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The Categorized of Surface Water Quality Variation using Multivariate Statistical Approaches: A Case Study of Ben Tre Province, Vietnam

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Abstract

This study evaluated surface water quality changes in Ben Tre province using multivariate statistical analyses. The water monitoring data were collected from the Department of Natural Resources and Environment of Ben Tre province in 2020, which 13 water parameters have been measured, including pH, water temperature (T), salinity (Sal), turbidity (Turb), total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+_N), nitrate (NO_3^-_N), orthophosphate (PO_4^{3-}_P), iron (Fe) and coliform bacteria. Water quality was assessed using national technical regulations on surface water quality of QCVN 08-MT: 2015/BTNMT. Spatiotemporal variation of water quality was evaluated using cluster analysis (CA) while potential pollution sources and key water variables influencing water quality were evaluated using principal component analysis (PCA). The findings showed that the water parameters of turbidity, salinity, TSS, DO, BOD, COD, NH_4^+_N, PO_4^{3-}_P, Fe and coliform exceeded the allowable limits of QCVN 08-MT:2015/BTNMT. The water parameters of BOD, COD, NO_3^-_N, PO_4^{3-}_P in the rainy season tended to be higher than those in the dry season. Cluster analysis divided surface water quality into 7 clusters, thus reducing 8 sampling sites, and 2 monitoring times of frequency. Principal component analysis identified 13 potential pollution sources affecting surface water quality in the study area, in which, 76.10 % of the variation in surface water quality were contributed by PC1, PC2, PC3, PC4 and PC5. PCA results also showed that 13 observed water parameters significantly contribute to the variation in water quality. The current study results could be very useful in reducing sites and frequency of surface water quality monitoring in Ben Tre province.

Keywords: Ben Tre province, Cluster analysis (CA), Microbiological parameters, Physio-chemical parameters, Principal component analysis (PCA), Surface water quality

Introduction

Ben Tre is a coastal province in the Vietnamese Mekong Delta, with a natural area of 2,360 km^2. The province is surrounded by An Hoa, Bao, and Minh islets and 4 branches of the Mekong River including Tien River, Ba Lai River, Ham Luong River and Co Chien River. With the advantage of natural conditions, the people of Ben Tre province have developed agriculture in all 3 ecological regions comprising salt, brackish and freshwater. However, the process of cultivation and aquaculture has caused residues of plant protection chemicals and antibiotics which could accumulate in the water leading to a decrease in the use value of the water source, causing negative effects on human health and aquatic species [1,2]. Along with the influences from the agricultural production process, domestic activities and industrial development also have a strong impact on surface water quality [3,4]. Changes in physical and chemical components in the water environment will affect the biodiversity of aquatic ecosystems [5,6].

Therefore, the assessment of surface water quality indicators and identification of trends in water quality changes in Ben Tre province is necessary and vital to assure the availability of quality water for its many uses. In Vietnam, water quality is assessed using water quality index (WQI) and limit values in the national technical regulations on surface water quality or QCVN 08-MT: 2015/BTNMT. However, the assessment of water quality in a large area is often made up of a program, which constitutes a large and complex data matrix. Recently, multivariate statistical techniques including cluster analysis (CA) and principal component analysis (PCA) have been widely applied in surface water quality [7-10]. These techniques are applied in many cases for verifying the temporal and spatial variation of surface and freshwater and coastal quality; it also allows for identification of possible factors/sources that lead to water pollution. These methods help to interpret complex data without omitting useful information and optimize the monitoring network, reducing heavy monitoring task and expensive cost. In which, CA groups the objects (cases) into classes (clusters) on the basis of similarities within a class and dissimilarities between different classes; this can help reduce the number of cases monitored (e.g. locations). PCA provides information on the most meaningful parameters, which describe whole data set, data reduction of original information; focus on the key factors. That's why this study used these 2 methods in assessing water quality in the study area. Thus, this study aimed to analyses surface water quality in Ben Tre province using national standards for surface water quality, CA for clustering water quality based on similarity index, PCA for key water parameters and potential polluting sources. The results of this study could significantly contribute to the completeness of the surface water monitoring system in the study area.

Materials and methods

Data collection

Surface water quality monitoring data of Ben Tre province in 2020 was collected at 42 locations in the province including Ben Tre city and 8 districts (Mo Cay Nam, Mo Cay Bac, Thanh Phu, Cho Lach, Chau Thanh, Giong Trom, Ba Tri and Binh Dai). In which, the background water samples for the monitoring task were collected at 2 upstream locations, namely Tan Phu, Chau Thanh District (HL1) and Phu Phung, Cho Lach District (CC6). The remaining locations were the impact monitoring samples, including 16 water samples collected in the main rivers and canals, 15 water samples flowing through Ben Tre city and towns and 9 samples of in-field canal water. The locations in the 4 main river branches were symbolized as Ham Luong River (from HL2 to HL5), Co Chien River (from CC7 to CC9), Tien River (from ST10 to ST12) and Ba Lai River (from BL13 to BL18). The water samples flowing through Ben Tre city and towns were collected at the locations such as Airport Bridge (CSB19), Cai Ca Bridge (CCC20), Ca Loc Bridge (CCL21), Go Dang Bridge (CGD22), Binh Nguyen Bridge (CBN23), Ba Mu Bridge (CBM24), Ba Lai Bridge (CBL25), Cho Lach Canal (CL26), Mo Cay Town River (MC27), An Thanh Commune (AT28), Thanh Thoi A Commune (TT29), Giong Trom Town River (GT30), Binh Thang river (BTH31), Ba Tri town river (BT32) and Thanh Phu town river (TP33). The remaining locations were collected in inland canals in communes of Binh Phu (BP34), Phu An Hoa (PAH35), Vinh Thanh (VT36), Tan Phu Tay (TPT37), Luong Quoi (LQ38), Tan Thuy (TTH39), Chau Hung (CH40), Quoi Dien (QD41) and Cam Son (CS42). The surface water sampling locations are shown in **Figure 1**.

