Acta Sci. Pol.
Formatio Circumiectus 20 (2) 2021, 55–65
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl/pl ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/2021.20.2.55

ORIGINAL PAPER Accepted: 5.08.2021

WATER QUALITY ASSESSMENT OF YASSIALAN DAM LAKE (KARADENIZ REGION, TURKEY) BY USING PRINCIPAL COMPONENT ANALYSIS AND WATER QUALITY INDEX

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ABSTRACT

Aim of the study
In this research, spatial–temporal variations of water quality in Yassıalan Dam Lake were investigated by determining a total of 28 limnologic parameters and by using Water Quality Index (WQI) and Principle Component (PCA).

Material and methods
Water samples were collected from seven stations selected on the reservoir monthly in 2018–2019 and total of 28 water quality parameters were measured in water samples. WQI was used for evaluating the water quality by using the parameters of pH, EC, Cl, NO_2, NO_3, SO_4, Na, Pb, Cu, Cd, Hg, Ni, Zn, and PCA was used for evaluating the water quality by using the variables of pH, BOD, EC, salinity, dissolved oxygen, total hardness, temperature, total alkalinity, Hg, Ca, NO_3, NO_2, NH_4, SO_4, Mg, Ca, Fe, Ni, Cl, Zn, Cd, S, Na, K, Pb, Cu.

Results and conclusions
According to data observed, water of the Yassıalan Dam Lake has 1st – 2nd Class water quality in general and according to the results of WQI, although it was determined that the water quality decreased significantly in summer period, the reservoir was found as "A Grade – Excellent" water quality (<50) in all the investigated months and at all the investigated stations. WQI values recorded in the dam lake were found as 15.3 – 26.1 and the detected limnologic parameters did not exceed the specified drinking water standards in all the investigated months and at all the investigated stations. According to the results of PCA, 3 factors explained 84.2% of total variances.

Keywords: Yassıalan Dam Lake, Water Quality Index, Principal Component Analysis

Highlights:
– Yassıalan Dam Lake has 1st–2nd Class water quality in general.
– WQI values recorded in the dam lake were found as 15.3–26.1 and it has "A Grade – Excellent" water quality.
– As a result of PCA, 3 factors explained 84.2% of total variances.

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INTRODUCTION

Contamination of freshwater habitats due to rapid population growth, developments in technology and industry is a significant environmental problem. Frequently monitoring of the quality of water environments is known as one of the main points on an effective management of freshwater resources (Tokatlı et al., 2014; 2016; Köse et al., 2014; 2016; Varol, 2019; Abdallah and Badr-ElDin, 2020; Parlak et al., 2021).

Pollution in freshwater habitats has been a significant problem, especially in recent years. New contamination risk assessment techniques are being applied to determine multiple effects of contaminants and many indices have been developed for this purpose (Varol and Davraz, 2015; Saleem et al., 2019; Varol, 2020; Ustaoğlu and Aydın, 2020; Tokatlı and Ustaoğlu, 2020). Water Quality Index (WQI) is one of the most commonly used freshwater quality indices and it is being calculated from the perspective of suitability of water for human consumption (Tyagi et al., 2013; Akter et al., 2016; Mukatea et al., 2019; Ustaoğlu and Tepe, 2019; Tokatlı, 2021).

Multivariate statistical techniques are being also used to assess the collective effects of pollutants on the water ecosystems. Principal Component Analysis (PCA) is an effective and widely used multi–statistical method. PCA helps to explain the variance of a large dataset of correlated variables with a smaller set of independent variables. It reduces the contribution of less important variables and makes a new group of variables detected from the data set (Tokatlı, 2017; Köse et al., 2018; Çiçek et al., 2019; Tokatlı and Varol, 2021).

Yassıalan Dam Lake is located within the borders of Yukarıkaracaören village in the Durağan district of Sinop province and the reservoir has a very special importance for the people of the region. The purpose of construction of this reservoir was to irrigate the agricultural land around it and the local communities would be seriously influenced, if the lake would be affected by any pollution. The aim of this research was to investigate the spatial–temporal variations of water quality in Yassıalan Dam Lake with a long-term monitoring period and to assess the levels of water contamination by using WQI and PCA.

