Pollution, 3(2): 311-323, Spring 2017
DOI: 10.7508/pj.2017.02. 012
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

Comparison between Water Quality Index (WQI) and biological indices, based on planktonic diatom for water quality assessment in the Dong Nai River, Vietnam

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Received: 29 Nov. 2016 Accepted: 27 Dec. 2016

ABSTRACT: The present study aims to have a comparative study of the results, from biological monitoring as well as conventional method, based on physico-chemical variables. Water quality index (WQI) and planktonic diatom metrics have been used to determine water quality and ecological conditions of the Dong Nai River (DNR) and Canonical Correspondence Analysis (CCA) to find out the main environmental variables that regulate the phytoplankton community. A total of 51 planktonic diatom species, belonging to 23 genera, have been identified during the study period. *Fragillaria* was the most dominant diatom in the upper course site, while the *Aulacoseira* was the most dominant species in the middle and lower ones. One-way ANOVA showed that the mean of turbidity, ammonium, nitrate, and phosphate were significantly different ($P<0.05$) among upper, middle, and lower course sites in both dry and wet seasons. The WQI showed that water quality in the Dong Nai River was classified in medium level at all sites, while water quality varied from good, moderate, to low level, based on the Biological Diatom Index (BDI) values. CCA indicated that nutrients (PO_4^{3-}, NO_3^-, NH_4^+) and turbidity were the most important factors, regulating the variation in structure of the planktonic community. In this study, the BDI has been applied for the first time to bio-monitor water quality in Vietnam. The sensitivity of the BDI to environmental stressors, supported the use of this index to bio-monitor surface water in tropical regions.

Keywords: bioindicators, ecological condition, physicochemical variables, tropical river.

INTRODUCTION

Water pollution poses a potential threat to primary producers, such as planktonic diatom, which might be a valuable indicator community for water quality assessment. Planktonic diatoms are ubiquitous and respond rapidly to environmental conditions; therefore, any alteration in their community composition may reflect past, present, and future water conditions (Almeida et al., 2014; Bellinger et al., 2006). Diatoms are used widely to monitor fresh bodies of water, particularly in Europe, North America, and Australia (Almeida et al., 2014; Chessman et al., 2009; Resende et al., 2010; Stevenson et al., 2008).

In Vietnam, there have been few related studies on algae as bioindicators. Physico-chemical is the traditional tool to monitor the

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surface water in Vietnam, and the QCVN 08:2015 is currently being used as the Vietnamese national technical regulations for surface water quality. The Water Quality Index (WQI) has been considered to give a criterion for surface water classification, based on the use of physico-chemical standard parameters for water characterization (Hanh et al., 2011; Cude, 2001). The WQI number ranges from 0 to 100, showing the water quality in terms of a number that signifies better water quality when it is higher. However, whether water quality is good or bad is not merely reflected in terms of physical and chemical parameters. Water quality or ecological health should be embodied in the response of all kinds of aquatic organisms, especially those that are considered to be sensitive to changes of environmental conditions, such as diatoms, zooplankton, macro-invertebrates (Chen et al., 2016). Compared to other groups such as zooplankton and macro-invertebrates diatom indices are increasingly used to assess the ecological status of rivers, because they consist of multi-functional species within the assemblage, which respond differently to various stressors and can reflect ecological status comprehensively (Reynolds, 2006). Diatom community is limited by a variety of factors in the aquatic environment. In general, the principal factors, affecting the growth of planktonic diatom, are the pH, water temperature, light conditions, nutrient concentrations, and predation by zooplankton and fish (Liu et al., 2016; Stevenson et al., 2008). Several biological indices based on diatom assemblages have been developed. Among the diatom metrics, developed to indicate the trophic level of running waters, the Biological Diatom Index (BDI), proposed by Lenoir and Coste (1996), and revised by Coste et al. (2009), has been widely used for water quality assessment.

The Dong Nai River (DNR) originates in the Central Highland region of the southern portion of Vietnam, northwest of Da Lat. It flows west and southwest for about 300 miles (480 km), joining the Saigon River, southwest of Bien Hoa, and empties into the East Sea (Fig. 1). Currently, the river basin is experiencing rapid urbanization, and includes the rapid growing cities of Ho Chi Minh City, Bien Hoa, and Thu Dau Mot town. Continued urbanization and growing economy have increased the stress on water quality of the river. The DNR is polluted by organic matters in terms of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), heavy metal, and toxic compounds that exceed the limits of raw surface water quality standards for water supply (column A_2 QCVN 08:2015/BTNMT) (Bui et al., 2016; Le et al., 2016).

The present study analyzes the relations of two different indices (WQI, based on physic-chemical variables and BDI, based on diatom assemblages) when they are used to characterize a set of sites (from reference sites to human-impacted ones) in the DNR, Vietnam. In addition, the critical environmental factors that strongly affect the distribution of planktonic diatom have been identified with a Canonical Correspondence Analysis (CCA).

MATERIALS AND METHODS

Study area

Planktonic diatom and water samples were taken at 10 stations, along DNR at three regions with distinct occupation characteristics: the upper course sites (DN1–DN2) show natural cover with little land used, the middle course sites (DN3–DN6) show intensive farming, and the lower course sites (DN7–DN10) present urban and industrial uses (Fig. 1). In Vinh Cuu district of Dong Nai Province, a dam has been constructed on the river to create the Tri An Reservoir, the main functions of which involve flood control and irrigation for agricultural purposes.

