Using Multicriteria Statistical Analysis for Interpreting the Spatiotemporal Fluctuations of Surface Water Quality in the Vietnamese Mekong Delta Province

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***Abstract*—This study evaluated variations in surface water quality indicators within the rivers and canals of Tien Giang province in the Vietnamese Mekong Delta. Water samples were collected at 34 locations, in the months of March, June, September, and November in 2021. Water quality was assessed through comparison with the National Technical Regulation on surface water quality (QCVN 08-MT: 2015/BTNMT, column A2). The pollution source was forecast using principal component analysis (PCA), whilst the similarity in water quality between locations was evaluated through cluster analysis (CA). Results show that surface waters were contaminated with organic matter, suspended solids, and nutrients. There was clear temporal pattern between rainy season (September and November) and dry season (March and June). PCA analysis predicted six pollution sources of which the three main sources were PC1, PC2, and PC3, explained 59.9% of variation in water quality. The parameters of temperature, biological oxygen demand, chemical oxygen demand, dissolved oxygen, total nitrogen, total suspended solids, nitrite, and sulfate exhibited influence on water quality. The CA results suggest that the 34 monitoring locations can be reduced to 29 locations, which would result in a 14.7% saving in monitoring costs. The results can be used to reevaluate the location and monitoring criteria for surface water quality in Tien Giang province.**

***Index Terms*—Cluster analysis, nutrients, organic pollution, principal component analysis, Tien Giang, water bodies, water quality**

I. INTRODUCTION

Tien Giang is a province in the Mekong Delta located in the southern key economic region, with an abundant freshwater source provided by the Tien River (a tributary of the Mekong River) with a length of 120 km and a system of canals crisscrossing the province. Every year surface water conveys a large volume of alluvium, which is fertile for agricultural land and socio-economic development [1]. Thereby showing that water is an indispensable basic element for maintaining life and all human activities. Therefore, surface water quality monitoring is the first objective of all countries in the world [2, 3]. Water quality monitoring is not only providing information towards the fulfilment of sustainable development goals in the Mekong Delta but also helps assess and predict pollution in the future [4–6]. Annually, the environmental monitoring of surface water is indertaken by the Ministry of Natural Resources and Environment and the People's Committees of 63 provinces and cities of Vietnam. The physical and chemical parameters tested include temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), ammonium (NH_4^+-N), nitrite (NO_2^--N), nitrate (NO_3^--N), sulfate (SO_4^{2-}), orthophosphate (PO_4^{3-}-P), chloride (Cl^-), total nitrogen (TN), total phosphorus (TP), and biological factors (coliform) [7]. In the previously reported studies, the results of water quality were evaluated using Vietnamese national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT) [7, 8] or water quality index [9]. However, these assessment methods are very simplistic, using a small dataset for comparison in water quality assessment; meanwhile, the vital information hidden in the large dataset was not explored, which has been demonstrated in the previous sstudies [8–10]. In the recent studies, multivariate statistical methods are commonly used for water quality assessments. These methods can include all the water quality parameters in the calculation simultaneously, which can evaluate the water quality more clearly from the dataset [6, 10]. In which, Principal Component Analysis (PCA) is a multivariate analysis technique used to assess water quality, identify sources of pollution, and determine the main indicators affecting water quality [11–13]. In addition, these methods can be used to assess both the spatial and temporal variations in water quality, assisting in the identification of pollution sources [14, 15]. Cluster analysis (CA) method is applied to group water sample survey sites according to physical, chemical, and biological criteria according to the principle that sampling sites with similar pollution characteristics will be grouped into the same group, and different pollution properties are grouped into another group and presented as a tree structure [13, 15, 16].

Former studies showed that multivariate statistics were very useful in analyzing and evaluating surface water environmental monitoring data. In this study, we applied these methods to assess surface water quality, the main criteria affecting water quality and identify sources of surface water pollution in Tien Giang province. The results could provide useful information to support the assessment of surface water quality for both planners and policy makers in Tien Giang province.

II. MATERIALS AND METHODS

A. Water Sampling and Analysis

The Mekong Delta region is located in the central tropical

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monsoon region of Asia. Therefore, climate was divided into both seasons. The rainy season started from May to October, and the dry season started from November to April next year. Besides, in the provincial monitoring program of Tien Giang province, they were collected the surface water samples in the dry season (March and November), and the rainy season (June and September). In particular, 34 monitoring locations were observed (Fig. 1). The monitoring locations included Tien river (NM1, NM2, NM3, NM4, NM5, NM6, NM7), the areas of Cai Be, Cai Lay and Tan Phuoc districts (NM8, NM9, NM10, NM11, NM12, NM13, NM14, NM15, NM16), the canal area adjacent to the territory of two provinces of Tien Giang and Long An (NM17, NM18, NM19, NM20), My Tho city, Chau Thanh and Cho Gao districts (NM21, NM22, NM23, NM24, NM25, NM26), Go Cong town, Go Cong Tay district, Go Cong Dong and Tan Phu Dong (NM27, NM28, NM29, NM30, NM31, NM32, NM33, NM34). The sampling locations can be seen in Fig. 1.

