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Full Length Research Paper

Comparative performance of diatom indices in aquatic pollution assessment

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The use of epilithic diatoms as indicators of river water quality was evaluated in two streams of south Turkey. Diatoms as well as physical and chemical variables were sampled monthly between May, 2002 and April 2003 at six sites that can represent the streams. A total of 110 diatom taxa belonging to 32 genera were found. The most tolerant taxa to organic pollution were *Nitzschia palea* (Kützing) W. Smith., *Craticula accomoda* (Hustedt) D.G. Mann., *Gomphonema parvulum* (Kützing) Kützing, *Navicula atomus* (Kützing) Grunow, *Navicula cryptocephala* Kützing. These species were dominant at the organically polluted stations. The performance of three types of benthic diatom index was compared (Swiss Diatom Index (DI-CH), Trophic Index (TI) and Saprobic Index (SI)) . The indices were significantly correlated with dissolved oxygen, chloride, biological oxygen demand (BOD_5), and concentrations of nutrients (NO_3-N, NO_2-N, NH_4-N, and PO_4-P). DI-CH, TI and SI had high correlations with the physicochemical variables but DI-CH and TI were more reliable than the SI. We concluded that in these rivers, DI-CH and TI could be more useful than SI. Based on the significant correlation with nutrients and organic pollution variables this study suggests that SI, TI and DI-CH are integrating the effects of organic pollution.

Key words: Diatom indices, pollution assessment, Turkey.

INTRODUCTION

The quality of running waters should be assessed by the use of physical, chemical and biological parameters (Sladecek, 1973; Helawell, 1986; Descy and Micha, 1988; Klee, 1991; Lobo et al., 2004). Classic physical and chemical monitoring reflects instantaneous measurements while biotic parameters provide better evaluation of environmental changes. Because community development integrates a period of time reflecting conditions that might not be any longer present at the time of sampling and analysis (Salomoni et al., 2006). Routine biological monitoring of all but the deepest rivers is based largely on macroinvertebrates (Metcalfe, 1989; De Pauw and Vanhooren, 1983). Following this many methods have been developed using other organisms, such as benthic algae, macrophytes and fishes. Particularly, diatoms are preferred more than other algae (Raund, 1993). There is a relatively long history of the use of diatoms for biological monitoring (Sladecek, 1973; Kelly et al., 1998; Loez and Topalian, 1999; Lowe and Pan, 1996; Dixit et al., 1992; Bate et al., 2004). Indices are mainly based on community structure of diatoms (e.g., diversity, evenness, richness, similarity) therefore, correlations between the various indices are generally high (Kelly et al., 1995). Diatoms are well suited for water quality assessments (Salomoni et al., 2006; Sebater and Sebater, 1988; Rott et al., 1997; Dixit et al., 1992; Prygiel and Coste, 1999; Passy and Bode, 2004; Goma, et al., 2005) because they have short generation time and many species have a specific sensitivity to ecological characteristics (Stevenson and Pan, 1999). Several diatom-based pollution indices have been developed and they are now on their way to being routinely used (Gomez, 1999). The newly developed indices have been based on saprobic system (Zelinka and Marvan, 1961; Sladecek, 1973; Gomez et al., 2001; Kupe et al., 2008). Diatoms are used as bioindicators in Europe (Kelly et al. 1998), in North

