of the Pearson correlation analysis and the coefficients of variation is provided in Table S-III. Values in the table are denoted as follows: * indicates that the correlation is significant at the 0.05 level ($p < 0.05$); ** indicates that the correlation is significant at the 0.01 level ($p < 0.01$); and - indicates that no statistically significant correlation was detected.

Spearman correlation analysis was applied to the variables that did not show normal distribution among the physicochemical parameters of water. A strong positive correlation was found between BOD and COD. A negative correlation was found between salinity and BOD, as well as between salinity and COD, and TH and BOD. The table showing the results of the Spearman correlation analysis and the coefficients of variation is provided in Table S-IV. Values in the table are denoted as follows: * indicates that the correlation is significant at the 0.05 level ($p < 0.05$); ** indicates that the correlation is significant at the 0.01 level ($p < 0.01$); and - indicates that no statistically significant correlation was detected.

The similarity of the stations in terms of physicochemical parameters was analyzed using Bray-Curtis similarity analysis. It was observed that the similarity between the stations was quite high. In the dry season, ST2 and ST3 showed 99.83% similarity, with station 1 also clustering with them. The Bray-Curtis similarity dendrogram for the stations is presented in Fig 2.

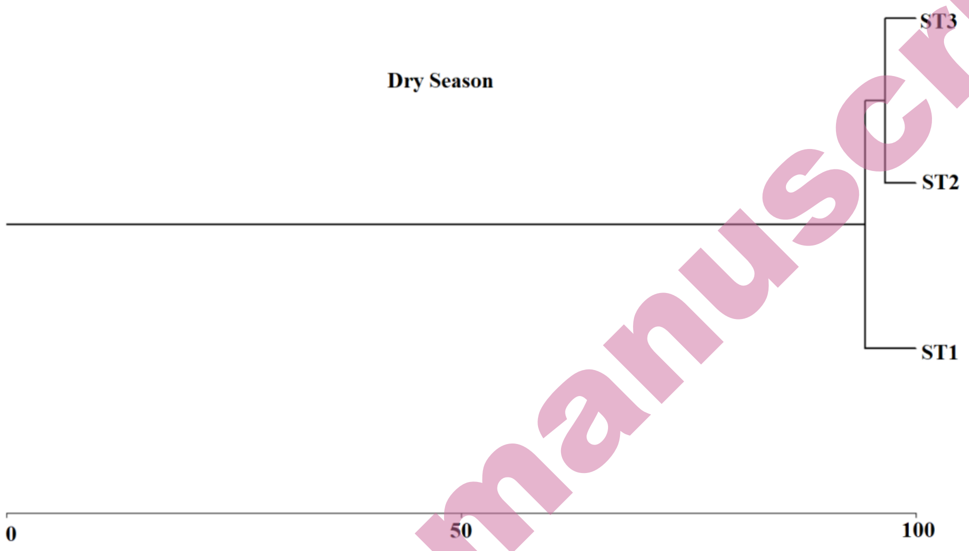

Fig. 2. Bray-Curtis similarity dendrogram of stations during the dry season

In the rainy season, the similarity between the stations was quite high. The ST1 and ST2 showed a similarity of 99.92 %, with ST3 clustering with them. The Bray-Curtis similarity dendrogram for the rainy season is shown in Fig. 3.