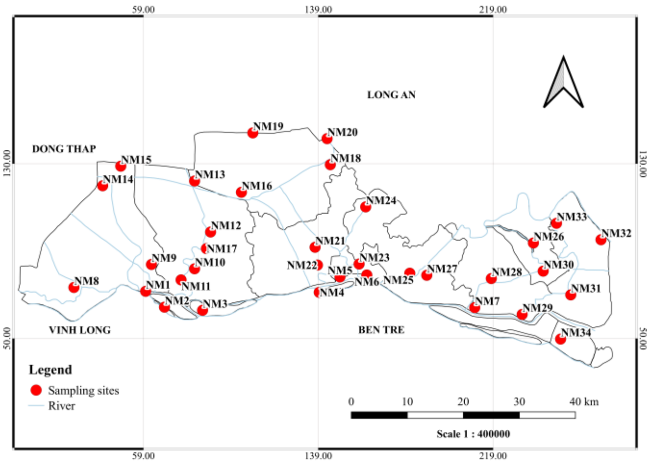

Fig. 1. Map of the official surface water sampling location in Tien Giang province [17].

TABLE I: ANALYTICAL METHODS FOR WATER ANALYSIS

Parameter	Unit	Analytical methods
Temp.	^oC	SMEWW 2550B:2017
pH	-	TCVN 6492:2011
EC	mS/cm	SMEWW 2510B:2017
TSS	mg/L	TCVN 6625:2000
DO	mg/L	TCVN 12026:2018
COD	mg/L	SMEWW 5220.C:2017
BOD	mg/L	TCVN 6001-1:2008
NH_4^+-N	mg/L	TCVN 6179-1:1996
NO_2^--N	mg/L	TCVN 6178:1996
NO_3^--N	mg/L	TCVN 6180:1996
PO_4^{3-}-N	mg/L	TCVN 6202:2008
TN	mg/L	TCVN 6638:2000
TP	mg/L	TCVN 6202:2008
Cl^-	mg/L	TCVN 6194:1996
PO_4^{3-}-P	mg/L	TCVN 6494-1:2011
Coliform	MPN/100nL	TCVN 6187-2:1996

Water samples were collected and preserved according to the instructions of the National technical regulation on surface water quality (QCVN 08-MT:2015/BTNMT) [7]. The pH, temperature, EC, TSS, DO, BOD, COD, NH_4^+-N, NO_2^--N, NO_3^--N, SO_4^{2-}, PO_4^{3-}-P, Cl^-, TN, TP and coliform were analyzed according to the measurement methods in Vietnamese standards [7]. However, the original data source was collected from the Department of Natural Resources and Environment of Tien Giang province in 2021. Therefore, the limit values for each parameter in measurement method as well as field measurement equipment were limited. The analytical methods of water quality are presented in Table I.

B. Data Processing

The mean values of the water quality parameters were compared with the standard values in national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT, column A2 - used for purposes of domestic water supply yet require suitable treatment technology [7] (Table I). In addition, the study applied one-way ANOVA with Duncan Test to determine the statistically significant differences at the 95% confidence level (corresponding to the 0.05 level of significance (p<0.05) for the mean values of water quality parameters over the sampling months. The analysis was performed using SPSS version 20.0 software (IBM Corp., New York, NY, USA).

In this study, CA has applied to group the survey locations of water samples according to both the physical and chemical criteria. Sampling locations with similar pollution characteristics were grouped together, and different pollution characteristics separated over, with results as a tree structure or dendrogram [13, 15, 16]. The cluster analysis was carried out according to Salah *et al*. [18]. PCA is widely used in multivariate analysis used to extract important information from the original datasets [13, 15, 16]. The PCA reduces the original data variables that don't make a significant contribution to the data variability, while creating a new group of variables termed the principal component (PC) variables. These PCs are unrelated to each other and appear in descending order of importance. An important value to consider in the main components is the eigenvalue coefficient, the larger the coefficient, the greater the contribution that major component contributes to explaining the variability of the original data set. The pivot method used in PCA is Varimax, each initial data variable will be assigned a factor and each factor will represent a small group of original variables [15]. The correlation between the principal component and the baseline data variables is indicated by the loading correlation coefficients [15]. In this study, CA and PCA were conducted using Primer 5.2 software for Windows (PRIMER-E Ltd, Plymouth, UK). Based on CA and PCA analysis, monitoring locations and monitoring criteria for water environment would be proposed.

III. RESULTS AND DISCUSSIONS

A. Changes in Surface Water Quality

Surface water quality in Tien Giang province is shown in Fig. 2. Box plots of water quality parameters showed variations over time. These plots were plotted by combining the data at all monitoring locations over months. The mean, first (Q1) and third quartile (Q3), lowest and highest values for a given period are determined for each parameter by data analysis for all operations within a specific time period. The box horizontal line represents the mean concentration and the bottom and top of the box for Q1 and Q3, respectively. The two horizontal bars below the box and above the box correspond to the lowest and highest values [13].