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America (Lowe and Pan 1996), in South America (Loez and Topalian 1999; Chessman et al. 1999), in Asia (Lobo et al., 1995; Rothfritz et al., 1997; Watanabe et al., 1986) and in Africa (Bate et al., 2004; Gasse et al., 1995). Some of these approaches are focused on inferring past hydro chemical characteristics in lakes (Gasse et al., 1995; Fritz et al., 1991), while others are designed to monitor present-day conditions in rivers and streams. The indices which are developed to observe the changes in water quality have been used in Europe since 1902 (Kolkwitz and Marson, 1902). However, little is known about the performance of these indices in Turkey. The first study in which diatoms were used to evaluate the water quality changes in Turkey was carried out by Kalyoncu and Barlas (1997) using saprobic index and followed by other researches (Kalyoncu et al., 2004; Kalyoncu et al., 2008; Kalyoncu et al., 2009). Moreover, there are two different examinations which use different indices. Gürbüz and Kıvrak (2002) have used diatom indices of DAIPo (Diatom Assemblage Index for Organic Pollution), SI (Saprobic Index), GI (Generic Index) and TDI (Trophic Diatom Index) respectively in Karasu River and reported that GI are slightly correlated with physico-chemical parameters. Solak et al. (2007) have used SLA (Sláde ek Index), DESCY, (DESCY Index), LMA (Leclercq and Maquet Index), WAT (Watanabe's Index), CEE (Index of European Economic Community), IDAP (Artois Picardie Diatom Index) indices with the help of Ominidia Software and found that DESCY seems to be the best for the region. Kalyoncu et al. (2009) compared species richness and diversity index with SI by evaluating 58 diatom taxa used in sabrobic index by principal component analysis and found that changes in water quality were better reflected by SI.

Aksu River is one of the biggest rivers in west Mediterranean. The most important sources of Aksu River are Darıören and Isparta streams. Aksu River carries great importance for Turkey from many aspects. There are two dams established upon this stream and the river is important for irrigation and breeding of fishes. Moreover it can be an important drinking water source for local society in the future. The final goal of this study is to assess the reliability among the diatom indices and compare their performance to assess the aquatic pollution. The indices tested were Swiss Diatom Index (Buwal, 2002), Trophic Index (Schmedtje et al., 1998) and Saprobic Index (Rott et al., 1997).

MATERIAL AND METHODS

Six sampling points (Figure 1) were chosen on Darıören and Isparta Streams. Sampling points I and II were chosen on the springs on southern side of Davraz Mountain, Darıören village (1200 m. alt.) where there was no urban waste water connection. Sampling point III is in the halfway of the stream, sampling point IV is before the meeting point of the Darıören stream and Isparta stream. Sampling point V is chosen on the meeting point of Isparta stream and Darıören stream. Sample point VI is after the meeting point of Isparta stream and Darıören stream (Figure 1). When choosing the sampling points on the stream, we took into consideration all those influencing the stream water quality, such as tributaries and mixing points of waste-water discharge. Each sampling site was visited monthly, between May, 2002 and April, 2003. Water samples for chemical analysis were collected from the 6 stations, using polyethylene bottles. All samples were transport to laboratory in an icebox and analyzed within 12 h after collection. Selected chemical-physical water quality analyses were made monthly at each sample location. These analyses included dissolved oxygen, nitrate-N, nitrite-N, ammonia-N, orthophosphate, conductivity, pH, Biological oxygen demand and chloride. Dissolved oxygen, pH and conductivity were measured in the field by using WTW (Wissenschaftlich-Technische Werkstätten GmbH) portable dissolved oxygen meters. The levels of nitrate-N, nitrite-N, ammonia-N, orthophosphate, Biological oxygen demand and chloride were determined in the laboratory according to Standard Methods (Anonymous 1965).

During the study period (May, 2002 - April, 2003), samples were taken on the middle of months except rainy days to avoid transient effects of the flood. The diatoms were sampled by scraping the 25 cm^2 upper surface of the epilithon, with a stiff toothbrush and collected in 250 ml sample bottle. The collected samples were transferred to the laboratory in an icebox. The composition and relative abundant of diatoms was estimated at 1000x magnification from acid-cleaned sub-samples, counted separately. Cleaned frustules were mounted on permanent slides using Naphrax resin. Identification and nomenclature were based on Krammer and Lange-Bertalot (1986; 1988; 1991a and 1991b), Lange-Bertalot (1980), Round et al. (1990), Hartley et al. (1996) . Three slides were prepared from each side and approximately 200 valves were enumerated in each slide to determine the relative abundance of each taxa. Swiss Diatom Index (DI- CH) according to BUWAL (2002), Trophic Index (TI) according to Schmedtje et al. (1998) and Saprobic Index (SI) according to Rott et al. (1997) were evaluated. The correlation analysis was done according to Pearson and statistical analyses were carried out on Statistical Package for the Social Sciences (SPSS INC, 2004).

