



## ASSESSING SURFACE WATER QUALITY IN TIEN RIVER BELONGING TO TIEN GIANG PROVINCE, VIETNAM

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### Abstract

*The study was conducted to evaluate surface water quality, location, frequency and monitoring indicators of surface water of Tien River, Tien Giang province in 2019. Data were collected from the Department of Natural Resources and Environment of Tien Giang Province at 7 survey locations at 4 times a year and water variables including pH, temperature, dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD) and biological oxygen (BOD), ammonium ( $N-NH_4^+$ ), nitrite ( $N-NO_2^-$ ), nitrate ( $N-NO_3^-$ ), orthophosphate ( $P-PO_4^{3-}$ ), total nitrogen (TN), total phosphorus (TP) and coliform. Surface water quality was compared with National technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT, column A1). The main water variables and potential sources of pollution affecting water quality were evaluated using principal component analysis (PCA), while the dense of water monitoring locations was assessed using cluster analysis (CA). The results showed that surface water of Tien River in Tien Giang province was contaminated with TSS, organic matters (low DO, high COD, high BOD), nutrients (TN, TP,  $P-PO_4^{3-}$ ) and coliform. Water quality was affected by several sources such as hydrology, residential areas, urban areas, industry, agriculture and fisheries. The PCA results showed that the main parameters affecting surface water were pH, DO, TSS, COD, BOD,  $N-NO_2^-$ ,  $N-NO_3^-$ ,  $P-PO_4^{3-}$ , TN, TP, coliform. The overall results suggested that pH, DO, TSS, COD,  $N-NO_3^-$ ,  $P-PO_4^{3-}$ , TN, TP, coliform should be included in the monitoring program in this river segment. CA results revealed that from 7 current monitoring locations can be reduced to 4 locations and 4 monitoring periods into 2 - 3 monitoring periods still ensuring the representativeness of water quality on Tien River in Tien Giang province. The research results provide important information to support surface water monitoring on the Tien River.*

**Keywords:** Surface water; Tien River; Tien Giang province; Principal component analysis; Cluster analysis.

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### 1. Introduction

Water, one of the most important resources of life on Earth, is a decisive factor for the survival and development

of life. Water is widely used in daily life, agricultural production, industry and transportation. Tien Giang is a coastal province in the Vietnamese Mekong

delta, like other provinces, Tien Giang has been investing in the development of urban infrastructure, industrial activities are increasingly developing with the establishment of industrial zones such as My Tho industrial park, Tan Huong industrial park, Long Giang industrial park, Xoai Rap petroleum industrial park, Binh Dong industrial park. Several industrial clusters with large scale such as An Thanh industrial cluster, Tan My Chanh industrial cluster, Binh Duc industrial cluster, Binh Xuan industrial cluster and several productions and business establishments outside the industrial cluster. Therefore, the development of the province has been threatening the environmental quality in the local and neighboring areas. The Tien River is the left downstream branch of the Mekong river, flowing from Cambodia into the Vietnamese Mekong delta, through the provinces of An Giang, Dong Thap, Tien Giang, Vinh Long, Tra Vinh, Ben Tre and then discharges into the East Sea. Tien River has total length of more than 234 km. Tien River flows through the territory of Tien Giang province with a length of 120 km, in terms of natural characteristics, 92 % of the area of Tien Giang province belongs to the Tien river basin and this river is the main source of irrigation water and domestic water for the whole province. Therefore, Tien river together with its branches play a very important role in the socio - economic development of Tien Giang province.

For Tien Giang province, Tien River plays a very important position in providing freshwater for agriculture, aquaculture, water supply for daily use of people along the two sides of the river bank. Especially, the river is the most important input water source for water plants, centers, centralized water supply stations, to treat

and supply the people. Besides, Tien River is the place receiving wastewater mostly from socio - economic activities on both sides of the river and a part of wastewater from the surrounding areas, canals pour into the river. Environmental monitoring plays a very important role in water quality management. But the selection of monitoring indicators, identification of sources of pollution, selection of sites and number of sampling sites is always a difficult problem. Water is an indispensable fundamental element in maintaining life and all activities of humans and organisms, so water quality monitoring plays an important role in the effective management of water resources [1 - 3]. In recent years, multivariate analysis techniques in which Principal Component Analysis (PCA) and Cluster Analysis (CA) have been used to evaluate changes in water quality in space and time, it supports the identification of sources of pollution [4 - 7]. From the above studies, it showed that PCA and CA can assist decision - making in identifying pollution sources, identifying water quality indicators and monitoring sites. The study was conducted to evaluate surface water quality of Tien River, to evaluate main polluting parameters, monitoring location and frequency on Tien River, Tien Giang province using multivariate statistical methods. The research results provide important information to support surface water monitoring on the Tien River.

