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Determination of water quality in the Köprüçay river (Antalya-Türkiye) using various epilithic diatom and water quality indices

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Abstract This study, carried out seasonally between October-2019 and July-2020, aimed to determine the water quality using some water and epilithic diatom indices of the Köprüçay River. It is located in the south of Türkiye and used for tourism, irrigation and drinking water. Ammonium nitrogen (NH_4–N), nitrate nitrogen (NO_3–N), sulfate (SO_4^{-2}), bicarbonate (HCO_3^-), orthophosphate (PO_4–P), chloride (Cl^-), biochemical oxygen demand (BOD_5), temperature (°C), dissolved oxygen, pH, and electrical conductivity were measured. Water quality was determined according to the Surface Water Quality Regulation (SWQR) and Water Quality Index (WQI). The water quality classes of the stream, based on epilithic diatom assemblages, were determined using the Generic Diatom Index (GDI), Saprobi Index (SI), Trophic Index (TI), Swiss Diatom Index (DI-CH), and Trophic Diatom Index (TDI). According to SWQR, the average values of the parameters at all sites were generally in the class I or II (high quality or lightly polluted water). WQI, was calculated based on seasonal and site and all results were determined as “excellent water”. 117 taxa belonging to 51 genera of epilithic diatoms were observed in the Köprüçay River. According to epilithic diatoms, generally all sites were in the range of very slightly polluted or partially polluted (I and II) water quality classes.

Keywords Epilithic · Diatom · Water pollution · Water Quality Index · Biological monitoring · Köprüçay River

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Introduction

The importance of environmental pollution, which is one of the many environmental problems existing today, is increasing. Technological developments have very positive effects on society, but they are also known to cause many negative effects on the environment. For this reason, the most important problem of the twentieth century for humanity was environmental pollution (Gönülol and Obalı 1986). The rapid increase in population and the consequent increase in agriculture and animal husbandry activities, domestic and industrial wastes cause continuous

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pollution in the world (Wetzel 2001; Uysal et al. 2009; Doherty et al. 2010). Many human activities, such as the accumulation of natural water resources in certain areas for various purposes (such as electrical energy production and irrigation), pesticides, industrial wastes, problems in urban waste management and the increase in urbanization, have caused water pollution and have become a serious threat to freshwater systems (Tekin-Özan 2005; Amoatey and Baawain 2019). This situation causes decrease in clean, reliable, high quality and usable water day by day. In addition to the use of water in different areas, population growth has led to an increase in the need for clean and usable water. However, the decrease in the quality of water because of pollution for various reasons makes it difficult for living things to access usable water. Since water is essential for life, it has become important and necessary to conducting studies monitoring and protecting its quality all over the world. Therefore, there has been an increase in studies which investigate the physical, chemical and biological properties of water in order to determine water quality and protect wetlands in recent years (Tepe 2009; Poonam et al. 2013; Mutlu et al. 2016; Zeybek 2017; Tian et al. 2020; Varol 2020; Soeprobowati et al. 2022; Ferdoushi et al. 2023; Patel et al. 2023; Ravindra et al. 2023; Savcı 2023; Şener et al. 2023; Shi et al. 2024; Özçelik and Tekin-Özan 2024; Tekin-Özan et al. 2024).

While physical and chemical examinations in some studies provide information about the instantaneous state of the water, biological examinations provide information about the long-term state of the water. Consequently, biological studies are crucial for determining water quality (Göksu 2003). Thus, using physical and chemical data to support biological examinations provides a holistic understanding of the study area.

In recent years, water quality indices have begun to be used to analyze the potential of water resources in studies conducted with physical and chemical data, in addition to evaluations according to national and international standards (Judran and Kumar 2020; Canbaz 2022; Şener and Şener 2022; Şimşek et al. 2022; Patel et al. 2023; Ravindra et al. 2023; Selvi 2023; Tekin-Özan et al. 2024). Water quality indices make evaluations more understandable and easier by ensuring that a large number of data determined in studies are in the form of single numbers (Taner 2007; Şahin 2018). This feature of the indices explains the reason why studies using water quality indices have become widespread.

Since algae used in biological studies are the primary producers of aquatic systems, determining the biodiversity of aquatic systems becomes even more important and necessary. Diatoms are a large group of algae that are widely used today in water quality studies of streams (Lange-Bertalot 1978; Steinberg and Schiefele 1988; Kalyoncu et al. 2004; Atazadeh 2007; Solak and Acs 2011; Atabay 2018; Mestik 2019; Boz 2022; Yıldız 2022; Gümüş 2023; Ogan 2023; Buçinca et al. 2024; Jin et al. 2024). Diatoms, which are of great biological importance, are also important ecologically and economically. Diatoms, also defined as photosynthetic algae, are known to live in a wide variety of aquatic environments (Çetin and Taş 2012). Diatoms exhibit diverse distribution patterns in aquatic environments, and are classified based on their substrate association as epiphytic (attached to plants), epizoic (attached to animals), epilithic (attached to rocks), epipelic (associated with sediments), and episammic (associated with sand) (Weitzel 1979; Aykut 2021). Diatoms are primarily used in studies to determine water quality because they collectively respond to environmental conditions in aquatic systems. At the same time, it is mostly preferred in studies when tolerance values vary from species to species (Kelly and Whitton 1995).

Considering all the reasons, studies carried out to determine the pollution level, water quality and diatom flora in streams are very important. In this study, epilithic diatoms were selected to determine water quality. Epilithic diatoms adhere to hard surfaces, primarily rocks, in freshwater environments and play a crucial role as bioindicators of water quality. Their unique habitats and morphological adaptations enable them to thrive in various ecological conditions and significantly contribute to primary production in aquatic ecosystems. Furthermore, they exhibit a sensitive response to changes in various environmental parameters, such as pH and pollution. Consequently, epilithic diatoms effectively reflect the ecological health of their environment, making them essential for freshwater quality and biomonitoring studies (Biology Notes Online 2023; Britannica 2023; LivetoPlant 2023). The utilization of physical and chemical parameters to supplement these crucial epilithic diatom data provides a comprehensive analysis, while the evaluation through various indices enhances the clarity and comprehensibility of the study.

This study aims to identify the epilithic diatom flora and some physical and chemical parameters of the Köprüçay River. Furthermore, this research seeks to compare the results with national and international water quality standards, to determine water quality based on physical and chemical parameters and diatom species using various indices, and to detect the relationships between physical and chemical parameters and diatom species using statistical analyses.

Materials and methods

Study area

Köprüçay River starts near the Sütçüler district of Isparta province and flows into the Mediterranean from the Serik district of Antalya province. Köprülü Canyon National Park, situated within the study area, is characterized by its diverse natural features. Furthermore, the substantial flow rate of the river within the canyon holds significant importance for rafting and water sports. Moreover, the river is highly valued for its multifaceted uses, including irrigation, aquaculture facilities, and tourism, which contribute significantly to the local economy. Consequently, the river is susceptible to anthropogenic pressures.

Sampling locations

Ten sites were selected along the Köprüçay River. At each site, physical and chemical parameters were measured, and epilithic diatom samples were collected to evaluate water quality. The study area and sites locations are shown in Fig. 1, while field photographs of the ten sites are given in Figs. 2, 3, 4, 5 and 6.

Site 1: This site within the borders of Isparta is located at an altitude of 1260 m and just after the

Fig. 1 Study Area; Köprüçay River and Sites

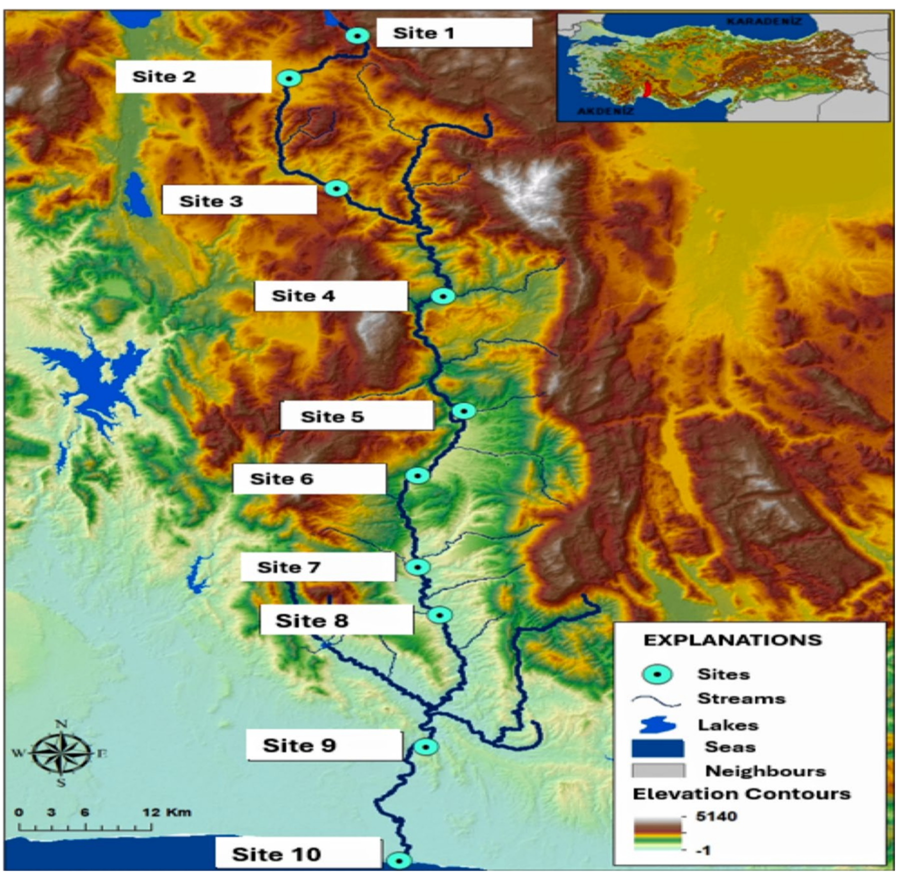

Fig. 2 Photos of Site 1 and 2

Fig. 3 Photos of Site 3 and 4

Fig. 4 Photos of Site 5 and 6

Fig. 5 Photos of Site 7 and 8

Fig. 6 Photos of Site 9 and 10

Sorgun Dam (Fig. 2). The bottom structure is stony and there is no settlement nearby.

Site 2: The second site with an altitude of 1190 m is located near Isparta-Pazarköy (Fig. 2). The bottom structure consists of sand and stones and there are trees around the site. It was also observed that there were fish farms between it and the first site.

