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Research Article

DIATOMS OF SEYDISUYU STREAM BASIN (TURKEY) AND ASSESSMENT OF WATER QUALITY BY STATISTICAL AND BIOLOGICAL APPROACHES

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ABSTRACT

In the present study, diatom flora of Seydisuyu Stream Basin (Turkey) was investigated and the water quality of the system was evaluated in a statistical and biological view. Epipelic (EPP), epilithic (EPL) and epifitic (EPF) diatoms were seasonally collected from 12 stations in 2012 along the Seydisuyu Stream Basin and some physical and chemical water quality parameters (temperature, salinity, TDS, pH, ORP, conductivity, nitrate, nitrite and phosphate) were measured during the field and laboratory studies. Biological Diatom Index (IBD) was used to assess the water quality of the basin and some mono (Pearson Correlation Index and Matrixplot Distribution Diagrams) and multi (Cluster Analysis and Factor Analysis) statistical methods were applied to detected all physical, chemical and biological data. According to data observed, Seydisuyu Stream Basin has II. – III. Class water quality in terms of investigated water quality parameters (Turkish Regulations) and a total of 48 diatom species were recorded for the basin by counting a total of 22.229 valves. *Cymbella lanceolata*, *Diatoma vulgare*, *Fragilaria construens*, *Hantzschia amphioxys*, *Meridion circulare*, *Navicula cincta*, *Neidium iridis*, *Navicula venata*, *Pinnularia brebissonii*, *Synedra acus* and *Surirella ovata* were the most dominant species in the region. According to result of IBD, the investigated region was in a mesotrophic state and has a moderate water quality. According to results of Factor Analysis, 9 factors explained 81.29% of the total variance and according to results of Cluster Analysis, stational similarity coefficients were determined as IBD Indices (0.98) > Environmental Parameters (0.85) > Diatom Flora (0.77) respectively.
Keywords: Seydisuyu stream basin, diatoms, biological diatom index (IBD), statistical evaluation.

1. INTRODUCTION

Developments of industry and rapid growth of world population cause many environmental problems and decreases the quality of limited freshwater of the world. Pollution of freshwater resources effects harmfully many aquatic and terrestrial organisms, which are sensitive to environmental changes and members of food chain. So monitoring water quality is a necessity both for human health and ecosystem health and one of the best protection techniques of aquatic ecosystems (Shrivastava et al., 2003; Tokatlı et al., 2013a; Köse et al., 2014). Using bio – indicator organisms , which is being used for a long time in scientific community, is an effective environmental monitoring method.

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Diatoms, which can be found in every surface water at any time and form a large part of the benthos (often 90 – 95%), are one of the most important aquatic producer groups and have quick reactions to the environmental variables. So the diatoms are an important part of water quality monitoring organisms and long been used to assess environmental conditions in a number of countries as indicators of water pollution (Goma et al., 2004; Atıcı and Obalı, 2006; Solak et al., 2007; Kalyoncu et al., 2009; Atıcı and Obalı, 2010; Tokatlı, 2013; Aydın and Büyükışık, 2014; Tan et al., 2017). Diatom indices developed by lots of countries for different environmental conditions are most widely used techniques in water quality assessment studies and Biological Diatom Index (IBD) is one of the most convenient index for evaluate the water quality (Coste et al., 2009).

Multivariate statistical techniques, which are widely used in water quality assessment studies, can help the interpretation of complex data matrices to better understand the ecological status of the studied ecosystems (Shrestha and Kazama 2007). Factor Analysis (FA) and Cluster Analysis (CA) are two of the most convenient multivariate statistical methods that are widely used for evaluating water quality of large numbers of different freshwater ecosystems all over the world (Akın et al., 2010; Najar and Khan, 2012; Tokatlı et al., 2014a; Köse et al., 2015).

Seydisuyu Stream, which has important agricultural lands on its basin, is one of the most important branches of Sakarya River that is the third longest river of Turkey. Turkey has 70% of the total boron reserve of the world, which is about 885 billion tons in the worldwide and Kırka county of Eskişehir province that is located in the border of Seydisuyu Stream Basin is one of the most important borate deposits of Turkey. In addition to the geological structure of the basin, agricultural applications, urban discharges and boron mines, which are located on the upside of the Seydisuyu Stream, are the main pollution sources for the system (Çiçek et al., 2013; Atıcı et al., 2016; Tokatlı et al., 2014b; Tokatlı et al., 2017; http://www.etimaden.gov.tr).

The aim of this study was to determine the diatom flora of Seydisuyu Stream Basin and evaluate the water quality by using some lymnological parameters, diatom indices and multistatistical techniques.

2. MATERIAL AND METHOD

2.1. Study Area

Seydisuyu Stream Basin, which is one of the most important mining and agricultural areas of Turkey, is located in the Central Anatolia Region between the locality of 38.0851 – 39.0361 N and 30.0161 – 31.0071 E. Seydisuyu Stream Basin, which has 2 dam lakes on the watershed, contains many agricultural and urban lands and significant borate deposits that have international importance in its border (Çiçek et al., 2013; Tokatlı et al., 2017). So the system is under effect of a significant organic and inorganic pressure and carries all these pollutions to the Black Sea through Sakarya River.

Water and diatom samples were collected with the period of three months from 12 selected stations on the Seydisuyu Stream Basin in 2012. Map of study area and selected stations are given in Figure 1.

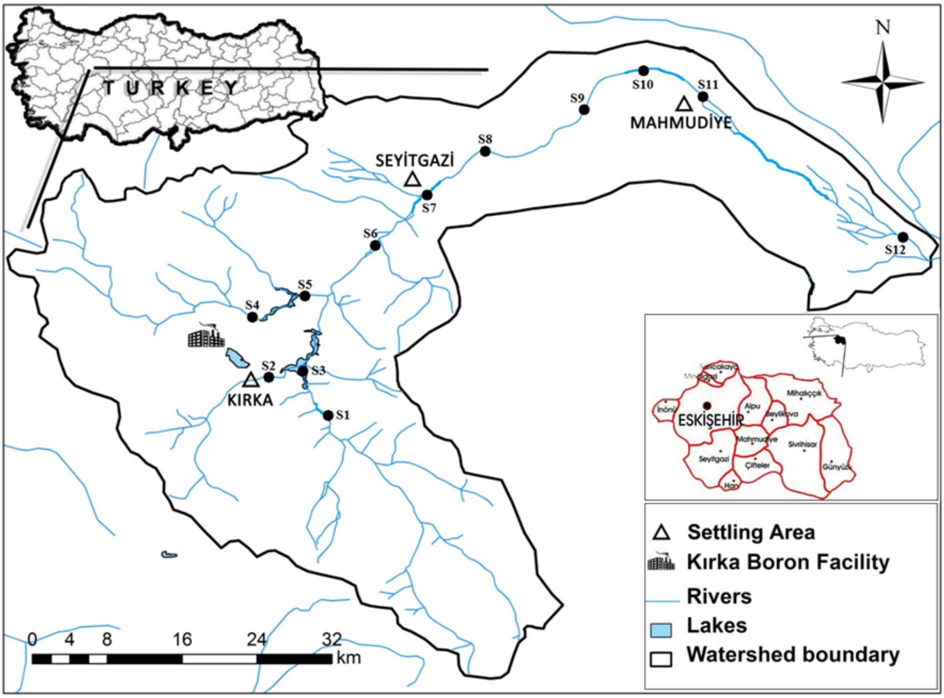

Figure 1. Seydisuyu Stream Basin and the selected stations

2.2. Physical and Chemical Parameters

Water samples were collected from the basin in 1 liter polyethylene bottles. Temperature, salinity, TDS, pH, ORP, and conductivity parameters were determined by using "Hydrolab DS5 Multiparameter Sonde (Hach Hydromet)" device during the field studies and nitrate, nitrite and phosphate parameters were determined by using "DR 2800 Spectrophotometer (Hach Lange)" during the laboratory studies.

