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Original Research

Evaluating Surface Water Quality in a Coastal Province of Vietnamese Mekong Delta Using Water Quality Index and Statistical Methods

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Abstract

The study assessed the variations of surface water quality in Soc Trang province, Vietnam using national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT, column B1) and water quality index (WQI), cluster analysis (CA), principal components analysis (PCA), discriminant analysis (DA), and correlation analysis. The results showed that the surface water was contaminated with organic matters and microorganisms. CA divided the monitoring months into three clusters representing dry season, transitional period, and rainy season, leading to a reduction of 75% monitoring cost. Correlation analysis showed turbidity, total suspended solids, organic matters, nitrogenous and phosphorus compounds, coliform were interrelated. The WQI indicated that the water quality ranged from poor to good. PCA showed five main factors explaing 88.8% of the variations in water quality. The surface water pollution sources were from domestic wastewater, wastewater from production activities, saltwater intrusion and stormwater runoff. Total organic carbon, total suspended solids, coliform, dissolved oxygen, temperature, pH, electrical conductivity, chloride, sulfate and chemical oxygen demand resulted in difference in water quality between seasons. The current findings provide important scientific information for the use and better management of surface water quality in the study area.

Keywords: water quality index, statistical analysis, Soc Trang province, surface water

Introduction

The Mekong Delta is an area located in the lower reaches of the Mekong River. With a dense system of rivers and canals, the Mekong Delta has become the center of aquaculture, fishing, processing and exporting seafood and a marine economic region of the country. Therefore, the water quality of the region is relatively complex, not only influenced by natural conditions, climate regimes, hydrology, but also affected by socio-economic development activities [1]. In recent years, surface water quality in the Mekong Delta has been seriously degraded. Many studies have shown that surface water quality in some Mekong Delta provinces (for instances An Giang, Kien Giang, Can Tho, Tra Vinh) is polluted by waste sources from agricultural, industrial and domestic activities [2, 3]. This has greatly

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affected on ecosystem and human health, especially in the coastal provinces of the Mekong Delta. Soc Trang is a coastal province in the Ca Mau Peninsula region of the Mekong Delta and this area has a rich and diverse ecosystem and is relatively sensitive to the impacts of natural conditions and anthropogenic activities. The two main river systems flowing in Soc Trang province are Hau River and My Thanh River. These two main canals, along with other small canals, both conducting fresh water and discharge floods, washing acid sulfate soil and salt for the area [4]. People in the province also rely on surface water for irrigation, aquaculture and mainly for domestic uses. However, saline intrusion and water pollution have affected surface water quality in rivers and canals in the province. The source of surface water pollution is mainly wastewater from agricultural, industrial and daily life activities [5]. Therefore, the monitoring and assessment of surface water quality is an important task that needs to be performed regularly.

Currently, several studies have applied calculation of water quality index and multivariable statistical analysis in surface water quality assessment. These are considered useful approaches and clearly assess the pollution status of a basin [6, 7]. In particular, WQI is a mathematical tool that significantly reduces complex water quality data sets and produces a single value that reflects the state of water quality [8]. Cluster analysis (CA), principal component analysis (PCA) and discriminant analysis (DA) classify surface water quality variables with similar properties, identify potential pollution sources, and find seasonal discriminant parameters [9]. Therefore, the objective of this study is to apply CA, PCA, DA and WQI methods to assess the spatial and temporal changes in water quality and find out the important parameters affecting water quality Soc Trang province in 2021. The results provide useful scientific information for environmental management agencies in Soc Trang province and neighboring coastal provinces to review the surface water monitoring system.

Materials and Methods

Study Area

Soc Trang is located in the southern downstream of Hau River in the Mekong Delta region with a total natural area of 3311.8 km^2. Soc Trang province includes 9 districts, 1 town and 1 city with 109 communes, wards and towns. The topography of the province is relatively flat, in the shape of a gentle basin, including flat land, alternating low-lying areas and sand dunes. The network of rivers and canals in the province is relative dense and evenly distributed throughout the province. Most of the province's rivers and canals have small flows and are influenced by the tidal regime of the East Sea, with the average tidal level ranging from 0.4 to 1 m. With a relatively low elevation and heavily dissected by a system of rivers and canals and irrigation canals, the province is susceptible to sea water intrusion. Soc Trang is located in the tropical monsoon climate, the rainy season starts from May to November, the dry season starts from December to April next year. The average annual temperature is about 27ºC, the average annual rainfall is about 1799.5 mm and the average humidity is 86%. This is an important food production area of the country and is home to abundant and diverse