MATERIAL AND METHODS

Study area and sample collection

Yassıalan Dam Lake, that has a great importance as an artificial lentic freshwater habitat for the region, is located in the Black Sea Region of Turkey and it was built for irrigation purposes. Yassıalan Dam Lake, which has freshwater and body fill type of clay core rock fill, provides a total of 70 ha irrigation area and has a volume of 0.45 hm3 (Anonymous, 2017).

Water samples were taken from 7 stations located on the Yassıalan Dam Lake monthly from October 2018 to September 2019 (a hydrological period – the total of 84 samples). The coordinate information of locations is presented in Table 1. The map of Yassıalan Dam Lake with the selected stations on the reservoir are presented in Figure 1.

Physical–chemical analysis

Dissolved oxygen (DO), temperature, pH, electrical conductivity (EC) (at 25 °C) and salinity parameters were determined with a pre-calibrated terrain type portable – digital multi – parameter device (Hach Lange, HQ40D). COD, chloride, sulphate, sulphur, phosphate, sodium, potassium, calcium, magnesium, nitrate, ammonium nitrogen, nitrite parameters were measured with a spectrophotometer device (WTW 7600 UV-VIS). BOD parameter was measured with a BOD measuring set (WTW OXITOP 12). Suspend-

Table 1. Coordinate information of stations

Stations	Coordinates	
	North	East
1. Station	41°26'12.90"N	35° 6'25.71"E
2. Station	41°26'14.89"N	35° 6'19.09"E
3. Station	41°26'24.43"N	35° 6'21.93"E
4. Station	41°26'31.77"N	35° 6'23.25"E
5. Station	41°26'29.62"N	35° 6'28.95"E
6. Station	41°26'24.17"N	35° 6'32.63"E
7. Station	41°26'17.05"N	35° 6'36.93"E

