

# ASSESSING SURFACE WATER QUALITY IN FRESHWATER RESERVOIRS IN AN GIANG PROVINCE, VIET NAM

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**Abstract** – *Water quality is critical for a healthy ecosystem, this study was conducted to evaluate the surface water quality in lakes in An Giang Province from 2017 to 2019. Water quality was assessed using variables of temperature, pH, dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), nitrate ( $\text{NO}_3^- - \text{N}$ ), phosphate ( $\text{PO}_4^{3-} - \text{P}$ ), ammonia ( $\text{NH}_4^+ - \text{N}$ ), and coliforms at nine locations belonging to seven reservoirs including O Tuk Sa, Thuy Liem, Soai So, Soai Chek, O Thum, O Ta Soc, and Bung Binh Thien. Water quality criteria were assessed according to the National Technical Regulation on Surface Water Quality (QCVN 08-MT: 2015/BTNMT). Cluster analysis (CA) and principal component analysis (PCA) were applied to group water quality to identify the main parameters affecting water quality in the reservoirs. The findings indicated that the water quality in the reservoirs were polluted by TSS, organic matters (DO was low, while COD and BOD were high), and microorganisms (coliforms). The PCA analysis showed that the water variables including temperature, pH, DO, TSS, COD, BOD,  $\text{NO}_3^- - \text{N}$ ,  $\text{PO}_4^{3-} - \text{P}$ ,  $\text{NO}_3^- - \text{N}$ , and coliforms significantly influenced the surface of the water in the reservoirs. It is necessary to investigate pollution sources to propose appropriate solutions to treat and maintain the water quality in the reservoirs of An Giang Province.*

**Keywords:** *An Giang Province, coliforms, lakes, organic pollution, principal component analysis, water quality.*

## I. INTRODUCTION

A system of lakes is one of the main features of Vietnam's natural topography, the Vietnamese Mekong Delta (VMD), which plays an important role in many aspects of life. Reservoirs help strengthen the storage and regulation of freshwater, provide water for domestic use and agricultural production in the dry season, and act as flood control in the rainy season. Furthermore, it also helps to irrigate fields and raise aquaculture. In particular, these bodies of water also play a role in regulating the climate in the region, creating ecological landscapes, as resorts and ecotourism, protecting biodiversity and the environment.

The study areas are the lakes in three districts of An Phu, Tinh Bien and Tri Ton, all in An Giang Province. The lakes in these districts are planned for tourism and to provide water for human activities. According to Tinh Bien district's assessment, the surface water is being polluted, it can only be used after proper treatment for production and daily life in the dry season. Most of the area around the lakes are inhabited by several households, where pollution sources are mainly from domestic activities, feces of cattle and poultry from livestock, wastes from unprocessed production and business establishments discharged directly into lakes contaminating these important water sources. In the context of climate change causing shortage of freshwater for life and production, maintaining water quality in the lakes is an extremely important task. This study assessed water quality in the lakes in An Giang Province to provide useful information on dynamics of lake water quality for better management of these water resources.

## II. BACKGROUND

There have been certain studies on water quality in lakes to timely assess water quality and

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propose management solutions to help protect the environment and contribute to socio-economic development. Research on factors affecting water quality of Da Den lake has shown that water quality of Da Den lake is being negatively affected by socio-economic activities such as agricultural activities, animal husbandry, industry, production, and urban development [1]. This study reported that water variables of chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), ammonium ( $\text{NO}_3^- - N$ ), nitrate ( $\text{NO}_3^- - N$ ), and coliforms exceeded the permissible standards in 2010 and 2011. Van et al. [2] studied water quality in the West Lake and concluded that the lake water quality had signs of pollution of organic matter, nutrients and coliforms.