2.3. Diatoms

Diatom samples were collected from sediment surface (epipelic; EPP), stones (epilithic; EPL) and plants (epifitic; EPF) with the period of three months. A glass pipe with a diameter of 0.8 cm and 100 – 150 cm long was used for capturing EPP samples. EPF samples were collected from the stems and leaf of some plants, which were found in costal water. EPL samples were taken from stone surface into water by using a brush.

All the diatom samples collected from the field were cleaned with acid (98% H_2SO_4 and 35% HNO_3) and mounted on microscope for observation with a magnification of 1000X. Slides were prepared and 150 valves enumerated in each slide to determine the relation and abundance of each taxa (Sladecova, 1962; Round, 1993). Diatoms were identified according to Cox (1996) and Krammer and Lange-Bertalot (1986; 1988; 1991a; 1991b). Frustules are counted and then the % of the single diatom species on the total count (relative abundance values) were calculated both for totally and stationally.

2.4. Biological Diatom Index (IBD)

Biological Diatom Index (IBD) values of all stations, seasons and habitats were automatically calculated by using the "Calculate IBD with Excel" program. And the trophic status and quality classes of freshwater according to IBD values are given in Table 1 (Lenoir and Coste, 1996; http://omnidia.free.fr/download.htm).

Table 1. Scale of IBD

Index Value	Quality Class	Trophic Status
> 17	High Quality	Oligotrophic
15 – 17	Fine Quality	Oligo – Mesotrophic
12 – 15	Moderate Quality	Mesotrophic
9 – 12	Low Quality	Meso – Eutrophic
< 9	Poor Quality	Eutrophic

2.5. Statistical Data

Cluster Analysis (CA) that is one of widely used multivariate statistical techniques classifies the objects. Hierarchical agglomerative clustering, which was used in the present study, is the most common approach in CA applications. It is typically illustrated by a tree diagram that provides a visual summary of the clustering processes (Tabachnick and Fidell 1996; Shrestha and Kazama 2007; Filik et al., 2008). Principle Component Analysis (PCA) is another widely used and powerful multivariate statistical technique to explain the variance of a large dataset of intercorrelated variables with a smaller set of independent variables (Simeonov et al. 2003). Factor Analysis (FA), which was used in the present study, reduces the contribution of less significant variables obtained from PCA (Vega et al. 1998; Wunderlin et al. 2001).

In the present study, Cluster Analysis (CA) according to Bray Curtis and Matrixplot Distribution Diagrams were applied to the results by using the "Past" package program. Pearson Correlation Index (PCI) and Factor Analysis (FA) were applied to the results by using the "SPSS 17" package program.

3. RESULTS

3.1. Physical and Chemical Data

Results of the averages of seasonal physicochemical data detected in 12 stations selected on the Seydisuyu Stream Basin with the standard deviation values (SD) were given in Figure 2.

Water quality regulations in Turkey separate the inland waters into four classes. Class I includes high quality water, which has a high potential to be used for drinking water, recreational purposes, and the production of trout. Class II refers to less contaminated water, which can be used as surface water is to become potential for drinking water outside of trout production and for all uses other than Class I. Class III includes polluted water, which can only be used as industrial water after treatment. Class IV refers to heavily polluted water, which should not be used at all (Turkish Regulations, 2015).

According to the criteria of SKKY identified for Turkey (Water Pollution Control Regulation in Turkey), Seydisuyu Stream Basin has I. – II. Class water quality in terms of temperature (<25 ^{0}C: I. – II. Class), pH (6.5 – 8.5: I. – II. Class), Total Dissolved Solids (<0.5 g/L: I. Class; 0.5 – 1.5 g/L: II. Class) and nitrate (<5 mg/L: I. Class) parameters; and II. – III. Class water quality in terms of nitrite (0.002 – 0.01 mg/L: II. Class; 0.01 – 0.05 mg/L: III. Class) parameter (Turkish Regulations, 2015).