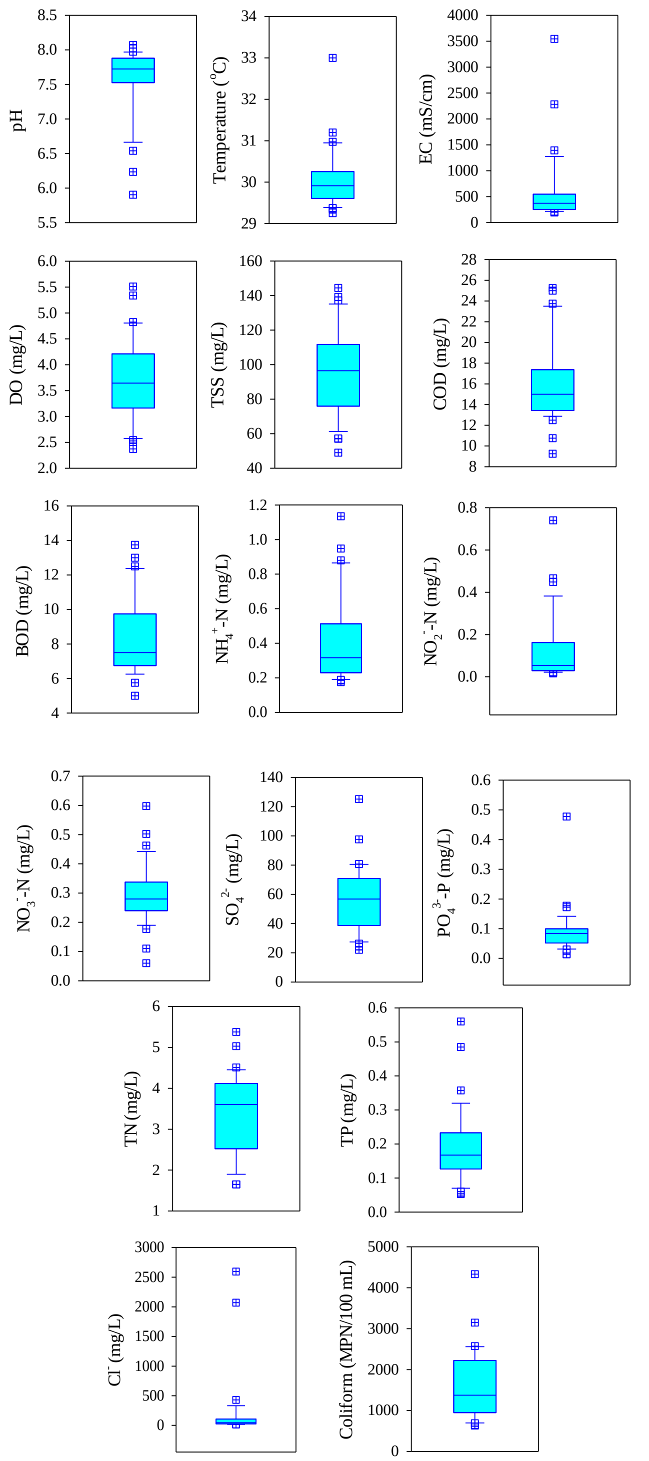

Fig. 2. Variations of surface water quality in Tien Giang province in 2021.

The average temperature reached 30.07±1.3 °C, while the lowest value was 27.8°C and the highest was 34.90 °C. There was a significant difference between June (31.16±1.03 °C) and September (28.95±1.39 °C); however, there was no significant difference between March (30.22±0.74 °C) and June, and between September and November (29.94±0.92 °C). According to Ly *et al.* [19], who surveyed water temperature in 2013 in the Mekong River basin including Laos (11 points), Thailand (8 points), Cambodia (19 points), and Vietnam (10 points), their results showed that water temperature fluctuated in the range of 19.9–32.2 °C. The difference in temperature may be due to the increase in temperature in the dry season and a decrease in the temperature in the rainy season. In addition, the temperature fluctuated depending on the time of day and the time of year when samples were collected. However, the water temperature in this study was still suitable for aquatic life, in the appropriate range of 25–32 °C [20].

The average pH value was 7.56±0.73 (4.14–8.89) which fell within the range of 6–8.5 of QCVN 08-MT: 2015/BTNMT for column A2. There were insignificantly differences in pH values over months (7.23±0.51, 7.47±1.14, 7.79±0.55, and 7.75±0.29 for March, June, September, and November, respectively). The pH values in surface water in Tien Giang were well matched with the general pattern of pH values in surface water in the main and tributary rivers of the Mekong River [7, 11, 21, 22]. This decrease in pH may be due to acid sulfate soil washing from agricultural and aquaculture farming activities [23, 24]. According to Boyd [25], the suitable pH for aquaculture ranges 7 – 9, and the pH values in surface water in Tien Giang were suitable for aquatic life.

The measurement results showed that EC values ranged largely from 92.30 µS/cm to 6,100 µS/cm, reaching the average value at 592.79±828.46 µS/cm. The EC value in June (992.76±1273.6 µS/cm) was significant ($p<0.05$) compared to the remaining months (540.55±473.14 µS/cm, 405.85±537.03 µS/cm, and 432.00±665.73 µS/cm for March, September, and November, respectively). According to Cat *et al.* [26], water quality is safe for irrigated crops when EC<750 µS/cm. This showed that the EC values in surface water in Tien Giang in June were higher than the safe level, so regular monitoring is required to manage the EC value.

The dissolved oxygen average, lowest, and highest were 3.68±1.14 mg/L, 0.82 mg/L, and 7.70 mg/L, respectively. There was no significant difference seen between March (4.01±1.22 mg/L), June (3.64±1.13 mg/L), and September (3.89±0.93 mg/L), but there was a significant difference between March and November (3.19±1.12 mg/L). In general, DO concentrations did not meet the limit of QCVN 08-MT:2015/BTNMT column A2 (≥5 mg/L). The appropriate DO in water for aquatic life is 5–7 mg/L, it depends on the temperature and the decomposition processes of organic compounds and the photosynthesis of aquatic plants [25, 26]. These results suggest that DO was depleted due to the decomposition of organic matter [23, 24].