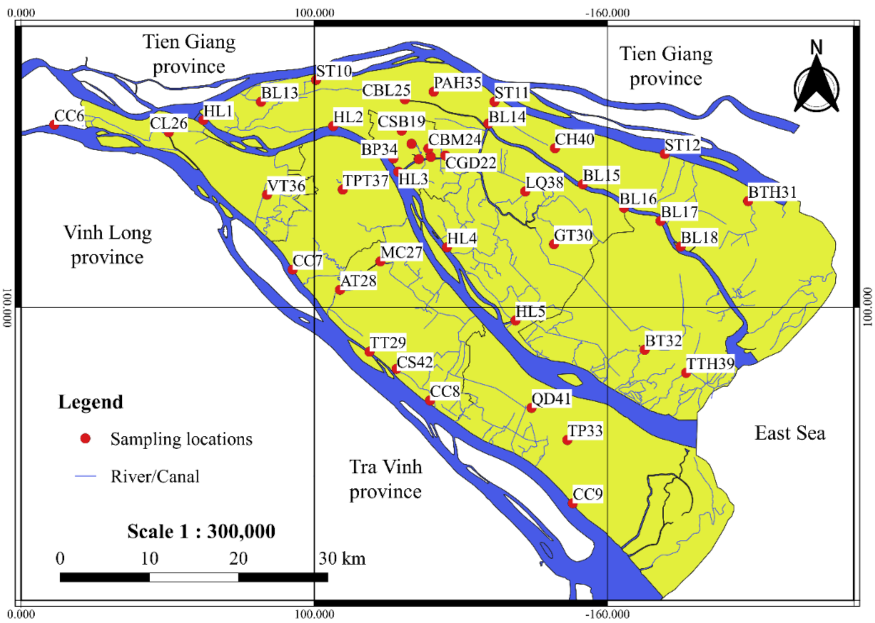

Figure 1 Surface water quality monitoring sites in Ben Tre province in 2020.

Surface water quality in the study area is assessed based on 13 physicochemical and microbiological parameters including pH, temperature (T), salinity (Sal), turbidity (Turb), total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+_N), nitrate (NO_3^-_N), orthophosphate (PO_4^{3-}_P), iron (Fe) and coliform bacteria. The observed samples were collected in March, June, August and October, and the sampling procedure was carried out in accordance with the guidance specified in ISO 5667 - 6:2014. The water parameters of pH, temperature, DO, salinity and turbidity were measured directly in the field by hand-held m (**Table 1**). The remaining indicators were measured, preserved and transported for analysis at the Center for Natural Resources and Environment Monitoring in Ben Tre province according to the standard methods shown in **Table 1**.

Table 1 Methods of field measurement and laboratory analysis.

	Parameters	Unit	Methods of field and laboratory measures
Measure directly in the field	pH	-	pH m, Hand y Lab 100 (Germany)
	Temp	^{o}C	Temperature m, Physics 300 (Germany)
	DO	mg/L	DO m, DO Multi 3620 IDS (USA)
	Sal	‰	WTW Cond 3310 (Germany)
	Turb	NTU	Turbidity m, 2100P-HACH (Germany)
Analysis in the laboratory	TSS	mg/L	SMEWW 2450D:2017
	BOD	mg/L	SMEWW 5210B:2017
	COD	mg/L	SMEWW 5220C:2017
	NH_4^+_N	mg/L	SMEWW 4500 NH_3 B&F:2017
	NO_3^-_N	mg/L	SMEWW 4500-NO_3^-.E:2017
	PO_4^{3-}_P	mg/L	SMEWW 4500P(E):2017
	Fe	mg/L	SMEWW 3111B:2017
	Coliform	MPN/100 mL	TCVN 6187-2:1996

Data processing

The results of measurement and analysis of surface water quality parameters at 42 sampling locations were compared with QCVN 08-MT: 2015/BTNMT - national technical regulations on surface water quality. Limit values of these parameters are shown in **Table 2**. The spatial and temporal classification of water quality was performed by cluster analysis (CA). In which, the mean values of parameters at 42 sampling locations were used as input data for spatial water quality clustering. The clustering results were presented in the form of dendrograms. The locations were clustered into the same clusters were the locations with similar surface water quality characteristics. Two factors that are used as the basis for effective site selection for reducing the locations of the current monitoring were that the locations must be in the same water body and the locations must be in the same cluster. Cluster analysis was also used for testing the current frequency of the water monitoring. The results of CA method could be used for optimizing the water monitoring sites and frequency [9,11,12].

Important information in the data set of the surface water quality in Ben Tre province were analyzed using principal component analysis (PCA). Each initial surface water parameter was classified into a principal component (PC) and each PC would represent a subset of the initial variables [11]. In studies of water quality analysis, PCs were considered sources of water pollution [9,11,12]. The magnitude of the weighted correlation coefficients (WF) represented the degree of correlation between sources of pollution generation and evaluation parameters. WF value > 0.75 shows a close correlation between PC and water monitoring parameters, WF from 0.50 - 0.75 shows the average correlation and weak correlation when WF is in the range of 0.3 - 0.5 [13]. The results of PCA helped in identifying the possible vital parameters and factors/sources that influence water quality that have important contributions to the variation of water quality in the study area. Two methods CA and PCA were performed using the copyrighted Primer 5.2 software for Windows.

Table 2 Limit values of surface water quality parameters.