Site 3: The altitude of this site, which is surrounded by bushes and trees, is 1070 m (Fig. 3). A road passes close to this site and there are no settlements nearby.

Site 4: This site is located in the area of Kasımlar Hydroelectric Power Plant (HPP) and its altitude is 760 m (Fig. 3). The bottom structure is stony and the water levels vary from time to time according to the amount of water released from the power plant.

Site 5: It is a large tributary formed by springs coming from the village of Değirmenözü within the borders of Antalya province (Fig. 4). The altitude is 520 m and there are large and small stones in the bottom structure.

Site 6: At this site located at 430 m altitude, it was observed that there was no flow in the autumn season and ponding occurred accordingly (Fig. 4). On the contrary, it was observed that the water level increased considerably and the flow accelerated especially in winter and spring seasons. According to the information obtained from the residents, the periodic closure of the dams located before this site causes the water level to decrease considerably in the summer and fall seasons.

Site 7: This site with an altitude of 170 m is located in Köprülü Canyon National Park (Fig. 5). The stream bed is wide and the current is quite high. Rafting is practiced in this area and there are plenty of restaurants around.

Site 8: Starting at the site 7, rafting sport continues in this site 8 (Fig. 5). The depth is high in most of this site with an altitude of 120 m.

Site 9: This site with an altitude of 90 m is located near Antalya Sarıabalı (Fig. 6). Citrus groves and greenhouses were observed around the site. In some seasons, people were seen having picnic on the banks of the river.

Site 10: This site, located at sea level, is a river mouth (Fig. 6). Fishing shelters and boats were observed in the vicinity.

Collection and storage of samples

Field work was carried out in during four seasons: Autumn-2020, Winter-2021, Spring-2021, and Summer-2021. Water samples were collected from midstream at each site using 1-L colored polyethylene bottles. 11 parameters were examined in water samples: temperature (°C), dissolved oxygen (mg/L), pH, electrical conductivity (µS/cm), ammonium nitrogen (NH_4–N), nitrate nitrogen (NO_3–N), sulfate (SO_4^{-2}), bicarbonate (HCO_3^-), orthophosphate (PO_4–P), chloride (Cl^-) and biochemical oxygen demand (BOD_5). Dissolved oxygen, temperature, pH, and electrical conductivity values were measured in using YSI 556 MPS multiparameter instrument (YSI Inc., Yellow Springs, OH, USA) during the field study. Biochemical oxygen demand (BOD_5) was measured at the Süleyman Demirel University Biological Monitoring Laboratory. Other analyses, including ammonium nitrogen (NH_4–N) (spectrophotometric), bicarbonate (HCO_3^-) (titrimetric), sulfate (SO_4^{-2}), nitrate nitrogen (NO_3–N), orthophosphate (PO_4–P), and chloride (Cl^-) (ion chromatography), were conducted by the Süleyman Demirel University Geothermal Energy, Groundwater, and Mineral Resources Research and Application Center.

To collect epilithic diatom samples from the sites, stones resistant to water flow were selected. A 25 cm^2 area was scraped from each stone, and the samples were placed in sterile collection containers. Subsequently, a 4% formaldehyde solution was added (Kelly 2000). Then, equal volumes of nitric acid (HNO_3) and sulfuric acid (H_2SO_4) mixture were added to the diatom samples, brought to Süleyman Demirel University Biological Monitoring Laboratory and boiled on the hot plate in the fume hood. After boiling, the samples were washed with distilled water to remove acidity. Leica light microscope with 10×100 magnification was used to examine the diatoms and various sources were used for identification (Krammer and Lange-Bertalot 1986, 1988, 1991a, b). The algaebase database was utilized to compile the taxon list (Guiry and Guiry 2023). At least 400 frustules were counted in each sample collected across all sites.

Determination of water quality based on physical and chemical data

Surface Water Quality Regulation (SWQR) (Anonymous 2021) and Water Pollution Control Regulation (WPCR) (Anonymous 2008) were used to determine water quality according to physical and chemical parameters. In addition, a comparison was made with the drinking water quality standards in WHO (2008), EPA (2018), EU (2020) and TSE (2005).

According to SWQR and WPCR, class I is considered as high quality water, class II as slightly polluted water, class III as polluted water, and class IV as highly polluted water.

Water quality ındex (WQI)

Water quality index (WQI), first used by Horton (1965), is an index applied to reveal the usability of water resources for drinking and potable water purposes (Varol and Şekerci 2018; Ustaoğlu et al. 2020; Canbaz 2022). In this study, 4 stages were followed while calculating WQI and water quality standard values of the parameters used according to WHO (2008) and TSE (2005) were used.

In the first step, 9 parameters (pH, EC, NH_4, NO_3, PO_4, SO_4, HCO_3, Cl, BOD_5) were used to determine the water quality of the Köprüçay River for using as drinking water. Then, a weight value (wi) is assigned to each of these parameters. This weight value should be from 1 to 5. When assigning weight values, the most important ones in determining water quality are assigned as 5 and the least important ones as 1 (Varol and Davraz 2015; Varol and Şekerci 2018; Judran and Kumar 2020).

In the second step, the wi values of each parameter in Table 1 were used when calculating the relative weight value.

$$Wi = \frac{\mathrm{wi}}{\sum_{i=1}^{n} \mathrm{wi}} \quad (1)$$

In the third step, the concentration (Ci) of each parameter measured in the water sample is multiplied by 100 by proportioning it to the quality standards (Si) in WHO (2008) and TSE (2005). The value found as a result of this process is called the rating scale (qi) (Varol and Davraz 2015; Varol and Şekerci 2018; Şener and Şener 2022). These calculations are made according to the following equation.

$$q_i = \mathrm{C_i}/\mathrm{S_i} \times 100 \quad (2)$$

In the fourth step, the sub-index (SI_i) value is determined for each parameter. When calculating this value, W_i (relative weight value) and qi (quality evaluation scale) values are multiplied. Then, to calculate WQI, the sum of the sub-index values is taken using the following equation (Şener and Şener 2022).

$$SI_i = \mathrm{W_i} \times \mathrm{q_i} \quad (3)$$

$$WQI = \sum \mathrm{SIi} \quad (4)$$

When determining water type according to WQI values, 5 classes were considered; $WQI < 50$ (Excellent water), $50 \leq WQI < 100.1$ (Good water), $100 < WQI < 200.1$ (Poor water), $200 < WQI < 300.1$ (Very poor water), $WQI > 300$ (Not suitable for drinking water) (Sahu and Sikdar 2008).

Determination of water quality based on epilithic diatoms

Currently, various diatom indices exist that facilitate the comprehension of eutrophication, organic pollution, or the status of specific pollutants in aquatic environments. While the majority of these indices are utilized globally, transcending their regional origins, some studies have focused on developing regional diatom indices, adopting similar methodological approaches (Kelly and Whitton 1995; Tang et al. 2006; Duong et al. 2007; Oeding and Taffs 2017; Torres-Franco et al. 2019; Liu et al. 2022). The universal distribution of diatom species has led to the acknowledgment of the effective applicability of diatom-based indices across diverse geographical regions (Lane et al. 2009; Mangadze et al. 2019; Liu et al. 2022).

While calculating water quality based on epilithic diatoms in Köprüçay River, Saprobi Index (SI) according to Rott et al. (1997), Trofi Index (TI) according to Schmedtje et al. (1998), Swiss Diatom Index (DI-CH) according to Buwal (2002), Trophic Diatom Index (TDI) according to Coring et al. (1999), Trophic Diatom Index (TDI) according to Kelly and Whitton (1995), and Generic Diatom Index (GDI) according to Rumeau and Coste (1988) were used. These indices, aligned with the study's objective, utilize the unique characteristics

Table 1 Weight and relative weight values of parameters

Parameters	WHO (2008)	TSE (2005)	Weight value (wi)	Relative weight value (Wi)
pH	6.5–8.5	6.5–9.5	4	0.1025
EC	–	2500	4	0.1025
NH_4-N	1.5	0.5	5	0.1282
NO_3-N	50	50	5	0.1282
PO_4-P	–	–	5	0.1282
SO_4^{-2}	250	250	5	0.1282
HCO_3^-	–	500	1	0.0256
Cl^-	250	250	5	0.1282
BOD_5	5	–	5	0.1282
			$\sum wi = 39$	

Table 2 Saprobi Index scale (Vogel 2004)

SI	Saprobic stages	Quality class	Pollution
1.0–1.34	Oligosaprob	I	Very slightly dirty
1.35–1.74	Oligo-bis β-mezosaprob	I–II	Slightly dirty
1.75–2.14	β-mezosaprob	II	Partially dirty
2.15–2.54	β-α-mezosaprob	II–III	Heavily partially dirty
2.55–3.04	α-mezosaprob	III	Heavily dirty
3.05–3.44	α-mezo- bis polisaprob	III–IV	Almost extremely dirty
3.45–4.0	Polisaprob	IV	Extremely dirty

Table 3 Trofi Index scale (Vogel 2004)

TI	Trophic stages	Quality class	Pollution
1.0–1.24	Oligotroph	I	Slight
1.25–1.74	Mesotroph	I–II	Moderate
1.75–2.24	Eutroph	II	Significant
2.25–2.74	Eu-Polytroph	II–III	Critical
2.75–3.24	Polytroph	III	Heavy
3.25–3.74	Poly-hypertroph	III–IV	Very heavy
3.75–4.0	Hypertroph	IV	Excessive

of diatom species distributions to provide insights into the health of aquatic ecosystems.

Biotic indices were calculated according to the formula created by Zelinka and Marvan (1961) and given below. The differences between the indices are due to the difference in index and indicator values.

$$Index\ Value = \frac{\sum_{i=1}^{n} X_i.Y_i.Z_i}{\sum_{i=1}^{n} Y_i.Z_i} \quad (5)$$

Xi: Index value of the taxon; Yi: Indicator value of the taxon; Zi: Density of the taxon, n: Number of taxa.

The values of X and Y vary across the indices. These values are based on Vogel (2004).

While calculating according to TDI (Kelly and Whitton 1995), the following formula was used in addition to the first formula to reach the result:

$$(\text{Index Value} \times 25) - 25 \quad (6)$$

In the GDI, the result obtained from the first formula is multiplied by 4.

Finally, the biotic index results were evaluated according to the scales given below for each index (Tables 2, 3, 4, 5, 6, 7).