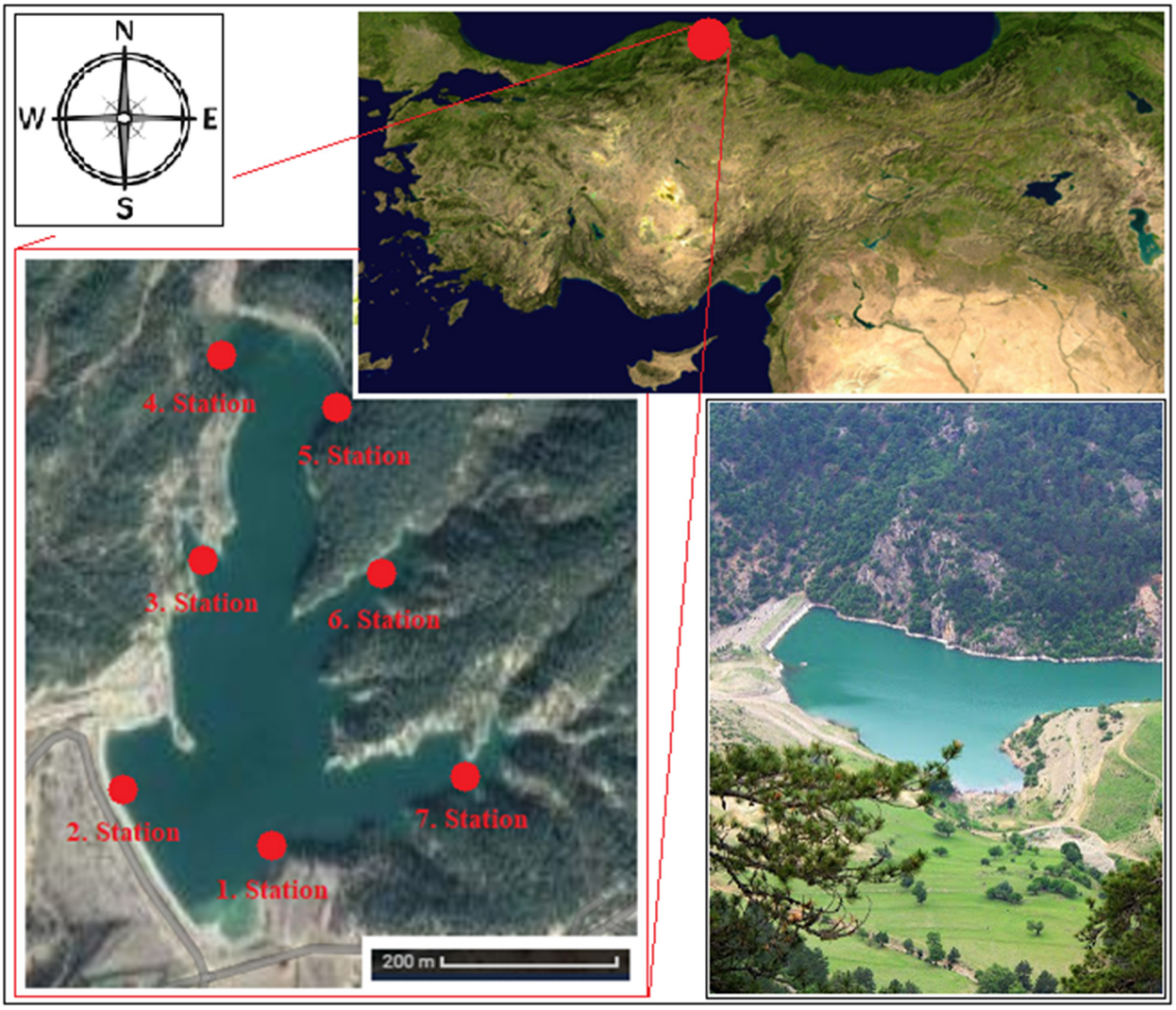

Fig. 1. Study area and selected stations (*Source*: own elaboration based on Google Maps)

ed solids parameter was measured by filtering with filter paper (Whatman) and total alkalinity and hardness parameters were measured by using the titrimetric method.

Element analysis

In determining the concentrations of macro and micro elements including sodium, potassium, magnesium, calcium, iron, lead, copper, cadmium, mercury, nickel, and zinc in water samples, pH values (one litre) were set to 2 by means of adding HNO_3 into each sample. Then, the water samples were filtered by means of a 0.45 µm cellulose nitrate filter. Then their volumes were completed to 50 ml with ultrapure distilled water. Macro and micro element concentrations were determined by using an ICP-OES device (Spectro, SpectroBlue) in Kastamonu University (EPA, 2001).

Statistical analysis

Principal Component Analysis (PCA) was applied to detected data in order to the define the effective varifactors on the system by using the "SPSS 23" package statistical program. A total of 25 variables (pH,

BOD, EC, salinity, dissolved oxygen, total hardness, temperature, total alkalinity, Hg, Ca, NO_3^-, NO_2^-, NH_4^+, SO_4^{2-}, Mg, Ca, Fe, Ni, Cl^-, Zn, Cd, S, Na, K, Pb, Cu) were used to determine the varifactors and n = 84 (7 stations × 12 months) for all parameters (Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalisation).

Water Quality Index (WQI)

WQI is an effective and widely used technique in order to assess the water (Wang et al., 2017; Tokatlı, 2019; Ustaoğlu et al., 2020; Tokatlı and Ustaoğlu, 2020; Tokatlı, 2021). The following formula was used in calculating WQI (Meng et al., 2016, Xiao et al., 2019);

$$WQI = \sum \left[W_i \times \left(\frac{C_i}{S_i} \right) \times 100 \right] \quad (1)$$

$$Wi = \frac{W_i}{\Sigma W_i} \quad (2)$$

where, W_i is relative weight, C_i is the measured parameter in water and S_i values are the standard values (TS266, 2005; EC, 2007; WHO, 2011).

RESULTS

Annual mean results of detected limnological parameters in Yassıalan Dam Lake with Standard Deviation values are given in Table 2. According to the Water Quality Control Regulations in Turkey (WQCR) (2004, 2015), the water of Yassıalan Dam Lake has 1st Class quality in terms of all the investigated parameters except phosphate. It has 2nd Class quality in terms of this parameter. It was also determined that any investigated locations did not exceed the standards specified for drinking water in terms of investigated parameters (TS266, 2005; EC, 2007; WHO, 2011).

PCA was applied to define the effective varifactors on water quality of Yassıalan Dam Lake by using related variables. Uncorrelated variables were removed from the data set in order to make the applied PCA more reliable and a total of 25 variables were used to determine the varifactors (n = 84 for all parameters). KMO (Kaiser-Meyer-Olkin) test was found as 0.728 that shows the sample adequacy was enough (> 0.5) (Liu et al., 2003). As a result of PCA, 3 factors explained 84.2% of the total variance. Loadings of the parameter for 3 components and the component plot are presented in Table 3 and Figure 2.