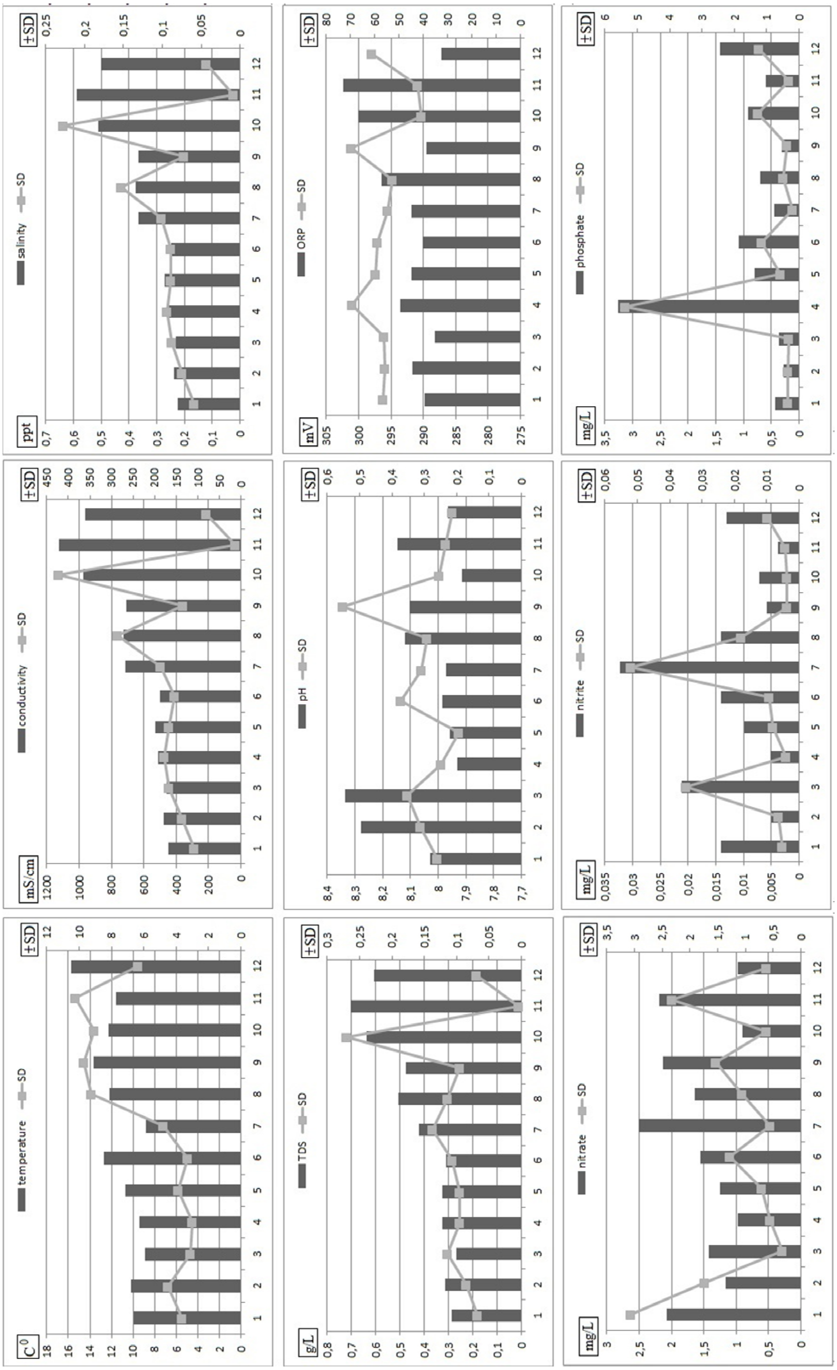

Figure 2. Annual averages of physicochemical parameters with SD values

3.2. Biological Data

During the present study, a total of 48 diatom species were recorded from epipelic (EPP), epilithic (EPL) and epifitic (EPF) habitats of Seydisuyu Stream Basin by counting a total of 22,229 valves. All diatom species detected in this study were new records for the Seydisuyu Stream Basin. All detected diatom species with the total relative abundance values in the basin and species codes used in statistical evaluation are given in Table 2. Relative abundance values of detected diatom species according to stations are given in Table 3.

Cymbella lanceolata, *Diatoma vulgare*, *Fragilaria construens*, *Hantzschia amphioxys*, *Meridion circulare*, *Navicula cincta*, *Neidium iridis*, *Navicula veneta*, *Pinnularia brebissonii*, *Synedra acus* and *Surirella ovata* were the most dominant species in the region.

Table 2. Diatom taxa identified in the basin with total relative abundance (RA)

Diatom taxa	Code	%RA	Diatom taxa	Code	%RA
Achnanthes lanceolata var. *elliptica* Grun.	d1	2.08	*Gomphonema parvulum* Kütz.	d25	0.69
Achnanthes lanceolata (Breb.) Grun.	d2	1.79	*Gyrosigma acuminatum* (Kütz.) Rabh.	d26	2.44
Amphora ovalis (Kützing) Kützing	d3	1.81	*Gyrosigma attennuatum* Bory.	d27	1.53
Anamoeneis sphaephora Grun.	d4	1.75	*Hantzschia amphioxys* (Ehrenberg) Grun.	d28	2.53
Aulacoseria granulata (Ehrenberg) Simonsen	d5	1.52	*Meridion circulare* Ag.	d29	2.58
Cymbella affinis (Kützing) Grunow	d6	1.79	*Melosira varians* Ag.	d30	1.32
Cymbella amphicephala Naeg.ex. Kütz.	d7	2.24	*Nitzschia acularis* (Kützing) W. Smith	d31	2.38
Cymbella cymbiformis (Ag.) Ag.	d8	1.80	*Navicula cincta* (Ehrenberg) Ralfs in Pritchard	d32	3.03
Cymbella helvetica Kütz	d9	2.04	*Navicula cryptocephala* Kütz.	d33	2.37
Cymbella lanceolata Ag.	d10	2.51	*Neidium dubium* Becker	d34	2.46
Cyclotella meneghiniana Kütz.	d11	1.70	*Neidium iridis* (Ehr.) Cleve	d35	2.79
Cyclotella ocellata (C.Agardh) Kützing	d12	1.87	*Navicula lanceolata* (Agardh) Kützing	d36	2.26
Cocconeis pediculus Ehrenberg	d13	1.69	*Nitzschia palea* (Kützing) W. Smith	d37	2.43
Cocconeis placentula Ehrenberg	d14	1.71	*Navicula pupula* Kütz.	d38	1.37
Coscinodiscus rothii (Ehrenberg) Grunow	d15	1.88	*Navicula radiosa* (Agardh) Kützing	d39	2.35
Cymbella ventricosa Agardh	d16	1.80	*Navicula veneta* Kützing	d40	2.79
Diatoma elongatum Bory.	d17	2.07	*Pinnularia borealis* Grun.	d41	1.27
Diatoma vulgare Bory	d18	2.63	*Pinnularia brebissonii* (Kütz.) Ralph.	d42	2.54
Eunotia sp.	d19	1.60	*Rhoicosphaenia curvata* (Kützing) Grunow	d43	2.34
Fragilaria construens (Ehrenberg) Hustedt	d20	2.53	*Synedra acus* Ehr.	d44	2.65
Fragilaria delicatissima (W.Smith) Lange Bertalot	d21	2.21	*Surirella ovata* Kützing	d45	2.92
Fragilaria sp.	d22	1.87	*Synedra ulna* (Nitzch) Ehrenberg	d46	2.34
Didymosphenia geminata (Lyng.) M.S.	d23	1.85	*Tabellaria fenestrata* (Lyngbye) Kützing	d47	2.32
Gomphonema olivaceum (Lyng.) Kütz.	d24	1.60	*Pinnularia sublinearis* (Grunow) Krammer	d48	1.96

