Environmental Science and Pollution Research (2023) 30:36143–36159
https://doi.org/10.1007/s11356-022-24747-2

RESEARCH ARTICLE

Eco-assessment of streams of Konya closed river basin (Turkey) using various ecoregional diatom indices

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Received: 21 October 2021 / Accepted: 9 December 2022 / Published online: 21 December 2022

Abstract

Ecological assessment of freshwater ecosystems based on diatom metrics is an important issue for attaining environmental sustainability. The present study aimed to evaluate differences in the diatom–stressor relationship in relatively least disturbed streams in the Konya closed river basin using multivariate analyses and to bio-assess streams by the application of different ecoregional diatom indices. *Cocconeis euglypta*, *Cymbella excisa*, *Cocconeis placentula*, and *Achnanthidium minutissimum* are the most contributing species to the dissimilarity of sampling stations between rainy (spring) and dry (summer and fall) seasons and also between altitude (A2 800- < 1600 m and A3 ≥ 1600 m) groups. The first two axes of canonical correspondence analysis revealed a significant (82.8%) relationship between diatom species and stressors. Diatom species displayed distinct responses to environmental variables (electrical conductivity, Ni, Cu, B, and altitude) playing important roles on the distribution of species. Diatom indices indicate different ecological statuses of stations, from bad to high. European diatom indices except Duero Diatom Index (DDI) and Trophic Diatom Index (TDI) showed good responses to the eco-assessment of streams and indicated high ecological status for the least disturbed sampling stations symbolized as S16, S20, S24, S25, S27-29, S37, and S39. These results were also supported by abiotic evaluation. Although TIT was more competitive in the bio-assessment of streams among diatom indices, it is necessary to increase its species list by determining their trophic weights in future studies. Therefore, the use of ecoregion-specific diatom indices is suggested along with increasing the number of used species to correctly interpret the water quality.

Keywords Bio-assessment · Ecological status · Freshwater · Trophic index Turkey · Stream systems

Introduction

Freshwater resources are mostly impacted by human activities and climate change, but there is not enough information about the multi-pressure environmental impacts on aquatic communities. Therefore, ecological monitoring and bio-assessment are needed to see the effects of the above-mentioned factors on the status of surface waters (Charles et al. 2021; Çelekli et al. 2021a). For this aim, the ecological assessment should be integrated with the biological quality tools such as phytobenthos (particularly diatoms), benthic macroinvertebrates, fishes, macrophytes, and phytoplankton into routine freshwater biomonitoring with respect to the European Union Water Framework Directive (WDF) (Directive 2000).

Ecological assessments of freshwater ecosystems based on bioindicator metrics are one of the crucial issues to attain environmental sustainability worldwide. Among them, diatoms are robust bioindicators of spatiotemporal changes in

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environmental conditions at any time of the year (e.g., Rott et al. 1999; Lobo et al. 2015; Delgado and Pardo 2015) and also, they are important primary producers in the energy and nutrient cycling of the biosphere (Smol and Stoermer 2010). Diatoms are valuable indicators of environmental conditions in lotic ecosystems because they quickly respond to spatial and temporal changes in environmental conditions in ecosystems, including nutrient concentrations, temperature, electrical conductivity, and pH (Charles et al. 2021; Çelekli et al. 2021b). Besides, ecology and taxonomy of diatom communities are reasonably well understood, and each diatom species provides important information about the environment where they live (Rott et al. 1999; Kelly et al. 2008; Çelekli et al. 2019).

Diatom species have strong relationships with nutrients especially total phosphate (TP), soluble reactive phosphorus, electrical conductivity, salinity, etc., which are quantifiable in the different trophic gradients from reference sites to highly disturbed areas to develop diatom indices (Charles et al. 2021; Çelekli et al. 2021a). Trophic Index-TI in Austria (Rott et al. 1999), Specific Pollution-Sensitive Index-IPS in France (Cemagref 1982), Trophic Diatom Index-TDI in the United Kingdom (Kelly et al. 2008), Eutrophication and/or Pollution Index Diatom-EPI-D in Italy (Dell'Uomo 2004), Duero Diatom Index-DDI in Spain (Álvarez-Blanco et al. 2013), and Trophic Index Turkey-TIT in Anatolia (Çelekli et al. 2019) in Europe; Trophic Water Quality Index-TWQI in Brazil (Lobo et al. 2015), Diatom Ecological Quality Index-DEQI in Mexico (Salinas-Camarillo et al. 2021) in South America; and Diatom Species Index Australian Rivers-DSIAR (Chessman et al. 2007) and Richmond River Diatom Index-RRDI (Oeding and Taffs 2017) in Australia are some of the indices developed in different ecoregions to evaluate the ecological status of water resources.

The least disturbed environmental conditions (i.e., minimal or no human impacts) of riverine ecosystems are necessary to determine the classification systems and the ecological quality class boundaries based on the bio-assessment approach of WFD (Directive 2000) to achieve a "good ecological status." Diatom metrics give strong reflectivity to different environments (physical, chemical, and hydro-morphological) from the least disturbed to the worst conditions (Karr and Chu 1998; Feio et al. 2014).

Ecoregional factors such as climate, geology, land use, and anthropogenic activities have significant effects on the ecological preferences of diatom species (Lobo et al. 2015; Çelekli and Kapı 2019; Salinas-Camarillo et al. 2021). Different stream typologies (e.g., altitude, catchment area, geology, flow regime, precipitation, and hydro-morphological dynamics) can also affect the diatom composition and their abundance (Çelekli et al. 2019; Charles et al. 2021; Salinas-Camarillo et al. 2021). In addition, each diatom species has a fundamental ecological niche with its optima and tolerance for stressors in complex environmental conditions (Hutchinson 1957). The trophic weight values and indicator scores of diatom species may show changes in the realized niches between different ecoregions (Rott et al. 1999; Çelekli and Kapı 2019; Pajunen et al. 2020). This highlights the importance of ecoregion-based indices.

The Konya closed river basin includes streams with different hydro-morphological properties under the pressures of natural and human activities. Until now, no study has been conducted to investigate the bio-assessment of stream conditions in the Konya closed river basin. Therefore, bio-assessments of streams in the Konya closed river basin by a few different ecoregional diatom metrics and by the application of multivariate analyses were done for the first time according to the implementations of the WFD. Accordingly, aims of the present study were to evaluate the differences in the diatom–environment relationship in relatively least disturbed streams using multivariate analyses and to dia-assess the sampling stations with different typologies using various ecoregional diatom indices.

Material and methods

Study area

The Konya closed river basin in central Anatolia covers a total area of 49,786 km^2 with plains and plateaus, surrounded by the Taurus, Geyik, Sultan, and Melendiz mountains (Fig. 1). It is mainly constituted by 9 provinces (Konya, Niğde, Aksaray, Karaman, Ankara, Isparta, Nevşehir, Mersin, and the north part of Antalya). This closed basin consists of various streams in the upper 1100 m asl. with different typologies (Table 1).

The Konya closed river basin consists of 57% agricultural areas (92% grains, 5% fruits, and 3% vegetable farming), 33% semi-natural areas (steppe, anthropogenic steppe, and forest), 7.9% wetlands, and 2.1% artificial areas (CLC 2018). There are a few wetlands having international importance based on the Ramsar Convention (e.g., Meke Maar and Kızören Sinkhole) and environmental protection status areas (e.g., Lake Tuz (Salt) and Ihlara Valley).

The Konya closed river basin is dominated by a central Anatolia continental climate as a semi-arid continental climate, which is characterized by seasonal differences (hot, dry summers and cold, snowy winters). Most of the basin has relatively low annual precipitation (340–380 mm). The Taurus Mountains (up to 3404 m asl.) are in the south of the basin, which have low temperatures, a lot of snow, and heavy rain. On the other hand, the plateau and plain areas are warmer with relatively low rainfall and more evaporation.

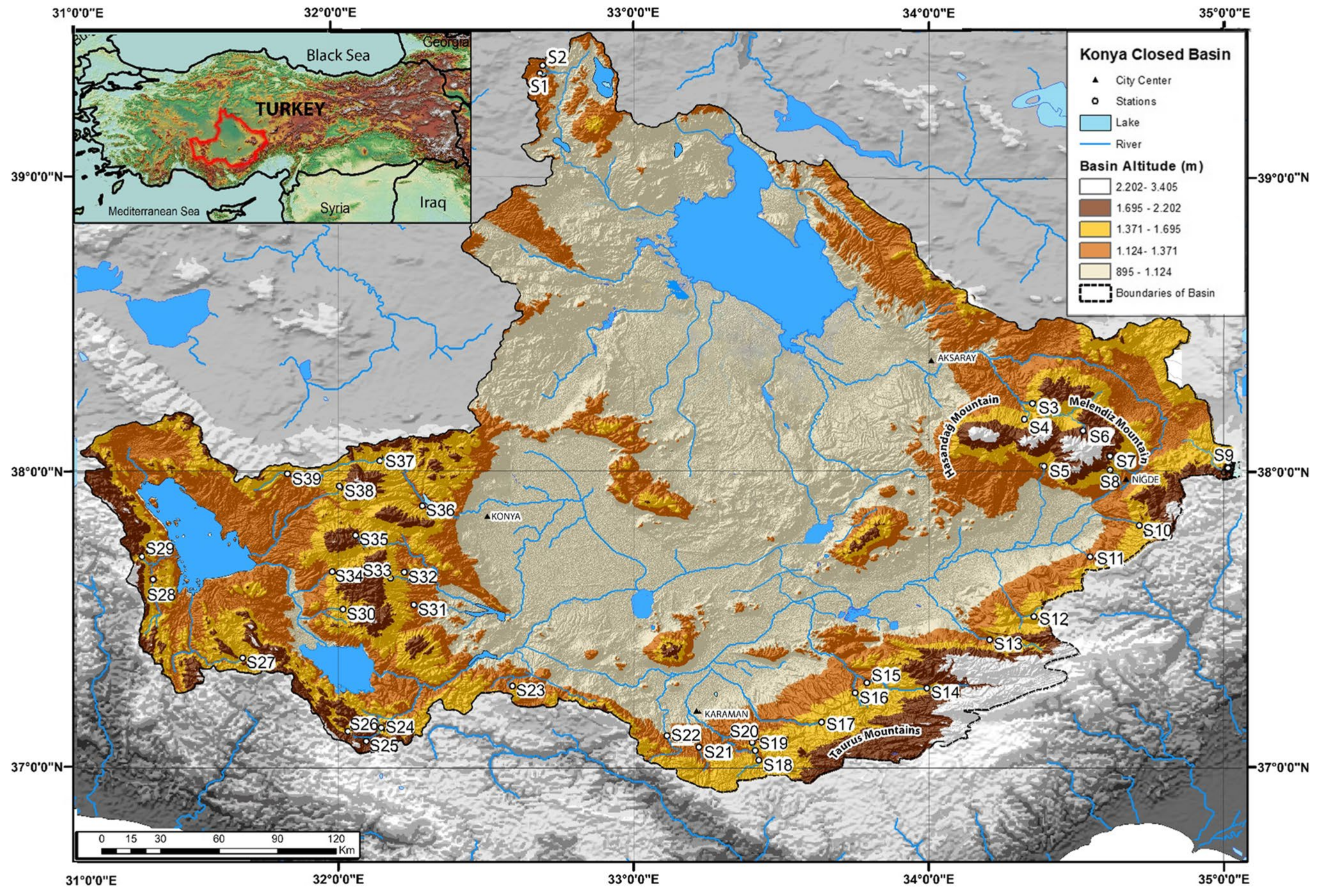

Fig. 1 Location of sampling stations in the Konya closed river basin. Full names of sampling stations symbolized with S1-S39 are given in Table 1

