Eco-Assessment of Streams of Konya Closed River Basin (Turkey) Using Various Ecoregional Diatom Indices

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Abstract

Ecological assessments of freshwater ecosystems based on diatom metrics are an important issue to attain environmental sustainability. The present study aimed to evaluate differences in the diatom-stressors relationship in relatively least disturbed streams in the Konya closed river basin using multivariate analyses and to bio-assess streams by application of different ecoregional diatom indices. *Cocconeis euglypta*, *Cymbella excisa*, *Cocconeis placentula*, and *Achnanthes minutissimum* are the most contributing species to the dissimilarity of sampling stations between rainy and dry seasons and also between altitude (A2 800- <1600 m and A3 $\geq$ 1600 m) groups. A strong (82.8%) correlation between diatom species and stressors was expressed by the first two axes of canonical correspondence analysis. Diatom species displayed distinct responses to environmental variables (electrical conductivity, Ni, Cu, B, and altitude) playing important roles on the distribution of diatom species. Diatom indices indicated different ecological statuses of stations from a bad to a high. European diatom indices except Duero Diatom Index-DDI and Trophic Diatom Index-TDI showed well 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 39. These results were also supported by abiotic evaluation. Among diatom indices, although TIT was more competitive in the bio-assessment of streams, it is necessary to increase its species list by determining their trophic weights in future studies. This indicates that the revision of ecoregional specific diatom metrics with the enhancement of diatom species numbers according to their ecological preferences is needed to correctly interpret the water quality.

Introduction

Freshwater resources are mostly impacted by human activities and climate changes, but there is still a lack of information about multi-pressure environmental impacts on aquatic communities. Therefore, the ecological monitoring and bio-assessment are needed to see effect of abovementioned 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 (especially diatoms), benthic macroinvertebrates, fishes, macrophytes, and phytoplankton into routine freshwater biomonitoring according to the requirements of the European Union Water Framework Directive-WFD (Directive 2000).

Ecological assessments of freshwater ecosystems based on bioindicator metrics are one of the important issues to attain environmental sustainability in the world. Among them, diatoms are robust bioindicators of spatiotemporal changes in environmental conditions at any time of the year (e.g., Rott et al. 1999, Lobo et al. 2015, Delgado and Pardo 2015) and they are important primary producers in energy and nutrient cycling of the biosphere (Smol and Stoermer 2010).

Relationships between diatom species and pollution gradient are quantified by diatom indices. Trophic Index-TI in Austria (Rott et al. 1999), the 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 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 reflects to different environments (physical, chemical, and hydro-morphological) from the least disturbed to 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 Kapi 2019, Salinas-Camarillo et al. 2021). Different stream typologies (e.g., altitude, catchment area, geology, flow regime, precipitation, and hydro-morphological dynamic) 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 can be changed in the realized niches between different ecoregions which are used in diatom indices (Rott et al. 1999, Çelekli and Kapi 2019, Pajunen et al. 2020).

Konya closed river system includes streams with different hydro-morphological properties under pressures of natural and human activities. To our best knowledge, no study has been conducted to investigate the bio-assessment of stream conditions in the Konya river basin in literature. Thus, bio-assessments of streams in the Konya closed river system by applying with a few different ecoregional diatom metrics and multivariate analyses are done the first time according to the implementations of the WFD. The present study aimed 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 system located in central Anatolia covers a total area of 49786 km² with plains and plateaus, which is surrounded by Taurus, Geyik, Sultan, and Melendiz mountains (Figure 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 located upper 1100 m asl. with different typologies (Table 1).

The Konya closed river basin consists of 57% agricultural area (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 of 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 catchment 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). Taurus Mountains (up to 3404 m asl.) is located in the south of the basin that has low temperatures, intense precipitation, and snow, whereas the plateau and plain areas are warmer with relatively low rainfall and intense evaporation.

Sampling

In the study, the least disturbed sampling areas with minimal human impacts were selected. Hydro-geographical features of 39 sampling stations symbolized by S1-S39 from 38 streams (Figure 1) are given in Table 1. A geographical positioning system (GPS, Garmin Vista HCx model) was used to obtain information about locations of sampling stations. 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 sampling stations were classified according to the rules of Ministry of Agriculture and Forestry, General Directorate of Water Management of Turkey.

Water and epilithic diatoms samples were collected from sampling stations in three seasons (spring, summer, and fall) of 2017. Water samples were maintained under cooler conditions until transferred to the laboratory for chemical analyses. Epilithic diatom samples were gathered by brushing 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).

