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ORIGINAL ARTICLE

Biological assessment of Demirci Stream in Gediz River Basin (West Anatolia of Turkey) and comparative performance of benthic macroinvertebrate-based metrics

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Abstract
Conserving freshwaters in West Anatolia requires biomonitoring tools to assess the ecological status of surface water bodies threatened by anthropogenic pollution. This study was carried out to determine water quality of Demirci Stream based on biotic indices. In this seasonal study, a total of seven sampling stations were determined. Asterics software was used to determine biotic and diversity index scores. Pearson's based correlations were applied in order to determine the proper biotic indices. Relationships between macrobenthic orders and physicochemical variables were revealed by Redundancy Analysis (RDA). Eleven taxonomic groups were found in Demirci Stream consisting of Hygrophlia, Arhynchobdellida, Isopoda, Tubificida, Amphipoda, Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera and Hemiptera. As a result of this research, the sampling pints 1, 2, 3 and 4 were of good water quality class while sampling points 5, 6 and 7 were polluted. Arhynchobdellida, Tubificida and Diptera orders showed positive correlations with BOI_5, EC, Cl^-, TDS, T^oC, NH_4-N, NO_2-N and NO_3-N variables, while negatively correlated with DO, Sat-O_2 and pH. SI, BMWP, ASPT and BBI were more proper than the FBI index to determine the water quality of Demirci Stream.

Keywords Biomonitoring · Benthic macroinvertebrates · Biotic index · Water quality

Introduction

The rapid growth of the world population, migrations, urbanization, industrialization, food crisis and the desire to reach better living standards affect freshwater ecosystems in an irreversible way. (Zhang et al. 2019; Sabha et al. 2022). The European Union Water Framework Directive (EU WFD) is the primary legal regulation for the protection of water resources. The WFD proposes the strategy of assessing environmental and ecological changes with a biological monitoring approach based on bioindicator organisms (Council of European Commission 2000).

Rapid changes in water chemistry, water quality and physical habitat can cause the survival of the most resistant species and the extinction of the sensitive species over a period of time (Kazancı et al. 2014). Therefore, the composition of macroinvertebrate species in a water body forms the basis of biological monitoring in determining pollution or morphological deterioration in that water body (Mahler and Barber 2017).

Many biotic indices (BMWP, ASPT, BBI etc.) have been developed by European countries using macroinvertebrate groups (Yorulmaz et al. 2015). Various studies have been carried out to evaluate the water quality of the freshwaters in Turkey through these developed indices (Akyildiz and Duran 2021; Ertaş et al. 2021a, b; Ertaş and Yorulmaz 2021; Öztürk 2021, Odabaşı et al. 2022). However, comparisons of these methods is relatively limited (Yorulmaz et al. 2015; Zeybek et al. 2014; Zeybek 2017; Ertaş and Yorulmaz 2021; Yorulmaz and Ertaş 2021; Ertaş et al. 2021a, c, 2022).

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The Gediz River Basin is one of the most important freshwater ecosystems of Turkey. The Gediz River is the second largest stream flowing into the Aegean Sea after the Great Meander River. The increasing population, agricultural and industrial activities of the settlements around the Gediz River Basin have negative effects on the water quality of the river (Ünlü 2013; Şenol et al. 2016). However, the pollution degree of the streams which drain to the Gediz River have not been researched yet. This study aims to assess the water quality of the Demirci Stream which is an important branch of the Gediz River Basin and to determine the comparative performance of biotic indices.

Materials and methods

Study area

This study was carried out in the Demirci Stream in the Gediz River Basin of West Anatolia, Turkey. The length of the Demirci Stream is 50 km. The Demirci Stream emerges from the Demirci-Simav Mountain (1,475 m a.s.l.), northeast to the Gediz River (Fig. 1).

The Demirci Stream is exposed to the negative effects of polluting factors such as hydroelectric power plant, trout farm, carpet factory and domestic wastes. Sampling stations were chosen according to criteria for selecting operational monitoring sites given in WFD Annex V 1.3.2. (WFD 2000). This research was carried out seasonally (winter – December 2020, spring - April 2021, summer - July 2021, autumn - October 2021) over a year in seven sampling stations (Table 1).

Benthic macroinvertebrates were sampled by using a classic bottom kick net of a 50×30 cm size and 250 µm mesh according to the literature (AQEM Consortium 2002). Collected organisms were immediately fixed in 4% formalin in the field and then transferred to 70% ethyl alcohol. The benthic macroinvertebrates were first sorted out, then identified to the lowest possible taxon (species, genus or family) and counted under a stereomicroscope.

Stations 1 and 2 were selected in the headwaters of the stream which was formed by intercalation of siltstone and claystone formation. In these stations, the stream bed is narrow, the area around the bed is wooded and no contaminants were found. Station 3 was geologically in the same area as the first two sampling stations. In this station, the stream bed is narrow and the riparian zone around the stream is covered with bushes and dwarf trees. In stations 4 and 5, the stream bed is wide and the water flow of the stream is low. The stations 6 and 7 were geologically almost in the same area. Station 7 is located in the part of the drain of the Demirci Stream into the Gediz River.

