Vietnam Journal of Agricultural Sciences

ISSN 2588-1299

VJAS 2021; 4(4): 1229-1240
https://doi.org/10.31817/vjas.2021.4.4.03

Water Quality Assessment and Eutrophic Classification of Hanoi Lakes Using Different Indices

Nguyen Thi Thu Ha[1], Dinh Tien Dzung[2], Ho Thi Thuy Hang[1], Trinh Quang Huy[1] & Nguyen Ngoc Tu[1]

[1]Faculty of Natural Resources and Environment, Vietnam National University of Agriculture, Hanoi 131000, Vietnam
[2]Center for Analysis and Transfer of Environmental Technology, Institute of Agricultural Environment, Hanoi 130760, Vietnam

Abstract

The trophic levels in urban lakes are typically based on the forms of nutrition and phytoplankton communities in the lakes. In this study, comparisons between eutrophication indices and the water quality index (VN-WQI) were used to classify the water quality of 20 lakes in Hanoi, Vietnam. The results showed that the water quality ranged from very bad to poor. High levels of the eutrophication phenomenon in terms of total N and P were observed in all sampling sites. Cyanobacteria was the dominate algae phylum making up 65.78% of the total population, whereas Chlorophyta (including 19 genera) was the most diverse phylum. The density of the algae was 5,000-14,000 cells mL^{-1} and the chlorophyll-a level was 10-40 µg L^{-1}. Based on this information, the water quality levels in the lakes were classified from eutrophic to polytrophic. The Trophic Status Index (TSI) and Trophic Level Index (TLI) values were 66.9-86.0 and 54.4-76.0 points, respectively, corresponding from eutrophic to extreme-trophic. Classifications based on algae community structure indices were from oligotrophic to eutrophic, similar and consistent with the TLI classifications. According to the results in this study, the TLI was found to be more accurate and precise than the other indices. It is recommended that the TLI is an applicable tool to classify eutrophication in urban lakes.

Keywords

Phytoplankton, Hanoi lakes, Water Quality Index, Eutrophication Index

Introduction

Eutrophication in closed lakes had been widely studied all over the world since the nineteenth century. Some studies have shown that the most important autotrophic explosions are usually created by phytoplankton species (Scholten *et al.*, 2005; Ferreira *et al.*, 2011).

Received: November 5, 2020
Accepted: December 8, 2021

Correspondence to
nguyenngoctu3@vnua.edu.vn

As for the nutritional components, depending on the proportions of the ingredients, N and P compounds are the factors limiting algal growth on the one hand but controlling the eutrophication levels on other hand (Scholten *et al.*, 2005). According to the Center for Environmental and Community Research (CECR, 2015), most of the 112 lakes in Hanoi are under bad hygienic conditions because of receiving domestic wastewater and urban runoff. This may lead to serious pollution of organic matter, increased turbidity, loss of nutrients, increased numbers of microorganisms, and the depletion of dissolved oxygen (DO) in some lakes such as Thien Quang, Truc Bach, and Thanh Nhan. These poor hygienic conditions can result in a series of environmental problems such as unpleasant odors and harmful algae blooms (HABs) leading to the death of fish in some lakes (West Lake, Van Quan Lake, Hoan Kiem Lake, etc.). The pollution causes negative impacts on the aesthetics of the landscape and ecological value of these lakes (Scholten *et al.*, 2005).

Recent studies have developed a range of different methods such as the Trophic Status Index (TSI), Trophic Level Index (TLI), and Algae Community Indices to assess water quality and eutrophic classifications. Methods for evaluating eutrophication based on chlorophyll-a (Chl-a) content and the density of algae and plants were determined as “direct effects” or “main symptoms” techniques. These methods are suitable for applying in the early stages of eutrophication. Techniques such as "indirect effects" or "side symptoms" based on DO levels, biodiversity loss, and harmful algae blooms (HABs) have also been used to indicate the effects of eutrophication on ecosystems. Other methods, for example, TSI using only chlorophyll-a, DO, or nutrients, have not been able to indicate the possibility of the HAB phenomenon (Ferreira *et al.*, 2011) as well as the changes in the structure of eutrophication in ecosystems (Bricker *et al.*, 2008). In addition, weights indicators or principal component analysis techniques for monitoring eutrophication levels have also been applied by some studies recently (Huo *et al.*, 2013; Liu *et al.*, 2019).

In terms of water quality assessment, the Water Quality Index (WQI) is considered to be an effective tool to monitoring surface water quality. This method also allows the use of integrated techniques to convert extensive water quality data into a single value or index. Globally, the WQI has been widely applied to evaluate water quality based on local water quality criteria. Since its development in the 1960s, it has been become a popular tool due to its generalized structure and ease-of-use (Uddin *et al.*, 2021). In Vietnam, the WQI is recognized as a useful tool to assess the quality of the surface water of drinking water supply sources since 2011. Since then, the VN-WQI has been applied for inland surface water assessment under the guidance of Decision N1460/2019/QD-TCMT.