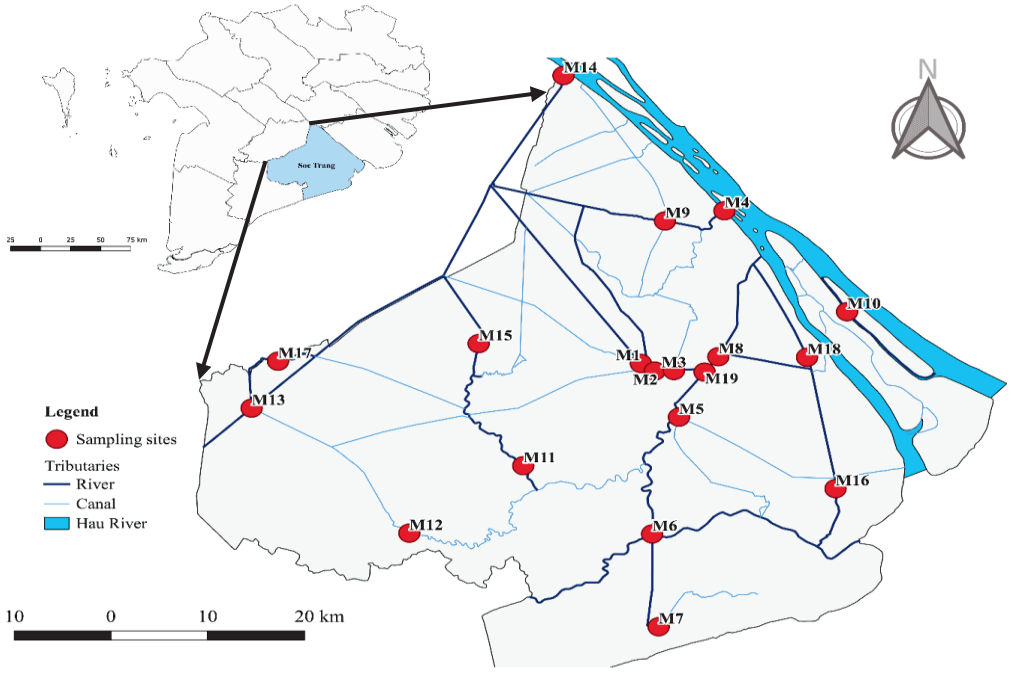

Fig. 1. Sampling location in Soc Trang province.

export products, especially rice and aquatic products, agricultural products and processed foods. Therefore, the surface water quality of the province is easily affected by the daily activities and production of the people. The sampling locations of surface water quality in Soc Trang province are shown in Fig. 1.

Surface Water Sampling and Analysis

Water quality monitoring data are collected from the Department of Natural Resources and Environment of Soc Trang province in 2021. The sampling points included Xang canal (M1), 30/4 canal (M2), Maspero river (M3), Hau river in Nhon My commune (M4), Thanh Loi canal (M5), Co Co market canal (M6) , canal of Vinh Chau town (M7), Saintard river (M8), canal No. 1 of Ke Sach town (M9), Ben Ba river of Cu Lao Dung town (M10), Nhu Gia river (M11), canal of Phu Loc town (M12), Nga Nam town canal (M13), Hau river at Cai Con (M14), Huynh Huu Nghia town canal (M15), Lich Hoi Thuong market canal (M16), Chau Thanh town canal (M17), Long Phu town canal (M18), Dinh river (M19). The samples were collected with a frequency of 12 times/year. Surface water quality parameters including Temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Turbidity, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonium ($N\text{-}NH_4^+$), Nitrate ($N\text{-}NO_3^-$), Nitrite ($N\text{-}NO_2^-$), Orthophosphate ($P\text{-}PO_4^{3-}$), Chloride (Cl^-), Total Iron (Fe), Total Nitrogen (TN), Total Phosphorus (TP), Sulfate (SO_4^{2-}), Coliform, Total Organic Carbon (TOC) and Total Oil and Grease (O&G) were used to assess water quality and as input data for multivariate statistical analysis. Water samples were collected and preserved in accordance with current standards (TCVN 6663-6:2018; TCVN 6663-3:2016; TCVN 6663-3:2008-ISO 5667-3:2003; TCVN 8880:2011). The parameters of pH, temperature, dissolved oxygen, turbidity and electrical conductivity were measured in the field while the remaining parameters were analyzed in the laboratory using standard methods [10]. The surface water quality parameters, units, analytical methods and allowable limits are presented in Table 1.

Data Analysis

Surface water quality data were averaged before statistical analysis and compared with National Technical Regulation on surface water quality column

Table 1. Analytical methods of surface water quality parameters.