In general, the results showed that average TSS concentration was quite high with 95.51±45.30 mg/L, fluctuating largely from 17.00 mg/L to 217.00 mg/L, approximately 3.2 times higher than column A2 (30 mg/L) of QCVN 08-MT:2015/BTNMT). The significant difference between March (78.85±53.22 mg/L) compared to June (121.82±50.12 mg/L) and November (103.65±34.69 mg/L), but there was no significant difference between March and September (77.74±21.31 mg/L). The large variation of TSS concentrations was also found in research on surface water in main and tributary rivers in the Mekong River [11, 15, 21, 22]. High concentrations of TSS are due to rainfall, runoff, erosion, and the presence of phytoplankton in the environment [27, 28]. Thereby, the strong fluctuation of TSS concentrations may be due to the influence of erosion process, alluvium transported from the upstream Mekong River.

According to QCVN 08-MT 2015/BTNMT for column A2, the appropriate COD concentration is 30 mg/L and BOD concentration is 6 mg/L. Our results showed that the average COD concentration (15.94±4.60 mg/L; 7.00–32.00 mg/L) was below the allowable limit, whereas inverse trend was seen in the BOD concentration (8.46±2.47mg/L; 4.00–16.00 mg/L). There were no significant differences seen in COD concentrations between March (14.44±4.78 mg/L), June (16.59±5.09 mg/L) and September (15.44±3.74 mg/L); however, there was a significant difference between March and November (17.29±4.35 mg/L). Higher COD at some locations is an indication of discharged wastewater from massive industrial and municipal applications [29]. The significantly temporal differences in BOD concentrations were not found (8.00±2.7 mg/L for March, 8.94±2.64 mg/L for June, 8.26±2.38 mg/L for September, and 8.65±2.14 mg/L for November). The results indicated that the surface water quality in Tien Giang province was contaminated with organic matters, it is necessary to apply mitigation measures to improve the water quality. Recent studies of surface water quality in the Mekong Delta have reported organic pollution levels, that could threaten water use of human, aquaculture and ecosystem health [30, 31].

The average concentration of NH_4^+-N was 0.41±0.41 mg/L (0.01–2.10 mg/L) which was a little higher than the water quality guidelines QCVN 08: 2008/BTNMT for column A2 (0.3 mg/L). The NH_4^+-N concentrations in the rainy season (0.54±0.45 mg/L and 0.52±0.49 mg/L for June and September, respectively) were significantly higher than those in the dry season (0.32±0.14 mg/L for March and 0.27±0.41 mg/L for November). It is assumed that concentrations of pollutants in the rainy season will be lower than those in the dry season due to contributions of dilution. Yet, results reflected the inverse trend, it suggests therefore, that unknown sources contributed to higher NH_4^+-N concentrations in the rainy season. The concentrations of NH_4^+-N in our study were similar to the research of Truc *et al*. [32] on surface water quality of upstream of Tien River flowing through An Giang province. The high ammonium in the water body may be caused by sources of nitrogen from rice farming and shrimp farming and catfish aquaculture [33].

The NO_2^--N concentration was 0.12±0.24 mg/L (0.00-0.52 mg/L). There were no significant differences seen NO_2^--N concentration between the rainy months and dry months. The significant lowest concentration of NO_2^--N (0.04±0.04 mg/L) was seen in the rainy month of September compared to the remaining months (0.10±0.17 mg/L, 0.17±0.32 mg/L, and 0.18±0.30 mg/L for March, June, and November, respectively). Boyd [25] suggested that NO_2^--N concentrations less than 0.3 mg/L are suitable for aquaculture. According to Schmittou [34], nitrite at concentrations of 0.1 mg/L can cause brown disease in fish. Column A2 in QCVN 08-MT: 2015/BTNMT specifies the allowable limit of NO_2^--N concentration as 0.05mg/L. This showed that the water quality in the study area was only suitable for aquaculture, but not within the allowable limits.

The NO_3^--N concentrations ranged from 0.01 mg/L to 0.12 mg/L (0.30±0.20 mg/L). There was no general pattern of changes in NO_3^--N concentration between the rainy season and dry season, the significant lowest NO_3^--N concentration (0.10±0.06 mg/L) accounted for November compared to remaining months (0.39±0.18 mg/L, 0.40±0.20 mg/L, and 0.28±0.11 mg/L for March, June, September, respectively). Indeed, the seasonal effect seemed to be less important than the spatial variation occurring among compartments of the water bodies (i.e., main river, tributaries, and canal [20]). The low NO_3^--N concentrations in surface water in Tien Giang met the ranges of NO_3^--N concentrations that found in main rivers, attributes, and canals in the Mekong Delta [35–38]. According to QCVN 08-MT: 2015/BTNMT for column A2, the surface water quality in Tien Giang province had NO_3^- value reaching the allowable limit (5 mg/L).

The concentration of TN was relatively stable, ranging from 1.65 mg/L to 6.32 mg/L (3.40±1.44 mg/L). There were no significant differences in concentrations of TN over months (1.54 mg/L for March, 1.49 mg/L for June, 1.34 mg/L for September, and 1.34 mg/L for November). On the other hand, Lien *et al*. [37] showed that the concentration of TN in the Hau River, another main branch of Mekong River fluctuated relatively highly. According to Boyd and Green [39] to minimize of the potential of eutrophication of water, TN should not exceed 3 mg/L. When TN is higher than 1.7 mg/L, the possibility of eutrophication is very high [39]. Thereby, it showed that the TN-N concentrations in Tien Giang's water bodies are likely to cause eutrophication. Chea *et al*. [28] reported that main sources of from livestock farming, aquaculture production and human waste are responsible for nitrogen loading into the lower Mekong Basin.

