Assessment of Macrophyte Biological Index for Rivers, and evaluation of physicochemical parameters in the Sakarya River Basin of Turkey

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Abstract

In this study, the Macrophyte Biological Index for Rivers (IBMR) method and physicochemical measurements were used to assess the trophic status of the Sakarya River Basin in Turkey. The most abundant macrophytes were *Phragmites australis*, *Thypa latifolia*, *Juncus* sp., and *Paspalum distichum*. The IBMR values varied between 6.00 and 13.00 in spring, and between 6.714 and 14.40 in the fall season. The sampling stations, which are under the influence of agricultural runoffs, domestic effluents, and industrial discharges, had hypoxia accompanied by eutrophic and/or hypertrophic conditions at least in one season. The individual trophy levels of the sampling sites in the basin have been assessed as mesotrophic to eutrophic. However, considering the average IBMR value of all stations, the general trophy level of the basin was close to eutrophic. The results indicate that the physicochemical parameters are affected by various effluents discharged to the basin as observed during field studies, and the obtained data would be useful to apply conservation measures.

Keywords: ecological quality, eutrophication, IBMR, macrophyte, Sakarya River Basin

Introduction

Industrial effluents, urbanization-related wastewater inputs, and excess fertilizer usage in agricultural activities are considered significant sources of increased eutrophication in freshwaters such as rivers, streams, and ponds (Chislock et al., 2013; Khatri and Tyagi, 2015). These factors modify the chemical and physical characteristics of freshwaters, thereby directly affecting the floral and faunal elements (Ceschin et al., 2010). Among these elements, macrophyte species have been used as indicators of ecological quality status in many studies (Haury et al., 2006; Szoszkiewicz et al., 2009; Manera et al., 2014; Özen et al., 2017). The growth, abundance, and association of macrophytes are altered depending on several abiotic factors such as climatic conditions, chemical composition (i.e., macro and microelement concentrations), pH, flow rate, hydrological properties of water, and type of substrate (Lopes et al., 2016). Also, anthropogenic impacts such as leakage of nutrients from agricultural lands can affect macrophyte composition and development (Elo et al., 2018). Therefore, several methods that depend on the evaluation of macrophyte associations and their abundances have been developed to estimate the ecological status of rivers and lakes (Ceschin et al., 2010). The determination of eutrophication levels in rivers is done according to three main methods, namely; Mean Trophic Rank (Dawson et al., 1996), Trophic Index with Macrophytes (Schneider and Melzer, 2003), and Macrophyte Biological Index for Rivers — Indice Biologique

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Fig. 1. Map of the Sakarya River Basin showing the sampling stations. The map has been provided by General Directorate of State Hydraulic Works of Turkey (DSI).

Macrophytique en Rivière (IBMR; Haury et al., 2006). The IBMR method has been officially adopted by several countries including France, where the method was first developed, Italy, Belgium (Wallonia), and Turkey to assess the ecological quality of freshwaters, as per the European Water Framework Directive (European Council 2000) of the European Parliament and the Council (Solimini et al., 2008; Manera et al., 2014).

Turkey's basins have been classified into 25 main sectors for hydrological studies. The Sakarya River Basin is one of Turkey's most significant river basins and is very diverse in terms of agricultural, industrial, and domestic usage. The basin is located in the northwest of the Anatolian Peninsula, having a drainage area of 58160 km^2 (DSİ, 2016). The rivers in the basin pass through 13 densely urbanized provinces (Eskişehir, Sakarya, Bilecik, Ankara, Bolu, Kütahya, Afyonkarahisar, Konya, Bursa, Kocaeli, Düzce, Çankırı, and Uşak) where many industrial facilities are located (Solak et al., 2020). Thus, monitoring the basin's ecological status is crucial for protecting freshwater sources and nature. To our knowledge, there is no study published in the open literature regarding macrophyte-based evaluation of ecological status, including the IBMR indices, which offers a practical assessment of watercourses in the Sakarya River Basin. Therefore, the aims of the present study are: 1) to assess the general ecological quality of the waterworks and effected factors in the Sakarya River Basin by estimating the trophic status of various sampling points; 2) to compare ecological quality and accompanied physicochemical parameter variations between fall and spring seasons.