Table 3. Relative abundance (RA) of diatoms according to stations

Diatom taxa	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
A. lanceolata var. *elliptica*	1.53	1.81	1.82	1.72	1.48	3.17	2.07	2.76	2.06	1.95	2.21	2.13
A. lanceolata	1.53	1.81	1.95	1.31	1.22	2.79	1.68	1.84	2.44	1.24	1.77	1.81
A. ovalis	1.22	1.93	1.56	0.55	1.27	2.93	2.75	2.86	2.01	1.14	1.33	1.48
A. sphaephora	1.99	1.81	1.43	0.00	1.85	2.65	2.15	1.43	1.84	1.46	1.66	2.02
A. granulata	0.66	1.50	0.91	1.79	1.38	1.61	1.98	2.97	1.08	1.78	0.77	1.59
C. affinis	2.55	1.44	1.17	1.24	2.22	1.84	2.19	1.28	1.25	3.57	1.16	1.15
C. amphicephala	2.45	2.05	1.56	1.10	2.44	1.98	2.11	3.48	2.77	2.33	1.99	2.30
C. cymbiformis	2.80	1.56	1.30	1.86	1.48	1.47	1.55	2.35	2.28	1.41	1.60	1.86
C. helvetica	3.41	1.68	1.56	1.52	1.64	1.80	1.16	3.79	1.84	1.89	2.10	1.97
C. lanceolata	3.26	2.29	2.40	3.38	2.86	1.37	2.62	2.61	2.77	1.95	2.32	2.46
C. meneghiniana	0.97	1.44	1.30	1.93	1.48	1.94	2.19	1.74	2.22	1.30	2.21	1.59
C. ocellata	1.43	2.05	2.08	1.79	1.59	0.43	2.15	2.97	2.55	1.73	1.82	1.97
C. pediculus	2.24	0.24	1.30	1.38	2.01	1.98	1.33	1.99	2.28	1.84	1.99	1.42
C. placentula	2.34	1.32	1.49	1.79	1.48	3.02	1.68	1.53	1.90	0.92	1.71	1.04
C. rothii	1.17	1.62	1.49	2.55	1.91	1.04	2.80	2.76	1.90	2.06	1.44	1.70
C. ventricosa	1.99	1.93	1.56	0.55	1.27	2.88	2.37	1.59	2.28	1.84	1.66	1.09
D. elongatum	2.80	1.81	2.66	1.38	1.59	2.36	2.58	2.76	1.25	2.06	1.71	1.53
D. vulgare	3.01	2.17	1.95	4.00	2.33	1.37	3.31	3.79	3.20	1.68	2.10	2.74
Eunotia sp.	1.94	2.53	2.47	2.97	1.96	2.74	0.00	1.13	0.00	1.89	0.00	2.30
F. construens	3.16	3.85	4.02	2.07	3.39	1.89	2.24	1.94	2.33	1.78	2.21	1.86
F. delicatissima	2.04	2.53	2.27	2.97	1.59	2.65	2.71	1.53	2.28	2.16	1.66	2.19
Fragilaria sp.	2.80	3.79	2.66	1.93	1.59	1.80	0.00	0.00	3.31	2.60	0.00	2.79
D. geminata	2.14	1.87	1.82	2.83	1.64	1.65	1.64	1.33	0.76	2.38	1.99	2.52
G. olivaceum	1.58	1.20	1.69	1.45	1.64	1.47	1.72	1.94	1.19	1.84	1.88	1.53
G. parvulum	0.66	0.84	0.52	0.83	0.21	1.13	1.08	0.36	0.65	0.32	0.66	0.88
G. acuminatum	2.85	2.53	2.47	2.76	3.02	1.37	2.07	1.94	2.82	2.60	2.10	3.12
G. attennuatum	0.82	1.50	1.17	0.28	0.74	1.75	1.89	1.99	1.52	1.78	2.49	2.02
H. amphioxys	2.55	2.89	2.73	2.90	1.22	2.74	1.51	3.02	4.01	2.65	1.77	2.79
M. circulare	2.60	3.49	2.73	0.00	2.54	2.60	3.01	2.92	3.63	2.70	1.44	2.68
M. varians	0.41	0.96	0.52	1.72	0.42	2.03	2.07	2.05	1.08	0.97	1.77	1.48
N. acularis	1.58	1.62	1.75	0.97	3.50	2.08	1.94	2.15	3.90	1.84	4.14	2.79
N. cincta	2.91	3.01	3.24	2.34	3.18	4.87	1.89	2.92	3.04	3.08	2.76	3.01
N. cryptocephala	1.27	1.08	1.17	2.21	2.44	2.17	2.80	3.27	2.77	2.97	3.43	2.41
N. dubium	2.40	2.71	2.14	3.03	2.49	1.94	4.39	1.89	1.79	2.11	2.49	1.86
N. iridis	3.26	4.15	4.02	2.90	2.91	1.61	3.18	1.94	0.76	1.41	5.25	2.57
N. lanceolata	1.78	1.56	2.08	1.66	3.34	1.28	3.92	1.99	1.52	2.49	1.99	3.06
N. palea	2.65	2.29	3.11	4.28	2.86	2.32	2.50	1.89	1.84	3.08	0.77	2.08
N. pupula	1.43	1.44	1.82	2.00	3.13	1.51	1.72	0.97	0.65	0.32	0.61	0.93
N. radiosa	2.45	2.95	3.05	3.59	2.65	1.80	1.42	1.43	2.82	2.49	2.49	1.86
N. venata	2.96	3.25	3.76	3.38	3.65	2.74	1.59	2.10	1.90	2.70	3.48	2.68
P. borealis	0.20	0.24	0.26	1.79	1.69	1.89	1.29	0.31	0.65	2.16	2.49	2.13
P. brebissonii	2.60	2.59	2.73	3.03	2.07	2.50	2.32	1.99	2.33	2.49	2.93	3.17
R. curvata	2.40	2.89	2.92	2.21	1.43	1.42	2.58	2.76	1.68	2.49	3.15	2.41
Synedra acus	2.55	2.29	2.60	2.14	3.55	2.27	2.32	2.20	2.33	5.08	2.49	1.91
S. ovata	2.91	2.77	3.44	3.86	3.39	2.65	3.01	1.94	2.77	2.92	3.04	2.63
S. ulna	1.99	2.17	2.40	2.07	2.12	2.41	3.10	1.89	2.06	2.54	2.87	2.30
T. fenestrata	2.19	2.77	3.05	3.79	2.86	1.84	0.00	1.79	2.39	2.22	3.54	2.57
P. sublinearis	1.58	1.81	1.95	2.21	1.27	2.27	1.42	1.89	3.31	1.78	2.60	1.64

3.3. Biological Diatom Index (IBD)

IBD scores of 3 different (EPF, EPP and EPL) and whole habitats in the basin according to stations and seasons were calculated separately and the results are given in Figure 3 by using Matrixplot Distribution Diagrams.

According to calculated IBD values for EPF, EPP, EPL and whole habitats, Seydisuyu Stream Basin was in a mesotrophic state and had a moderate water quality in general. Significant differences were not recorded among the IBD values of habitats and seasons. Detected stational variations of IBD values (SD=0.33) were significantly higher than the detected seasonal (SD=0.15) and habitatal (SD=0.05) variations in Seydisuyu Stream Basin.