RESULTS

Variation in nutrient content in stream waters was the principal difference found between different sampling sites. Nutrient levels were higher at sample points 5 and 6 than at sampling point 1, 2, 3 and 4. Greater amounts of PO_4–P were detected at sampling point 5 which can probably be attributed to agricultural and domestic waste disposal. The BOD_5, chloride, conductivity, ammonia nitrogen, nitrate nitrogen, and nitrite nitrogen increased especially at sampling points 5 and 6, but dissolved oxygen decreased at sampling point 5 and 6. pH is generally stable at sampling points 1, 2, 3, and 4, but a little higher at sampling point 5 and 6. Conductivity level was lowest at sampling point 1. The Physico-chemical parameters were found higher at Isparta stream than Darıören stream (Table 1).

A total of 110 epilithic algal taxa were recorded (Table 2). A higher abundance of epilithic algae was recorded at stations III and I than at station IV throughout the study. During spring, numbers of diatoms were very low at station V and VI. *Tabellaria flocculosa* (Roth) Kützing, was dominant at station I, II, III and IV. On the other hand, *Nitzschia palea*, *Craticula accomoda* were mainly

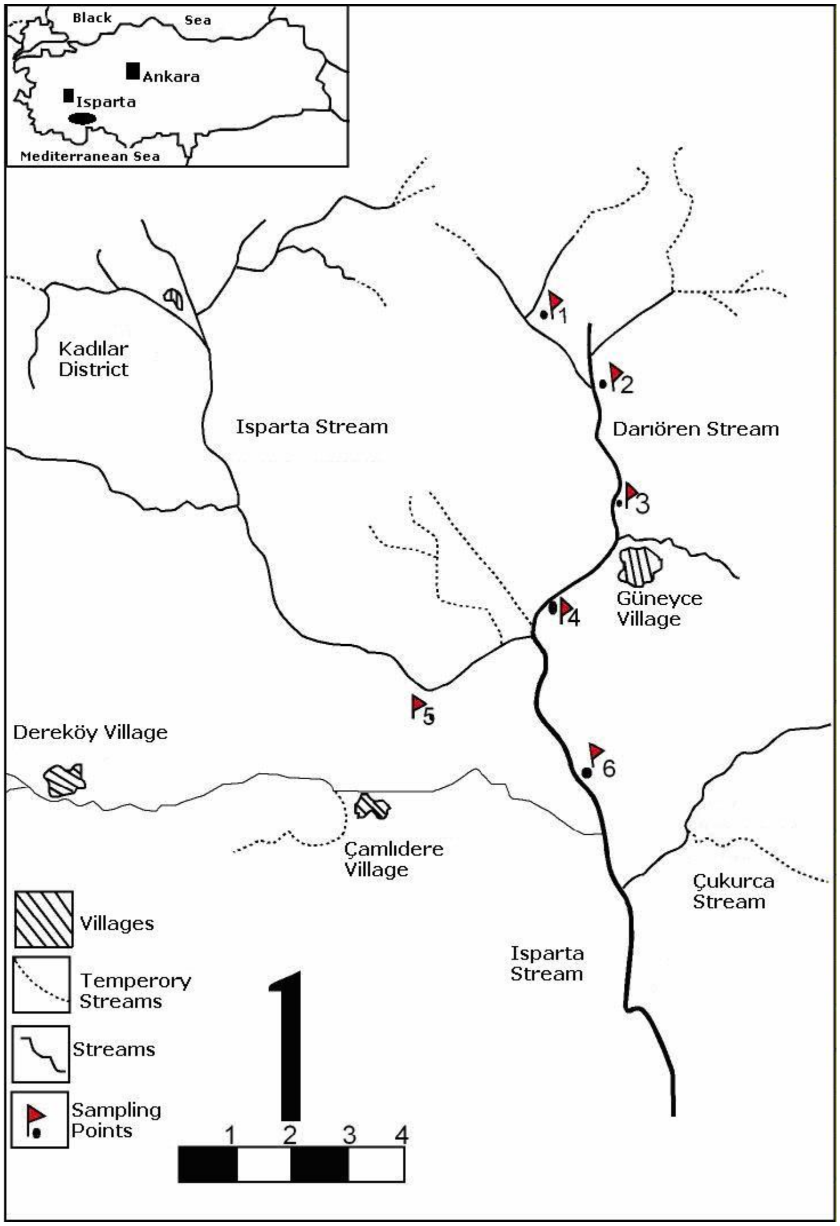

Figure 1. Study area and sampling sites on Darıören and Isparta stream.

Table 1. The average, minimum and maximum levels of physicochemical parameters.

Parameters	Mean	Minimum	Maximum
DO (mgL^{-1})	6,14	4,41	11,31
NO_3-N (mgL^{-1})	0,8	0,01	3,14
NO_2-N (mgL^{-1})	0,2	<0,01	4,84
NH_4-N (mgL^{-1})	0,92	<0,01	5,55
PO_4-P (mgL^{-1})	1,08	<0,01	8,65
E.C. (µmhos/cm)	455,68	350	765
BOD_5 (mgL^{-1})	7,29	1,5	55
pH (mgL^{-1})	7,5	7	8,7
Cl^- (mgL^{-1})	13,34	4,2	62,5

dominant at station V and VI during the study.

All of the diatom indices showed strong correlation with Cl^-, pH, PO_4-P, NH_4-N and E.C. ($p < 0.01$). This study determined low relation between TI and physico-chemical parameters (Correlation coefficients; between DO (0.276 $p < 0.05$) and DI-CH with NO_2-N (0.275 $p < 0.05$). SI was the only the one which did not correlate significantly with DO. Besides, the lowest relation was found between SI and BOD_5 (0.262 $p < 0.05$). All of indices showed that highest correlation with NH_4-N. But TI had a higher correlation than other indices (Table 3). In general, most of the diatom indices could suggest the strong correlation with most of the water quality variables.

Significant correlations were found between all of the

Table 2. The taxa list of diatoms according to sampling points.