## **2. Material and methods**

In this study, surface water quality data at 7 monitoring points (NM1 - NM7) with the frequency of four times per year (March, June, September and November) on Tien River in 2019 were collected (Table 1). The studied water

quality parameters were pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium (N-NH<sub>4</sub><sup>+</sup>), nitrite (N-NO<sub>2</sub><sup>-</sup>), nitrate (N-NO<sub>3</sub><sup>-</sup>), orthophosphate (P-PO<sub>4</sub><sup>3-</sup>), total nitrogen (TN), total phosphorus (TP) and coliform. The

water quality parameters such as pH, DO were measured in the field while BOD, COD, TSS, N-NH<sub>4</sub><sup>+</sup>, N-NO<sub>2</sub><sup>-</sup>, N-NO<sub>3</sub><sup>-</sup>, TN, P-PO<sub>4</sub><sup>3-</sup>, TP and coliform were analyzed at the laboratory of Tien Giang Natural Resources and Environment Monitoring Center according to standard methods [7].

**Table 1. Description of the monitoring site**

Code	Sampling coordinates		Purposes of the sampling sites
	Longitude	Latitude	
NM1	106° 02' 0,35"	10° 19' 28"	The site influenced by residential area
NM2	106° 03' 48"	10° 19' 24"	The site influenced by residential area
NM3	106° 07' 0,3"	10° 18' 16,08"	The site influenced by transportation
NM4	106° 20' 3,4"	10° 20' 44,7"	The site influenced by food processing industry, My Kho industrial area
NM5	106° 21' 44"	10° 21' 11,8"	The site influenced by residential area, water supply
NM6	106° 22' 21,6"	10° 20' 30,6"	The site influenced by wastewater from Fish processing industry at fish port
NM7	106° 32' 52,4"	10° 18' 7,2"	The site influenced by residential area

Principal Component Analysis (PCA) was used to determine the most influential water quality indicators and forecast sources of water pollution. This method can reduce orthogonal and non correlated variables, which allows to explain the total variation and make a new set of principal components (PCs) with the limited loss of important information. To extract PCs, a standardization of the data was conducted, known as the covariance matrix. Based on the covariance matrix, the eigenvalues that are from the eigenvectors were generated. The main component was evaluated through the eigenvalues coefficient. The larger this coefficient, the greater the principal component that contributes to the explanation of the variation of the original data set. Correlation

between the principal component and the primary data variables is explained by the weighted correlation data [8]. 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 very strong, from 0.5 - 0.75 a moderate correlation and less than 0.5 a weak correlation [9]. Cluster analysis (CA) was used to group sites with similar water quality by Ward's method and create a dendrogram model. Euclidean distance and average linkage method were applied to produce the dendrogram. PCA and CA analysis were analyzed using Primer V5.2 for Windows copyright software (PRIMER - E Ltd, Plymouth, UK).

### 3. Results and discussion

#### *3.1. Description of water quality in Tien River in 2019 in the study area*

The average pH over the survey locations ranged from 7.71 to 8.0 pH on Tien River fluctuated according to seasons, the lowest pH in dry season (March), the highest in rainy season (September). However, pH on Tien River was within the permissible limits of QCVN 08-MT:2015/BTNMT, column A1 (6 - 8.5). Previous research showed that pH on canals in An Giang 2006 - 2009 ranged from 6.9 - 7.1 (Ly and Giao, 2018), on main rivers and tributaries of Hau River in 2016 ranged from 6.3 - 8.0 [10] and Hau River, An Giang, Hau Giang section, ranged from 6.7 - 7.12 [3]. In general, pH values in studies have the similarity that pH has little variation in space and time and is within the allowable range of the National Technical Regulation on surface water quality QCVN 08-MT:2015/BTNMT. The fluctuation range of pH value on Tien River in 2019 was very suitable for the development of aquatic organisms [11].