Normally, to assess the eutrophication level in a lake, it is not only the results of environmental monitoring based on nutrient concentrations but also the possibility of HABs. Therefore, the assessment of algae density (either the density of cells or chlorophyll-a concentration) is considered an effective method for assessing eutrophication levels in some research (Wetzel, 2001; Ferreira *et al.*, 2011). The algae community structure index is also used in some studies to classify the level of lake eutrophication using the scale of Tomachevski (1975; Nguyen Van Tuyen, 2003; Nguyen Thi Thu Ha *et al.*, 2018). These indices have been applied in Hanoi lakes and have shown quite satisfactory results (Nguyen Thi Bich Ngoc *et al.*, 2017; Ta Dang Thuan, 2019). Thus, the eutrophication level or its severity in the water source are highly dependent on the dominant algae compositions in the water body (Dang Ngoc Thanh *et al.*, 2002). Therefore, different indices were applied to assess the water quality and eutrophication levels in several lakes in Hanoi in this study to compare which is the most useful and competitive.

Materials and Methods

Research area

Twenty representative lakes in Hanoi were selected for this study to assess their water quality and to classify their level of eutrophication. These lakes have a total area of 8,959,000m^2 with a total volume of about 10,800,000m^3 (CECR, 2015). The sampling locations of these lakes are shown in **Figure 1** and some properties of the lakes are shown in **Table 1**.

Methods

Water quality assessment

Water samples were collected according to the guidance of ISO 5667: 2006 - part 1, part 3, and part 4 with 3-9 sites around each lake depending on their area and shape. The samples were collected at a distance of at least 3 meters from the shore, at a depth of 10-15 centimeters from the surface. Samples were analyzed for the Secchi depth (SD), pH, DO, total suspended solids (TSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), amount of orthophosphate as phosphorus ($P\text{-}PO_4^{3-}$), amount of ammonium as nitrogen ($N\text{-}NH_4^+$), amount of nitrate as nitrogen ($N\text{-}NO_3^-$), and total coliforms according to the methods guided by the National Technical Regulations 08-MT: 2015/MONRE. The water samples were collected in February, April, and June, 2020. The VN-WQI under Decision 1460/2019/QD-TCMT was used to assess the water quality. In addition, the chlorophyll-a content was directly measured in the water by using hand-held meters (HACH BW680).

Phytoplankton community structure evaluation

Phytoplankton (algae) samples were collected by a plankton net (300 holes cm^{-2}) according to the WWSEM 10300 instructions for phytoplankton, and then preserved in 5-10% formalin solution (Federation & Association, 2017). The genus composition of the phytoplankton was determined through a classification key by the microscopy method with 40-100 times magnification. Algae density was determined by a plankton counting chamber with 10-40 times magnification of an objective microscopy (Duong Duc Tien & Vo Hanh, 1997; Nguyen Van Tuyen, 2003).

Eutrophication classification

To classify the water trophic level, the parameters of SD, TN, TP, and chlorophyll-a, and the methods of Trophic Status Index –TSI (Carlson, 1977), Trophic Level Index – TLI (Huo *et al.*, 2013) as well as algae community structure index (Nguyen Van Tuyen, 2003) were used. The classification of eutrophication (**Table 2**) was determined according to the following formulas:

TSI = [TSI (SD) + TSI (Chl-a) + TSI (TP) + TSI (TN)]/4

where

$TSI\ (Chl\text{-}a) = 9.81 \ln(Chl\text{-}a) + 30.6$

$TSI\ (TP) = 14.42 \ln(TP) + 4.15$

$TSI\ (TN) = 14.43 \ln(TN) + 54.45$

TLI = 0.2663 TLI (Chl-a) + 0.1879 TLI (TP) + 0.1790 TLI (TN) + 0.1834 TLI (COD)

where

$TLI\ (Chl\text{-}a) = 10\ [2.5 + 1.086 \ln(Chl\text{-}a)]$

$TLI\ (TP) = 10\ [9.436 + 1.624 \ln(TP)]$

$TLI\ (TN) = 10\ [5.453 + 1.694 \ln(TN)]$

$TLI\ (COD) = 10\ [0.109 + 2.661 \ln(COD)]$

Cyanobacteria index (CyI) = Cy/D

Chlorophyta index (ChI) = Ch/D

Diatom index (DI) = C/P

Euglenophyta index (EI) = E/(Cy + Ch)

Algae index (AI) = (Cy + Ch + C + E)/E

where:

Ch are the Chlorococcales

Cy are the Cyanobacteria

C are the Centrales

P are the Pennales

E are the Euglenophyta

D are the Desmidiaceae

Data analysis

The data were evaluated for each lake (mean of variation among sampling points during a sampling period) using minimum, maximum,

Table 1. Properties of the Hanoi lakes sampled in this study

No.	Lake name	Site (district)	Area (m^2)	Depth (m)	Number of samples
1	Giang Vo	Ba Dinh	60,000	2.5-3	3
2	Hai Ba Trung		8,000	1.5-2.5	3
3	Truc Bach		90,000	1.5-2	5
4	Can		77,000	2.5-3	5
5	Van Chuong	Dong Da	51,000	1.5-3	3
6	Ba Mau		46,000	2.5-3	3
7	Quynh		65,000	1.5-2	3
8	Dong Da		150,000	3-5	5
9	Cau Tinh	Gia Lam	32,000	2-4	3
10	Van Quan	Ha Dong	17,000	1.5-3	3
11	Thanh Nhan	Hai Ba Trung	9,000	2-4	3
12	Thien Quang		59,000	3-4	3
13	Hoan Kiem	Hoan Kiem	120,000	1.5-2	5
14	Linh Dam	Hoang Mai	730,000	2-3	5
15	Yen So		1,370,000	1.5-2.5	7
16	Ben	Long Bien	18,000	2-4	3
17	Tai Trau		40,000	2-4	3
18	Kim Quan		63,000	3-4	5
19	Gia Lam Park		35,000	1.5-2.5	3
20	West	Tay Ho	5,300,000	2.5-4	9