Sampling

In the study, the least disturbed sampling areas with minimal human impacts were selected. Hydro-geographical features of 39 sampling stations symbolized with S1-S39 from 38 streams (Fig. 1) are given in Table 1. A geographical positioning system (GPS, Garmin Vista HCx model) was used to obtain information about the locations of sampling stations. The sampling stations were classified according to typological criteria (altitude with A2 800–< 1600 m and A3 ≥ 1600 m, geology with G1-high and G2-low mineralization, drainage area with D1-wet and D2-dry regions, flow regime with F1-the seasonal and F2-continuous, slope with S1 < 2% and S2 > 2%, and precipitation with P1 < 400 mm and P2 ≥ 400 mm) of the Ministry of Agriculture and Forestry, General Directorate of Water Management of Turkey.

Water and epilithic diatom samples were collected from sampling stations in three seasons (spring, summer, and fall) of 2017 where there are two hydrological periods (rainy (spring) and dry (summer and fall) seasons). Water samples were maintained under cooler conditions until transferred to the laboratory for chemical analyses. Epilithic diatom samples were gathered by brushing the upper surfaces of at least five stones taken from the riffle parts of streams in 100 mL of distilled water, and then, they were fixed with a Lugol–glycerol solution (EC 2014).

Physicochemical analysis

Environmental variables (e.g., water temperature (°C), electrical conductivity (EC µS/cm), pH, dissolved oxygen concentration (DO, mg/L), and salinity (ppt) were measured by an oxygen–temperature meter (YSI professional plus) in situ. Values of chemical variables like TN (total nitrogen), N-NO_3 (nitrate-nitrogen), TP (total phosphorus), and TOC (total organic carbon) and biochemical oxygen demand (BOD_5) of water samples were determined according to standard methods of APHA (2012). The amount of metal ions in water was measured by an inductively coupled plasma–optical emission spectrometer (Perkin Elmer, Optima 2100 DV).

Table 1 Hydro-geographical features of streams

Typology	Code	Stream name	Latitude	Longitude	Altitude (m)
A2G2D2F1S1P1	S1	Gök	39.37644	32.69279	1175
A2G2D2F1S1P1	S2	Anaçay	39.34952	32.68346	1213
A2G2D1F2S1P1	S3	Ilısu	38.22927	34.35836	1337
A2G2D1F2S1P1	S4	Güvercinlik	38.17593	34.33116	1458
A2G2D2F2S1P1	S5	Okçu	38.01621	34.39826	1373
A3G2D1F2S1P1	S6	Yağıl	38.13673	34.53077	1802
A3G2D1F2S1P1	S7	Baldıran	38.05115	34.62203	1761
A2G2D1F2S1P1	S8	Çağlağa	38.00392	34.62231	1466
A2G2D2F2S1P1	S9	Kovalık	38.01048	35.02297	1599
A2G1D2F2S1P1	S10	Halaç	37.81533	34.72165	1392
A2G1D2F2S1P1	S11	Zorlak	37.70904	34.55486	1191
A2G1D2F2S1P1	S12	Göşer	37.50563	34.36353	1444
A2G1D1F2S1P1	S13	İvriz	37.42703	34.2132	1191
A2G1D2F2S2P2	S14	Ulu	37.26263	33.9997	1525
A2G1D2F2S2P2	S15	Geleri	37.28099	33.7959	1268
A2G1D2F2S2P2	S16	Buğdaylı	37.24674	33.75599	1274
A2G1D1F2S1P2	S17	Yeşil	37.14727	33.64177	1389
A2G1D1F2S1P2	S18	Karagöz	37.01851	33.42835	1352
A2G1D2F2S1P2	S19	Güdet	37.05095	33.41611	1256
A2G1D2F2S1P2	S20	Avşar	37.07839	33.40542	1247
A2G1D2F2S1P2	S21	Seydihasan	37.06288	33.22478	1152
A2G1D2F2S1P2	S22	Duma	37.1016	33.11579	1153
A2G2D2F2S1P2	S23	Doğuca	37.26988	32.59029	1285
A2G2D2F2S1P2	S24	Çarşamba	37.12847	32.14433	1374
A3G1D1F1S2P2	S25	Çarşamba	37.08255	32.09332	1743
A3G1D2F2S2P2	S26	Sülek	37.11627	32.03149	1652
A2G2D2F2S1P2	S27	Bendboğazı	37.36513	31.67335	1397
A2G1D1F2S2P2	S28	Kurucaova	37.68709	31.37171	1209
A2G1D1F2S2P2	S29	Huzur	37.70973	31.33069	1427
A2G2D1F1S2P2	S30	Suludere	37.53073	32.01402	1416
A2G2D2F1S1P2	S31	Bıçakçı	37.54622	32.2552	1217
A2G2D2F1S1P2	S32	Asın	37.65688	32.2228	1273
A3G2D2F1S1P2	S33	Genge	37.63576	32.17606	1600
A2G2D1F2S1P2	S34	Uluçay	37.65824	31.97739	1362
A2G2D2F2S1P2	S35	Çamurluiret	37.78198	32.05725	1622
A2G1D1F1S2P2	S36	Ulumuhsine	37.88175	32.28354	1270
A2G1D1F2S1P2	S37	Beylik	38.03499	32.13975	1426
A2G2D2F2S1P2	S38	Üçyatak	37.94936	32.00163	1512
A2G2D2F2S1P2	S39	Osman	37.99102	31.82505	1325

A, altitude (A2 800–$<$1600 m and A3$\geq$1600 m); *F*, flow regime (F1: intermittent and F2: permanent); *S*, slope (S1$<$2% and S2$>$2%); *G*, geology (G1: high and G2: low mineralization); *P*, precipitation (P1$<$400 mm and P2$\geq$400 mm), and *D*, drainage area (D1: wet and D2: dry regions)

Identification and preparing permanent slides of epilithic diatoms

Hot acids (H_2SO_4: HNO_3 as 2: 1) were used to digest diatom samples and to clean the organic materials, and then, diatom samples were washed following the European EN 13,946 (EC 2014). The Naphrax, with a refractive index of at least 1.74, was used to mount diatoms on each slide under a light microscope (Olympus BX53 model with a DP73 attached) at 1000 × magnification and then at least 500 valves of diatom species were counted per slide. Species identification was done according to taxonomic keys provided in Krammer (2000, 2002), Lange-Bertalot (2001), Bey and Ector (2013), and Lange-Bertalot et al. (2017). Besides, the nomenclature was checked using AlgaeBase (Guiry and Guiry 2021) and diatoms of North America (Spaulding et al. 2019). The threat status and ecological attributes of diatom species were assigned by following Hofmann et al (2018).

Dia-assessment of sampling stations

Several diatom indices, such as EPI-D (Dell'Uomo 2004), IPS (Cemagref 1982), TI (Rott et al. 1999), DDI (Álvarez-Blanco et al. 2013), TDI (Kelly et al. 2008), TIT (Çelekli et al. 2019), TWOI (Lobo et al. 2015), DSIAR (Chessman et al. 2007), and DEQI (Salinas-Camarillo et al. 2021) were used to assess the ecological status of sampling stations in the Konya closed river basin. The diatom indices' scores were calculated with an excel program. The TP gradient has positive relationships with the TI, TIT, EPI-D, and TDI diatom indices, but negative with DSIAR, DDI, and EPI-D.

Statistical analyses

Differences in mean environmental data between/among sampling stations were revealed by one-way ANOVA and Duncan's multiple range test (SPSS version 15.0, USA). The Spearman correlation test (SPSS version 15.0, USA) was applied to elucidate diatom metrics–environment correlations. The percentile analysis (SPSS version 15.0, USA) was used to figure out the 25th, 50th, and 75th percentiles of the data. An analysis of similarities (ANOSIM) test was used to evaluate whether there were significant differences between the sample groups from Konya closed river basin stations. An analysis of similarity percentage (SIMPER) test was applied to determine the similarity status of the sampling groups depending on the diatom composition with the contributions of diatom species affecting these dis/similarity situations when the results of ANOSIM were significant. Bray–Curtis (similarity coefficient) was used to test the null hypothesis (there is no difference in the diatom composition of sampling stations among sampling seasons). ANOSIM and SIMPER analyses were performed using Community Analysis Package version 4.1.3 software (Seaby and Henderson 2007).

Detrended correspondence analysis (DCA) test was used to estimate gradient lengths. A gradient length greater than 3.0 was calculated for the first two axes (>6.0) that indicates the suitability of a direct gradient analysis technique. Therefore, a canonical correspondence analysis (CCA) using CANOCO 4.5 software was applied to explain relationships between five transformed environmental variables ($\ln(x+1)$) and 98 diatom species in the Konya closed river basin (ter Braak and Smilauer 2002). Monte Carlo permutation test (CANOCO 4.5 software) was used to reveal which environmental factors significantly affect the distribution of diatom species. Thus, only significant explanatory factors were exhibited in the ordination. The weighted average (WA) regression model of the CALIBRATE program was carried out to predict the optima of diatom species for significant environmental stressors (Juggins and ter Braak 1992). Diatom species (98 taxa) occurred three or more times were used in multivariate statistical analyses (Supplementary 1).

Results

Physical and chemical variables of sampling stations

Physical and chemical variables varied among sampling stations and their results are given in Table 2. Streams in the Konya closed river basin had alkali waters with a pH range of 7.5 at Asın Stream (S32) and 8.8 at Gök Stream (S1). The mean EC values ranged from 64 µS/cm at Baldıran Stream (S7) to 723 µS/cm at Anaçay Stream (S2). Sampling stations S1, S2, S10–12, S15, S22, and S23 had EC values of more than 500 µS/cm.