The temperature on Tien River was in the range of 29.35 - 30.2 °C and there was no statistically significant difference ( $p > 0.05$ ). The water temperature of Hau River ranged from 27.1 - 32.0 [3, 10, 13] and on the Mekong river was from 19.9 - 32.2 °C [2, 12]. Water temperature tended to decrease in September [10], however, fluctuations in water temperature were not large [13] due to the function of water conditioning. Temperatures were within the range suitable for the growth of aquatic organisms [11, 14]. Suitable temperature for aquatic life ranges from 25 - 32 °C [14]. Thus, the water temperature in the

current study fluctuates in the general range of the area and was still suitable for the development of aquatic life.

TSS in Tien River varied greatly from 72.5 to 133 mg/L (Table 2). In the canals of An Giang province in the period 2009 - 2016, TSS ranged from  $25.0 \pm 11.5$  mg/L to  $93.7 \pm 28.3$  mg/L [13]; Particularly for Hau River in the period 2009 - 2016 it was 40.1 - 68.0 mg/L [13] and in 2018 it was  $41.16 \pm 35.81$  -  $48.67 \pm 9.07$  mg/L [3]. In canals in Soc Trang province, TSS was in the range of 16 - 176 mg/L [15]. TSS in March (dry season) was lower than those in other months (rainy season) probably because this time in the rainy season, the water flow on the river is high, water flows strongly, floods from upstream bring a lot of silt plus material washed away from both sides of the river. Research by [10] also showed that water quality was heavily influenced by time, in which the TSS rainy season was always higher than the season due to the effects of storm water runoff and erosion. TSS upstream tended to be higher than downstream because of the flow rate and the amount of sediment contained in the water column [3]. The lowest TSS was 20 mg/L in March at Ngu Hiep ferry terminal - Song Nam Thon - Cai Lay district. The highest TSS was 184 mg/L in November in the seafood processing area (My Tho industrial park). The difference between the highest and lowest TSS content was 164 mg/L, 9.2 times more. TSS at most positions exceeded the limits of QCVN 08-MT:2015/BTNMT column A1 (20 mg/L).

Average DO ranged from 3.56 to 4.83 mg/L (Table 2). The lowest DO is 2.2 mg/L in November in Vam Cai Be - Nguyen Cai raft where the residential area affected. The highest DO was 5.4

mg/L in June at Cong Vam Giong - Tien River in Go Cong Tay district influenced by the residential area. The average DO in the upstream waters of An Giang ranged from 4.0 - 5.2 mg/L [13] and the Hau River in 2016 was  $4.8 \pm 1.1 - 5.5 \pm 0.7$  mg/L [10], that in 2018 was  $5.29 \pm 0.33 - 5.56 \pm 0.56$  mg/L [3]. In canals in Soc Trang province, DO was lower than

other studies, ranging from 1.7 - 6.17 mg/L (Tuan et al., 2019). Average DO values in this study at all locations did not meet QCVN 08-MT:2015/BTNMT, column A1 ( $\geq 6$  mg/L). According to [14] that the appropriate DO in water was 5 - 7 (mg/L), it can be seen that the average DO at locations was not in this suitable range.

**Table 2. Summary of surface water quality in Tien River belonging to Tien Giang province**

KHM	NM1	NM2	NM3	NM4	NM5	NM6	NM7	QCVN*
pH	7.84	7.94	7.73	7.71	7.75	7.79	8.07	6 - 8,5
Temp	30.20	30.03	29.35	29.68	29.85	29.75	29.53	-
DO	3.56	3.69	3.92	4.40	4.57	4.43	4.83	$\geq 6$
TSS	72.50	106.25	77.75	133.00	106.75	111.25	119.25	20
COD	10.75	13.50	13.75	13.50	13.75	15.50	14.50	10
BOD	5.75	6.75	7.00	6.75	6.75	7.50	7.25	4
N-NH <sub>4</sub> <sup>+</sup>	0.20	0.20	0.18	0.33	0.26	0.19	0.21	0.3
N-NO <sub>2</sub> <sup>-</sup>	0.03	0.02	0.04	0.03	0.06	0.02	0.03	0.05
N-NO <sub>3</sub> <sup>-</sup>	0.28	0.31	0.33	0.46	0.50	0.33	0.23	2
TN	4.09	2.20	2.55	3.65	1.65	3.57	2.78	-
P-PO <sub>4</sub> <sup>3-</sup>	0.18	0.09	0.10	0.48	0.08	0.09	0.05	0.1
TP	0.26	0.28	0.19	0.56	0.11	0.19	0.27	-
Coliform	1042.50	1350.00	1375.00	1695.85	1087.50	975.00	817.50	2500

\*National technical regulation on surface water quality (QCVN:08-MT:2015/BTNMT). A1 means water quality used for domestic purposes (after normal treatment has been applied), conservation of aquatic plants and animals and other purposes; A2 is used for domestic purposes but treatment technology must be applied.