To effectively obtain good information in the monitoring or environmental data, multivariate statistical methods can be applied [3]. Using multivariate statistical techniques would allow one to reduce data dimensions and interpret the analyzed environmental data with insignificant loss of information in the initial dataset [4]. Multivariate statistical techniques were successfully applied for explaining spatial and temporal water quality data in rivers [3, 4], identifying sources of water pollution [3, 5], designing sampling networks [6], and extracting the most crucial water quality parameters for evaluating water quality variability [7]. In Viet Nam, Nhan [8] used data on population, industrial production, agriculture, and services to find the three main socio-economic regions of Tra Vinh using CA and PCA, and Au et al. [9] used multivariate analysis of CA and PCA to assess groundwater quality - and to evaluate the surface water monitoring system on Hau river [10].

### III. MATERIALS AND METHODS

#### A. Study areas

The study areas in An Giang Province included three districts of An Phu, Tinh Bien and Tri Ton. The lakes included O Tuk Sa lake, Thuy Liem lake, Soai So lake, Soai Chêk lake, O Thum lake, O Ta Soc lake, and Bung Binh Thien lake. These research sites are used for tourism, wetland ecology conservation (Bung Binh Thien),

water quality control, and domestic uses. The location map of the sampling points was shown in Figure 1.

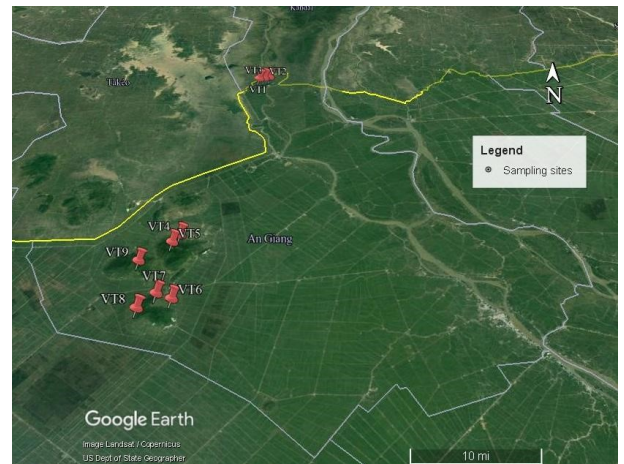


Fig. 1: Locations of lake water sampling

(Source: Google earth, 2020)

#### B. Data collection and analysis

The data of surface water quality was collected at nine locations over a period of three years (2017 to 2019). At Bung Binh Thien lake, three samples were collected and symbolized as VT1, VT2, VT3 respectively; O Tuk Sa lake (VT4); Thuy Liem lake (VT5); Soai So (VT6); Soai Chêk lake (VT7); O Thum lake (VT8) and Ta Soc lake (VT9). The parameters included pH, dissolved oxygen (DO, mg/L), and temperature which were measured at the fields, whereas total suspended solids (TSS, mg/L), biological oxygen demand (BOD, mg/L), chemical oxygen demand (COD, mg/L), nitrate ( $\text{NO}_3^- - N$ , mg/L), ammonia ( $\text{NO}_3^- - N$ , mg/L), and orthophosphate ( $\text{PO}_4^{3-} - P$ , mg/L) were measured in the laboratory using standard methods. Water quality indicators were collected, stored, and analyzed as indicated in Table 2.

Data for yearly differences in water quality at the sampling locations was analyzed by a one-way analysis of variance (one-way ANOVA) method at a significant level of 5% by Duncan test using IBM SPSS statistics for Windows software Version 20.0 (IBM Corp. Armonk, NY, USA). After that, water quality analysis data