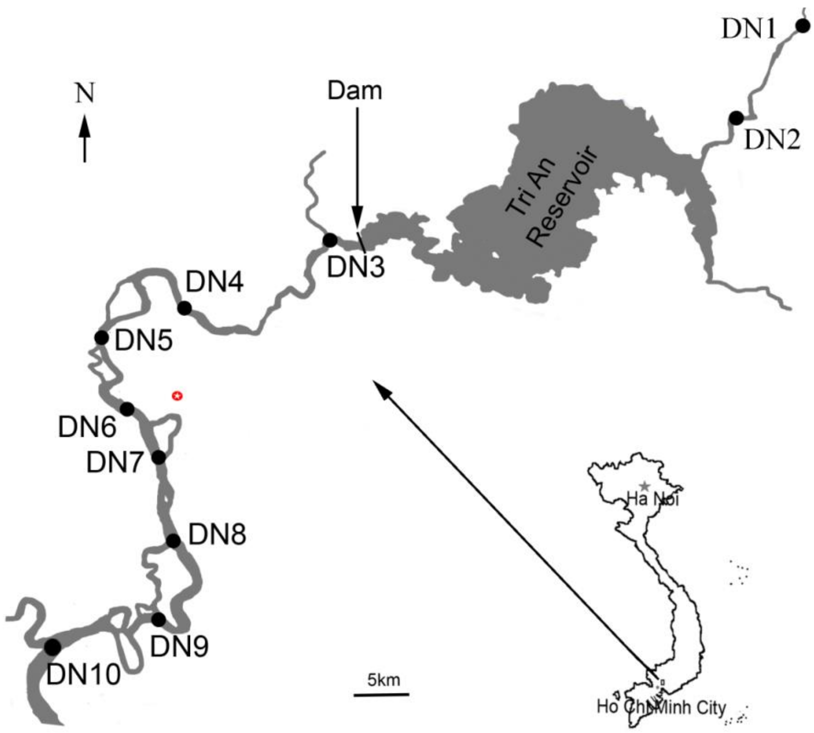

Fig. 1. Map of the Dong Nai River and the 10 sampling locations

Field sampling and nutrient analyses

Two surveys were conducted at 10 stations in the DNR in March (dry season) and in September (rain season), 2010 (Fig. 1). Water samples were collected from the surface, with three replicas gathered at each station. Water temperature, pH, DO, and turbidity were measured in situ, by using a multi-parameter (Hach 156, Co, USA). In order to measure inorganic nutrient parameters, surface water sample was collected, using plastic containers (each with a capacity of 2 liters). The plastic containers were rinsed thoroughly with sampling water before use. After filling the containers, they were sealed, kept in ice-boxes, and transferred to the laboratory for the nutrient concentrations. Dissolved nutrients, i.e. nitrate (N-NO_3^-), ammonium (N-NH_4^+), and phosphate (P-PO_4^{3-}), were measured according to APHA methods (2005).

Planktonic diatom samples were collected from the surface waters by towing a plankton net (with a mouth diameter of 0.4 m), made of bolting silk (No. mesh size 25 μm). Subsequently, samples were kept in 150 ml plastic bottle, preserved in 4% neutralized formalin, and used for qualitative analysis, which involved filtering 10 l of surface waters through the plankton net and concentrated to 50 ml, then preserved in 4% neutralized formalin.

Planktonic diatom identification

The quantitative samples, amounting to about (10) ml, were oxidized with acid H_2SO_4 20% v/v for a few hours in order to remove the organic matter and H_2SO_4 50% v/v was added to eliminate carbonates, as described in Renberg (1990). After washing with distilled water, clean valves were permanently mounted with glycerol agent. Slides were examined with an Olypus BX51TRF light microscope, equipped with differential interference contrast at a magnification of ×40. At least 400 valves were counted under Sedgewick counting technique (Lund et al., 1958; Wetzel & Likens, 2000) and the diatoms were identified by means of identification books of Krammer and Lange-Bertalot (1986, 1988, 1991a,b), Rumrich et al. (2000), and

Metzeltin and Lange-Bertalot (1998, 2002, 2007). The classification of phytoplankton into taxonomic groups as well as the verification of currently-accepted taxonomic names followed AlgaeBase web (Guiry & Guiry, 2016).

Data analysis

The rates of turbidity, pH, conductivity, nitrate-N, phosphate-P, DO, and temperature have contributed to the calculation of WQI, in accordance with the method of Ott (1978).

$$\mathrm{WQI} = \sum_{i=1}^{n} Wi \times Qi$$

where, Wi is the weight and Qi, the quality score of variable i. WQI is a number between 0 and 100. For WQI method, the ratings of water quality have been defined by using the classification in Table 1 (Ott, 1978).

Table 1. Water quality classification, based on WQI

WQI Value	Rating Water Quality
91–100	Excellent water quality
71–90	Good water quality
51–70	Medium water quality
26–50	Bad water quality
0–25	Very bad water quality

The planktonic diatom community structural attributes of species richness Margalef's index (S), Shannon–Weiner diversity index (H'), and Biological Diatom Index (BDI), commonly used in water quality bio-assessment, were employed to characterize the phytoplankton community at each site (Agrawal & Gopal, 2013). These metrics were calculated by means of the Primer VI analytical package developed by Plymouth Marine Laboratory, U.K.

The BDI index was determined according to the new version of BDI-2006 (Coste et al., 2009), being calculated automatically by means of both Calculate BDI and Excel. Table 2 gives the trophic status and water quality classes, belonging to the BDI values (Szulc & Katarzyna, 2013).