Table 4 Swiss Diatom Index scale (Vogel 2004; Hürlimann and Niederhauser 2007; Apothéloz-Perret-Gentil et al. 2020)

DI-CH	Quality class	Situation
1.0–1.49	1	Very good
1.5–2.49	2	Very good
2.5–3.49	3	Very good
3.5–4.49	4	Good
4.5–5.49	5	Average
5.5–6.49	6	Bad
6.5–7.49	7	Bad
7.5–8.0	8	Bad

Table 5 Trophic Diatom Index scale (Vogel 2004)

TDI	Trophic stages	Quality class	Pollution
< 1.85	Oligotroph	I	Very slightly
1.75–2.40	Mesotroph	I–II	Slightly
2.30–2.75	Eutroph	II	Partially
2.65–3.05	Eu-Polytroph	II–III	Heavily partially
2.95–3.25	Polytroph	III	Heavily
3.15–3.50	Poly-saprotroph	III–IV	Almost extremely
> 3.40	Saprotroph	IV	Extremely

Table 6 Trophic Diatom Index scale (Kelly and Whitton 1995)

TDI	Trophic stages	Quality class	Pollution
< 35	Oligotrophic	I	High
35–50	Oligo-mesotrophic	II	Good
50–60	Mesotrophic	III	Average
60–75	Eutrophic	IV	Poor
> 75	Hypertrophic	V	Weak

Table 7 Generic Diatom Index scale (Szczepocka et al. 2014)

GDI	Ecological situation	Quality class
> 17	Very Good	I
14–17	Good	II
11–14	Average	III
8–11	Poor	IV
< 8	Bad	V

Statistical analysis

SPSS 22 statistical program was uesd for statistical analyses. Pearson Correlation Coefficient (PCC) (Pearson 1900) was used to determine the relationship between physical and chemical parameters and diatoms. Repeated Measures ANOVA was used for graphs.

Indices

In this study, frequency, dominance, similarity, and diversity analyzes were used. In the similarity analysis application Sørensen Similarity Index (Krebs 1989) was used, while Margalef Diversity Index (Margalef 1957) and the Shannon Diversity Index (Shannon-Weiner Diversity Index) (Shannon 1948) were used for diversity analysis calculations. It is known that species are examined in 5 levels in terms of frequency. In this case, 1–20%: Very rare, 21–40%: Rarely found, 41–60%: Usually found, 61–80%: Often found, 81–100%: Always found (Kocataş 2014).

Frequency represents the percentage of a species occurrence within the study area and is calculated using the following formula.

$$Frequency(F) = \frac{\mathrm{N_a}}{\mathrm{N_n}} \times 100 \tag{7}$$

Na = the number of samples containing species a; Nn = the total number of samples.

Based on the results of the calculations, species are evaluated as follows: 1–20%: very rare, 21–40%: rare, 41–60%: common, 61–80%: frequent, 81–100%: constantly present (Kocataş 2014).

Dominance is expressed as the percentage of the ratio of the number of individuals of a species to the total number of individuals of all species. Overall dominance was assessed by calculating the percentage of a species' total number of individuals across all samples relative to the total number of individuals of all species across all samples. Furthermore, dominance was also evaluated for each site based on the total across all four seasons. A dominant species is defined as the most prominent element within a community. Dominance calculations are performed according to the following formula.

$$Dominance(D) = \frac{\mathrm{N_A}}{\mathrm{N_N}} \times 100 \tag{8}$$

$\mathrm{N_A}$ = The number of individuals belonging to species A; $\mathrm{N_N}$ = The total number of individuals across all species (Kocataş 2014).

Results

Physical and chemical parameters in river water

Some physical and chemical parameters were measured during the study and are shown in Table 8. Temperature ranged from 2.03 to 31.44 °C. The lowest annual average temperature was 7.87 °C at site 1, and the highest was 19.81 °C at the site 6. pH values varied from 6.65 to 8.92, with the lowest annual average of 7.23 at the site 7 and the highest of 8.06 at the site 10. Electrical conductivity ranged from 279.3 to 1195 µS/cm, with the lowest annual average of 318.85 µS/cm at the site 4 and the highest of 819.43 µS/cm at the site 10. Dissolved oxygen ranged from 3.9 to 9.7 mg/L, with the lowest annual average of 5.95 mg/L at the site 6 and the highest of 8.08 mg/L at the site 9. Ammonium concentrations were below the detection limit (< 0.05 mg/L) at all sites in all seasons. Nitrate concentrations ranged from 0.02 to 1.26 mg/L, with the lowest annual average of 0.15 mg/L at the site 4 and the highest of 0.61 mg/L at site 10. Orthophosphate concentrations were below the detection limit (< 0.05 mg/L) at all sites in all seasons. Sulfate concentrations ranged from 2.75 to 27.82 mg/L, with the lowest annual average of 5.24 mg/L at site 2 and the highest of 19.86 mg/L at site 10. Bicarbonate concentrations ranged from 164.7 to 366 mg/L, with the lowest annual average of 192.15 mg/L at site 4 and the highest of 291.28 mg/L at site 8. Chloride concentrations ranged from 1.52 to 193.78 mg/L, with the lowest annual average of

Table 8 Physical and chemical values of the sites (Min: minimum, Max: maximum, Mean: average, SD: Standard deviation) (Values are given as min–max, mean ± SD.)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Temp. (°C)	2.03–18.16	5.24–14.60	4.51–20.30	5.47–16.06	10.59–16.71	11.45–31.44	11.35–15.83	12.33–18.12	13.20–19.26	13.08–23.51
	7.87 ± 7.31	9.29 ± 4.67	10.62 ± 7.48	11.12 ± 5.55	13.17 ± 2.72	19.81 ± 9.45	13.17 ± 2.07	14.77 ± 2.82	15.66 ± 2.88	17.24 ± 5.09
pH	6.84–8.28	6.82–8.14	7.28–8.40	6.70–8.47	7.16–8.34	6.65–8.36	6.74–7.60	6.80–7.97	7.30–8.84	7.24–8.92
	7.57 ± 0.70	7.61 ± 0.56	7.98 ± 0.49	7.60 ± 0.80	7.82 ± 0.49	7.68 ± 0.81	7.23 ± 0.36	7.53 ± 0.55	8.03 ± 0.64	8.06 ± 0.69
EC (µS/cm)	301.90–541.10	360.1–517.1	420.4–460.2	279.3–365.0	367.7–513.3	378.6–684.0	439.0–555.0	439.1–544.7	454.1–521.7	511.4–1195.0
	391.65 ± 103.56	437.85 ± 79.89	446.98 ± 18.11	318.85 ± 38.31	428.45 ± 68.59	487.23 ± 142.98	501.23 ± 56.80	492.38 ± 50.95	487.40 ± 34.53	819.43 ± 313.60
DO (mg/L)	5.30–8.20	5.00–8.20	4.50–7.50	5.50–8.80	5.70–8.40	3.90–8.50	4.50–9.50	5.60–8.60	6.40–9.70	4.80–8.50
	6.28 ± 1.35	6.65 ± 1.46	6.33 ± 1.46	7.33 ± 1.59	7.18 ± 1.33	5.95 ± 2.31	6.78 ± 2.33	7.30 ± 1.31	8.08 ± 1.35	6.448 ± 1.54
NH_4-N (mg/L)	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05
NO_3-N (mg/L)	0.02–0.38	0.28–0.56	0.05–0.38	0.03–0.23	0.20–0.41	0.16–0.33	0.37–0.56	0.33–0.48	0.34–0.43	0.37–1.26
	0.22 ± 0.17	0.39 ± 0.12	0.19 ± 0.14	0.15 ± 0.08	0.31 ± 0.09	0.23 ± 0.08	0.46 ± 0.09	0.41 ± 0.08	0.41 ± 0.04	0.61 ± 0.44
PO_4-P (mg/L)	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05
SO_4^{-2} (mg/L)	4.10–6.94	4.49–5.55	4.30–7.02	4.34–7.15	2.75–10.95	7.14–8.32	7.06–8.56	6.93–8.62	8.25–8.88	13.21–27.82
	5.96 ± 1.27	5.24 ± 0.50	5.44 ± 1.20	5.77 ± 1.59	6.83 ± 4.19	7.63 ± 0.50	7.82 ± 0.67	7.85 ± 0.70	8.50 ± 0.28	19.86 ± 7.64
HCO_3^- (mg/L)	170.80–274.50	213.5–298.9	244.0–268.4	164.7–237.9	207.4–292.8	231.80–366.00	244.0–317.2	262.3–317.2	244.0–298.9	262.30–298.90
	215.03 ± 44.37	237.90 ± 41.07	259.25 ± 11.68	192.15 ± 32.09	250.10 ± 37.93	280.60 ± 63.78	280.60 ± 35.92	291.28 ± 26.99	268.40 ± 23.89	279.08 ± 16.80
Cl^- (mg/L)	1.52–2.42	1.73–2.32	2.39–3.26	1.96–3.61	2.89–3.20	3.15–3.29	3.46–4.41	3.55–4.39	3.86–4.46	13.05–193.78
	1.78 ± 0.48	2.02 ± 0.25	2.92 ± 0.39	2.77 ± 0.77	3.08 ± 0.14	3.21 ± 0.06	3.92 ± 0.45	3.95 ± 0.41	4.10 ± 0.29	100.89 ± 87.21
BOD_5 (mg/L)	0.35–2.20	0.74–4.10	0.30–2.40	0.60–3.60	0.24–3.40	0.30–3.50	0.17–4.70	0.14–2.80	1.40–4.10	0.25–2.20
	1.24 ± 0.82	1.89 ± 1.51	1.25 ± 0.97	2.10 ± 1.29	1.91 ± 1.30	1.41 ± 1.51	1.94 ± 1.96	1.54 ± 1.09	2.33 ± 1.27	1.39 ± 0.82

1.78 mg/L at site 1 and the highest of 100.89 mg/L at site 10. BOD_5 ranged from 0.14 to 4.7 mg/L, with the lowest annual average of 0.14 mg/L at site 8 and the highest of 4.70 mg/L at site 7.

In addition, in order to see the seasonal variation of physical and chemical parameters and their relationship with each other more clearly, the plots of the Repeated Measures ANOVA are given in Fig. 7.

Table 9 presents the water quality classification based on the annual average values of physical and chemical parameters. The water quality classes, as defined by the SWQR, are: class I, high quality water (Excellent); class II, slightly polluted water (Good); and class III, dirty water (Medium) (Anonymous 2021). Furthermore, Table 4 compares the average values with drinking water quality standards established by the WHO (2008), EPA (2018), EU (2020), and TSE (2005).

pH, electrical conductivity, NO_3–N, SO_4, Cl, and BOD_5 values were used in WQI calculations. WQI values and water types of the results obtained from these calculations according to sites and seasons were given in Table 10. As a result of the evaluations, it was determined that all sites in the study area were "excellent water" type.