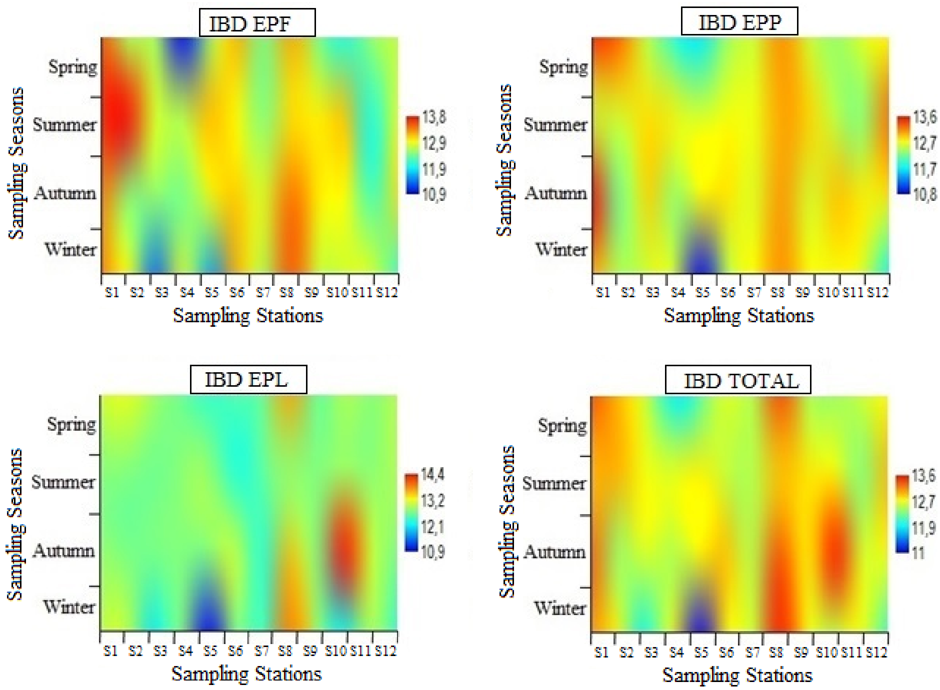

Figure 3. IBD scores of stations and seasons for different habitats

3.4. Pearson Correlation Index (PCI)

In the present study, some mono (Pearson Corelation Index) and multi (Factor Analysis and Cluster Analysis) statistical techniques were used to obtain a sophisticated ecological assessment by using environmental, biological and biotic index results. Pearson Correlation Index (PCI) was applied to the results to determine the relationships between all detected physiochemical parameters and biotic index data with densities of diatom populations. All detected positive and negative relations were given in Table 4. According to results of PCI, the relations between "temperature" with "population densities of *A. granulata, C. amphicephala, C. placentula, C. rothii, G. acuminatum, G. attennuatum, H. amphioxys, M. varians, N. cincta, N. cryptocephala, N. venata, P. brebissonii* and *P. sublinearis*" were significantly positive; the relations between "conductivity, salinity and TDS" with "*M. varians, N. dubium* and *N. lanceolata*" were significantly positive and with "*N. pupula*" were significantly negative; the relation between "pH" with "*M. circulare*" was significantly positive; the relations between "nitrite" with "*A. lanceolata var. elliptica, A. lanceolata, N. palea* and *S. acus*" were significantly positive; the relations between "phosphate" with "*M. circulare* and *N. radiosa*" were significantly negative (P<0.01). According to PCI results, nitrate was the most unrelated parameter on the population densities of diatoms in the basin and it was unrelated with any diatom taxa. Oxidation – Redaction Potential (ORP) was the most relative parameter on the population densities of diatoms in the basin and it was positively related with almost all the diatom taxa at the 0.01 significance level (Table 4).

Scores of Biological Diatom Index (IBD) calculated separately by using data of EPF, EPP and EPL habitats and all detected diatom data from all habitats as a whole were positively related with each other at the 0.01 significance level and positively related with lots of diatom taxa at the 0.01 and 0.05 significance levels (Table 4).

3.5. Cluster Analysis (CA)

In the present study, CA was applied to the results to classify the stations according to physicochemical parameters, diatom floras and diatom indices. According to the first Cluster Analysis (CA1) determined by using physiochemical parameters (temperature, conductivity, salinity, TDS, pH, ORP, nitrate, nitrite and phosphate) with a total of 0.85 stational similarity coefficient (SC), maximum similarity was observed between Stations 5. and 6. (96.4%) and minimum similarities were observed between Stations 1. and 11. (68.4%) (Figure 4). According to the second Cluster Analysis (CA2) determined by using diatom population densities with a total of 0.77 stational similarity coefficient (SC), maximum similarity was observed between 10. and 12. stations (82.7%) and minimum similarity was observed between 4. and 7. stations (66.0%) (Figure 4). According to the third Cluster Analysis (CA3) determined by using data of Biological Diatom Indices (IBD) with a total of 0.98 stational similarity coefficient (SC), maximum similarity was observed between Stations 7. and 9. (99.2%) and minimum similarity was observed between Stations 3. and 8. (96.7%) (Figure 4).

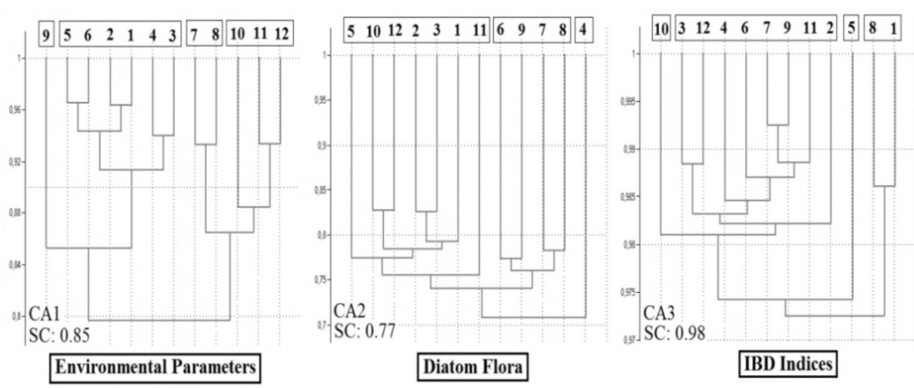

Figure 4. Tree dendrograms of CA for different data sets (SC: Similarity Coefficient)

Table 4. Pearson Correlation Index coefficients with significance levels (*n* = 48)