COD on Tien River ranged from 10.75 to 15.5 mg/L, the lowest was 7 mg/L in March at Cong Vam Giong - Song Tien in Go Cong Tay district where was affected by the residential area. Highest COD 20 mg/L in November at Ben Chuong Duong - My Tho City was also influenced by residential areas. COD did not have a large difference in COD values in the dry and rainy seasons in Tien River. CODs in Tien River at all locations exceeded the permitted limits of QCVN 08-MT:2015/BTNMT, column A1 (10 mg/L). According to Thao's study (2016), the average COD (11.55 - 17.82 mg/L) in

certain major rivers and canals in Can Tho city all exceeded QCVN 08-MT:2015/BTNMT, column A1 (10 mg/L).

Similar to COD, the BOD at all positions (5.75 - 7.5 mg/L) was higher than the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (4 mg/L). According to [16] reported that the BOD in canals of Can Tho city was in the range of 7.23 - 15.59 mg/L which was higher than this study. BOD in Tien River has seasonal variation, with the lowest in March (4 mg/L) and highest in November (9 mg/L). BOD in rivers and canals including infield canals and Hau River of

An Giang province were in the range of  $6.6 \pm 1.2 - 8.2 \pm 2.5$  mg/L [13], canals in Soc Trang province were in the range of  $2.2 - 22.4$  mg/L [15] almost surpassed QCVN 08-MT:2015/BTNMT, column A1. River water with a BOD exceeding QCVN causes many risks when used as water supply because carbon compounds can combine with chlorine in the sterilization process to produce compounds that are hazardous to health when exposed to community through water use [17]. Like TSS, organic pollution due to high BOD content is a common problem of water bodies in the Mekong delta. The source of BOD generation can be waste from farming, livestock, landfills, domestic activities and services that discharge untreated waste into surface water [2, 18, 19]. The research results showed that the water quality of Tien River was polluted organically, not suitable for domestic water supply purposes, only for irrigation and irrigation purposes.

$\text{N-NH}_4^+$  at the study sites ranged from 0.18 to 0.33 mg/L (Table 2).  $\text{N-NH}_4^+$  in rainy season was higher than dry season. The lowest  $\text{N-NH}_4^+$  was 0.01 mg / L in November at Cong Vam Giong - Song Tien in Go Cong Tay district affected by the residential area, the highest was 0.7 mg/L in March in the region of seafood processing (My Tho industrial park) influenced by the seafood processing area - My Tho industrial park.  $\text{N-NH}_4^+$  were within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1 (0.3 mg/L) (except for NM4 position 0.33 mg/L). Phuong (2016) reported  $\text{N-NH}_4^+$  in certain main rivers and canals in Hau Giang province ranged from 0.245 to 0.948 mg/L, in Soc Trang ranged from 0.02 - 4.15 mg/L [15] all positions exceeded QCVN 08-MT:2015/

BTNMT, column A1 (0.3 mg/L) and higher than  $\text{N-NH}_4^+$  in Tien River. Nitrite in Tien River is in the range of 0.020 - 0.061 mg/L, of which, NM5 position has the highest average nitrite protein (0.061 mg/L) because it is located in Ben Chuong Duong area - My Tho city influenced by the residential area and the lowest nitrite was 0.0025 mg/L at Ca My Tho port - Ward 8 - My Tho city. Former study showed that nitrite in canals in Hau Giang province was in the range of 0.001 - 0.56 mg/L, higher than those in Tien River in Tien Giang province. Average nitrite nitrogen of Tien River (except NM5), the remaining locations all met the limits of QCVN 08-MT:2015/BTNMT, column A1 (0.05 mg/L) [20].

Average nitrate nitrogen across the locations ranged from 0.23 to 0.50 mg/L. Nitrate in March in most locations was higher than the rest. Nitrate in the dry season had higher concentration than that in the rainy season. Previous study showed that the nitrate in Hau River ranged from 0.002 - 0.395 mg/L [10], in An Giang canal from  $0.31 \pm 0.3$  to  $0.58 \pm 0.64$  mg/L [13], in the canals of Soc Trang province 0.05 - 0.14 mg/L [15]. Thus, nitrate in the rivers of the Vietnamese Mekong delta fluctuates greatly, according to seasons, according to sampling locations, however, it is still within the permitted limits of QCVN 08-MT:2015/BTNMT, column A1 (2 mg/L). The concentration of nitrate is greater than 0.7 mg/L and in the range of 0.2 - 10 mg/L has potential to cause eutrophication and is suitable for aquatic life [12, 14]. In this study, the average nitrate at all locations was much lower than the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (2 mg/L). The concentration of nitrate suitable for aquaculture is from 0.2 to 10 mg/L [14].