Parameters	Unit	Limit values	
		QCVN A1	**QCVN A2**
pH	-	6 - 8.5	6 - 8.5
Temp	℃	-	-
Sal	‰	-	-
Turb	NTU	-	-
TSS	mg/L	20	30
DO	mg/L	≥ 6	≥ 5
BOD_5	mg/L	4	6
COD	mg/L	10	15
NH_4^+_N	mg/L	0.3	0.3
NO_3^-_N	mg/L	2	5
PO_4^{3-}_P	mg/L	0.1	0.2
Fe	mg/L	0.5	1
Coliform	MPN/100mL	2,500	5,000

QCVN A1 is water used for domestic water supply purposes (after conventional treatment is applied), for the conservation of aquatic animals and for other purposes; QCVN A2 is used for the purpose of supplying domestic water but must apply appropriate treatment technology.

Results and discussion

Evaluation surface water quality in Ben Tre province in 2020

The fluctuation trend of surface water quality parameters in Ben Tre province during the 4 sampling phases is shown in the plots in **Figure 2**. pH value ranged from 6.53 - 8.02 and the average was at 7.20 ± 0.20. Lowest pH was measured at the TT29 site (August) and highest at the CC9 site (October). However, the fluctuation range of pH value in the study area is still within the permissible limits of QCVN 08-MT: 2015/BTNMT (column A1) which is used for the purpose of water supply and conservation of aquatic animals and plants (**Table 2**). The results of this study are consistent with the neutral pH range recorded in the previous studies. Specifically, pH in canals in An Giang and Hau Giang provinces fluctuated from 6.90 - 7.10 and 6.80 - 7.10, respectively [9,14]. In the Hau river, pH fluctuated between 6.30 - 8.00 in the main rivers and tributaries [15] and ranged from 6.70 - 7.12 over the section passing An Giang and Hau Giang provinces [9]. Temperatures in the rivers and canals in Ben Tre province tended to decrease during the rainy season due to the influence of the rainfall. The temperature values ranged from 26.30 - 32.90 ℃, the average was 29.14 ± 1.50 ℃. The variation in temperature in this study is similar to that of 28.1 - 31.3 ℃ in in-field canals of An Giang province [14] and about 28.60 - 29.60 ℃ in Hau Giang province [9]. However, surface water in Ben Tre province has a higher temperature ranging from 28.90 ± 0.40 - 29.00 ± 0.50 ℃ in the Hau River [16]. In general, the fluctuations of temperature in the above studies are within the permissible limits of WHO and suitable for the development of aquatic organisms [17,18].

Salinity concentration in surface water samples in Ben Tre province ranged from 0 - 25.50 ‰, the salinity tended to increase gradually towards the estuary and was remarkably high in the dry season. Salinity levels observed in March were 1.8, 2.7 and 4.8 times higher compared to that of June, August and October, respectively (**Figure 2**). While many monitoring locations in the rainy season have a salinity of 0 ‰, the salinity value recorded during the March observation period was from 0.20 - 25.50 ‰, the highest salinity concentration was measured at the Ba Lai dam site, Ba Tri district (BL18). In addition, the locations near the sea mouths such as CC9, ST12, BL18, BTH31, BT32 and TP33 had high salinity concentrations and were outside the normal distribution of the observed value range in the rainy season. Similar results were recorded in Tien River when salinity was concentrated at the end of the dry season (fluctuated 20 - 25 ‰) and decreases significantly in the rainy season. At the same time, the salinity on the Tien River also decreased gradually upstream [19]. The monitoring results showed that the water bodies in Ben Tre province are affected by saline intrusion. Salinity concentration depends on meteorological, hydrological and tidal factors.

The fluctuation range of turbidity at the monitoring locations was relatively large, ranging from 4.11 - 182.90 NTU, averaging at 41.64 ± 25.2 NTU. This value far exceeded the limit of QCVN 02:2009/BYT, the standard on domestic water quality (5 NTU). Most observed locations in March had lower turbidity than those of the months in the rainy season, except for BL16. Observations in the main river and tributaries of the Hau River showed that the turbidity also increases during the rainy season and was recorded at a large range from 14 - 225 NTU [15], which was higher than the values in the current research. The cause of the increased turbidity in the rainy season is due to the material washout on both sides of the rainwater along with the amount of sediment drawn from the floodwaters from upstream. In addition, domestic wastewater also contributed to increased turbidity in the water [15]. Because TSS is closely related to turbidity, the TSS concentration in the study area also fluctuated relatively large (3.50 - 143.50 mg/L). The average TSS concentration was 36.90 ± 19.60 mg/L, exceeding the permitted value of QCVN 08-MT:2015/BTNMT (column A2). Sites on the Ba Lai River (BL14, BL16 and BL17) had high TSS concentrations. Rainwater runoff, erosion and the presence of phytoplankton are thought to be the causes of high TSS concentrations in water [20,21]. Likely to the turbidity, the suspended solids concentration in the Hau river was also higher than in that in the water bodies in Ben Tre province with TSS values ranging from 5 - 161 mg/L. In addition, in-field canals in Soc Trang province also recorded high levels of TSS, ranging from 16 - 176 mg/L [22]. Meanwhile, TSS values in An Giang and Hau Giang provinces only fluctuated between 25.00 - 93.70 mg/L and 32.80 - 101.80 mg/L, respectively [9,14] which were lower than the TSS concentrations in the current study. The results of the above studies show that coastal provinces such as Ben Tre and Soc Trang had higher levels of TSS than that in the freshwater areas, possibly due to the influence of alluvial flats and estuaries [9]. DO concentration in the monitoring periods ranged from 0.33 - 9.61 mg/L, averaging at 5.8 ± 0.8 mg/L. Many locations in in-field canals and in the canals that run through Ben Tre city and towns (CSB19, CBN23, CBM24, BT32, and PAH35) had lower DO concentrations than that in the main rivers. Since tributaries and in-field canals directly received wastewater from domestic activities and agricultural production with a high content of organic matters, a large amount of dissolved oxygen was consumed, leading to a decrease in DO in the water. In particular, the location of CBN23 had a DO of less than 4 mg/L at all monitoring phases, negatively affecting the aquatic ecosystem [23]. In the in-field canals of Hau Giang province, DO values fluctuated in a narrower range than DO in the current study with DO ranging from 3.2 ± 0.10 - 5.2 ± 0.77 mg/L [9]. In addition, dissolved oxygen concentrations ranged from 4.90 - 5.50 mg/L in in-field canals in An Giang province [14] and about 1.70 - 6.20 mg/L in the water bodies in Soc Trang province [22].