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Data analysis

Physicochemical parameters were measured by using CyberScan Series 600 Waterproof- Portable Meter and Oxi 315i/ SET WTW Oxygenmeter. The evaluation of water quality based on physicochemical parameters was made according to Klee's method (Klee 1991).

Saprobe Index (SI), several modifications of Biological Monitoring Working Party (BMWP) [BMWP Original (BMWP-O), BMWP Spanish (BMWP-S), BMWP Hungarian (BMWP-H), BMWP Polish (BMWP-P), BMWP Czech (BMWP-C)], several modifications of Average Score Per Taxon (ASPT) [ASPT Original (ASPT-O), ASPT Hungarian (ASPT-H), ASPT Czech (ASPT-C)], Belgian Biotic Index (BBI), Family Biotic Index (FBI), Simpson's (SDI), Shannon-Wiener (SWDI) and Margalef (MDI) diversity indices were applied on benthic macroinvertebrate data set by using ASTERICS Software (AQEM Consortium 2002). Pearson's based correlation analyses between the biotic indices were performed by using SPSS version 20.0. Relationships between macrobenthic orders and physicochemical variables were revealed by Redundancy Analysis (RDA) on CANOCO-4.5 software. The compatibility of the RDA data has been tested with DCA (Detrended Correspondence Analysis) (ter Braak 1988).

Results and discussion

The range, mean and standard deviations of physicochemical variables are summarized in Table 2. According to the One Way ANOVA test, all physicochemical parameters differed significantly between stations ($p < 0.05$), but there was no significant difference between seasonal groups.

A total of 45 taxa and 7,444 specimens of benthic invertebrates were revealed in the stream (additional data are given in Online resource 1). Among all taxa, ten belonged to the order Ephemeroptera (Insecta), eight to the order Trichoptera (Insecta), five each to the orders Hygrophlia (Gastropoda) and Coleoptera (Insecta), six to the order Diptera (Insecta), four to the order Plecoptera (Insecta), two to the orders Tubificida (Oligochaeta) and Hemiptera (Insecta), and one each to the orders Arhynchobdellida (Hirudinea), Amphipoda (Malacostraca) and Isopoda (Malacostraca). The most dominant group was Insecta. Different researchers found similar results in different freshwater ecosystem (Guellaf and Kettani 2021; Kumari and Maiti 2020; Mehrjo et al. 2020; Sotomayor et al. 2020; Guellaf et al. 2021; Kabore et al. 2022). In spring. Trichoptera was the most dominant group (37.8%) and Amphipoda was the second