	Sampling points					
Diatom Taxa	**I**	**II**	**III**	**IV**	**V**	**VI**
Melosira varians C. Agardh			+			
Rhizosolenia minima Levander			+		+	+
Meridion circulare Agardh	+	+	+	+	+	
Cyclotella comta (Ehrenberg) Kützing			+			
Diatoma elongatum (Lyngbye) C. Agardh			+			
D. tenuis C. Agardh				+		
D. anceps var. *linearis* M. Peragallo			+			
D. vulgaris Bory	+	+	+	+		+
D. vulgare f. *producta* (A. Grunow) A. Kurz			+			
Denticula tenuis Kütz.	+		+			
Fragilaria sp.				+		
Synedra acus Kützing		+				
S. minuscula Grunow	+			+		
Synedra affinis var. *fasiculata* (Kützing) Grunow	+					
S. ulna var. *subaequalis* Grunov	+			+		
S. amphicephala Kützing					+	
Tabularia fasciculata (C. Agardh) D.M. Williams & Round						+
Tabellaria flocculosa (Roth) Kützing	+	+	+	+	+	+
Ulnaria ulna (Nitzsch) P. Compère	+	+	+	+	+	+
Achnanthes linearis (W. Smith) Grunow			+			
A. minutissima Kütz.	+	+	+			
A. lanceolata Bréb.	+					
Achnanthes sp	+	+	+	+	+	
A. gibberula Grun		+		+		
A. lemmermannii Hustedt			+			
Cocconeis placentula Ehrenberg	+		+	+		
C. placentula var. *euglypta* (Ehrenberg) Grunow	+	+	+	+		
C. placentula var. *klinoraphis* Geitler	+					
C. placentula var. *lineata* (Ehrenberg) van Heurck				+		
C. disculus (Schumann) Cleve	+					
C. pediculus Ehrenberg	+		+	+		
Nitzschia acicularis (Küetzing) W. Smith						+
N. brevissima Grunow						+
N. constricta (Nitz.) W. Smith	+	+	+		+	
N. hybrida Grunow	+				+	+
N. palea (Kütz.) W. Smith	+	+	+	+	+	+
N. solita Hustedt						+
Nitzschia sp.					+	+
N. thermalis Kützing					+	+
N. umbonata (Ehrenberg) Lange-Bertalot					+	
N. vitrea G. Norman	+					
Tryblionella hungarica (Grunow) Frenguelli	+					
Rhopalodia gibba (Ehrenberg) O.F. Müller	+					
R. gibba var. *ventricosa* (Ehrenberg) Grunow	+					
R. gibberula (Ehrenberg) O.F. Müler	+					
R. parallela (Grunow) O.Müller			+			
Adlafia minuscula (Grunow) H. Lange-Bertalot						+
Amphora ovalis (Kützing) Kützing	+			+		
A. veneta Kützing	+		+	+		
Caloneis silicula (Ehrenberg) Cleve				+		

Table 2. Contd.

Cavinula cocconeiformis (Gregory ex Greville) D.G. Mann & A.J.			+			