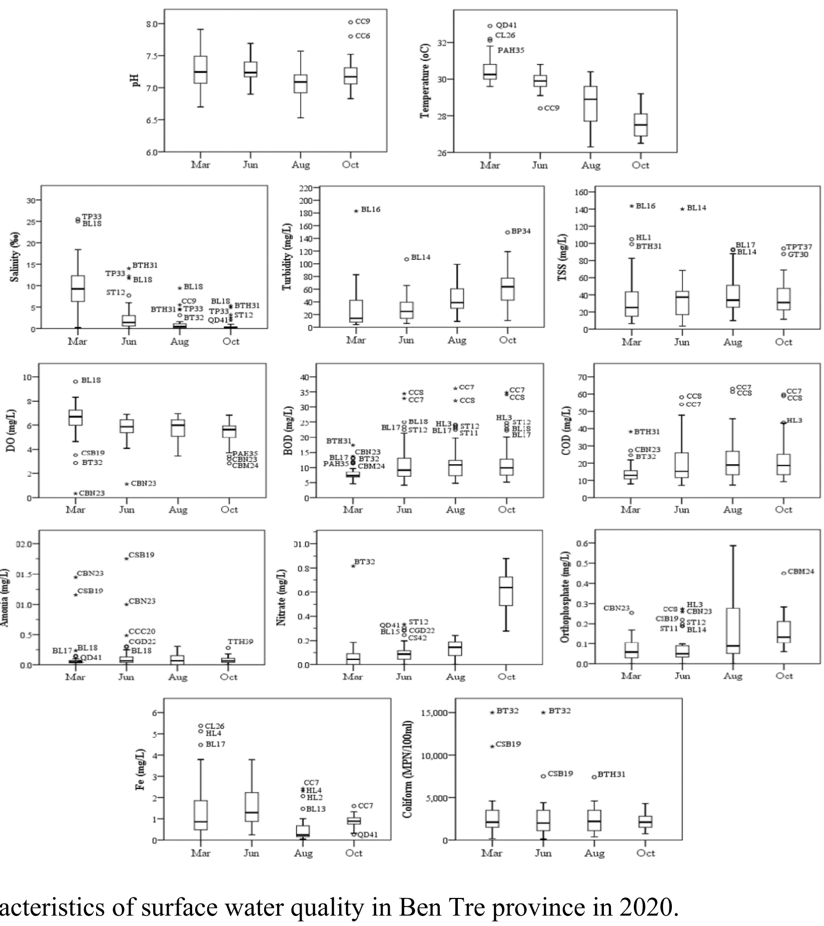

Figure 2 Characteristics of surface water quality in Ben Tre province in 2020.

In addition, the monitoring results showed that surface water in Ben Tre province has been organically polluted, which BOD and COD concentrations varied from 4.18 - 36.08 and 7.21 - 59.74 mg/L, respectively. The March observation period had high concentrations of BOD and COD in the tributaries such as CBN23, BTH31 and BT32. Meanwhile, the observations in the rainy season had high concentrations of BOD and COD at the monitoring locations in the main rivers, especially in the Co Chien River. In addition, the concentration of both BOD and COD parameters tended to increase in the rainy season, which was different from the research results in the Hau river. COD values in the Hau river ranged from 2.56 - 35.84 mg/L with concentrations in the dry season higher than that in the rainy season in both main and tributary rivers [15]. This could imply that, in addition to the pollutants from domestic and production wastewater, the water flowing from the upstream also contains a large amount of organic matter. Furthermore, the rivers and canals of Ben Tre province had a higher level of organic pollution than that in in-field canals in An Giang, Soc Trang and Hau Giang provinces. In which, BOD concentration in An Giang province fluctuated in the range of 4.70 ± 2.30 - 12.30 ± 9.20 mg/L [14], BOD and COD concentrations ranged from 2.20 - 22.40 mg/L and from 6.0 - 44.90 mg/L, respectively in the water bodies of Soc Trang province [22], BOD and COD fluctuated between 6.30 ± 0.50 - 14 ± 4.50 mg/L and 14 ± 4.50 - 25 ± 8.90 mg/L, respectively in the in-field canals of Hau Giang province [9]. The previous survey results on surface water quality in the Ba Lai River also showed that the level of organic pollution was from medium to heavy and it gradually decreased toward the upstream [6].

The concentration of NH_4^+_N and NO_3^-_N fluctuated between 0 - 1.75 and 0 - 0.88 mg/L, respectively (**Figure 2**). As can be seen that the concentration of NH_4^+-N in March and June monitoring period was higher than that in August and October monitoring period. In which, the monitoring locations in Ben Tre city (CBN23, CSB19, CCC20 and CGD22) had NH_4^+-N concentrations outside the normal distribution of the observed range. The concentrations of NH_4^+-N at these locations were above the allowable limit of QCVN 08-MT: 2015/BTNMT columns A1 and A2 (0.3 mg/L). However, NH_4^+-N value in this study was lower than the range of NH_4^+-N of 0.02 - 4.15 mg/L in the water bodies in Soc Trang province [22]. On the other hand, NH_4^+-N concentrations in canals in Hau Giang province ranged from 0 - 0.92 mg/L [9], lower than the NH_4^+-N concentrations in the water bodies in Ben Tre and Soc Trang. The sources of ammonia can be generated from domestic wastes and agricultural production. NO_3^-_N concentration ranged from 0 - 0.88 mg/L and tended to increase gradually during the rainy season (**Figure 2**). The October observation period revealed that NO_3^-_N concentration was significantly higher than that in the previous 3 observations. But in general, the fluctuation range of nitrate in the main rivers and in-field canals in Ben Tre was still within the permissible limit of QCVN 08-MT: 2015/BTNMT (column A1). Different from the fluctuation trend in the current study, NO_3^-_N concentration in the Hau river in the dry season was higher than that in the rainy season with the range from 0.00 - 0.40 mg/L [15]. Meanwhile, NO_3^-_N concentration in the water bodies in Ben Tre province was similar to NO_3^-_N concentration in the canals and rivers in A Giang province (0.03 - 1.76 mg/L), Soc Trang (0.05 - 1.14 mg/L) and Hau Giang (0.23 - 0.54 mg/L) [9, 21, 22]. Oxidation of organic matters and human wastes can be responsible for the fluctuations of nitrate in water [24].