Table 1: Characteristics of sampling locations

Sign	X	Y	Lake	Description of sampling locations
VT1	10 <sup>0</sup> 55'6,33"N	105 <sup>0</sup> 18'34,4"E	Bung Binh Thien lake	Tourism, conservation of flooded ecosystems
VT2	10 <sup>0</sup> 55'4,90"N	105 <sup>0</sup> 19'11,09"E	Bung Binh Thien lake	Tourism, conservation of flooded ecosystems
VT3	10 <sup>0</sup> 55'23,17"N	105 <sup>0</sup> 19'57,98"E	Bung Binh Thien lake	Tourism, conservation of flooded ecosystems
VT4	10 <sup>0</sup> 29'27,64"N	105 <sup>0</sup> 14'51,21"E	O Tuk Sa lake	Controlling the water quality of O Tuk Sa lake, serving daily life
VT5	10 <sup>0</sup> 30'11,94"N	105 <sup>0</sup> 13'50,03"E	Thuy Lien lake	Controlling the water quality of Thuy Lien lake, serving daily life
VT6	10 <sup>0</sup> 23'33,47"N	105 <sup>0</sup> 15'4,90"E	Soai So lake	Controlling the water quality of Soai So lake, serving daily life
VT7	10 <sup>0</sup> 24'18,19"N	105 <sup>0</sup> 13'36,92"E	Soai Chek lake	Controlling the water quality of Soai Chek lake, serving daily life
VT8	10 <sup>0</sup> 22'37,57"N	105 <sup>0</sup> 12'8,94"E	O Thum lake	Controlling the water quality of O Thum lake, serving daily life
VT9	10 <sup>0</sup> 27'34,26"N	105 <sup>0</sup> 11'24,6"E	O Ta Soc lake	Controlling the water quality of O Ta Soc lake, serving daily life

Table 2: Water quality variables and analysis

STT	Variables	Unit	Analytical method
1	Temperature	°C	SMEWW 2550B:20 12
2	pH	-	TCVN 6492:201 1
3	Total suspended solids (TSS)	mg/L	SMEWW 2540D:20 12
4	Dissolved oxygen (DO)	mg/L	TCVN 7325:200 4
5	Biological oxygen demand (BOD)	mg/L	SMEWW 5210B:20 12
6	Chemical oxygen demand (COD)	mg/L	SMEWW 5220C:20 12
7	Nitrate (NO <sub>3</sub> <sup>-</sup> -N)	mg/L	SMEWW 4500- NO <sub>3</sub> <sup>-</sup> - E:2012
8	Amoni (NH <sub>4</sub> <sup>+</sup> -N)	mg/L	SMEWW 4500- NH <sub>3</sub> .B&F :2012
9	orthophosphate (PO <sub>4</sub> <sup>3-</sup> -P)	mg/L	SMEWW 4500-P- E:2012
10	Coliforms	MPN/100mL	TCVN 6187- 2:1996

was used to calculate WQI water quality index and Cluster analysis and Principle component analysis.

The water quality index was calculated by the formula (1): In which:

WQII: The results of the calculation for parameter group I (pH)

WQIII: The results of the calculation for parameter group II (DO, BOD, COD, NO<sub>3</sub><sup>-</sup> - N, NO<sub>3</sub><sup>-</sup> - N, PO<sub>4</sub><sup>3-</sup> - P)

WQIII: The results of the calculation for parameter group III (Coliforms)

The Viet Nam Environment Administration (2019) uses the water quality index (WQI) to classify water quality. The water quality is assessed according to 6 levels based on the WQI index from 0 to 100. Level 1, very good water quality with the WQI index ranging from 91-100, can be used as drinking water. Level 2, good water quality, WQI values from 76 to 90 are used for domestic water but appropriate treatment is needed. Level 3 is the average water quality used for irrigation and similar purposes, with a WQI from 51 to 75. WQI values between 26 and 50 are classified as poor water quality (Level 4) suitable only for transport purposes. Level 5 with values from 10 to 25 indicates the quality of

heavily polluted water, which requires treatment in the future. Finally, water with a WQI index  $<10$  indicates that the water environment is heavily polluted (Level 6), contaminated water requires immediate treatment.