Craticula accomoda (Hustedt) D.G. Mann			+		+	+
C. halophila (Grunow in Van Heurck) D.G. Mann					+	
Cymbella affinis Kützing	+	+	+	+	+	
C. mesiana Cholnoky		+				
C. amphicephala Näegeli	+	+	+	+		
C. cymbiformis C. Agardh	+	+	+			
C. cistula (Hemprich & Ehrenberg) O. Kirchner				+		
C. helvetica Kützing	+	+	+	+		
C. minuta var. pseudogracilis Choln.			+			
C. naviculiformis (Auerswald)			+	+		
C. prostrata (Berkeley) Cleve	+	+	+			
C. turgidula Grunow	+	+	+	+		
Encyonema auerswaldii Rabenhorst	+					
E. minutum (Hilse in Rabenhorst) D.G. Mann	**+**	**+**	**+**	**+**		
E. silesiacum (Bleisch) D.G. Mann in Round	+	+	+	+		
Encyonopsis microcephala (Grunow) Krammer	+	+	+	+		
Gomphonema affine var. insigne (Greg) Andrew			+			
G. angustatum (Kütz) Rabh.	+	+	+	+	+	+
G. angustatum var. producta Grunow			+			
G. angustatum var. *citera* (M.H. Hohn & J. Hellerman) R.M. Patrick				+		
G. longiceps Ehrenberg		+				
G. longiceps var. *subclavata* (A. Grunow) F. Hustedt			+			
G. olivaceum (Lyngbye) Bréisson	+	+	+	+	+	+
G. olivaceum var. minutissima Hust	+	+	+	+		
G. parvulum Kützing	+	+	+	+	+	+
G. parvulum var. *micropus* (Kützing) Cleve	+	+	+	+	+	+
Gyrosigma exilis (Grunow) C.W.Reimer	+					
Navicula atomus (Kützing) Grunow			+	+	+	+
N. cari Ehrenberg	+	+				
N. graciolides A. Mayer			+			
N. cincta (Ehrenberg) Kützing	+	+		+	+	
N. cryptocephala Kützing	+		+	+		
N. cryptonella Lange-Bertalot			+	+	+	
N. exigua Gregory		+				
N. gottlandica Grunow		+				
N. gregaria Donkin			+	+		
N. lanceolata (C. Agardh) Kützing			+			
N. mutica var. *binodis* Hustedt				+		
N. radiosa Kützing	+		+	+	+	
N. rhynchocephala Kützing	+					+
N. schoenfeldii Hustedt	+	+			+	
N. subrhyncocephala Hustedt					+	
N. subtilissima Cleve					+	
N. tripunctata (O.F. Müller) Bory	+	+	+	+	+	
N. veneta Kützing			+		+	
Navicula sp.			+		+	+
Neidium affine (Ehrenberg) Pfizer				+		+
Neidium sp.	+					
Pinnularia abaujensis (Pantocsek) R. Ross			+			
P. gibba var. *parva* (Ehrenberg) Grunow				+		
P. microstauron (Ehrenberg) Cleve	+					

