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REVIEW

Water Quality Monitoring in European and Turkish Rivers Using Diatoms

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Abstract

Water is one of the most essential factors for civilization, and also among the most important items in the new world order due to its unrenewable feature. In this regard, developed countries have continually been monitoring and classifying their water. For this reason, a number of EU countries have developed a national water quality system, considering characteristic structure of their own rivers and have used this type of indices for revealing the current stituation of their water quality level. While water quality monitoring was first determined according to physical and chemical parameters, biological factors such as algae, especially diatoms, benthic macroinvertebrates and fish have recently been used for this purpose. Investigation of benthic diatoms is recommended by the Water Framework Directives (WFD) and European Parliament 2000 directive, 2000/60/EC. They are considered key organisms in ecological quality analyses of water courses and have been applied for more than a decade in several countries of Europe (Austria, Switzerland, Germany, Belgium, France, Poland, Finland, Luxemburg, United Kingdom, Spain, Portugal, Italy). Water quality monitoring, based on diatom indices, is a new topic for Turkey especially after the 2000s, and it is getting more and more important each day. The aim of this study, was to form a database for future studies based on diatoms in Turkey.

Keywords: Biomonitoring, diatom indices, rivers, Turkey, WFD.

Diatom Kullanılan Avrupa ve Türk Nehirlerinde Su Kalitesinin İzlenmesi

Özet

Su, yenilenemeyen bir kaynak olmasından dolayı yeni dünya düzeninde en önemli unsurlardan biridir. Gelişmiş ülkeler su kaynaklarının kalitesini sürekli izlemekte ve çeşitli kalite sınıflarına ayırmaktadırlar. Bu nedenle, AB ülkelerinin çoğu kendi nehir sistemlerine özgü ulusal su kalitesi sistemlerini geliştirmişlerdir. İlk zamanlarda, suyun kalitesinin tespitinde fiziko-kimyasal parametreler kullanılırken, algler, özellikle diyatomeler, büyük taban omurgasızları ve balıklar da son zamanlarda bu amaçla kullanılmaktadır. Bentik diyatomelerin bu şekilde incelenmesi “Su Kalitesi Kontrol Yönetmeliği (WFD)” ve Avrupa Parlamentosu “2000/60/EC” yönetmeliğiyle önerilmiştir. Bu organizmalar suyun ekolojik açıdan incelenmesinde kullanılan temel organizmalar olarak ele alınmaktadır ve son yıllarda birçok Avrupa ülkesinde bu amaçla kullanılmaktadır. Suyun kalitesinin diyatome indekslerine bağlı incelenmesi konusu ülkemiz için yeni olup özellikle 2000 li yıllarından başından ibaren gün geçtikçe daha da önem kazanmaktadır. Bu çalışmanın amacı, Türkiye’de diyatome indeksleri kullanılarak yapılacak ilerideki çalışmalara veri sağlamasıdır.

Anahtar Kelimeler: Biyolojik izleme, diyatome indeksleri, nehirler, Türkiye, WFD.

Introduction

Benthic diatom communities react rapidly to disturbance of water, e.g. physicochemical conditions of water or to pollution-affected catchment area. Very often they change their species composition or diversity, which can vary from species-rich to monotonous communities. Because of this characteristic, benthic diatom communities are useful tools in detecting anthropogenic impacts (Ács *et al.*, 2004).

Investigation of benthic diatoms is recommended by the Water Framework Directives (Water Framework Directive, European Parliament 2000 directive, 2000/60/EC). They are considered key organisms in ecological quality analyses of water courses and have been applied for more than a decade in several countries of Europe (Austria, Switzerland, Germany, Belgium, France, Poland, Finland, Luxemburg, United Kingdom, Spain, Portugal, Italy).

One of the main goals of the WFD is, to assign the extent of difference to which ecosystems differ from high ecological status, where there are no or only very minor anthropogenic alterations (reference ecosystems) (Ács *et al*., 2004).