The average orthophosphate concentration across the sampling sites ranged from 0.05 to 0.48 mg/L (Table 2). The orthophosphate concentration of the dry season was higher than that in the rainy season, the reason was that the water flow on the river was low in the dry season, so the dilution of wastewater from seafood processing, domestic activities and animal husbandry was lower than that in the rainy season. Orthophosphate in infield canals and Hau River in An Giang province ranged from 0.02 to 0.47 mg/L [13], in Hau River An Giang - Hau Giang section 0.04 - 0.11 mg/L [3], in canals of Soc Trang province 0.05 - 0.9 mg/L [15] showed that orthophosphate in surface water environment in the Vietnamese Mekong delta has exceeded QCVN 08-MT:2015/BTNMT, column A1. In this study, most average orthophosphate positions were in the limit of column A1 (0.1 mg/L) of QCVN 08-MT:2015/BTNMT (except NM1 and NM4). The source of phosphorus can be attributed to fertilizers, detergents from farming, animal husbandry and industry [21].

Average TN at different locations ranged from 1.65 - 4.09 mg/L. The lowest average TN in Ben Chuong Duong - My Tho city influenced by the residential area and the highest average TN in Vam Cai Be - Cai Be district also influenced by the residential area. High TN may be due to river water receiving domestic and industrial wastewater and wastewater from agriculture and livestock. The sampling times in the rainy season had lower TN than that in the dry season, except for the location of the Ba Lai estuary and the area affected by wastewater from seafood processing. The highest TN was 5.23 mg/L in March at Ngu Hiep ferry terminal - Song Nam Thon - Cai Lay district, the

lowest was 1.65 mg/L at several different locations. The difference between the highest and the lowest TN was 3.58 mg/L. According to [22], in order to minimize the ability of water eutrophication, TN should not exceed 3 mg/L. When TN is higher than 1.7 mg/L, the ability to cause water eutrophication is high [12]. The positions NM1 (4.09 mg/L), NM4 (3.65 mg/L) and NM6 (3.57 mg/L) had the average TN higher than 3 mg/L. The highest TN was 5.23 mg/L in March at Ngu Hiep ferry terminal - Song Nam Thon - Cai Lay district, affected by river transport activities.

It was found that the average TP on Tien River ranges from 0.11 - 0.56 mg/L. The lowest TP in Ben Chuong Duong - My Tho city is affected by domestic and agricultural wastewater. The highest TP was found in the Seafood Processing Area (My Tho industrial park). TP at the time of sampling in the dry season was higher than that in the rainy season. According to [22], TP > 0.1 mg/L, eutrophication is very likely to occur. The average TP in the survey locations were all higher than 0.1 mg/L, this proves that the water in these locations is likely to be eutrophic.

In the Tien River in Tien Giang province, the average coliforms ranged from 817.5 - 2545 MPN/100 mL, the lowest density was in Cong Vam Giong - Song Tien in Go Cong Tay district and the highest density was found in the seafood processing area (My Tho industrial park). Former study by [13] showed that coliforms in surface water of An Giang province in the period of 2009 - 2016 exceeded the permitted limit by 2.14 - 7.02 times. In canals of Soc Trang province, coliforms exceeded 1 to 36 times [15]. Coliforms are groups of bacteria used to evaluate natural water and these bacteria

is commonly found in the digestive tract of hot - blooded animals. Therefore, the cause of high coliforms is the waste from seafood processing zones. The number of coliforms in rainy season was higher than that in dry season. Husbandry activities and discharging waste from family activities as well as fields directly into the river without any treatment contributed to increasing coliform pollution in the water. The highest coliform was 3600 MPN/100 mL in June in the seafood processing area (My Tho industrial park) affected by the seafood processing area - My Tho industrial park, the lowest density was 210 MPN/100 mL in March at Cong Vam Giong - Song Tien in Go Cong Tay district influenced by residential area. The study results showed that all sampling locations had coliforms lower than the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (2500 MPN/100 mL), except for position NM4 which was higher than regulation 1.44 times.

