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ECOLOGY

The Effect of Water Quality on the Structure and Distribution of Benthic Community and Evaluation of the Lake's Water with Some Water Quality Indices: A Case Study of Büyük Akgöl Lake

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Abstract—In Büyük Akgöl, one of the most important lakes of Sakarya province in the Marmara region of Turkey, water and benthic sampling was carried out from five stations representing the lake seasonally between 2009 and 2010. As a result of the study, a total of 8736 individuals were collected from lake and that was a total of 24 species belonging to 36 taxa were identified. The benthic fauna community structure of the lake was classified with Turkish Biological Monitoring Working Party, Average Score Per-Taxon and Pielou's Evenness, Shannon–Wiener. According to the TR-BMWP scores were in the IV and the III class while the ASPT analysis was classified as moderate, and was as very poor. J' values ranged between 0.62 and 0.73, and H' values ranged from 1.74 to 2.14. The water quality parameters of the lake were classified as "unsuitable" by WQI and as "very polluted" according to HEI whereas the SAR, Na, and NPI were classified as 'excellent, good and no pollution.' According to the classification of water pollution control regulation it was showed 1st, 2nd and 3rd quality water characteristic. Pb, Hg, Al, Se, Cd concentrations and turbidity were exceeded the limit values set by WHO.

Keywords: benthic fauna, WQI, HEI, SAR, NPI, Na%, Turkey

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INTRODUCTION

Turkey is a country rich in freshwater potential, divided into 25 river basins containing more than 100 streams and 200 natural lakes; at the same time, due to its geographical location, it is a bridge between Europe and the Middle East and has transboundary water resources. Maintaining and sustainability the water quality of lakes and rivers, which constitute a very small part of the freshwater resources in the world, is important for researchers in Turkey as well as in all countries. Since environmental pollution, urbanization, technology, agricultural activities and many other factors deteriorate the quality of water resources, it is of great importance to conduct studies on water management and monitoring. Freshwaters provide habitat for aquatic organisms, and changes in the diversity and abundance of these organisms may occur due to effects that degrade water quality. For this reason, according to the Water Framework Directive (WFD) 2000/60/EC, using the ecological quality indicator feature, five biological (such as phytoplankton, phytobenthic, benthic invertebrates, macrophyte and fish) and water parameters are evaluated, and especially 3rd and 4th class quality waters are solutions have been proposed. Benthic invertebrates are used as one of five biological factors in water quality monitoring and management studies because they are stable, ubiquitous, abundant, and play an important role in the food chain and which these properties have been the subject of numerous studies (Girgin et al., 2003; Dügel and Kazancı, 2004; Kazancı et al., 2008a). These organisms are categorized as over-tolerant, tolerant, semi-tolerant, or sensitive, depending on how they react to change of the water's quality (Rosenberg and Resh, 1993; Kazanci et al., 1997; Mooraki et al., 2009). Turkish Biological Monitoring Working Party (TR-BMWP) system considers the sensitivity of benthic invertebrates to pollution, and every family is marked with a point ranging from 1–10; finally, each family value is added together and categorized as 100 (clean) and 10 (much polluted) (Kazancı et al., 2016). The Average Score Per-Taxon (ASPT) is the average sensitivity of families and is obtained by dividing the TR-BMWP point by the current taxon number. High ASPT points indicate an increased number of taxon with a high score; therefore, the water is considered clean (Armitage et al., 1983). No studies have previously been conducted on the faunistic and ecological properties of Büyük Akgöl, but research has been conducted on other lakes in the same region. In the conclusion of one of these studies, conducted by Özbek and Sarı (2007), it was stated that no zoobenthic groups were identified; in another study conducted by Taşdemir et al. (2008), only a few species belonging to the Chironomidae group were identified. The studies by Arslan et al., conducted in 2012, 2014, monitored the zoobenthic structure of the lake. Based on this information, the existing benthic invertebrate existence of the lake was revealed and the effect of environmental variables on the distribution and abundance of benthic invertebrates was evaluated with diversity indices (BMWP, ASPT, J', H'), contributing to the literature. On the other hand, indices that transform the physicochemical data of water into a single value with special formulas are used as tools in many studies that determine both the classification of water quality and the suitability of water for human use (Allison et al., 2020; Varol, 2020; Mutlu et al., 2021; Döndü et al., 2022; Varol et al., 2022). For example; water quality index (WQI), first developed by Horton in 1965, classified water quality into five categories as "unsuitable" and as "excellent," with scores ranging from 0 to 100 (Miraj and Bhattacharya, 2017; Kükrer and Mutlu, 2019). Sodium Adsorption Rate (SAR) index has classified suitability of using surface waters as irrigation water in 4 categories with ranging from 0 to >26, divided into "excellent" and "poor" (Richards, 1954); while Sodium percentage (Na%) index has classified "excellent" and "unsuitable" in 5 categories changed ranging from <20 to >80 (Wilcox, 1995). In order to determine the nutrient pollution status of the water, the Nutrient Pollution Index (NPI) provides classification in 4 categories as "no pollution" and "very high polluted" ranging from <1 to >6 (Isiuku and Enyoh, 2020; Larrea et al., 2022). The Heavy Metal Evaluation Index (HEI), which provides information on heavy metal concentrations in water, classifies water in 3 categories as "low" and "high," with values ranging from <10 to >20 (Edet and Offiong, 2002), and all of these indices have been widely used in water quality studies (Singh et al., 2005; Varol et al., 2012; Sener at al., 2017; Wu et al., 2018; Haider et al., 2019; Tian et al., 2019; Ustaoglu et al., 2020). In this study, the physicochemical properties of the lake water have been compared with the Turkish Water Quality Control Regulation (WPCR) and the World Health Organization (WHO); with the commonly used indices such as WQI, SAR, Na%, NPI and HEI the water quality of the lake water for irrigation and drinking water purposes classified. Thus, the lake water was evaluated with both water quality indices and biological factors. With the results obtained, it is thought that the data to be taken as a basis for ensuring the sustainability of freshwaters are provided.

MATERIALS AND METHODS

Description of the Study Area

Büyük Akgöl, located in the Sakarya basin (the Marmara Region) at 41°01′ N, 30°33′ E coordinates, is a shallow lake with an area of 3.6 km^2 and a drainage area of 47 km^2; located 4 km west of the Sakarya River, lake is 39 km away from Adapazarı city center and which 4–5 km inland from the Black Sea coast and has the status of a Nature Protection Area (Fig. 1). While there are 236 industrial facilities in Adapazarı, where the lake is located, the Marmara region is also a region with intense industrialization. There is a picnic area and a restaurant near the lake. While the water of the lake, where 2000 people lived in 1997, was used as drinking and utility water by the Gölkent Municipality, today the lake is facing dangers due to pollution and destruction; it is not currently used for human water consumption or irrigation purposes.