Mean values of bio-physicochemical parameters at all locations were input sources for Cluster analysis (CA) and Principal Component Analysis (PCA). Cluster Analysis (CA) was used to group water quality by locations in the way that the same water quality locations are grouped in the same clusters and vice versa. The CA was implemented according to Ward's method and represented by a dendrogram [11]. Principal Component Analysis (PCA) is the axis rotation method using Varimax [4]. PCA was used to reduce the starting parameters that do not cause the variation of the whole dataset. The origin variables were placed in forms of principal components and their relationships were illustrated by the weighing factors ranging from -1 to 1 [12]. The absolute value of the weighted correlation coefficient greater than 0.75 means that the correlation between the main component and the water quality parameter is close, 0.75-0.5 is the medium correlation, and 0.5-0.3 is weakly correlated [12]. CA and PCA were performed using copyrighted software Primer V5.2.9 (PRIMER-E Ltd, Plymouth, UK).

#### IV. RESULTS AND DISCUSSION

##### A. Water quality in the lakes

The quality of surface water in the lakes in An Giang Province during a period of 3 years from 2017 to 2019 was presented in Table 3. The pH in the lakes ranged from  $7.10 \pm 0.04$  to  $7.51 \pm 0.37$ , within the permitted limits of QCVN 08-MT: 2015/BTNMT, Column A1 [13]. The mean temperature in the lakes ranged from  $28.03 \pm 0.90$  to  $29.93 \pm 0.48^\circ\text{C}$ . This result is consistent with the temperature range for the development of aquatic species is 25 to  $32^\circ\text{C}$  [14]. A previous study in the canals of An Giang also showed that the temperature fluctuated between 29 to  $30^\circ\text{C}$  between 2009 and 2016 [15]. The dissolved oxygen (DO) concentration through the sampling places was lower than the permitted standard, having the highest value of  $5.85 \pm 0.76$  mg/L

recorded at VT5 (Thuy Liem lake) and lowest at VT1 with a value of  $4.62 \pm 0.55$  mg/L. The DO in the surface water environment in An Giang Province ranged from 4.0 to 5.2 mg/L [15] which was in the same range with the current study.

The mean values of water quality indicators including TSS, COD, BOD, and coliforms in all research locations exceeded the permissible thresholds according to QCVN 08-MT: 2015/BTNMT [13], Column A1 (Table 3). TSS, COD, BOD, and coliform at VT7 (Soai Chek lake) were highest and exceeded the permitted limits of QCVN 08-MT: 2015/BTNMT, Column A1 [13]. Specifically, TSS values at VT7 ranged from  $34.89 \pm 9.34$  to  $177.22 \pm 201.46$  mg/L, 8 times higher than the standard; COD has the lowest value at VT6 ( $18.00 \pm 4.38$  mg/L) and the highest at VT7 ( $57.57 \pm 37.73$  mg/L); similarly, BOD of VT7 exceeded 9 times ranging from  $11.67 \pm 2.80$  to  $37.33 \pm 24.18$  mg/L; the lowest coliform was  $3,633 \pm 728$  MPN/100mL, the highest was  $20,507 \pm 45,235$  MPN/100mL, 8 times higher than the permitted levels. The results of this study were in line with the former studies that reported that the water quality in the Mekong Delta of Viet Nam has long been polluted by TSS, COD, BOD, and coliforms [10, 15-17]. Total suspended solids resulted in cost concern for water supply, transporting contaminants including microorganisms, heavy metals, and pesticides [16]. BOD could lead to formation of disinfection byproducts (DBPs) where chlorine mixed with treated water containing organic carbon could pose high risk to human health [18]. Former study found that BOD in the surface waters in An Giang Province ranged from  $4.7 \pm 2.3$  to  $12.3 \pm 9.2$  mg/L [15]; BOD and COD in canals in Soc Trang Province was 2.2 - 22.4 and 6.0 - 44.9 mg/L, respectively [17]; and COD in Hau river was in the range of  $10.4 \pm 1.2$  -  $16.5 \pm 4.1$  mg/L [10]. Both BOD and COD were used as indicators of organic waste concentration in water [19, 20]. Previous studies reported that the coliforms in surface water in An Giang, Soc Trang, and Hau river were 2260-155000 MPN/100 mL, 2300-89000 MPN/100 mL, and 1346-86338 MPN/100 mL, respectively [10, 15, 17]. The occurrence of coliforms indicates waters have been receiving