Relatively low variations were found in the nutrient gradients of sampling stations. The highest mean TP was found in Asın Stream (S32) with 142 µg/L, followed by Uluçay Stream (S34) with 116 µg/L. On the other hand, several streams (e.g., Avşar, Kurucaova, and Baldıran streams) had TP values smaller than 10 µg/L. NO_2-N was not detected in most of the sampling stations (see Table 2). Mean TN in the Konya closed river basin varied between 1.98 mg/L in Seydihasan Stream (S21) and 0.28 mg/L in Çarşamba Stream (S25)

Concerning heavy metal variations, the highest mean nickel (Ni) concentration was determined in Kovalık Stream (S9) with 13.10 µg/L, followed with 11.67 µg/L in Güvercinlik Stream (S4), whereas the lowest mean concentration of Ni (1.6 µg/L) was found in 17 sampling stations (Table 2). Some metals were measured in a few regions, such as relatively high iron (Fe) values were measured in S30–S34 (>231.0 µg/L) at Erenler Mountain, S3 (632.1 µg/L) and S5 (501.7 µg/L) at Melendiz Mountains, and S14 (417.8 µg/L) at Taurus Mountains. The highest mean boron (B) value was found in Ilısu Stream (S3) with 601.7 µg/L, followed by Yağıl Stream (S6) with 309.5 µg/L and Okçu Stream (S5) with 208.9 µg/L. Ilısu Stream also had relatively high concentrations of metals like arsenic (As), boron (B), iron (Fe), Ti, and V (see Table 2).

Diatom composition

A total of 201 diatom taxa were identified in sampling stations in the Konya closed river basin (Supplementary 1). Biological condition gradient (BCG) attributes of species were estimated according to Hausman et al. (2016) and given in Supplementary 1. *Achnanthidium minutissimum*,

Table 2 Mean values of environmental variables of sampling stations in the Konya closed river basin

	Temp °C	pH	EC µS/cm	DO mg/L	Salinity ppt	Alka mg/L	BOD_5 mg/L	TOC mg/L	TN mg/L	NH_4^+ mg/L	NO_2^- mg/L	NO_3^- mg/L	TP µg/L
S01	17.0 ± 2.7	8.8 ± 0.1	640 ± 60	7.69 ± 0.64	0.31 ± 0.04	334 ± 21	4.9 ± 0.3	8.08 ± 1.10	0.95 ± 0.49	0.05 ± 0.01	0.01 ± 0.00	0.54 ± 0.01	13 ± 1
S02	16.4 ± 2.5	8.5 ± 0.1	723 ± 140	6.00 ± 0.72	0.35 ± 0.05	331 ± 18	5.1 ± 0.3	15.54 ± 2.34	1.24 ± 0.74	0.05 ± 0.01	0.01 ± 0.00	0.49 ± 0.01	51 ± 3
S03	17.3 ± 2.8	8.4 ± 0.1	317 ± 96	8.40 ± 0.67	0.16 ± 0.03	129 ± 67	1.9 ± 0.1	2.18 ± 1.11	1.37 ± 0.97	0.08 ± 0.03	0.02 ± 0.02	0.48 ± 0.54	51 ± 48
S04	18.9 ± 3.0	8.6 ± 0.1	81 ± 30	7.58 ± 0.55	0.04 ± 0.00	36 ± 9	1.9 ± 0.1	0.90 ± 0.34	1.03 ± 0.80	0.05 ± 0.01	nd	0.09 ± 0.00	35 ± 5
S05	19.5 ± 2.7	8.0 ± 0.3	191 ± 133	7.09 ± 0.67	0.08 ± 0.03	73 ± 33	1.9 ± 0.1	5.47 ± 3.97	0.59 ± 0.44	0.05 ± 0.01	nd	0.09 ± 0.02	18 ± 5
S06	21.5 ± 6.0	8.2 ± 0.6	78 ± 23	8.66 ± 0.53	0.03 ± 0.04	188 ± 43	1.9 ± 0.0	0.90 ± 0.52	0.83 ± 0.09	0.05 ± 0.01	nd	0.09 ± 0.00	10 ± 7
S07	19.4 ± 6.5	7.8 ± 1.3	64 ± 29	6.28 ± 0.25	0.03 ± 0.01	49 ± 7	1.9 ± 0.1	0.90 ± 0.41	0.50 ± 0.21	0.05 ± 0.00	nd	0.10 ± 0.01	7 ± 3
S08	13.3 ± 4.6	8.1 ± 0.1	185 ± 70	7.53 ± 0.68	0.10 ± 0.01	97 ± 23	1.9 ± 0.1	2.90 ± 0.78	1.05 ± 0.60	0.05 ± 0.01	nd	0.17 ± 0.00	43 ± 4
S09	13.4 ± 4.3	8.0 ± 0.1	255 ± 88	6.96 ± 0.74	0.12 ± 0.01	119 ± 24	1.9 ± 0.0	1.40 ± 0.63	0.74 ± 0.30	0.05 ± 0.00	nd	0.21 ± 0.01	15 ± 2
S10	10.0 ± 3.6	8.2 ± 0.1	513 ± 96	9.14 ± 0.58	0.26 ± 0.03	235 ± 32	2.1 ± 0.1	4.11 ± 1.04	0.94 ± 0.30	0.05 ± 0.01	nd	0.09 ± 0.00	10 ± 1
S11	12.2 ± 4.2	8.1 ± 0.1	707 ± 145	8.08 ± 0.77	0.35 ± 0.05	270 ± 24	1.9 ± 0.0	0.90 ± 0.32	0.96 ± 0.24	0.05 ± 0.00	nd	0.39 ± 0.01	15 ± 2
S12	13.9 ± 4.4	8.2 ± 0.1	545 ± 146	7.69 ± 0.80	0.27 ± 0.04	250 ± 23	1.9 ± 0.1	0.90 ± 0.36	0.85 ± 0.23	0.05 ± 0.01	nd	0.09 ± 0.00	5 ± 0
S13	15.5 ± 4.8	8.5 ± 0.2	386 ± 139	8.50 ± 0.74	0.18 ± 0.03	242 ± 75	2.3 ± 0.5	5.51 ± 4.00	1.16 ± 0.71	0.5 ± 0.40	0.01 ± 0.01	0.34 ± 0.44	18 ± 5
S14	15.3 ± 4.7	8.7 ± 0.1	332 ± 98	8.02 ± 0.82	0.16 ± 0.02	149 ± 11	1.9 ± 0.0	3.51 ± 1.00	1.47 ± 0.62	0.84 ± 0.01	0.02 ± 0.00	0.16 ± 0.01	68 ± 6
S15	14.3 ± 4.3	8.5 ± 0.1	546 ± 121	8.58 ± 0.98	0.26 ± 0.03	175 ± 14	3.1 ± 0.2	12.68 ± 3.10	1.07 ± 0.70	0.10 ± 0.00	nd	0.09 ± 0.00	14 ± 2
S16	18.5 ± 6.5	8.4 ± 0.3	368 ± 26	8.20 ± 0.74	0.17 ± 0.03	165 ± 17	1.9 ± 0.1	0.90 ± 0.30	0.95 ± 0.07	0.05 ± 0.00	nd	0.13 ± 0.04	11 ± 7
S17	16.7 ± 3.4	8.5 ± 0.3	364 ± 55	8.81 ± 0.37	0.15 ± 0.02	168 ± 8	1.9 ± 0.0	0.90 ± 0.33	1.02 ± 0.32	0.05 ± 0.01	nd	0.43 ± 0.13	11 ± 4
S18	16.2 ± 4.4	7.8 ± 0.6	328 ± 35	8.12 ± 0.66	0.15 ± 0.01	152 ± 15	1.9 ± 0.1	0.90 ± 0.310	1.11 ± 0.87	0.05 ± 0.00	nd	0.51 ± 0.42	9 ± 1
S19	15.0 ± 2.5	8.2 ± 0.3	407 ± 39	8.19 ± 0.63	0.18 ± 0.02	183 ± 11	2.6 ± 1.3	5.35 ± 7.71	1.22 ± 0.65	1.5 ± 2.50	nd	0.61 ± 0.45	20 ± 9
S20	16.0 ± 2.8	8.4 ± 0.2	341 ± 45	8.55 ± 0.57	0.16 ± 0.01	176 ± 15	1.9 ± 0.0	0.90 ± 0.28	0.94 ± 0.32	0.5 ± 0.00	0.01 ± 0.00	0.44 ± 0.02	5 ± 0
S21	22.1 ± 3.0	8.5 ± 0.3	475 ± 57	7.96 ± 0.86	0.23 ± 0.03	191 ± 16	1.9 ± 0.1	0.90 ± 0.31	1.98 ± 0.38	1.2 ± 0.01	nd	0.59 ± 0.03	48 ± 7
S22	16.8 ± 2.8	8.1 ± 0.1	577 ± 89	7.41 ± 0.74	0.28 ± 0.03	289 ± 20	3.6 ± 0.2	12.13 ± 3.14	1.18 ± 0.46	0.05 ± 0.01	nd	0.48 ± 0.04	15 ± 2
S23	16.9 ± 3.0	8.3 ± 0.2	530 ± 102	8.00 ± 0.68	0.26 ± 0.02	310 ± 21	1.9 ± 0.0	16.59 ± 4.2	0.62 ± 0.21	0.05 ± 0.00	nd	0.09 ± 0.00	18 ± 2
S24	17.0 ± 2.1	8.3 ± 0.1	288 ± 168	8.89 ± 0.25	0.14 ± 0.08	145 ± 19	1.9 ± 0.1	0.90 ± 0.30	0.39 ± 0.42	0.05 ± 0.00	nd	0.13 ± 0.07	7 ± 4
S25	18.8 ± 6.7	8.1 ± 0.1	272 ± 183	8.64 ± 1.36	0.14 ± 0.09	150 ± 16	7.5 ± 7.1	22.60 ± 13.19	0.28 ± 0.26	0.05 ± 0.01	nd	0.09 ± 0.01	5 ± 0
S26	18.9 ± 12.0	8.2 ± 0.7	177 ± 25	7.89 ± 0.91	0.09 ± 0.01	130 ± 60	1.9 ± 0.0	0.90 ± 0.27	0.47 ± 0.53	0.05 ± 0.00	nd	0.09 ± 0.01	24 ± 13
S27	12.5 ± 3.6	8.7 ± 0.3	227 ± 68	8.76 ± 0.82	0.11 ± 0.02	113 ± 10	2.1 ± 0.1	8.21 ± 2.20	0.56 ± 0.21	0.05 ± 0.00	nd	0.09 ± 0.01	5 ± 0
S28	14.3 ± 4.0	8.6 ± 0.3	178 ± 34	8.93 ± 0.76	0.08 ± 0.01	102 ± 13	4.9 ± 0.2	8.35 ± 1.80	0.90 ± 0.26	0.05 ± 0.01	nd	0.09 ± 0.01	5 ± 0
S29	10.9 ± 2.7	8.2 ± 0.5	188 ± 72	8.89 ± 0.56	0.09 ± 0.03	113 ± 7	5.2 ± 5.8	1.83 ± 1.62	0.74 ± 0.27	0.05 ± 0.01	nd	0.09 ± 0.01	10 ± 3
S30	22.8 ± 3.6	8.4 ± 0.2	360 ± 87	6.70 ± 0.58	0.17 ± 0.02	85 ± 8	1.9 ± 0.0	5.49 ± 2.10	1.64 ± 0.42	0.70 ± 0.01	0.05 ± 0.01	0.53 ± 0.04	21 ± 3
S31	16.3 ± 3.8	8.3 ± 0.3	176 ± 50	8.01 ± 0.50	0.08 ± 0.02	96 ± 37	3.9 ± 2.9	11.53 ± 10.89	0.94 ± 0.17	0.05 ± 0.01	nd	0.13 ± 0.06	51 ± 14
S32	14.4 ± 3.4	7.5 ± 0.1	426 ± 78	8.87 ± 0.80	0.11 ± 0.02	312 ± 12	7.2 ± 0.0	25.48 ± 9.30	1.50 ± 0.52	1.0 ± 0.01	nd	0.21 ± 0.02	142 ± 16
S33	14.8 ± 3.6	8.2 ± 0.2	98.9 ± 20	8.30 ± 0.68	0.05 ± 0.01	55 ± 9	1.9 ± 0.0	0.90 ± 0.30	0.58 ± 0.18	0.05 ± 0.00	nd	0.09 ± 0.01	18 ± 2
S34	17.3 ± 3.0	8.7 ± 0.3	243 ± 58	9.01 ± 0.65	0.12 ± 0.02	113 ± 13	1.9 ± 0.0	9.64 ± 3.20	0.84 ± 0.26	0.05 ± 0.01	0.01 ± 0.00	0.23 ± 0.03	116 ± 17
S35	16.2 ± 2.7	8.1 ± 0.4	218 ± 49	7.53 ± 0.33	0.10 ± 0.02	102 ± 29	1.9 ± 0.0	5.40 ± 3.90	0.61 ± 0.40	0.05 ± 0.00	nd	0.09 ± 0.01	51 ± 40
S36	12.8 ± 2.6	8.0 ± 0.1	475 ± 82	8.33 ± 0.50	0.23 ± 0.03	254 ± 18	8.5 ± 0.0	12.75 ± 4.00	1.00 ± 0.57	0.05 ± 0.00	nd	0.09 ± 0.01	25 ± 3
S37	11.6 ± 2.7	8.4 ± 0.2	322 ± 46	9.06 ± 0.70	0.15 ± 0.01	164 ± 12	4.5 ± 0.0	8.22 ± 3.10	0.56 ± 0.12	0.05 ± 0.01	nd	0.09 ± 0.01	5 ± 0