Table 1. Locations of the sampling stations

Station code	Location	Station code	Location
S1	Eskişehir — Sivrihisar	*S20*	Ankara — Altındağ
S2	Eskişehir — Sivrihisar	*S21*	Eskişehir — City Center
S3	Eskişehir — Sivrihisar	*S22*	Kütahya — City Center
S4	Kocaeli — City Center	*S23*	Eskişehir — Sivrihisar
S5	Eskişehir — Sivrihisar	*S24*	Bolu — Seben
S6	Ankara — Nallıhan	*S25*	Ankara — Nallıhan
S7	Ankara — Nallıhan	*S26*	Eskişehir — Mihalıççık
S8	Bursa — Yenişehir	*S27*	Bilecik — İnhisar
S9	Bilecik — City Center	*S28*	Ankara — Kızılcahamam
S10	Bilecik — City Center	*S29*	Ankara — Nallıhan
S11	Bilecik — Osmaneli	*S30*	Eskişehir — Beylikova
S12	Sakarya — Pamukova	*S31*	Ankara — Çamlıdere
S13	Kütahya — Altıntaş	*S32*	Eskişehir — City Center
S14	Eskişehir — Sivrihisar	*S33*	Bursa — İnegöl
S15	Ankara — Polatlı	*S34*	Bursa — İnegöl
S16	Ankara — Polatlı	*S35*	Bursa — İnegöl
S17	Ankara — Sincan	*S36*	Bursa — Yenişehir
S18	Konya — Ilgın	*S37*	Bursa — Yenişehir
S19	Eskişehir — City Center		

Locations are given as the names of "province — district".

Material and methods

Study Site and Sampling Stations

The Sakarya River Basin is an individual river (Sakarya River) basin covering about 7% of Turkey. The total length of the Sakarya River with its tributaries is 720 km. The mean annual rainfall of the basin is estimated at 479 mm, while the total annual rainfall is 32 billion m^3. The drainage density of the basin is 0.31 km km^{-2}. The basin's mean slope is 18.09%, with a mean altitude of 969 m (DSİ 2016). The sampling was carried out during November 2017 and May 2018 in 37 sampling locations throughout the basin (Fig. 1). Locations and codes of the stations are provided in Table 1.

Macrophyte Sampling Methodology and Species Identification

The sampling was done by observing macrophytes at rivers for a range of 100 m (transect). This range was divided into four equal subranges (quadrates) when applicable to enable a homogenous sampling. The macrophyte species were sampled by rake, grapple, or directly by hand and then identified according to the proper keys in *Flora of Turkey* (Davis et al., 1985) and Cook et al.'s manual for identification of freshwater macrophyte genera (1974).

Estimation of IBMR

The IBMR values of the sampling stations were estimated according to the technical norm developed by the French Association for Normalization (AFNOR, 2003). The frequency and coverage of the listed species were estimated according to their visual appearances in the sampling stations. The variations in the IBMR values between fall and spring seasons were compared, and accompanied physicochemical values were evaluated. To enable a more accurate comparison between sampling seasons, we discarded from the IBMR calculation any stations having lesser than three macrophyte species that were not predominant in the river bed (and therefore characterized by very low coverage value at least in one sampling season), as well as stations with a dried waterbed in any sampling season. The changes in the values were discussed in terms of the macrophyte composition and anthropogenic factors. The following formula was used to determine IBMR value:

$$IBMR = \frac{\sum_i^n Ei \times Ki \times CSi}{\sum_i^n Ei \times Ki}, \quad (1)$$

where *CS*i is a score of a macrophyte taxon, varying between 0 and 20 depending on tolerance to ammonium, orthophosphate, and heavy organic pollution; *E*i indicates the coefficient of ecological amplitude; *K*i represents the scale of cover for macrophytes, where i is the number of contributory species, and n stands for the total number of contributory species (Haury et al., 2006).

The scale of Haury et al. (2006) describes the trophic status of water bodies based on their IBMR values in the following scale decreasing from oligotrophic to hypertrophic: IBMR > 14, Very good; 14 ≥ IBMR > 12, Good; 12 ≥ IBMR > 10, Moderate; 10 ≥ IBMR > 8, Poor; 8 ≥ IBMR, Bad.

Physicochemical Measurements

The pH values, electrical conductivities (μS cm^{-1}), and dissolved oxygen concentrations (mg L^{-1}) of the waters in the stations were measured using a multi-parameter data sonde (Hydrolab-DS5), while flow rates (m^3 s^{-1}) were measured through an electronic flow probe (AKIM, Turkey). The measurements were done twice, at the same time as biological sampling.

Statistical analysis

The Pearson correlation was used to evaluate correlations between two dependent variables at 95 % and 99 % confidence levels. The statistical comparison was applied to the yearly values calculated as the arithmetic mean of the data obtained in both sampling seasons (Supplementary File 1).