Table 2. Trophic status and water quality class, based on BDI index

BDI value	Water quality class	Ecological status
> 17	I	Very good
13 - 16.9	II	Good
9 - 12.9	III	Moderate
5 - 8.9	IV	Low
< 4.9	V	Poor

One-way analysis of variance (ANOVA) was used to test the significance of the differences among the groups of study sites. The analysis was completed, using Tukey's HSD test significant difference. Canonical correspondence analysis (CCA) was used to elucidate the main environmental driving force in the planktonic diatom community (Braak & Verdonschot, 1995). All variables (except NH_4^+, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, PO_4^{3+}, and pH) were log-transformed to normalize their distributions before analysis. Monte Carlo permutation tests were taken to further reduce the environmental variables to those, correlated significantly with the derived axes. Only the taxa, observed in more than 10% of the samples, were included in the analyses of taxa abundances to minimize the influence of the rare ones. CCA and ordination plot were performed using CANOCO version 4.5 for Windows (Leps & Smilauer, 2003).

RESULTS

Physico-chemical and nutrient variables

Figure 2 illustrates the average physico-chemical variables concentrations from the surface waters of DNR in both dry and wet seasons. The results of One-way ANOVA and Tukey's HSD test show that the mean of temperature, turbidity, and nitrate in the dry season have been significantly higher than those of the wet season ($P<0.05$); however, no significant difference in other environmental variables has been detected between the two seasons ($p>0.05$). The seasonally fluctuations of pH varied between 6.2 and 8.9 with both minimum and maximum rates occurring in the dry season.

The surface water temperature varied between a minimum rate of 28.1 in the wet season and a maximum rate of 31.8°C in the dry one. The mean seasonally dissolved oxygen values ranged from 4.5 to 6.6 mg/L. Turbidity varied between 12.3 and 179.7 NTU, with its minimum rate belonging to the dry and maximum rate to the rainy season. Nutrients such as nitrate, varied between 0.04 and 0.39 mg/L with the minimum occurring in the wet and the maximum one in the dry season. Amonium varied from 0.03 to 0.17 mg/l; its minimum rate happened during the rainy season, while its maximum rate belonged to the dry seasons. Inorganic phosphate ranged between 0.01 and 0.14 mg/L with its minimum during dry and maximum during wet season.

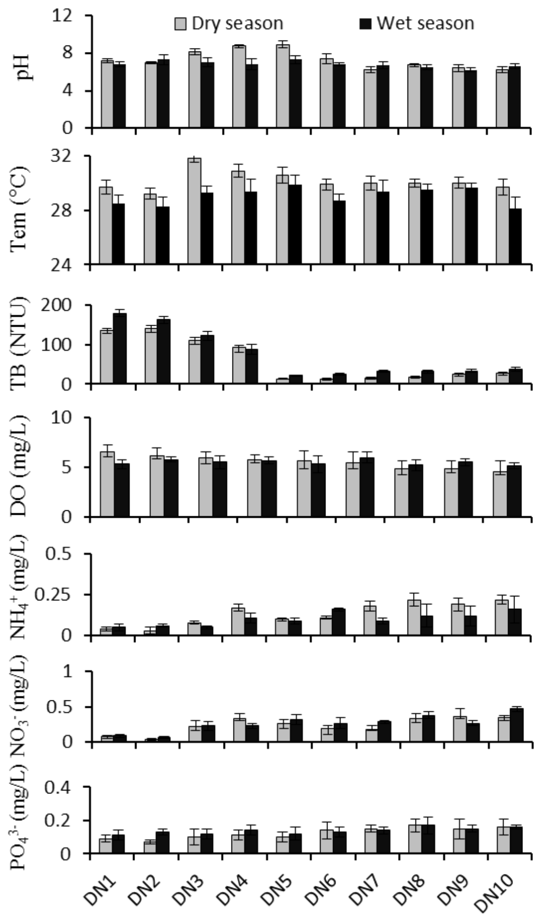

Fig. 2. Median (mean ± SD) water quality variables from sampling sites in dry and wet seasons

In general, the lower course sites had higher nutrient but lower turbidity concentrations than the upper course ones. One-way ANOVA and Tukey's HSD test show that the mean of turbidity, ammonium, nitrate, and phosphate differed significantly (*P*<0.05) among upper, middle, and lower course sites in both dry and wet seasons. The water quality has generally tended to deteriorate down-stream, as the river pass through urban areas, due to the discharge of treated and untreated domestic and industrial effluent as well as other diffuse sources of pollution from the cities and towns along the river. The pH has increased slightly at the middle sites in dry season, though without any statistically significant difference (ANOVA, *P*> 0.05) among the three site categories. On the other hand, nutrient concentrations such as NH_4^+, NO_3^-, and

PO_4^{3+} have increased significantly downstream (ANOVA, $p<0.05$) (Fig. 2).

Planktonic diatom community structure

A total of 51 planktonic diatom species, belonging to 23 genera, have been identified during the study period. *Achnanthidium*, *Aulacoseira*, *Cymbella*, *Fragillaria*, *Gyrosigma*, *Navicula*, *Nitzschia,* and *Surirella* were the dominant ones (Table 3). While *Fragillaria* was the most dominant diatom in the upper course sites, Aulacoseira was the most dominant species in the middle and lower course sites. List of most abundant species from the Dong Nai has been demonstrated in Appendix 1. Among the diatoms *Fragilaria virescens,* Achnanthidium minutissimum, *Eunotia robusta*, and *Synedra ulna* were the most dominant species in the upper course sites, while *Aulacoseira granulata*, Cyclotella meneghiniana, Coscinodiscus subtilis, Navicula elegans, and Surrirella robusta were found to be the commonly occurring species in the samples collected in the middle and the lower course sites. As pollution increased (i.e. increasing in terms of the nutrients and decreasing in terms of dissolved oxygen levels), low or moderate pollution tolerant species, such as *F. virescens,* A. minutissimum, *Eunotia robusta, Synedra ulna* were replaced by high pollution tolerant species, like *Aulacoseira granulata*, Cyclotella meneghiniana and *Nitzschia linearis*.