Table 2 (continued)

S38	12.5 ± 2.6	8.4 ± 0.1	411 ± 62	8.49 ± 0.62	0.20 ± 0.02	223 ± 15	1.9 ± 0.0	7.27 ± 2.08	0.54 ± 0.14	0.05 ± 0.00	nd	0.09 ± 0.00	5 ± 1
S39	13.0 ± 3.0	8.4 ± 0.2	374 ± 74	8.60 ± 0.56	0.18 ± 0.01	192 ± 12	1.9 ± 0.0	7.36 ± 2.08	1.21 ± 0.34	0.05 ± 0.01	0.01 ± 0.00	0.41 ± 0.04	5 ± 0
	Al	As	Cu	B	Zn	Fe	Co	Ti	V	Sn	Ni		
	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L		
S01	0.10 ± 0.00	0.46 ± 0.02	1.94 ± 1.05	27.3 ± 0.2	8.88 ± 0.30	132.5 ± 10.2	0.10 ± 0.00	0.45 ± 0.06	1.12 ± 0.20	0.45 ± 0.06	7.81 ± 2.28		
S02	0.35 ± 0.04	0.81 ± 0.02	1.47 ± 0.80	92.4 ± 0.7	0.89 ± 0.27	448.4 ± 18.4	0.62 ± 0.11	11.39 ± 2.12	4.02 ± 0.68	0.45 ± 0.08	11.03 ± 3.32		
S03	1.16 ± 1.62	9.24 ± 3.34	1.71 ± 1.31	601.7 ± 658	29.54 ± 46.75	632.1 ± 696.8	0.57 ± 0.95	8.18 ± 10.17	10.75 ± 4.43	12.33 ± 11.58	1.60 ± 0.40		
S04	0.21 ± 0.03	0.46 ± 0.03	1.68 ± 0.94	9.5 ± 0.1	7.43 ± 1.04	122.7 ± 11.0	0.03 ± 0.00	7.89 ± 2.13	1.92 ± 0.52	0.45 ± 0.07	11.67 ± 2.76		
S05	0.07 ± 0.01	1.19 ± 0.65	1.57 ± 1.06	208.9 ± 263	3.95 ± 5.30	501.7 ± 424.5	0.08 ± 0.1	2.57 ± 3.66	1.95 ± 1.08	35.79 ± 39.30	4.81 ± 5.56		
S06	0.04 ± 0.01	0.70 ± 0.05	0.96 ± 0.20	309.5 ± 259	7.25 ± 8.99	22.7 ± 0.9	0.20 ± 0.01	4.29 ± 5.43	9.13 ± 10.54	47.75 ± 17.04	1.60 ± 0.56		
S07	nd	0.45 ± 0.02	0.96 ± 0.10	170.5 ± 61	4.48 ± 5.08	215.2 ± 210.4	0.03 ± 0.00	0.45 ± 0.08	1.92 ± 1.09	58.33 ± 31.58	1.60 ± 0.50		
S08	0.17 ± 0.01	0.64 ± 0.03	1.40 ± 0.62	9.5 ± 0.8	18.29 ± 5.08	107.2 ± 14.0	0.12 ± 0.01	3.37 ± 1.05	3.38 ± 1.00	0.45 ± 0.06	11.00 ± 2.80		
S09	0.10 ± 0.00	2.51 ± 0.44	2.55 ± 1.04	42.1 ± 2.3	15.99 ± 2.07	372.0 ± 23.0	0.29 ± 0.01	0.74 ± 0.10	0.64 ± 0.16	0.45 ± 0.10	13.10 ± 3.10		
S10	0.06 ± 0.00	2.67 ± 0.62	0.96 ± 0.10	9.5 ± 0.3	0.89 ± 0.08	41.3 ± 2.0	0.03 ± 0.00	0.45 ± 0.02	1.09 ± 0.78	0.45 ± 0.00	5.92 ± 1.12		
S11	0.05 ± 0.00	0.46 ± 0.02	1.25 ± 0.58	64.4 ± 1.6	0.89 ± 0.06	48.5 ± 4.0	0.03 ± 0.00	0.45 ± 0.03	2.11 ± 1.10	0.45 ± 0.08	4.21 ± 1.19		
S12	0.01 ± 0.00	0.46 ± 0.03	3.19 ± 1.32	9.5 ± 0.4	5.82 ± 1.50	33.2 ± 2.0	0.03 ± 0.01	0.45 ± 0.02	5.84 ± 1.87	0.45 ± 0.06	4.53 ± 1.20		
S13	0.06 ± 0.11	0.45 ± 0.01	2.85 ± 3.28	77.1 ± 60	11.33 ± 14.08	187.0 ± 108.6	0.18 ± 0.27	0.67 ± 0.38	1.57 ± 1.29	12.07 ± 20.12	5.29 ± 6.40		
S14	0.40 ± 0.05	1.98 ± 0.56	5.59 ± 3.24	9.5 ± 0.1	22.53 ± 3.06	417.8 ± 23.0	1.58 ± 0.45	1.32 ± 0.40	2.06 ± 1.17	0.45 ± 0.04	9.15 ± 2.72		
S15	0.08 ± 0.00	0.66 ± 0.03	3.64 ± 1.10	9.5 ± 0.1	5.38 ± 1.34	104.0 ± 16.0	0.11 ± 0.00	4.77 ± 1.28	3.63 ± 1.30	0.45 ± 0.07	7.00 ± 2.10		
S16	0.12 ± 0.01	0.72 ± 0.24	2.04 ± 1.88	64.1 ± 49	2.91 ± 3.50	73.4 ± 65.4	0.18 ± 0.16	1.65 ± 2.08	1.86 ± 1.30	11 ± 18.27	3.35 ± 3.04		
S17	0.11 ± 0.10	0.61 ± 0.15	0.96 ± 0.20	79.1 ± 60	0.89 ± 0.20	90.8 ± 66.0	0.06 ± 0.07	0.45 ± 0.02	1.22 ± 1.12	11.97 ± 19.95	2.74 ± 1.98		
S18	nd	0.45 ± 0.01	0.96 ± 0.08	139.9 ± 150	0.89 ± 0.10	4.5 ± 2.0	0.03 ± 0.00	0.45 ± 0.04	1.82 ± 0.44	37.85 ± 37.88	3.19 ± 2.75		
S19	nd	0.53 ± 0.13	0.96 ± 0.11	51.2 ± 47	0.89 ± 0.26	6.4 ± 3.3	0.03 ± 0.00	0.45 ± 0.00	1.37 ± 0.49	10.4 ± 17.23	2.86 ± 2.19		
S20	0.01 ± 0.00	0.70 ± 0.00	0.96 ± 0.00	9.5 ± 0.2	0.89 ± 0.08	13.4 ± 1.0	0.03 ± 0.00	0.45 ± 0.03	1.0 ± 0.21	0.45 ± 0.06	5.22 ± 2.10		
S21	nd	0.46 ± 0.02	0.96 ± 0.10	9.5 ± 0.0	0.89 ± 0.12	4.5 ± 1.0	0.03 ± 0.00	0.45 ± 0.02	0.62 ± 0.18	0.45 ± 0.08	7.00 ± 2.42		
S22	0.15 ± 0.02	0.46 ± 0.01	0.96 ± 0.10	9.5 ± 0.1	0.89 ± 0.19	74.7 ± 7.0	0.03 ± 0.00	8.82 ± 1.24	1.70 ± 0.46	0.45 ± 0.08	6.02 ± 1.70		
S23	0.10 ± 0.00	0.51 ± 0.04	4.36 ± 1.18	93.5 ± 4.2	16.25 ± 3.07	73.7 ± 6.0	0.17 ± 0.02	1.77 ± 0.34	1.49 ± 0.20	0.45 ± 0.07	2.80 ± 1.00		
S24	0.07 ± 0.01	0.45 ± 0.01	3.12 ± 3.74	21.2 ± 13.0	8.44 ± 12.22	56.7 ± 38.6	0.07 ± 0.07	1.65 ± 2.09	0.45 ± 0.08	0.45 ± 0.05	1.60 ± 0.70		
S25	0.14 ± 0.13	0.45 ± 0.01	0.96 ± 0.08	31.7 ± 31.2	6.28 ± 5.27	148.9 ± 123.1	0.03 ± 0.00	2.82 ± 2.35	0.45 ± 0.06	0.45 ± 0.06	1.60 ± 0.56		
S26	0.16 ± 0.11	0.56 ± 0.14	2.76 ± 2.55	24.8 ± 14.0	13.33 ± 13.73	227.3 ± 103.7	0.45 ± 0.46	1.20 ± 0.03	0.96 ± 0.05	0.45 ± 0.04	3.29 ± 2.38		
S27	nd	0.46 ± 0.02	0.96 ± 0.06	9.5 ± 0.2	0.89 ± 0.08	4.5 ± 1.0	0.03 ± 0.00	0.45 ± 0.01	0.45 ± 0.10	0.45 ± 0.08	1.60 ± 0.76		
S28	nd	0.46 ± 0.02	0.96 ± 0.00	9.5 ± 0.4	0.89 ± 0.20	4.5 ± 0.8	0.03 ± 0.01	0.45 ± 0.00	0.45 ± 0.08	0.45 ± 0.06	1.60 ± 0.40		
S29	0.07 ± 0.10	0.56 ± 0.18	0.96 ± 0.10	75.8 ± 114	6.29 ± 9.36	97.3 ± 130.8	0.08 ± 0.09	0.45 ± 0.03	0.45 ± 0.06	0.45 ± 0.08	1.60 ± 0.38		
S30	0.26 ± 0.00	0.59 ± 0.03	6.66 ± 1.18	14.3 ± 1.2	27.91 ± 4.20	362.7 ± 21.0	0.54 ± 0.02	3.52 ± 0.86	3.02 ± 0.88	0.45 ± 0.07	1.60 ± 0.56		
S31	0.12 ± 0.00	1.89 ± 1.09	1.66 ± 1.21	31.7 ± 18.0	17.47 ± 14.81	298.7 ± 81.5	0.11 ± 0.08	3.63 ± 2.53	3.67 ± 1.50	0.45 ± 0.11	1.60 ± 0.80		
S32	0.11 ± 0.00	1.88 ± 0.72	4.43 ± 1.14	39.0 ± 2.3	21.82 ± 4.09	231.2 ± 19.0	0.26 ± 0.01	3.51 ± 1.68	5.0 ± 1.60	0.45 ± 0.08	1.60 ± 0.67		
S33	0.14 ± 0.00	0.46 ± 0.03	19.28 ± 2.10	34.07 ± 4.6	26.97 ± 5.10	250.6 ± 24.0	0.28 ± 0.01	5.74 ± 2.33	1.56 ± 0.00	0.45 ± 0.06	2.13 ± 1.10		