The results of the discussion of water quality assessment parameters showed that Tien River water in Tien Giang province was not suitable for domestic purposes. The water parameters of DO, TSS, COD, BOD, TN and TP were higher than the permitted limits. Tien river water in Tien Giang province has high turbidity, high organic matters and high nutrients that could cause eutrophication of water sources while low dissolved in water that could cause lack of oxygen for organisms in the water. Besides, the water quality of NM4 and NM6 locations should be paid special attention because these two locations were affected by fish processing wastewater. This could prove that the surface water source did not guarantee the quality of water used for domestic purposes, so it is recommended that people

living along rivers and surrounding areas need to take measures to treat thoroughly before put to use to ensure the safety.

### ***3.2. Main variables influencing surface water quality in the study area***

Principal component analysis was used to analyze the main factors affecting water quality at 7 sampling locations on Tien River, Tien Giang province in 2019 using 13 water indicators at 7 water monitoring points. PCA results were shown in Table 3. The results presented that there were 5 sources of pollution that could explain 94.8 % of the variation in water quality in the study area.

Component 1 (PC1) accounted for 33.3 % of the total variance, including the indicators of pH (0.315),  $P-PO_4^{3-}$  (-0,385), coliform (-0,369) correlated weakly with PC1. Thus, PC1 explained for the variation of water quality in the area influenced by pH, nutrient and microorganisms. PC1 could be a mixed source due to the impact of hydrological conditions, natural factors, livestock and human wastes [21, 23, 24]. Component 2 (PC2) explained 27 % of the variation in water quality through the criteria DO (0.414), TSS (0.415), COD (0.367), BOD (0.349). These parameters were correlated positively and weakly with PC2. This could imply that the sources of pollution for water quality were organic matters and suspended solids. The high concentration of BOD and COD in river water was mainly due to the influence of socio - economic activities such as agriculture, industry, services, population and urban [1, 6]. The high TSS is due to storm water runoff, riverbank erosion and the presence of phytoplankton (Giao, 2020). Total variance of 17.5 % of PC3 included pH (-0.316),  $N-NO_2^-$

(0.488), N-NO<sub>3</sub><sup>-</sup> (0.347), TN (-0,368), TP (-0.412). These parameters were correlated weakly with PC3, in which N-NO<sub>2</sub><sup>-</sup>, N-NO<sub>3</sub><sup>-</sup> correlated positively with PC3. It could be seen that PC3 characterized the pollution source arising from agricultural production and human activities. PC4 had a total variance of 10.6%, including parameters COD(0.337), BOD (0.358), N-NH<sub>4</sub><sup>+</sup> (-0.312), N-NO<sub>2</sub><sup>-</sup> (-0,364). Component 5 (PC5) has a total variance of 6.3 % with the contribution of the temperature (0.691), TSS (0.345).

In general, Tien River in the study area was affected by 5 pollution sources PC1 - PC5 representing natural and man - made pollution sources including hydrological regime, agricultural production, industry, residential areas, urban areas. The main parameters affecting the quality of surface water in the study area include pH, temperature, DO, TSS, COD, BOD, N-NO<sub>2</sub><sup>-</sup>, N-NO<sub>3</sub><sup>-</sup>, P-PO<sub>4</sub><sup>3-</sup>, TN, TP, coliform, therefore needs to be monitored in the monitoring program.

**Table 3. Main variables influencing surface water quality in the study area**

Variables	PC1	PC2	PC3	PC4	PC5
pH	0,315	-0,059	-0,316	-0,222	0,176
Temp	-0,099	-0,288	-0,029	-0,218	0,691
DO	0,144	0,414	0,015	-0,233	-0,074
TSS	-0,028	0,415	-0,204	-0,089	0,345
COD	0,196	0,367	0,030	0,337	0,084
BOD	0,216	0,349	-0,006	0,358	-0,036
N-NH <sub>4</sub> <sup>+</sup>	-0,296	0,283	-0,035	-0,312	0,112
N-NO <sub>2</sub> <sup>-</sup>	-0,032	0,082	0,488	-0,364	-0,240
N-NO <sub>3</sub> <sup>-</sup>	-0,267	0,231	0,347	-0,095	0,194
P-PO <sub>4</sub> <sup>3-</sup>	-0,385	0,134	-0,201	-0,082	-0,079
TN	-0,159	-0,121	-0,368	0,039	-0,189
TP	-0,278	0,140	-0,412	-0,055	-0,037
Coliform	-0,369	0,198	-0,103	0,004	-0,239
Eigenvalues	5,33	4,32	2,80	1,70	1,01
Variance (%)	33,3	27,0	17,5	10,6	6,3
Cum. Var (%)	33,3	60,4	77,9	88,5	94,8