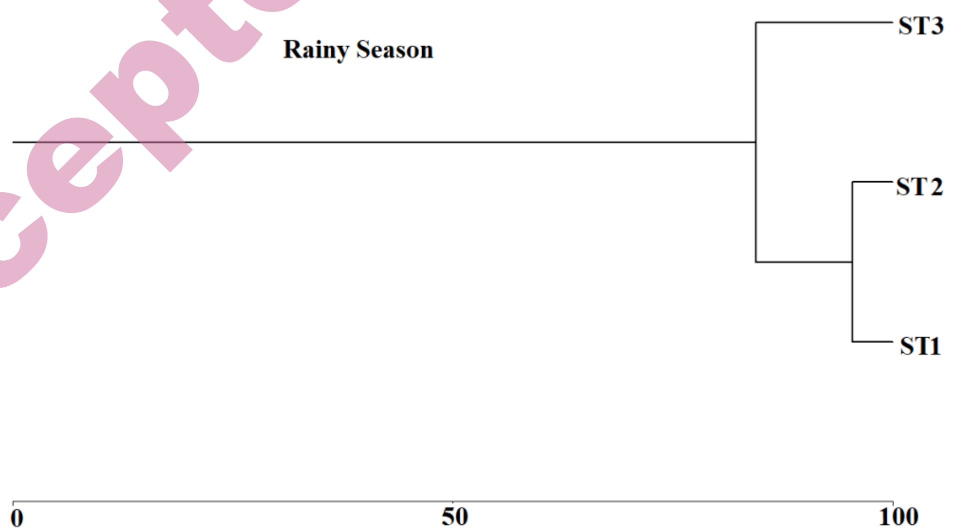

Fig. 3. Bray-Curtis similarity dendogram of stations during the rainy season

In this paper, the analyses conducted at three selected stations in the Yapıaltın dam lake during both dry and rainy seasons are discussed in detail. It was found that the WT, pH, COD, TDS, Cl, NO_2-N, NH_4-N, and SO_4 values of the dam lake were within the first class water quality standards.[13,14] The EC value was determined to fall between class I and II water quality standards.[13,14] The DO and NO_3-N values of the dam lake water were found to range between class II and III water quality.[13,14] Additionally, the BOD_5 value was identified to be within the III class quality range.[13,14]

It is observed that the water temperature values of the dam lake are higher in summer (dry season). This variation may be attributed to seasonal temperature changes. The WT is a critical climatic factor that enhances biological activity rates and reduces oxygen saturation.[15] The DO values of the lake also exhibited significant differences between dry and rainy seasons. The solubility of oxygen in water increases as temperature decreases.[16] In this study, it can be observed that the lowest DO values were recorded during the dry season when temperatures were highest, whereas the highest DO values were observed in the rainy season when temperatures were lowest (Table S-II).

The pH value of the lake was determined to be alkaline. It was observed that TDS levels were low during the dry season and high during the rainy season (Table S-II). Precipitation is likely the primary reason for this variation, as rainwater runoff carries dissolved solids into the lake. It has been noted that water conductivity values vary based on geological structure and precipitation levels, rather than nutrient salts in the water.[17] Specifically, conductivity in the dam lake was lowest only in ST3 during the rainy season. It is recognized that regions with high rainfall generally have less saline surface waters due to continuous soil washing.[15] The salinity values were found to be higher in the rainy season compared to the dry season, with minimal difference in Cl values.

The Ca levels in the water were higher than the Mg levels, which may be attributed to the geological composition of the lake. During the rainy season, Ca levels peaked in ST1 and ST3 (Table S-II). In terms of NO_3-N values, they were classified as water quality class I and II during the dry season, while in ST2 they reached class III during the rainy season. This variation could be linked to livestock grazing near ST2, with animal feces potentially contributing to increased NO_3-N levels in that area. NH_4-N values were found in first class water quality. PO_4 content of the lake was found to be quite low.

SO_4 levels were higher during the dry season and lower during the rainy season. This seasonal variation is expected and can be attributed to the dilution effect of rainfall during the rainy season.

The BOD represents the amount of oxygen consumed by bacteria and other microorganisms when decomposing organic matter under aerobic conditions at a given temperature.[18] The COD is the amount of oxygen required for the oxidation of organic matter and inorganic chemicals. The COD value is higher than the BOD value.[19] In the study, COD values were higher than BOD values.

In this study, it was found that the water quality level indices obtained from the results of EI, OPI, NPI, WQI calculated using parameters other than WT, TDS, TSS, Cl, Salinity, Ca, Mg and TH were very similar to each other. When evaluated in terms of indices, since EI values ≥ 1 in all stations, it is seen that there is eutrophication in the lake both in dry and rainy seasons. Since the OPI values were > 4, the lake was found to be extremely organically polluted. Since the NPI values were >6 in the seasons and all stations examined in the lake, it was found that there was very high pollution. ST1 in dry season and ST1 and ST3 in rainy season were found to have poor water quality, while the other stations were found to have very poor water quality in dry and rainy seasons. During the dry season, all three stations were found to have extremely poor water quality. An increase in dam lake water temperature leads to higher evaporation from the dam lake's surface, which lowers the lake level and alters the water quality.[20] It was determined that ST2 had very poor water quality during the rainy season. During this period, ST1 and ST3 were found to have poor water quality. According to all index results, eutrophication was observed in the lake, and overall, the lake had poor water quality. During the rainy season, the increase in rainfall on the lake's surface can lead to changes in the amount of water in the lake, which may affect the water quality of the dam lake.

According to the Bray-Curtis dendrogram, the highest similarity rates between ST1 and ST2 occurred during the rainy season. The primary reason for this could be the absence of factors affecting these stations during this season. In contrast, ST3, situated near agricultural areas, experiences heavy pesticide use during May fertilization period. These pesticides can be transported via irrigation or rainwater into the lake, altering its physicochemical parameters and distinguishing it from other stations. In the dry season, ST2 and ST3 exhibited the highest similarity rates. The primary reason for this could be attributed to several factors: firstly, the high rate of water evaporation from the lake due to warming weather conditions, leading to a decrease in lake water levels. Additionally, water withdrawal from the lake for irrigation purposes in agricultural areas near the ST3 further reduces the lake's water volume, thereby increasing the concentration of physicochemical substances in the remaining water. Furthermore, around the ST2, grazing of animals may contribute to the transport of animal feces into the water. This, coupled with pesticides applied to nearby agricultural areas, can lead to changes in the physical, chemical, and biological composition of the lake water.