Biological results

Diatom sampling was done seasonally at 10 sites selected on the Köprüçay River and 117 epilithic diatom taxa belonging to 51 genera were detected. The genus with the highest number of species was *Nitzschia* with 11 species. The sites where the determined taxa were found and their frequency (%) were given in Table 11. *Achnanthidium minutissimum* and *Cocconeis euglypta* were observed at 100% frequency (consistently) at each site.

Among the 117 taxa identified, *Achnanthidium minutissimum* (48.64%) was the most dominant taxon according to the overall dominance assessment. This taxon was followed by *Diatoma moniliformis* (6.37%), *Gomphonella olivacea* (4.93%), *Cymbella affinis* (4.85%), *Cocconeis euglypta* (3.89%), *Encyonema minutum* (3.52%), *Navicula gregaria* (2.75%), *Nitzschia dissipata* (2.14%), *Cymbella cistula* (1.89%), and *Diatoma vulgaris* (1.73%). Furthermore, calculations based on the total of all samples collected across the four seasons for each site also indicated *Achnanthidium minutissimum* as the most dominant taxon in every site. Analysis using the Sørensen Similarity Index revealed the highest similarity between sites 9 and 10 (82%), while the lowest similarity was observed between sites 3 and 7 (65%). The Margalef Diversity Index indicated the lowest diversity at site 6 during autumn (5.62) and the highest diversity at site 9 during winter (15.65). Furthermore, the Shannon Diversity Index determined that the lowest diversity was at site 6 during winter (0.75), and the highest diversity was at site 8 during the same season (2.70). In this study, water quality classes according to the seasonal averages of the sites obtained from the biotic index calculations used to determine the organic pollution of the Köprüçay River were given in Table 12.

Statistical analysis results

Pearson Correlation Coefficient (PCC) was used to determine the correlation between physical and chemical parameters and diatom dominance (Table 13). To calculate PCC, 9 physical and chemical parameters and 10 most dominant species identified in the study were used. Negative significant correlations were determined between temperature and *Achnanthidium minutissimum, Cocconeis euglypta, Cymbella cistula, Gomphonella olivacea, Nitzschia dissipata*, pH and *Cocconeis euglypta, Cymbella affinis, Diatoma moniliformis, Encyonema minutum, Navicula gregaria, Nitzschia dissipata*, electrical conductivity and *Achnanthidium minutissimum, Cocconeis euglypta, Cymbella cistula, Encyonema minutum*, dissolved oxygen and *Cocconeis euglypta, Cymbella affinis, Encyonema minutum, Navicula gregaria*, nitrate nitrogen and *Cocconeis euglypta, Cymbella cistula, Diatoma moniliformis, Gomphonella olivacea, Navicula gregaria*, sulphate and *Achnanthidium minutissimum, Cocconeis euglypta, Encyonema minutum*, HCO_3 and *Achnanthidium minutissimum, Cocconeis euglypta, Gomphonella olivacea*, Cl and *Achnanthidium minutissimum, Cocconeis euglypta, Cymbella cistula, Encyonema minutum, Navicula gregaria, Nitzschia dissipata*, BOD_5 and *Cocconeis euglypta, Cymbella affinis, Diatoma vulgaris, Encyonema minutum, Navicula gregaria*. Other relationships between parameters and diatoms were positive. Significant relationships were determined between some physical and chemical parameters and diatoms as a result of PCC analysis. Significant differences were found between

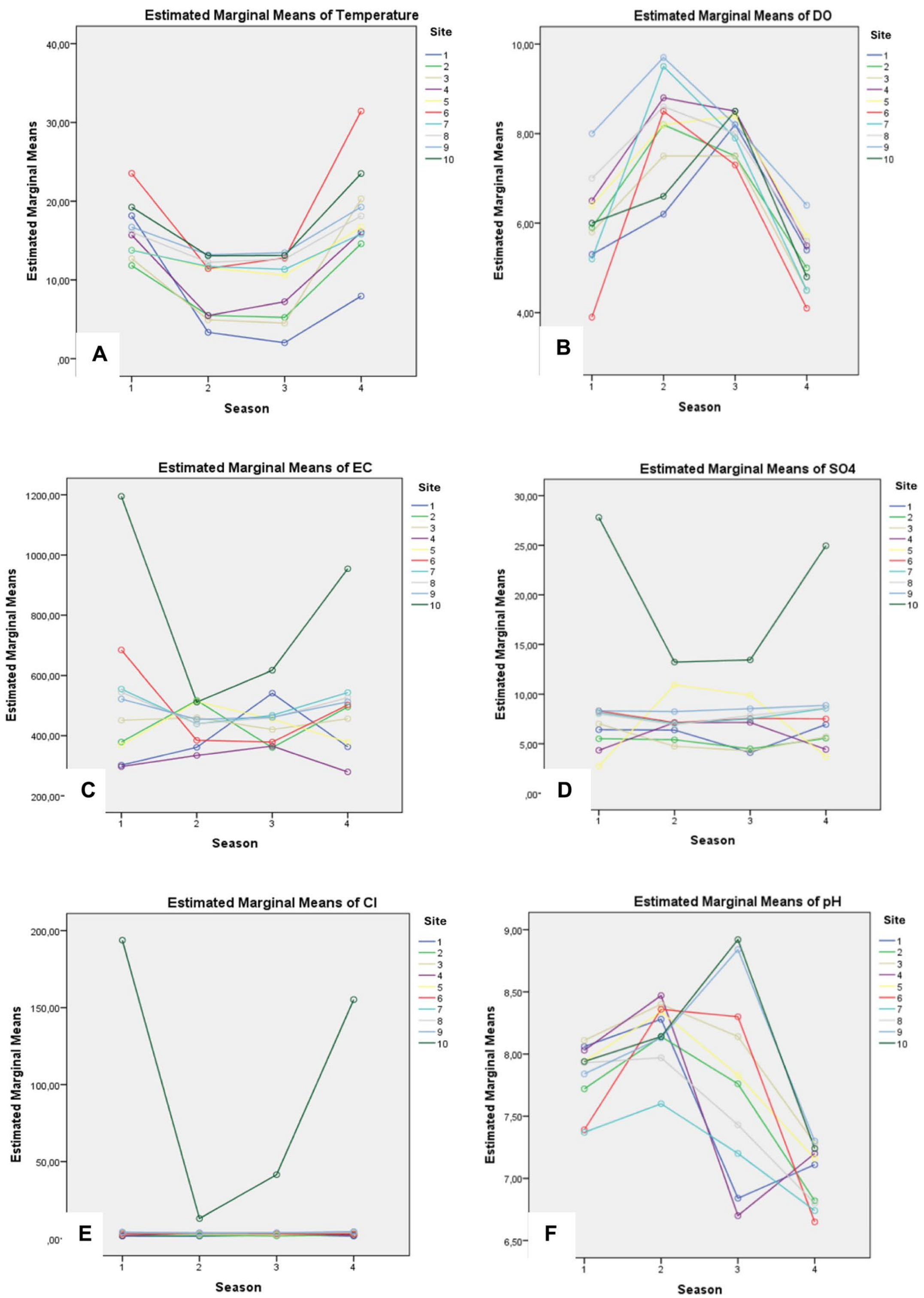

Fig. 7 Seasonal variation of physical and chemical parameters: **A** Temperature, **B** Dissolved Oxygen, **C** Electrical Conductivity, **D** Sulfate, **E** Chloride, **F** pH, **G** Nitrate Nitrogen, **H** Bicarbonate, **I** Biochemical Oxygen Demand (Season 1: Autumn, 2: Winter, 3: Spring, 4: Summer)

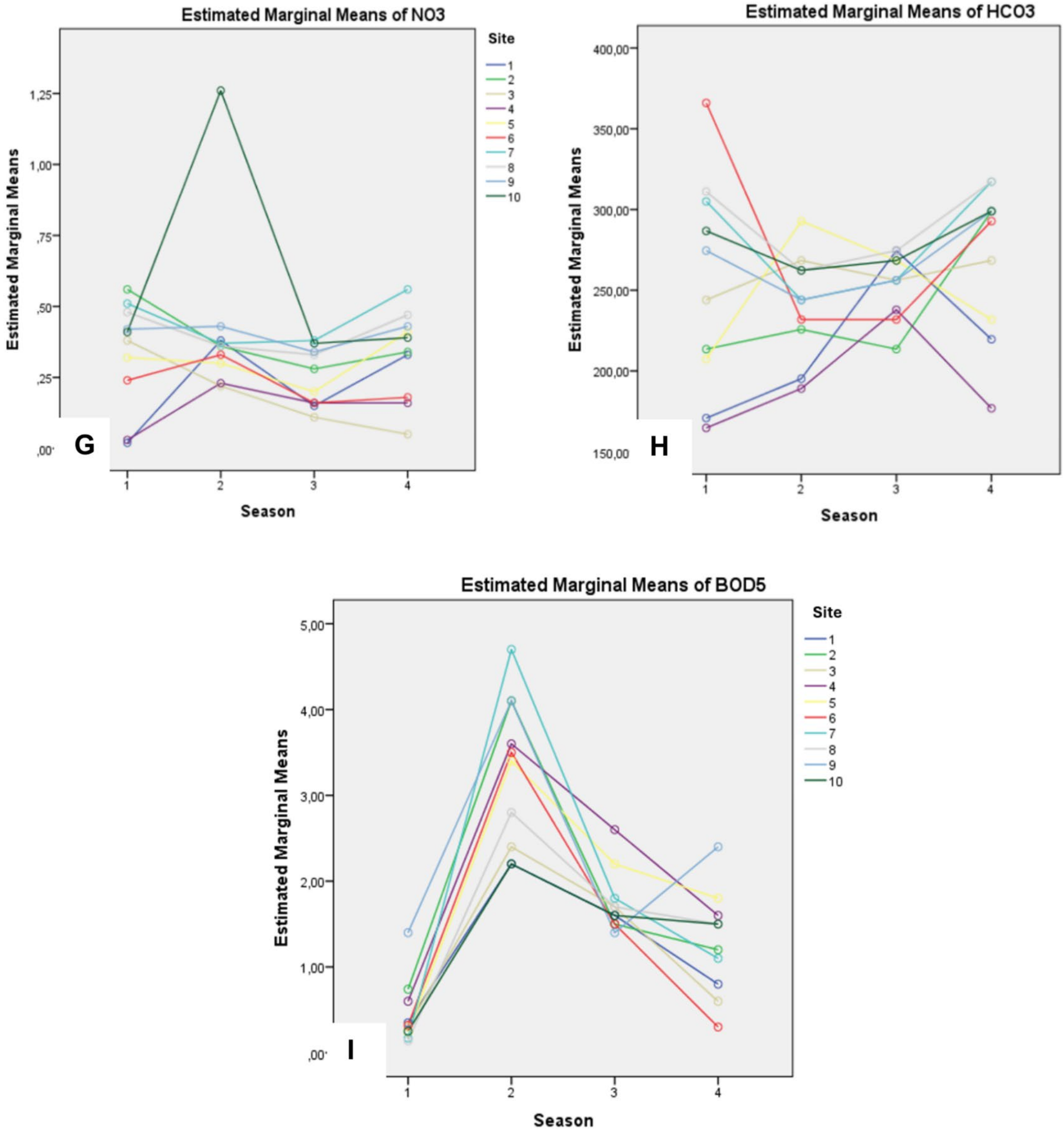

Fig. 7 (continued)