Table 1. Hydro-geographical features of streams. A-altitude (A2 800–<1600 m and A3 ≥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 ≥ 400 mm), and D-drainage area (D1-wet and D2-dry regions)

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	İlsu	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	Çamurluıret	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

Physicochemical analyses

Environmental variables (e.g., water temperature (°C), electrical conductivity (EC $\mu\text{S}/\text{cm}$), pH, dissolved oxygen concentration (DO, mg/L), and salinity (ppt) *in situ* were measured by an oxygen–temperature meter (YSI professional plus). Values of chemical variables like TN-total nitrogen, N-NO₃-nitrate-nitrogen, TP-total phosphorus, and TOC-total organic carbon, etc. and biochemical oxygen demand (BOD₅) of water samples

were determined according to standard methods of APHA (2012). Water metal ions concentrations were quantified by using an inductively coupled plasma-optical emission spectrometry (Perkin Elmer, Optima 2100 DV).

Identification and prepare permanent slides of epilithic diatom

Hot acids ($\text{H}_2\text{SO}_4:\text{HNO}_3$ 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 13946 (EC 2014). The Naphrax was used to mount diatom slides to examine under a light microscope (Olympus BX53 model attached a DP73) at the 1000x magnification and to count at least 500 valves per slide. Species identification was done according to diatom taxonomic books (Krammer 2000, 2002, Lange-Bertalot 2001, Bey and Ector 2013, Lange-Bertalot et al. 2017). Besides, the nomenclature was checked by using AlgaeBase (Guiry and Guiry 2021) and diatoms of North America (Spaulding et al. 2019). 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 Konya closed river basin. Diatom indices' scores were calculated with the aid of excel program.

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 25th, 50th, and 75th percentiles of data were calculated by applying the percentile analysis (SPSS version 15.0, USA). Analysis of similarities (ANOSIM) test was used to evaluate whether there were significant differences between the sample groups from Konya river basin stations. Analysis of similarity percentage (SIMPER) test was applied to determine both the similarity status of the sampling groups depend on their 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). Community Analysis Package version 4.1.3 software (Seaby and Henderson 2007) was used to perform ANOSIM and SIMPER analyses.

Detrended correspondence analysis (DCA) test estimates gradient lengths (>6.0) greater than 3.0 for the first two axes, which 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 Šmilauer 2002). Monte Carlo permutation test (CANOCO 4.5 software) was done to reveal which environmental factors significantly affect distribution of diatom species. Thus, only significant explanatory factors were exhibited in the ordination. The weighted averaging (WA) regression model of CALIBRATE

program was carried out to predict the optima of diatom species for the 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 mainly alkali waters and it ranged between 7.5 at Asın Stream (S32) and 8.8 at Gök Stream (S1). The mean EC values ranged from 64 $\mu\text{S}/\text{cm}$ at Baldıran Stream (S7) to 723 $\mu\text{S}/\text{cm}$ at Anaçay Stream (S2). Sampling stations S1, S2, S10-12, S15, S22, and S23 had EC values more than 500 $\mu\text{S}/\text{cm}$.

Relatively low variations were found in the nutrient gradient of sampling stations. The highest mean TP was found in Asın Stream (S32) with 142 $\mu\text{g}/\text{L}$, followed by Uluçay Stream (S34) with 116 $\mu\text{g}/\text{L}$, whereas several streams (e.g., Avşar, Kurucaova, and Baldıran streams) had TP values smaller than 10 $\mu\text{g}/\text{L}$. $\text{NO}_2\text{-N}$ was not detected in most of sampling stations (see Table 2). Mean TN varied between 1.64 mg/L in Suludere Stream (S30) and 0.28 mg/L in Çarşamba Stream (S25).

Table 2. Mean values of environmental variables of sampling stations in the Konya closed river basin. Abbreviations and full names of stations are given in Table 1. nd is not detected.