Water and Benthic Fauna Sampling

Water and benthic invertebrate samples from the lake were collected from five stations seasonally, summer in August 2009, autumn in November 2009, winter in February 2010 and spring in April 2010. One liter water samples from each station were taking into plastic bottles, stored at 4°C until they were analyzed get laboratory and adjusted to pH 2 by adding HNO_3 before analyzed. Biological oxygen demand, chemical oxygen demand, sulphate, total phosphorus, nitrite, nitrate, ammonium nitrogen, and some metals (Na, K, Mg, Ca, Fe, Pb, Cu, Cd, Hg, Ni, Zn, Al, P, S, Si, Ag, B, Mn, Se, and Cr) were analyzed according to standard methods at laboratory (APHA, 2005), while temperature, pH, turbidity, salinity, conductivity, dissolved oxygen, and electrical conductivity of the lake water were measured in-situ by using a multiparameter analyzer (WQC 22A). Benthic samples were taken from stations using two times (500 m^2) Ekman-dredge about 1.5–2 m depth, while littoral sampling was done with hand net (25 × 25 cm^2). Samples were preserved in a 4% formaldehyde solution in the study area after being sieved on a 0.5 mm sieve. Afterwards, the samples were brought to the laboratory, separated into groups and stored in 70% ethanol. Separated benthic samples were identified according to their genus or species level except Trichoptera, Ceratopogonidae, Ephemeroptera, Odonata, Chaoboridae, and Hirudinea with compound microscopes.

Data Processing and Assessment Indexes

Büyük Akgöl's water quality was determined using TR-BMWP versions of benthic fauna biological index score, Kazancı et al. (2016); ASPT scores were used according to Armitage et al. (1983). Shannon–Wiener (H') species diversity (based on the 10) and Evenness (J') values as diversity indices were calculated using the

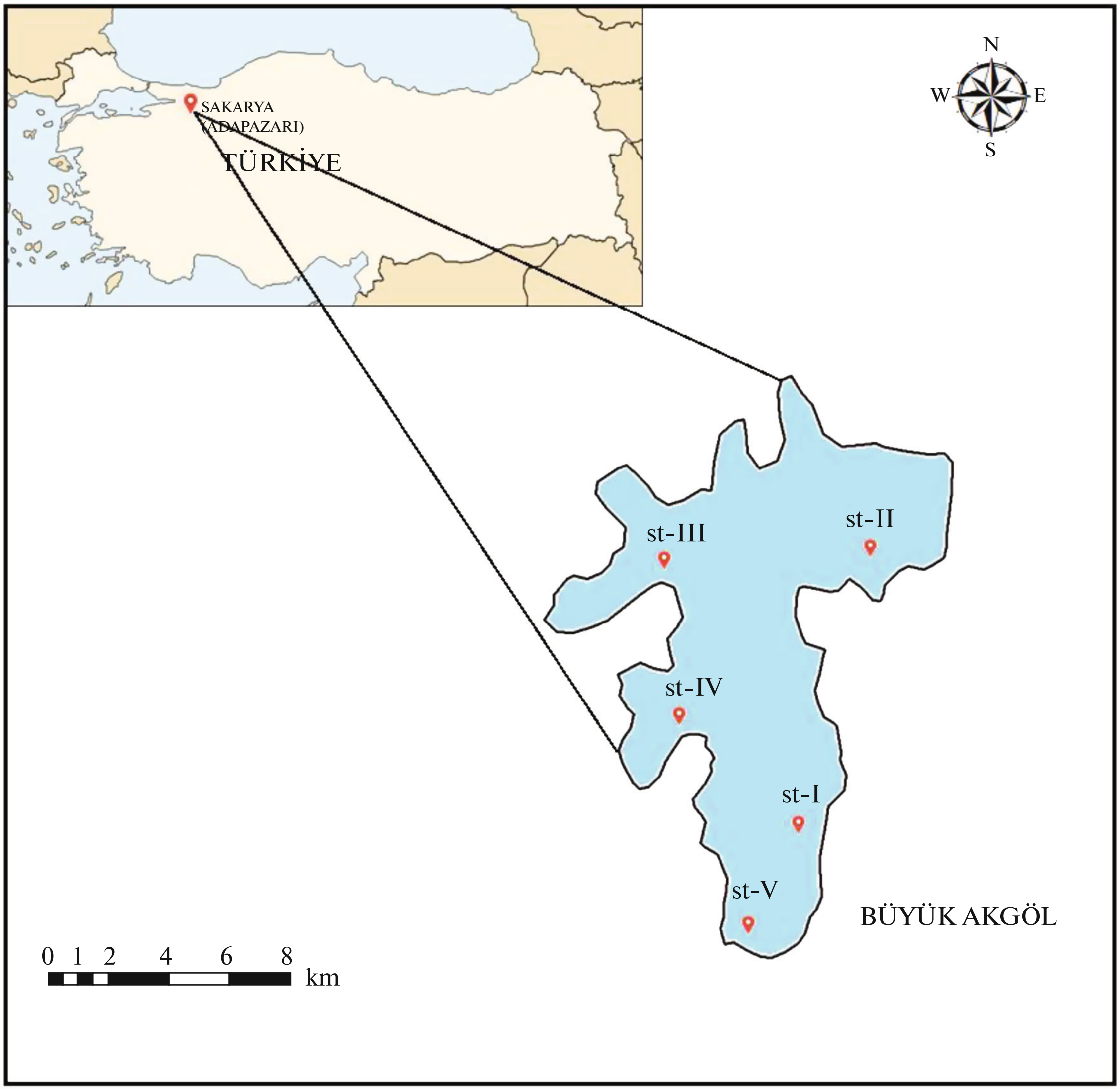

Fig. 1. Sampling stations benthic fauna and water of Büyük Akgöl.

PAST statistical program from Microsoft Windows and all results are given in Table 4.

Station similarities according to the distribution of taxa of individuals obtained from Büyük Akgöl at stations were examined using the Bray-Curtis Analysis method and are given in Table 3.

Water quality classification was made by comparing the physicochemical parameter values and heavy metal values of the water with the limits of the WRPC and WHO parameters, and the results are given in Table 5.

The suitability of the lake water as a source of irrigation and drinking water has been evaluated with indices such as SAR, Na%, HEI, NPI, WQI and the lake water has been classified according to these indices. The indices formulas and class categories used in the application are given in Table 1.

RESULTS

Biological Results

As a result of the examination of benthic samples from five stations in Büyük Akgöl, a total of 8736 samples were collected, and a total of 24 species belonging to 36 taxa were identified, of which nine belong to Oligochaeta, eight to Gastropoda, one to Bivalvia, and six to the Chironomidae groups out of 36 taxa. Precisely 53.9% of the benthic fauna belonged to the Gastropoda group, followed by 26.9% from Bivalvia, 12.1% from Oligochaeta, and 5.9% from Chironomidae; exactly 0.98% were from other taxonomic groups (Trichoptera, Ceratopogonidae, Ephemeroptera, Odonata, Chaoboridae, and Hirudinea) (Table 2).