Table 2. The list of identified macrophyte plant species observed at the sampling stations, and their life forms

Taxon name	Life form	Taxon name	Life form
Agrostis stolonifera	A	*Myriophyllum spicatum*	SM
Alisma plantago-aquatica	SM-E	*Nasturtium officinale*	SM
Apium nodiflorum	E	*Myriophyllum spicatum*	SM-F
Berula erecta	E	*Paspalum distichum*	SM-E
Callitriche stagnalis	SM	*Phragmites australis*	E
Carex cyperoides	E	*Plantago lanceolata*	A
Carex flacca	E-A	*Plantago major*	A
Carex paniculata	E	*Persicaria hydropiper*	E
Catabrosa aquatica	E	*Persicaria maculosa*	A
Ceratophyllum demersum	SM-F	*Potamogeton crispus*	SM-F
Ceratophyllum submersum	SM-F	*Potamogeton nodosus*	SM-F
Cyperus longus	E	*Ranunculus aquatilis*	SM-E
Eleocharis palustris	SM-E	*Ranunculus trichophyllus*	SM-E
Iris pseudacorus	SM-E	*Rumex crispus*	A
Juncus acutus	E	*Rumex hydrolapathum*	E
Juncus bulbosus	E	*Sagittaria sagittifolia*	SM
Juncus conglomeratus	E	*Schoenoplectus lacustris*	SM
Juncus inflexus	E	*Typha latifolia*	E
Juncus effusus	E	*Typha minima*	E
Lemna minor	F	*Veronica anagallis-aquatica*	E
Mentha aquatica	SM-E	*Veronica beccabunga*	E

A: Amphibious, E: Emerged, F: Floating, SM: Submerged.

Results

The most abundant macrophyte species at the sampling stations were determined as *Phragmites australis*, *Thypa latifolia*, *Juncus* sp., and *Paspalum distichum,* which are primarily localized at river banks. The macrophyte plant species were observed mostly in "submerged" and "emerged" life forms. Only the species belonging to *Ceratophyllum*, *Potamogeton*, *Myriophyllum*, and *Lemna* genera were observed as floating macrophytes. The identified macrophyte plant species observed at the sampling stations are given in Table 2.

The trophic status of seven stations, representing 18.9 % of all the stations, was found as "bad" in the fall season, while the stations having a bad trophic status increased to 24.3 % in the spring season. In both seasons, 40.5 % of the stations had poor trophic status, while 21.6 % of the stations were found with moderate trophic status in the same sampling period. In the fall, 13.5 % of stations were found with a good trophic status, while this number decreased to 10.8 % in the spring season (Table 3).

In the fall, the highest species richness (7 species) was found in 4 stations, while the lowest (3 species) was observed in 13 stations. On the other hand, in the spring, the highest species richness (10 species) was found in 4 stations, while 7 stations had the lowest (7 species). In general, macrophyte richness increased in the spring season (Table 3).

The pH values of water in the sampling stations varied between 8.18 and 9.62 in the fall season. However, these values were found between 7.18 and 8.75 in the spring season (Table 3). Therefore, a remarkable decrease was found in the pH values between the sampling seasons.

Table 3. Season-based IBMR values and physicochemical parameters of the sampling stations