temperature and *Cymbella affinis*; electrical conductivity and *Diatoma vulgaris*; dissolved oxygen and *Cymbella cistula*, *Navicula gregaria*; SO_4 and *Diatoma moniliformis*; HCO_3 and *Navicula gregaria*; BOD_5 and *Gomphonella olivacea* at 0.05 level, while significant differences were found between *Cymbella affinis* and electrical conductivity, SO_4, Cl, *Diatoma vulgaris* and SO_4, Cl; *Gomphonella olivacea* and dissolved oxygen at 0.01 level.

Discussion

Temperature in the Köprüçay River ranged from 2.03 °C at site 1–31.44 °C at site 6. Temperature values are typically lower at the beginning of the stream (Schmitz 1954). In this study, the lowest values were generally observed at the site closest to the starting point of the stream. Other studies reported temperatures ranging from 9.5 to 26 °C in Kocaçay

Table 9 Water quality classes according to physical and chemical parameters and WHO (2008), EPA (2018), EU (2020) and TSE (2005) drinking water quality standards

Sıtes		Parameters									
		Temperature (˚C)	pH	E.C. (μS/cm)	D.O. (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)	$SO_4{}^{-2}$ (mg/L)	Cl^- (mg/L)	BOD_5 (mg/L)
Site 1	Value	7.87	7.57	391.6	6.28	< 0.05	0.22	< 0.05	5.96	1.78	1.24
	SWQR	I	I	I	II	I	I	I	I	I	I
Site 2	Value	9.29	7.61	437.8	6.65	< 0.05	0.39	< 0.05	5.24	2.02	1.89
	SWQR	I	I	II	I	I	I	I	I	I	I
Site 3	Value	10.6	8	446.9	6	< 0.05	0.19	< 0.05	5.44	2.92	1.25
	SWQR	I	I	II	II	I	I	I	I	I	I
Site 4	Value	11.12	7.6	318.8	7.33	< 0.05	0.15	< 0.05	5.77	2.77	2.1
	SWQR	I	I	I	II	I	I	I	I	I	I
Site 5	Value	13.17	7.82	428.4	7.18	< 0.05	0.31	< 0.05	6.83	3.08	1.91
	SWQR	I	I	II	II	I	I	I	I	I	I
Site 6	Value	19.81	7.68	487.2	5.95	< 0.05	0.23	< 0.05	7.63	3.21	1.41
	SWQR	I	I	II	III	I	I	I	I	I	I
Site 7	Value	13.17	7.23	501.2	6.78	< 0.05	0.46	< 0.05	7.82	3.92	1.94
	SWQR	I	I	II	II	I	I	I	I	I	I
Site 8	Value	14.77	7.53	492.3	7.3	< 0.05	0.41	< 0.05	7.85	3.95	1.54
	SWQR	I	I	II	II	I	I	I	I	I	I
Site 9	Value	15.66	8.03	487.4	8.08	< 0.05	0.41	< 0.05	8.5	4.1	2.33
	SWQR	I	I	II	I	I	I	I	I	I	I
Site 10	Value	17.24	8.06	819.4	6.48	< 0.05	0.61	< 0.05	19.86	100.9	1.39
	SWQR	I	I	II	II	I	I	I	I	II	I
WHO (2008)	Standard	–	6.5–8.5	–	–	1.5	50	–	250	250	5*
EPA (2018)	Standard	–	6.5–8.5	–	–	–	10	–	250	250	–
EU (2020)	Standard	–	≤ 9.5–6.5 ≤	2500	–	0.5	50	–	250	250	–
TSE (2005)	Standard	–	6.5–9.5	2500	–	0.5	50	–	250	250	–

[*] Alobaidy et al. (2010), Şener et al. (2019)

Table 10 WQI values and water types of Köprüçay River according to sites and seasons

Sites and seasons	WQI	Water type
Site 1	16.69156	Excellent water
Site 2	18.72712	Excellent water
Site 3	17.76178	Excellent water
Site 4	18.54614	Excellent water
Site 5	19.21565	Excellent water
Site 6	18.15024	Excellent water
Site 7	19.07827	Excellent water
Site 8	18.46085	Excellent water
Site 9	21.06519	Excellent water
Site 10	25.72063	Excellent water
Autumn	17.01116	Excellent water
Winter	23.41365	Excellent water
Spring	19.13057	Excellent water
Summer	17.81159	Excellent water

(Balıkesir) (Çelik 2022), 6.7–17.9 °C in İsrafil Stream (Denizli) (Akar 2023), and 13.63–31.23 °C in Gorveshwari River, Bangladesh (Ferdoushi et al. 2023). It was observed that the lowest temperature of the Köprüçay River is quite low compared to the data in other studies. It was thought that this is due to the fact that the site where the lowest temperature was determined is at a high altitude and the climate of the region where it was located. It was estimated that the reason for the very high values measured at the site 6, where the highest temperature was seen, was that the dam gates located before this site were closed during certain periods and a large amount of water was withdrawn for irrigation purposes.

pH values outside the range of 5–9 are toxic to aquatic life (Hynes 1977). pH in the Köprüçay River ranged from 6.65 at site 6–8.92 at site 10. pH ranged from 7.35 to 8.87 in Köprüçay River (Çiçek 2011), 7.23–8.95 in Eğirdir Lake (Isparta) (Kaptan and Tekin-Özan 2014), 7.16–7.35 in Karapınar Stream (Mersin) (Gülşen et al. 2021), and 6.23–8.93 in the Gorveshwari River, Bangladesh (Ferdoushi et al. 2023). It has been determined that the pH data of the Köprüçay River and other aquatic systems are different from ecah other. This difference may be due to the different geomorphology of the rivers (Şener 2010). According to other study (Çiçek 2011) conducted on the Köprüçay River and the results of this study, it was determined that the river was alkaline. In this study, the pH value was measured below 7 at a few sites only during the seasons when the water level dropped. pH values in streams were affected by the water flow and biological events in the water (Küçük 1997; Tanyolaç 2004). Due to the decrease in water level, currents and biological events slow down. pH values may have decreased for this reason.

Electrical conductivity in this study ranged from 279.3 µS/cm at site 4–1195 µS/cm at site 10. Since electrical conductivity increases with increasing salinity (Barlas and Kiriş 2004), the highest values were observed at site 10, located at the river mouth, which is influenced by seawater. Electrical conductivity ranged from 188 to 4470 µS/cm in the Köprüçay River (Çiçek 2011), 216–359 µS/cm in the Kahta Stream (Gölbaşı and Şen 2019), 983–1678 µS/cm in the Al-Gharraf River (Judran and Kumar 2020), 187–986 µS/cm in streams feeding İznik Lake (Savcı 2023), and 162–8990 in the Fetzara Lake (Algeria) (Zahi et al. 2024). These variations can be attributed to factors such as proximity to the sea and the degree of seawater influence.

Dissolved oxygen ranged from 3.9 mg/L at site 6–9.7 mg/L at the site 9. As temperature increases, the solubility of oxygen in water decreases (Tanyolaç 2011). Furthermore, PCC analysis revealed a significant negative correlation between temperature and dissolved oxygen ($p < 0.01$). The measurements made at all sites except the site 6 in the autumn season, when the lowest value was measured in the Köprüçay River, confirm this information. It is thought that the dissolved oxygen value was quite low due to the decrease in the amount of water at the site 6 and the formation of ponding in the water. Dissolved oxygen ranged from 4.12 to 11.61 mg/L in the Büyük Menderes River (Baydar 2020), 5.96–12.85 mg/L in the streams feeding İznik Lake (Savcı 2023), and 7.15–9.40 mg/L in the Gorveshwari River, Bangladesh (Ferdoushi et al. 2023). It was observed that the values were similar to other studies. It was thought that the minor differences may be due to differences in current speeds in the rivers.

Although ammonium is found in trace amounts in clean waters, it increases in pollution caused by domestic and agricultural waste (Tanyolaç 2011; Göksu 2015). In this study, it is suggested that agricultural or domestic waste did not significantly contribute to NH_4-N levels in the river, as NH_4–N concentrations were below the detection limit