Dressenia polymorpha, at 19.6%, was found to be the dominant taxon of the lake in the species category, followed by 16.8% *Viviparus viviparus*, 12.8% *Lymnea*

Table 1. The water quality indices used in the study, formulas used in calculation and water quality classes

Quality Index	Formula of Index	Quality class		References
Water Quality Index (WQI)	$\mathrm{WQI} = \sum Q_n W_n / \sum W_n$ *	0–25	Excellent	(Brown et al., 1972; Miraj and Bhattacharya, 2017)
		26–50	Good	
		51–75	Poor	
		76–100	Very poor	
		>100	Unsuitable	
Sodium Adsorption Rate (SAR)	$\mathrm{SAR} = \dfrac{\mathrm{Na}^{+}}{\sqrt{\dfrac{\mathrm{Ca}^{2+} + \mathrm{M}g^{2+}}{2}}}$	0–10	Excellent	(Richards, 1954)
		10–18	Good	
		18–26	Fair	
		>26	Poor	
Nutrient Pollution Index (NPI)	$\mathrm{NPI} = \dfrac{C_{\mathrm{N}}}{\mathrm{MAC_N}} + \dfrac{C_{\mathrm{P}}}{\mathrm{MAC_P}}$ **	<1	No pollution	(Larrea-Murrell et al., 2022; Isiuku and Enyoh, 2020)
		1 < 3	Moderate polluted	
		3 > 6	Considerable polluted	
		>6	Very high polluted	
Percent Sodium (Na %)	$\mathrm{Na}\,\% = \dfrac{\mathrm{Na + K}}{(\mathrm{Ca + Mg + K + Na})} \times 100$	<20	Excellent	(Wilcox, 1995)
		20–40	Good	
		40–60	Permissible	
		60–80	Doubtful	
		>80	Unsuitable	
Heavy Metal Evaluation Index (HEI)	$\mathrm{HEI} = \sum_{i=1}^{n} H_c / H_{\mathrm{mac}}$ ***	<10	Low	(Edet and Offiong, 2002)
		10–20	Between	
		>20	High	

* Q_n: the *n*th water quality parameters quality rating, Wn: the *n*th water quality parameters unit weight.

** C_{N}: the amount of NO_3–N in a water sample (mg/L), C_{P}: the amount of PO_4–P in a water sample (mg/L), $\mathrm{MAC_N}$: maximum limit value of NO_3–N (mg/L), $\mathrm{MAC_P}$: maximum limit value of PO_4–P (mg/L).

*** H_c: the *i*th parameter's monitored value, H_{mac}: the *i*th parameter's maximum allowable concentration.

stagnalis, 10.5% *Borysthenia naticina*, 8.4% *Potamothrix hammoniensis*, and 7.3% *Bivalvia* sp. as the top five species in this specific order (Table 2).

As can be seen in Figs. 2 and 3, Büyük Akgöl's benthos does not show a high taxonomic diversity, and the dominant taxa are organisms with a high tolerance to pollution; the distribution of organisms sensitive to pollution in the lake (0.98%) was found to be quite low. The distribution of the total number of individuals depending on the season (spring > autumn > winter > summer) can be found in Fig. 2. When observing the distribution of the total number of individual specimens found at each station, the most significant number was recorded at station II, which is located in an area northeast of the lake; the lowest numbers were recorded in the south (st-V), west (st-IV), southeast (st-I), and northwest (st-III) stations, respectively.

Station similarities according to the distribution of taxa of individuals obtained from Büyük Akgöl in stations were examined using the Bray-Curtis Analysis method; the results are given in Fig. 4 and Table 3. According to the distribution of taxa, st-I and st-III show a similarity of 65%. St-IV, st-II, and st-V join the group formed by st-I and st-III st-V is the station that differs the most compared to other sampling areas.

The number of taxa and individuals in the stations were counted, and their biological index scores (BMWP and ASPT), the Shannon–Wiener Diversity, and Pielou's Evenness analyses were completed; the results are given in Table 4.

As seen in Table 4, the stations with the highest taxonomic diversity are listed from largest to smallest as I > II > III > V > IV. In terms of the number of individuals, the most significant number of individuals was found at st-II, followed by st-V, st-IV, st-I, and st-III. In terms of the Shannon diversity index, the stations are I > III > V > II > IV, in order from largest to smallest. According to the BMWP scores, while the water quality of st-I, st-II, and st-III was found to be in the III Class moderate category, st-IV and st-V were classified as poor (Class IV). Similarly, ASPT analysis showed that st-I and st-II were moderate, st-III and st-IV were poor, and st-V was placed in the very poor class category. The low distribution (0.98%) of organisms sensitive to pollution in the lake was found to support the water quality classification (Figs. 2 and 3).

Table 2. Distribution of zoobenthic taxa detected in Büyük Akgöl and their average dominance ratios according to stations and seasons (AIG: Abundance in group; AIT: Abundance in total as %)

	Taxa	Stations					%		Season			
		I	II	III	IV	V	AIG	AIT	Summer	Autumn	Winter	Spring
Gastropoda (53.9%)	*Planorbarius corneus*	97	0	390	0	0	10.3	5.6	75	201	86	125
	Lymnea stagnalis	91	803	0	0	224	23.7	12.8	195	463	286	174
	Viviparus viviparus	298	353	144	677	0	31.2	16.8	105	168	803	396
	Theodoxus fluviatilis	117	171	133	32	0	9.6	5.2	41	121	62	229
	Bithynia sp.	0	55	48	0	0	2.2	1.2	25	31	26	21
	Valvata piscinalis	0	0	0	0	73	1.5	0.8	29	44	0	0
	Borystenia naticina	233	92	60	240	289	19.4	10.5	42	114	495	263
	Gryallus sp.	0	5	0	0	50	1.2	0.6	17	15	23	0
	Physa acuta	0	0	0	38	0	0.8	0.4	1	1	36	0
	Radix labiata	0	0	0	0	0	0.0	0.0	0	0	0	0
Oligochaeta (12.1%)	*P. hammoniensis*	153	96	148	99	235	68.8	8.4	250	131	182	168
	Tubifex tubifex	26	0	31	29	15	9.5	1.2	15	24	39	23
	Limnodrilus hoffmeisteri	22	0	0	0	0	2.1	0.3	7	2	2	11
	Potamothrix bedoti	6	0	27	0	10	4.0	0.5	5	8	10	20
	Dero digitata	4	11	0	0	12	2.5	0.3	10	5	4	8
	Nais communis	8	18	33	0	0	5.6	0.7	5	3	23	28
	Ophidonais serpentina	0	27	4	44	0	7.1	0.9	2	1	28	44
	Stylaria lacustris	0	1	0	0	0	0.1	0.0	1	0	0	0
	Pristina aeguiseta	0	0	0	0	4	0.4	0.0	2	1	0	1
Chironomidae (5.9%)	*Procladius* (*Holotanypus*) sp.	24	0	29	17	51	23.3	1.4	27	46	30	18
	Fleuria lacustris	5	0	14	0	0	3.7	0.2	12	3	3	1
	Zalutschia sp.	1	0	0	0	0	0.2	0.0	0	0	0	1
	Einfeldia pagana	0	20	18	19	25	15.8	0.9	24	17	34	7
	Parachironomus swammerdami	0	6	0	64	0	13.5	0.8	30	15	16	9
	Chironomus plumosus	29	0	0	0	0	5.6	0.3	9	7	11	2
	Chironomus (*Camptoch*) *tentans*	0	44	0	0	67	21.3	1.3	31	43	12	25
	Monopsectrocladius sp.	0	0	14	0	0	2.7	0.2	8	2	3	1
	Dicrotendipes nervosus	0	0	0	39	34	14.0	0.8	29	21	10	13
Bivalvia (26.9%)	*Dressenia polymorpha*	218	323	237	401	540	73.0	19.6	120	547	798	254
	Bivalvia sp.	130	113	88	115	189	27.0	7.3	44	203	293	95
Others (0.98%)	Trichoptera	28	15	1	0	0	100	0.5	39	0	5	0
	Ceratopogonidae	2	1	0	0	0	100	0.03	2	0	0	1
	Ephemeroptera	3	3	13	0	0	100	0.2	17	2	0	0
	Odanata	2	0	0	0	0	100	0.02	2	0	0	0
	Chaoboridae	1	3	2	6	5	100	0.1	3	9	5	0
	Hirudinea	1	0	0	0	0	100	0.01	0	1	0	0