Diatoms are an important group of water ecosystems. They form a large part of the benthos (often 90–95%) and they have become an important part of water quality monitoring. The advantage in benthic diatoms is that they can be found in every surface water, at any time. Furthermore, in the form of preserved slides or acid digested sample slides, collected diatom samples can be preserved for an unlimited period of time, thus can be reinvestigated whenever necessary. It is also incomplicated to decide what to consider an individual. However, a disadvantage in investigating diatoms is that it requires a thorough taxonomic knowledge (Ács *et al*., 2004).

The development of diatom-based pollution indices prior to 1980 is summarised in Prygiel *et al.* (1999). Whilst many indices and approaches had been developed, few were adopted by regulatory agencies as there was no legislative requirement for this type of monitoring and little perceived benefit in using diatoms, rather than invertebrates, for general water-quality assessment. The most significant development during the 1980s was that of the Indice de Polluosensibilité (IPS; Coste in CEMAGREF 1982), a metric, based on the weighted averaging quation of Zelinka and Marvan (1961), that claimed to provide integrated assessments of a range of water quality variables, including organic pollution, eutrophication, salinity and toxic materials. Some work on this topic had already been done in Germany (Steinberg and Schiefele, 1988), the Trophic Diatom Index (TDI) in the UK (Kelly and Whitton, 1995); an index, also called the Trophic Diatom Index, in Germany (Coring *et al*., 1999); and the Trophienindex (TI) in Austria (Rott *et al*., 1999). A separate metric for assessing organic-pollution (saprobic) effects, called the Saprobienindex (SI), was developed alongside the TI (Rott *et al*., 1997). At about the same time, the Indice Biologique Diatomique (IBD) was developed in France; this focused on organic and saline pollution effects but had a more sophisticated computational basis than the IPS, along with simplifi ed taxonomy (Lenoir and Coste, 1996) (Figure 1) (Kelly *et al*., 2009).

Water quality monitoring, based on diatom indices, is a new topic in Turkey and is getting more and more important with each day (Solak *et al.*, 2007a). The review has been prepared especially on the bases of the Works of Prygiel *et al.* (1999), Whitton *et al.* (1991), Whitton and Rott (1996) and Ács *et al*. (2004). All the biotic indices determined are briefly described in Table 1 according to Blanco and Bécares (2010).

Diatom Indices and the Software Omnidia

Software Omnidia (Lecointe *et al*., 1993) is a computer programme, with the help of which 17 different diatom indices can be calculated. Furthermore, it calculates diversity and evenness values and also contains four ecological qualification scales. Most of the diatom indices are based on weighted average of the Zelinka-Marvan equation (1961);

$$ID = \sum_{İ=1}^{n} Aj . Ij . Vj$$

with: Aj: species abundance, Ij: pollution index of species, Vj: indicative value or stenoecy degree of the species.

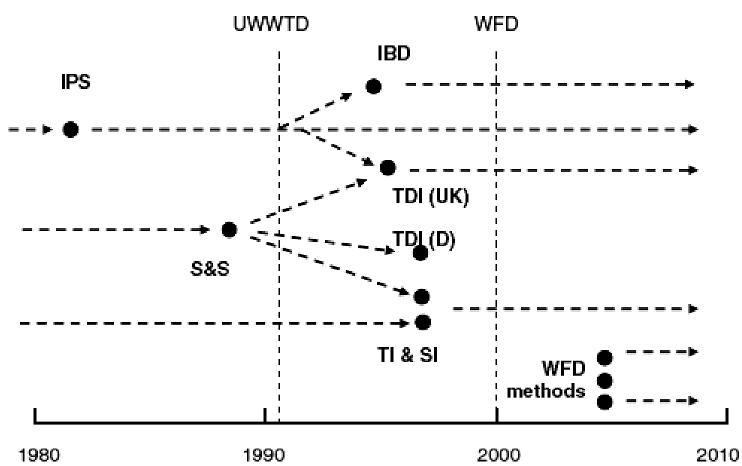

Figure 1. Schematic overview of the development of Diatom-based metrics for evaluating water quality in Europe since 1980. UWWTD= Urban Waste Water Treatment Directive; WFD= Water Framework Directive (According to Kelly *et al*. 2009).