Figure 1. Locations of the water sample sites
Source: Google Earth Pro. from Garmin

Table 2. Scale of eutrophication by nutrients, chlorophyll-a, algae density, TSI, TLI, and algae community structure index

Trophic level	TSI*/ TLI**	Chl-a* ($\mu g\ L^{-1}$)	SD* (m)	TP* ($mg\ L^{-1}$)	TN** ($mg\ L^{-1}$)	Algae density ($cells\ mL^{-1}$) ***	Structure index***				
							CyI	ChI	DI	EI	AI
Oligotrophic	<30	<0.95	>8	<0.006	<0.1	50	0.1-0.3	<1	0-0.2	0-0.1	<1
Oligo-mesotrophic	30-40	0.95-2.6	4-8	0.006-0.012	0.1-0.3	50-100	-	-	-	-	-
Mesotrophic	40-50	2.6-7.3	2-4	0.012-0.024	0.3-0.5	100-1000	-	-	-	-	-
Eutrophic	50-60	7.3-20	1-2	0.024-0.048	0.5-1.2	1000-10,000	0.3-3.0	1-2.5	0.2-3.0	0.1-0.4	1-5
Polytrophic	60-70	20-56	0.5-1	0.048-0.096	1.2-2.3	10,000-50,000	0.5-5.0	2.5-3.1	0.4-6.0	0.4-0.5	5-20
Hypertrophic	70-80	56-155	0.25-0.5	0.096-0.192	2.3-9.0	50,000-500,000	>5.0	>5	>6	>1	>20
Extremetrophic	>80	>155	<0.25	0.192-384	>9.0	>500,000	-	-	-	-	-

*Source: * (Carlson, 1977); ** (Huo et al., 2013); and *** (Nguyen Van Tuyen, 2003)*

mean, and standard deviation values. Correlation analysis in pairs was used to evaluate the relationship between the water quality index (VN-WQI) and eutrophication indices, and between different eutrophication indices:

$$Z = \frac{|R|}{\sqrt{1-R^2}}\sqrt{n-2}$$

Where: $R = \frac{1}{n}\sum_{i=1}^{1}\left(\frac{x_i-\bar{x}}{S_x}\right)\left(\frac{y_{i-\bar{y}}}{S_y}\right)$; n = number of samples

In addition, a one-way ANOVA test and Fisher's Least Significant Difference (LSD) post hoc paired comparisons were used to examine whether values on the eutrophication subclasses were significantly different.

Results and Discussion

Classification of eutrophication based on nutrient concentrations

During the monitoring period from February to June, 2020, a total of 82 water samples were taken from the 20 lakes, and the average results of the water quality parameters are shown in **Table 3**. The water quality results showed that most of the lakes were contaminated or polluted by organic substances, nutrients, TSS, and DO depletion. Seven of the 20 lakes (35%) exceeded the regulations in the National Technical Regulation 08-MT:2015/MONRE on surface water quality in terms COD, BOD_5, and $N\text{-}NH_4^+$. Additionally, a high suspended solids concentration in the lakes (23-64 $mg\ L^{-1}$) measured by the Secchi disc method was also a parameter showing the low water quality in the monitored lakes.

The Vietnam water quality index (VN-WQI) in the lakes ranged widely from 13.5 to 70.5 points, 20% of which were determined as polluted (0-25 points), namely the lakes of Van Chuong, Van Quan, Kim Quan, and Thien Quang; another 25% of the total were rated as having low quality water (25-50 points), namely the lakes of Hoan Kiem, Yen So, Ben, Thanh Nhan, and Gia Lam Park; the remaining 55% had a poor water quality level (50-75 points); and none of the case lakes had good quality water (75-100 points). These results were compliant with other research at the same lakes (CECR, 2015; Nguyen Thi Bich Ngoc *et al.*, 2017) or in rivers (Cao Truong Son *et al.*, 2020) in Vietnam.

Regarding the eutrophication levels, the results of the eutrophication classification by the TN-based indexes were all at high eutrophication levels. The eutrophic lakes in terms of N were also polluted in terms of TP, organic substances, TSS, ammonium, and phosphate. The optimum N:P ratio for algae growth is 16:1 (Scholten *et al.*, 2005), which means if this ratio is greater than 16, the phosphorus content would be the limiting