First factor (Component 1) named as "Lithogenic Factor" explained 31.1% of total variance and it was related to the variables of pH, biological oxygen demand (BOD), electrical conductivity (EC), dissolved oxygen (DO), total hardness (TH), temperature (Temp), total alkalinity (TA), mercury (Hg), calcium (Ca), nitrate (NO_3^-) and magnesium (Mg). All parameters except DO were strong (< 0.75) – moderate (0.75 – 0.50) positively loaded with this factor, while the DO parameter strong (< 0.75) negatively loaded with this factor. The source of Ca and Mg could be from weathering of Ca-Mg-rich bedrocks at many local areas and it is known that Ca and Mg have a significant effect on the total hardness and total alkalinity of the water bodies (Tokatlı et al., 2014).

Second factor (Component 2) named as "Agricultural Factor" explained 28.8% of total variance and it was related to the variables of calcium (Ca), ammonium (NH_4^+), nitrite (NO_2^-), iron (Fe), nickel (Ni), chlorine (Cl^-), nitrate (NO_3^-), magnesium (Mg), zinc (Zn) and cadmium (Cd). All parameters were strong (< 0.75) – moderate (0.75 – 0.50) positively loaded with this factor (see: Fig. 2, Table 3).

Third factor (Component 3) named as "Salinity Factor" explained 24.2% of total variance and it was related to the variables of sulphur (S), sulphate (SO_4^{2-}), sodium (Na), potassium (K), lead (Pb), copper (Cu) and salinity (Sal). All parameters were strong (< 0.75) – moderate (0.75 – 0.50) positively loaded with this factor (see: Fig. 2, Table 3).

Monomial and multinomial risks of pH, EC, CI, SO_4^{2-}, Na, NO_2^-, NO_3^-, Pb, Cu, Cd, Hg, Ni and Zn parameters in water of Yassıalan Dam Lake were determined for all the investigated habitats and seasons by using Water Quality Index (WQI). The limit values of WHO (2011) and the relative weight data are given in Table 4 and the detected data are given in Figure 3. According to the results of WQI, the values of overall WQI were within the permissible limits (< 100), and all the investigated stations on the Yassıalan Dam Lake in all the seasons were found as "A grade – Excellent" water quality characteristic.

Table 2. Descriptive statistics of physical and chemical data

Number of Variable	Parameter	min	max	mean	SD	Quality Class*
1	Dissolved Oxygen (ppm)	11.700	16.040	14.322	1.539	1st Class
2	Salinity (‰)	0.010	0.400	0.064	0.080	–
3	pH	8.180	8.690	8.421	0.144	1st Class
4	Temperature (^{0}C)	0.900	50.200	11.514	7.661	1st Class
5	EC (µS/cm – 25 ^{0}C)	130.840	286.500	208.401	52.903	1st Class
6	Suspended Solids (mg/L)	0.040	1.180	0.430	0.367	–
7	COD (mg/L)	0.010	2.100	0.767	0.560	1st Class
8	BOD (mg/L)	0.010	1.230	0.580	0.397	1st Class
9	Chlorine (mg/L)	2.800	6.180	4.821	1.035	1st Class
10	Phosphate (mg/L)	0.052	0.276	0.146	0.070	**2nd Class**
11	Sulphate (mg/L)	20.400	66.220	40.928	13.790	1st Class
12	Sulphur (mg/L)	0.040	2.440	0.985	0.696	1st Class
13	Sodium (mg/L)	39.520	74.800	50.485	12.089	1st Class
14	Potassium (mg/L)	3.700	16.120	6.784	3.293	–
15	Total Hardness (mg/L)	145.120	212.420	179.434	20.814	–
16	Total Alkalinity (mg/L)	155.200	218.300	187.703	19.014	–
17	Magnesium (mg/L)	12.540	37.280	24.798	7.833	–
18	Calcium (mg/L)	11.340	60.180	37.975	15.653	–
19	Nitrite (mg/L)	0.001	0.005	0.003	0.001	1st Class
20	Nitrate (mg/L)	0.160	2.060	1.135	0.597	1st Class
21	Ammonium (mg/L)	UDL	0.004	0.002	0.001	1st Class
22	Iron (µg/L)	0.003	0.012	0.007	0.003	1st Class
23	Lead (µg/L)	UDL	1.900	0.660	0.475	1st Class
24	Copper (µg/L)	UDL	15.000	4.905	3.428	1st Class
25	Cadmium (µg/L)	UDL	0.200	0.117	0.080	1st Class
26	Mercury (µg/L)	UDL	0.007	0.002	0.002	1st Class
27	Nickel (µg/L)	UDL	3.000	0.917	0.715	1st Class
28	Zinc (µg/L)	1.000	14.000	5.131	3.498	1st Class