The orthophosphate concentration ranged from 0 - 0.59 mg/L (**Figure 2**). **Figure 2** showed that concentration of PO_4^{3-}-P in the August fluctuated in a wide range and was higher than the rest of the months, the highest PO_4^{3-}-P value was measured at position BL18. Similar concentrations of PO_4^{3-}-P were also recorded in the Hau river (0.01 - 0.51 mg/L) and in the canals of Hau Giang province (0.10 - 0.36 mg/L) [15, 16]. However, the concentration of PO_4^{3-}-P in the Hau River tended to increase during the dry season. In addition, PO_4^{3-}-P concentration also fluctuated at a high level (0 - 0.90 mg/L) in the water bodies of Soc Trang province [22]. The results showed that PO_4^{3-}-P pollution in the river system in the Mekong Delta is a problem that needs attention because the concentration exceeds the limit value specified in QCVN 08-MT: 2015/BTNMT in both columns A1 and A2. The sources of orthophosphate generation are from domestic, agricultural and industrial wastes [25]. Surface water environment in Ben Tre province in 2020 had iron concentrations ranging from 0 - 5.38 mg/L (**Figure 2**), this concentration tended to decrease gradually in the rainy season. The highest values of iron in the monitoring period of March, June, August and October were 5.38, 3.54, 2.38 and 1.60 mg/L, respectively. During the dry and early rainy seasons, the iron concentrations in the rivers passing through towns and in-field canals of Ben Tre province were higher than those in the main river branches. In contrast, the iron concentrations in major tributaries (such as the Ham Luong, Ba Lai and Co Chien Rivers) were higher than those in in-field canals during the rainy season. In addition to the influence of natural conditions, iron concentrations are also derived from human activities, especially intensive agricultural production [9]. The iron concentration observed in this study was higher than that in the in-field canals of Soc Trang province ranging from 0.30 - 3.75 mg/L [22]. At the same time, this concentration was also higher than the value recorded in the water bodies in Hau Giang province with the range from 0.50 ± 0.20 - 2.26 ± 0.50 mg/L in the in-field canals and 0.3 ± 0.10 - 0.47 ± 0.20 mg/L in Hau River [16]. High iron concentration in water increases treatment cost, affects human health and affects aesthetic value [9].

The density of coliforms in the water bodies in Ben Tre province ranged from 110 - 15,000 MPN/100 mL (**Figure 2**). Most of the monitoring locations had coliforms density lower than 5,000 MPN/100 mL and within the allowable limits of QCVN 08-MT: 2015/BTNMT column A2. Particularly, the locations BT32, CSB19 and BTH31 in the monitoring period in March, June and August had rather high coliform density and were outside the normal distribution of the observed value ranges (**Figure 2**). The presence of coliform with high densities indicated that surface water in the study area may be contaminated with human and animal feces [26]. However, levels of coliform pollution in the water bodies in Ben Tre province were lower than that in the water bodies in A Giang (2,260 - 155,000 MPN/100 mL), Soc Trang (2,300 - 89,000 MPN/100 mL) and Hau Giang (1,156.3 - 15,275 MPN/100 mL) [9,14,22]. In summary, surface water quality in Ben Tre province in 2020 was polluted turbidity, TSS, DO, BOD, COD, NH_4^+-N, PO_4^{3-}-P and iron. Livelihood activities, agricultural cultivation, industrial production and the flow are the main causes of the pollution. In addition, the locations near the sea mouth have an exceptionally high salinity due to the influence of meteorological, hydrological and tidal factors. In addition, water samples collected in tributary rivers running through Ben Tre city, Binh Dai district and Ba Tri district had coliforms density higher than the permitted limit of QCVN 08-MT:2015/BTNMT.

Assessing current surface water environment monitoring in Ben Tre province in 2020

Evaluating location and frequency of surface water quality monitoring

Surface water quality at 42 sampling sites was classified into 9 clusters (**Figure 3**). Cluster 1, cluster 3, 4 and cluster 8 had only 1 monitoring location CC7, TPT37, CBN23 and BL18, respectively. These sites had different water quality compared to the rest sites so it should be included for the monitoring task.