	Temp	pH	EC	DO	Sali	Alka	BOD	COD	TOC	TN	NH ₄	NO ₂	NO ₃	TP
	°C		µS/cm	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L
S01	17.0	8.8	640	7.69	0.31	334	4.9	26.2	8.08	0.95	0.05	0.01	0.54	13
S02	16.4	8.5	723	6.01	0.35	331	5.1	24.9	15.54	1.24	0.05	0.01	0.49	51
S03	17.3	8.4	317	8.42	0.16	129	1.9	10.1	2.18	1.37	0.08	0.02	0.48	51
S04	18.9	8.6	81	7.58	0.04	36	1.9	9.0	0.90	1.03	0.05	nd	0.09	35
S05	19.5	8.0	191	7.09	0.08	73	1.9	12.0	5.47	0.59	0.05	nd	0.09	18
S06	21.5	8.2	78	8.66	0.03	188	1.9	9.0	0.90	0.83	0.05	nd	0.09	10
S07	19.4	7.8	64	6.28	0.03	49	1.9	9.0	0.90	0.50	0.05	nd	0.10	7
S08	13.3	8.1	185	7.53	0.10	97	1.9	9.0	2.90	1.05	0.05	nd	0.17	43
S09	13.4	8.0	255	6.96	0.12	119	1.9	9.0	1.40	0.74	0.05	nd	0.21	15
S10	10.0	8.2	513	9.14	0.26	235	2.1	13.9	4.11	0.94	0.05	nd	0.09	10
S11	12.2	8.1	707	8.08	0.35	270	1.9	12.4	0.90	0.96	0.05	nd	0.39	15
S12	13.9	8.2	545	7.69	0.27	250	1.9	9.6	0.90	0.85	0.05	nd	0.09	5
S13	15.5	8.5	386	8.51	0.18	242	2.3	14.8	5.51	1.16	0.50	0.01	0.34	18
S14	15.3	8.7	332	8.02	0.16	149	1.9	10.3	3.51	1.47	0.84	0.02	0.16	68
S15	14.3	8.5	546	8.58	0.26	175	3.1	23.4	12.68	1.07	0.11	nd	0.09	14
S16	18.5	8.4	368	8.21	0.17	165	1.9	9.7	0.90	0.95	0.05	nd	0.13	11
S17	16.7	8.5	364	8.81	0.15	168	1.9	9.0	0.90	1.02	0.05	nd	0.43	11
S18	16.2	7.8	328	8.12	0.15	152	1.9	9.0	0.90	1.11	0.05	nd	0.51	9
S19	15.0	8.2	407	8.19	0.18	183	2.6	163	5.35	1.22	1.51	nd	0.61	20
S20	16.0	8.4	341	8.55	0.16	176	1.9	9.0	0.90	0.94	0.52	0.01	0.44	5
S21	22.1	8.5	475	7.96	0.23	191	1.9	9.0	0.90	1.98	1.20	nd	0.59	48
S22	16.8	8.1	577	7.41	0.28	289	3.6	35.7	12.13	1.18	0.05	nd	0.48	15
S23	16.9	8.3	530	8.00	0.26	310	1.9	22.4	16.59	0.62	0.05	nd	0.09	18
S24	17.0	8.3	288	8.89	0.14	145	1.9	9.0	0.90	0.39	0.05	nd	0.13	7
S25	18.8	8.1	272	8.64	0.14	150	7.5	435.0	22.61	0.28	0.05	nd	0.09	5
S26	18.9	8.2	177	7.89	0.09	130	1.9	9.0	0.90	0.47	0.05	nd	0.09	24
S27	12.5	8.7	227	8.76	0.11	113	2.1	15.3	8.21	0.56	0.05	nd	0.09	5
S28	14.3	8.6	178	8.93	0.08	102	4.9	25.3	8.35	0.90	0.05	nd	0.09	5
S29	10.9	8.2	188	8.89	0.09	113	5.2	30.7	1.83	0.74	0.05	nd	0.09	10
S30	22.8	8.4	360	6.71	0.17	85	1.9	15.6	5.49	1.64	0.70	0.05	0.53	21
S31	16.3	8.3	176	8.01	0.08	96	3.9	19.2	11.53	0.94	0.05	nd	0.13	51
S32	14.4	7.5	426	8.87	0.11	312	7.2	45.6	25.48	1.50	1.00	nd	0.21	142
S33	14.8	8.2	98.9	8.30	0.05	55	1.9	9.0	0.90	0.58	0.05	nd	0.09	18
S34	17.3	8.7	243	9.01	0.12	113	1.9	15.2	9.64	0.84	0.05	0.01	0.23	116
S35	16.2	8.1	218	7.53	0.10	102	1.9	12.9	5.40	0.61	0.05	nd	0.09	51
S36	12.8	8.0	475	8.33	0.23	254	8.5	36.3	12.75	1.00	0.05	nd	0.09	25
S37	11.6	8.4	322	9.06	0.15	164	4.5	24.3	8.22	0.56	0.05	nd	0.09	5
S38	12.5	8.4	411	8.49	0.20	223	1.9	12.8	7.27	0.54	0.05	nd	0.09	5
S39	13.0	8.4	374	8.62	0.18	192	1.9	13.6	7.36	1.21	0.05	0.01	0.41	5