*2nd Class water qualities are given in bold
UDL: Under the detection limit

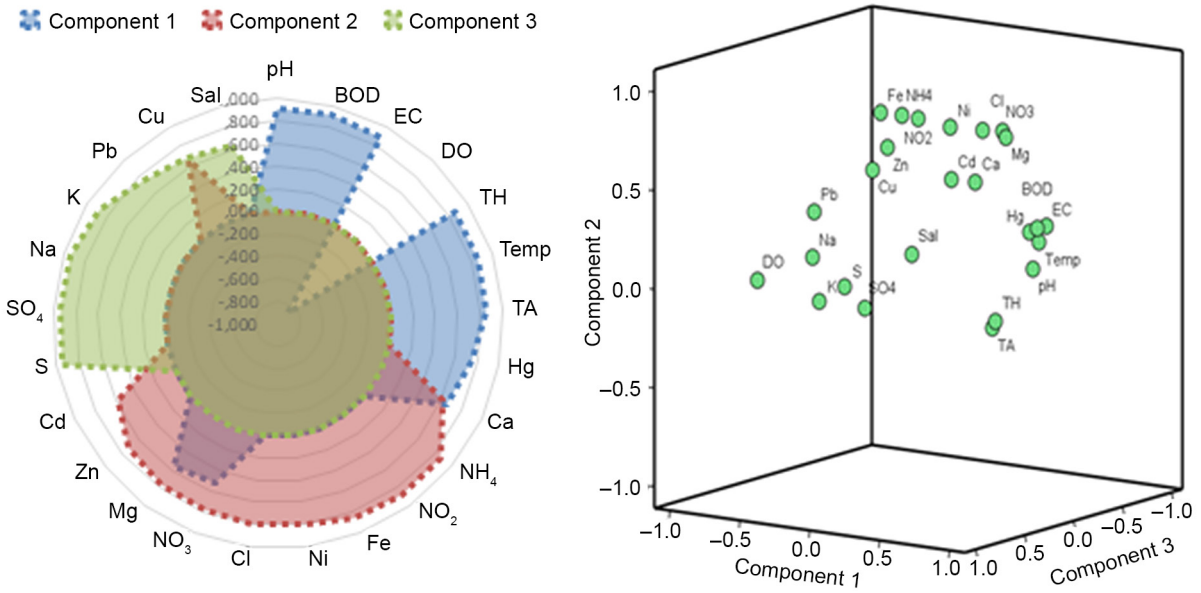

Fig. 2. Rotated component matrix (left) and component plot in rotated space (right)

Table 3. Factor loads after rotation

Parameters	Component		
	F1	F2	F3
pH	0.914		
BOD	0.914		
EC	0.885		
DO	–0.867		
TH	0.860		
Temp	0.860		
TA	0.843		
Hg	0.743		
Ca	0.666	0.613	
NH_4		0.880	
NO_2		0.878	
Fe		0.851	
Ni		0.801	
Cl		0.790	
NO_3	0.519	0.786	
Mg	0.567	0.764	
Zn		0.736	
Cd		0.575	
S			0.958
SO_4			0.943
Na			0.942
K			0.879
Pb			0.748
Cu		0.667	0.676
Sal			0.633