Table 2 (continued)

S34	0.18 ± 0.01	1.45 ± 0.62	3.91 ± 1.16	17.5 ± 1.2	17.31 ± 2.40	279.0 ± 27.0	0.24 ± 0.02	4.21 ± 1.29	4.65 ± 0.00	0.45 ± 0.07	1.60 ± 0.60
S35	0.15 ± 0.01	2.80 ± 2.92	2.87 ± 3.32	139.5 ± 141.0	57.15 ± 78.31	207.7 ± 90.8	0.11 ± 0.14	1.86 ± 1.37	3.03 ± 0.62	10.83 ± 17.98	1.60 ± 0.70
S36	nd	0.46 ± 0.01	0.96 ± 0.00	9.5 ± 0.3	0.89 ± 0.10	4.5 ± 2.0	0.03 ± 0.00	0.45 ± 0.02	0.45 ± 0.00	0.45 ± 0.08	1.60 ± 0.64
S37	nd	0.46 ± 0.03	0.96 ± 0.07	9.5 ± 0.1	0.89 ± 0.14	4.5 ± 1.0	0.03 ± 0.00	0.45 ± 0.01	0.45 ± 0.00	0.45 ± 0.06	1.60 ± 0.68
S38	nd	0.46 ± 0.02	0.96 ± 0.08	9.5 ± 0.0	0.89 ± 0.16	4.5 ± 1.0	0.03 ± 0.00	0.45 ± 0.03	0.45 ± 0.00	0.45 ± 0.08	1.60 ± 0.58
S39	nd	0.46 ± 0.00	0.96 ± 0.10	9.5 ± 0.4	0.89 ± 0.09	4.5 ± 2.0	0.03 ± 0.00	0.45 ± 0.00	0.45 ± 0.00	0.45 ± 0.07	1.60 ± 0.64

Temp, temperature; *EC*, electrical conductivity; *DO*, dissolved oxygen; *BOD*$_5$,biological oxygen demand; *TOC*, total organic carbon; *TN*, total nitrogen; *NO*$_2$*-N*, nitrite; *NO*$_3$*-N*, nitrate; *TP*, total phosphorus; *Al*, aluminum; *As*, arsenic; *Cu*, copper; *Co*, cobalt; *B*, boron; *Zn*, zinc; *Fe*, iron; *Ti*, titanium; *V*, vanadium; *Sn*, tin; and *Ni*, nickel. Abbreviations and full names of stations are given in Table 1. nd means not detected

Cocconeis euglypta, *C. placentula*, *Cymbella excisa*, *Fragilaria capucina*, *Encyonopsis minuta*, *Gomphonema parvulum*, *Meridion circulare*, *Navicula tripunctata*, *Reimeria sinuata*, and *Ulnaria ulna* were commonly encountered species during the study. Among the species in the present study, *Achnanthidium subatomus*, *Gomphonema calcifugum*, *G. exilissimum*, *G. lateripunctatum*, *Hannaea arcus*, *Pinnularia microstauron*, and *Stauroneis anceps* are listed in Red-List (RL) threat–category data. *Brachysira exilis*, *Cymbella* (*C. cymbiformis*, *C. excisiformis*, *C. laevis*, and *C. subhelvetica*) are endangered, while *Gomphonema stauroneiforme*, *Navicula dealpina*, *N. leptostriata*, and *Nitzschia gessneri* are on the seriously endangered list. Of the species, *Achnanthidium atomoides*, *Cocconeis pseudolineata, Fragilaria pectinalis*, *Gomphonema cuneolus*, *N. dealpina*, *Pinnularia isselana*, *Planothidium biporomum*, *Psammothidium bioretii*, *Staurosirella ovata*, and *Surirella terricola* were new records for the diatom database of Turkey.

ANOSIM indicated that differences between spring and autumn ($p < 0.01$) and between spring and summer ($p < 0.01$) groups are significant, while the difference ($p = 0.70$) between autumn and summer is not. ANOSIM results showed that diatom composition in sampling stations was different between the rainy (spring) and the dry (summer and fall) seasons. The results of SIMPER revealed a 94.1% dissimilarity between the spring and autumn groups that is provided by *C. excisa* (8.0%), *C. euglypta* (7.9%), *A. minutissimum* (5.5%), *C. placentula* (5.4%), *Achnanthidium pyrenaicum* (4.5%), and *Cocconeis euglyptoides* (3.0%). The spring–summer dissimilarity as 92.2% was contributed by *C. euglypta* (9.8%), *C. excisa* (8.1%), *C. placentula* (5.5%), *Cocconeis lineata* (4.2%), *A. minutissimum* (3.2%), *Nitzschia costei* (3.1%), and *Gomphonema minutum* (3.0%). *Cocconeis euglypta* (12.8%), *C. placentula* (6.6%), *A. pyrenaicum* (5.2%), *C. euglypotides* (4.2%), and *C. lineata* (4.2%) caused an 87.4% difference between autumn and summer seasons.

In the Konya closed river basin, within-group similarity was 14.9%, 14.4%, and 11.0% for the spring, summer, and fall seasons, respectively. *Cymbella excisa* (43.7%), *C. euglypotides* (41.3%), and *C. euglypotides* (39.0%) were the most contributing species for the spring, summer, and fall seasons, respectively.

Concerning altitude (A2 800- < 1600 and A3 ≥ 1600 m), there was a significant difference between the A2 and A3 groups ($p = 0.012$) according to ANOSIM. Results of SIMPER indicated that the dissimilarity between A2 and A3 groups was 90.9%, which was presented by *C. euglypta* (14.6%), *C. excisa* (6.6%), *A. minutissimum* (4.7%) *C. placentula* (4.7%), *C. lineata* (4.0%), *Epithemia sorex* (3.9%), *R. sinuata* (3.4%), *Gomphonema cuneolus* (2.8%), *G. parvulum* (2.5%), *G. minutum* (2.4%), *F. capucina* (2.3%), and *C. euglypotides* (2.2%). *Cocconeis euglypotides* (54.1%), *R. sinuata* (11.7%), and *G. parvulum* (5.1%) were the most

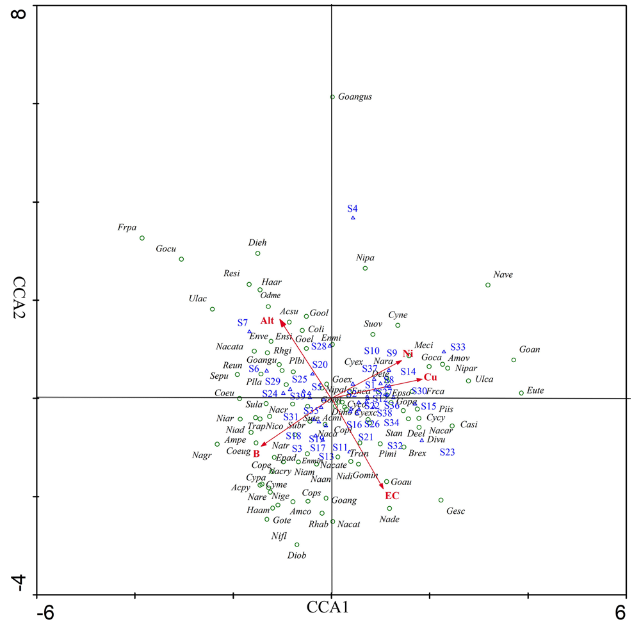

Fig. 2 CCA diagram of species (circle)–environmental (arrow) relationships in the sampling stations (up triangle). Ni nickel, B boron, EC electrical conductivity, Cu copper, and Alt altitude. Full names of S symbols of sampling stations and species codes are given in Table 1 and Supplementary 1, respectively

contributing species to 16.4% within-A2 similarity, while within-A3 similarity as 12.2% was contributed by *C. excisa* (30.9%), *C. placentula* (18,6%), *F. capucina* (7.9%), and *A. minutissimum* (5.7%).