Planktonic diatom abundance

Figure 3 shows the abundance of planktonic diatom in DNR. There was a distinct seasonal variation in phytoplankton structure with high cells density in dry season and low values in rainy season. The highest planktonic diatom abundance (3.97×10^5 cells/L from station DN4) was observed in dry season while the lowest (0.57×10^5 cells/L from station DN1) was found in wet season (Fig. 3). There was a clear temporal difference in phytoplankton abundance with significantly lower ($P<0.002$) mean abundance in the upper course sites in both seasons. The planktonic diatom abundance clearly divided the study sites into three different "zones" in dry season. As the upper course site had a low density; the lower course sites had a denser, whereas highest abundance belonged to the middle course sites. The abundance of diatom in the DNR followed almost the same trend during the study period.

Table 3. Taxonomic composition of planktonic diatom and the number of taxa present in the Dong Nai River

Genus	No. of taxa	Genus	No. of taxa
Achnanthidium	3	*Gomphonema*	2
Actinoptychus	1	*Gyrosigma*	3
Amphipleura	1	*Navicula*	5
Aulacoseira	4	*Nitzschia*	3
Climacosphenia	1	*Pinnularia*	1
Coscinodiscus	2	*Pleurosigma*	2
Cyclotella	2	*Skeletonema*	1
Cymbella	3	*Stephanodiscus*	1
Diatoma	1	*Surirella*	3
Diploneis	2	*Synedra*	2
Eunotia	2	*Tabellaria*	1
Fragilaria	3		

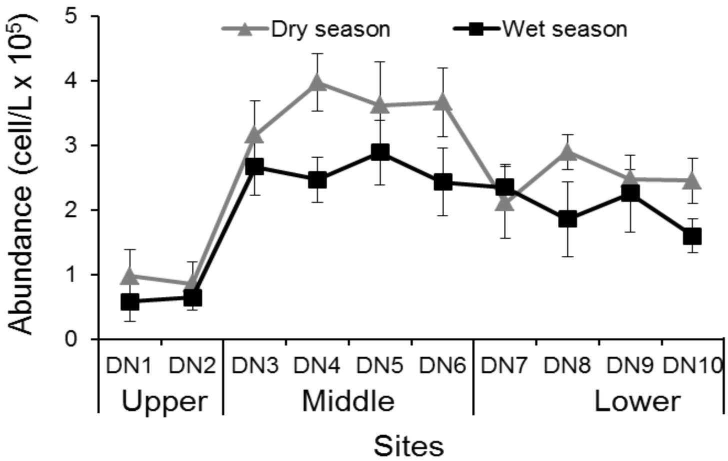

Fig. 3. Planktonic diatom abundance in dry and wet season

Water quality index and diatom metrics

Figure 4 shows the variation of the WQI, BDI, Shannon and Wiener index (H'), and species richness Margalef's index (S). In general, the middle and lower course sites had the lowest rates of WQI, BDI, H', and S in all groups. The WQI ranged from 55 to 65 and from 57 to 64 in dry and wet seasons, respectively (Fig. 4A). The BDI ranged from 8.3 to 12.2 and from 9.0 to 12.8 in dry and wet seasons, respectively (Fig. 4B). The BDI was clearly different in the upper course sites and the middle to lower course sites (*P*<0.05). The Shannon diversity index ranged from 1.8 to 3.1 and from 2.0 to 3.3 in dry and wet seasons, respectively (Fig. 4C) with significant differences between the upper course sites and middle to lower course sites (*P*<0.05). The species richness index ranged from 18 to 27 and from 21 to 29 in dry and wet seasons, respectively (Fig. 4D).