Table 2. Contd.

Stauroneis sp.	+					
Rhoicosphenia abbreviata (C. Agardh) Lange-Bertalot	+	+	+	+		
Cymatopleura solea (Brébisson) W. Smith					+	+
Surirella angusta Kützing					+	+
S. linearis W. Smith					+	
S. ovalis Brébisson					+	
S. ovata Kützing	+	+	+	+	+	+
S. ovata var. *pinnata* (W. Smith) Brun	+	+	+		+	+

Table 3. Correlation matrix between physical-chemical parameters and biological indices

	Cl	NH_4-N	NO_2-N	NO_3-N	DO	BOI$_5$	PO_4-P	pH	E.C.
TI	0,668(**)	0,751(**)	0,369(**)	0,432(**)	0,276(*)	0,537(**)	0,570(**)	0,447(**)	0,650(**)
DI-CH	0,585(**)	0,633(**)	0,275(*)	0,344(**)	0,371(**)	0,481(**)	0,476(**)	0,437(**)	0,592(**)
SI	0,564(**)	0,519(**)	0,340(**)	0,262(*)	0,201	0,262(*)	0,379(**)	0,488(**)	0,636(**)

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*P < 0.05 (n = 12); ** p < 0.01 (n = 12);
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

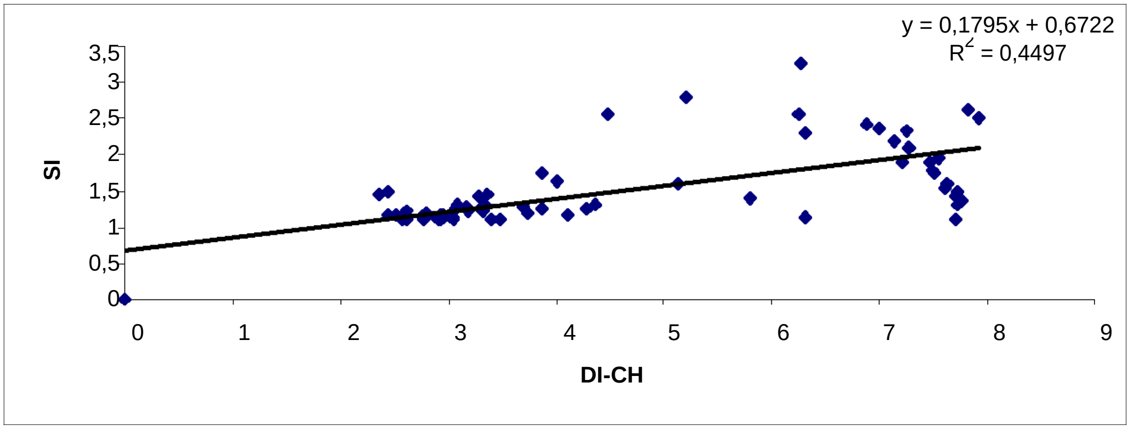

Figure 2. The relationship between SI and DI-CH indices.

evaluated diatom indices [(p < 0.01) (Figure 2, 3 and 4)]. The strongest positive correlation was identified between DI-CH and TI (Figure 4). The minimum correlation was identified between SI and DI-CH (Figure 3).