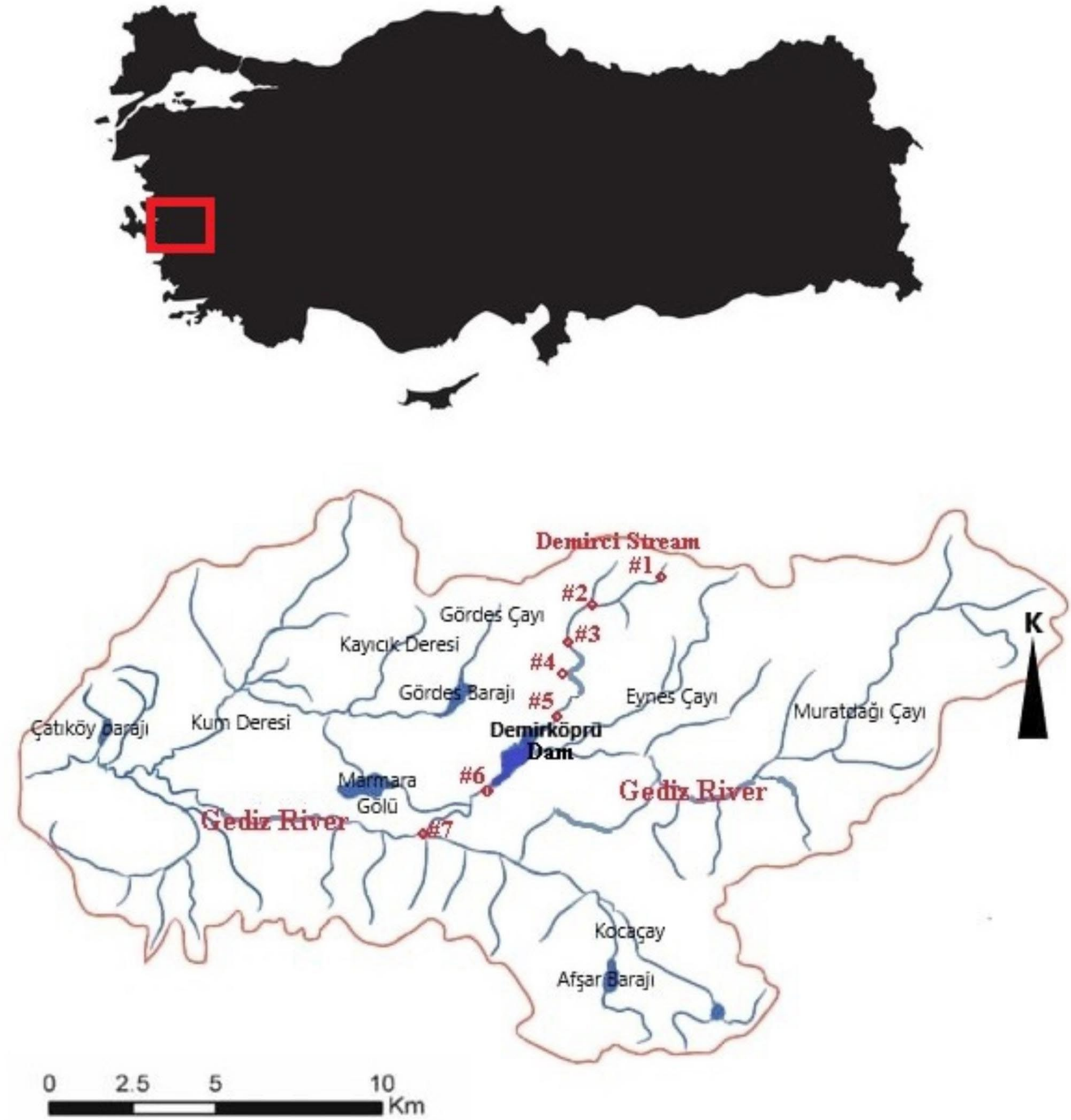

Fig. 1 Sampling stations in the Demirci Stream

Table 1 Altitude, latitude and longitude of the stations in the Demirci Stream

Stations	Latitude	Longitude
Station 1	38°58’58.0"N	28°35’57.0"E
Station 2	38°58’07.0"N	28°31’55.8"E
Station 3	38°53’52.7"N	28°31’28.3"E
Station 4	38°47’53.7"N	28°30’53.5"E
Station 5	38°44’43.6"N	28°28’44.3"E
Station 6	38°37’00.7"N	28°18’39.8"E
Station 7	38°36’35.4"N	28°17’53.0"E

dominant group (34.1%). On summer, Isopoda was the most dominant group (44.4%) and 0 Plecoptera was the second dominant group (27.3%). In autumn, Arhynchobdellida was the most dominant group (40.4%) and Hemiptera was second dominant group (39.2%). In winter, Plecoptera was the most dominant group (44.4%) and Diptera was the second dominant group (25.1%). The highest number of organisms was determined at the station 1 (1,396), and

Table 2 Range (R), mean (M) and standard deviation (SD) of water quality parameters at the sampling stations in the Demirci Stream

		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
T (°C)	R	9–13	9–13	11–14	12–16	15–18	18–24	18–24
	M ± SD	11 ± 1.82	11 ± 1.83	12 ± 1.41	13.8 ± 2.06	16.3 ± 1.5	21 ± 2.94	21 ± 2.94
pH	R	7.0-7.1	7.0-7.1	6.9-7.0	6.9-7.0	6.8–6.9	6.7–6.8	6.7–6.8
	M ± SD	7.1 ± 0.06	7.1 ± 0.06	6.95 ± 0.06	6.9 ± 0	6.8 ± 0.06	6.7 ± 0.01	6.7 ± 0.01
EC	R	285–367	296–389	309–395	357–416	373–422	392–510	398–513
($\mu S\ cm^{-1}$)	M ± SD	333 ± 34.3	353 ± 40.1	369 ± 40.1	396 ± 26.3	405 ± 22.3	473 ± 54.8	479 ± 54.4
TDS	R	112–146	119–168	127–179	154–203	192–288	397–489	402–503
(ppt)	M ± SD	128.5 ± 14.1	141.8 ± 20.1	151 ± 21.5	185 ± 21.5	229 ± 41.2	451 ± 38.7	473 ± 47.7
DO	R	8.38–9.45	8.22–9.13	8.13–8.67	7.7-8.0	5.58-6.00	4.0-4.86	3.45–4.45
($mg\ L^{-1}$)	M ± SD	8.87 ± 0.46	8.66 ± 0.44	8.38 ± 0.27	7.9 ± 0.13	5.76 ± 0.19	4.43 ± 0.46	3.96 ± 0.50
Sat-O_2	R	86–94	81–92	79–87	71–78	62–68	51–56	43–53
(%)	M ± SD	89 ± 3.82	86 ± 4.97	82.8 ± 3.86	75.5 ± 3.11	64 ± 2.63	53 ± 2.22	48 ± 4.99
BOI_5	R	1.4–1.8	1.6–1.9	2.0-2.7	4.3–5.8	4.8–5.9	11.2–13.5	11.9–14,0.8
($mg\ L^{-1}$)	M ± SD	1.67 ± 0.18	1.78 ± 0.13	2.45 ± 0.31	5.35 ± 0.70	5.59 ± 0.52	12.7 ± 1.04	13.8 ± 1.31
NH_4-N	R	0.07–0.09	0.07–0.09	0.08–0.1	0.1–0.12	0.18–0.22	1.87–2.43	2.94–3.68
($mg\ L^{-1}$)	M ± SD	0.08 ± 0.01	0.09 ± 0.01	0.10 ± 0.01	0.11 ± 0.01	0.21 ± 0.02	2.25 ± 0.26	3.23 ± 0.31
NO_2-N	R	0.003–0.01	0.004–0.01	0.005–0.007	0.01–0.02	0.02–0.023	0.19–0.27	0.23–0.29
($mg\ L^{-1}$)	M ± SD	0.004 ± 0.001	0.01 ± 0.001	0.006 ± 0.001	0.01 ± 0.002	0.022 ± 0.001	0.22 ± 0.03	0.26 ± 0.03
NO_3-N	R	0.86–0.98	0.97–1.14	1.13–1.31	1.43–1.78	2.01–2.57	5.7–7.92	6.9–8.48
($mg\ L^{-1}$)	M ± SD	0.92 ± 0.05	1.07 ± 0.07	1.23 ± 0.08	1.65 ± 0.15	2.32 ± 0.23	7.24 ± 1.03	8.04 ± 0.77
Cl	R	3.05–3.38	3.13–3.69	3.25–3.78	3.37–3.83	3.58–3.91	3.76–4.17	4.01–4.67
($mg\ L^{-1}$)	M ± SD	3.21 ± 0.13	3.46 ± 0.24	3.56 ± 0.22	3.66 ± 0.21	3.78 ± 0.14	4.00 ± 0.17	4.38 ± 027
TN	R	2.21–2.65	2.34–2.91	2.56–3.28	2.69–3.56	2.92–3.98	3.67–4.28	3.71–4.41
($mg\ L^{-1}$)	M ± SD	2.43 ± 0.18	2.67 ± 0.24	2.96 ± 0.30	3.27 ± 0.41	3.68 ± 0.51	4.07 ± 0.27	4.18 ± 0.32
TP	R	0.92–1.03	0.97–1.24	1.09–1.35	1.67–2.57	1.87–2.86	2.11–2.91	2.18–2.99
($mg\ L^{-1}$)	M ± SD	0.97 ± 0.05	1.11 ± 0.11	1.23 ± 0.11	2.24 ± 0.39	2.48 ± 0.43	2.63 ± 0.36	2.73 ± 0.37