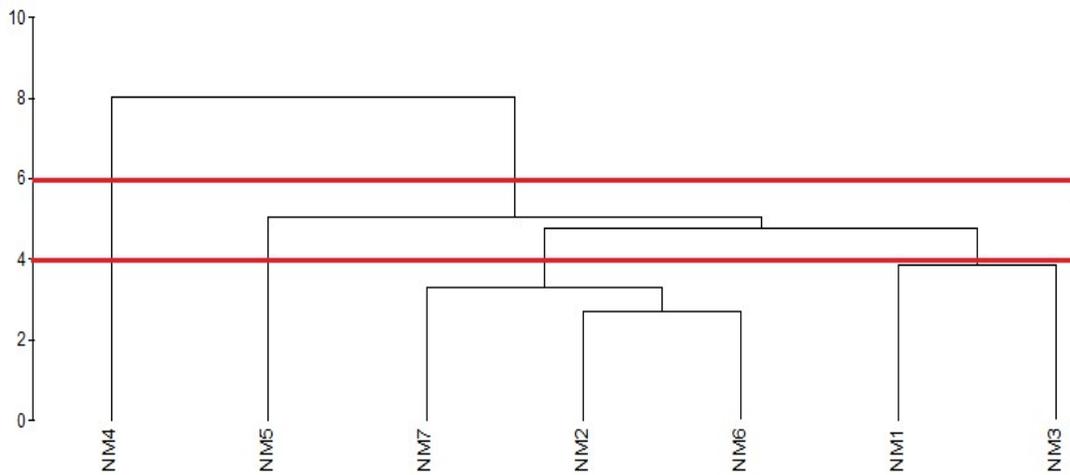
### **3.3. Analysis of sampling locations and frequency of surface water quality in Tien River segment belonging to Tien Giang province**

Cluster analysis was performed using the mean values of pH, temperature, DO, TSS, COD, BOD, N-NH<sub>4</sub><sup>+</sup>, N-NO<sub>2</sub><sup>-</sup>, N-NO<sub>3</sub><sup>-</sup>, orthophosphate (P-PO<sub>4</sub><sup>3-</sup>),

total nitrogen (TN), total phosphorus (TP), coliform at 7 sampling locations in 4 months (March, June, September, November). CA results was illustrated in Figure 1. At Euclid distance 6, 7 sampling locations were divided into 2 clusters including cluster 1 (NM4) and cluster 2 (NM5, NM7, NM2, NM6, NM1, NM3). At Euclid distance 4, 7 sampling

locations were divided into 4 clusters including cluster 1 (NM4), cluster 2 (NM5), cluster 3 (NM2, NM6, NM7) and cluster 4 (NM1, NM3). Cluster 1 (NM4) was separated because this was located in the area between the source affected by the seafood processing area, the water quality parameters at this location have been contaminated with organic matters, nutrients and microorganisms. The water quality variables of DO, TSS, COD, BOD, N-NH<sub>4</sub><sup>+</sup>, P-PO<sub>4</sub><sup>3-</sup>, TN, TP, coliform all exceeded the allowable limits of QCVN 08-MT:2015/BTNMT column A1. Cluster 2 (NM5) represented the location with a dense population (residential area) in My Tho City, affected by wastewater