Table 3: Summary of water quality in the lakes

Variables	VT1			VT2			VT3		VT4		VT5		QCVN 08-MT:2015/ BTNMT
<b>Temp</b>	29.	93±0.	48 <sup>a</sup>	29.	88±0.	66 <sup>a</sup>	29.	66±0.	28.	32±0.	28.	03±0.	-
<b>pH</b>	7.	20±0.	26 <sup>a</sup>	7.	20±0.	16 <sup>a</sup>	7.	17±0.	7.	22±0.	7.	10±0.	6-8. 5
<b>DO</b>	4.	62±0.	55 <sup>b</sup>	4.	69±0.	46 <sup>b</sup>	4.	66±0.	5.	79±0.	5.	85±0.	≥6
<b>TSS</b>	<b>44.</b>	<b>78±10.</b>	<b>64<sup>b</sup></b>	<b>44.</b>	<b>22±3.</b>	<b>23<sup>b</sup></b>	<b>43.</b>	<b>56±9.</b>	<b>42.</b>	<b>33±7.</b>	<b>46.</b>	<b>11±6.</b>	20
<b>COD</b>	<b>19.</b>	<b>44±2.</b>	<b>22<sup>b</sup></b>	<b>19.</b>	<b>44±3.</b>	<b>96<sup>b</sup></b>	<b>19.</b>	<b>22±3.</b>	<b>23.</b>	<b>11±3.</b>	<b>26.</b>	<b>33±1.</b>	10
<b>BOD</b>	<b>12.</b>	<b>78±1.</b>	<b>77<sup>b</sup></b>	<b>12.</b>	<b>67±2.</b>	<b>36<sup>b</sup></b>	<b>12.</b>	<b>44±2.</b>	<b>15.</b>	<b>00±2.</b>	<b>17.</b>	<b>11±1.</b>	4
<b>NO<sub>3</sub><sup>-</sup>-N</b>	0.	03±0.	03 <sup>a</sup>	0.	04±0.	02 <sup>a</sup>	0.	03±0.	0.	03±0.	0.	03±0.	2
<b>PO<sub>4</sub><sup>3-</sup>-P</b>	0.	02±0.	02 <sup>a</sup>	0.	02±0.	02 <sup>a</sup>	0.	03±0.	0.	02±0.	0		0. 1
<b>NH<sub>4</sub><sup>+</sup>-N</b>	0.	15±0.	06 <sup>a</sup>	0.	10±0.	07 <sup>a</sup>	0.	07±0.	0.	14±0.	0.	16±0.	0. 3
<b>Coliforms</b>	<b>10066±4143<sup>a</sup></b>			<b>16655±9980<sup>a</sup></b>			<b>17688±17685<sup>a</sup></b>		<b>3633±728<sup>a</sup></b>		<b>7192±4460<sup>a</sup></b>		<b>2500</b>
Variables	VT6			VT7			VT8		VT9		QCVN 08-MT:2015/ BTNMT		T
<b>Temp</b>	29.	04±0.	60 <sup>ab</sup>	29.	19±0.	92 <sup>ab</sup>	28.	74±0.	29.	04±0.			-
<b>pH</b>	7.	29±0.	18 <sup>a</sup>	7.	46±0.	70 <sup>a</sup>	7.	13±0.	7.	51±0.			6-8. 5
<b>DO</b>	5.	65±0.	41 <sup>a</sup>	5.	49±0.	43 <sup>ab</sup>	5.	46±0.	5.	78±0.			≥6
<b>TSS</b>	<b>34.</b>	<b>89±9.</b>	<b>34<sup>b</sup></b>	<b>177.</b>	<b>22±201.</b>	<b>46<sup>a</sup></b>	<b>95.</b>	<b>22±68.</b>	<b>40.</b>	<b>78±7.</b>			20
<b>COD</b>	<b>18.</b>	<b>00±4.</b>	<b>38<sup>b</sup></b>	<b>57.</b>	<b>67±37.</b>	<b>73<sup>a</sup></b>	<b>26.</b>	<b>89±8.</b>	<b>28.</b>	<b>44±4.</b>			10
<b>BOD</b>	<b>11.</b>	<b>67±2.</b>	<b>80<sup>b</sup></b>	<b>37.</b>	<b>33±24.</b>	<b>18<sup>a</sup></b>	<b>17.</b>	<b>67±5.</b>	<b>18.</b>	<b>67±2.</b>			4
<b>NO<sub>3</sub><sup>-</sup>-N</b>	0.	05±0.	03 <sup>a</sup>	0.	04±0.	03 <sup>a</sup>	0.	04±0.	0.	03±0.			2
<b>PO<sub>4</sub><sup>3-</sup>-P</b>	0.	03±0.	08 <sup>a</sup>	0.	23±0.	52 <sup>a</sup>	0.	44±1.	0.	01±0.			0. 1
<b>NH<sub>4</sub><sup>+</sup>-N</b>	0.	20±0.	03 <sup>a</sup>	1.	38±3.	60 <sup>a</sup>	0.	67±1.	0.	14±0.			0. 3
<b>Coliforms</b>	<b>3916±1286<sup>a</sup></b>			<b>11288±10027<sup>a</sup></b>			<b>20507±45235<sup>a</sup></b>		<b>12766±1399</b>		<b>2<sup>a</sup></b>		<b>2500</b>