Table 3. Water quality parameters and WQI values

Lake name	SD	pH	DO	$P\text{-}PO_4^{3}$	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	COD	BOD	TSS	TN	TP	Coliform	WQI
	m	-	mg L^{-1}									MPN 100mL^{-1}	
Giang Vo	0.80	7.56	4.17	0.036	0.68	0.49	21.5	15.7	24.7	2.32	0.25	4100	64.1
Hai Ba Trung	0.90	7.54	3.13	0.025	0.75	3.25	13.5	10.8	25.1	3.64	0.16	3200	60.4
Truc Bach	0.58	6.79	4.55	0.032	0.58	0.26	24.5	17.1	34.7	2.76	0.28	4600	70.5
Can	0.46	7.29	4.55	0.371	0.67	0.28	26.4	16.1	35.4	2.17	0.64	3500	66.4
Van Chuong	0.90	6.89	4.01	0.465	16.34	0.57	32.1	41.7	23.2	13.7	0.79	7200	17.9
Ba Mau	0.72	7.34	3.45	0.022	0.65	0.42	29.5	20.7	28	2.77	0.32	5200	60.2
Quynh	0.70	7.64	3.05	0.021	0.67	1.55	23	18.2	28.3	3.26	0.25	4500	61.8
Dong Da	0.60	7.12	5.14	0.038	0.62	0.31	24.3	18.3	32.2	2.82	0.28	5050	69.1
Cau Tinh	0.70	7.63	3.35	0.021	0.46	0.35	42.1	31.6	29.4	2.66	0.44	6800	53.9
Van Quan	0.32	7.45	0.59	0.027	19.76	0.21	89.5	77.3	51.2	18.9	0.92	6300	13.5
Thanh Nhan	0.50	6.94	1.48	0.021	2.17	4.37	41.5	29.7	40.1	7.1	0.44	9800	40.0
Thien Quang	0.44	7.74	0.99	0.121	12.44	0.85	43	42.6	45.8	11.7	0.55	7500	20.5
Hoan Kiem	0.64	8.39	1.45	0.031	0.17	0.14	93.5	60.2	28.8	6.44	0.97	2400	38.0
Linh Dam	0.54	7.24	2.58	0.011	0.41	2.94	23	17.9	29.6	3.99	0.24	4800	66.2
Yen So	0.70	8.04	1.74	0.043	6.99	5.43	18.5	12.9	30.8	9.1	0.23	2500	32.6
Ben	0.60	6.87	4.02	0.423	2.14	4.22	32.6	39.1	32.2	14.4	0.75	4200	39.1
Tai Trau	0.54	7.12	1.22	0.032	0.51	0.46	46	21.4	36.7	4.05	0.49	2100	51.4
Kim Quan	0.36	7.24	0.67	0.442	16.99	0.54	77.5	67.4	63.7	16.6	1.22	9100	14.5
Gia Lam Park	0.30	6.76	2.44	0.311	0.72	0.25	34.2	51.2	64.4	5.26	0.65	8200	45.7
West	0.64	7.62	2.97	0.065	0.71	0.22	45	25.8	32	3.19	0.52	6500	53.6
NTR 08-MT		5.5-9	4	0.3	0.9	10	30	15	50	-	-	7500	-

factor for the growth of algae and vice versa. Thus, the P content played an important role in the growth of algae in the lakes of Tai Trau, Van Quan, Thanh Nhan, Truc Bach, and Yen So. Meanwhile, the N content regulated the growth rate of algae in the lakes of Van Chuong, Linh Dam, Thien Quang, and Gia Lam Park. Based on the classifications in **Table 2**, all of the lakes in this study were evaluated as having a high eutrophication level whether by TN, TP, or both of them.

Classification of eutrophication based on algae composition and density

In the 82 sampling locations, there appeared 60 genera of algae belonging to five phyla: Cyanobacteria with 14 genera (popular genera included *Merismopedia*, *Anphanocapsa*, *Microcystis*, *Oscillatoria*, and *Lyngbia*), Chlorophyta with 19 genera (popular genera included *Scenedesmus*, *Chlorella*, *Pediastrum*, and *Ankistrodesmus*), Bacillariophyta with 15 genera (popular genera included *Naviculla*, *Nitzschia*, and *Cyclotella*), Euglenophyta with 5 genera (popular genera included *Euglena* and *Phacus*), and Pyrrophyta with 7 genera. In which, Chlorophyta was the phylum with the highest level of biodiversity and Cyanobacteria was the phylum with the largest predominance, reaching 65.78% of the total density.

In each lake, only 15-38 genera were found in all the surveyed sites, of which the lakes of Yen So, Thanh Nhan, Hai Ba Trung, and Giang Vo had relative diverse algae appearances. In comparisons among the lakes, it was shown that Van Quan, Ben, Thanh Nhan, and Tai Trau were dominated by Cyanobacteria while the lakes of Dong Da, Truc Bach, and West had an abundant