Table 3. Bray-Curtis similarity percentages of stations according to distribution of taxa

	Stations				
	I	II	III	IV	V
I	1	0.58	0.65	0.63	0.52
II	0.58	1	0.47	0.53	0.46
III	0.65	0.47	1	0.44	0.37
IV	0.63	0.53	0.44	1	0.51
V	0.52	0.46	0.37	0.51	1

Table 4. Biological index scores and diversity indexes of the stations (S: Total number of taxa. N: Total number of individuals. J': Pielou's Evenness. H': Shannon–Weiner Diversity)

	BMWP		ASPT		Diversity			
	value	class	value	class	S	N	J'	H'
St-I	66	III-Moderate	3.14	Moderate	23	1499	0.69	2.14
St-II	55	III-Moderate	3.23	Moderate	20	2160	0.62	1.84
St-III	50	III-Moderate	2.94	Poor	19	1434	0.73	2.12
St-IV	31	IV-Poor	2.58	Poor	14	1820	0.68	1.74
St-V	24	IV-Poor	1.84	Very poor	16	1823	0.69	1.88

Physicochemical Parameters and Quality Index Results

Table 5 data compares the physicochemical parameters and heavy metal average values measured in the lake to Turkish WPCR (2016) and WHO values. The water quality in Turkey is examined in four categories: general parameters, oxygenation parameters, nutrient content parameters, trace elements (metals), and inorganic pollution parameters, according to the Surface Water Quality Management Regulation (WPCR, 2015). When categorized according to these, the water quality of Büyük Akgöl showed 1st-quality water for general parameters (pH, WT) and 2nd-quality water for electrical conductivity. The water was classified as 2nd and 3rd-quality water for oxygenation parameters (DO, BOD, COD), 2nd and 3rd-quality water for nutrient content (phosphor, nitrite), and 2nd

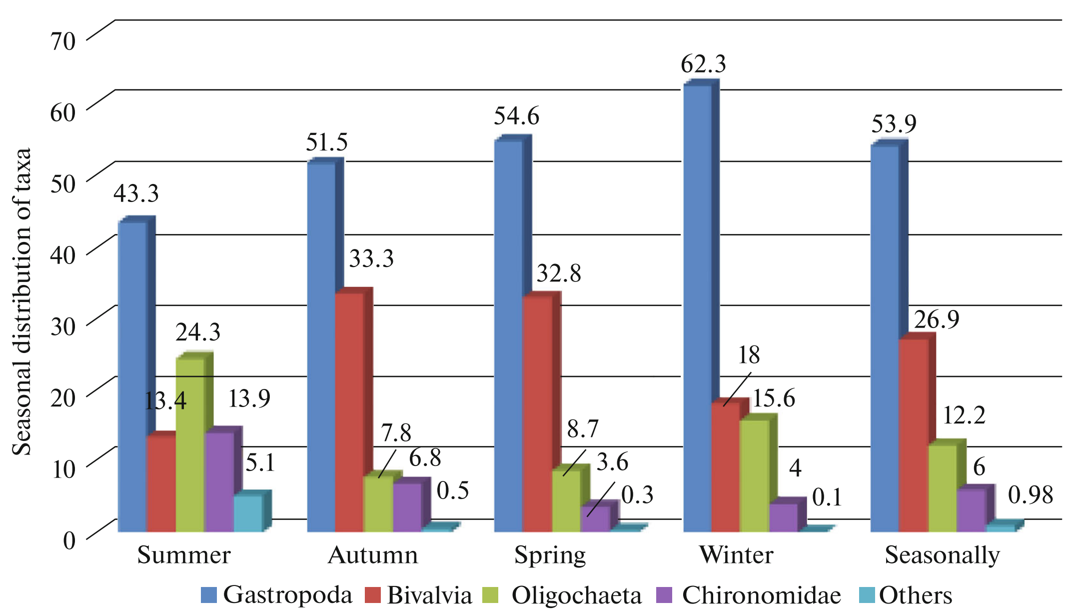

Fig. 2. Dominance distribution of taxa on seasonally.

Table 5. Physicochemical parameter and heavy metal values and WHO limit and WPCR class quality values of Büyük Akgöl