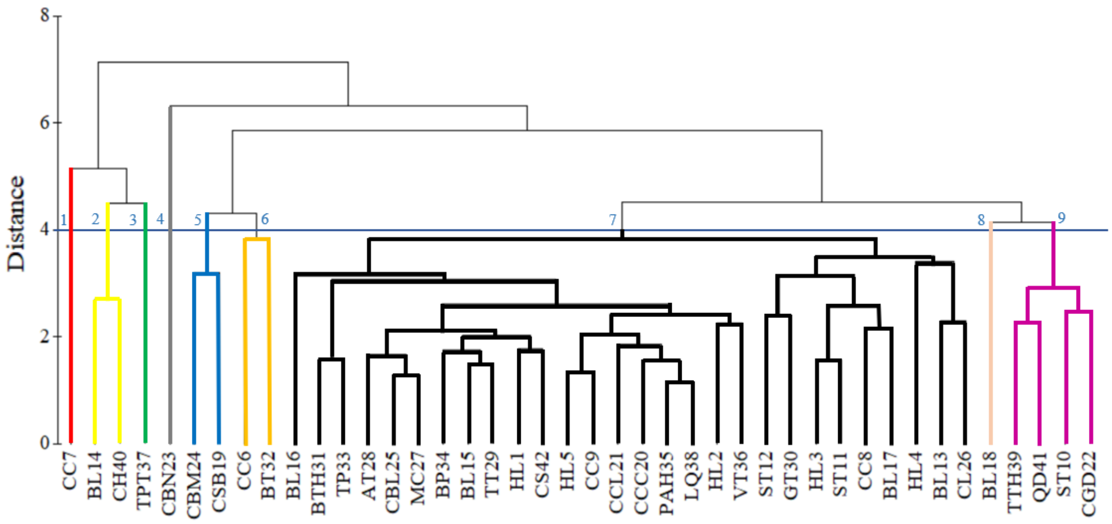

Figure 3 Clustering surface water quality in Ben Tre province in 2020.

Cluster 1 had higher mean BOD and COD values than the rest because it was influenced by the activities of Bang Tra market in Phuc Tan commune, Mo Cay Bac district (**Table 3**). Besides cluster 1, all the remaining clusters had high BOD and COD values and exceeded the limits specified in QCVN 08-MT: 2015/BTNMT. In addition, cluster 1 also had iron concentration in excess of the standard. The nutrient parameters were especially high in the cluster 3 and 4. In which, the position of cluster 3 was collected in the field, influenced by agricultural activities, so the NO_3^--N value was high, but the value was still within the allowed limit (**Table 3**). However, the concentrations of NH_4^+-N and PO_4^{3-}-P in cluster 4 exceeded the permitted standard. The reason may be the sites were influenced by livelihood activities and fertilizer use in agricultural production. In addition, the water quality in cluster 4 also had very low DO, not suitable for the growth and development of aquatic plants and animals. Meanwhile, the salinity concentration in cluster 8 was different from the other clusters because this was the monitoring position at the saline prevention dam sluice.

The sites in clusters 2, 5, 6 and 9 were also used for the next survey since it was not located in the same river. The pairs of position in cluster 2, cluster 5 and 6 were BL14 and CH40, CBM24 and CSB19, CC6 and BT31, respectively. Meanwhile, Cluster 9 included 4 locations of TTH39, QD41, ST10 and CGD22. Cluster 2 has exceptionally high turbidity and TSS values, especially TSS was 2.1 times higher than the limit value in column A2 of the regulation. The average density of coliform in cluster 6 was the highest level and exceeded the standard QCVN 08-MT: 2015/BTNMT (column A2), making up the difference of the cluster (**Table 3**).

Cluster 7 comprised 28 remaining positions. In which, the positions of BTH31, TP33, AT28, CBL25, MC27, BP34, TT29, SC42, CCL21, CCC20, PAH35, LQ38, VT36, GT30, CL26 should be maintained in the monitoring task since these locations were located in different water bodies. The remaining 13 locations in main rivers, including 5 locations in Ham Luong river (from HL1 to HL5), 4 locations in Ba Lai river (BL13, BL15, BL16, BL17), 2 locations in Co Chien river (CC8, CC9) and 2 locations in Tien River (ST11, ST12) where representative sites should be selected for saving the monitoring costs. Ham Luong River alone could have 2 positions from 4 positions (HL2, HL3, HL4 and HL5) to compare the trend of surface water fluctuation between the upstream and the tributary. From the result of this study, 8 - 9 current monitoring sites in the existing water monitoring network of Ben Tre province can be reduced and this leads to a saving of 19 - 21 % of the monitoring costs. The suggested locations for future water quality monitoring are presented in **Figure 4**.

Table 3 Average values of the water parameters by clustering results.

Parameters	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Cluster 9
pH	7.34	7.24	6.84	6.91	7.02	7.29	7.22	7.31	7.16
Temp	29.60	28.81	28.73	28.85	29.16	29.04	29.18	28.88	29.25
DO	6.47	6.21	5.57	**2.04**	4.36	5.35	5.96	6.99	5.95
Sal	0.10	2.76	2.93	2.75	2.89	2.99	3.36	**12.98**	3.38
Turb	49.66	**62.92**	28.95	34.09	24.68	31.54	46.00	17.07	23.18
TSS	41.00	**61.69**	36.13	21.13	23.25	30.38	39.10	39.00	21.81
BOD	**27.60**	12.26	8.37	8.21	7.38	7.74	11.31	19.70	7.48
COD	**46.72**	18.13	14.54	15.73	12.81	13.22	20.87	34.89	12.99
$NH_4^+\_N$	0.04	0.06	0.08	**0.69**	0.45	0.03	0.07	0.22	0.10
$NO_3^-\_N$	0.20	0.17	**0.30**	0.27	0.21	0.26	0.21	0.27	0.27
$PO_4^{3-}\_P$	0.08	0.09	0.08	**0.33**	0.21	0.08	0.11	0.20	0.10
Fe	**1.51**	0.97	1.36	1.04	0.81	0.68	1.07	1.21	1.19
Coliform	1,358	1,308	925	2,400	4,185	**5,738**	2,438	2,170	1,534