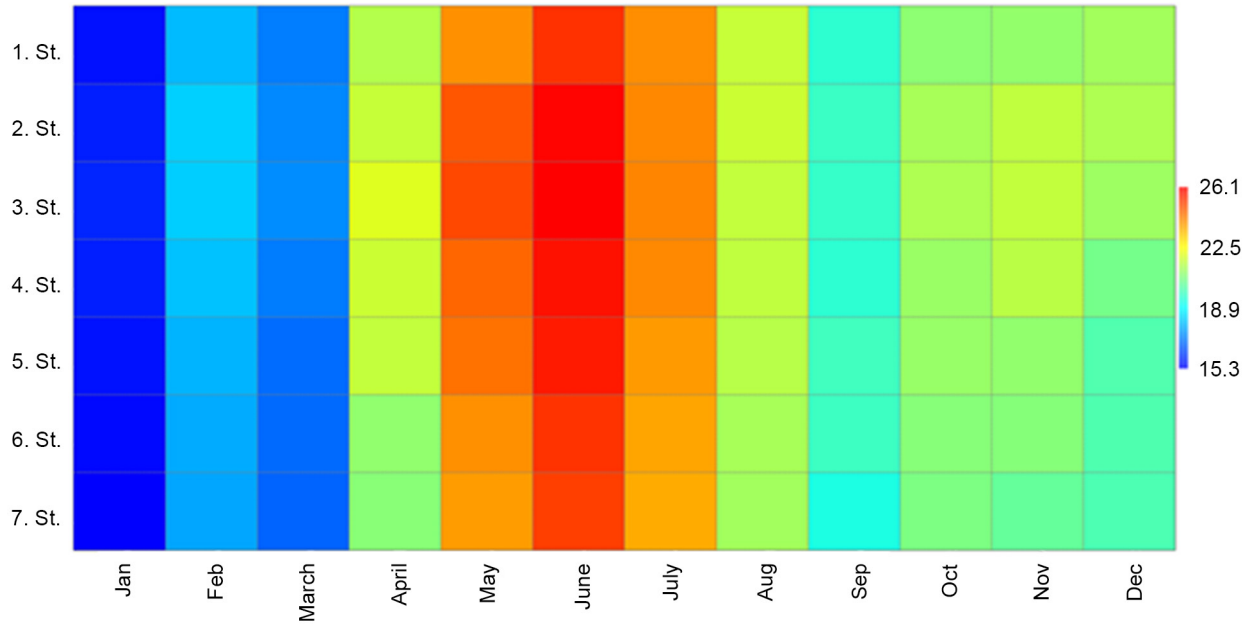

Fig. 3. WQI scores

Table 4. Drinking water limits and relative weight values

Parameters	Standard Values (Si)	Assigned Weight (AW)	Relative Weight (Wi)
pH	7.5	3	0.056
EC (µS/cm)	1500	4	0.075
Cl (mg/L)	5	3	0.056
SO_4 (mg/L)	250	3	0.056
Na (mg/L)	50	3	0.056
NO_2 (mg/L)	3	5	0.094
NO_3 (mg/L)	50	5	0.094
Pb (µg/L)	10	5	0.094
Cu (µg/L)	2000	3	0.056
Cd (µg/L)	3	5	0.094
Hg (µg/L)	6	5	0.094
Ni (µg/L)	70	5	0.094
Zn (µg/L)	3000	4	0.075

DISCUSSION

As a result of this research, it was determined that the water of the Yassıalan Dam Lake has first class water quality in general and the dam lake was found to be quite clean and one of the rare uncontaminated wetlands. According to the applied WQI results, despite the slight increase in WQI score observed due to the decrease in the water level of the dam lake in the summer months, it was determined that the dam lake has "A grade – Excellent" water quality characteristic in general.

Many studies conducted in the Black Sea Region reveal that the aquatic ecosystems located in this region are quite clean. In a study performed in the Black See Region, WQI was used to evaluate the water quality of Turnasuyu Stream. As similar with the current data, it was reported that the investigated lentic habitat in the Black See Region has "A Grade – Excellent" water quality (Ustaoğlu et al., 2020). In another research conducted in the same region as the present investigation, water quality of Saraydüzü Dam Lake was monitored for a 1-year period by determining 28 basic variables and WQI was applied to data in order to assess the water quality. As a result of this investigation, as similar to the current research, investigated parameters did not exceed the recommended drinking water standards and WQI scores were found to be between 17.62–29.88 (Kükrer and Mutlu, 2019). In another study performed in the Thrace Region, known to be an agricultural and industrial area, groundwater quality of Ergene River Basin was evaluated by using WQI. As a result of this research, although the WQI scores are considerably higher than the ones from the current study, the investigated heavy metals were recorded in the range of human consumption limits because of the investigated aquatic habitat was groundwater (Tokatlı, 2019). In a lentic freshwater quality assessment research in the Thrace Region of Turkey, WQI was used to evaluate the water qualities of Altınyazı, Karaidemir, Kayalıköy, Kırklareli, Sultanköy and Süloğlu Dam Lakes. According to the results of this study, as similar to the present investigation, the reservoirs was found to have "A grade – Excellent" water quality and the recorded WQI scores were within the permissible limits (< 100) (Tokatlı, 2020).