Station	Parameters											
	IBMR-F	IBMR-S	Sp-F	Sp-S	pH-F	pH-S	Fr-F	Fr-S	Co-F	Co-S	DO-F	DO-S
S1	12.207	7.200	3	6	8.56	7.94	10.80	5.84	752	1092	10.10	6.19
S2	7.789	8.750	3	3	8.52	7.84	11.90	5.81	770	1100	8.54	8.65
S3	10.207	9.000	3	4	8.67	8.00	0.00	0.00	806	1395	9.29	11.15
S4	9.463	8.370	6	10	8.23	7.22	0.78	1.40	350	311	6.74	4.18
S5	13.273	9.333	3	5	8.56	8.21	1.49	0.72	734	1065	9.39	8.91
S6	11.000	10.560	3	4	8.69	8.39	0.24	1.23	684	532	8.55	8.98
S7	9.209	7.385	4	6	8.25	8.44	0.00	0.00	917	1037	1.62	9.18
S8	10.585	7.800	4	8	8.33	7.71	0.00	0.00	1538	593	2.39	3.75
S9	7.774	9.515	6	10	8.46	8.16	1.77	0.00	627	405	8.56	8.66
S10	8.340	10.129	5	8	8.55	7.18	34.50	17.60	882	818	9.65	8.46
S11	9.077	11.789	6	10	8.86	8.10	1.13	20.10	735	346	10.82	10.15
S12	9.852	11.440	7	7	8.39	8.02	7.23	55.90	844	540	8.23	8.84
S13	9.867	9.150	6	8	8.68	8.35	0.00	0.00	459	489	11.67	10.0
S14	7.900	8.769	4	3	8.84	8.10	0.28	0.57	638	550	10.34	1.7
S15	10.167	9.097	6	4	8.26	7.70	14.80	18.00	1438	1426	1.10	2.17
S16	12.385	12.300	3	3	8.82	8.06	12.60	5.10	990	2059	9.89	5.96
S17	7.667	8.087	4	3	9.62	7.90	4.64	4.64	1535	1397	0.75	0.56
S18	7.824	6.692	5	7	8.70	8.70	0.00	0.00	378	378	12.21	12.21
S19	8.600	9.382	7	7	8.90	7.92	0.37	0.39	467	466	12.14	7.28
S20	9.250	9.214	3	3	8.19	7.90	0.27	0.42	890	1061	9.66	3.88
S21	11.500	12.818	5	4	8.26	8.08	0.30	1.92	508	481	7.24	9.12
S22	8.909	8.545	4	4	8.18	7.69	2.39	4.48	583	592	1.58	3.50
S23	11.039	8.000	3	9	8.57	8.05	5.48	2.40	691	910	8.94	8.06
S24	12.125	10.738	7	5	8.87	7.47	0.31	2.09	144	300	11.86	9.56
S25	13.633	13.000	7	6	8.94	8.45	0.03	0.03	478	510	10.58	8.91
S26	9.222	10.962	4	3	8.76	8.14	0.54	0.49	443	495	9.13	8.58
S27	14.039	12.316	5	6	8.94	8.46	4.33	4.16	904	412	12.40	9.25
S28	10.250	11.091	3	3	8.54	8.40	0.00	0.03	199	289	11.32	7.90
S29	10.034	9.250	7	5	8.59	8.36	0.00	9.34	400	359	9.80	9.75
S30	8.865	6.500	3	8	8.79	7.82	3.43	9.34	830	764	7.97	5.00
S31	14.400	8.700	3	4	9.01	8.75	0.00	0.22	144	180	12.32	8.29
S32	9.794	11.636	6	10	8.74	8.10	0.19	0.21	444	417	10.34	8.79
S33	9.481	7.314	6	9	8.27	8.27	0.63	29.30	685	685	4.25	4.25
S34	8.556	6.000	3	5	9.16	8.21	0.72	7.80	265	141	11.71	10.26
S35	7.667	7.043	4	6	9.08	7.99	0.00	7.35	375	183	12.86	10.08
S36	6.714	7.765	3	4	8.44	8.02	0.55	5.03	836	445	8.18	8.56
S37	9.018	8.522	4	8	8.49	8.19	0.84	18.90	802	404	9.75	9.13
MEAN	*9.937*	9.302	4.5	5.9	8.64	8.06	3.31	6.51	680	666	8.70	7.56

S: Spring, F: Fall, Sp: Number of species, Fr: Flow rate ($m^3 s^{-1}$), Co: Conductivity ($\mu S cm^{-1}$), DO: Dissolved oxygen ($mg L^{-1}$).

CONSERVATION BIOLOGY

The highest water flow rate values increased to 34.5 $m^3 s^{-1}$ and 55.9 $m^3 s^{-1}$ in the fall and spring seasons, respectively, whereas stagnant water was observed in 9 stations in fall and 6 stations in the spring season (Table 3).

The water bodies' electrical conductivity in the stations was found between 144 and 1538 $\mu S\ cm^{-1}$ in the fall season. However, the electrical conductivity value varied between 141 and 2059 $\mu S\ cm^{-1}$ in the spring season (Table 3). The most striking change in the electrical conductivity values was found from the S16 station. In the S16 station, the conductivity value was almost doubled in the spring season, while a decrease of 61.3 % was found in the S8 station.