Stations/ Parameters, mg/L	St-I	St-II	St-III	St-IV	St-V	Mean	Summer	Autumn	Winter	Spring	Annual	WHO	WPRC I	WPRC II	WPRC III
DO	8.2	8.2	8.1	8.1	8.1	8.1	6.7	9.6	6.1	6.5	7.23		>8	6	6
Salinity, ‰	0.02	0.01	0.03	0.01	0.01	0.02	0.03	0.01	0.01	0.02	0.02				
pH	8.2	8.2	8.1	8.1	8.1	8.1	8.7	7.6	8.02	8.3	8.16	6.5–8.5	6–9	6–9	6–9
WT, °C	15.6	14.8	14.8	14	15.3	14.9	24.4	12.4	7.9	14.9	14.9	12–25	≤25	≤25	≤30
EC, µs/cm	**427**	368	359	350	362	381	332	346	384	**433**	373	400	<400	1000	>1000
Turbidity	**6.7**	**6.7**	4.6	5	**5.3**	**5.6**	**7**	**7**	**6.4**	3.6	**6.00**	5			
COD	21.8	24.3	21.2	23.05	22.4	22.5	35.7	25.5	13.8	15.2	22.55		<25	50	>50
BOD	4	3.3	4.6	5.3	4.3	4.3	8.4	2.6	2	–	4.33		<4	8	>8
PO_4–P	0.46	0.42	0.45	0.44	0.48	0.4	0.4	0.5	0.5	0.3	0.43		<0.05	0.16	>0.16
SO_4	32.4	31.2	31.7	62.1	32.3	37.9	62.7	85.8	3.07	0.2	37.94	250	<50	160	>160
NO_2–N	0.02	0.03	0.03	0.16	0.03	0.05	0.01	0.1	0.01	0.01	0.03	3	<0.01	0.06	0.12
NO_3–N	2.3	1.01	1.1	0.8	1	1.24	0.9	1.04	1.9	1.1	1.24	50	<3	10	>20
NH_4–N	0.1	0.07	0.05	0.08	0.08	0.08	0	0.1	0.08	0.1	0.07	200	<0.2	1	>1
Na	7.7	7.3	7.5	8.0	7.7	7.6	15.06	10.5	0.9	9.09	8.89	200			
K	8.4	6.3	5.7	5.5	7.2	6.6	5.54	7.11	10.5	3.84	6.75	20			
Mg	10.9	10.2	10.2	9.9	10.7	10.3	7.98	7.22	15.6	8.66	9.87	50			
Ca	26.9	25.2	31.5	26.2	26.1	27.1	31.53	33.29	0.88	47.29	28.25	200			
Fe	–0.2	–0.2	–0.2	–0.2	–0.1	–0.1	–0.31	–0.50	–0.27	0	–0.27	0.3	≤0.3	1	5
Pb	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	**0.03**	**0.05**	**0.002**	**0.03**	0.01	<0.01	0.02	0.05
Cu	0.04	0.03	0.04	0.03	0.04	0.04	0.03	0.03	0.07	0.01	0.04	2	≤0.02	0.05	0.2
Cd	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.01**	0.007	**0.04**	**0.023**	**0.02**	0.003	<0.2	1	2
Hg	**0.009**	0.01	**0.007**	**0.007**	**0.007**	**0.01**	**0.01**	**0.02**	0	0.003	**0.01**	0.006	≤0.0001	0.0005	0.002
Ni	0.01	0.01	0.01	0.01	0.01	0.01	0.004	0.004	0.05	0	0.01	0.07	≤0.02	0.05	0.2
Zn	0.01	0.009	0.01	0.02	0.07	0.02	0.10	0.12	0.005	0.005	0.06	0.01–3	≤0.2	0.5	2
Al	0.04	0.1	0.1	0.1	0.08	0.08	0	0	**0.29**	0	0.07	0.2	≤2	5	7
P	0.2	0.2	0.2	0.2	0.2	0.2	0.23	0.25	0.26	0.18	0.23	6	≤0.08	0.2	>0.2
S	6.8	6.3	6.4	6.5	6.7	6.5	7.02	7.09	7.2	5.34	6.66	70	≤20	50	200
Si	1.9	1.8	1.8	1.8	1.9	1.8	1.4	1.47	3.7	0.57	1.79	3000	≤200	500	2000
Ag	0.003	0.003	0.003	0.003	0.001	0.002	0.002	0.001	0.002	0.005	0.0				
B	0.09	0.08	0.4	0.08	0.08	0.1	0.38	0.12	0.05	0.07	0.16	2.4			
Mn	0.04	0.04	0.04	0.04	0.05	0.04	0.07	0.04	0.05	0	0.04	0.1–0.5	≤0.1	0.5	>0.5
Se	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	**0.05**	0.001	0.03	0.04	≤0.001	0.015	>0.015
Cr	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.03	**0.07**	0.02	0.03	0.05			

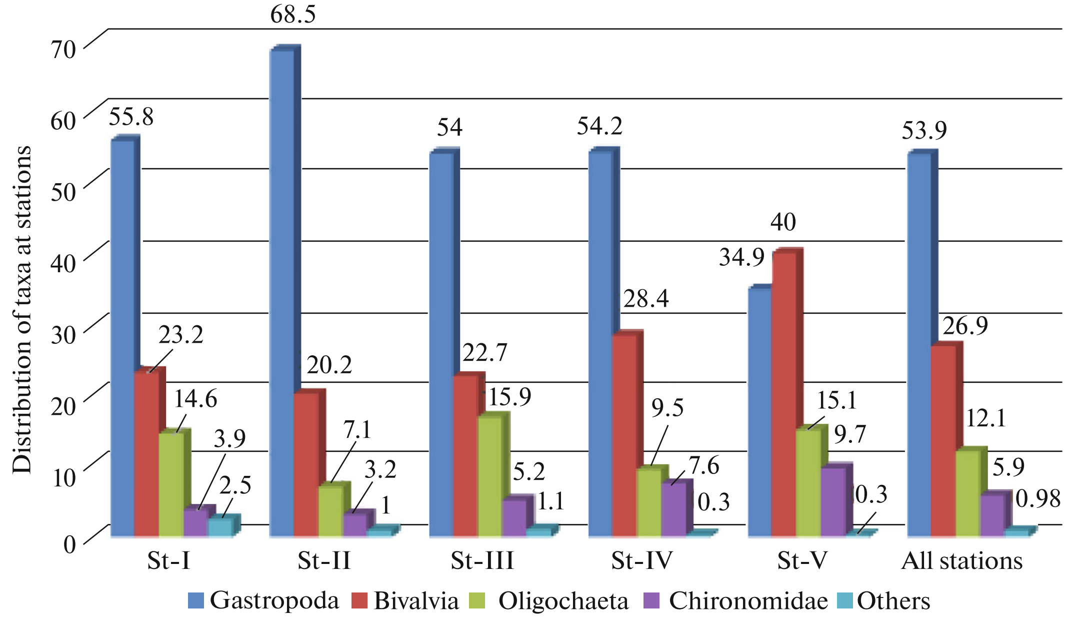

Fig. 3. Dominance values of taxa at stations.

and 3rd-quality water for water trace elements and inorganic pollution (Cu, Ni, Pb, Hg, and Se). The concentrations of lead, mercury, aluminium, selenium, cadmium, and turbidity measured in the lake water exceeded the limit values determined by the WHO.

The WQI of Büyük Akgöl has a mean value of 424.12 and 408.26; at these values, the water quality is classified as unsuitable (Tables 6 and 7). The SAR (1.72–2.03), Na% (27.7%–28.9%), and NPI (0.75–0.72) were all classified as "excellent, good, and no pollution," respectively, whereas HEI (21.7–23) analysis determined that the lake water quality was "highly polluted" (Tables 8 and 9).