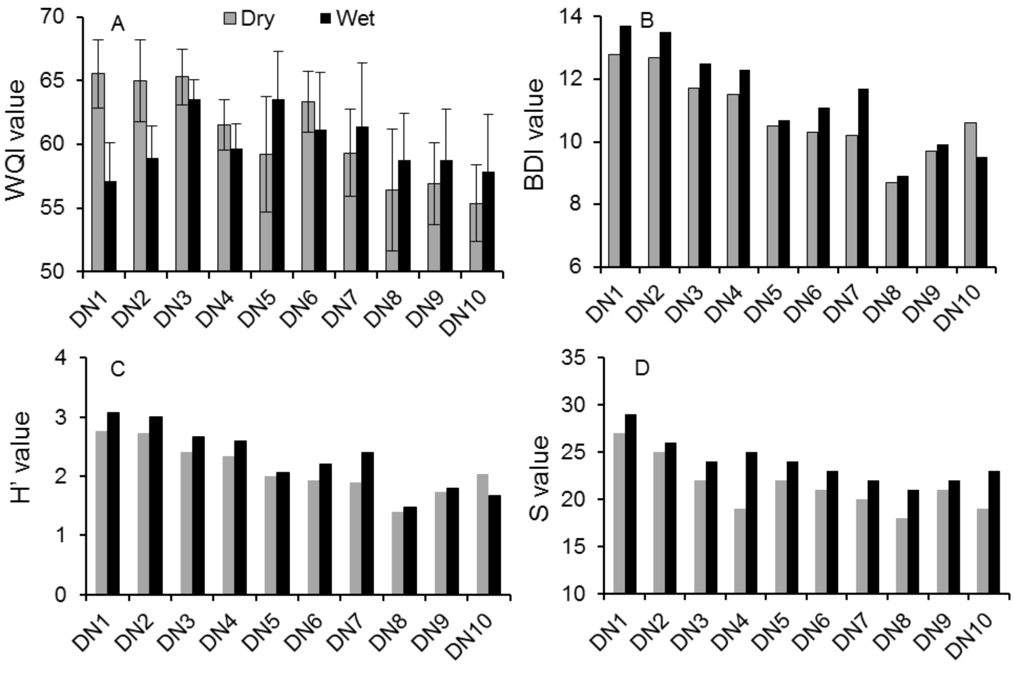

Fig. 4. Value of the Water Quality Index (WQI), Biological Diatom Index (BDI), Shannon-Wiener index (H'), and Species richness (S) in dry and wet seasons

Based on WQI and BDI indices, the water quality and ecological status at each site were classified (Table 4). Based on the WQI, the water quality in the DNR was classified in medium level; however, based on the BDI values, the water quality in the DNR varied from good to low status, corresponding to water quality class II to IV based on the classification systems of Szulc & Katarzyna (2013).

Relation of phytoplankton assemblages to environment variables

Of the 51 phytoplankton species, identified in this investigation, 23 taxa were included in data analysis using CCA (Fig. 5). Results from a CCA analysis for dry season, based on normalized environmental variables, showed that axis 1, explaining 61.7% of the variation, was positively correlated with nutrient concentrations and may present an upper to lower of water quality gradient, while the second axis (accounting for 17.5% of the variance) was related to turbidity and, to a lesser extent, temperature and DO (Fig. 5A). In wet season, the first 2 axes explained about 85.9% of the variance for planktonic diatom assemblages (Axis 1 accounted for 71.6%, axis 2 for 14.3% of the variance). Axis 1 was correlated with PO_4^{3-}, NO_3^-, temperature, and- to a lesser extent- turbidity and pH. It may represent an upper course to lower course of water quality gradient. Axis 2 was correlated with DO, likely to represent an urban impact or water quality degradation gradient (Fig. 5B).

Table 4. Results of ecological status and water quality based on WQI index and diatom indices

	Based on diatom indices		Water quality based on WQI
	Water quality class	Ecological status	
DN1	II	Good	Medium
DN2	II	Good	Medium
DN3	III	Moderate	Medium
DN4	III	Moderate	Medium
DN5	III	Moderate	Medium
DN6	III	Moderate	Medium
DN7	III	Moderate	Medium
DN8	IV	Low	Medium
DN9	III	Moderate	Medium
DN10	III	Moderate	Medium

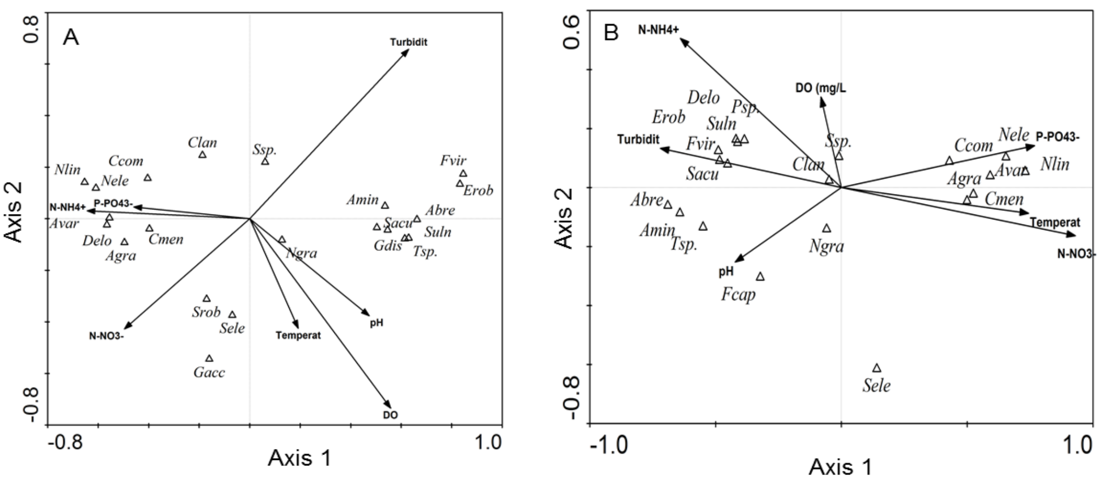

Fig. 5. Biplot of canonical correspondence analysis, relating abundance of dominant taxa and physico-chemical variables in (A) dry season and (B) wet season

In both seasons, the CCA biplots divided the planktonic diatoms in two groups with difference species indicators. Group 1 involved those species, preferred in the upper course sites with higher turbidity and lower nutrient concentration conditions. These parameters were highly associated with diatom *Achnanthidium minutissimum*, *Eunotia robusta*, *Fragilaria virescens*, *Synedra acus*, and *Tabellaria* sp. Another group included species, preferred for high nutrient concentrations in the lower course sites. Those species were positively correlated with NO_3^-, NH_4^+, and PO_4^{3-}, associating with most other diatoms such as *Aulacoseira granulata*, *A. varians*, *Cyclotella meneghiniana*, *Diatoma elongatum*, *Navicula elegans*, and *Nitzschia linearis*.