The results showed that PO_4^{3-}-P concentration fluctuated slightly in the range of 0.01–0.85 mg/L (0.09 ± 0.11 mg/L), but will not significantly difference between months (0.08±0.16 mg/L for March, 0.10±0.05 mg/L for June, 0.08±0.05 mg/L for September, and 0.1±0.14 mg/L for November), and was within allowable limit column A2 (0.2 mg/L) QCVN 08-MT: 2015/BTNMT. According to Chapman *et al*. [1], normally the dissolved phosphorus concentration in natural surface water exists in the range 0.005–0.02 mg/L. Furthermore, according to Boyd [25] the appropriate concentration of PO_4^{3-}-P in aquaculture is 0.005–0.02 mg/L. The results of PO_4^{3-}-P concentration reflected non-pollution of dissolved phosphorus in surface water in Tien Giang province.

The TP concentration was quite stable (0.19±0.18 mg/L; 0.02–1.09 mg/L). The significantly higher TP concentration in June (0.30±0.2 mg/L) compared to other months (0.11±0.19 mg/L, 0.20±0.12 mg/L, and 0.14±0.15 mg/L for March, September, and November, respectively) was found ($p<0.05$). According to research by Lien *et al*. [37], found that TP was low in the rainy season and high in the dry season. Inversely, TP concentrations in this study tended to be higher in the rainy season compared to dry season. Our study results concur with the study of Liljeström *et al*. [40] which showed that TP slightly increased during rainy season and peaked in July-September. According to Boyd and Green [39] if TP > 0.1 mg/L, eutrophication is likely to occur. Thereby, it implied that TP in Tien Giang's water bodies had a high possibility resulting in eutrophication. According to a recent study on nutrient dynamics, 75% of TP in Lower Mekong River originats from intensive agricultural activities, particularly the use of fertilizers [40].

The Cl^{-} values were seen to fluctuate from 10.20 to 5,270.00 mg/L (206.31±664.72 mg/L). The highest Cl- value was in very dry month of March (366.37±1104.45 mg/L), and it had no statistical difference compared with remaining months (254.19±641.9 mg/L for March, 118.69±261.89 mg/L for September, and 85.98±235.68 mg/L for November). High Cl^{-} concentration can be caused by agricultural activities, industrial wastewater, and seawater intrusion. Chloride increases electrical conductivity in water, thereby increasing the water's ability to corrode metal equipment. According to QCVN 08-MT: 2015/BTNMT, column A2 stipulates that the Cl^{-} value in water should be 350 mg/L, compared with the results of this study, many Cl^{-} values had exceeded the standard. The Cl^{-} concentrations in the range below 70 mg/L are considered safe; however, Cl^{-} can have harmful effects on agriculture if it is higher than 350 mg/L [41]. Therefore, Cl^{-} concentrations in water bodies in Tien Giang may be unsafe, with Cl^{-} concentrations in March were considered unsuitable for irrigation [41].

In general, SO_4^{2-} concentrations highly fluctuated. The mean SO_4^{2-} concentration was 56.40±30.45 mg/L, ranging from 8.92mg/L to 224.00 mg/L. The SO_4^{2-} concentrations in March, June, September, and November were 61.91±31.54, 67.55±41.45, 57.42±21.91 and 39±15.38 mg/L, respectively. The concentration was statistically significant between March, June and September compared to November. The large fluctuation of SO_4^{2-} concentration in surface water was also found in the study of Truc *et al*. [32] on surface water quality in An Giang province. The high concentrations of Cl^{-} and SO_4^{2-} in March indicated that the water bodies in Tien Giang province in 2021 were heavily affected by saline intrusion, and it was a typical case of increase of concentrations of Cl^{-} and SO_4^{2-} in many other coastal areas in the Mekong Delta.

The average coliform density in the months of March, June, September, and November was 972.9±718.28, 1556.33±1023.69, 1762.33±790.86, 2261.21±1348.99 MPN/100mL, respectively. Coliform density was highest in November and lowest in March thereby indicating that coliform levels fluctuated greatly and the difference was statistically significant. It was found that the presence of coliforms in Tien Giang's rivers and canals was still within the allowable limit for column A2 (5,000 MPN/100mL) of QCVN 08-MT: 2015/BTNMT. In comparison, to some previous reports of coliform in the water bodies in provinces in the Mekong Delta of Hau Giang, Can Tho, and Soc Trang [42], coliform density in the surface water in Tien Giang Province was likely lower. The domestic wastewater and waste from livestock and humans are the main sources of coliform. It likely that coliform pollution may not be the main pollution problem in rivers and canals in Tien Giang province.

B. Determining the Main Factors Affecting Water Quality

The PCA of the water quality data set included 34 monitoring locations with 16 measured parameters and evaluated with respective eigenvalues. The research of Boyacioglu and Boyacioglu [43] and Uddin *et al*. [44] also used the principal component analysis for assessing the water quality parameters. The Eigenvalues (EV) of greater than 01 are used to evaluate the discriminant between the variables [43]. It was shown in Table II that 6 PCs contributed significantly to explain 83.5% of water quality variation in Tien Giang province in 2021. PC1-PC6 explained the variation of water quality with different rates of 29%, 16.2%, 14.7%, 9.5%, 7.8%, and 6.4%, respectively. PC1 explained that the fluctuations of EC (−0.322), COD (−0.394), BOD (−0.412), NH_4^{+}-N (−0.305), and coliforms (−0.332) parameters were weakly correlated. PC1 represented organic pollution indicator parameters related to anthropogenic sources of pollution [45].