Table 11 Frequency values (%) in determined taxa and sites

Identified Taxa	Frequency (%)									
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Achnanthidium minutissimum	100	100	100	100	100	100	100	100	100	100
Amphipleura pellucida	25	0	25	25	0	0	0	0	0	0
Amphora copulata	75	100	100	50	50	25	50	50	75	100
Amphora ovalis	0	0	50	0	25	25	25	75	100	100
Asterionella formosa	0	0	0	75	0	0	0	0	0	0
Cocconeis euglypta	100	100	100	100	100	100	100	100	100	100
Cocconeis lineata	50	50	100	0	50	25	50	0	0	25
Cocconeis pediculus	25	50	100	50	50	25	0	100	100	100
Cocconeis placentula	100	100	100	75	100	50	75	100	100	100
Craticula ambigua	0	0	0	0	0	0	0	0	50	0
Cymatopleura elliptica	25	50	25	0	0	0	0	25	50	25
Cymbella affinis	75	100	75	75	100	100	100	100	100	100
Cymbella aspera	0	0	0	0	0	25	0	0	50	25
Cymbella cistula	25	0	25	75	50	50	50	100	100	75
Cymbella excisa	0	0	0	0	0	0	0	0	50	0
Cymbella helvetica	50	0	0	25	25	0	50	50	50	75
Cymbella neocistula	0	0	25	25	0	50	0	50	100	50
Cymbella tumida	50	25	50	25	0	25	0	0	0	75
Cymbopleura amphicephala	25	0	0	0	25	50	25	25	75	75
Cymbopleura lata	25	0	0	0	0	25	25	0	0	25
Cymbopleura naviculiformis	0	0	0	0	0	0	0	0	25	0
Denticula kuetzingii	50	25	50	75	50	75	100	75	100	100
Denticula tenuis	0	75	0	50	100	25	25	50	50	25
Diatoma ehrenbergii	0	25	25	75	25	25	25	25	25	25
Diatoma moniliformis	75	50	25	100	75	75	100	100	100	100
Diatoma vulgaris	25	100	50	75	75	50	50	75	100	100
Didymosphenia geminata	0	25	0	50	0	0	25	0	0	0
Diploneis elliptica	0	0	50	0	50	25	0	0	25	50
Diploneis ovalis	0	25	50	25	50	0	25	25	25	25
Encyonema cespitosum	0	0	0	50	25	75	25	50	75	100
Encyonema leibleinii	0	0	0	50	0	0	0	0	0	75
Encyonema minutum	100	100	100	75	100	100	100	100	100	100
Encyonema silesiacum	25	75	25	75	75	25	75	50	100	50
Encyonema ventricosum	50	50	75	25	0	25	75	25	75	50
Encyonopsis microcephala	25	0	25	25	25	75	25	75	75	100
Epithemia adnata	0	25	50	25	0	0	0	0	25	25
Epithemia sorex	25	25	50	0	0	25	0	0	0	0
Frustulia rhomboides	0	0	0	0	25	0	0	0	0	0
Frustulia vulgaris	0	25	0	0	0	25	0	0	0	25
Gogorevia exilis	25	0	25	0	0	0	0	0	0	0
Gomphonella olivacea	25	100	100	50	75	100	100	100	100	100
Gomphonema acuminatum	0	0	75	25	0	0	0	0	0	0
Gomphonema angustatum	0	0	0	0	0	0	0	0	0	25
Gomphonema angustum	0	25	25	0	50	25	25	0	0	0

Table 11 (continued)

Identified Taxa	Frequency (%) Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Gomphonema augur	25	100	0	0	25	0	25	0	0	0
Gomphonema gracile	25	0	50	25	25	25	0	0	0	0
Gomphonema insigne	25	25	50	50	75	75	50	50	50	75
Gomphonema minutum	25	50	0	50	100	50	50	75	25	0
Gomphonema parvulum	100	100	100	75	100	100	75	50	75	100
Gomphonema pumilum	50	75	100	25	100	75	50	100	25	100
Gomphonema truncatum	0	0	75	0	50	0	0	0	25	75
Grunowia tabellaria	0	0	0	25	25	25	0	0	0	25
Gyrosigma acuminatum	25	0	100	25	50	0	25	25	75	50
Gyrosigma obtusatum	0	0	25	0	25	0	0	75	50	100
Hannaea arcus	0	0	0	25	0	25	0	0	0	0
Hantzschia amphioxys	50	25	25	25	0	0	25	0	25	50
Hantzschia virgata	0	0	0	0	0	0	0	0	0	25
Hippodonta capitata	0	25	25	25	25	25	0	75	25	0
Iconella helvetica	0	0	0	0	0	0	0	0	25	25
Iconella hibernica	0	0	50	0	0	0	0	0	0	0
Iconella splendida	0	0	25	0	0	0	0	0	0	0
Karayevia amoena	0	0	0	0	0	0	0	25	0	0
Karayevia laterostrata	0	0	25	0	0	0	0	25	0	0
Lindavia bodanica	25	0	0	50	0	0	0	0	25	0
Luticola mutica	0	25	0	0	0	0	0	0	0	0
Mayamaea atomus	50	0	0	25	50	0	25	0	50	0
Mayamaea permitis	25	50	50	0	0	0	0	0	0	25
Melosira varians	25	100	75	50	50	25	75	75	100	50
Meridion circulare	50	25	50	50	75	50	50	25	75	50
Navicula capitatoradiata	0	0	0	0	0	0	0	0	0	25
Navicula cari	100	100	100	100	100	0	50	100	100	100
Navicula cryptocephala	25	75	50	50	50	25	25	50	50	50
Navicula cryptotenella	50	50	75	75	25	0	75	50	75	100
Navicula gregaria	100	50	25	50	0	50	0	25	50	75
Navicula lanceolata	50	25	0	0	0	0	25	50	50	25
Navicula radiosa	75	50	100	50	100	25	0	50	100	25
Navicula sp.	50	100	100	100	100	50	100	75	75	50
Navicula viridula	50	25	50	0	0	0	75	50	50	50
Neidium affine	25	25	0	0	50	50	0	25	75	100
Neidium hitchcockii	0	0	25	0	0	0	0	0	0	0
Nitzschia acicularis	25	0	0	0	0	0	0	0	0	0
Nitzschia dissipata	50	25	100	100	75	50	100	100	100	100
Nitzschia filiformis	0	0	0	0	0	0	50	0	25	0
Nitzschia flexa	0	0	0	0	0	0	50	25	0	0
Nitzschia heufleriana	25	50	75	25	50	0	25	50	75	50
Nitzschia linearis	25	25	25	25	0	25	0	0	25	0
Nitzschia palea	50	75	50	25	50	50	100	75	100	100
Nitzschia recta	25	25	0	25	50	25	25	0	50	0

Table 11 (continued)

Identified Taxa	Frequency (%)									
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Nitzschia scalpelliformis	0	0	0	0	0	0	0	0	0	25
Nitzschia sigma	25	0	0	0	0	0	0	25	0	75
Nitzschia sigmoidea	0	0	25	0	0	0	0	0	50	50
Odontidium anceps	0	0	0	0	0	0	0	0	0	25
Odontidium mesodon	0	25	0	25	25	25	25	0	0	0
Pantocsekiella ocellata	100	100	50	100	50	75	25	50	50	25
Pinnularia major	0	25	0	0	0	0	0	0	25	0
Placoneis clementis	0	0	0	0	0	0	0	25	0	0
Planothidium lanceolatum	25	100	25	25	0	0	0	50	0	0
Reimeria sinuata	75	100	75	100	50	25	50	50	50	25
Rhoicosphenia abbreviata	0	0	25	0	25	0	25	100	50	100
Sellaphora bacillum	25	0	25	0	0	0	50	25	75	50
Sellaphora pupula	0	25	50	25	25	25	0	25	50	50
Stauroneis anceps	25	0	0	0	0	0	0	0	0	0
Stauroneis phoenicenteron	0	0	25	0	0	0	0	0	0	0
Stauroneis smithii	50	25	50	0	25	0	0	25	0	0
Staurosirella pinnata	0	25	0	0	0	0	0	0	25	25
Staurosirella rhomboides	0	0	0	25	0	0	0	0	0	0
Stephanocyclus meneghinianus	0	0	75	0	0	0	0	0	0	0
Stephanodiscus hantzschii	0	0	0	0	0	0	0	25	0	75
Surirella angusta	50	75	100	0	50	25	0	0	25	25
Surirella brebissonii	0	50	0	0	25	0	0	0	0	25
Surirella librile	0	0	0	0	0	0	0	25	50	50
Surirella minuta	50	50	100	25	25	25	25	50	50	50
Tabularia fasciculata	25	25	100	100	50	0	75	50	75	100
Tryblionella apiculata	0	0	50	0	0	0	25	0	50	75
Tryblionella granulata	0	0	0	0	0	0	0	0	0	75
Ulnaria acus	50	0	0	50	25	50	50	0	50	25
Ulnaria ulna	75	100	75	50	75	100	100	100	75	100

(< 0.05 mg/L). NH_4–N concentrations ranged from 0.84 mg/L in the Köprüçay River (Çiçek 2011), 0–1.046 mg/L in the Elekçi Stream (Taş et al. 2021), 0–5 mg/L in the Jijel region (Algeria) (Drouiche et al. 2022), and 0.036–187 mg/L in the Murgul Stream (Osmanaoğlu and Özalp 2023). Although the lowest value was compatible with other studies, the maximum values were higher than the values in our study suggesting that there was no pollution caused by ammonium in the Köprüçay River.

The lowest NO_3–N concentration, 0.02 mg/L, was observed at site 1, and the highest, 1.26 mg/L, was observed at site 10 during winter. Although NO_3–N is found in trace amounts in clean waters, it increases due to organic pollution or as a result of the burning of fossil fuels (Gray 2008; Selek and Karaaslan 2019). NO_3–N concentrations ranged from 0 to 1.37 mg/L in the Köprüçay River (Çiçek 2011), 0.99–16.8 mg/L in the Isparta Stream (Özel et al. 2019), 0.01–0.21 mg/L in the Guenitra Dam (Algeria) (Hadef et al. 2021), 0.43–0.86 mg/L in the Kille Stream (Çelik 2023), and 1.1–4.85 mg/L in the Al-Gharraf River (Judran and Kumar 2020). Compared withthese studies, it was observed that the values were close to each other and the values were much higher than our study. It was thought that there was no organic pollution caused by NO_3–N in the Köprüçay River.

Table 12 Water quality classes of sites according to seasonal averages of biotic indices

Sites	Biotic indices											
	SI		TDI (Coring et al.)		TI		DI-CH		TDI (Kelly and Whitton)		GDI	
Site 1	I–II	Slightly	I–II	Slightly	II	Significant	4	Good	II	Good	II	Good
Site 2	II	Partially	I–II	Slightly	II	Significant	4	Good	II	Good	I	Very Good
Site 3	II	Partially	I–II	Slightly	II	Significant	4	Good	II	Good	II	Good
Site 4	II	Partially	I–II	Slightly	II	Significant	3	Very Good	II	Good	II	Good
Site 5	I–II	Slightly	I	Very Slightly	I–II	Moderate	3	Very Good	I	High	I	Very Good
Site 6	II	Partially	I–II	Slightly	II	Significant	3	Very Good	II	Good	I	Very Good
Site 7	I–II	Slightly	I–II	Slightly	II	Significant	3	Very Good	II	Good	I	Very Good
Site 8	I–II	Slightly	I–II	Slightly	II	Significant	3	Very Good	II	Good	I	Very Good
Site 9	I–II	Slightly	I–II	Slightly	II	Significant	3	Very Good	II	Good	I	Very Good
Site 10	I–II	Slightly	I–II	Slightly	II	Significant	3	Very Good	II	Good	I	Very Good

Orthophosphate (PO_4–P) is the dissolved form of phosphorus (Egemen and Sunlu 1996). When there is not enough phosphorus in natural waters, nutrient deficiency occurs and the efficiency of the system decreases accordingly (Tanyolaç 2004). In this study, all PO_4–P concentrations were below the detection limit (<0.05). PO_4–P concentrations were below the detection limit in Kargı Stream (Zeybek 2017), ranged from 1.25 to 11.3 mg/L in the Derinçay Stream (İpek 2022), 0.054–0.47 mg/L in the Aksaz wetland (Gümüş 2023), and 0.04–0.21 mg/L in the Al-Gharraf River (Judran and Kumar 2020). The similarities and differences between studies may be due to the different environmental impacts on rivers.