The highest dissolved oxygen concentration in the fall season was measured as 12.86 mg L^{-1} in the S35 station, while the maximum value for this parameter was found as 12.21 mg L^{-1} in the S18 station (Table 3). The dissolved oxygen levels were below hypoxic levels (< 3 mg L^{-1}) in S5 and S3 stations during the fall and spring seasons, respectively. The minimum dissolved oxygen concentrations were recorded as 0.56 and 0.75 mg L^{-1}. In the S14 station, the dissolved oxygen concentration decreased by 83.2 % in the spring season, while the same parameter increased 5.67-fold in the S7 station (Table 3). A positive correlation (r = 0.45) between the pH and dissolved oxygen levels was found from the mean values. However, mean pH values were negatively correlated (r = –0.33) with the mean flow rate levels. Another negative correlation (r = –0.60) between mean conductivity and dissolved oxygen values was found (Table 4).

Table 4. Pearson correlation coefficient (r) values between the mean values of the parameters investigated

Parameters	IBMR	Sp	pH	Fr	Co	Do
IBMR		0.11	0.17	–0.24	–0.22	0.25
Sp			–0.18	–0.23	–0.29	0.12
pH				–0.33*	–0.24	0.45**
Fr					0.29	–0.14
Co						–0.60**
DO						

The asterisks indicate the significant correlations at the 0.05* and 0.01** levels.

Discussion

The data collected in the present study were used to evaluate the trophy levels and some physicochemical parameters of watercourses throughout the Sakarya River Basin of Turkey. In previous reports, trophy statues and qualities of some standing water bodies have been evaluated in the Sakarya River Basin (Burnak and Beklioğlu, 2000; Karakoç et al., 2003; Muhammetoglu et al., 2005; Akin et al., 2011; Akkoyunlu and Ekiner, 2012). However, most of these studies evaluated chemical data and did not implement a model based on macrophytes. The IBMR is based on three metrics: field cover percentage, the species trophic score, and a coefficient of ecological amplitude that measures the variety of habitats in which a species can survive (Wiederkehr et al., 2015). Thus, IBMR is solely based on the abundance and diversity of macrophyte species, and it is considered as an useful index to evaluate the ecological status of running water affected by nutrient input or organic pollutants (Haury et al., 2006). Nevertheless, IBMR data should be supported with analyses of hydro-chemical data obtained from environmental monitoring (Marzin et al., 2012). Some macrophyte species such as *Typha latifolia* and *Phragmites australis* have been reported as indicators of water quality and contamination (Bonnano and Giudice, 2010; Klink et al., 2013). On the other hand, IBMR presents not a single-species-based evaluation of the ecological quality assessment method, but represents a holistic approach to the environment assessed by covering all the water-related macro plant species.

The primary factor that causes water eutrophication is considered to be excessive phosphorus (P) and nitrogen (N) input into the water system, since these elements regulate primary production (Yang et al., 2008). However, Dauvin et al. (2007) stated that it might be more connected to P and N's imbalanced loading into the water concerning silicon dioxide (SiO_2). A drop in dissolved silica availability reduces the development of diatoms, whereas in this case, non-siliceous organisms increase, likely leading to unwanted eutrophication (Amann, 2014). An eutrophicated water system shows symptoms such as algal blooms, oxygen deficiency, and increased sedimentation (Rydin et al., 2017). Algal blooms are seen more commonly in lakes, ponds, or sea since they have low turbidity and flow, presenting a favorable condition for algal growth. Although no algal blooms were observed in the sampling stations during the present study, the sampled stations with IBMR values of less than 8 are hypertrophic. However, seasonal changes in the macrophyte abundance and composition should be taken into account when deciding the station's final trophy level. Therefore, the stations having IBMR values less than 8 in both sampling seasons (S18, S35, and S36) of our study were considered hypertrophic. On the other hand, considering the mean IBMR values of its running waters (9.937 in the fall and 9.302 in the spring seasons, n = 37), the general trophy level of the Sakarya River Basin should be evaluated as eutrophic. In a study conducted for the evolution of the aquatic vegetation and ecological status of the Semois-Chiers Basin in Belgium, the researchers reported that physicochemical properties and anthropogenic pressure play a significant role in macrophyte distribution among the stations, especially of resistant species, thereby leading to the variations in the IBMR values (Khadija et al., 2015). In this context, it should be noted that a high IBMR value is not thoroughly associated with a high number of species sampled, but it is related to the CSi scores of these species. In our study, the Pearson correlation between IBMR values and species number were insignificant ($P > 0.05$, $n = 37$) for both seasons. The low IBMR values in the presence of a high number of species can be explained by macrophyte species' associations with low CSi scores, since a low CSi score indicates heavy organic pollution and heterotrophic species. In contrast, high CSi values indicate oligotrophic species susceptible to the factors mentioned above (Haury et al., 2006).