DISCUSSION

The water quality index (WQI) has been widely used for surface water classification, based on the use of standard parameters for water characterization (Chaturvedi & Bassin, 2010; Hanh et al., 2011; Varol & Davraz, 2015). Our results from WQI values in every site during the study period indicate that the water quality in DNR is of medium quality; however, based on BDI index, water quality in the upstream sections is better than the downstream river sections. There has been a significant increase in values of nutrient parameters downstream the river, which indicates that the local and industrial pollutants may be contributing incrementally to the degradation of river water quality. These results also confirm the results of Le et al. (2016), who state that water quality in DNR has decreased downstream. Water pollution from the DNR' tributaries adversely affect raw water quality of the river, resulting in increased amount of NH_4^+, NO_3^-, and PO_4^{3-} at downstream sites. According to previous studies, water quality of DNR is mainly polluted by organic matter, heavy metal, e-EDCs and microorganisms (Huy et al., 2003; Bui et al., 2016; Le et al., 2016). Particularly, bacteria, heavy metals of Fe, Cu, and Mn and e-EDCs have higher risk potentials, quite likely to affect human health as well as the safety of the water supply (Bui et al., 2016; Lan et al., 2013; Le et al., 2016). Results of this study show that water quality of DNR has also been contaminated with nutrient concentration, particularly ammonia, nitric, nitrate, and phosphate. This may be associated with storm water runoff, increased industrial development and caused by discharging waste water from human activities.

The standardized BDI was first developed and applied in France (Lenoir & Coste, 1996) for the surveillance of watercourse quality. It was then revised (BDI-2006) (Coste et al., 2009) for better suitability to the European Water Framework Directive (WFD). Because of its usefulness in ecological indication, the BDI has been widely used in Euro (Szulc & Katarzyna, 2013; Almeida et al., 2014), China (Chen et al., 2016; Tan et al., 2013), and Africa (Bere et al., 2014) for water quality monitoring. In this study, the BDI was applied for the first time on water quality assessment in Vietnam. The use of aquatic indicators, such as diatom species achieved a more realistic approach for water quality assessment. Physico-chemical data give basic and very important information on the present status of water quality but do not display the ecological status of the river which can be pre-received by the study of planktonic diatom community, growing over an extended period of time (Duong et al., 2007). The results of diatom metrics show that water quality in the DNR varies from good to low status, based on the classification systems of Szulc and Katarzyna (2013). This has been corroborated for the biological indices which reveal that the water quality from DN1 to DN2 has demonstrated a good status, during the sampling period, while DN3 to DN10 have presented general moderate water quality, except for DN8 which has shown low status. This common trend of declining index values as water flows downstream is due to an increase in human pressures and municipal wastewater (Bui et al., 2016; Lam et al., 2015; Le et al., 2016). Our results indicate that water quality classification, combined with diatom species, can give a more accurate assessment of water quality than measurement of physico-chemical parameters alone. Decreases in environmental quality of DNR have been indicated by the diatom indices more than by the physico-chemical variables. Biological indices are shown to be one of the most effective tools to monitor biological quality and ecological status of the river (Stevenson et al., 2008). The results of this study suggest that planktonic diatom community and its biological indices should be able to differentiate sites of various degrees of contamination and, therefore, seem adequate to be used for surface water monitoring purposes.

Diatoms are primary producers and thus they are more likely to be sensitive to the trophic status of a waterbody. Therefore, they are routinely used as bio-indicators of water quality or ecosystem health (Stevenson et al., 2008; Chen et al., 2016; Szulc and Katarzyna, 2013). The diatom species diversity, found in DNR, is similar to the one, found in other Vietnam rivers (Duong et al., 2007; Pham, 2016). The diatom species composition in DNR, however, is very different among the sites and could be clearly divided into two groups through CCA analysis. These groups seem to have ecological significance, based on species' responses to environmental conditions. For example, *A. minutissima* and *F. virescens*, considered to be a low nutrient and unstable water indicator species (Potapova & Charles, 2007) were dominant species in the upper stream sites; while all three species of *A. granulata*, *C. meneghiniana*, and *S.* robusta, thought to be tolerant of heavy pollution (Akinyemi et al., 2007; Tan et al., 2013), have been dominant in downstream sites. CCA results show that nutrients and turbidity are the important factors in structuring benthic diatom community in the study area. The diatom composition in upper stream sites are greatly influenced by high turbidity concentration, which may be due to the surface runoff from agricultural land use. In contrast, the diatom community in downstream sites is highly associated with nutrient concentrations, which may be due to the emissions of urban sewage (Bui et al., 2016; Le et al., 2016; Thai, 2011).

CONCLUSIONS

The present study has applied the planktonic diatom metrics and WQI, based on physico-chemical variables, in order to assess water quality and ecological status of DNR. Results indicate that the planktonic diatom composition is more sensitive and a better indicator than the routine investigation of water physico-chemical parameters. It provides important complimentary information for ecological status and conditions in DNR, Vietnam. Therefore, it is necessary to use diatoms, along with water physical and chemical parameters, for surface water quality monitoring. The water pollution and human impacts have become a big problem in DNR; therefore, responsible authorities need to take counter-active measures to improve the water quality of this river and reduce public health risks.

Appendix 1.

List of 23 the most-frequently-occurring diatom species from Dong Nai River, Vietnam. The code number of diatom species was used in CCA analysis.