	temp	cond	sal	TDS	pH	ORP	NO_3	NO_2	PO_4	IBDf	IBDp	IBDl	IBDt
temp	1												
cond	-.035	1											
sal	-.030	**.999****	1										
TDS	-.003	**.971****	**.972****	1									
pH	**-.297***	.096	.102	.057	1								
ORP	**.312***	.159	.166	.146	**.521****	1							
NO_3	**-.308***	.060	.058	.034	-.025	**-.366***	1						
NO_2	.001	-.071	-.070	-.062	.160	.173	-.029	1					
PO_4	-.080	.086	.085	.087	-.189	-.101	-.188	-.074	1				
IBDf	.102	-.073	-.074	-.016	.091	.267	-.031	-.096	.026	1			
IBDp	.111	.072	.074	.112	.162	.206	.186	.020	-.052	**.578****	1		
IBDl	.043	.097	.103	.168	.037	.051	.104	-.235	-.051	**.465****	**.629****	1	
IBDt	.096	.048	.051	.117	.104	.203	.084	-.146	-.011	**.820****	**.849****	**.841****	1
d1	**.333***	-.044	-.040	.009	.107	**.500****	-.119	**.451****	-.055	**.347***	**.296***	.261	**.356***
d2	.262	.026	.031	.040	.143	**.489****	.044	**.430****	-.147	.113	.246	.154	.192
d3	**.311***	.051	.056	.091	.208	**.450****	.029	**.308***	**-.312***	.272	**.365***	.218	**.322***
d4	.208	.149	.146	.125	.235	**.528****	.086	.241	-.154	.156	.257	.123	.194
d5	**.440****	.147	.145	.119	.181	**.523****	-.045	.205	-.162	.139	.147	.111	.155
d6	**.349***	-.123	-.126	-.127	.141	**.405****	.014	**.332***	-.238	**.346***	**.335***	.098	.284
d7	**.444****	-.019	-.021	.004	.133	**.494****	-.059	**.308***	-.240	**.336***	**.368***	.175	**.332***
d8	**.356***	-.068	-.070	-.054	.275	**.550****	-.006	.220	-.284	**.426****	**.345***	.156	**.354***
d9	**.357***	-.052	-.053	-.092	.068	**.381****	.081	.262	-.271	**.423****	.283	.067	**.293***
d10	**.343***	-.058	-.061	-.094	.135	**.519****	-.006	.247	**-.301***	**.379****	**.319***	.081	**.295***
d11	.269	-.196	-.197	-.221	.152	**.510****	-.001	.248	-.165	**.428****	**.288***	.054	**.293***
d12	**.287***	.066	.071	.095	.038	**.413****	.235	.140	-.232	**.360***	**.315***	.223	**.352***
d13	.101	.048	.054	.051	.110	**.344***	.097	.125	-.192	**.308***	**.291***	**.405****	**.430****
d14	**.399****	.003	.009	.061	.134	**.486****	.054	.186	**-.328***	**.518****	**.415****	.280	**.473****
d15	**.414****	-.197	-.189	-.119	.067	**.467****	-.029	.216	-.226	**.501****	**.455****	.272	**.482****
d16	.242	-.007	.001	.060	.231	**.448****	.035	.211	**-.285***	**.586****	**.604****	**.447****	**.637****
d17	.192	-.073	-.069	-.105	.223	**.516****	.105	.183	-.270	**.317***	**.326***	.197	**.323***
d18	.196	-.029	-.026	-.006	.117	**.409****	.077	.179	-.178	**.321***	**.382****	.197	**.349***
d19	.231	-.167	-.166	-.179	.150	**.474****	.081	**.307***	**-.301***	**.440****	**.518****	.207	**.439****
d20	**.323***	.077	.078	.056	.059	**.558****	-.214	.215	-.157	.252	.165	.139	.223
d21	.218	**-.345***	**-.345***	**-.339***	.052	.264	-.168	-.060	-.018	**.319***	.196	.145	.261
d22	.276	-.157	-.166	-.193	.178	**.504****	.028	**.294***	-.144	.275	.276	.019	.217
d23	.226	-.241	-.236	-.208	.203	.272	-.239	-.122	-.114	**.300***	.183	.047	.218
d24	-.022	.274	.273	.256	.196	.204	.014	.055	.049	.167	.147	-.245	.031
d25	**.288***	.183	.185	.187	.219	**.695****	.064	.238	-.261	**.343***	**.412****	.240	**.383****
d26	**.408****	-.085	-.088	-.119	.186	**.508****	.031	**.306***	-.164	.243	.185	-.037	.145
d27	**.443****	-.077	-.078	-.015	.179	**.498****	-.083	.098	-.237	**.357***	**.400****	.185	**.360***
d28	**.378****	-.114	-.114	-.083	.159	**.373****	.027	.226	**-.286***	**.408****	**.338***	.107	**.334***
d29	.158	**-.328***	**-.326***	**-.347***	**.398****	**.580****	-.103	.227	**-.369****	**.290***	.197	-.078	.145
d30	**.390****	**.389****	**.386****	**.392****	.089	**.426****	-.018	.209	-.164	.256	.236	.184	.261
d31	**.304***	.118	.120	.132	.114	**.381****	-.029	**.301***	-.211	.129	.282	.207	.233
d32	**.371****	.096	.093	.048	.067	**.555****	-.013	.186	-.228	.178	.224	.113	.188
d33	**.476****	.096	.095	.107	.132	**.575****	.051	.149	-.217	.227	.282	.224	.278
d34	.283	**.402****	**.400****	**.346***	-.057	**.451****	-.083	.128	.008	-.025	-.022	.031	-.006
d35	**.347***	-.099	-.099	-.103	.069	**.452****	-.025	.013	-.196	**.387****	.217	.133	.284
d36	**.345***	**.422****	**.422****	**.423****	-.095	**.398****	.102	.183	-.120	.152	.172	.207	.202
d37	.208	.193	.194	.122	.009	**.387****	.011	**.371****	-.212	.043	.037	-.047	.010
d38	.118	**-.374****	**-.370****	**-.419****	.134	**.422****	-.004	**.303***	-.125	.103	-.020	-.223	-.064
d39	**.339***	-.211	-.208	-.195	.202	**.581****	-.170	.066	**-.378****	.010	.041	-.021	.003
d40	**.369****	-.101	-.100	-.115	.145	**.552****	-.228	.148	**-.302***	.119	.008	-.067	.013
d41	.198	-.280	-.277	**-.294***	-.070	**.434****	-.223	**.357***	-.088	.024	-.002	-.093	-.021
d42	**.424****	.278	.283	.283	.133	**.451****	-.016	.168	-.253	.093	.045	-.037	.031
d43	-.066	.055	.053	-.001	**.323***	**.389****	-.036	.158	-.160	-.036	.100	.021	.012
d44	.145	-.034	-.034	-.084	.058	**.493****	.048	**.440****	-.115	.085	.050	-.094	.011
d45	**.349***	.124	.127	.062	.082	**.573****	.067	**.287***	**-.329***	.065	.141	.022	.074
d46	.178	.183	.193	.192	.113	**.473****	-.101	.084	-.189	.173	.190	**.396****	**.330***
d47	.284	-.120	-.118	-.175	.143	**.584****	-.045	**.314***	**-.355***	-.124	-.153	-.279	-.225
d48	**.411****	-.042	-.034	.013	.185	**.476****	-.207	-.169	-.144	.056	.067	.148	.102

temp: temperature; cond: conductivity; sal: salinity; IBDf: epifitic, p: epipelic, l: epilitic, t: total

*: correlation is significant at the 0.05 level ($P<0.05$); **: correlation is significant at the 0.01 level ($P<0.01$)

3.6. Factor Analysis (FA)

FA was used to determine the effective varifactors on Seydisuyu Stream Basin by using correlated variables. Uncorrelated variables were removed to increase the reliability of FA. A total of 46 variables (8 psychochemical variables, 34 diatom variables and 4 indices variables) were used to determine the varifactors (n = 48 for all parameters). Eigenvalues higher than one were taken as criterion for evaluate the principal components required to explain the sources of variance in the data.

According to rotated cumulative percentage variance, nine factors explained 81.29% of the total variance. The factor loadings are classified according to loading values as "strong (>0.75)", "moderate (0.75 – 0.50)" and "weak (0.50 – 0.30)" (Liu *et al*., 2003). All the parameter loadings for nine components after rotation are given in Table 5. The percentage variance counted, cumulative percentage variance and component loadings (unrotated and rotated) are given in Table 6.

Table 5. Extracted values of PCA parameters

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings** (unrotated)			**Rotation Sums of Squared Loadings** (rotated)		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	17.694	38.466	38.466	17.694	38.466	38.466	10.301	22.393	22.393
2	4.820	10.479	48.945	4.820	10.479	48.945	4.894	10.639	33.032
3	3.891	8.459	57.403	3.891	8.459	57.403	4.728	10.279	43.310
4	2.566	5.577	62.981	2.566	5.577	62.981	4.408	9.583	52.894
5	2.442	5.309	68.290	2.442	5.309	68.290	4.118	8.953	61.846
6	1.722	3.743	72.033	1.722	3.743	72.033	2.849	6.193	68.040
7	1.644	3.574	75.607	1.644	3.574	75.607	2.635	5.727	73.767
8	1.416	3.078	78.685	1.416	3.078	78.685	1.773	3.855	77.622
9	1.198	2.605	81.290	1.198	2.605	81.290	1.688	3.669	**81.290**

First factor (F1), named as "Alpha – Mesosaprobus Diatoms Factor" explains 22.3% of total variance and it is related to the variables of alpha – mesosaprobic diatom species in general. *C. helvetica, C. lanceolata, C. cymbiformis, C. affinis, C. amphicephala, N. iridis* were strong positively and *C. meneghiniana, G. acuminatum, H. amphioxys, M. varians, S. ovata, Eunotia sp., C. placentula, N. lanceolata, C. ocellata, G. attennuatum, G. parvulum* were moderate positively loaded with this factor (Hofmann, 1994; Van Dam et al., 1994).