TABLE II: KEY WATER QUALITY PARAMETERS AFFECTING WATER QUALITY

Parameters	PC1	PC2	PC3	PC4	PC5	PC6
pH	0.126	−0.059	**0.35**	**−0.351**	−0.285	**0.456**
Temp	−0.174	−0.096	−0.187	−0.188	**−0.641**	0.049
EC	**−0.322**	**−0.338**	0.229	0.056	−0.016	−0.161
DO	0.082	**−0.438**	0.262	0.032	−0.208	−0.216
TSS	−0.066	**0.389**	0.297	0.001	−0.121	−0.118
COD	**−0.394**	0.057	0.121	0.128	0.107	0.257
BOD	**−0.412**	0.035	0.108	0.067	0.006	0.268
NH_4^{+}-N	**−0.305**	0.132	−0.058	**0.465**	0.157	0.192
NO_2^{-}-N	−0.285	**0.306**	−0.095	**−0.333**	0.008	0.08
NO_3^{-}-N	0.121	0.159	0.289	**−0.357**	**0.45**	−0.23
SO_4^{2-}	−0.281	0.14	−0.106	**−0.432**	−0.069	−0.238
PO_4^{3-}-P	0.163	0.236	**0.416**	0.201	−0.111	−0.2
Cl^{-}	−0.269	**−0.363**	0.264	0.079	0.035	−0.227
TN	−0.152	0.235	−0.248	0.175	−0.264	**−0.548**
TP	0.12	**0.352**	**0.333**	0.257	**−0.345**	0.068
Coliform	**−0.332**	0.045	0.291	−0.176	0.069	−0.129
EV	4.63	2.59	2.36	1.52	1.24	1.02
%Var	29	16.2	14.7	9.5	7.8	6.4
Cum.%Var	29	45.2	59.9	69.4	77.1	83.5

PC2 accounted for 16.2% of the total variance contributed by the parameters EC (−0.338), DO (−0.438), TSS (0.389), NO_2^{-}-N (0.306), Cl^{-} (−0.363), and TP (0.352) in weak correlation. PC3 accounted for 14.7% of the total variance contributed by parameters pH (0.35), PO_4^{3-}-P (0.416), TP (0.333) at a weak correlation. Thereby, it can be seen that water sources were affected by agriculture and wastewater from industrial zones. For the remaining PCs, the contribution of temperature parameters (−0.641), TN (−0.548), TSS (0.542), TP (−0.597), NO_2^{-}-N (−0.557), and SO_4^{2-} (0.583) were at average correlation. This group of nutritional parameters also reflected the levels of eutrophication and organic pollution, indicating that anthropogenic pollution mainly originated from both domestic and industrial discharge, as well as from agricultural wastewater. The results of PCA analysis showed that most of the indicators were affected by PCs, however, there were a few indicators that were less affected such as COD, BOD, Cl^{-} and coliforms. The study by Chounlamany *et al*. [13] also highlighted that each PCs is representative of a pollution source. In addition, indicators with average or higher correlation should be included in the monitoring program [46]. Thereby, the parameters of temperature, TN, TSS, NO_2^--N, and SO_4^{2-} need to be included in the monitoring program because they affect surface water quality in Tien Giang province.

C. Evaluation of Water Quality Monitoring Position

Fig. 3 shows that the clustering according to the red line it could be divided into three groups at a distance of 6. On the other hand, for a more detailed observation of water quality changes, it was possible to follow the blue line to divide into seven groups at a distance of 4.5.

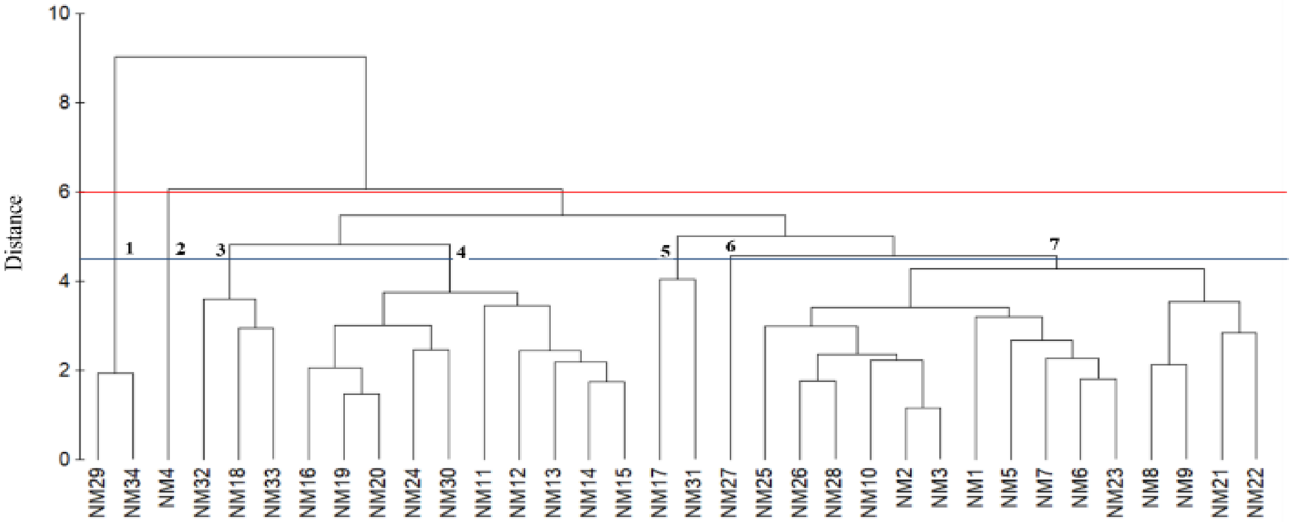

Fig. 3. Clustering surface water quality in Tien Giang's water bodies.