The lack of dissolved oxygen in the water, which is an unfavorable condition for aquatic fauna elements, can be one of the consequences of eutrophication (Coffin et al., 2018). In the present study, the dissolved oxygen concentrations were below hypoxia level (< 3 mg L^{-1}) in the stations S7, S8, S14, S15, S17, and S22 at least in one season. Also, the eutrophic and/or hypertrophic conditions were accompanied by hypoxia in all these stations except S8. The stations S7 (Gökçekaya Stream, Nallıhan-Ankara), S14 (Pürlek Creek, Sivrihisar-Eskişehir), and S15 (Ankara Stream, Polatlı-Ankara) are located close to agricultural areas. Also, the station S8 (Karadere Creek, Yenişehir District, Bursa) is located close to a populated city center, and the stations S17 (Ankara Stream, Sincan-Ankara) and S22 (Porsuk Stream, City Center-Kütahya) are located near industrial areas. According to the field observations, the waters in these stations were not clear, which might indicate possible contamination. However, this observation should be validated through analytical experiments. Although some plant species can adapt to oxygen deprivation through various mechanisms such as metabolic rate decrement and removal of toxic anaerobic products, to be exposed to hypoxic conditions for a long time could bring irreversible breakdowns in biodiversity (Chirkova and Yemelyanov, 2018). Therefore, suitable wastewater treatment should be considered around these localities if water contamination is found in future studies. The remarkable seasonal variation between dissolved oxygen concentrations measured, e.g., in S7 (1.62 and 9.18 mg L^{-1} in fall and spring, respectively), and S14 (10.34 and 1.7 mg L^{-1} in fall and spring, respectively) could be attributed to changes in weather conditions (e.g., winds and rainfall). Besides dissolved oxygen, water pH and conductivity may play a key role in eutrophication. The pH of river water can be affected by the ground's mineralogical content consisting of different substratum types (Mihu-Pintilie et al., 2014). However, a more significant contribution to pH change might originate from the effluents of various sources (Morrison et al., 2001). A change in pH can influence floral composition (Palagushkina et al., 2019), ionization of electrolytes, dissolved silica uptake by diatoms, and higher plants; accordingly it can influence the trophic status of the ecosystem by promoting undesirable organisms' proliferation (Yang et al., 2008; Amann et al., 2014). Furthermore, a change in the pH would directly affect the macrophyte abundance and composition in the rivers (Reitsema et al., 2018). The conductivity of water can be affected by temperature, pollution, and organic materials. Therefore, increased conductivity in the sampling stations might signal the external input of organic nutrients to the river. In a study conducted at the Ceyhan River Basin located in Turkey's southern Anatolia, 33 macrophyte taxa were observed, and the researchers evaluated the ecological status of the Ceyhan River Basin from moderate to bad, which shows similarities to the Sakarya River Basin's status (Özbay et al., 2019). In a study conducted on the lakes of Balkan countries such as Albania, North Macedonia, Montenegro, and Serbia, where the researchers analyzed submerged aquatic vegetation, water chemistry, and sediment total phosphorus content, it was found that macrophyte indices such as the BMI (Balkan Macrophyte Index) may not be valid in lakes with annual variations in water levels, because macrophyte vegetation in such lakes may be absent or dominated by oligotrophic or eutrophic plants (Schneider et al., 2020). Other research performed on bryophyte and macrophyte species of Bulgarian rivers found that bryophyte populations were affected mostly by the velocity of water flow, while shading was the most significant factor determining the vascular plant composition at the sampling sites. The researchers reported that an increase in the number of sampled macrophytes occurs with decreasing shading gradient; therefore, riverside vegetation along lowland rivers can prevent macrophyte growth (Gecheva et al., 2013). Therefore, countries should consider building their macrophyte indexes optimized according to their rivers' and lakes' physicochemical and biotic status to ensure reliable ecological monitoring and assessment.

Conclusions

Numerous environmental factors affect the Sakarya River's water quality, since it is one of the largest basins in Turkey. Therefore, practical tools and a holistic approach, including physicochemical parameters and several ecological quality metrics applied to other living components of the freshwaters, should be employed to screen the Sakarya River Basin's environmental quality. Therefore, to enable a complete screening of ecological quality, phytobenthos and water-related fauna should be taken into consideration and simultaneously evaluated with macrophytes and physicochemical data. The domestic, industrial, and agricultural discharge points on the basin should be strictly controlled. The present study results would be useful for applying conservation measures on the basin and fulfilling the regulation of the Water Framework Directive (WFD).

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