Table 1. The list of calculated diatom indices by OMNIDIA (according to Blanco and Bécares, 2010)

Diatom Index	Description	References
SPI (Specific pollution index)	Based on the Zelinka and Marvan forumla (1961); all known freshwater species are used	CEMAGREF (1982)
BDI (Biological diatom index)	Based on the Zelinka and Marvan forumla (1961); 209 common species are used	Lenoir and Coste (1996)
CEE (European index)	Based on a two fold quality grid; 208 common species are used	Descy and Coste (1991)
EPI-D (Eutrophication pollution index)	Sensitivity of the species is an integrated index running from 0 to 4, while reliability scores range from 1 to 5	Dell'Uomo (2004)
SLA (Sladeček's index)	Based on the Zelinka and Marvan forumla (1961); 323 species are used	Sladeček (1986)
GDI (Generic diatom index)	Requires determination to genus level; all freshwater genera included	Rumeau and Coste (1988)
DI-CH (Swiss diatom index)	Based on the Zelinka and Marvan forumla (1961); 188 species are used	Hurlimann and Niederhauser (2006)
TDI (Trophic diatom index)	Based on the Zelinka and Marvan forumla (1961); designed to detect eutrophication	Kelly and Whitton (1995)
PT% (% of Pollution tolerant taxa)	Separates organic pollution from eutrophication	
SHE (Steinberg and Schiefele's index)	Uses 386 species grouped in seven assemblages by trophic state and pollution resistance	Steinberg and Schiefele (1988)
LMA (Leclercq and Maquet's index)	Based on the Zelinka and Marvan forumla (1961); 210 common species are used	Leclercq and Maquet (1987)
DAIpo (Diatom assemblage index for organic Pollution)	Classifies taxa according to pollution tolerance (BOD5); 226 taxa are used	Watanabe *et al*. (1988)
APDI (Artois-picardie diatom index)	Based on the Zelinka and Marvan forumla (1961); 45 species and 91 genera are used	Prygiel *et al*. (1996)
DES (Descy's index)	Based on the Zelinka and Marvan forumla (1961); 106 common species are used	Descy (1979)
PDI (Pampean diatom index)	Based on the Zelinka and Marvan forumla (1961); 210 common species are used	Gomez and Licursi (2001)
LOBO (Lobo's index)	Based on the Zelinka and Marvan formula (60); 239 common species are used	Lobo *et al*. (2002)
SID (Rott's Saprobic index)	Measures the saprobic status of the water; 650 common species are used	Rott *et al*. (1997)
TID (Rott's trophic index)	Measures the trophic status of the water; 650 common species are used	Rott *et al*. (1999)

Some Applications in European Countries

Austria

In Austria, two major applied projects have been completed since 1995. One was the analyses and control of a regional diatom data set, while the other was the establishment of a checklist of benthic algae based on data from the previous 15 years in which abundance, frequency, saprobic value and indicating weight was given for most species. On the basis of this list, a Regional Trophity Index (ROT) was developed, which works with macro and microalgae. However, it can be used exclusively on the basis of diatoms, too. Water quality monitoring has been going on in Austria for several years. The surveys are on the first place diatom-based, but sometimes based on the analyses of the whole periphyton community.

Benelux States

Until recently, algae have only occasionally been used by the administrative bodies responsible for river biomonitoring in Belgium and Luxembourg. Nevertheless, algal study has great tradition in Belgium. Among European countries, both Belgium and Luxembourg were one the first European countries to use benthic diatoms for monitoring river water quality analysis. Triest *et al*. (2003) proposed BDI as well as IPS as diatom indices for Fleminsh water courses (De Jonge *et al*., 2008). Also, De Jonge *et al*. (2008) investigated the river Dommel and reported that IPS is the only index that shows a slight change in water quality and ILM and IDG are the only indices which are the current diatom index used for water quality assessment in France and also proposed for application in Belgium. In Luxembourg, algal studies has rather been a neglected field. The use of diatom indices has also been sporadic. Based on the investigations of the last 25 years which have been carried out by universities and research institutes rather than by governmental water management bodies, we have a certain amount of information about the water quality of several rivers of these three countries. Furthermore, these research activities contributed to our knowledge about the autecology of diatoms and to the development of diatom indices. In spite of this, benthic diatom-based water quality monitoring is disregarded from the side of the governmental water management bodies. According to Rimet *et al*. (2004), IPS index is ideal for monitoring rivers in Luxemburg.