The phosphate parameter was recorded as one of the most critical parameters for the Yassıalan Dam Lake and it was found to have 2nd Class water quality in terms of this parameter in general. Although phosphorus is an essential element, it can speed up eutrophication of lakes by means of a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients, when its content in water is too high. Phosphates may enter the water ecosystems by means of phosphorus-rich bedrock, human and animal waste, laundry, cleaning, industrial effluents, fertiliser runoff and especially sewage waste containing detergents, and these phosphate contaminations become a significant risk factor especially for lentic habitats because they overfertilise the algae and cause eutrophication. Agricultural applications and domestic waste are among the most significant phosphate sources for surface waters especially in rural areas (Wetzel, 2001; Manahan, 2011). Although there are many agricultural lands around the Yassıalan Dam Lake, according to the results of the applied PCA, the phosphate parameter was not included in the 2. Factor (Component 2) named as "Agricultural Factor", which was included important agricultural variables such as ammonium, nitrite and nitrate. Therefore, it is thought that exposure of the streams feeding the dam to sewage wastes are one the main reasons of the detected reasonably high phosphorus compounds in the water of the Yassıalan Dam Lake.

CONCLUSIONS

In the present investigation, water quality in Yassıalan Dam Lake was assessed by using Water Quality Index (WQI) and Principal Component Analysis (PCA). As a result of this research, although the water of the reservoir was found as 1st Class quality in general, it was found as 2nd Class quality in terms of phosphate parameter. As a result of WQI, although the water quality of the dam lake decreased significantly in summer season, it was found as "A Grade – Excellent" water quality (< 50) in all the seasons and stations and as a result of PCA, 3 factors explained 84.2% of total variances. In conclusion, although the water quality of the Yassıalan Dam Lake is found to be at a quite high level, the detected quite high phosphate accumulations in water indicate that the system is being affected by the agricultural activities, and this situation suggests that the reservoir should be constantly monitored to pro-

tect this significant artificial aquatic ecosystem. In addition, Yassıalan Dam Lake is also used by the local people as a recreation area and has an important place in ecotourism activities due to its natural beauties. Therefore, it should not be forgotten that all these anthropogenic activities may be a small pressure factor on the water quality of the lake.

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OCENA JAKOŚCI WODY W JEZIORZE YASSIALAN (REGION KARADENIZ, TURCJA) ZA POMOCĄ ANALIZY GŁÓWNYCH SKŁADOWYCH I WSKAŹNIKA JAKOŚCI WODY

ABSTRAKT

Cel pracy

W ramach niniejszych badań zbadano przestrzenno-czasowe wahania jakości wody w jeziorze Yassialan, określając łącznie 28 parametrów limnologicznych oraz stosując wskaźnik jakości wody (WQI) i analizę głównych składowych (PCA).

Materiał i metody

Co miesiąc w latach 2018–2019 pobierano próbki wody z wybranych siedmiu stacji na jeziorze i w mierzono w nich 28 parametrów jakości wody. Do oceny jakości wody pod kątem parametrów pH, EC, Cl, NO_2, NO_3, SO_4, Na, Pb, Cu, Cd, Hg, Ni i Zn zastosowano wskaźnik WQI, a do oceny jakości wody pod kątem zmiennych pH, BZT, EC, zasolenie, tlen rozpuszczony, twardość całkowita, temperatura, zasadowość całkowita, Hg, Ca, NO_3, NO_2, NH_4, SO_4, Mg, Ca, Fe, Ni, Cl, Zn, Cd, S, Na, K, Pb i Cu zastosowano analizę PCA.

Wnioski

Według zaobserwowanych danych woda jeziora Yassıalan jest ogólnej jakości na poziomie I–II klasy i zgodnie z wynikami wskaźnika WQI – chociaż ustalono, że jakość wody znacznie się pogorszyła w okresie letnim – jezioru przypisano klasę A – doskonała jakość wody (<50) we wszystkich badanych miesiącach i we wszystkich badanych stacjach. Wartości WQI zarejestrowane w jeziorze wynosiły 15,3–26,1, a wykryte parametry limnologiczne nie przekraczały określonych norm wody pitnej we wszystkich badanych miesiącach i we wszystkich badanych stacjach. Według wyników analizy PCA 3 czynniki wyjaśniały 84,2% wszystkich wariancji.

Słowa kluczowe: jezioro Yassialan, wskaźnik jakości wody, analiza głównych składowych