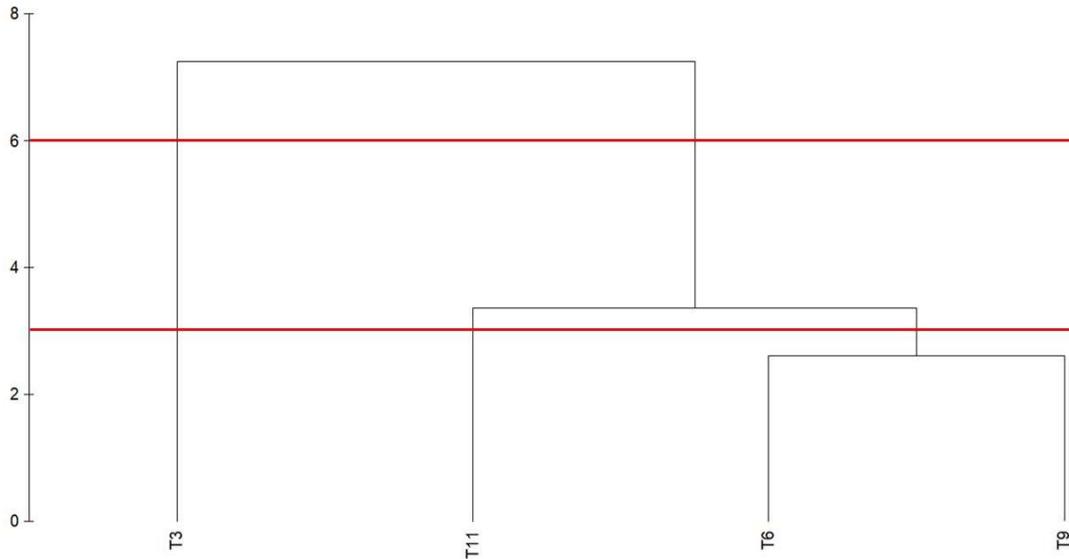
from an urban area, production activities and services influencing water supply. The water indicators of DO, TSS, COD, BOD, N-NO<sub>2</sub><sup>-</sup>, TP all exceeded the limits of QCVN 08-MT:2015/BTNMT, column A1. Cluster 3 (NM2, NM6, NM7) with the water parameters of DO, TSS, COD, BOD and TP exceeded the allowable limits of QCVN 08-MT:2015/BTNMT, column A1. NM6 location was affected by wastewater in the fishing port area, so TN also exceeded the allowable limit. Cluster 4 (NM1 and NM3) with the parameters of DO, TSS, COD, BOD and TP that did not reach the allowable limits of QCVN 08-MT:2015/BTNMT, column A1.



**Figure 1: Clustering water quality according to the sampling sites**

CA revealed that from 7 water monitoring locations could be reduced to 4 locations. NM1 represents the place where water just flows into the segment of Tien River belonging to Tien Giang province. NM1 has more water parameters (7 variables) exceeding the allowed limits of QCVN 08-MT:2015/BTNMT, column A1; NM4, the middle area, represented the area affected by fish industry wastewater. In this location, the river water has been polluted by organic matters and nutrients resulting in high potential of

DO deficiency and eutrophication. NM5 was the site where is influenced by the residential area affecting the water supply of My Tho city. NM6 represented the end of the monitoring area, which is also the location affected by the wastewater in the fishing port area in My Tho city. Clustering the current sampling sites revealed that there is chance for reducing the cost and time of monitoring surface water quality in Tien Giang province but remains the representativeness.



**Figure 2: Clustering water quality according to sampling frequency**

The results of clustering water quality according to the sampling frequency (March, June, September and November) were presented in Figure 2. The findings indicated that at the Euclid distance 6, the sampling frequency could be divided into 2 clusters including cluster 1 (March) and cluster 2 (June, September and November). At the Euclid distance 3, the sampling frequency could be divided into 3 clusters, including cluster 1 in late March of the dry season, group 2 in November and early dry season, group 3 in rainy months (June and September). Through CA analysis results, 4 water monitoring times could be reduced to 3 times a year including March (dry season), June or September (rainy season), November (intersection between rainy and dry seasons).

#### 4. Conclusion

The results revealed that surface water quality on Tien River was polluted with suspended solids, organic, nutrients and coliform. The water in the study area had the risk of causing eutrophication of water sources and the water was not suitable for domestic water supply (after

conventional treatment is applied). Water quality is influenced by several scattered sources such as hydrological regimes, residential areas, urban areas, industry, agriculture and fisheries. PCA results presented that the water monitoring indicators including pH, DO, TSS, COD, BOD, N-NO<sub>2</sub><sup>-</sup>, N-NO<sub>3</sub><sup>-</sup>, P-PO<sub>4</sub><sup>3-</sup>, TN, TP, coliform all contributed to the surface water variation in Tien River. The overall results suggested that pH, DO, TSS, COD, N-NO<sub>3</sub><sup>-</sup>, P-PO<sub>4</sub><sup>3-</sup>, TN, TP, coliform should be included in the monitoring program in this river segment. CA results revealed that from 7 current monitoring locations can be reduced to 4 locations and 4 monitoring periods into 2 - 3 monitoring periods still ensuring the representativeness of water quality on Tien River in Tien Giang province. Tien Giang Environmental Management Agency can consider reducing the water quality parameters, time and thus reducing the cost of environmental monitoring. Since the assessment was conducted only in 2019, it is necessary to have further long - term studies to comprehensively assess

the change in surface water quality on Tien River.

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