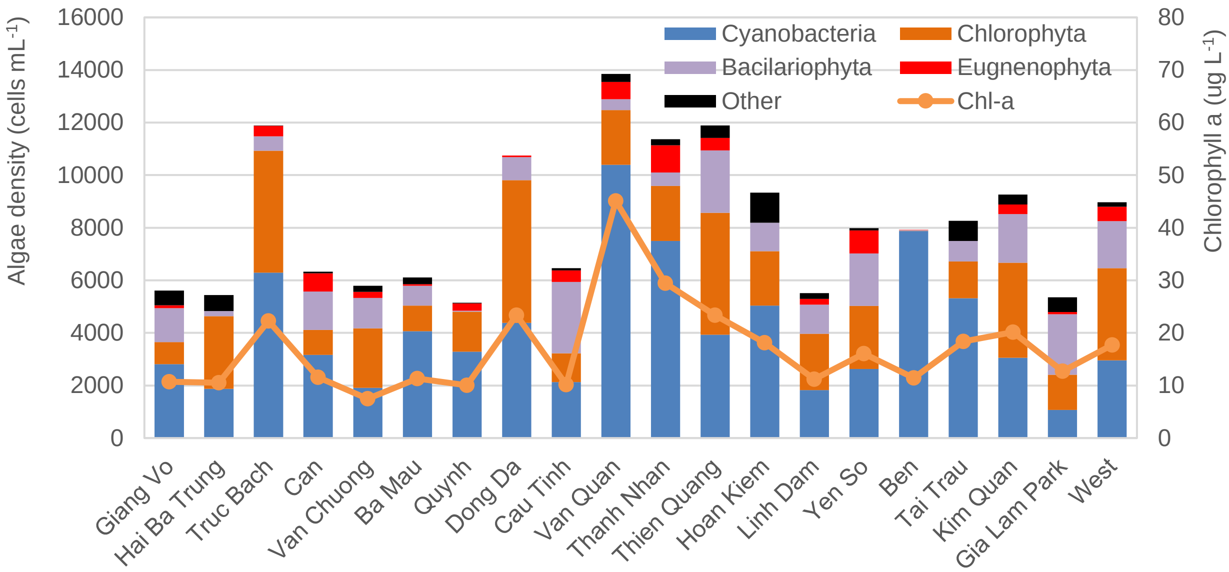

Figure 2. Average chlorophyll-a, algae composition, and algae density in lakes

Chlorphyta composition. On the contrary, the lakes of Gia Lam Park, Cau Tinh, and Thien Quang had a significant proportion of Bacillariophyta (**Figure 2**). Meanwhile, across the survey locations, there were significant differences in density but fewer differences in genus composition. This was considered as due to the influence of different currents and winds among the lakes.

In this study, based on the chlorophyll-a content and algae density criteria (shown in **Table 2**), the number of lakes classified as eutrophic and polytrophic was (70%) and (30%), respectively. The lakes of Van Quan, Thien Quang, Truc Bach, Thanh Nhan, Huu Tiep, and Dong Da had high algae densities (more than 10,000 cells mL^{-1}, with the maximum value of 14,000 cells mL^{-1}) and were classified as polytrophic. The other lakes of Quynh, Gia Lam Park, Hai Ba Trung, and Giang Vo were classified as eutrophic because their algae densities were lower, reaching only 5,000 cells mL^{-1}. The concentrations of chlorophyll-a remained stable, around 10-40 g L^{-1}, during the study period from February to June, 2020 (**Figure 2**). These results were similar to the results in lakes that received the same agricultural and domestic wastewater (Ta Dang Thuan, 2019).

Normally, a eutrophication classification may be classified by algae density, by nutrient concentration, or by both factors. Some lakes with high algae densities, for example Van Quan, Thien Quang, Truc Bach, and Thanh Nhan, also had high nutrient concentrations. But this correlation is not always true. This was probably due to the close relationship between nutrients and algae in two trends: (1) high nutrition promotes growth in algae biomasses, and (2) algae growth in the water reduces the concentration of pollutants (Scholten *et al.*, 2005). In contrast to the above results, the lakes of Linh Dam, Ba Mau, and Gia Lam Park had very high nutrient concentrations, but lower algal densities. According to other points of view, the criteria based on algae density was found to be more accurate than nutrition content such as N and P (Carlson, 1977; Vollenweider *et al.*, 1998).

Classification based on eutrophication and structure indices

This study used the TSI, TLI, and algae community structure indices to assess the trophic levels of 20 lakes. The detailed results of the indices are shown in **Table 4**.

The TSI values varied widely between 66.9-86.0, corresponding to the levels of polytrophic to extreme trophic, of which the highest eutrophication levels were indicated in Thanh Nhan, Gia Lam Park, and Van Quan lakes. The TLI values fluctuated between 54.4-76.0, corresponding to the levels of eutrophic to

Table 4. Eutrophication and structure index values, and classification of eutrophication levels

No.	Lake name	TSI	TLI	Structure indices					Trophic level
				CyI	ChI	DI	EI	AI	
1	Giang Vo	66.9	54.5	4	2	1	0		Oligo-Polytrophic
2	Hai Ba Trung	69.0	55.9		1	0.3			Eu-Polytrophic
3	Truc Bach	68.3	54.4			1	0.2	8	Eu-Polytrophic
4	Can	72.2	58.4		2	1	1		Eu-Hypertrophic
5	Van Chuong	76.1	64.3				0.1		Eu-Hypertrophic
6	Ba Mau	68.7	56.0			1	0.2	8	Eu-Polytrophic
7	Quynh	68.9	55.9		1	0.3	0		Oligo-Polytrophic
8	Dong Da	70.7	59.6			0.5	0.2	8	Eu-Hypertrophic
9	Cau Tinh	69.8	59.8			0.2	0	5	Oligo-Polytrophic
10	Van Quan	86.0	76.0			1	0.3	6	Eu-Extremetrophic
11	Thanh Nhan	80.2	68.1			0.5	0		Oligo-Extremetrophic
12	Thien Quang	76.5	65.1				0.1	0.8	Oligo-Hypertrophic
13	Hoan Kiem	77.5	70.4	2	1	0.3		5.5	Eu-Hypertrophic
14	Linh Dam	70.2	56.5	4	4	1	0.1	11	Eu-Hypertrophic
15	Yen So	72.9	58.8	4	4	0.3	0.6	2.8	Eu-Hypertrophic
16	Ben	77.0	62.4	4	2	0.5	0.1	3	Eu-Hypertrophic
17	Tai Trau	79.8	67.0	2	1	1			Eu-Hypertrophic
18	Kim Quan	74.3	63.8	4		1	0.2		Eu-Hypertrophic
19	Gia Lam Park	83.0	72.0				0.2	6	Eu-Extremetrophic
20	West	72.7	62.7	4	1	0.3	0.1	12	Eu-Hypertrophic

hypertrophic, in which the lakes mentioned previously, and Tai Trau and Hoan Kiem lakes were identified as having the highest eutrophication levels (but one level lower than using TSI). In a comparison between these two indices, it was found that significant differences were mainly caused by the weights of the sub-indices, which emphasized the importance of chlorophyll-a in the eutrophic assessment. The TSI results in this study were very similar to other studies (Nguyen Thi Bich Ngoc *et al.*, 2017; Ta Dang Thuan, 2019) or similar to the results using TSI or TLI indices carried out by other authors on inland water bodies all over the world (Huo *et al.*, 2013; Liu *et al.*, 2019; Lin *et al.*, 2020).