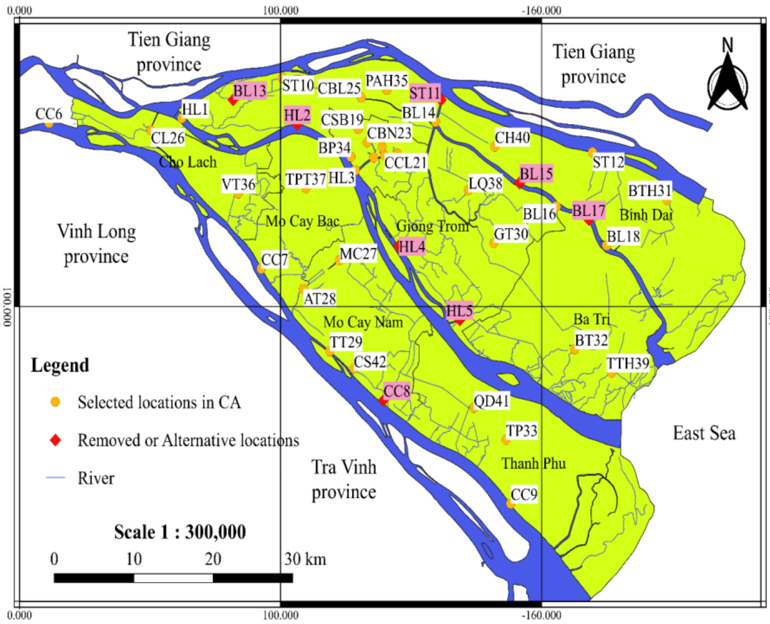

Figure 4 Proposed locations for surface water quality monitoring in Ben Tre province.

Besides, the reduction of sampling frequency also helps to save costs for annual monitoring. The results of clustering surface water quality according to the times of sampling were the basis for selecting a representative time to future monitoring. According to the clustering results, water quality observed in Ben Tre province in 2020 was divided into 2 clusters (**Figure 5**). Cluster 1 included 2 observations in August and October (rainy season), cluster 2 includes March and June (dry season). Due to the similar characteristics, it is possible to choose one monitoring period in each cluster for future monitoring. Thus, the monitoring frequency can be reduced from 4 to 2 times/year, reducing 50 % of the annual water quality monitoring cost.

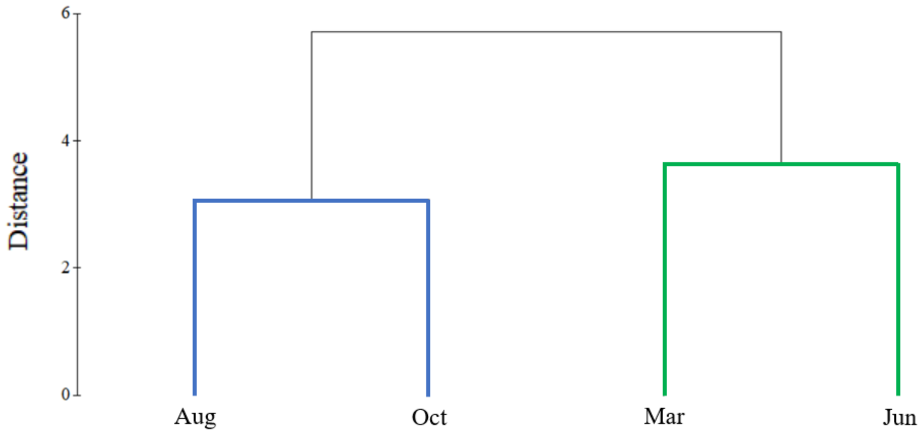

Figure 5 Classification of surface water quality by sampling frequency.

Table 4 Main factors influencing surface water quality in Ben Tre province.

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
pH	**−0.37**	−0.12	0.09	**0.38**	−0.26	0.15	−0.14	−0.27	0.06	**−0.56**	0.24	−0.38	−0.01
Temp	−0.14	**−0.32**	**0.32**	**0.31**	**−0.43**	0.06	0.11	**0.49**	0.16	**0.46**	0.00	−0.11	−0.02
DO	**−0.41**	−0.28	0.07	0.16	0.20	0.05	−0.07	0.06	−0.08	−0.22	**−0.66**	**0.42**	0.04
Salinity	−0.02	0.22	−0.10	**0.59**	**0.35**	0.06	**−0.53**	0.03	−0.16	**0.31**	0.20	0.11	−0.05
Turbidity	**−0.31**	0.19	**−0.33**	−0.19	**−0.33**	**0.40**	−0.04	0.20	0.08	−0.06	**0.34**	**0.54**	0.00
TSS	**−0.30**	0.21	**−0.49**	−0.19	−0.06	0.16	−0.18	0.16	−0.01	0.20	**−0.39**	**−0.56**	−0.01
BOD	**−0.34**	**0.42**	0.17	0.05	0.11	−0.27	0.30	0.11	0.01	−0.04	0.02	0.00	**−0.70**
COD	**−0.34**	**0.44**	0.17	0.09	0.11	−0.23	0.27	0.07	0.00	0.03	0.07	−0.02	**0.71**
NH_4^+_N	**0.31**	**0.31**	0.18	0.04	**−0.37**	−0.01	−0.17	**0.35**	**−0.60**	**−0.30**	−0.18	0.00	0.02
NO_3^-_N	0.29	0.00	−0.24	0.27	**0.37**	0.26	**0.33**	**0.52**	0.25	**−0.36**	0.03	−0.11	0.03
PO_4^{3-}_P	0.24	**0.43**	0.28	0.05	−0.17	0.16	−0.26	−0.13	**0.65**	−0.05	**−0.32**	0.09	0.00
Fe	−0.06	0.08	**0.45**	-0.16	0.26	**0.74**	0.16	−0.15	−0.25	0.16	0.02	−0.13	−0.03
Coliform	0.16	0.14	**−0.32**	**0.45**	−0.29	0.14	**0.50**	**−0.42**	−0.15	0.18	−0.23	0.11	−0.02
Eigenvalues	3.63	2.09	1.60	1.38	1.19	0.88	0.72	0.54	0.33	0.27	0.21	0.14	0.02
%Variation	27.90	16.10	12.30	10.60	9.20	6.70	5.50	4.10	2.60	2.10	1.60	1.10	0.10
Cum.%Variation	27.9	44.0	56.3	66.9	76.1	82.9	88.4	92.5	95.1	97.2	98.8	99.9	100.0