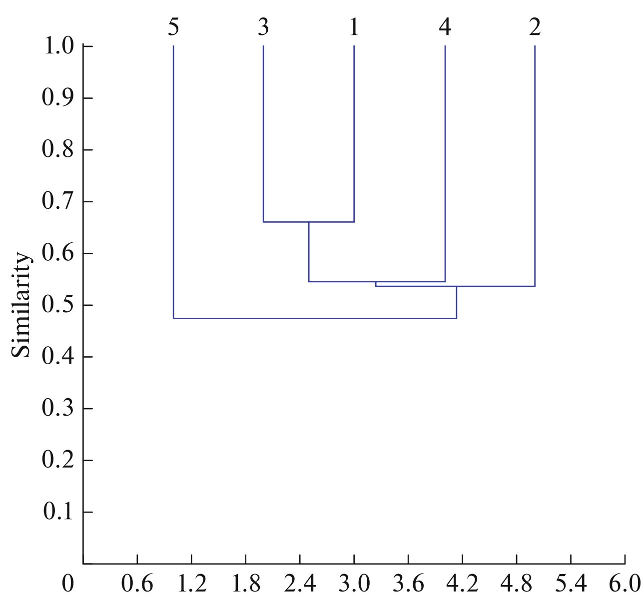

Fig. 4. Analysis Diagram of Bray-Curtis similarities of stations according to distribution of taxa.

DISCUSSION

A total of 8736 individual specimens were collected in Büyük Akgöl; the dominant groups are Gastropoda, Bivalvia, Oligochaeta, and Chironomidae. Most of the detected species (such as *Lymnea stagnalis, Viviparus viviparus, Dressenia polymorpha, Potamothrix hammoniensis, Limnodrillus hoffmeisteri, Chironomus plumosus, Chironomus* (*Camptoch*) *tentans*) can adapt to all kinds of habitat conditions and have a wide tolerance range (Brinkhurst and Jamieson, 1971; Cranston, 1982; Sarkka, 1994).

Dressenia polymorpha, also called zebra mussels, make up the most significant percentage of zoobenthos in the lake at 19.6% (Table 2). *D. polymorpha* are a native species of the Black and Caspian seas and, at present, are found in nearly all parts of Europe, Western Asia, and southern Turkey. They are small, easily and rapidly growing Bivalvia that can cause economic damage to the ecosystem they live in (Stanczykowska, 1977; Mackie, 1989). It has been reported that *D. polymorpha* mostly prefer cool waters and relatively rocky places with hard substrate structures and that have abundant macrophytes (Busch et al., 1995). Almost all of Büyük Akgöl is covered with macrophytes, and this species has been detected at a high rate in the lake, which is in line with the previously-mentioned data. *D. polymorpha* have a high filtration capacity and indi-

Table 6. Calculation of water quality index of Büyük Akgöl Lake at station. Water quality index (WQI) = $\sum W_n Q_n / \sum W_n$ = 408.26

Parametres	Standard value (Vs)	Mean concentration value (Vn)	W_n	Q_n	$W_n Q_n$
pH	8.5	8.1	0.0002	73.3	0.012
Sulphate	250	37.9	0.00	15.1	0.0001
Sodium (Na)	200	7.6	0.00	3.8	0.00
Nitrite	3	0.05	0.0005	1.6	0.0008
Nitrate	50	1.2	0.00	2.4	0.0001
Lead (Pb)	0.01	0.02	0.14	200	29.9
Copper (Cu)	2	0.04	0.0007	2	0.001
Cadmium (Cd)	0.003	0.02	0.49	666.6	332.4
Mercury (Hg)	0.006	0.01	0.24	166.6	41.5
Nickel (Ni)	0.07	0.01	0.02	14.2	0.3
Zinc (Zn)	3	0.02	0.0005	0.6	0.0003
Chromium (Cr)	0.05	0.03	0.02	60	1.79
Manganese (Mn)	0.5	0.04	0.003	8	0.02
Aluminum (Al)	0.2	0.08	0.007	40	0.29
Boron (B)	2.4	0.1	0.0006	4.1	0.002
Selenium (Se)	0.04	0.02	0.03	50	1.87
Turbidity	5	5.6	0.0003	112	0.03
Potassium (K)	20	6.6	0.0001	33	0.002
Magnesium (Mg)	50	10.3	0.00	20.6	0.006
Calcium (Ca)	200	27.1	0.00	13.5	0.0001
Phosphorus (P)	6	0.2	0.0002	3.3	0.0008
			$\sum W_n = 1$		$\sum W_n = 408.26$

rectly positively affect the eutrophication process by reducing blue-green algae growth and water turbidity (Hamburger et al., 1990). However, *D. polymorpha* use the bark of species belonging to the red-listed Unio and Anodonta genera as an adhesion substrate, thus preventing the filtration of these species, reducing their population density, and causing their extinction (Bohmer et al., 2001). Few specimens other than *D. polymorpha* from the Bivalvia group were encountered in Büyük Akgöl, which has negatively affected the development of other Bivalvia species due to the abovementioned characteristics. In terms of economy, *D. polymorpha* rapidly reproduce, form heaps, and clog water pipes, causing damage in places where drinking and domestic water is obtained; they cover the bottom of boats and ships and create deformation in aquaculture tools and equipment (Gollasch and Leppäkoski, 1999; Minchin t al., 2002). Their decay accelerates corrosion when they die due to their large numbers (Bernauer et al., 1996). In a study conducted by Arslan et al., we can observe that the dominance of the species in Büyük Akgöl (32.4% in 2012 and 34.8% in 2014) is gradually increasing (2018) and, therefore, the *D. polymorpha* population should be brought under control.

The species belonging to the Pulmonata subclass of gastropods can spread in many water systems due to its wide ecological tolerance limits; there is no significant distinctiveness in its zoogeographic distribution, and the qualitative and quantitative distributions of the species can provide clues about the ecological characteristics of the aquatic system in which they are found (Ertan et al., 1996; Elangovan et al., 1997). Other dominant species in Büyük Akgöl are the *Viviparus viviparus, Lymnea stagnalis, Borysthenia naticina*, and *Planorbarius corneus* euryök species from the Gastropoda (53.9%) family. The large number of specimens and the dominance of the species mentioned above in the lake zoobenthos group support this data.

The *Gyraulus*, *Radix*, and *Physa* genera within the Pulmonata group are considered bioindicator species in detecting water pollution (Harman, 1974). Similarly, *Gyraulus albus* and *Physa acuta* were the most tolerant to pollution among the Gastropoda family. The fact that these three Pulmonate species were detected in the lake, albeit in small numbers, is an indicator of Büyük Akgöl's pollution levels.