From the results of cluster analysis divided into seven groups, the average result of each group can be calculated as shown in Table 2. In Group 1 (NM29, NM34), the conductivity value of 2915 µS/cm was higher than that of Group 1 (NM29, NM34). Pollution effects of water with high conductivity were often related to the toxicity of water-soluble ions [47]. Cl^- value in this group was also very high 2332.05 µS/cm. Because these sites were located in the coastal area, leading to high conductivity and Cl^-, which could affect domestic uses. Group 2 had only one NM4 site, because this location was observed in the seafood processing area (My Tho industrial park), so the PO_4^{3-}-P (0.48 mg/L) concentration was 2.4 times higher than that of group 2. With a high concentration of PO_4^{3-}-P, if not treated, it will cause eutrophication. In addition, DO, TSS, BOD, NH_4^+-N did not meet the limits of QCVN 08-MT: 2015/BTNMT, column A2. In Group 3 (NM18, NM32, NM33), Group 4 (NM11, NM12, NM13, NM14, NM15, NM16, NM19, NM20, NM24, NM30) and Group 5 (NM17, NM31) showed polluted water quality through DO, TSS, COD, BOD, NH_4^+-N, and NO_2^--N. The DO concentration in all groups did not meet the standards of QCVN 08-MT: 2015/BTNMT, column A2 because TSS in these groups was high, reducing light affecting the photosynthesis of algae. Furthermore, when the organic matter in the water body is abundant, the decomposition of organic matter consumes dissolved oxygen, which will pollute the water body [48, 49]. Group 6 (NM27) indicated the water was mainly organic polluted, which may be due to the influence of residential areas and livestock. For positions NM1, NM2, NM3, NM5, NM6, NM7, NM8, NM9, NM10, NM21, NM22, NM23, NM25, NM26, NM28 in Group 7, most of the positions in this group were affected by residential areas. Therefore, the parameters of DO, TSS, BOD, NO_2^--N all exceeded the limits of column A2 of QCVN 08-MT: 2015/BTNMT.

The results of Table III show that group 1 was more polluted than the other groups based on the average values of EC, TSS, COD, BOD, NH_4^+-N, NO_2^--N, Cl^-. In general, the surface water quality in Tien Giang province was mainly poor due to organically polluted. As a result, CA can reduce the locations on the same river in the group from 34 sites to 29 (Fig. 4). Because some monitoring locations have similar values or are located on the similar rivers, such as NM1, NM2, NM3, NM5, and NM13. Therefore, this study suggested that location for monitoring should be reduced the sampling location for the local gorvement. They would be saved the monitoring costs, approximately 14.7%.

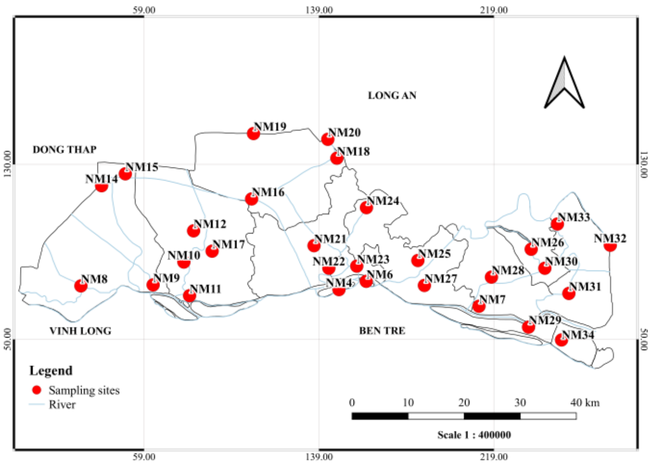

Fig. 4. Map of proposed water sampling locations after clustering.

The correlation between 16 variables at 34 sampling locations along rivers in Tien Giang province in 2021 is presented in Table IV. The results show that EC was positively correlated with DO, COD, BOD, Cl^-, and coliform. The study also recorded that TSS had negative correlation with PO_4^{3-}-P and TP. It was shown that the suspended solids in water tended to adsorb PO_4^{3-}-P [50]. DO had significant positive relationship with Cl^-, which has also have been well explained by [51]. COD was correlated positively with BOD at a high level (r=0.97, $p<0.01$). There was no statistically significant difference between two parameters, meaning that most organic matter was quickly biodegraded. Besides, NO_3^- confirmed positive relationship PO_4^{3-} (r=0.37, $p<0.05$), which also recorded in [52]. In addition, COD and BOD also moderate positive correlation with NH_4^+-N, NO_2^--N, Cl^-, coliform. Meanwhile, NH_4^+-N parameter was positively correlated with NO_2^--N (r=0.35, $p<0.05$) and negatively correlated with NO_3^--N (r=−0.34, $p<0.05$).

In general, the highlights of this study could support the water quality monitoring program in Tien Giang province. However, to sustainable development and resolves water surface pollution issues in future, the local authorities should draft strategies for future planning purposes to reduce contaminants from agricultural fields and industrial fields. Besides the current monitoring program of Tien Giang province, the local government should be applied suitable management strategies to improve water surface quality in catchments of Tien Giang province, such as risk assessment for effective restoration management and watershed conservation management, which was applied in the previous studies [53–55]. On the other hand, a comprehensive and flexible framework is needed to manages the surface water quality, the soil environment, and protects the aquatic life. In addition, the wastewater treatment in industrial zones should also be strictly monitored.