Second factor (F2), named as "Biological Diatom Indices Factor" explains 10.6% of total variance and it is related to the variables of IBD indices. IBD total, IBD epl, IBD epp, IBD epf were strong positively and *C. ventricosa* was moderate positively loaded with this factor.

Third factor (F3), named as "ORP Factor" explains 10.2% of total variance and it is related to the variables of ORP and some diatom species. *N. radiosa, N. venata* were strong positively and ORP, *F. delicatissima, T. fenestrata, P. borealis* were moderate positively loaded with this factor.

Fourth factor (F4), named as "Ionic Factor" explains 9.5% of total variance and it is related to the variables of nutrient parameters. Salinity, conductivity, TDS were strong positively and *N. lanceolata* was moderate positively loaded with this factor.

Fifth factor (F5), named as "Beta – Mesosaprobus Diatoms Factor" explains 8.9% of total variance it is related to the variables of beta – mesosaprobic diatom species in general. *D. vulgare,* *D. elongatum* were strong positively and *C. rothii, C. ocellata, A. ovalis* were moderate positively loaded with this factor (Hofmann, 1994; Van Dam et al., 1994).

Sixth factor (F6), named as "Nitrite Factor" explains 6.1% of total variance and it is related to the variables of nitrite and some diatom species. *N. acularis,* nitrite, *A. lanceolata* var. *elliptica, A. ovalis* were moderate positively loaded with this factor.

Seventh factor (F7), named as "Polysaprobus Diatoms Factor" explains 5.7% of total variance and it is related to the variables of polysaprobic diatom species in general. *S. ulna, C. pediculus* were strong positively loaded with this factor (Hofmann, 1994; Van Dam et al., 1994).

Eighth factor (F8), named as "pH Factor" explains 3.8% of total variance and it is related to the variables of pH, temperature and some diatom species. pH was strong positively, *M. circulare* was weak positively and temperature was moderate negatively loaded with this factor.

Ninth factor (F9), named as "Phosphate Factor" explains 3.6% of total variance and it is related to the variables of phosphate and some diatom species. Phosphate was moderate negatively, *F. delicatissima* was weak negatively and *H. amphioxys, M. circulare* were weak positively loaded with this factor.

Table 6. Rotated component matrix of extracted factors

Parameters	Components								
	F1	F2	F3	F4	F5	F6	F7	F8	F9
d9	**.877**	.106	.047	-.055	.106	.054	.252	.000	.123
d10	**.870**	.093	.127	-.034	.137	.096	.221	.032	.175
d8	**.851**	.212	.260	-.002	.138	.044	-.041	.109	.048
d6	**.826**	.139	-.024	-.078	.153	**.348**	.024	-.016	.093
d7	**.822**	.223	.205	.052	.074	.266	.013	-.063	-.035
d35	**.761**	.177	**.399**	-.054	-.104	-.192	.148	-.061	-.036
d11	**.738**	.100	.195	-.163	**.346**	-.086	.071	.109	-.114
d26	**.670**	-.018	.257	-.045	.173	.190	-.006	.083	-.094
d28	**.665**	.230	.040	-.108	.113	.294	.160	.001	**.391**
d30	**.656**	.101	.061	**.460**	.050	**.379**	.052	-.101	.148
d45	**.611**	-.148	.302	.181	**.316**	.239	**.302**	-.051	.086
d19	**.608**	**.308**	.166	-.160	.265	**.309**	.267	.071	.044
d14	**.551**	**.388**	.154	.049	**.473**	.258	.051	-.089	.201
d36	**.541**	.037	.028	**.507**	**.430**	.191	.142	-.269	-.035
d12	**.539**	.228	.155	.136	**.508**	-.205	.230	-.092	.029
d27	**.508**	**.363**	**.446**	.002	.118	.106	-.268	-.073	.221
d25	**.506**	.237	**.399**	.233	**.382**	.250	**.313**	.085	.003
IBDtotal	.169	**.948**	-.031	.041	.104	.005	.149	.014	-.020
IBDepl	-.058	**.821**	-.045	.142	.005	.029	.274	-.140	.046
IBDepp	.190	**.807**	-.024	.044	.126	.126	.024	.106	.018
IBDepf	**.338**	**.749**	-.005	-.101	.149	-.111	.005	.099	-.090
d16	**.378**	**.620**	.177	.021	**.390**	.103	.000	.085	.067
d39	.127	-.042	**.834**	-.117	.262	.043	.108	.008	.272
d40	.245	-.059	**.812**	-.043	.127	.048	.164	.018	.080
ORP	**.374**	.116	**.618**	.229	.254	.173	.075	.352	-.054
d21	.196	**.304**	**.607**	**-.371**	-.245	-.098	.127	.003	**-.316**
d47	**.374**	**-.376**	**.537**	-.069	**.404**	.200	.286	.035	.154

d41	.162	-.114	**.503**	**-.302**	.287	**.331**	**.359**	-.100	-.235
d29	**.330**	.053	**.468**	**-.330**	.225	.175	.211	**.388**	**.310**
sal	-.044	.008	-.068	**.970**	-.018	-.004	.061	.065	-.033
cond	-.039	.004	-.072	**.970**	-.023	-.006	.057	.064	-.034
TDS	-.066	.103	-.066	**.959**	-.024	.027	.013	.005	-.015
d34	**.425**	-.182	**.390**	**.469**	.136	.012	**.349**	-.185	-.293
d18	.202	.241	.055	-.002	**.815**	**.300**	-.052	.011	.061
d17	.189	.178	.294	-.062	**.763**	.172	.230	.115	.113
d15	**.405**	**.416**	.297	-.137	**.545**	.182	-.057	-.117	.137
d38	**.347**	-.199	**.351**	**-.392**	**.412**	.116	.263	.184	-.237
d31	.209	.116	.213	.168	.239	**.676**	.122	-.064	.246
NO2	.257	-.223	-.060	-.101	.129	**.604**	.072	.234	-.174
d1	**.503**	.270	.158	.018	.269	**.597**	.093	-.084	-.242
d3	.234	.277	.184	.099	**.496**	**.550**	-.074	.017	.239
d46	.203	.212	.288	.194	.016	.092	**.811**	-.010	.116
d13	.264	.290	.128	.027	.124	.055	**.803**	.044	.086
pH	.088	.116	.193	.109	.002	.102	-.074	**.873**	.147
temp	**.353**	.085	**.411**	.048	.014	.166	-.167	**-.581**	.126
PO4	-.191	.039	-.159	.070	-.144	.006	-.126	-.089	**-.716**

Factor loadings > 0.3 highlighted in bold
IBD data shaded in light grey
Environmental data shaded in dark grey

4. DISCUSSION

Diatoms are one of the most under influenced freshwater benthic organism group by environmental variables, which often have strong relations with particular chemical conditions such as pH, ORP and nutrient concentrations (Stoermer and Smol, 1999; Potapova and Charles, 2003; 2007). Streams have naturally different diatom floras, because of draining from different geological structures. However, anthropogenic impacts such as agricultural, urban and industrial activities may change adversely the water quality and therefore may influence the composition of assemblages of diatoms (Biggs, 1995; Carpenter and Waite, 2000; Leland and Porter, 2000). In the present study, significant relations determined between the diatom populations densities of Seydisuyu Stream Basin and investigated environmental parameters. According to results of Pearson Correlation Index (PCI), Oxidation – Reduction Potential (ORP) of the water was recorded as the most effective parameter on benthic diatoms of the basin and significant positive correlations were observed between ORP and densities of almost all diatom species at the 0.01 significance level.