Evaluating key parameters influencing surface water quality

PCA analysis results identified 13 pollution sources (PCs) that affect surface water quality in Ben Tre province in 2020 (**Table 4**). In which, pollution sources from PC1 to PC5 had eigenvalues coefficients greater than 1 and these were considered to be 5 main pollution sources [27]. The main sources of pollution contributed 76.10 % of the variation in surface water quality in Ben Tre province while the remaining 8 sources (from PC6 to PC13) only contributed 23.90 %. Among pollution sources, PC1 was the source with the most correlation with several water criteria (pH, DO, turbidity, TSS, BOD, COD and NH_4^+-N) and explains 27.90 % of the surface water quality variation. The correlation between PC1 and the water parameters showed that this may be the source of pollution from people's daily activities and the change of rivers/canals' flow. The analysis results showed that the observed water parameters had a weak to moderate correlation with sources of pollution. In which, pH had average correlation with PC10 (−0.56) and weak correlation with PC1 (−0.37) and PC4 (0.38). Temperature was explained by several pollution sources, including PC2, PC3, PC4, PC5, PC8 and PC10 with correlation coefficients ranging from 0.308 to 0.48 (weak correlation). Sources affecting pH and temperature can be hydrological regime and weather factors [9]. Besides, salinity was explained by average correlation with PC4 (0.59), PC7 (−0.53) and weak correlation with PC5 (0.35) and PC10 (0.31). This can be the impact of factors such as meteorology, hydrology, tides and especially saline prevention sluice. The PC1, PC3, PC11 and 12 were the explanatory pollution sources for both turbidity and TSS parameters with average correlation. The effects of runoff from upstream dragging sediment and storm water runoff and erosion could be the representative sources for this relationship. In addition, turbidity had average correlation with PC5 (−0.33) and PC6 (0.40).

DO concentration in the water bodies was influenced by many factors such as temperature, diffusion and presence of phytoplankton and organic matter [12]. These factors may be the representative sources of pollution for PC1, PC11 and 12. Weak correlation was formed between DO and the sources of PC1, PC12 with correlation coefficients of −0.41 and 0.42, respectively. Meanwhile, between DO and PC11 formed an average correlation (−0.66). The sources of organic pollution (BOD and COD) were mainly explained by PC1, PC2 and PC12. In which, a weak correlation was formed between these 2 parameters with PC1 (-0.34 and −0.34) and PC2 (0.42 and 0.44). The correlation coefficient between BOD and COD and PC12 were -0.70 and 0.71, respectively (average correlation). These are sources of pollution that are representative of livelihood activities, industrial production - agriculture and tourism development [28, 29]. The presence of NH_4^+-N and NO_3^--N was also related to agricultural production and people's daily life activities [29]. These 2 indicators were also explained by PC5 (−0.37; 0.37), PC8 (0.35; 0.52) and PC10 (−0.30; −0.36). In addition, NH_4^+-N had average correlation with PC9 (−0.60) and weak correlation with PC1 (0.31) and PC2 (0.31).

Besides, a correlation from weak to moderate was also formed between indicators PO_4^{3-}-P and sources PC2, PC9 and PC11. PO_4^{3-}-P was a product of organic matter decomposition from domestic wastewater and chemical fertilizers [12,25,29], so PCs were correlated with PO_4^{3-}-P can be a source of pollution from residential and agricultural activities. Correlation coefficient between iron and PC6 was asymptotic with a close correlation (0.74). This can be a source of living and production activities, especially intensive agricultural production [9]. In addition, iron was also weakly correlated with PC3 (0.45). On the other hand, sources of PC3, PC4, PC7 and 8 contributed significantly to the pollution of coliforms in water bodies in Ben Tre province. In which, the correlation was formed with the coefficients, respectively PC3 (-0.32), PC4 (0.45), PC7 (0.50) and PC8 (−0.42). These sources represented sources generated from human and animal excreted wastes [26]. The results confirm that all 13 water parameters (pH, temperature, salinity, turbidity, TSS, DO, BOD, COD, ammonia, nitrate, orthophosphate, Fe and coliform) in the water bodies in Ben Tre province in the current water quality monitoring network in 2020 are important implications for the variation in surface water quality. In which, the parameters of salinity, TSS, BOD, COD, NH_4^+_N have the most impact on the change of water quality in the area and were presented in most of the significant pollution sources. Therefore, these parameters need to be continuously observed to monitor and evaluate the current state of surface water quality in the province in the coming time.

Conclusions

The results showed that surface water quality in Ben Tre province in 2020 was polluted with physical and chemical parameters such as turbidity, TSS, DO, BOD, COD, ammonia, orthophosphate and iron. In which, organic parameters (COD, BOD), nutrients parameters (NO_3^--N, PO_4^{3-}-P) tended to increase in the rainy season. In addition, the river network in the study area was also affected by saline intrusion, especially the locations near the sea mouth had an exceptionally high salinity concentration. In addition, coliform parameter in the water samples collected in tributaries running through Ben Tre city, Binh Dai district and Ba Tri district had coliforms density higher than the permitted limit of QCVN 08-MT:2015/BTNMT. CA results 8 - 9 current monitoring sites in the existing water monitoring network of Ben Tre province can be reduced and this leads to a saving of 19 - 21 % of the monitoring costs. In addition, PCA analysis has identified 13 pollution sources affecting the variation in surface water quality in Ben Tre province. In which, 5 main pollution sources (from PC1 to PC5) contribute to 76.1 % of variation. Furthermore, PCA results also showed that all 13 monitoring indicators in the study have important implications for the variation in surface water quality in Ben Tre province in 2020. The findings from this study could be applied for optimizing the sampling sites and frequency of surface water quality monitoring in Ben Tre province.

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