Diatom assemblages–environment relationship

The first two axes of the CCA diagram elucidated 82.8% of the species–environment correlation. Diatom species have distinct responses to environmental variables in the basin system (Fig. 2), and they were significantly affected by EC, Ni, Cu, B, and altitude ($F = 1.802$ and $p = 0.008$). The close relationship between EC and Zorlak (S11), Doğuca (S23), Asın (S32), and Seydihasan (S21) streams was characterized by some diatom species (e.g., *N. dealpina*, *Geissleria schoenfeldii*, *C. cymbiformis*, *Gomphonema augur*, *Gomphonema angustius, Caloneis silicula*, *Diploneis oblongella*, *C. pseudolineata Nitzschia dissipata*, *Navicula cari*, and *Stauroneis anceps*). The relatively high EC preferences of these species were confirmed by the results of WA regression (Fig. 3a). *Navicula veneta*, *Nitzschia palea*, *Cymbella neocistula*, *Gomphonema angustatum*, *Surirella ovalis*, *Nitzschia parvula*, and *Amphora ovalis* are associated with Nickel (Ni) in S1, S8, S9, S14, and S15 (Fig. 2). These species had Ni optima higher than the 75th percentile (Fig. 3b). CCA diagram indicated close relationships of *G. angustatum*, *N. veneta*, *N. parvula*, and *A. ovalis* with copper (Cu), which are associated with Genge (S33), Ulu (S14), and Geleri (S15) streams. This assignment was also confirmed by WA (Fig. 3c). Close integration between Ilısu (S3) and boron (B) was found in the CCA ordination, and it was also characterized by *Nitzschia flexa*, *Navicula gregaria*, *Hantzschia amphioxys*, and *Rhoicosphenia abbreviata*, in agreement with findings of WA (Fig. 3d). Some stations (S24 and S27-S29) were on the other side of the EC variable that are associated with *H. arcus*, *Diatoma ehrenbergii*, *Odontidium mesodon*, *Encyonema minutum*, *Encyonema silesiacum*, and *A. subatomus*.

Bio-assessment of sampling stations

Dia-assessments of sampling stations in the Konya closed river basin are given in Table 3. Ecological conditions ranging from high to bad were found in the Konya closed river basin according to responses of different ecoregional diatom indices. Percentages of the ecological quality status of diatom indices are provided in Fig. 4. The highest percentage of high ecological status (30.8%) was determined by the TIT, followed by EPI-D (23.1%), DEQI (20.1%), and IPS (10.8%) (Fig. 4). DSIAR and DDI could not separate the ecological status of sampling stations.

Diatom indices showed different ecological conditions for sampling stations (Table 3). For instance, S32 had five different environmental conditions, such as a bad status due to TIT and TWQI; a poor condition according to TI; a moderate status after being evaluated by EPI-D, IPS, and TDI; and a good status after being assessed by DEQI. Similarly, four different ecological conditions were found in S33. European indices displayed a good status for S9, whereas it was assigned a bad condition according to DEQI. European diatom indices except DDI mainly displayed similar behavior in eco-assessment of sampling stations in the Konya closed river basin (Table 3 and Fig. 4). European diatom indices indicated that the least disturbed areas are S16, S20, S24, S25, S27–29, S37, and 39 with high ecological status in the Konya closed river basin.

Correlations between diatom indices and environmental variables are represented in Table 4. IPS, DSIAR, and DDI showed inverse correlations with environmental pollution, while others indicated direct correlations. A few diatom indices such as TIT ($p < 0.01$, $r = 0.506$), TI ($p < 0.01$, $r = 0.386$), EPI-D ($p < 0.01$, $r = 0.367$) had significant positive correlations with the TP gradient, whereas IPS ($p < 0.01$, $r = -0.477$) and DDI ($p < 0.05$, $r = -0.304$) displayed significantly negative correlations with TP (see more in Table 4). There was no significant correlation between the diatom indices and EC and BOD5, which are not shown in Table 4. TIT, TI, EPI-D, and TDI had positive correlations with B and V, whereas IPS and DDI were negatively correlated (Table 4).

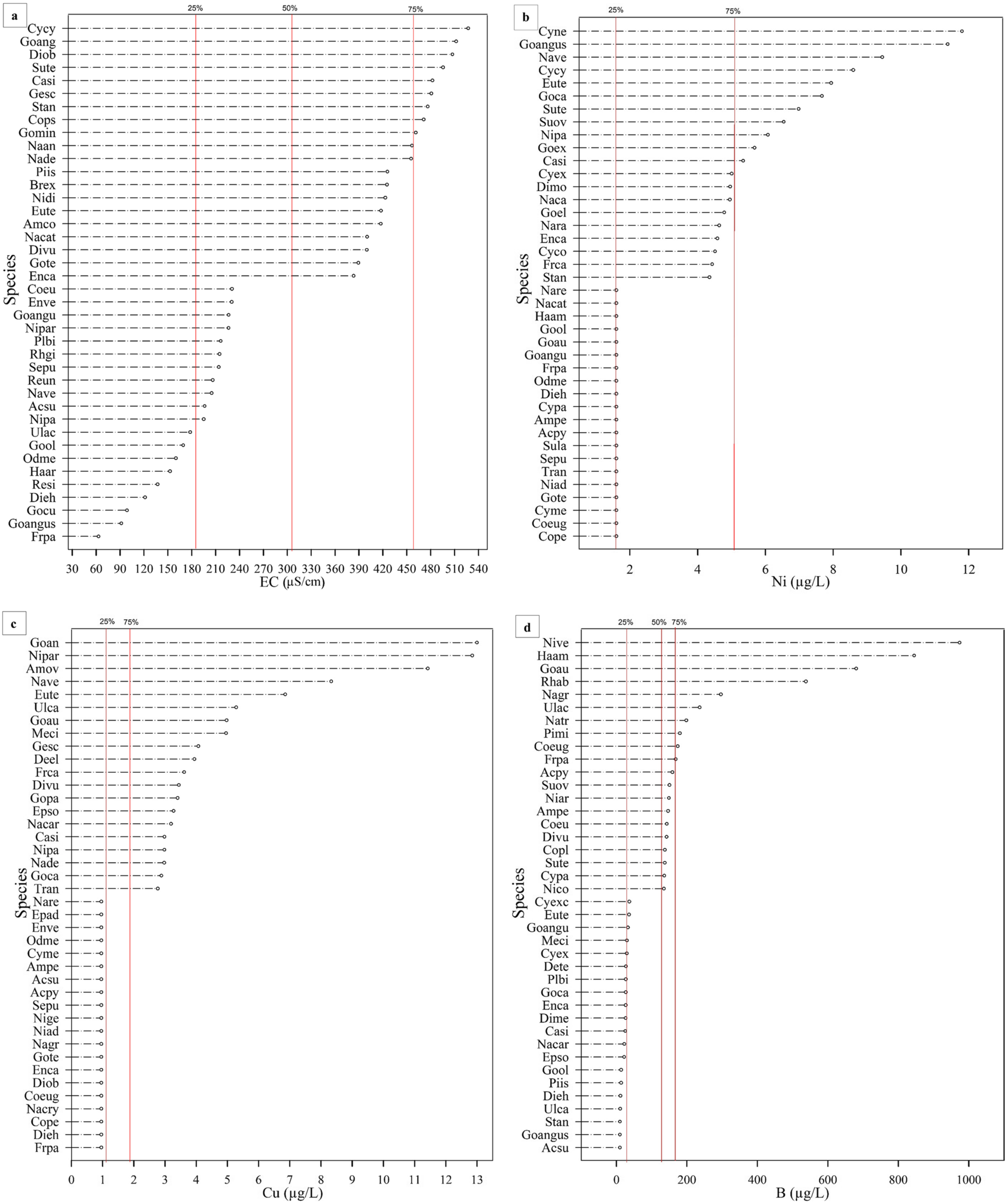

Fig. 3 Optimum values of diatom species for electrical conductivity (EC) (**a**), nickel (Ni) (**b**), copper (Cu) (**c**), and boron (B) (**d**). Red lines on the plots indicate percentile levels (25%, 50%, and 75%)

Table 3 Different ecoregional diatom indices' scores of the sampling stations.

	TIT	TI	EPI-D	IPS	TDI	DSIAR	DEQI	TWQI	DDI
S01	2.31	0.83	1.02	4.15	33.1	47.7	0.00	0.00	9.32
S02	1.04	1.67	1.07	3.64	28.4	50.5	1.79	2.59	9.29
S03	2.41	2.92	1.77	2.68	48.4	42.1	2.39	2.75	9.14
S04	2.72	1.94	1.00	2.62	66.7	44.3	4.27	3.87	8.77
S05	1.74	2.56	1.14	2.91	36.3	43.4	1.90	2.51	9.30
S06	2.24	2.55	1.48	2.60	60.6	47.1	3.02	2.60	9.30
S07	1.89	2.37	1.23	3.47	44.4	51.7	2.84	2.55	9.14
S08	1.86	2.51	0.70	3.60	25.0	57.0	2.89	2.50	9.39
S09	2.13	1.59	1.42	3.54	24.1	58.1	5.00	nd	9.20
S10	1.46	1.58	0.91	3.28	35.7	58.5	3.48	2.50	9.32
S11	2.38	2.05	1.41	4.21	45.3	51.3	1.24	2.50	9.28
S12	1.94	2.23	1.05	3.54	38.8	47.3	2.39	2.58	9.21
S13	2.50	1.85	1.48	4.00	56.1	52.5	2.27	2.50	9.31
S14	2.36	1.46	1.16	3.55	28.1	58.5	nd	3.10	9.24
S15	2.10	2.15	0.99	3.44	44.7	47.3	2.71	2.86	9.24
S16	1.50	1.46	0.82	4.07	24.3	52.8	1.58	2.50	9.41
S17	2.31	1.98	1.36	3.27	38.2	51.2	3.12	2.63	9.10
S18	2.38	2.81	1.56	2.83	47.1	50.5	2.11	3.11	9.05
S19	2.27	2.41	1.57	3.00	35.0	43.4	2.12	2.00	9.09
S20	1.24	0.87	0.86	4.17	24.2	57.8	1.00	2.50	9.40
S21	2.42	2.76	1.36	1.93	32.1	42.1	2.33	2.54	9.33
S22	2.30	1.95	1.20	3.52	46.3	31.2	3.56	2.50	9.19
S23	2.51	2.43	1.23	2.08	31.6	53.3	3.28	2.50	9.27
S24	1.31	1.97	1.01	4.07	35.2	45.9	1.41	2.51	9.35
S25	1.46	1.91	0.96	3.72	35.2	50.5	1.54	2.52	9.18
S26	2.48	2.67	1.72	3.07	64.2	46.9	3.72	2.93	9.08
S27	1.41	0.99	1.07	4.04	30.9	52.5	1.68	2.54	9.33
S28	1.07	1.65	0.75	3.30	21.7	57.2	2.73	2.50	9.47
S29	1.49	1.11	1.18	4.56	28.6	29.3	1.13	1.66	9.40
S30	1.35	2.27	1.09	2.50	15.7	57.1	2.30	3.25	9.32
S31	2.34	2.75	1.63	2.41	66.2	46.0	2.73	2.54	9.08
S32	3.39	2.81	1.77	2.42	53.6	49.2	2.44	3.95	9.04
S33	1.23	2.85	1.04	1.21	29.0	62.7	2.93	2.50	9.10
S34	2.58	1.81	1.12	3.22	33.0	51.8	2.76	2.50	9.27
S35	2.52	2.63	1.42	3.13	44.8	44.8	2.27	2.71	9.11
S36	2.29	2.50	1.15	3.64	25.0	45.4	2.68	2.96	9.24
S37	1.35	1.85	0.89	4.01	25.0	52.8	2.96	2.82	9.31
S38	1.58	2.25	1.31	3.74	43.4	52.8	2.83	2.65	9.31
S39	1.18	1.70	1.04	3.70	39.8	55.2	1.45	2.50	9.35