Table 2 continued

	Al	Sb	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	µg/L
S01	0.10	0.15	0.46	1.94	27.3	8.88	132.5	0.10	0.45	1.12	0.45	7.81
S02	0.35	0.15	0.81	1.47	92.4	0.89	448.4	0.62	11.39	4.02	0.45	11.03
S03	1.16	0.15	9.24	1.71	601.7	29.54	632.1	0.57	8.18	10.74	12.33	1.60
S04	0.21	0.15	0.46	1.68	9.5	7.43	122.7	0.03	7.89	1.92	0.45	11.67
S05	0.07	0.15	1.19	1.57	208.9	3.95	501.7	0.08	2.57	1.95	35.79	4.81
S06	0.04	7.52	0.71	0.96	309.5	7.25	22.7	0.20	4.29	9.13	47.75	1.60
S07	nd	0.15	0.45	0.96	170.5	4.48	215.2	0.03	0.45	1.92	58.33	1.60
S08	0.17	0.15	0.64	1.40	9.5	18.29	107.2	0.12	3.37	3.38	0.45	11.00
S09	0.10	0.15	2.51	2.55	42.1	15.99	372.0	0.29	0.74	0.64	0.45	13.10
S10	0.06	0.15	2.67	0.96	9.5	0.89	41.3	0.03	0.45	1.09	0.45	5.92
S11	0.05	0.15	0.46	1.25	64.4	0.89	48.5	0.03	0.45	2.11	0.45	4.21
S12	0.01	0.15	0.46	3.19	9.5	5.82	33.2	0.03	0.45	5.84	0.45	4.53
S13	0.06	0.15	0.45	2.85	77.1	11.33	187.0	0.18	0.67	1.57	12.07	5.29
S14	0.41	1.21	1.98	5.59	9.5	22.53	417.8	1.58	1.32	2.06	0.45	9.15
S15	0.08	0.15	0.66	3.64	9.5	5.38	104	0.11	4.77	3.63	0.45	7.00
S16	0.12	0.15	0.72	2.04	64.1	2.91	73.4	0.18	1.65	1.86	11.00	3.35
S17	0.11	0.15	0.61	0.96	79.1	0.89	90.8	0.06	0.45	1.22	11.97	2.74
S18	nd	0.15	0.45	0.96	139.9	0.89	4.5	0.03	0.45	1.82	37.84	3.19
S19	nd	0.15	0.53	0.96	51.2	0.89	6.4	0.03	0.45	1.37	10.40	2.86
S20	0.01	0.15	0.70	0.96	9.5	0.89	13.4	0.03	0.45	1.00	0.45	5.22
S21	nd	0.15	0.46	0.96	9.5	0.89	4.5	0.03	0.45	0.62	0.45	7.00
S22	0.15	0.15	0.46	0.96	9.5	0.89	74.7	0.03	8.82	1.70	0.45	6.02
S23	0.10	1.21	0.51	4.36	93.5	16.25	73.7	0.17	1.77	1.49	0.45	2.80
S24	0.07	0.15	0.45	3.12	21.2	8.44	56.7	0.07	1.65	0.45	0.45	1.60
S25	0.14	0.15	0.45	0.96	31.7	6.28	148.9	0.03	2.82	0.45	0.45	1.60
S26	0.16	0.99	0.56	2.76	24.8	13.33	227.3	0.44	1.20	0.96	0.45	3.29
S27	nd	0.15	0.46	0.96	9.5	0.89	4.5	0.03	0.45	0.45	0.45	1.60
S28	nd	0.15	0.46	0.96	9.5	0.89	4.5	0.03	0.45	0.45	0.45	1.60
S29	0.07	0.58	0.56	0.96	75.8	6.29	97.3	0.08	0.45	0.45	0.45	1.60
S30	0.26	0.15	0.59	6.66	14.3	27.91	362.7	0.54	3.52	3.02	0.45	1.60
S31	0.12	0.68	1.89	1.66	31.7	17.47	298.7	0.10	3.63	3.67	0.45	1.60
S32	0.11	1.72	1.88	4.43	39.0	21.82	231.2	0.26	3.51	5.00	0.45	1.60
S33	0.14	1.78	0.46	19.28	34.07	26.97	250.6	0.28	5.74	1.56	0.45	2.13
S34	0.18	0.15	1.45	3.91	17.5	17.31	279.0	0.24	4.21	4.65	0.45	1.60
S35	0.15	0.15	2.80	2.87	139.5	57.15	207.7	0.11	1.86	3.03	10.83	1.60
S36	nd	0.15	0.46	0.96	9.5	0.89	4.5	0.03	0.45	0.45	0.45	1.60
S37	nd	0.15	0.46	0.96	9.5	0.89	4.5	0.03	0.45	0.45	0.45	1.60
S38	nd	0.15	0.46	0.96	9.5	0.89	4.5	0.03	0.45	0.45	0.45	1.60
S39	nd	0.15	0.46	0.96	9.5	0.89	4.5	0.03	0.45	0.45	0.45	1.60