No.	Code	Species	Dry	Wet
1	Abre	*Achnanthidium brevipes*	+	+
2	Amin	*Achnanthidium minutissimum*	+	+
3	Agra	*Aulacoseira granulata*	+	+
4	Avar	*Aulacoseira varians*	+	+
5	Ccom	*Cyclotella comta*	+	+
6	Cmen	*Cyclotella meneghiniana*	+	+
7	Clan	*Cymbella lanceolata*	+	+
8	Delo	*Diatoma elongatum*	+	+
9	Erob	*Eunotia robusta*	+	+
10	Fvir	*Fragilaria virescens*	+	+
11	Fvir	*Fragilaria capucina*		+
12	Gacc	*Gyrosigma accuminatum*	+	
13	Gdis	*Gyrosigma distortum*	+	
14	Nele	*Navicula elegans*	+	+
15	Ngra	*Navicula granii*	+	+
16	Nlin	*Nitzschia linearis*	+	+
17	Psp.	*Pinnularia* sp.		+
18	Ssp.	*Stephanodiscus* sp.	+	+
19	Sele	*Surirella elegens*	+	+
20	Srob	*Surirella robusta*	+	
21	Sacu	*Synedra acus*	+	+
22	Suln	*Synedra ulna*	+	+
23	Tsp.	*Tabellaria* sp.	+	+

REFERENCE

Agrawal, A. and Gopal, K. (2013). Biomonitoring of water and waste water. Springer New Delhi Heidelberg New York Dordrecht London.

Akinyemi, S.A., Nwankwo, S.A. and Fasuyi, A.O. (2007). Diatoms as indicator of pollution in Awon Reservior, Oyo Town, Nigeria. Res. J. Microbiol., 2(3), 228-238.

Almeida, S.F.P., Elias, C., Ferreira, J., Tornés, E., Puccinelli, C., Delmas, F., Dörflinger, G., Urbanič, G., Marcheggiani, S., Rosebery, J., Mancini, L. and Sabater, S. (2014). Water quality assessment of rivers using diatom metrics across Mediterranean Europe: A methods intercalibration exercise. Sci. Total Environ., 1(476-477), 768-776.

APHA. (2005). Standard methods for the examination of water and wastewater. Washington DC., USA, 1496 pp.

Bellinger, B.J., Cocquyt, C. and O'Reilly, C.M. (2006). Benthic diatoms as indicators of eutrophication in tropical streams. Hydrobiologia, 573(1), 75-87.

Bere, T., Mangadze, T. and Mwedzi, T. (2014). The application and testing of diatom-based indices of stream water quality in Chinhoyi Town, Zimbabwe. Water SA, 40, 503-512.

Braak, C.J.F.T. and Verdonschot, P.F.M. (1995). Canonical correspondence analysis and related multivariate methods in aquatic ecology. Aquat. Sci., 57(3), 255-289.

Bui, T.K.L., Do-Hong, L.C., Dao, T.S. and Hoang, T.C. (2016). Copper toxicity and the influence of water quality of Dongnai River and Mekong River waters on copper bioavailability and toxicity to three tropical species. Chemosphere, 144, 872-878.

Chaturvedi, M.K. and Bassin, J.K. (2010). Assessing the water quality index of water treatment plant and bore wells, in Delhi, India. .Environ. Monit. Assess, 163(1-4), 449-453.

Chen, X., Zhou, W., Pickett, S.T.A., Li, W., Han, L. and Ren, Y. (2016). Diatoms are better indicators of urban stream conditions: A case study in Beijing, China. Ecol. Indic., 60, 265-274.

Chessman, B.C., Bate, N., Gell, P.A. and Newall, P. (2009). A diatom species index for bioassessment of Australian rivers. Mar. Freshwater Res., 58, 542-557.

Coste, M., Boutry, S., Tison-Rosebery, J. and Delmas, F. (2009). Improvements of the Biological Diatom

Index (BDI): Description and efficiency of the new version (BDI-2006). Ecol. Indic., 9(4), 621-650.

Cude, C.G. (2001). Oregon water quality index a tool for evaluating water quality management effectiveness. J. Am. Water. Resour. Assoc. 37(1), 125-137.

Duong, T.T., Feurtet-Mazel, A., Coste, M., Dang, D.K. and Boudou, A. (2007). Dynamics of diatom colonization process in some rivers influenced by urban pollution (Hanoi, Vietnam). Ecol. Indic., 7(4), 839-851.

Guiry, M.D. and Guiry, G.M. AlgaeBase (2016). (World-Wide Electronic Publication). National University of Ireland, Galway〈http://www.algaebase.org〉(searched on 18 Sep, 2016).

Hanh, P.T.M., Sthiannopkao, S., Ba, D.T. and Kim, K.W. (2011). Development of Water Quality Indexes to identify pollutants in Vietnam's surface water. J. Environ. Eng., 137(4), 273-283.

Huy, N., Luyen, T., Phe, T. and Mai, N. (2003). Toxic elements and heavy metals in sediments in Tham Luong Canal, Ho Chi Minh City, Vietnam. Environ. Geol., 43(7), 836-841.

Krammer, K. and Lange-Bertalot, H. (1986). Bacillariophyceae. 1. Teil: Naviculaceae. In Ettl H., Gerloff J., Heynig H. and Mollenhauer D. (eds) Süsswasser flora von Mitteleuropa, Band 2/1. Gustav Fischer Verlag: Stuttgart, New York, 876 p.

Krammer, K., Lange-Bertalot, H. (1988). Bacillariophyceae 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In Ettl H., Gerloff J., Heynig H. and Mollenhauer D. (eds) Süsswasserflora von Mitteleuropa, Band 2/2. VEB Gustav Fischer Verlag: Jena, 596 p.