According to evaluation of water quality, the stream contains three different water quality regions according to SI. First, second, third and fourth stations were classified as clean. Fifth station was classified as II - III quality class, critically polluted. Sixth station was classified as II quality class, moderately polluted.

According to TI and DI-CH, there are three different water quality classes. According to TI, first, second, third and fourth stations were determined within I-II quality (Mesotroph) class. Following, the 5th station was found III quality (polytroph) class and 6th station is III-IV quality (poly-hypertroph) class. According to DI-CH, 1st, 2nd and 4th sampling sites were classified as quality class III (Less polluted); sampling site 3 was classified as quality class IV (moderately polluted), 5th and 6th sites were classified as quality class VII (exceedingly polluted). Sampling station 5 is more polluted than station 6. Consequently, the most polluted sampling site was the 5th sampling site according to SI and DI-CH values. According to TI values, 6th sampling point was the most polluted one. According to all indices, 1st and 2nd sampling points were not polluted points (Figure 5). When the stations are classified in view of taxa richness, the station 3rd sampling point has the highest taxa richness, followed by 1st, 4th,

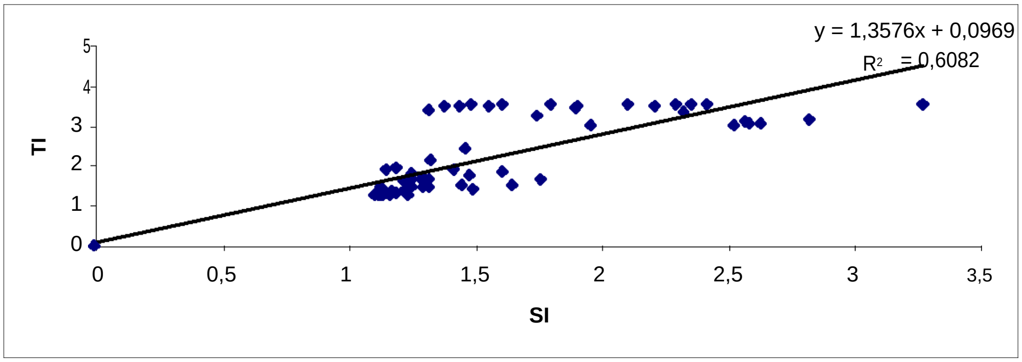

Figure 3. The relationship between TI and SI indices.

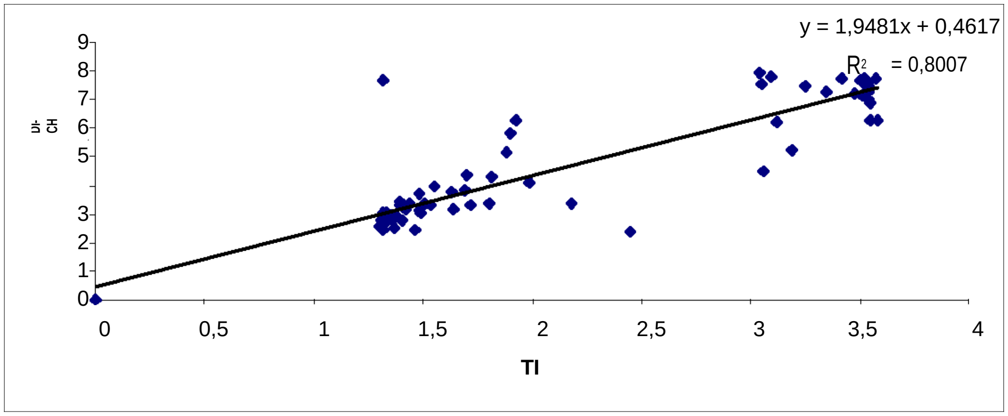

Figure 4. The relationship between DI-CH and TI indices.