The primary purpose of Cluster Analysis (CA), which is an important group of multivariate statistical techniques, is to assemble objects based on the characteristics they possess. CA classifies the objects, so that each object is similar to the others in the cluster with respect to a pre observed selection criterion. Hierarchical agglomerative clustering, which is the most common approach, provides intuitive similarity relationships between any one sample and the entire data set. It is typically illustrated by a dendrogram that provides a visual summary of the clustering processes (Tabachnick and Fidell, 1996; Shrestha and Kazama, 2007; Tokatlı et al., 2014a).

In the present study, three CA based on different characteristics of the basin were applied to the biotic and abiotic data in order to estimate the best data set, which are effective on determining stational differences of the region. According to the results of CA, similarity coefficients of stations were recorded as CA3 (based IBD values; 0.98) > CA1 (based environmental parameters; 0.85) > CA2 (based diatom floras; 0.77) respectively. As it was stated before, the Seydisuyu Stream Basin is under affected by many different pollution sources. So detected quite low similarity coefficient of stations according to environmental parameters (0.85) was an expected situation. But the observed a lower similarity coefficient according to diatom flora (0.77) than detected according to environmental parameters reflect that minor changes of environmental conditions may cause major effects on the diatom communities in the basin.

Physical and chemical parameters used to determine the water quality may indicate just the current status of aquatic ecosystem. But diatoms, which are one of the most important groups used in water quality monitoring, may indicate the long term effects on freshwater ecosystems (Torissi and Dell'Uomo, 2006). Therefore detected higher similarity coefficient in CA1 than detected in CA2 was an expected situation and reflects that the biotic components of aquatic habitats like diatoms have to be used in ecosystem quality assessment studies in order to make an objective and more reliable evaluation.

Principal Component Analysis (PCA), which is a powerful pattern recognition tool, attempts to explain the variance of a large dataset of inter correlated variables with a smaller set of independent variables. Factor Analysis (FA) reduces the contribution of less significant variables and makes new group of variables detected from PCA. New group of variables, which are known as varifactors, are extracted through rotating the axis defined by PCA. A varifactor can include unobservable, hypothetical, latent variables, while a principle component is a linear combination of observable variables (Vega et al., 1998; Wunderlin et al., 2001; Simeonov et al. 2003; Tokatlı et al., 2014a; Tokatlı, C., 2017).

In the present study, nine factors explaining 81.29% of the total variance were determined as the most effective agents on the basin, which were occurred from densities of different diatom species representing different trophic levels; results of Biological Diatom Indices (IBD) calculated for each different substrates (EPL, EPP, EPF); and water quality status of the basin based on some lymnological parameters.

Diatoms, which should be used in monitoring programs for rivers ecological assessment according to Water Framework Directive (WFD), are widely used for the bioassessment of rivers and streams due to their broad distribution and their ability to integrate changes occurring in water composition. They are considered as key organisms in water quality assessment studies and have been applied for a long time in almost all the countries of Europe (Acs et al., 2004; Solak and Acs, 2011).

In a study performed in Balearic Islands in Spain, a diatom multimetric index (DIATMIB) based the changes in the structure of diatom communities was developed to assess the ecological status of temporary streams and the study confirmed the application of a diatom multimetric index as a good approach to classify the ecological status of Mediterranean temporary streams (Delgado et al., 2012). In another study using the diatom indices, water quality was evaluated by using some diatom indices and physical - chemical variables in Han River in China. According to results of this study, diatom indices used in the study have shown that benthic diatoms respond sensitively to ambient environmental factors (Tan et al., 2014).

Although the water quality assessment by using diatom indices is a new topic in Turkey, several studies have been carried out in especially last 10 – 15 years. Gürbüz and Kıvrak (2002) were used diatom indices in Karasu River by using a total of 73 diatom taxa belonging to 22 genera and they suggested that the Karasu River were eutrophicated and organically polluted according to saprobity index (SI), trophic diatom index (TDI) and the percentage pollution tolerant valves values. Kalyoncu et al. (2009) investigated the Darıören Stream by ecological methodologies using species richness, diversity and saprobic indices to assess the impact of the pollution on epilithic diatom assemblages. SLA, EPI-D, TDI and DESCY indices were used by Solak (2011) in Upper Porsuk River (Kütahya) and water quality levels were found in different levels between the detected stations.

Biological Diatom Index (IBD), which is a standardized method rarely used in Turkey for the surveillance of freshwater quality, provides information about trophic levels of the aquatic ecosystems. IBD, based on 209 most widely distributed diatom taxa and the formula that was developed by Zelinka and Marvan (1961), are widely applied in order to determine the trophic levels of aquatic ecosystems (Lenoir and Coste, 1996). In the present study, IBD was used to evaluate the water quality of Seydisuyu Stream Basin and the data of IBD were compared with lymnological parameters detected in the region. As similar to water quality status of the basin in terms of detected physicochemical parameters, Seydisuyu Stream Basin is in a mesotrophic state and has a moderate water quality in terms of calculated IBD values. In a study performed in Turkey in Gürleyik Stream, Biological Diatom Index was used to evaluate the water quality and a total of 45 diatom species belonging 19 genus were identified for this purpose. As similar to the present study, Gürleyik Stream and Ankara stream was in a mesotrophic state according to IBD index (Tokatlı, 2012, Atici ve Ahiska, 2005).

In contrast to general water quality status of the region according to biotic and abiotic data, any statistically significant correlation was not observed between IBD and environmental values. In a study performed in Guadalquivir River Basin (Spain), IBD scores were significantly correlated with the conductivity, nitrate and nitrite parameters (Martin et al., 2010). Detected no significant correlations between the IBD scores from different substrates and physical – chemical characteristics of the Seydisuyu Stream Basin; recorded high statistical similarity (98%) according to Cluster Analysis (CA) in terms of IBD scores; and detected no related environmental parameter loadings with the second factor named as "Biological Diatom Indices Factor" according to Factor Analysis (FA) indicate the deficiencies of the IBD based on different substrates used in the study area. But in general, detected similar water quality status according to IBD scores and lymnological parameters indicate that IBD may be used to reflect changes in ecological conditions of the basin after making some revisions.

5. CONCLUSION

As it is known that biological indicators are much more efficient on reflecting the long term effects on aquatic ecosystems than environmental parameters detected in water, which provide information just about the current status. Therefore environmental parameters have to be supported by biological data in order to make a much better evaluation. Also it is clearly known that multistatistical techniques are essential for especially sophisticated environmental evaluations. In the present study, diatom flora of Seydisuyu Stream Basin was investigated and water quality of the system was evaluated by using Biological Diatom Index and detected some lymnological parameters in water. Also all the detected physical, chemical and biological data were evaluated by using statistical techniques in a sophisticated approach. Results of the present study reveal the benefits of using biotic and abiotic factors of aquatic ecosystems together and emphasis integrating the biotic and abiotic data to the statistical approaches in freshwater evaluation studies.

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