TIT, Trophic index Turkey; *TI*, Trophic Index; *EPI-D*, Eutrophication and/or Pollution Index-Diatom; *TWOI*, Trophic Water Quality Index; *DEQI*, Diatom Ecological Quality Index; *DDI*, Duero Diatom Index; *IPS*, Pollution Sensitivity Index; *TDI*, Trophic Diatom Index; and *DSIAR*, Diatom Species Index Australian Rivers (DSIAR). The meaning of different colors used in the table is as follows: blue—high quality, green—good quality, yellow—moderate quality, orange—poor quality, red—bad quality. *nd*, not detected scores

Discussion

It is the first study to describe the diatom composition of river ecosystems in the Konya closed basin and to provide the eco-assessment of sampling stations as a benchmark for future limno-ecological studies. According to Turkish surface water quality regulation standards (TSWQR 2016), sampling stations except S32 and S34 have class I water quality based on TP, TN, and NO3-N variables. Similar nitrogen values were found in the Antalya River Basin (Çelekli et al. 2021b), which is a contiguous basin to the Konya closed river basin. In contrast, TP values are higher than those of the Antalya River system. The Antalya River basin has different ecological areas with different altitudes and higher annual precipitation compared to the Konya closed river basin. TP values in the European Mediterranean Rivers with the least disturbed conditions (Feio et al. 2014) were lower than those measured in the present study. The maximum threshold values of total phosphorus as a limiting factor (Reddy et al. 1999) are 70 µg/L for European

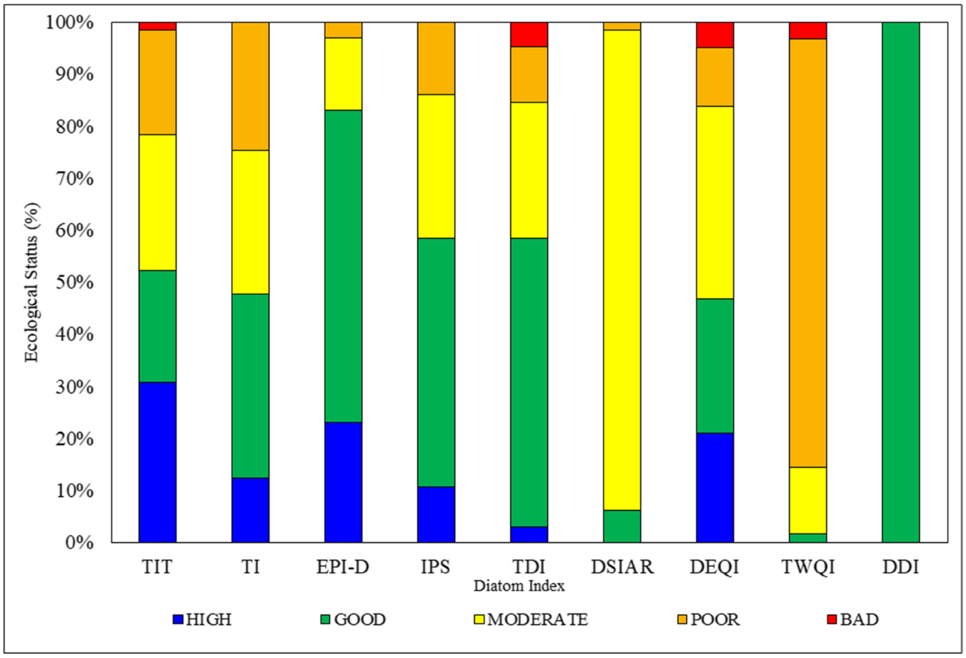

Fig. 4 The percentages of ecological quality status of diatom indices in the Konya closed river basin

Table 4 Spearman's rank correlations between diatom indices and environmental factors

	TIT	TI	EPI-D	IPS	TDI	DSIAR	DEQI	TWQI	DDI
Temp	0.164	0.302*	0.223	−0.349**	0.122	−0.258*	0.017	0.168	−0.139
pH	−0.126	−0.350**	−0.149	0.114	−0.028	0.072	−0.035	−0.164	0.216
NO_2^-	−0.065	−0.137	−0.007	0.025	−0.285*	0.154	−0.229	−0.282*	0.122
NO_3^-	0.066	0.029	0.154	0.006	−0.044	−0.053	−0.296*	−0.278*	−0.098
TP	**0.506****	**0.386****	**0.367****	**−0.477****	**0.159**	**−0.147**	**0.188**	**0.181**	**−0.304***
Ni	−0.086	−0.278*	−0.237	0.017	−0.123	0.319**	0.073	−0.116	−0.007
Cu	0.021	−0.070	−0.088	−0.145	−0.098	0.339**	0.139	−0.068	0.053
B	0.340**	0.473**	0.495**	−0.277*	0.257*	−0.230	0.031	0.110	−0.301*
As	0.144	0.138	0.212	−0.340**	−0.002	−0.042	0.119	0.172	−0.083
Ti	0.026	0.110	0.060	−0.290*	0.147	0.067	0.258*	0.197	−0.126
V	0.351**	0.389**	0.334**	−0.450**	0.326**	−0.158	0.147	0.129	−0.301*
Sn	0.081	0.335**	0.278*	−0.175	0.137	−0.217	0.027	0.096	−0.207
TIT		0.531**	0.649**	−0.499**	0.487**	−0.222	0.293*	0.427**	−0.507**
TI			0.666**	−0.722**	0.417**	−0.342**	0.191	0.432**	−0.612**
EPI-D				−0.563**	0.456**	−0.299*	0.184	0.320**	−0.548**
IPS					−0.314*	0.050	−0.407**	−0.454**	0.548**
TDI						−0.360**	0.136	0.223	−0.508**
DSIAR							0.121	0.068	0.230
DEQI								0.135	−0.074
TWQI									−0.422**
DDI									

The correlation between diatom indices and TP (a relevant chemical to quantify the trophic weight of species) is given in bold

* and ** show significant levels at 0.05 and 0.01, respectively. Abbreviations of environmental variables and diatom indices are given in Tables 2 and 3, respectively

Mediterranean Rivers (Feio et al. 2014), 30 µg/L for New York State (Smith and Tran 2010), and 80 µg/L for Turkey (TSWQR 2016). Increasing of phosphorus in streams is closely related to human activities as a result of runoff fertilizer from agricultural lands, wastewater discharge, etc. (Feio et al. 2014). Turkish regulation standard for surface water indicates that sampling stations except S1, S2, S10, S11, S12, S15, S19, S21-23, S32, S36, and S38 have high-water qualities according to EC gradient (EC < 400 µS/cm) (Das et al. 2006; Çelekli et al. 2019). Relatively high values of some heavy metal ions were found in some stations: Ni in S4, S8–10 located at Melendiz and Taurus mountains, Cu in S33 and S32 located at Erenler Mountain and S14 and S15 at Taurus Mountains, B in S3, S5, and S6 at Melendiz Mountain, and Fe in S3–S5, S7, and S8 at Melendiz Mountain and S30–34 at Erenler Mountain. There are no industrial activities in these mountainous regions, but mineral mining near sampling stations on these mountains might be the cause of these heavy metals in the southeast of Anatolia (Çelekli et al. 2017). Heavy metal values in the present study were higher than those of rivers in the Antalya river system (Çelekli et al. 2021b). Turkish regulation standard for surface water represents that S6, S12, S18-S21, S27, S28, and S36–S39 have high-water qualities when the remaining sampling stations are of water quality II according to Fe ion gradient (TSWQR 2016).

Diatom species showed distinct responses to environmental variables such as EC, Ni, Cu, B, and altitude, driving the distribution of diatom species in the Konya closed river system. Relatively high EC values were found in Zorlak, Doğuca, Asın, and Seydihasan streams, which are characterized by some diatom species (e.g., *N. dealpina*, *G. schoenfeldii*, *C. cymbiformis*, *G. augur*, *G. angustius*, *C. silicula*, *D. oblongella*, *C. pseudolineata*, *N. dissipata*, and *N. cari* (Fig. 2)) in agreement with WA's results (Fig. 3a). *Navicula dealpina* is a species in the Red List (RL) threat–category 2 in serious danger (Hofmann et al. 2018) and no information is available about its ecological status and biological condition gradient-BCG attribute (Hausmann et al. 2016). In addition, used diatom indices have no trophic weight for this species while it had a 93.3 µg/L TP optima in the Konya closed river basin. A medium EC optimum level of *N. dealpina* in the present study supported the finding of Cantonati et al (2016). Also, they reported that *N. dealpina* was assigned as a characteristic species of oligotrophic and calcium–bicarbonate-rich environments. *Geissleria schoenfeldii* is in the RL threat-category X and in serious danger lists (Hofmann et al. 2018), and its ecological status is eutrophic. The present study resulted in a 12.8 µg/L TP optimum for this species. This species (synonym *Navicula schoenfeldii*) is not found in the used diatom indices database and so more studies are needed to determine the ecological preference of this species in the riverine system. *Cymbella cymbiformis* is related to oligotrophic, predominantly slightly acidic, more or less humin-rich waters and species is in the RL threat–category 3 (endangered) (Hofmann et al. 2018). The present study revealed that its TP optimum is 25.1 µg/L. TIT indicated that this species prefers moderately deteriorated ecosystems, whereas TI, IPS, and EPI-D showed that it has a low trophic weight in the least disturbed waters. *Gomphonema augur* prefers eutrophic conditions (Hofmann et al. 2018). In the Konya closed river basin, this species occurred in deteriorated ecosystems with its high TP optimum of 63.1 µg/L, which is confirmed by TIT, TI, and EPI-D. *Gomphonema angustius* was shown to be a characteristic species of oligotrophic-calcareous waters (Reichardt 2009). This species had a 12.1 µg/L TP optimum in the Konya closed river basin. Among the used diatom indices, IPS only includes this species with low trophic weight (Cemagref 1982). *Caloneis silicula* preferred moderate environmental conditions based on TIT, TI, and DSIAR, whereas a good environment according to EPI-D and IPS. *Navicula cari* (36.8 µg/L TP optimum in the present study) is considered a characteristic species of the eutrophic environment (Hofmann et al. 2018) and has BCG attribute 4 as an intermediate tolerant species (Hausmann et al. 2016). Cantonati et al. (2016) reported that *N. cari* is related to eutrophic waters with higher electrolyte content. Besides, this species has a higher trophic weight in TIT (Çelekli et al. 2019) than those of TI (Rott et al. 1999), EPI-D (Dell'Uomo 2004), and IPS (Cemagref 1982). *Cocconeis pseudolineata* had a 15.8 µg/L TP optimum in the present study. It has a medium trophic weight in TDI (Kelly et al. 2008), whereas IPS indicates that it is a sensitive species to pollution (Cemagref 1982).