Estonia

Algal studies were started in 1991 in Estonia with a seven-year project. In 1994, a new project with extended hydrobiological, chemical, biological investigations was started in order to get an idea about the water quality of 25 rivers. The target of algal studies were mainly pigment content, individual number and dominant species of phytoplankton. Diatom flora of rivers has been less frequently investigated in Estonia with benthic diatom investigations having been carried out only in seven rivers. In 1995, 1998 and 1999, benthic diatoms and chemical parameters of three rivers were investigated in order to make water quality analyses. Based on these studies, application of benthic diatom communities have been proposed for monitoring water quality. The trial of benthic diatom indices will happen in future (Vilbaste, 2001). According to Vilbaste (2004), IDAP and IDG indices are convinient for monitoring rivers in Estonia.

Finland

Surface water monitoring in Finland started in the 1960s. Monitoring was first based only on water chemistry, but soon, more emphasis was placed on studying the biomass and community stucture of freshwater biota (Raunio and Soininen, 2007). The index values were correlated to chemical parameters (Eloranta, 1995; Eloranta and Andersson, 1998; Eloranta and Soininen, 2002; Soininen and Könönen, 2004). Since humic acid content of the Finnish waters is generally high and also has an effect on the chemistry of the water, this has to be taken into consideration when evaluating the index results. On the basis of preliminary investigations, Finnish researchers have concluded that several indices developed in Europe are most probably well usable in Finland, too. Nevertheless, they work with several indices at the same time and because of the special character of the Finnish waters, the results are handled with caution.

France

Periphytic diatom investigations have been carried out in France since 1980 and several indices have been constructed. Since 1991, water quality monitoring is being continuously performed in which process a considerable network has been made for mapping the water quality of water courses. In the past few years, the French water authorities have been working on the development of an index (IBD), which can be used throughout the country as a routine method. Before the index became standardised, they made steps to facilitate the use of these indices. A CD was created for light microscopy identifications, and not only have the indices been integrated into Omnidia, but also, a special software for calculating the indices was designed (Omnidia). A group of specialists facilitated the samplings and identification. Moreover, a new index (EDI-Ecological Distance Index) has been improved by Tison *et al*. (2008) and the results showed a good correlation between the EDI and the IPS indices.

Germany

A Red List for algae was completed in Germany in 1996, which comprises all the algal taxa found in Germany. Furthermore, it contains autecological information. Most of the monitoring methods in Germany are diatom-based. The differentiating species system was used for monitoring organic pollution. Salinity is estimated by the Ziemann halobic index, the trophic state by the Hofmann and Schiefele-Kohmann trophity indices and acidification monitored with the Diatom Assemblage Type Analysis of Coring and with SHE index. SPI index is also applied, being a combined system for measuring both trophity and organic pollution. Uniform water quality monitoring was not in a very progressive state in Germany in the year 2000. In 2004, the results of a study which had 150 sampling stations, was presented in the “Use of Algae for Monitoring Rivers-Krakow” symposium. According to the results, the diatoms were divided into four different groups: A (sensitive species), B (less sensitive species), C (eutrophication indicator species) and D (very high eutrophication indicator species) (Foerster *et al.*, 2004, Gutowski *et al.*, 2004, Foerster and Gutowski 2006).

Greece

Greece was still not prepared to meet the rquirements of the WFD for inland waters because the availability of biological data for validation purposes was limited (Ziller and Montesanto, 2004). In some Greek rivers there are available biological data useful for the implementation of the WFD, whereas in the rivers of the Peloponissos, only the first fauna is studied to an extent (Economou, 2001). Ziller and Montesanto (2004) practised CEE and IPS indices that said that, in the headwaters, no significant difference in values of the Diatom Indices was detected, an indication of very good to excellent water quality in both rivers and springs throughtout the study period. The results of this first approach have to be validated with more samplings and sampling sites.