TABLE III: WATER QUALITY IN THE IDENTIFIED GROUPS

Variables	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	QCVN, A2
pH	7.47	7.71	7.65	7.26	7	7.86	7.78	6–8.5
Temperature (^{0}C)	30.23	29.68	30,.72	30.23	30.60	29.80	29.75	-
EC (µS/cm)	**2915**	211.25	897.19	437.76	431.88	892.25	279.87	-
DO (mg/L)	5.06	**4.40**	**4.20**	**2.95**	**3.40**	**3.20**	**3.83**	≥5
TSS (mg/L)	**89.88**	**133**	**83.06**	**100.5**	**110.25**	**124.50**	**88.62**	30
COD (mg/L)	**20.63**	13.50	**16.69**	**17.98**	**17.13**	13.50	13.45	15
BOD (mg/L)	**11.38**	**6.75**	**9.06**	**9.60**	**9.63**	**7.50**	**6.90**	6
NH_4^+-N (mg/L)	**0.564**	**0.328**	**0.437**	**0.496**	**1.008**	**0.485**	0.259	0.3
NO_2^--N (mg/L)	**0.095**	0.025	**0.141**	**0.252**	**0.150**	0.034	**0.061**	0.05
NO_3^--N (mg/L)	0.243	0.463	0,.262	0.295	0.144	0.315	0.315	5
SO_4^{2-} (mg/L)	69.82	24.38	46.51	72.85	53.71	66.20	45.79	-
PO_4^{3-}-P (mg/L)	0.06	**0.48**	0.14	0.07	0.08	0.17	0.09	0.2
Cl^- (mg/L)	**2332.05**	24.85	226.28	53.90	78.01	78.53	37.22	350
TN (mg/L)	3.22	3.65	4.06	3.87	3,.94	4,.11	2.81	-
TP (mg/L)	0.098	0.560	0.198	0.159	0.328	0.235	0.190	-
Coliforms (MPN/100 mL)	3366.67	2545	1816.25	2171	1120	847.50	1128.17	5000

TABLE IV: PEARSON CORRELATION AMONG WATER VARIABLES IN WATER BODIES

Variables	pH	Temp.	EC	DO	TSS	COD	BOD	NH_4^+-N	NO_2^--N	NO_3^--N	SO_4^{2-}	PO_4^{3-}-P	Cl^-	TN	TP
Temp.	0.013	1													
EC	0.017	0.187	1												
DO	0.212	0.107	**0.376***	1											
TSS	0.111	-0.144	−0.074	−0.118	1										
COD	−0.146	0.175	**0.519****	−0.141	0.262	1									
BOD	−0.097	0.306	**0.561****	−0.122	0.228	**0.971****	1								
NH_4^+-N	**−0.470****	0.032	0.332	−0.331	0.112	**0.651****	**0.632****	1							
NO_2^--N	−0.066	0.272	0.097	−0**.561****	0.247	**0.409***	**0.446****	**0.352***	1						
NO_3^--N	0.176	−0**.398***	−0.200	0.024	0.243	−0.103	−0.163	−0**.344***	0.024	1					
SO_4^{2-}	−0.150	**0.341***	0.245	−0.244	0.248	0.324	**0.421***	0.135	**0.627****	0.020	1				
PO_4^{3-}-P	0.210	−0.254	−0.169	0.089	**0.346***	−0.195	−0.222	−0.079	−0.192	**0.375***	−0.318	1			
Cl^-	−0.005	0.074	**0.947****	**0.425***	−0.081	**0.405***	**0.429***	0.233	−0.002	−0.158	0.149	−0.129	1		
TN	**−0.470****	0.252	0.024	−0.320	0.177	0.154	0.147	0.233	0.294	−0.236	0.298	−0.055	−0.052	1	
TP	0.306	−0.164	−0.286	−0.091	**0.532****	−0.090	−0.100	0.038	−0.067	0.066	−0.227	**0.703****	−0.231	0.061	1
Coliform	0.031	0.143	**0.597****	−0.080	0.202	**0.576****	**0.604****	0.293	**0.532****	0.147	**0.433***	0.086	**0.574****	0.084	0.014

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

IV. CONCLUSIONS

Multivariate statistics were useful to assess surface water quality in Tien Giang province. The results of the study showed that the surface water of Tien Giang province in 2021 was contaminated with organic matter, suspended solids, and nutrients. In general, there was no general pattern for temporal differences in parameters of surface water quality between the rainy season (September and November) and the dry season (March and June) in Tien Giang province in 2021. The PCA analysis predicted 6 pollution sources of which three main sources are PC1, PC2, and PC3 which explained

59.9% of variation in water quality. The PCA results also showed that the parameters of temperature, BOD, COD, DO, TN, TSS, NO_2^--N, and SO_4^{2-} had the main influence on surface water quality in Tien Giang province, so it is necessary to continue monitoring. The main sources of pollution were rainwater runoff, impacts of agriculture, residential areas, and industrial zones. The CA analysis results showed that with the current monitoring system, 34 locations can be reduced to 29 locations, reducing monitoring costs by about 14.7%. The results of this study can help managers review locations and indicators of surface water environment monitoring in Tien Giang province. Further studies need to investigate specifically the sources that affect water quality in order to have a good management solution.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Nguyen Cong Thuan conducted the designation of research, and collection and analysis of the data; Nguyen Cong Thuan and Huynh Cong Khanh wrote and revised the manuscript. All authors had approved the final version.

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