Sulfate (SO_4^{-2}) should be present in natural waters as it increases biological productivity (Tepe 2009). In this study, SO_4^{-2} concentrations ranged from 2.75 mg/L at site 5–27.82 mg/L at site 10. The highest sulfate concentrations in each season were observed at site 10, the estuary, which is a seawater-influenced area. PCC analysis revealed a strong positive correlation between electrical conductivity and sulfate ($p<0.01$). Sulfate concentrations ranged from <1.0 to 117 mg/L in the aquifer in and around the East Kolkata Wetlands (Sahu and Sikdar 2008), 1–58 mg/L in the Çarşıbaşı Stream (Könez 2019), 3–32 mg/L in the Elekçi Stream (Taş et al. 2021), and 0.63–12.98 mg/L in the Guenitra Dam (Algeria) (Hadef et al. 2021). When we compared this study with other studies, it was seen that there was not much difference.

Bicarbonate (HCO_3) is mostly found in water when pH values are between 7 and 9 (Tanyolaç 2011). In this study, bicarbonate concentrations ranged from 164.7 mg/L at site 4–366 mg/L at site 6. HCO_3 concentrations varied between 280 and 592 mg/L in the aquifer in and around the East Kolkata Wetlands (Sahu and Sikdar 2008), 122 and 322.08 mg/L in the Köprüçay River (Çiçek and Ertan 2012), 36.6 and 122 mg/L in the Fırtına Creek (Gedik et al. 2010), 282.23 and 372.8 mg/L in the Deliçay (Yıldırım et al. 2020), and 73.2 and 156.75 mg/L in the Jijel region (Algeria) (Drouiche et al. 2022). When we were compared it with other studies, although there were similar data to our study, they varies depending on the pH values measured in the studies. The bicarbonate value is higher in basic waters.

Chloride concentrations in the Köprüçay River ranged from 1.52 mg/L at site 1–193.78 mg/L at site 10. Chloride mixes with water naturally and through the seas (Güler 1997; Göksu 2015). The observation of the highest chloride concentrations at site 10 (estuary) in each season is consistent with this. Accordingly, PCC analysis showed a strong positive correlation between electrical conductivity, sulfate, and chloride ($p<0.01$). Chloride concentrations ranged from 2.39 to 132.21 mg/L in the Kargı Stream (Zeybek and Kalyoncu 2016), 11.59–46.53 mg/L in the İsrafil Stream (Akar 2023), and 125–250 mg/L in the Al-Gharraf River (Judran and Kumar 2020). Although the data in this study were generally similar when compared to different studies, the chloride values of rivers that were not connected to the sea were lower.

Table 13 Pearson correlation matrix showing the correlation coefficients between physical and chemical parameters of waterand the dominance of diatom species

	Temperature	pH	EC	DO	NO_3-N	SO_4	HCO_3	Cl^-	BOD_5	*Achnanthidium minutissimum*	*Cocconeis euglypta*	*Cymbella affinis*	*Cymbella cistula*	*Diatoma moniliformis*	*Diatoma vulgaris*	*Encyonema minutum*	*Gomphonella olivacea*	*Navicula gregaria*	*Nitzschia dissipata*
Temperature	1	− 0.308	.379*	− .606**	0.038	.376*	.411**	0.307	− .493**	− 0.153	− 0.093	.313*	− 0.033	0.049	0.249	0.225	− 0.124	0.277	− 0.040
pH		1	− 0.096	.470**	0.007	0.018	− .367*	0.016	0.256	0.251	− 0.150	− 0.038	0.020	− 0.052	0.124	− 0.236	0.222	− 0.096	− 0.053
EC			1	− 0.194	0.237	.861**	.627**	.863**	− 0.195	− 0.018	− 0.282	.446**	− 0.031	0.175	.323*	− 0.060	0.117	0.196	0.032
DO				1	− 0.022	− 0.144	− 0.264	− 0.171	.736**	0.259	− 0.305	− 0.051	.336*	0.096	0.020	− 0.192	.517**	− .334*	0.082
NO_3–N					1	0.311	0.274	0.116	0.068	0.260	− 0.256	0.090	− 0.061	− 0.101	0.064	0.071	− 0.086	− 0.094	0.241
SO_4						1	.333*	.914**	− 0.151	− 0.078	− 0.282	.429**	0.110	.360*	.491**	− 0.060	0.258	0.014	0.034
HCO_3							1	0.213	− 0.240	− 0.105	− 0.256	0.210	0.048	0.090	0.140	0.185	− 0.047	.396*	0.137
Cl^-								1	− 0.156	− 0.001	− 0.185	.480**	− 0.001	0.300	.412**	− 0.106	0.148	− 0.037	− 0.066
BOD_5									1	0.169	− 0.140	− 0.250	0.091	0.021	− 0.120	− 0.196	.330*	− 0.188	0.049
Achnanthidium minutissimum										1	− .388*	0.050	− 0.138	− 0.231	− 0.105	0.046	− 0.127	− 0.300	− 0.150
Cocconeis euglypta											1	− 0.301	− 0.299	− 0.280	− 0.248	− 0.201	− 0.290	− 0.075	− 0.209
Cymbella affinis												1	.317*	.351*	.462**	.323*	0.182	− 0.132	− 0.028
Cymbella cistula													1	.697**	.600**	.346*	.483**	− 0.099	0.088
Diatoma moniliformis														1	.712**	0.270	.441**	− 0.109	− 0.053
Diatoma vulgaris															1	0.290	0.286	− 0.113	0.110
Encyonema minutum																1	0.167	− 0.140	0.114
Gomphonella olivacea																	1	− 0.132	0.179
Navicula gregaria																		1	− 0.078
Nitzschia dissipata																			1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Biochemical oxygen demand (BOD_5) is a measurement of organic pollution in water (Egemen and Sunlu 1996). In this study, BOD_5 concentrations ranged from 0.14 mg/L at site 8–4.7 mg/L at site 7. PCC analysis revealed a significant positive correlation between BOD_5 and dissolved oxygen and a significant negative correlation between BOD_5 and temperature ($p < 0.01$). BOD_5 concentrations varied between 1 and 4 mg/L in the Kargı Stream (Zeybek 2017), 2.5 and 4.19 mg/L in the Dipsiz-Çine Stream (Kızılkaya 2022a, b), and 3 and 9 mg/L in the Değirmendere and Bulaklı Streams (Yıldız 2022). Although similar values were observed when we was compared this study with other studies, it can be said that the values in the Köprüçay River was lower and the organic matter intrusion into this stream was lower.

The average values of the physical and chemical parameters determined in the Köprüçay River were evaluated according to the water quality classes specified in SWQR and WPCR. Consequently, all sites were classified as class I according to temperature, pH, ammonium, sulphate, and BOD_5. According to electrical conductivity, sites 1 and 4 were classified as class I, while the other sites were classified as class II. According to dissolved oxygen, site 9 was classified as class I, site 6 as class III, and the other sites as class II. All sites were classified as class I according to both nitrate and orthophosphate. According to chloride, only site 10 was classified as class II, while the other sites were classified as class I.

When we were evaluated the average values of physical and chemical data according to WHO (2008), EPA (2018), EU (2020) and TSE (2005), all values were determined within the standard values range. In this case, it was thought that the Köprüçay River is suitable for human consumption purposes. In order to determine the water quality of the Köprüçay River, WQI was calculated both on a site basis and seasonally, and according to all data, the river was determined in the "excellent water" category. Since most of the physical and chemical parameters used were within the range of WHO (2008) and TSE (2005) standards were utilized in the calculations, such a result comes to mind.

Diatoms are vital to aquatic systems as they are primary producers in food webs. They are also used to determine water quality because they are sensitive to changes in nutrient levels and anthropogenic impacts such as pollution. Certain groups, such as *Amphora, Navicula, Nitzschia, Pantocsekiella*, and *Ulnaria*, identified in the Köprüçay River, are of critical importance as bioindicators. Therefore, many diatom-based indices used to assess water pollution levels and nutrient loads utilize these genera and their species composition (Kobayasi and Mayama 1989; Sahraoui et al. 2012; Kulikovskiy 2016; Solak et al. 2020; Marchenkov et al. 2024; Melzi et al. 2024; Pane et al. 2024).

In this study, 117 taxa belonging to 51 genera were identified in epilithic diatom samples taken from 10 sites. As in many studies, the species in the Pennales order were determined to be considerably higher in terms of variety and number of individuals than the species in the Centrales order (Tokatlı and Dayıoğlu 2011; Erdem 2013; Mohammed et al. 2017; Pala et al. 2018; Yay et al. 2019; Aykut 2021; Kızılkaya 2022a, b). Additionally, as a result of the evaluations, *Nitzschia* was the genus with the highest number of species, with 11 species. This result was observed in studies conducted in different aquatic systems (Çiçek 2011; Hasret 2017; Mestik 2019; Yay et al. 2019; Boz 2022; Ogan 2023). The genus *Nitzschia* was followed by *Gomphonema* (10), *Navicula* (9) and *Cymbella* (7).

It was observed that the most dominant taxon among 117 taxa was *Achnanthidium minutissimum*. In addition, this species was the most dominant taxon in all seasons at the sites 4, 5, 8, 9 and 10. This species was also one of the two species that were found 100% (consistently) at every site, according to frequency calculations. Although it was known that this species were generally found in sufficiently oxygenated, clean fresh waters, it tolerates different pollution levels (Van Dam et al. 1994; Köster and Hübener 2001; Taylor et al. 2007; Mestik 2019). In this study, its occurrence at every site from source to downstream shows that it was tolerant.

The second most dominant taxon among 117 taxa was *Diatoma moniliformis*. In addition, according to frequency calculations, it was determined that this taxon was found at each site at certain times. It is known that this species is found in waters with high electrical conductivity and pH above 7 (Kelly 2000). The pH and electrical conductivity data in this study confirm this information. In addition, PCC analysis showed a significant positive correlation between *Diatoma moniliformis* and sulfate at 0.05 level.