Table 7. Calculation of water quality index of Büyük Akgöl Lake at all season. Water quality index (WQI) = $\sum W_n Q_n / \sum W_n$ = 424.12

Parametres	Standard value (Vs)	Mean concentration value (Vn)	W_n	Q_n	$W_n Q_n$
pH	8.5	8.1	0.0002	73.3	0.01
Sulphate	250	37.9	0.00	15.16	0.0001
Sodium (Na)	200	8.8	0.00	4.4	0.00
Nitrite	3	0.03	0.0005	1	0.0005
Nitrate	50	1.24	0.00	2.48	0.0001
Lead (Pb)	0.01	0.03	0.14	300	44.8
Copper (Cu)	2	0.04	0.0007	2	0.001
Cadmium (Cd)	0.003	0.02	0.49	666.6	332.4
Mercury (Hg)	0.006	0.01	0.24	166.6	41.5
Nickel (Ni)	0.07	0.01	0.02	14.2	0.3
Zinc (Zn)	3	0.06	0.0005	2	0.001
Chromium (Cr)	0.05	0.03	0.02	60	1.79
Manganese (Mn)	0.5	0.04	0.003	8	0.02
Aluminum (Al)	0.2	0.07	0.007	35	0.26
Boron (B)	2.4	0.16	0.006	6.6	0.004
Selenium (Se)	0.04	0.03	0.03	75	2.8
Turbidity	5	6	0.0003	120	0.03
Potassium (K)	20	6.7	0.0001	33.5	0.002
Magnesium (Mg)	50	9.8	0.00	19.6	0.0006
Calcium (Ca)	200	28.2	0.00	14.1	0.0001
Phosphorus (P)	6	0.2	0.0002	3.3	0.0008
			$\sum W_n = 1$		$\sum W_n = 424.12$

Table 8. Water quality index (WQI), sodium adsorption rate (SAR), nutrient pollution index (NPI), sodium percentage (%Na), heavy metal evaluation index (HEI) and quality class categories of the lake according to stations and seasonal average values

Indexes	WQI	Class	SAR	Class	NPI	Class	Na%	Class	HEI	Class
All stations mean value	408.2	Unsuitable	1.72	Excellent	0.75	No pollution	27.7	Good	23	High
All seasonal mean value	424.1	Unsuitable	2.03	Excellent	0.72	No pollution	28.9	Good	21.7	High

Individuals belonging to the Prosobranchia subclass, which spread in freshwater, are generally accepted as steno species with limited tolerance to ecological factors. *Valvata piscinalis*, reported to be common in all of Europe except Iceland (Ilies, 1978), was one of the prosobranch species with the lowest population density (0.8%) in our study area, along with *Bithynia* sp. The population percentage of this species in the lake (1.2%) is very low compared to other Pulmonates. Hyman et al. reported that all members of the Bithynia genus live in freshwater and can be found in waters rich in organic matter (Hyman, 1967). These findings support the information about the distribution restrictions and low tolerance ranges of Prosobranchs in freshwater.

Oligochaeta, the other benthic living group in Büyük Akgöl, is used by ecologists as a bioindicator species in water quality studies due to its ecological preferences and tolerance. Oligochaeta specimens constitute 12.1% of Büyük Akgöl's zoobenthos. *Potamothrix hammoniensis, Tubifex tubifex*, *Limnodrilus hoffmeisteri*, *Potamothrix bedoti*, *Dero digitata*, *Nais communis*, and *Ophidonais serpentina* are euryök species that can live in any water system. However, their tolerance to metal pollution is lower than that of other groups (Brinkhurst and Jamieson, 1971; Wetzel et al., 2000).

Mollusca, Chironomidae (Diptera), and Oligochaeta are generally more abundant than other groups, although there are exceptions due to their wide tolerance ranges in the freshwater bottom (Mandaville, 2002). The dominance of Bivalvia and Gastropoda specimens in this study is in line with this information. However, the number of Oligochaeta and Chironomidae is quite low compared to the individual numbers of these two dominant groups because the habitat preferences of Oligochaeta and Chironomidae can be explained by the fact that they favour soft soils and the negative effect of *D. polymorpha* on the substrate structure and, therefore, of benthos diversity, as previously mentioned. In previous studies, it has been observed that there is a correlation between the abundance of Chironomidae and Oligochaeta species; it has even been determined that the abundance of Oligochaeta and Chironomidae species increases or decreases in opposition to each other over long periods (Milbrink, 1980; Ponyi, 1983; Langdon et al., 2006). In addition, it has been observed that some Tanypodinae (Chironomidae) species, especially the Procladius species, are Oligochaete predators and considered to be euryok. The *Procladius* (*Holotanypus*) sp. detected in Büyük Akgöl constitute approximately 1.4% of benthos, which negatively affects Oligochaeta abundance due to the predatory nature of the species. Although Chironomidae (5.9%) are not the dominant species in Büyük Akgöl, compared to other groups, *Chironomus* (Camptoch) *tentans* constitute 1.3% of the benthos (Table 1). *Chironomus plumosus* and *Chironomus* (Camptoch) *tentans*, pollution indicators used as bioindicator species, are considered the most common species in eutrophicated lakes. The fact that all three species were detected in our study area indicates organic pollution in the lake water. The larvae of Chironomus, which spread in the Holarctic, prefer stagnant or slow-flowing parts of rivers and muddy substrates, especially pools or small lakes. In addition, some Procladius species can colonize large profundal regions of deep lakes (Loden, 1974; Armitage et al., 1994; Brodersen et al., 2001). This information is in line with our findings. As seen in the bidirectional Bray-Curtis Analysis Diagram, there are similarities and differences between the habitat preferences of the identified taxa (Fig. 4). *Limnodrilus hoffmeisteri* and *Chironomus plumosus*, *Monopsectroladius* sp. and *Fleuria lacustris*, *Potamothrix hammoniensis* and *Borysthenia naticina*, and *Gryallus* sp. and *Valvata picinalis* prefer similar habitats, and similarity was observed in their distribution.

In conclusion, this study shows that Büyük Akgöl zoobenthos is composed of groups known as tolerant species. The presence and density of these species, the weak zoobenthic structure, and the low diversity of taxa indicate that the lake is polluted and has entered the eutrophication process.

Considering the annual average values of all stations and seasons, the total phosphorus class III, nitrite class II and III, copper class II, lead class II and III, mercury, and selenium have been determined to be in class III; in addition, selenium exceeded the limit value proposed by the WHO. Annual averages of all other parameters show that Büyük Akgöl water values are class I.