In addition, to assess the eutrophication levels of the lakes in Hanoi, this study also applied the algae density and algae community structure ratio (according to the formulas in section 2.2.3). Due to the lack of Desmidiaceae (not found in 14 lakes) or Euglenophyta (not found in 3 lakes), the evaluation results of the structure index were not calculated. However, the results of the algae community structure index also showed that most of the lakes were classified in the levels of eutrophic to polytrophic (see **Table 4**), which was consistent with the classifications of the algae densities and nutrient concentrations (calculated based on TN or TP). As exceptions, the lakes of Giang Vo, Quynh, Cau Tinh, Nhanh Nhan, and Thien Quang had both high nutrient levels and high algae densities, but because the algae compositions were mainly Chlorophyta or Bacillariophyta, these lakes were evaluated as oligotrophic.

The results of the eutrophication classifications based on the algae community structure indices were similar in comparison with the results based on nutrient concentrations and algae densities. The classifying levels were significantly higher than the levels of eutrophication of the water in nature but were consistent with the lakes receiving urban wastewater (Dang Ngoc Thanh *et al.*, 2002; Nguyen Van Tuyen, 2003). The above results once again confirmed that the eutrophication levels were not only dependent on the algae density, but also on the main composition of the algae species, especially when a bloom occurred (Wetzel, 2001; Scholten *et al.*, 2005).

Comparison of the indices for classification of eutrophication

The results of evaluating in pairs the correlation of the nutrient concentrations and other indices showed that there was a close relationship between them. This correlation may be explained by the effects of TN and TP on the algae densities, chlorophyll-a as well as algae community structures, and vice versa with a significance level of P = 0.05 (**Table 5**). The values in **Table 5** also show that the water quality indices had a close relationship with the eutrophication indices, suggesting that the effects of the waste sources also had a higher risk of eutrophication. From **Table 5**, it can be seen that the algae density was influenced by the TN concentration more than TP, while the Chlorophyta composition was influenced by TP. These results can be applied to determine the roles of nutrients and algae composition in the eutrophication levels in Hanoi lakes or other water bodies having the same conditions.

Looking at the water quality indicated by the different indices (**Figure 3**), it was found that depending on the different eutrophication classification methods, the results mainly fluctuated between eutrophic and polytrophic. Most of the lakes in this study were classified at the polytrophic level if using the indices of TN, TP, Secchi depth, cyanobacteria index, and algae index. But the results could indicate the eutrophic level if using other information such as chlorophyll-a content, algae density, TLI, Chlorophyta index, Bacillariophyta index, and Euglenophyta index. If nutrient richness was considered as the primary manifestation of eutrophication, the algal blooms were the real manifestations of eutrophication according to the above points of view, most of which were classified at the eutrophic level. Thus, in terms of the evaluation range, TLI can be considered as a consistent index with the indices of algae density and community structure.

Evaluations of the significant differences among sub-classes of different eutrophication levels according to TLI are presented in **Table 5**. The results showed that the eutrophic and

Table 5. Correlation matrix: pairwise correlation coefficients between indices

	TN	TP	Chl-a	Density	TSI	TLI	WQI	CyI	ChI	DI	EI	AI
TN	1	0.72**	0.48*	0.29*	0.76**	0.81**	-0.71**	-0.67**	0.04	0.18	-0.10	-0.29*
TP		1	0.22*	0.10	0.83**	0.87**	-0.63**	-0.79**	-0.49*	0.00	0.01	-0.19
Chl-a			1	0.91**	0.40*	0.59**	-0.27*	-0.45*	-0.17	0.21	-0.04	-0.08
Density				1	0.29*	0.47*	-0.37*	-0.38*	-0.18	0.13	-0.14	-0.19
TSI					1	0.83**	-0.50*	-0.70**	-0.19	0.16	-0.08	-0.36*
TLI						1	-0.65**	-0.78**	-0.37*	-0.02	-0.16	-0.27*
WQI							1	0.52**	-0.12	0.05	0.15	0.48*
CyI								1	0.58**	0.04	0.22*	0.17
ChI									1	0.27*	0.07	-0.14
DI										1	0.10	0.35*
EI											1	-0.33*
AI												1

Note: Correlations are statistically significant at P< 0.05 (*) and P< 0.01 (**) with n = 82 samples.