Temp-Temperature, EC-electrical conductivity, DO-dissolved oxygen, BOD-biological oxygen demand, COD-chemical oxygen demand, TOC-total organic carbon, TN-total nitrogen, N-NO₂-nitrite, N-NO₃-nitrate, TP-total phosphorus, CaCO₃-calcium carbonate, Al-Aluminum, Sb-Antimony, As-Arsenic, Cu-Copper, Co-Cobalt, B-Boron, Zn-Zinc, Fe-iron, Ti-Titanium, V-Vanadium, Sn-Tin, and Ni-Nickel.

Concerning heavy metals 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 equals to 1.6 µg/L Ni were found in 17 sampling stations (Table 2). Some metals were measured in a few regions such as relatively high iron (Fe) values were found 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 Ilisu Stream (S3) with 601.7 µg/L, following by Yağıl Stream (S6) with 309.5 µg/L and Okçu Stream (S5) with 208.9 µg/L. Ilisu 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 Konya closed river basin (Supplementary 1). Threat status and ecological attributes of diatom species were determined according to Hofmann et al (2018). Biological condition gradient (BCG) attributes of species are given in Supplementary 1 according to Hausman et al (2016). *Achnantheidium minutissimum*, *Cocconeis euglypta*, *Cocconeis 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 species in the present study, *Achnantheidium subatomus*, *Gomphonema calcifugum*, *Gomphonema exilissimum*, *Gomphonema lateripunctatum*, *Hannaea arcus*, *Pinnularia microstauron*, and *Stauroneis anceps* are listed in Red-List (RL) threat-category data. Diatom species, *Brachysira exilis*, *Cymbella* (*C. cymbiformis*, *C. excisiformis*, *C. laevis*, and *C. subhelvetica*) are endangered, while *Gomphonema stauroneiforme*, *Navicula dealpina*, *Navicula leptostriata*, and *Nitzschia gessneri* are in the serious danger list. Of the species, *Achnantheidium atomoides*, *Cocconeis pseudolineata*, *Fragilaria pectinalis*, *Gomphonema cuneolus*, *Navicula dealpina*, *Pinnularia isselana*, *Planothidium biporum*, *Psammothidium bioretii*, *Staurosirella ovata*, and *Surirella terricola* were new records for 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, when the difference ($p = 0.70$) between autumn and summer is not. SIMPER revealed that the dissimilarity between the spring and autumn groups was 94.1% with contributions of *C. excisa* (8.0%), *C. euglypta* (7.9%), *A. minutissimum* (5.5%), *C. placentula* (5.4%), *Achnantheidium 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%). An 87.4% difference between autumn and summer groups was provided by *C. euglypta* (12.8%), *C. placentula* (6.6%), *A. pyrenaicum* (5.2%), *C. euglyptoides* (4.2%), and *C. lineata* (4.2%).

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

Concerning altitude (A_2 800–1600 and $A_3 \geq 1600$ m), there was a significant difference between A_2 and A_3 groups ($p = 0.012$) according to ANOSIM. Results of SIMPER indicated that the dissimilarity between A_2 and A_3 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%), *Fragilaria capucina* (2.3%), and *C. euglyptoides* (2.2%). *Cocconeis euglyptoides* (54.1%), *R. sinuata* (11.7%), and *G. parvulum* (5.1%) were the most