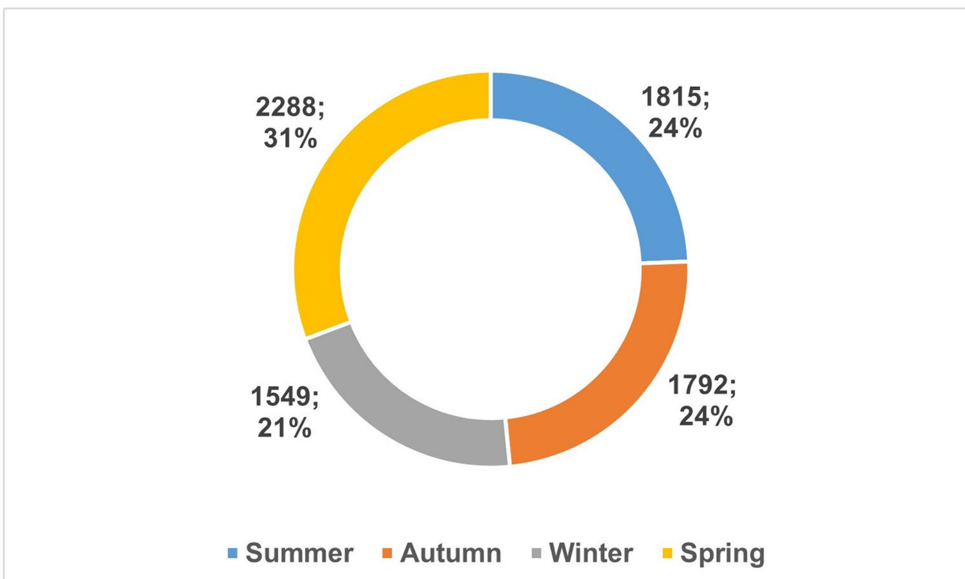

Fig. 2 The total number of benthic macroinvertebrates collected seasonally in the Demirci Stream

the lowest number at the station 7 (803) The lowest number of organisms was determined in winter, while the highest number was found in spring (Fig. 2). The maximum density of benthic fauna was observed during spring, this can be related to the availability of phytoplankton population in the form of food supply. Spring drifts that drive the vegetation were also factors affecting the abundance of benthic fauna. On the other hand, decline in the density of benthic fauna during winter may be due to the increased load of suspended solids, reduced transparency and increased water flow.