When comparing this study with previous research conducted in lakes;[21] utilized the WQI based on 13 water quality parameters in the Kastamonu Karaçomak dam lake. They found that WQI values varied from poor to excellent water quality, attributing these variations to seasonal changes and surface runoff in the downstream area, which contributed to water quality degradation. It is noted that the EC, BOD, COD, NH_4-N, NO_3-N, and NO_2-N values measured in this current study are consistent with their findings. When comparing this study with the findings of[22] on four dam lakes in Poland, several similarities and differences are noted. In their study,[22] found that WQI values ranged between moderate and poor. Specifically: DO ratios were higher in this current study compared to their findings. EC values were similar between both studies. NO_3-N values were lower in this current study. SO_4 and Ca values were higher in this current study. Mg values were comparable between the two studies. These comparisons suggest both similarities and variations in water quality parameters between the two studies conducted in different dam lakes.

Researchers were conducted an analysis of 17 water quality parameters by sampling water from a dam lake in Mexico across different months.[23] Their study revealed several key findings: They found no significant difference in WQI values between the selected stations within the dam. They observed seasonal variations in WQI, indicating that water quality varied throughout the year. The categorization of water quality varied from poor in some months to moderate to good in others, and moderate to poor in yet other months. These findings underscore the dynamic nature of water quality in dam lake ecosystems, influenced by seasonal changes and possibly local environmental conditions. Comparisons with their study can provide valuable insights into the variability and factors affecting water quality assessments in different geographical contexts.

Also, a research conducted an assessment of water quality by calculating the WQI using 22 physicochemical parameters from waters sampled from Mumcular and Geyik dam lakes, as well as Çamköy underground wells.[24] The study reported finding very low WQI values, indicating poor water quality. Specifically, the dam lakes evaluated, which are used as sources of drinking water, were identified as requiring treatment before use to meet quality standards. This highlights the importance of ongoing monitoring and treatment processes to ensure safe drinking water supply from these sources.

The studies provide various information to examine whether the dam lake are suitable for the purpose for which they will be used. The common point seen in all studies is that water quality parameters vary seasonally. In the studies, various suggestions are also given about the purpose for which the dam water can be used or not. In this study, various recommendations on the sustainable use of the dam lake were summarised in the conclusion section.

CONCLUSION

In conclusion, this study analyzed water samples collected from three stations in Yapıaltın Dam Lake, during both dry and rainy seasons. Significant relationships were identified regarding seasonal variations in water quality indices. It was observed that agricultural activities and livestock breeding near water sources could lead to reductions in water quality parameters, potentially shifting from class I to class III water quality standards.

To ensure the sustainable use of the dam lake, regular monitoring of water quality is crucial. Additionally, as well as assessments for toxic metals, microbiological contaminants, pesticides, and algal biodiversity are recommended. These measures are essential for maintaining and improving water quality standards, safeguarding both ecological health and the suitability of the dam lake as a water resource.

SUPPLEMENTARY MATERIAL

Additional data are available electronically at the pages of journal website: https://www.shd-pub.org.rs/index.php/JSCS/article/view/13049, or from the corresponding author on request.

ИЗВОД

ПРОЦЕНА КВАЛИТЕТА ВОДЕ У ЈЕЗЕРУ YAPIALTIN DAM (СИВАС, ТУРСКА) ТОКОМ СУШНИХ И КИШНИХ СЕЗОНА, КОРИШЋЕЊЕМ РАЗЛИЧИТИХ ПАРАМЕТАРА И ИНДЕКСА КВАЛИТЕТА ВОДЕ

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Постоји много језера насталих изградњом брана у округу Şarkışla у Сивасу, где су пољопривредне активности интензивне. Језеро Yapialtin Dam, које чини подручје нашег истраживања, је једно од њих. Истраживање је спроведено на три станице у језеру Yapialtin Dam током сушне сезоне у августу 2023. и кишне сезоне у мају 2024. Измерено је осамнаест физичко-хемијских варијабли језерске воде. Квалитет воде у језерским бранама је процењен коришћењем индекса као што су индекс еутрофикације (EI), индекс органског загађења (OPI), индекс загађења нутријентима (NPI) и Индекс квалитета воде (WQI). Сличност станица у погледу физичко-хемијских параметара утврђена је помоћу Bray-Curtis анализе сличности. Поред тога, коришћене су Пирсонове и Спирманове корелационе анализе да би се испитале везе између физичко-хемијских података. Анализе су откриле сезонске варијације у свим индексима квалитета воде. У закључку, студија даје препоруке за одрживо коришћење језера насталих изградњом бране.

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