contributing species to 16.4% within-A2 similarity, while within-A3 similarity as 12.2% were 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 (Figure 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), Asin (S32), and Seydihasan (S21) streams was characterized by some diatom species (e.g., *Navicula dealpina*, *Geissleria schoenfeldii*, *Cymbella cymbiformis*, *Gomphonema augur*, *Gomphonema angustius*, *Caloneis silicula*, *Diploneis oblongella*, *Cocconeis pseudolineata* *Nitzschia dissipata*, *Navicula cari*, and *Stauroneis anceps*). Relatively high EC preferences of these species were approved by results of WA regression (Figure 3a). S1, S8, S9, S14, S15 showed the relation to Nickel (Ni), which is associated with *Navicula veneta*, *Nitzschia palea*, *Cymbella neocistula*, *Gomphonema angustatum*, *Surirella ovalis*, *Nitzschia parvula*, and *Amphora ovalis* (Figure 2). WA indicated that mentioned species had Ni optima higher than 75th percentile (Figure 3b). CCA diagram indicated that *G. angustatum*, *N. veneta*, *N. parvula*, and *A. ovalis* preferred Copper (Cu), which are associated to Genge (S33), Ulu (S14), and Geleri (S15) streams. This assignment was also confirmed by WA (Figure 3c). Close integration between Ilisu (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 (Figure 3d). Some stations (S24 and S27-S29) are located at opposite of EC variable and are associated to *Hannaea arcus*, *Diatoma ehrenbergii*, *Odontidium mesodon*, *Encyonema minutum*, *Encyonema silesiacum*, and *Achnantheidium subatomus*.

Bio-assessment of sampling stations

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

Diatom indices showed different ecological status 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 evaluated by EPI-D, IPS, and TDI; and a good status after assessed by DEQI. Likely, four different ecological conditions are found in S33. European indices displayed that S9 had a good status, whereas it was assigned as 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 Figure 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 system.

Table 3. Different ecoregional diatom indices' scores of the sampling stations. Trophic index Turkey (TIT), Trophic Index (TI), Eutrophication and/or Pollution Index-Diatom (EPI-D), Trophic Diatom Index for Lakes (TDIL), Trophic Water Quality Index (TWQI), Diatom Ecological Quality Index (DEQI), Duero Diatom Index (DDI), Pollution Sensitivity Index (IPS), Trophic Diatom Index (TDI), and 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.

	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

Correlations between diatom indices and environmental variables are represented in Table 4. IPS, DSIAR, and DDI showed inverse correlation 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 TP gradient, whereas IPS ($p < 0.01$ $r = -0.477$) and DDI ($p < 0.05$ $r = -0.304$) displays significantly negative correlations with TP (see more in Table 4).

Table 4. Spearman's rank correlations between diatom indices and environmental factors. Abbreviations of diatom indices are given in Table 3.

	TIT	TI	EPI-D	IPS	TDI	DSIAR	DEQI	TWQI	DDI
Temp.	0.164	.302*	0.223	-.349**	0.122	-.258*	0.017	0.168	-0.139
pH	-0.126	-.350**	-0.149	0.114	-0.028	0.072	-0.035	-0.164	0.216
NO2	-0.065	-0.137	-0.007	0.025	-.285*	0.154	-0.229	-.282*	0.122
NO3	0.066	0.029	0.154	0.006	-0.044	-0.053	-.296*	-.278*	-0.098
TP	.506**	.386**	.367**	-.477**	0.159	-0.147	0.188	0.181	-.304*
Ni	-0.086	-.278*	-0.237	0.017	-0.123	.319**	0.073	-0.116	-0.007
Cu	0.021	-0.070	-0.088	-0.145	-0.098	.339**	0.139	-0.068	0.053
B	.340**	.473**	.495**	-.277*	.257*	-0.230	0.031	0.110	-.301*
Sb	0.039	0.165	0.210	-.332**	0.123	0.102	0.082	.254*	-0.156
As	0.144	0.138	0.212	-.340**	-0.002	-0.042	0.119	0.172	-0.083
Ti	0.026	0.110	0.060	-.290*	0.147	0.067	.258*	0.197	-0.126
V	.351**	.389**	.334**	-.450**	.326**	-0.158	0.147	0.129	-.301*
Sn	0.081	.335**	.278*	-0.175	0.137	-0.217	0.027	0.096	-0.207
TIT		.531**	.649**	-.499**	.487**	-0.222	.293*	.427**	-.507**
TI			.666**	-.722**	.417**	-.342**	0.191	.432**	-.612**
EPI-D				-.563**	.456**	-.299*	0.184	.320**	-.548**
IPS					-.314*	0.050	-.407**	-.454**	.548**
TDI						-.360**	0.136	0.223	-.508**
DSIAR							0.121	0.068	0.230
DEQI								0.135	-0.074
TWQI									-.422**
DDI									

* and ** show significant levels at 0.05 and 0.01, respectively.