(Note: The values selected in the surface water standard QCVN 08-MT: 2015/BTNMT [13] in column A1 is used for supply of water for living and conservation of aquatic plants and animals; mean ± SE (n = 9), a, b: Different characters in the same row are statistically different at 5%.)

fecal materials from humans and animals [21]. The study areas were seriously polluted by organic matters and microorganisms; thus, it is not safe for domestic use.

The analysis results also showed that  $\text{NO}_3^- - \text{N}$  values ranged from  $0.07 \pm 0.08$  to  $1.38 \pm 3.60$  mg/L. The highest concentrations of  $\text{NO}_3^- - \text{N}$  were found at VT7 and VT8, exceeding the permitted level QCVN 08-MT: 2015/BTNMT, Column A1 [13]. A former study reported that  $\text{NO}_3^- - \text{N}$  in Hau Giang' waters was in the range of  $0.27 \pm 0.16$  mg/L [10]. Where the high levels of  $\text{NO}_3^- - \text{N}$  could cause toxicity for aquatic plants and its sources could be from degradation of organic matter, and fertilizers from agricultural activities.  $\text{NO}_3^- - \text{N}$  was low ranging from  $0.03 \pm 0.02$  to  $0.04 \pm 0.02$  mg/L. Previous studies have shown that  $\text{NO}_3^- - \text{N}$  concentration in Hau river  $0.002-0.395$  mg/L [22], in canals in An Giang Province  $0.31 \pm 0.3-0.58 \pm 0.64$  mg/L [15], in surface water in Soc Trang Province  $0.05-0.14$  mg/L [17].  $\text{NO}_3^- - \text{N}$  is likely to fluctuate over time, but  $\text{NO}_3^- - \text{N}$  rarely exceeded the QCVN 08-MT: 2015/BTNMT, column A1 (2 mg/L) [13].  $\text{PO}_4^{3-} - \text{P}$  values ranged from 0 (VT5) to  $0.44 \pm 0.24$  mg/L (VT8). High concentrations of  $\text{PO}_4^{3-} - \text{P}$  were found at VT7 and VT8, while the remaining locations had  $\text{PO}_4^{3-} - \text{P}$  found ranging from 0 to  $0.03 \pm 0.02$  mg/L. Former studies presented that  $\text{PO}_4^{3-} - \text{P}$  in the waters of An Giang  $0.02-0.47$  mg/L [15], in Hau river  $0.04-0.11$  mg/L [10], in Soc Trang  $0.05-0.9$  mg/L [17]. There was no significant difference ( $p > 0.05$ ) in the water quality in all study sites.  $\text{PO}_4^{3-} - \text{P}$  was not the problem for water quality in the lakes, except VT7 (Soai Chek lake) and VT8 (O Thum lake). The sources of orthophosphate in the water environment are agricultural runoff, livestock, domestic and industrial wastes [23].