The third most dominant taxon was *Gomphonella olivacea*. In addition, according to frequency calculations, it was determined that this taxon was found at each site at certain times. Lange-Bertalot (1978) classified this species within the class II–III water quality, Çiçek and Ertan (2015) categorized it within the class I–II. In the present study, this species was observed predominantly at sites classified as I–II or II quality based on biotic indices. Furthermore, PCC analysis demonstrated a statistically significant positive correlation between this taxon and BOD_5, an indicator of organic pollution, at the $p < 0.05$ significance level. This correlation correlation suggests that the abundance of this taxon increased in response to a specific level of organic pollution.

The fourth most dominant taxon was *Cymbella affinis*. In addition, according to frequency calculations, it was determined that this taxon was found at each site at certain times. Van Dam et al. (1994) have observed that this taxon was found in waters with beta-mesosaprobe properties. Conversely, He et al. (2016) reported that this species is also found in clean and alkaline waters, such as the Köprüçay River. *C. affinis*, known to prefer nutrient-rich waters (Hoagland et al. 1982; Patrick and Palavage 1994), has also been identified as a highly tolerant species (Bhatt et al. 2025). As a result of all evaluations, it was determined that *Cymbella affinis* can generally be found in clean or slightly polluted waters. PCC analysis revealed a significant positive correlation between this taxon and electrical conductivity, sulfate, chloride at 0.01 level. According to this relationship, it can be said that this taxon has increased due to the increase in the marine effect.

The fifth most dominant taxon was *Cocconeis euglypta*. This species was also one of the two species that was found 100% (consistently) at every site, according to frequency calculations. Since this species was detected in every sampling in the Köprüçay River, it has been observed that it can be found in clean waters to partially polluted waters. Although *Achnanthidium minutissimum* and *Cocconeis euglypta* were found consistently at each site, there was a negative correlation between the two taxa at 0.05 level.

Among the groups identified in our study, *Pantocsekiella* and *Ulnaria* are known to thrive in regions with good water quality, while *Amphora* and *Navicula* are known to be sensitive to pollution. Certain species of *Nitzschia* are pollution-tolerant groups that can develop in deteriorating water conditions (Lee and Round 1987; Amin et al. 2012; Chen et al. 2016; Olszyński et al. 2019; Okada et al. 2023; Marchenkov et al. 2024). In the Köprüçay River, the dominance of species belonging to these groups was determined as 0.85% for *P. ocellata*, 1.24% for *U. ulna*, 0.25% for *U. acus*, 0.56% for *A. copulata*, and 0.16% for *A. ovalis*. *N. gregaria* (2.75%) from the genus *Navicula* and *N. dissipata* (2.14%) from the genus *Nitzschia* were among the top 10 dominant taxa. Furthermore, species such as *Cymbella excisa*, *Didymosphenia geminata*, *Hannaea arcus*, and *Navicula radiosa*, identified in certain sites within our study, are known to be sensitive to pollution, while species like *Gomphonema parvulum*, *Navicula cryptocephala, Navicula cryptotenella*, and *Stephanocyclus meneghinianus* are known to be pollution-tolerant (Rott et al. 1999; Beltrami et al. 2007; Delgado et al. 2012; Wang et al. 2014; Çelekli et al. 2018a, b). However, the dominance of these species in the Köprüçay River was determined to be less than 0.1%.

Sørensen Similarity Index was used to determine the similarity of the selected sites on the Köprüçay River to each other according to epilithic diatom samples. According to the index results, the lowest similarity was determined as 65% between the site 3 and 7, and the highest similarity was 82% between the site 9 and 10. In this study, it was observed that the similarity levels were not very low and the similarity decreased as the distance between the sites increased. Similarity values in other studies were 66–97% in Balıklı Tohma Stream (Malatya) (Çağlar et al. 2017), 50–88% in Boğa Stream (Antalya) (Bakioğlu 2019), and 63–87% in Ulupınar Stream and Olympos Stream (Yay 2019).

Margalef Diversity Index was used to determine species diversity. Since there is no specific limit range in this index, relative comparisons are made and as a result, species diversity increases as the values obtained increase (Kocataş 2014). In this study, the lowest diversity value was determined as 5.62 at the site 6 in autumn and the highest value was 15.65 at the site 9 in winter. It was thought that since the amount of water at the site where the lowest value was seen was low and ponded during sampling, it caused a decrease in species diversity due to pollution. In other studies Margalef Diversity Index values were determined as 2.64–15.28 in Köprüçay River (Çiçek

2011), 2.41–3.18 in Morand River (Madhya Pradesh, India) (Sharma et al. 2013), 0–2.99 in Isparta Stream (Özel 2019), and 0.33–2.14 in the Dehbar, Zoshk and Kang Rivers (Iran) (Malvandi et al. 2021). Compared to other studies, species diversity in the Köprüçay River was quite high. This may be due to the fact that the sites were suitable for life because the amount of water was generally high and they were not under intense pollution pressure.

To determine species diversity, the Shannon Diversity Index was also utilized. It is understood that as the value of the results obtained from this index approaches 5, species diversity increases (Kocataş 2014). The calculations determined that the lowest value was recorded at site 6 (0,75) during winter, and the highest value was recorded at site 8 (2,70), also during winter. Similar to the other diversity index, the lowest value was determined at the same station during a different period. It was observed that the lowest value, interpreted in relation to water level in autumn for the Margalef diversity index, was also low (0.87) according to this index. Based on the results, this trend was found to persist during the winter season. Previous research reported Shannon Diversity Index values ranging from 1.84 to 3.83 in the Andık River, Turkey (Dayıoğlu 2011), 0.86–1.00 in the Liman Lake, Samsun, Turkey (Soylu et al. 2011), and 3.46–3.84 in the lower Zab River, Iraq (Bashir and Ali 2024). A comparison with other studies revealed that the diversity values of the Köprüçay River are within a moderate range.

Biotic indices measure the response of the community to organic pollution, so they are not sufficient to detect other types of pollution (Mason 1981). In this study, evaluations were made by applying some biotic indices. Based on the SI (Rott et al. 1997), sites 1, 5, 7, 8, 9, and 10 were classified as I-II, indicating oligosaprobic/betamesosaprobic conditions, corresponding to slightly polluted water. Sites 2, 3, 4, and 6 were classified as II, indicating betamesosaprobic conditions, corresponding to partially polluted water. Consistent with these findings, previous studies on the Köprüçay River (Çiçek 2011) and Kovada Lake and Kovada Canal (Isparta) (Çiçek and Yamuç 2017) also reported water quality classifications of I–II or II, and I, I–II, and II, respectively, using the SI. Based on the TI (Schmedtje et al. 1998), water quality at site 5 was classified as I–II, indicating mesotrophic conditions, while all other sites were classified as II, indicating eutrophic conditions. Consistent with these findings, previous studies using the TI reported water quality classifications of I–II, III, and III–IV in the Darıören and Isparta Streams (Kalyoncu et al. 2009), and I–II or II in the Ulupınar and Olympos Streams (Yay et al. 2019). Based on the DI-CH index (Buwal 2002), sites 1, 2, and 3 were classified as IV, while all other sites were designated as III. Consistent with these findings, previous studies using the DI-CH index reported water quality classifications ranging from III to V in Swiss water sources (Taxböck and Preisig 2007) and III–IV in the Sakarya River (Morkoyunlu Yüce and Gönülol 2016). Based on the Trophic Diatom Index (TDI) (Coring et al. 1999), water quality at site 5 was classified as I, indicating oligotrophy, while other sites were classified as I–II, indicating mesotrophy. Similarly, using the TDI (Kelly and Whitton 1995), site 5 was classified as I, indicating oligotrophic conditions, and other sites were classified as II, indicating oligo-mesotrophic conditions. Consistent with these observations, previous studies using the TDI reported water quality classifications of III and IV in the Mert River, Samsun (Maraşlıoğlu et al. 2020), and ranging from I to V in streams and lakes in Eskişehir province (Ogan 2023). Based on the Generic Diatom Index (GDI) (Rumeau and Coste 1988), sites 1, 3, and 4 were classified as II (good), and all other sites were classified as I (excellent). Previous studies using the GDI reported water quality classifications of predominantly III (intermediate) with one site classified as IV (weak) in the Linda River, Poland (Szczepocka et al. 2014), and classifications of II, III, and V in the Kaveri River, India (Venkatachalapathy and Karthikeyan 2015).

Based on PCC analysis, it was thought that diatom species may be generally sensitive to environmental changes. Some diatom species were also found to be related to each other (Table 13). Significant negative relationships were found between *Achnanthidium minutissimum* and *Cocconeis euglypta* ($p<0.05$), positive relationships between *Cymbella affinis* and *Cymbella cistula*, *Diatoma moniliformis*, *Encyonema minutum* ($p<0.05$) between *Cymbella affinis* and *Diatoma vulgaris* ($p<0.01$), between *Cymbella cistula* and *Diatoma moniliformis*, *Diatoma vulgaris*, *Gomphonella olivacea* ($p<0.01$), between *Cymbella cistula* and *Encyonema minutum* ($p<0.05$), and between *Diatoma moniliformis* and *Diatoma vulgaris*, *Gomphonella olivacea* ($p<0.01$). These results suggest that depending on whether the relationships of the species were positive or negative, it may be helpful in terms of making evaluations in terms of similar or different ecological characteristics.

Conclusions

When all data obtained from both physical, chemical and biological data were evaluated together, a low or medium level of pollution was detected at all sites. It has been observed that pollution is greater in areas or times where human intervention is high. It has been determined that the water quality of the river is negatively affected due to factors such as the sites being located after fish farms, being situated along the roadside, and the presence of restaurants or fields in the vicinity. In the Köprüçay River, which holds significant ecological and economic importance, it is necessary to ensure that water use for different purposes should be balanced and efficient, should be minimize existing pollutants and should be control the treatment methods for wastewater entering the river. Awareness of people should be raised in order to prevent pollution that may occur especially during periods when a large number of people and their animals stay around the river for transhumance activities and when water sports are intensively practiced. Additionally, within the scope of river sustainability, it is recommended that necessary studies should be taken to prevent the pollution level of the river from getting worse than is current situation and, if possible, to improve it. Studies carry out for this purpose are very important for the protection biodiversity in the Köprüçay River and the can use of the river for different purposes such as irrigation, fish production facilities, water sports and tourism.

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Data availability The data can be available upon request.

Declarations

Competing interest The authors declare no competing interests.

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