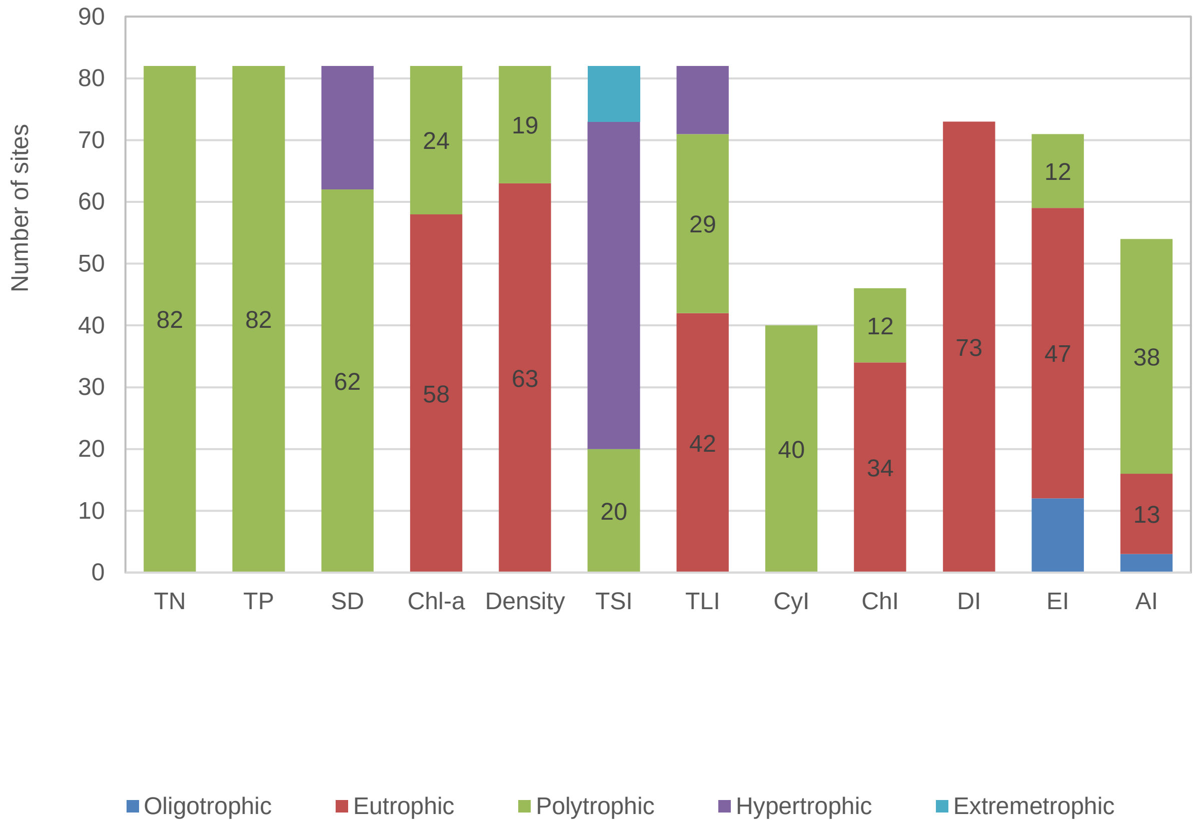

Figure 3. Classified eutrophication levels of the sampling sites

Table 6. Fisher's LSD post hoc paired comparisons of three trophic levels

Indicators	Eutrophic (n = 42)	Polytrophic (n = 29)	Hypertrophic (n = 11)
Lake depth (m)	2.32^{a}	2.76^{a}	2.07^{a}
Secchi depth (m)	0.67^{a}	0.56^{b}	0.44^{c}
pH	7.42^{a}	7.13^{a}	7.69^{a}
DO (mg L^{-1})	3.57^{a}	2.45^{a}	0.90^{b}
BOD (mg L^{-1})	17.93^{a}	35.92^{ab}	68.30^{b}
TSS (mg L^{-1})	29.82^{a}	39.20^{ab}	47.90^{b}
TN (mg L^{-1})	3.55^{a}	8.49^{b}	13.98^{c}
TP (mg L^{-1})	0.31^{a}	0.60^{ab}	1.04^{b}
Coliform (MPN 100 mL^{-1})	4425^{a}	6500^{b}	5933^{b}
Chlorophyll a (µg L^{-1})	13.72^{a}	18.28^{ab}	25.30^{b}
Algae density (cells mL^{-1})	$7,120^{a}$	$9,067^{b}$	$9,511^{b}$
WQI	49.73^{a}	48.22^{a}	41.89^{b}

Note: Means within rows with differing superscripts are significantly different at the $P< 0.05$ level based on Fisher's LSD post hoc paired comparisons.

polytrophic ratings were not dependent on the depth of the lake or pH value. However, there were significant differences in the concentrations of TSS, BOD, TN, TP, total coliform, and algae density as well as the WQI among the sampling locations (**Table 6**).

Conclusions

The 20 selected lakes in Hanoi were directly affected by wastewater and urban runoff, causing the water quality to deteriorate strongly with symptoms such as increased organic substrates, nitrogen and phosphorus concentrations, turbidity, and dissolved oxygen depletion. In these study sites, Cyanobacteria was the dominate algal phylum making up 65.78% of the total population whereas Chlorophyta (19 genera) was the most diverse phylum. The density of algae was 5,000-14,000 cells mL^{-1}, chlorophyll-a level was 10-40 $\mu g\ L^{-1}$, and the lakes ranged from eutrophic to polytrophic. The TSI and TLI values were 66.9-86.0 and 54.4-76.0 points, respectively, corresponding from eutrophic to extreme-trophic. Classifications based on the algae community structure indices were from oligotrophic to eutrophic, similar and consistent with the TLI classification. Accordingly, the TLI was determined to be an accurate and precise index, applicable to the classification of eutrophication in urban lakes.