The results of WQI calculation showed that water quality at the locations VT1, VT2, VT3 (Bung Binh Thien), VT7 (Soai Chêk lake), VT8 (O Thum lake), VT9 (Ta Soc lake) are at level 5 (heavy pollution), and need to be treated in the future (Figure 2). While VT4 (O Tuck Sa lake) and VT6 (Soai So) have water quality that can be used for domestic purposes, appropriate

treatment is needed; VT5 (Thuy Liem lake) can only be used for irrigation and other similar purposes. The results indicated that the water quality in Bung Binh Thien (An Phu District) and the water bodies of lakes (Soai So, Soai Chêk, O Thum, O Ta Soc in Tri Ton District) were more polluted than the reservoirs in Tinh Bien District (O Tuk Sa and Thuy Liem lakes).

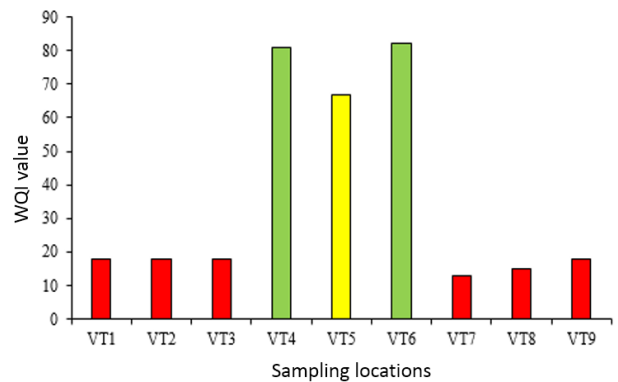


Fig. 2: Water quality index at the lakes

The CA result was presented in Figure 3. As can be seen that at distance 3, water quality was divided into five clusters including, cluster 1 (VT7), cluster 2 (VT8), cluster 3 (VT1, VT2, and VT3), clusters 4 (VT9) and cluster 5 (VT4, VT5, VT6). The water quality division is relatively consistent with the previous WQI analysis. Water quality at Bung Binh Thien (VT1, VT2, and VT3) were distributed in the same group, clearly differentiated from the other lakes.