Krammer, K. and Lange-Bertalot, H. (1991a). Bacillariophyceae, 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In Ettl H., Gerloff J., Heynig H. and Mollenhauer D. (eds) Süsswasserflora von Mitteleuropa, Band 2/3. Gustav Fischer Verlag: Stuttgart, Jena, 576 p.

Krammer, K. and Lange-Bertalot, H. (1991b). Bacillariophyceae, 4. Teil: Achnanthaceae, Kritische Ergänzungen zu Navicula (Lineolatae) und Gomphonema, Gesamtliteraturverzeichnis Teil 1-4. In Ettl H., Gärtner G., Gerloff J., Heynig H. and Mollenhauer D. (eds) Süsswasserflora von Mitteleuropa, Band 2/4. Gustav Fischer Verlag: Stuttgart, Jena, 437 p.

Lan, T.T.N., Ngo, Q.L. and Nguyen, T.T.B. (2013). Personal exposure to benzene of selected population groups and impact of commuting modes in Ho Chi Minh, Vietnam. Environ. Pollut., 175: 56-63.

Lam, N.V.T. and Vilas, N. (2015). Assessment of vulnerabilities to climate change for urban water and wastewater infrastructure management: Case study in Dong Nai river basin, Vietnam. Environ. Dev., 16: 119-137.

Le, T.M.T, Dan, N.P., Tuc, D.Q., Ngo, H.H., Lan-Chi, D.H. (2016). Presence of e-EDCs in surface water and effluents of pollution sources in Sai Gon and Dong Nai river basin. Sustain. Environ. Res. 26(1): 20-27.

Lenoir, A. and Coste, M., (1996). Development of a practical diatom index of overall water quality applicable to the French national water board network. In: B.A. Whitton and E. Rott (Eds.), Use of algae for monitoring rivers II, Institut fur Botanik. Univ Innsbruck, Innsbruck. 29-43.

Leps, J. and Smilauer, P. (2003). Multivariate analysis of ecological data using CANOCO, Cambridge University Press.

Liu, S., Xie, G., Wang, L., Cottenie, K., Liu, D. and Wang, B. (2016). Different roles of environmental variables and spatial factors in structuring stream benthic diatom and macroinvertebrate in Yangtze River Delta, China. Ecol. Indic., 61(2), 602-611.

Lund, J.W.G., Kipling, C. and Cren, E.D.L. (1958). The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. Hydrobiologia, 11(2), 143-170.

Metzeltin, D. and Lange-Bertalot, H. (1998). Tropical Diatoms of the South America I. Iconographia Diatomologica 5. A.R.G. Gantner Verlag K.G. Koenigstein, 695 p.

Metzeltin, D. and Lange-Bertalot, H. (2002). Diatoms from the "Island Continent" Madagascar. Iconographia Diatomologica 11. A.R.G. Gantner Verlag K.G. Koenigstein, 286 p.

Metzeltin, D. and Lange-Bertalot, H. (2007). Tropical Diatoms of the South America II. Iconographia Diatomologica 18: A.R.G. Gantner Verlag K.G. Koenigstein, 877 p.

Ott, W.R. (1978). Water Quality Index, A Survey of Indices used in the United States, Environmental Protection Agency, Washington D.C, EPA-600/4-78-005.

Pham, T.L. (2016). The seasonal and spatial variations of phytoplankton community and their correlation with environmental factors in the Saigon River, Vietnam. J. Sci. Tech., Industrial University of Ho Chi Minh city, 23(1), 55-64

Potapova, M. and Charles, D.F. (2007). Diatom metrics for monitoring eutrophication in rivers of the United States. Ecol. Indic., 7(1), 48-70.

Resende, P.C., Resende, P., Pardal, M., Almeida, S. and Azeiteiro, U. (2010). Use of biological indicators to assess water quality of the Ul River (Portugal). Environ. Monit. Assess., 170(1), 535-544.

Renberg, I. (1990). A procedure for preparing large sets of diatom slides from sediment cores. J. Paleolimnol., 4(1), 87-90.

Reynolds C.S. (2006) The ecology of phytoplankton. Cambridge University Press, 551 pp.

Rumrich, U., Lange–Bertalot, H. and Rumrich, M. (2000). Diatoms of the Andes: from Venezuela to Patagonia/Tierra del Fuego, Iconographia Diatomologica 9, 649 p.

Stevenson, R.J., Pan, Y., Manoylov, K.M., Parker, C.A., Larsen, D.P. and Herlihy, A.T. (2008). Development of diatom indicators of ecological conditions for streams of the western US. J. N. Am. Benthol. Soc., 27(4), 1000-1016.

Szulc, B. and Katarzyna, S. (2013). The use of the Biological Diatom Index (BDI) for the assessment of water quality in the Pilica River, Poland. Oceanol. Hydrobiol. Stud., 42(2), 188-194.

Thai, H.T. (2011). Assessment of climate change impacts on flooding in the downstream of the Dong Nai River. VN J. Sci., Earth Sci., 27, 25-31.

Tan, X., Sheldon, F., Bunn, S.E. and Zhang, Q. (2013). Using diatom indices for water quality assessment in a subtropical river, China. Environ. Sci. Pollut. Res., 20(6), 4164-4175.

Varol, S. and Davraz, A. (2015). Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). Environ. Earth Sci., 73(4), 1725-1744.

Wetzel, R.G. and Likens, G.E. (2000). Limnological analyses. Springer, New York, 382 p.