Hungary

Benthic algal studies have been sporadic in Hungary since the 1960s. These studies focussed first on large rivers. Sporadic benthic diatom studies, where diatom indices were used for quality analysis of water, have also been carried out (Szabó *et al.*, 2004). In 2007, two different diatom indices were investigated, TDIL (Trophic Diatom Index for Lakes) by Stenger-Kovács *et al*. (2007) and SCIL (Sodic Conductivity Index for Lakes) by Ács (2007). Also, Ács *et al*. (2009) investigated Hungarian running waters with diatoms. Firstly, they determined which diatom indices correlated significantly with the majority of investigated chemical parameters. They used IPS, SID and TID indices and found that, more than half of the 398 streams investigated, achieved the level of good ecological status (15 with high, 204 good, 165 moderate, 11 poor and 3 with bad condition).

Italy

An index for monitoring Italian rivers based on diatoms was proposed in the last decade and recently improved, and tasted. During the monitoring of several central Apennean water courses entering the Adriatic Sea by means of EPI-D, diatom index was able to assess their general stituation and identify many sites with excellent or good water quality, not always upstream, that are worth preserving, at least in their current status and a similar number of sites that are more or less damaged by antropogenic acivities, not always downstream, with restoration (Dell'Uomo and Torrisi, 2009). In most cases, the index value showed positive correlation with the biological oxygen demand (BOI_5), phosphate, inorganic nitrogen, conductivity and chloride concentration and negative correlation with oxygen concentration. According to the results, EPI-D index showed very high correlation with IPS, IDG and CEE indices. On the other hand, EPI-D and EBI (Extended Biotic Index for benthic macroinvertebrates) were used for River Tenna by Torrisi *et al*. (2010) and finally found that, two indices were in good correlation between them.

Latvia

In Latvia, the examination of benthic diatoms started practically with their participation in the STAR project. They studied middle-sized, lowland rivers simultaneously with macrophyton, macrozoobenthos and fish. They found makrophyton and fish on a large scale give less, while on smaller scale, phytobenthos and macrozoobenthos give more information to the evaluation of ecological state (Springe *et al*., 2006).

Poland

Monitoring of surface waters has been carried out in Poland since 1960, although the monitoring system was only unified in 1990. At that time, three categories were defined on the basis of physical, chemical and biological parameters such as colititer, chlorophyll content and Pantle-Buck saprobity. Omnidia was widely used in Polish rivers (the Rivers Vistula, Raba, Wisoka, Dunajec and their tributaries) (Dumnicka *et al*., 2006; Wojtal and Kwandrans, 2009; Szczepocka and Szulc, 2009) and also spring in Southern Poland (Wojtal, 2009, 2010). With the aid of algal studies, chemical and physical data of 38 rivers, Omnidia indices have already been tested and IPS and GDI indices have been found to be the most appropriate for Polish conditions (Kwandrans *et al*., 1997).

Portugal

According to the Portuguese law enacted in 1991, only physical, chemical and a few bacteriological variables are to be measured for routine water quality evaluation. Therefore, diatom-based monitoring was sporadic and not uniform. Studies of this kind are being carried out mostly by university research groups and are quite recent. During the 70s and 80s, the Pantle-Buck, Zelinka-Marvan, later the Descy, Coste and Shannon-Weaver indices were used on several rivers with variable results. In Portugal, the use of biological indicators to assess water quality in rivers has increased greatly (Resende *et al*., 2010). According to Almeida (2001), the use of CEE and IPS indices are recommended for routine water quality monitoring in Portugal. Also, Feio *et al*. (2009) investigated Mondego, Vouga and Lis rivers and reported that, the most similar results were between BDI/IPS and BDI/CEE indices.

Slovakia and Czech Republic

Phytoplankton and phytobenthos investigations have continuously been carried out at 244 sampling points according to the Slovakian national standard, which considers first of all, chlorophyll-a content, cell number and saprobity index values. Because of this, these countries possess information on water quality of their most important rivers. The integration of EU standards into the national standards has been started. Also according to Hlubikova *et al*. (2006), CEE, IPS and EPI-D, indices are suitable indices for monitoring rivers in Slovakia.