Acknowledgments

This research was funded by Vietnam National University of Agriculture (Grant number: T2020-04-22).

References

Bricker S. B., Longstaff B., Dennison W., Jones A., Boicourt K., Wicks C. & Woerner J. (2008). Effects of nutrient enrichment in the nation's estuaries: a decade of change. Harmful Algae. 8(1): 21-32. DOI: 10.1016/j.hal.2008.08.028.

Carlson R. E. (1977). A trophic state index for lakes. Limnology and oceanography. 22(2): 361-369. DOI: 10.4319/lo.1977.22.2.0361.

CECR (2015). Hanoi Lakes report 2015. Women Publishing House. Hanoi. 399 (in Vietnamese).

Federation W. E. & Association A. P. H. (2017). Standard methods for the examination of water and wastewater 23rd ed. American Public Health Association (APHA): Washington DC, USA..

Ferreira J. G., Andersen J. H., Borja A., Bricker S. B., Camp J., Da Silva M. C., Garcés E., Heiskanen A.-S., Humborg C. & Ignatiades L. (2011). Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science. 93(2): 117-131. DOI: 10.1016/j.ecss.2011.03.014.

General Department of Standards, Metrology and Quality (2011). TCVN 6663: 2011 - ISO 5667:2996 - Water quality - Sampling (in Vietnamese).

General Department of Environment (2019). Decision No. 1460/2019/QD-TCMT - Technical guidelines for calculation and publication of Vietnam's water quality index (VN_WQI) (in Vietnamese).

Nguyen Thi Thu Ha, Pham Gia Thang, Le Thu Phuong, Dinh Tien Dzung & Do Phuong Chi (2018). Using phytoplankton community structure index to classify eutrophication level on Hanoi lakes. Journal of Agricultural Science and Technology No. 6 (91): 111-117 (in Vietnamese).

Huo S., Ma C., Xi B., Su J., Zan F., Ji D. & He Z. (2013). Establishing eutrophication assessment standards for four lake regions, China. Journal of Environmental Sciences. 25(10): 2014-2022. DOI: 10.1016/S1001-0742(12)60250-2.

Lang N. A. (2015). Building a group of quality indicators to evaluate and classify eutrophication status in Hanoi lakes. Master thesis. Hanoi University of Technology (in Vietnamese).

Liu X., Zhang G., Sun G., Wu Y. & Chen Y. (2019). Assessment of Lake water quality and eutrophication risk in an agricultural irrigation area: A case study of the Chagan Lake in Northeast China. Water. 11(11): 2380. DOI: 10.3390/w11112380.

Nguyen Thi Bich Ngoc, Vu Duy An, Le Thi Phuong Quynh, Nguyen Bich Thuy, Le Duc Nghia, Duong Thi Thuy & Ho Tu Cuong (2017). Assess the level of eutrophication of some Hanoi city lake. Journal of science and technology. 55(1): 84-92 (in Vietnamese).

Scholten M. C., Foekema E. M., Dokkum H. P., Jak R. G. & Kaag N. H. (2005). Eutrophication management and ecotoxicology. Springer Science & Business Media. New York.

Cao Truong Son, Nguyen Thi Huong Giang, Thao T. P., Nguyen Hai Nui, Nguyen Thanh Lam & Vo Huu Cong (2020). Assessment of Cau River water quality assessment using a combination of water quality and pollution indices. Journal of Water Supply: Research and Technology AQUA. 69(2): 160-172. DOI: 10.2166/aqua.2020.122.

Lin S. S., Shen S. L., Zhou A., Lyu H. M. (2020). Sustainable development and environmental restoration in Lake Erhai, China. Journal of Cleaner Production. 258. DOI: 10.1016/j.jclepro.2020.120758.

Ministry of Natural Resources and Environment - MONRE (2015). NTR 08-MT:2015/MONRE - National technical regulation on surface water quality (in Vietnamese).

Dang Ngoc Thanh, Ho Thanh Hai, Duong Duc Tien & Mai Dinh Yen (2002). Bio-aquatic freshwater studies inland Vietnam. Science and Technology Publishing House. Hanoi (in Vietnamese).

Ta Dang Thuan (2019). Analysis of seasonal variations of factors affecting algal growth in a lake in Hanoi using the eutrophication model. Journal of Irrigation Science and Environment. 64: 60-68 (in Vietnamese).

Duong Duc Tien & Vo Hanh (1997). Vietnamese freshwater algae - green algae classification (Chlorococcales). Agricultural Publishing House. Hanoi (in Vietnamese).

Nguyen Van Tuyen (2003). Algae biodiversity in inland waters of Vietnam-Prospects and challenges. Agricultural Publishing House. Hanoi (in Vietnamese).

Uddin M. G., Nash S. & Olbert A. I. (2021). A review of water quality index models and their use for assessing surface water quality. Ecol. Indic. 122: 107218. DOI: 10.1016/j.ecolind.2020.107218

Vollenweider R., Giovanardi F., Montanari G. & Rinaldi A. (1998). Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index. Environmetrics: The official journal of the International Environmetrics Society. 9(3): 329-357. DOI: 10.1002/(SICI)1099-095X(199805/06)9:3<329::AID-ENV308>3.0.CO;2-9

Wetzel R. G. (2001). Limnology: lake and river ecosystems. Gulf professional publishing. Elsevier Academic press. London.