Dominancy of benthic macroinvertebrate species at the stations are shown in Fig. 3. *Baetis* sp., *Baetis rhodani* (Pictet, 1843) and *Simulium* sp. were dominant in stations 1 and 2. *Gammarus* sp., *Baetis* sp. and *Ibisia marginata* (Fabricius, 1781) were dominant in station 3. *Simulium* sp., *Gammarus* sp. and *Chironomus* sp. were dominant in

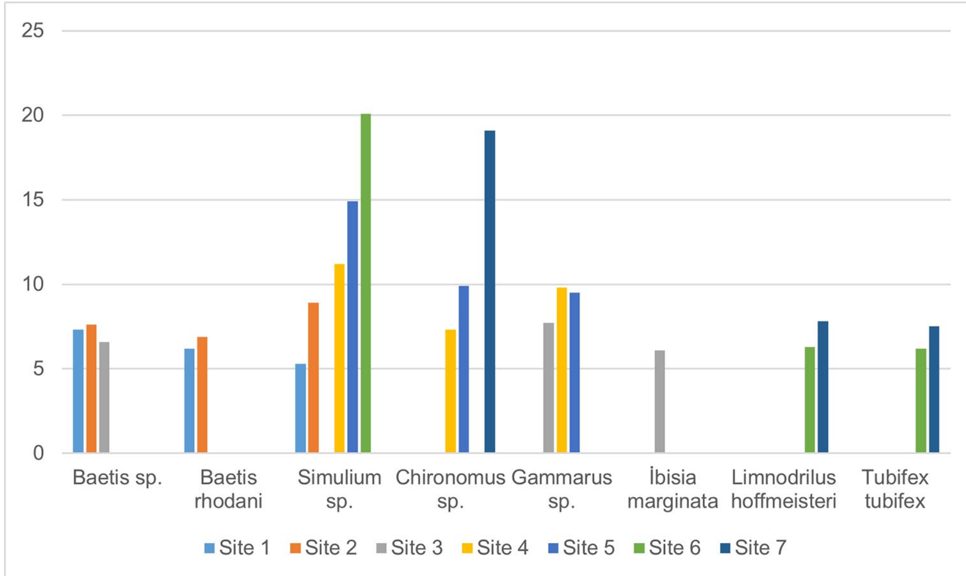

Fig. 3 Dominancy (%) of taxa of benthic macroinvertebrates at the stations in the Demirci Stream

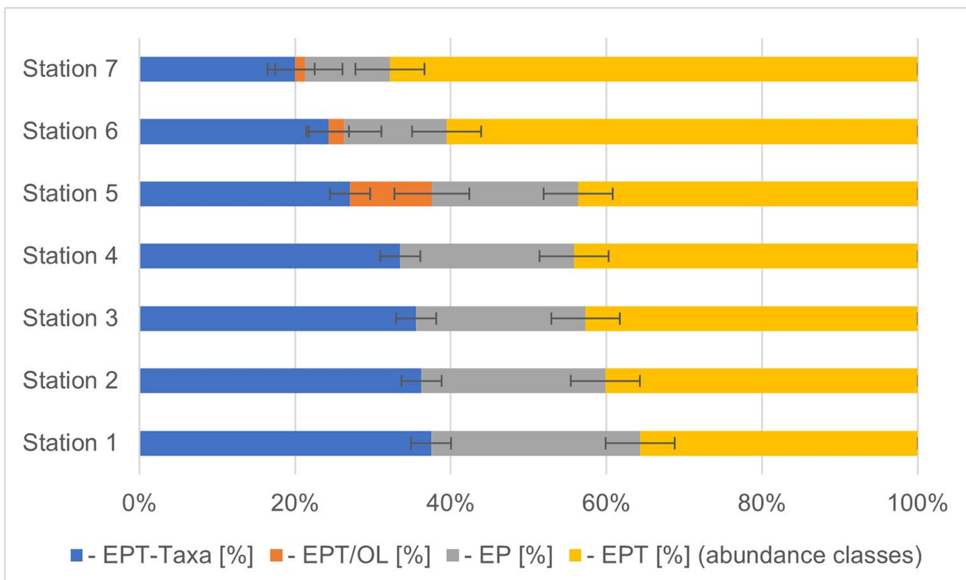

Fig. 4 Distribution of seasonal EPT-taxa [%], EPT/OL [%], EP [%] and EPT [%] abundance class values in sampling stations of the Demirci Stream

stations 4 and 5. *Simulium* sp., *Limnodrilus hoffmeisteri* (Claparede, 1862) and *Tubifex tubifex* (O. F. Müller, 1774) were dominant in station 6. *Chironomus* sp., *L. hoffmeisteri* and *T. tubifex* were dominant in station 7.

Ephemeroptera- Plecoptera- Trichoptera (EPT) taxa are the main indicator groups of unpolluted waters. The EPT fauna of the freshwaters showed completely parallel results with the water quality of the stations. The accordance between the water quality classes determined according to physicochemical measurements and the dominance of the EPT species found in these freshwaters are shown very clearly. It is indicated that Oligochaeta species are dominant in polluted waters (Ode et al. 2005; DeWalt et al. 2012; Kazancı et al. 2014; Öztürk et al. 2022). In our study, the highest EPT-taxa (%) values were obtained in upstream stations in all seasons, while the lowest EPT-taxa (%) values were obtained in downstream stations (Fig. 4).