Discussion

It is the first study describing the diatom composition of river ecosystems in the Konya closed basin and providing eco-assessment of sampling stations as a benchmark for future limno-ecological studies. Sampling stations except S32 and S34 have class I water quality based on TP, TN, and NO₃-N variables according to Turkish surface water quality regulation standards (TSWQR 2016). Similar nitrogen values were found in the Antalya River Basin (Çelekli et al. 2021b), which is a contiguous basin to the Konya closed basin. Contrary, 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 basin. Lower TP values were found in the European Mediterranean Rivers having least disturbed conditions (Feio et al.

2014) than 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 Mediterranean Rivers (Feio et al. 2014), 30 µm/L for New York State (Smith and Tran 2010), and 80 µg/L for Turkey (TSWQR 2016). Enhancement of phosphorus in streams is closely related to human activities as result of runoff fertilizer from agricultural lands, wastewaters discharge, etc. (Feio et al. 2014). Turkish regulation standard for surface water (EC <400 µS/cm) 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 (Das et al. 2006, Çelekli et al. 2019). Relatively high values of some heavy metal ions are 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 at these mountainous regions, but mineral mining nearby of sampling stations on these mountains might show as 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). In addition, amount of metal ions in sampled stations except S33 for iron ions were above the permissible limit according to the standard of US EPA (2004).

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., *Navicula dealpina*, *Geissleria schoenfeldii*, *Cymbella cymbiformis*, *Gomphonema augur*, *Gomphonema angustius*, *Caloneis silicula*, *Diploneis oblongella*, *Cocconeis pseudolineata*, *Nitzschia dissipata*, and *Navicula cari* (Figure 2)) with agreement of WA's results (Figure 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, diatom indices used in the bioassessment have no trophic weight of this species while it had a 93.3 µg/L TP optima in the Konya river system. *Navicula dealpina* had medium EC optimum in the present study, in agreement with the finding of Cantonati et al (2016). Also, they reported that *N. dealpina* was assigned to as a characteristic species of oligotrophic and calcium–bicarbonate rich environments. *Geissleria schoenfeldii* is in the RL threat-category X in serious danger (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 in the RL threat-category 3 in endangered (Hofmann et al. 2018). The present study revealed that its TP optimum is 25.1 µg/L. TIT indicates that this species prefers moderately deteriorated ecosystems, whereas TI, IPS, and EPI-D show that it has a low trophic weight in the least disturbed waters. *Gomphonema augur* preferred eutrophic conditions (Hofmann et al. 2018). This species occurred in deteriorated ecosystems with its high TP optimum as 63.1 µg/L in the Konya river systems, which is confirmed by TIT, TI, and EPI-D. *Gomphonema angustius* was showed as a characteristic species of oligotrophic-calcareous waters (Reichardt 2009). This species had 12.1 µg/L TP optimum in the Konya river system. Among 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 as a characteristic of 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 average to higher electrolyte content environments. Besides, this species has 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 15.8 µg/L TP optimum in the present study. Its trophic weight is a medium score in TDI (Kelly et al. 2008), whereas IPS indicates that it is a pollution-sensitive species (Cemagref 1982).

Sampling stations 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 (Figure 2), which is also confirmed by the WA findings (Figure 3b). These species and *N. parvula* had Cu optima higher than the 75% in the Konya river basin (Figure 3c). *Navicula veneta* prefers an eutrophic environment (Hofmann et al. 2018) and is grouped in the BCG attribute 4 (Hausmann et al. 2016). *Nitzschia palea* is a characteristic species of the eutrophic environment (Hofmann et al. 2018), which is confirmed by the presence of it in the BCG attribute 5 as a tolerant taxon (Hausmann et al. 2016). *Nitzschia palea* is also considered a pollution-tolerant species and has a broad range of nutrient gradients 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 *Navicula veneta* and *N. palea* with Ni, Cu, and Cd ions were reported in Junction Creek of Ontario, Canada (Lavoie et al. 2018) and in Frood Branch and Nolin creeks of the Greater Sudbury, Canada (Lavoie et al. 2018). Amount of these metal ions is 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). These ecosystems (S1, S8, S9, S14, and S15) were categorized as reference status and are affected by the mining activity.