Spain

Throughout the 80s and 90s, benthic diatom samplings were carried out on River Ter in order to analyse the water quality. Data were processed with the help of parallel water chemistry data and principal component analysis. The researchers drew the conclusion that benthic diatoms are well applicable for the water qualification of water courses. Different regions were investigated in Spain: Notre 2003-2004, Deuro 2004-2005, Ebro 2002-2007, Catalonia 2002-2003, Jucar 2001 and Guadalquivir 2003-2004 (Sabater and Sabater, 1988; Navarro *et al.*, 2002; Gomá *et al.*, 2004; Blanco *et al.*, 2006; Martin *et al.*, 2010).

Sweden

In Sweden national monitoring program practically does not exist until now, where they would have used the diatoms routinely, as bio-indicators. However, until now, more than 200 rivers have been studied and the IPS and EQR boundaries determined. Though they found the IPS index useful, they have also developed a new acidity index (AJK,) into which they integrated the IPS index but allow for proportion of the alkalofil, alkalobiont and tolerant species, too. The IPS supplementing with the TDI and PTV% indices, and AKJ index are recommended in the national monitoring.

United Kingdom

Development of indices appropriate for river monitoring was started in the United Kingdom in 1989, with the formation of the National Rivers Authority. The Urban Wastewater Treatment Directive of the EU requires the identification of stretches of rivers, which are vulnerable to eutrophication. Trophic Diatom Index was developed parallel to this work. This index was used by “Environment Agency” for monitoring surface water between 1994 and 1997. For the first version, 100 taxa were included – a mixture of genera and species, and this figure expanded to 113 in the latest version (Kelly, 2003).

Turkey

Water quality monitoring, based on diatom indices, is a new topic in Turkey especially after the 2000s, and is getting more and more important each day. For this reason, by doing more and more studies using the indices, it is believed that the current monitoring procedure could be restructured with respect to the aquatic organisms such as diatom. Several studies have been carried out in the Antalya River basin (Kalyoncu, 2002; Solak *et al*., 2007a; Kalyoncu *et al*., 2009), Büyük Menderes River basin (Barlas *et al*., 2001, 2002; Solak *et al*., 2007b), Fırat River basin (Gürbüz and Kıvrak 2002), Kızılırmak River basin (Akbulut *et al*., 2010), Sakarya River basin (Solak *et al*., 2009; Solak 2011) and Susurluk River basin (Dalkıran *et al*., 2008; Karacaoğlu *et al*., 2008; Solak *et al*., 2011).

Firstly, TDI, SI, GI ve DAIpo indices were used by Gürbüz and Kıvrak (2002) in Karasu River and TDI was used in Emet Stream by Karacaoğlu *et al*. (2008) and in Orhaneli Stream by Dalkıran *et al*. (2008). Isparta and Darıören Streams were investigated using DI-CH, TI and SI by Kalyoncu *et al*. (2009). Also, SLA, EPI-D, TDI and DESCY indices were used by Solak (2011) in Upper Porsuk River (Kütahya). OMNIDIA Software Program was used first in Akçay (Muğla) by Solak *et al.* (2007a), in Düden Waterfall by Solak *et al.* (2007b), Felent Stream (Solak 2009, Solak *et al*. 2009) and Kızılırmak River (Akbulut *et al*., 2010). According to the results, DESCY seems to be the best for Akçay Stream and there was a high correlation between physico-cehmical parameters and BDI in Düden Waterfall while, IDAP, WAT, CEE and IPS indices had a high correlation with physico-chemical parameters in Felent Stream and Kızılırmak River.

As a conclusion, current studies must be kept as a database for Turkey. Many more studies should be done to fill the gab in this topic in order to reveal the most suitable diatom index for Turkish rivers. Our priority of our scientists must be to do some projects especially concerning water quality all over Turkey’s waters and be supported by related institutions such as universities, DPT and TUBITAK.

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