Roline (1988), Clement et al. (1992), and Stoyanova et al. (2014) stated that Plecoptera and many Ephemeroptera species changed their habitat according to pollution The presence of EPT taxa in the upstream stations can be explained by the fact that agricultural and other anthropogenic activities around the Demirci Stream have not yet caused pollution pressure. Various researchers observed that EPT taxa were the most dominant in upstream sampling stations of their studies (Aazami et al. 2020; Mehrjo et al. 2020; Guellaf et al. 2021). *Gammarus* sp. was dominant in stations 3, 4 and 5 in the Demirci Stream. *Gammarus* sp., which belongs to the group of Amphipoda is found in low polluted river sections (Meyer 1987). *Chironomus* sp. was dominant in stations 4, 5, 6 and 7. *Chironomus* species are indicators for polysaprobic (heavy polluted) aquatic systems (Shaha and Pandit 2022; Shahidi-Hakak et al. 2022). According to Moisan and Pelletier (2008), the tolerance range of these organisms is high. They can be found at low or high DO (mg L^{-1}) concentrations, Sat O_2 (%) and T (°C). The lowest benthic maroinvertebrate number was found in stations 6 and 7. Diptera was the most dominant taxon in stations 6 and 7, Chironomidae and Oligochaeta followed. Pollution tolerance ranges of these organisms are high (Popovic et al. 2022; Rosa et al. 2022). They can be found at low or high DO (mg L^{-1}) conentrations, Sat O_2 (%) and T (°C). There is a trout farm around the stations 6 and 7 of the Demirci Stream. According to physicochemical variables, the organic matter is abundant there. *Tubifex tubifex* are abundant in these stations where the organic pollution pressures are high in the stream. Existing abundance of the organic matter is favorable for benthic macroinvertebrates such as Diptera and Oligochaeta (Brysiewicz et al. 2022).

Depending on changes in the chemical properties of the water, many parameters such as temperature, DO and pH can increase or decrease. The increase in water temperature is an environmental problem that speeds up the growth of aquatic plants and algae, increases the content of dissolved nutrients in the water, and increases the primary productivity of the ecosystem, generally leading to the depletion of oxygen by increasing abundance of bacteria. This situation causes eutrophication and deterioration in water quality and has negative consequences on many aquatic organisms (Pineda et al. 2022). As a result of these changes, many structural and distributional features of the macrobenthic fauna living in the aquatic system, such as their growth rates, metabolism and productivity, are affected. Although the tolerance of these living groups towards temperature varies according to the species, very few of them can show a high tolerance to temperature (Hussain and Pandit 2012).

While it was observed that the variables related to pollution such as T°C, EC, Cl^{-}, TDS, NH_4-N, NO_2-N, NO_3-N, TN and TP increased noticeably at stations 6 and 7, it is seen that the variables that are indicators of clean conditions such as DO and Sat O_2 have decreased. This is due to the close proximity of these stations to the downstream region and, accordingly, the changes in the chemical properties of the water (decreased flow rate, widening of the stream bed and increase of organic pollution due to the ingress of organic debris into the water). These changes were less common at other stations. According to Hynes (1994), presence of highly tolerant organisms usually indicates poor water quality. In stations 6 and 7, the macroinvertebrate samples consisted from Oligochaeta worms and Diptera, which were present in high abundances. They are known as tolerant to bad or poor water quality and can tolerate heavy to extreme pollution. According to Hachi et al. (2022), many species of Oligochaeta are tolerant to low oxygen concentration and can live in anoxic conditions.

The increased number of species in station 5 occured as the result of increased water level and flow velocity. Due to this improvement in environmental conditions in this station, the number of taxa further increased. In total 28 families were present, 10 belonging to the sensitive and semi-sensitive EPT group, and the rest consisted of semi tolerant-tolerant organisms (Baetidae, Chironomidae, Blephariceridae, Tubificidae, Athericidae, Tabanidae, Corixidae and Gerridae). In conclusion, the ecological conditions of the Demirci Stream indicate that the stream is disturbed by anthropogenic activities.

Table 3 shows the biological quality scores and quality classes in the Demirci Stream. According to Klee's method, the water quality class in stations 1, 2 and 3 is oligo-betamesosaprob (Class I-II), in station 4 it is betamesosaprob (Class II), in station 5 beta-alphamesosaprob (Class II-III), in station 6 alphamesosaprob (Class III) and in station 7 polysaprob (Class IV) in summer and autumn. In winter and spring, the water quality class in stations 1 and 2 is oligosaprob (Class I), in station 3 oligo-betamesosaprob (Class I-II), in stations 4 and 5 betamesosaprob (Class II), in station 6 alphamesosaprob (Class III), and in station 7 it is alpha-polysaprob (Class III-IV).

All diversity indices showed the highest values in station 1, whereas the lowest values were registered in station 7. High species diversity at the upstream stations indicates unpolluted conditions whereas low species diversity in stations 6 and 7 indicates environmental stress. The sampling stations 6 and 7 are heavily disturbed due to many domestic wastes discharged in this part of the stream.