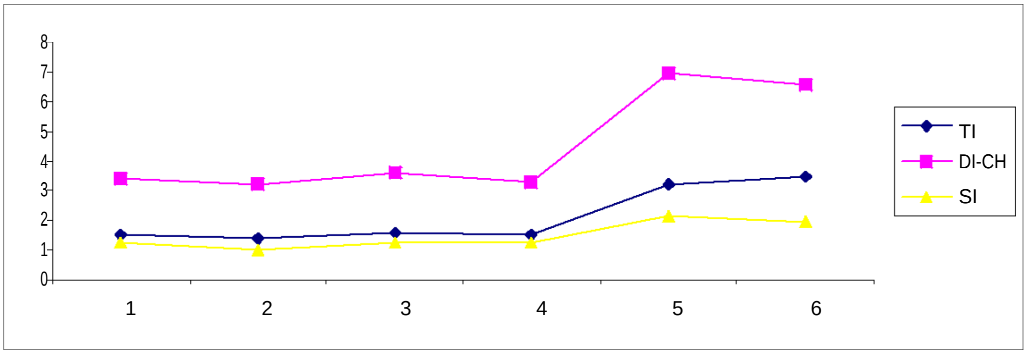

Figure 5. The water quality change according to sites.

2nd, 5th and 6th respectively.

DISCUSSION

The stream diatom assemblages on Darören stream and Isparta stream were mainly associated with physico-chemical habitat conditions. The sampling sites along Darıören stream can be classified, on the basis of physical and chemical characteristics as well as specific tolerance of diatom species (Diatom based indices; TI, DI-CH and SI) as clean while the sites along Isparta steam can be classified as polluted. The classification in this study according to diatoms correspond the classification of other researchers (Prygiel and Coste 1999; Gomez 1999). Highly tolerant species; *Nitzschia palea, Craticula accomoda, Gomphonema parvulum, Navicula atomus* and *Navicula cryptocephala* were dominant in polluted sites while pollution sensitive species *Cymbella affinis* Kütz., *Tabellaria flocculosa*, *Diatoma vulgare* Bory, *Achnanthes lanceolata*, *Achnanthes minitussima* and *Gomphonema angustatum* were dominant in unpolluted and moderately polluted sites.

Significant correlations were observed between the three indices examined. These indices have been used first time for Turkey and the detailed interactions among different indices have been submitted newly by this paper. According to our results, TI, DI-CH and SI correlated ($p < 0.05$; $p < 0.01$) with parameters related to organic pollution. The saprobic index (Rott et al., 1997) and Trophic Indices (Schmedtje et al. 1998) describe, by definition, the capacity for two different biological processes, decomposition of organic material and primary productivity, respectively. Organic pollution is usually closely related with enhanced nutrient concentrations. Based on the significant correlation with nutrients and organic pollution variables this study suggests that SI, TI and DI- CH are integrating the effects of enrichment of organic pollution. Among the observed diatom indices, TI and DI-CH better reflects the changes in water quality than the Saprobic Index. Kalyoncu et al. (2009) found that changes in water quality of Darıören stream were better reflected by SI than species richness and diversity index. The significant correlation between diatom indices and chemical data were reported by other studies of different types of water. Gomez (1999) mentioned that Sladecek's index was relatively weak with respect to diagnosing changes in water quality in the Matanza-Riachuelo River.

The Swiss Trophic Index was correlated with nutrients, e.g., nitrogen and sulfur compounds in rivers which have rich flora. In contrast, the Saprobic Index SI classifies rivers based on the load of dissolved organic materials originating from untreated or insufficiently treated municipal wastewater. Kupe et al. (2008) reported that DI-CH and the SI follow similar trends.

In summary, diatom based assessments as well as classic physico-chemical methods suggest that the sampling sites on Darıören stream were not polluted while the sampling sites on Isparta stream were polluted. We conclude that diatom assemblages are useful for assessing the stream ecological status, and reported diatom based indices can be used for further studies in Mediterranean region of Turkey.

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