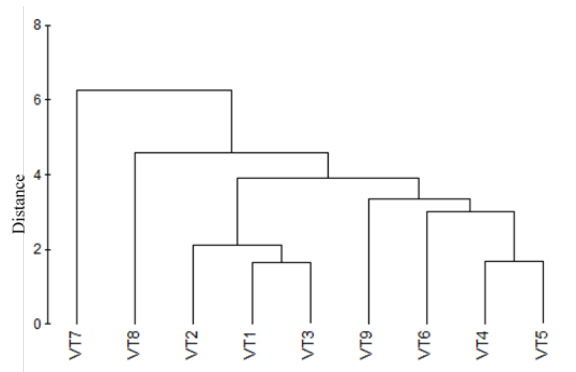


Fig. 3: Clustering water quality at the lakes

### B. Key variables influencing water quality in the lakes

The PCA result was presented in Table 4. PC1, PC2, PC3 and PC4 had the eigenvalues 4.61, 2.34, 1.41, and 1.02, respectively. Therefore, PC1, PC2, PC3 and PC4 are the main factors, or sources of pollutants, accounting for 93.8% of the total variation of surface water quality data in the lakes. The PCA results showed that the water quality indicators affecting water quality by PC1 were TSS, COD, BOD,  $\text{NO}_3^- - N$ ; PC2 was temperature, DO and coliforms; PC3 was pH and  $\text{PO}_4^{3-} - P$ ;  $\text{NO}_3^- - N$  in PC4. PC1 explained 46.1% the variation of water quality in the lakes, mainly contributed by organic matters and total suspended solids. This is a typical form of pollution of lakes in the Mekong Delta, caused by people's daily habits, for instance discharging domestic waste into bodies of water. In addition, rainwater runoff and erosion also significantly contributed to increase the concentration of suspended solids and organic matter [10, 16, 24]. Wastes from agricultural activities, such as fertilizers and animal waste, also pollute water sources if not treated before being discharged into the environment. The use of fertilizers and pesticides as well as their release into the environment are one of the common causes of surface water pollution [16]. PCA results showed that the parameters of temperature, pH, DO, TSS, COD, BOD,  $\text{NO}_3^- - N$ ,  $\text{PO}_4^{3-} - P$ ,  $\text{NO}_3^- - N$  and coliforms all have a significant impact on the quality of surface water at the lakes. This information has been recorded in some previous studies by Ty [24], Giao [10] and Giao [25] in the Mekong Delta and Bung Binh Thien lake. However, the number of analyzed parameters may have limited the principal component analysis, which could mean that when more water quality parameters were added, the better selection of key water parameters influencing the water quality.

### V. CONCLUSION

The results of the study showed that water quality in the lakes in An Giang Province in the period of 2017 to 2019 was polluted by low DO, high TSS, COD, BOD,  $\text{PO}_4^{3-} - P$ ,  $\text{NO}_3^- - N$ , and coliforms. The main sources of water pollution

Table 4. Key water parameters influencing water quality in the lakes

Parameter	PC1	PC2	PC3	PC4	PC5
Temp	0.078	<b>-0.537</b>	-0.401	0.248	0.054
pH	0.246	0.114	<b>-0.520</b>	0.341	<b>0.604</b>
DO	0.156	<b>0.562</b>	0.228	0.062	0.370
TSS	<b>0.449</b>	-0.122	0.011	-0.047	0.245
COD	<b>0.449</b>	0.051	-0.177	-0.079	0.122
BOD	<b>0.449</b>	0.049	-0.175	-0.081	0.111
$\text{NO}_3^- - N$	0.057	-0.171	0.398	<b>0.818</b>	0.024
$\text{PO}_4^{3-} - P$	<b>0.301</b>	-0.229	<b>0.523</b>	-0.084	0.218
$\text{NH}_4^+ - N$	<b>0.454</b>	-0.083	0.058	0.041	0.207
Coliforms	0.060	<b>-0.524</b>	0.138	-0.355	<b>0.562</b>
Eigenvalue	4.61	2.34	1.41	1.02	0.51
Variation (%)	46.1	23.4	14.1	10.2	5.1
Cum. Var (%)	46.1	69.6	83.7	93.8	98.9

could be potentially from rainwater runoff, livestock, poultry, farming, and community activities. The results of WQI assessment showed that water quality in the lakes in An Phu and Tri Ton Districts were more polluted than that in Tinh Bien. Water quality in these water bodies only met the water requirements for agricultural production, and does not meet the requirements for domestic water supply. The PCA analysis showed that the water quality variables of temperature, pH, DO, TSS, COD, BOD,  $\text{NO}_3^- - N$ ,  $\text{PO}_4^{3-} - P$ ,  $\text{NO}_3^- - N$ , and coliforms need to be monitored to assess water quality in the lakes. Future studies should focus on investigating and eliminating sources of pollution to maintain and improve surface water quality of the lakes in An Giang Province.

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