Since anions and cations are two of the most prevalent water resource parameters, monitoring them regularly is crucial. For this reason, some quality indexes such as SAR, Na%, NPI, WQI, and HEI were calculated according to the concentrations of these two parameters of the lake water (Table 8). These indices show the suitability of the examined water for agricultural irrigation or drinking water. A standard method for assessing nutrient pollution in surface water resources is the NPI, based on the concentration of NO_3–N and PO_4–P (Isiuku and Enyoh, 2020). This makes it easier to quickly and efficiently assess the overall quality of surface waters. According to Tokatlı (2021) study results, NPI scores, using the parameters of nitrate and phosphate detected in the drinking waters of İpsala, Keşan, Meriç, and Uzunköprü districts, all of the investigated area studies determined the water quality as having "no pollution." As a result of a survey of the Varol et al. (2022), Karasu River, the authors classified the NPI as showing "no pollution." Isiuku and Enyoh (2020), classified, on an annual basis, several lakes and streams in south-eastern Nigeria as "moderately polluted" based on NPI concentration while classifying them as "no pollution," "very polluted," and "significantly polluted" during the wet and dry seasons. In the study, the mean NPI values (0.72–0.75) were below 1 at all stations and in all months, indicating that the lake was "not polluted." Our study results are similar to the other study results mentioned here. These findings demonstrate that these water quality indices are effective methods for assessing water quality status or the pollution level of freshwater. Therefore, they can be practical tools for managing water quality (Nong et al., 2020; Pak et al., 2021).

SAR analyses the high salt concentration in relation to calcium and magnesium, which lowers the soil's permeability and obstructs the flow of water to crops (Aly et al., 2015). When SAR is between 0–10, freshwater is considered excellent for irrigation and sufficient for all soils and plants except for sodium-sensitive species (Richards, 1954). In their surface water quality study in Sankey tank and Mallathahalli lake in India, Ravikumar et al. (2013), calculated the SAR value to be a minimum of 0.18 and a maximum of 2.34; the authors evaluated the water to be "excellent" for irrigation. In a study titled "Data on the assessment of groundwater quality for drinking and irrigation in rural areas" by Soleimani et al. (2018), the SAR value was determined to be in the range of 0.04–0.63, and the quality of water used for agriculture reported as belonging to the good and excellent category. In "Assessment of surface water quality using water quality index and multivariate statistical analyses in Saraydüzü Dam Lake, Turkey," by Kukrer and Mutlu (2019), the mean SAR value was calculated as 1.56

and, according to these values, the authors reported that the lake water is classified as "very good" irrigation water. In a study titled "Assessment and modeling of groundwater quality using WQI and GIS for the Upper Egypt region," Rabeiy (2018), reported the SAR value as suitable for agriculture. When the SAR values (1.72 and 2.03) of Büyük Akgöl were compared with the results of these studies, similar rates were determined, and the lake water was classified as excellent.

Quality water is essential for irrigation, and another parameter, Na%, was evaluated in this study. The Na% results were found to be in the "good" quality category, with values of 27.7–28.9. Many studies have been conducted on groundwater; for example, Soleimani et al. (2018), reported that the Na% weight was 15.37–15.59% in their study and that groundwater was in the "excellent" category. Additionally, Yousefi et al. (2017), found the Na% value in ground waters to be 63.8–66.5% and evaluated it as in the "doubtful" category. Badmus et al. (2014), found the Na% value of groundwater to be at least 25.5% and at most 60.3%. Acharya et al. (2018), studied the Na% values of groundwaters in India, and they reported a minimum of 10.3% and a maximum of 71.6%. Comparing these studies with the Na% value of Büyük Akgöl shows that the lake water is suitable for irrigation.

Using WQIs is another method for assessing the quality of freshwater (Aly et al., 2015; Nong et al., 2020). This method aims to combine a variety of water quality criteria and transform them into a single value that represents the state of the freshwater water quality (Miraj and Bhattacharya, 2017). The WQI is categorized in different ranges and changes between 0–25 (excellent) and above 100 (unsuitable) (Brown et al., 1972). The WQI has been widely applied in investigations on water quality assessment and is considered essential to water quality control. As an example, Varol (2020), rated the water quality of Turkey's Sürgü Stream as "good" to "excellent." In another study, Varol (2022), suggested that the Karasu River was not polluted and had "good" and "excellent" water quality.

Palit et al. (2018), in their results on the Water Quality Index of selected pit-lakes in the Raniganj Coal Field Area of India, showed that most of the water samples fell under the "poor water category." The WQI scores of the five pit lakes ranged from 53.54 to 77.21. Acharya et al. (2018), in their assessment of the WQI of groundwater quality in South West Delhi, India, showed that, as drinking water, 34% of the samples were in the "good" category and 66% were in the "unsuitable" category. Döndü et al. (2022), found the average WQI values to be "good" and "excellent" in their study titled, "Seasonal evaluation of the effect of fresh water feeding the Gulf of Gökova with the water quality index (WQI) and comprehensive pollution index (CPI)." In our study, to evaluate the existing water quality for Büyük Akgöl, five sampling points were selected, and WQI values were calculated (Tables 5 and 6) according to 21 key parameters. The average values of WQI are given in Table 7. The WQI scores were 408.2 in all stations and 424 on a seasonal basis. This study's results show that the lake water's water quality is "unsuitable" for recreational use. The study area is surrounded by intensive industrial activities and approximately 15000 decares of agricultural land. Considering the physicochemical parameter values of the water (Table 1), it was found that Pb, Cu, Hg, Cd, Se, P, PO_4–P, and lake water II and III, classified as 7 of the 21 parameters used in the WQI, exceed WPRC and WHO limit values. As a result, it is conceivable that these data affected the high WQI score.

The HEI is a way to determine water quality with a concentration of heavy metals in water. This index gives a general evaluation of the water's quality in terms of heavy metals. Proshad et al. (2020), reported that they found low levels of heavy metal pollution (less than 10) in the Rupsa River water in Bangladesh according to the HEI classification. The present study calculated the HEI value for Pb, Cu, Cd, Hg, Ni, Zn, Cr, Mn, Al, B, and Se. The average HEI values for the season and at the individual stations were 21.7 and 23, respectively. According to the study results, the HEI value of the lake water was classified as "high."

CONCLUSIONS

Turkey's Marmara region is characterized by intense industrial activity. Approximately 15000 decares of agricultural land also surround Büyük Akgöl. Therefore, agricultural and industrial matter with polluting characteristics enters the lake through drainage waters or the excessive use of fertilizers and pesticides. The data obtained in this study shows that the lake is under pressure from pollution. As a result, water quality indices have been practical tools in determining the lake's current state and pollution level.

The aim of "water resources management," developed to promote the planned and economical use of water—a natural resource with no alternative—is to detect and prevent problems that threaten water resources—and protect water and water resources. For a water source to serve its purpose, it must be monitored continuously. Therefore, managed monitoring program that thoroughly evaluates the data will provide useful information for environmental management.

When we observe the zoobenthic structure of Büyük Akgöl's water, creatures with high tolerance to water pollution are abundant. For example, *D. polymorpha* have the characteristics of an invasive species, and their population should be controlled; in addition, biological control practices should be developed as needed. However, the density of the specimens sensitive to the water population is very low. Therefore, the lake water should be continuously examined and monitored, under the guidance of an expert, to prevent pollution loads at their source and protect and improve the lake's zoobenthic structure that has sensitive species.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects. Ethical permission is not required for benthic invertebrates.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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