According to the BMWP- S, BMWP- H, BMWP- P and BMWP- C, the highest score values were found in the stations 1, 2 and 3. According to the BMWP- O, the highest score value was found in the station 5. According to all versions of ASPT, the highest score values were found in stations 1, 2 and 3, while the lowest score value was found in station 7. According to the BBI, the water quality class is unpolluted in stations 1, 2, 3, 4 and 5 (Class I) while stations 6 and 7 are lightly contaminated (Class II). According to the FBI, the water quality class is lightly contaminated in stations 1 and 2 (Class II) while stations 3, 4, 5, 6 and 7 are critically contaminated (Class II-III). According to the SI, the water quality class is oligosaprob/betamesosaprob in stations 1, 2 and 3 (Class I-II); betamesosaprob in stations 4 and 5 (Class II); α- mesosaprob in station 6 (Class III), and α- mesosaprob/ polysaprob in station 7 (Class III-IV). This index scores indicate that in the upstream stations, due to the distance with inhabited areas and lack of waste discharge, the water has a minimum human impact and is of high

Table 3 Average score values of all indices and water quality classes in the Demirci Stream

İndices		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Klee's (1991)	Class	**I-II**	**I-II**	**I-II**	**II**	**II-III**	**III**	**IV**
Biotic indices								
SI	Score	1.785	1.779	1.771	1.929	2.180	2.969	3.225
	Class	**I-II**	**I-II**	**I-II**	**II**	**II**	**III**	**III-IV**
FBI	Score	4.52	4.70	5.15	5.33	5.50	5.69	5.72
	Class	**II**	**II**	**II-III**	**II-III**	**II-III**	**II-III**	**II-III**
BBI	Score	10	10	10	10	10	8	7
	Class	**I**	**I**	**I**	**I**	**I**	**II**	**II**
ASPT- O	Score	6.684	6.684	6.087	5.960	5.769	5.227	4.714
	Class	**I**	**I**	**I**	**II**	**II**	**II**	**III**
ASPT- H	Score	6.421	6.421	5.870	5.640	5.640	5.048	4.615
	Class	**I**	**I**	**II**	**II**	**II**	**II**	**III**
ASPT- C	Score	7.136	7.136	6.423	6.179	6.000	5.765	5.760
	Class	**I**	**I**	**I**	**I**	**II**	**II**	**II**
BMWP- O	Score	127	127	140	149	150	115	66
	Class	**II**	**II**	**II**	**II**	**II**	**II**	**III**
BMWP- S	Score	156	165	166	143	143	131	82
	Class	**I**	**I**	**I**	**II**	**II**	**II**	**III**
BMWP- H	Score	122	122	135	141	141	106	60
	Class	**II**	**II**	**II**	**II**	**II**	**II**	**III**
BMWP- P	Score	144	144	137	118	118	113	69
	Class	**II**	**II**	**II**	**II**	**II**	**II**	**III**
BMWP- C	Score	174	173	167	157	157	144	98
	Class	**I**	**I**	**I**	**I**	**I**	**II**	**III**
Species Diversity Indices								
SDI		0.962	0.956	0.955	0.954	0.943	0.906	0.868
SWDI		3.367	3.292	3.299	3.366	3.272	2.765	2.420
MDI		6.071	5.843	5.557	4.707	4.856	4.557	3.439

Explanations: Biological Monitoring Working Party (BMWP) [BMWP Original (BMWP-O), BMWP Spanish (BMWP-S), BMWP Hungarian (BMWP-H), BMWP Polish (BMWP-P), BMWP Czech (BMWP-C)], Average Score Per Taxon (ASPT) [ASPT Original (ASPT-O), ASPT Hungarian (ASPT-H), ASPT Czech (ASPT-C)], Belgian Biotic Index (BBI), Family Biotic Index (FBI), Simpson's (SDI), Shannon-Wiener (SWDI), Margalef (MDI) diversity indices

quality. In downstream stations, human activities become more intensive and they impact physical and chemical quality of the water in the Demirci Stream.

Among the applied indices, positive correlations were observed between BMWP (Original, Spanish, Hungarian, Czech and Polish versions) and ASPT (Original, Hungarian and Czech versions) (Table 4). A highly significant correlation was observed between the BMWP- O and BMWP- S (*r-value* 1.000, $p < 0.01$). Another highly significant correlation was determined between BMWP- O, BMWP- H and BMWP- C (*r-value* 0.998, $p < 0.01$); BMWP-S, BMWP- H and BMWP- C (*r-value* 0.998, $p < 0.01$). All versions of BMWP were positively and significantly correlated with each other ($p < 0.01$). All versions of ASPT indices were also positively and significantly correlated with each other ($p < 0.01$). All versions of BMWP were positively and significantly correlated with the BBI, while they did not correlate with FBI. ASPT- O and ASPT- H were positively and signifiantly correlated with the BBI while they negatively and signifiantly correlated with FBI. The SI showed significantly negative correlation with all indies except BMWP- P and MDI. All versions of BMWP showed positive significant correlations with all diversity indices.