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 of WA (Figure 3d). *Navicula gregaria* is related to the BCG attribute 4 as intermediate tolerant and ubiquitous taxon (Hausmann et al. 2016) and has relatively high trophic weight (Rott et al. 1999, Dell'Uomo 2004). *Hantzschia amphioxys* prefers aerophilic habitats (Hofmann et al. 2018) and is a pollution tolerant organism (Rott et al. 1999, Dell'Uomo 2004). *Rhoicosphenia abbreviata* is commonly found in eutrophic environment (Hofmann et al. 2018) and in the BCG attribute 3 as an intermediate sensitive species (Hausmann et al. 2016), which is 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 some stations, S24 and S27-S29 in the Konya closed river basin. Mentioned pollution sensitive species (Cemagref 1982, Dell'Uomo 2004, Çelekli et al. 2019) have been commonly 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 systems indicated that diatom indices have various scores resulting in different ecological statuses from a bad to a high environmental condition. TIT had the highest percentage of high ecological status that is 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, COD, and TOC with medium EC, which suggests class II water quality according to Turkish regulation standards (TSWQR 2016). Urbanization, agricultural activity, and land uses were present around S32. S33 had four different ecological conditions based on the findings of diatom indices (Table 3). S33 had a high ecological status based on TIT, whereas IPS and TI indicated a poor environmental condition with EPI-D, TDI, and DDI indicated 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, *Meridion circulare* has a low trophic weight of TIT and EPI-D compared to TI, IPS, and DSIAR. Streambed (S33) consists of rocks, stones, and sands, 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 bad condition with DEQI. 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. Enhancement in diatom scores could be due to metal ions contamination in the present study, in agreement with findings of the eastern Canadian diatom index-IDEC in Frood Branch and Nolin creeks, Canada (Lavoie et al. 2018).

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 Figure 4). Some indices (e.g., DDI, DSIAR, and TWQI) could not separate the ecological status of sampling stations in Konya closed river basin, in agreement with results of the Antalya river basin (Çelekli et al. 2021b). This may be because they are not sensitive to the environmental variations between sampling sites. 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 bioassessment 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 bioassessment of freshwater ecosystems. DSIAR and TWQI were developed from different ecoregions which closely affect trophic weights of diatoms species in the database of diatom indices. Another important factor is that how many diatom species found in the Konya river basin were used in the performed 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 occurred in the station S9 are not used in the TWQI index database and so, 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 system. Species diversity and trophic weights (distinct tolerant/sensitivity values) of diatom species are different in the tested diatom database, which closely affect results of the bio- assessment water quality of streams in the Konya river basin. This is because different

ecoregions (e.g., geology, human activities, climate, vegetation, wildlife, and hydromorphology) strongly affect environmental factors result in changing 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.

Diatom indices, 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 water quality of European water bodies incorporating nutrients and hydromorphology. Among them, TIT was more competitive based on the Spearman correlation coefficient in bio-assessment 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 Gaziantep catchment (Çelekli and Kapi 2019) and in the North Aegean catchment (Çelekli et al. 2018) than those of the Konya closed river basin. Diatom list of the performed diatom indices do not include all the diatom species found in sampling stations in the Konya closed river system, which is a limiting factor to assess the water quality. Concerning that, IPS (71%) included the highest species number, followed by TI (62%), and EPI-D (60%). Although TIT with the lowest species number (38%) among European diatom indices, it was found as a competitive index. Considering these points, it is needed to revise ecoregional specific diatom metrics like TIT with the enhancement of diatom species number in the future according to ecological preferences of diatom taxa.

Conclusion

The present study underlines that diatom species have distinct responses to environmental variables in the Konya closed river system, significantly affected by EC, Ni, Cu, B, and altitude. *Cocconeis euglypta*, *C. excisa*, *C. placentula*, and *A. minutissimum* play 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 a bad to a high condition of sampling stations in the Konya closed river systems. European diatom indices except DDI and TDI indicated that the least disturbed areas are S16, S20, S24, S25, S27-29, S37, and 39 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 according to ecological preferences of diatom taxa to enhance interpretation of water quality.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Authors Contributions: 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.

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Figures

Figure 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.

Figure 2

CCA diagram of species (circle)-environmental (arrow) relationships in the sampling stations (up triangle). Ni–nickel, B–Boron, EC–electrical conductivity, Cu–Copper. Full names of S symbols and species codes are given in Table 1.

Figure 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%)

Figure 4

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

Supplementary Files

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