S1, S8, S9, S14, and S15 were characterized by the association of *N. veneta*, *N. palea*, *G. angustatum*, *S. ovalis*, and *A. ovalis* with Ni ions (Fig. 2), which is also confirmed by the WA findings (Fig. 3b). These species and *N. parvula* had Cu optima higher than 75% in the Konya river basin (Fig. 3c). *Navicula veneta* prefers eutrophic environments (Hofmann et al. 2018) and is grouped under the BCG attribute 4 (Hausmann et al. 2016). *Nitzschia palea* is a characteristic species of the eutrophic environment (Hofmann et al. 2018), which is described in the BCG attribute 5 as a tolerant taxon (Hausmann et al. 2016). *Nitzschia palea* is also considered a pollution-tolerant species, with nutrient gradients ranging from low in the least disturbed areas (Almeida et al. 2014; Çelekli et al. 2021b) to high in the wastewater (Çelekli and Şahin 2021). Previously, close relationships of *N. veneta* and *N. palea* with Ni, Cu, and Cd ions were reported in Junction Creek, Ontario, Canada (Lavoie et al. 2018) and in Frood Branch and Nolin creeks of Greater Sudbury, Canada (Lavoie et al. 2018). The amounts of these metal ions are lower than those of the present study. *Nitzschia palea* is also known as a heavy metal tolerant species (Chen et al. 2014). Besides, *N. veneta* and *N. palea* are put in the species group with high tolerance to higher nutrient levels (Lavoie et al. 2018).

S3 was characterized by *N. flexa*, *N. gregaria*, *H. amphioxys*, and *R. abbreviata* and showed a close relationship with

B in the CCA ordination. This association was also supported by findings from WA (Fig. 3d). *Navicula gregaria* is related to the BCG attribute 4 as an intermediate tolerant and ubiquitous taxon (Hausmann et al. 2016) and has a relatively high trophic weight (Rott et al. 1999; Dell'Uomo 2004). *Hantzschia amphioxys* prefers aerophilic habitats (Hofmann et al. 2018) and is shown as a pollution tolerant organism (Rott et al. 1999; Dell'Uomo 2004). *Rhoicosphenia abbreviata* is commonly found in eutrophic environments (Hofmann et al. 2018), and it is indicated in the BCG attribute 3 as an intermediate sensitive species (Hausmann et al. 2016). These findings were also supported by the findings of TIT (Çelekli et al. 2019) and TI (Rott et al. 1999).

Pollution-sensitive species such as *H. arcus*, *D. ehrenbergii*, *O. mesodon*, *E. minutum*, *E. silesiacum*, and *A. subatomus* were associated with S24 and S27–S29 stations in the Konya closed river basin. These pollution-sensitive species (Cemagref 1982; Dell'Uomo 2004; Çelekli et al. 2019) have been found in European Mediterranean Rivers (Feio et al. 2014; Kim and Lee 2017; Pestryakova et al. 2018) and in the Antalya river basin (Çelekli et al. 2021b).

The eco-assessment of sampling stations in the Konya closed river basin indicated that diatom indices have various scores resulting in different ecological statuses ranging from a bad to a high environmental condition. TIT had the highest percentage of high ecological status, which was followed by EPI-D, DEQI, and IPS (Fig. 3).

Diatom indices had different behaviors in the bio-assessment of some sampling stations, such as S32, S33, and S9 in the Konya closed river basin. Similar results were also found in the study comparing European and American diatom indices (Lavoie et al. 2009), southeast Anatolia (Çelekli and Bilgi 2019) and in the Antalya river basin (Çelekli et al. 2021b). Five different ecological conditions were reported in S32: a bad status with TIT and TWQI; a poor condition with TI; a moderate status with EPI-D, IPS, and TDI; and a good status with DEQI. S32 had the highest values of TP, BOD, and TOC with medium EC, which suggests class II water quality according to Turkish regulation standards (TSWQR 2016). Urbanization, agricultural activity, and land use are present around S32. S33 had four different ecological conditions based on used diatom indices (Table 3). S33 was of a high ecological status based on TIT, whereas IPS, TI, EPI-D, and TDI indicated a poor environmental condition. Another index. DDI depicted a good ecological status for S33. Differences in the bio-assessment may be explained by the variation in the trophic weights of diatom species in diatom indices. For instance, *M. circulare* has a low trophic weight of TIT and EPI-D compared to TI, IPS, and DSIAR. Streambed (S33) consists of rocks, stones, and sand, which is surrounded by a small amount of agricultural land, including mostly poplar trees. European indices displayed that S9 had a good status whereas it was assigned as a station with bad condition based on the DEQI result. Mean values of EC, BOD, TN, and TP indicated that S9 has class I water quality according to Turkish regulation standards (TSWQR 2016). In terms of metal content, this stream had relatively high Fe and Ni ions, which could affect diatom composition and their abundances. Similar to the findings of the eastern Canadian diatom index-IDEC in Frood Branch and Nolin creeks, Canada (Lavoie et al. 2018), increasing in diatom scores could have been caused by metal ion contamination in the present study.

European diatom indices, TI (Rott et al. 1999), TIT (Çelekli et al. 2019), EPI-D (Dell'Uomo 2004), and IPS (Cemagref 1982) except DDI, mainly displayed similar behavior in eco-assessment of sampling stations in the Konya closed river basin (Table 3 and Fig. 4). Some indices (e.g., DDI, DSIAR, and TWQI) could not separate the ecological status of sampling stations in the Konya closed river basin, in agreement with results from the Antalya river basin (Çelekli et al. 2021b). This may be due to the insensitiveness of theses indices to the environmental variations between sampling sites. The high and good ecological quality class boundaries of the DDI are between 10.00 and 8.50–9.99, respectively (Álvarez-Blanco et al. 2013), which strongly affect the bio-assessment results as good ecological status for all stations. Similar results were obtained from the DDI evaluation in the Antalya river basin (Çelekli et al. 2021b). Thus, determination of class boundaries of diatom indices can accurately facilitate the bio-assessment of freshwater ecosystems. DSIAR and TWQI were developed from different ecoregions, which closely affect the trophic weights of diatom species in the database of diatom indices. Another important factor is how many diatom species found in the Konya river basin were used in the diatom indices. For instance, DEQI only included *N. veneta* (trophic weight equal to 5), which is used in the bio-evaluation of S9 as a bad condition. Besides, diatom species found in the station S9 are not used in the TWQI index database and so, the TWQI index could not be used to assess the ecological status of S9 (Table 3).

European diatom indices indicated that the least disturbed areas are S20, S24, S25, S27–29, S37, and 39 with high ecological status in the Konya closed river basin. Diatom species diversity and trophic weights (distinct tolerant/sensitivity values) are different in the tested diatom database, which closely affects results of the bio-assessment of streams in the Konya river basin. This is because different ecoregions (e.g., geology, human activities, climate, vegetation, wildlife, and hydromorphology) strongly affect the trophic weight values of species (Lobo et al. 2015; Çelekli et al. 2019; Salinas-Camarillo et al. 2021). Therefore, diatom indices developed in different ecoregions can give distinct ecological status for the same sampling site.

TI (Rott et al. 1999), TIT (Çelekli et al. 2019), IPS (Cemagref 1982), and EPI-D (Dell'Uomo 2004) significantly correlated with environmental variables, especially TP, which is used as a relevant chemical to quantify the trophic weight of species. Thus, TI, IPS, and EPI-D are commonly used to assess the water quality of European water bodies incorporating nutrients and hydromorphology. Among them, TIT was shown to be a more competitive index for the bioassessment of rivers in the Antalya river basin (Çelekli et al. 2021b), the West Mediterranean basin of Turkey (Çelekli and Lekesiz 2020), eight creeks in the Lake Sapanca basin (Sevindik et al. 2021), the west of the Gaziantep catchment (Çelekli and Kapı 2019) and the North Aegean catchment (Çelekli et al. 2018) than those of the Konya closed river basin. The diatom list of the performed diatom indices does not include all the diatom species found in sampling stations in the Konya closed river basin, which is a limiting factor in assessing the water quality. Although TIT had the lowest species number (38%) among European diatom indices (e.g., IPS (71%), TI (62%), and EPI-D (60%)), it was found to be a competitive index. In light of this information, ecoregionally specific diatom indices like TIT need to be revised in the future by increasing the number of diatom species taking into account the ecological preferences of diatom taxa to make bioassessment more accurate.

Conclusion

The present study underlines that diatom species have distinct responses to environmental variables in the Konya closed river basin, significantly affected by EC, Ni, Cu, B, and altitude. *Cocconeis euglypta*, *C. excisa*, *C. placentula*, and *A. minutissimum* played significant roles in the dissimilarity of sampling stations not only between rainy and dry seasons but also between altitude typological criteria A2 and A3 in the Konya closed river basin. Results of the bio-assessment revealed that diatom indices have various scores, resulting in different ecological statuses from bad to high ecological conditions of sampling stations in the Konya closed river basin. European diatom indices except DDI and TDI indicated that the least disturbed areas are S16, S20, S24, S25, S27-29, S37, and S39 with high ecological status, which was also confirmed by physico-chemical and hydromorphological evaluations of streams. TIT, TI, EPI-D, and IPS could be suitable diatom metrics for assessing the ecological status of sampling stations in this region. Results also indicated that revision of ecoregional specific diatom metrics like TIT with the enhancement of diatom species number is needed along with the ecological preferences of diatom taxa to effectively interpret the water quality.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11356-022-24747-2.

Acknowledgements We thank Dr. Mehmet Yavuzatmaca for reading the manuscript and Research Assistant Enes Ertan Kulaksız for his support for drawing the map.

Author contribution AÇ applied the sampling methodology, collected samples, analyzed physico-chemical variables, identified diatom species, applied statistical analyses, written, reviewed, and edited the article. ÖL collected samples, analyzed physico-chemical variables, identified diatom species, and drawn the map of the studied region. TÇ applied the sampling methodology. All authors read and approved the final manuscript.

Funding This study was supported by T.R. Ministry of Agriculture and Forestry, General Directorate of Water Management, Çınar Engineering Co., and the Scientific Research Projects Executive Council of Gaziantep University, which supported this research.

Data availability This is not applicable.

Declarations

Ethics approval and consent to participate This is not applicable.

Consent for publication This is not applicable.

Competing interests The authors declare that they have no competing interests.

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