According to DCA analysis, axis lengths were determined below three. This situation made it suitable for RDA analysis, which is a linear method. RDA analysis explained 75.2% of the variations between 11 sets and 13 ecological variables (Axis 2). Arhynchobdellida, Tubificida and Diptera orders showed positive correlations with BOI_5, EC, Cl^-, TDS, T°C, NH_4-N, NO_2-N and NO_3-N variables, while negatively correlated with DO, Sa-O_2 and pH (Fig. 5; Table 5). Although Tubificida includes different species living in clean and polluted environments, most of the species are found in environments with high organic pollution (Atanackovic et al. 2011). Taxa belonging to the order Diptera can be found in all environments from clean water to polluted water (Ertaş et al. 2022). Many species belonging to the order Arhynchobdellida are tolerant

Table 4 Pearson's correlation assesment between biotic indices and species diversity indices in the Demirci Stream

	SI	BMWP- O	BMWP- S	BMWP- H	BMWP- P	BMWP- C	ASPT- O	ASPT- H	ASPT- C	BBI	FBI	SDI	SWDI	MDI
SI	1	-0.785*	-0.785*	-0.822*	-0.734	-0.811*	-0.934**	-0.925**	-0.781*	-0.967**	0.798*	-0.975**	-0.965**	-0.571
BMWP- O		1	1.000**	0.998**	0.993**	0.998**	0.644	0.631	0.311	0.903**	-0.344	0.874*	0.905**	0.940**
BMWP- S			1	0.998**	0.993**	0.998**	0.644	0.631	0.311	0.903**	-0.344	0.874*	0.905**	0.940**
BMWP- H				1	0.987**	0.999**	0.684	0.671	0.362	0.926**	-0.394	0.900**	0.927**	0.922**
BMWP- P					1	0.985**	0.561	0.546	0.212	0.861*	-0.247	0.824*	0.861*	0.970**
BMWP- C						1	0.686	0.674	0.365	0.919**	-0.396	0.898**	0.922**	0.918**
ASPT- O							1	0.997**	0.927**	0.878**	-0.935**	0.926**	0.887**	0.353
ASPT- H								1	0.931**	0.874*	-0.936**	0.915**	0.876**	0.342
ASPT- C									1	0.654	-0.993**	0.724	0.662	-0.018
BBI										1	-0.676	0.983**	0.994**	0.734
FBI											1	-0.751	-0.691	-0.013
SDI												1	0.992**	0.667
SWDI													1	0.724
MDI														1

Explanations: *. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed). For abbreviations see Table 3

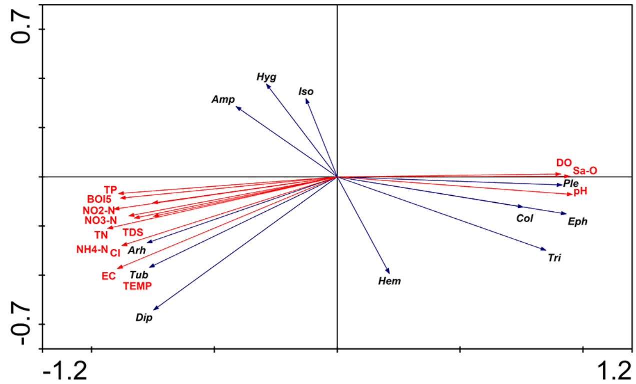

Fig. 5 RDA analysis between benthic macroinvertebrate orders and environmental variables in the Demirci Stream. Hyg: Hygrophlia, Iso: Isopoda, Amp: Amphipoda, Dip: Diptera, Tub: Tubificida, Arh: Arhynchobdellida, Hem: Hemiptera, Tri: Trichoptera, Col: Coleoptera, Eph: Ephemeroptera, Ple: Plecoptera

Table 5 Summary table of RDA calculated between benthic macroinvertebrate orders and environmental variables (*DCA results)

Axes	1	2	3	4	Total inertia
Eigenvalues:	0.295	0.031	0.008	0.006	0.440
Lengths of gradient*:	1.879	0.715	0.608	0.308	
Species-environment correlations:	0.983	0.869	0.918	0.863	
Cumulative percentage variance					
of species data:	66.9	73.9	75.8	77.2	
of species-environment relation:	70.6	75.2	0.0	0.0	
Sum of all eigenvalues:					0.440
Sum of all canonical eigenvalues:					0.407

to organic pollution and can survive for a long time in oxygen-free environments (Cılız and Kırkağaç 2022). The distributions of Ephemeroptera- Plecoptera- Trichoptera (EPT) and Coleoptera species are positively correlated to DO, Sa- O_2 and pH. It has been stated in some studies that the EPT group is found in the regions of rivers with high oxygen content (Wallace et al. 1996; Kazancı 2014; Serdar and Verep 2018).

Conclusion

The Demirci Stream was chosen as a study area since the Gediz River Basin served as one of the pilot basins for WFD applications in Turkey. Based on foregoing analyses, it was clearly shown that water quality of the Demirci Stream directly correlated with human influences and in turn affected the distribution of benthic macroinvertebrate community. The main findings of this study were as follows:

(1) SI, BMWP, ASPT and BBI were more proper than FBI index to determine the water quality of the Demirci Stream. (2) In order to protect the water quality of the surface water resources of the Gediz River basin, intermittent biological monitoring studies should be carried out. Strategic planning of underground dams in the region should be started urgently in order to prevent water scarcity in the basin and to provide year-round water to agricultural lands. (3) Rainwater and sewage systems should be separated from each other in the settlements of the Gediz River basin.

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Declarations

Conflicts of interest/competing interests Authors declare that they have no conflict of interest.

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