Parameters	Description	Unit	Analytical methods	QCVN 08, B1
pH	pH	-	TCVN 6492:2011	5.5-9.0
Temp	Temperature	^oC	SMEWW 2550B:2017	Not specified
EC	Electrical conductivity	mS/m	SMEWW 2510B:2017	Not specified
Turb	Turbidity	NTU	TCVN 6184:2008	Not specified
DO	Dissolved oxygen	mg/l	TCVN 7325:2016	≥ 4
BOD	Biological Oxygen Demand	mg/l	TCVN 6001-1:2008	15
COD	Chemical Oxygen Demand	mg/l	SMEWW 5220C:2017	30
TSS	Total Suspended solids	mg/l	TCVN 6625:2000	50
$N\text{-}NH_4^+$	Ammonium	mg/l	TCVN 6179-1:1996	0.9
Fe	Total Iron	mg/l	TCVN 6177:1996	1.5
$N\text{-}NO_2^-$	Nitrite	mg/l	TCVN 6178:1996	0.05
$N\text{-}NO_3^-$	Nitrate	mg/l	TCVN 6180:1996	10
$P\text{-}PO_4^{3-}$	Phosphate	mg/l	TCVN 6202:2008	0.3
Cl^-	Chloride	mg/l	TCVN 6194:1996	350
TN	Total Nitrogen	mg/l	TCVN 6638:2000	Not specified
TP	Total Phosphorus	mg/l	TCVN 6202:2008	Not specified
SO_4^{2-}	Sulfate	mg/l	SMEWW 4500-SO_4^{2-}.E:2017	Not specified
Coliform	Coliform	MPN/ 100ml	TCVN 6187-2:1996	7500
TOC	Total Organic Carbon	mg/l	TCVN 6634:2000	4
O&G	Oil & Grease	mg/l	SMEWW 5520B:2017	1

B1 (QCVN 08-MT:2015/BTNMT, B1) [11]. One-way analysis of variance (ANOVA) and Duncan's test at 5% significance level were used to compare the significant difference in surface water quality over time. The relationship and interdependence between water quality parameters are described through Pearson correlation analysis method. The closer the correlation coefficient (r) is to 1, the stronger the relationship between those two parameters [12]. Discriminant Analysis (DA) aims to find the key parameters causing the difference between seasons in this study. ANOVA, correlation and DA analyzes were processed using the IBM SPSS Statistics 20 for Windows statistical software [13].

Principal Component Analysis (PCA) was used to determine the parameters that have the most influence on surface water quality in Soc Trang province. The method used in PCA is Varimax and only extracts components with an eigenvalue greater than 1 [14]. Meanwhile, Cluster Analysis (CA) was used to classify the sampling locations and months into statistically significant groups based on differences or similarities in water pollution levels. PCA and CA analysis were performed using the Primer V5.2 for Windows license software (PRIMER-E Ltd, Plymouth, UK).

The WQI water quality index is calculated according to the guidance of the Vietnam Environment Administration [15] according to equation (1) for three groups of parameters and presented in the form of a map through the software QGIS version 3.16 (Open Source Geospatial Foundation - OSGeo, Chicago, IL, USA). Then, the various colors in the map indicated different levels of overall surface water quality.

$$WQI = \frac{WQI_I}{100} \times \left[\left(\frac{1}{k}\sum_{i=1}^{k} WQI_{IV}\right)^2 \times \frac{1}{l}\sum_{i=1}^{l} WQI_V\right]^{\frac{1}{3}} \quad (1)$$

In which: WQI_I: Calculated WQI value for pH parameter; WQI_{IV}: WQI value calculated for 08 parameters: DO, BOD_5, COD, TOC, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$ and $P\text{-}PO_4^{3-}$; WQI_V: Calculated WQI value for the Coliform.

Water quality is classified into 6 levels. Level 1 (WQI = 91-100, excellent) is used for domestic water supply purposes. Level 2 (WQI = 76-90, good) is used for domestic water supply purposes but needs appropriate treatment measures. Level 3 (WQI = 51-75, medium) is used for irrigation and other equivalent purposes. Level 4 (WQI = 26-50, bad) is used for navigation and other equivalent purposes. Level 5 (WQI = 10-25, poor) water is heavily polluted and needs future treatment measures. Level 6 (WQI<10, highly polluted) contaminated water and need remedial measures.

Results and Discussion

Temporal Variations of Surface Water Quality

The results of cluster analysis evaluated by 20 water quality parameters at 19 sampling locations on rivers and canals in Soc Trang province are shown in Fig. 2. As can be seen, the change over time of the quality surface water has been grouped for 12 months into three separate clusters (at Euclidean distance of 6). The first cluster includes February, March and April corresponding to the dry season in Soc Trang province. According to [4] these months have relatively low average water levels. Cluster two includes June and July, representing the transition period from the dry season to the rainy season (seasonal change). These two months have the lowest average water level compared to that in the other months. Cluster three includes the remaining months, corresponding to the rainy season in the study area, the average water level is relatively high at this time and the flow rate is high. The change of water quality over time depends largely on the climatic and hydrological conditions of the study area [16]. From the CA results, it is shown that the frequency of water sampling in Soc Trang province should be performed at least three times, corresponding to three clusters resulting in 75% of monitoring costs saving annually.

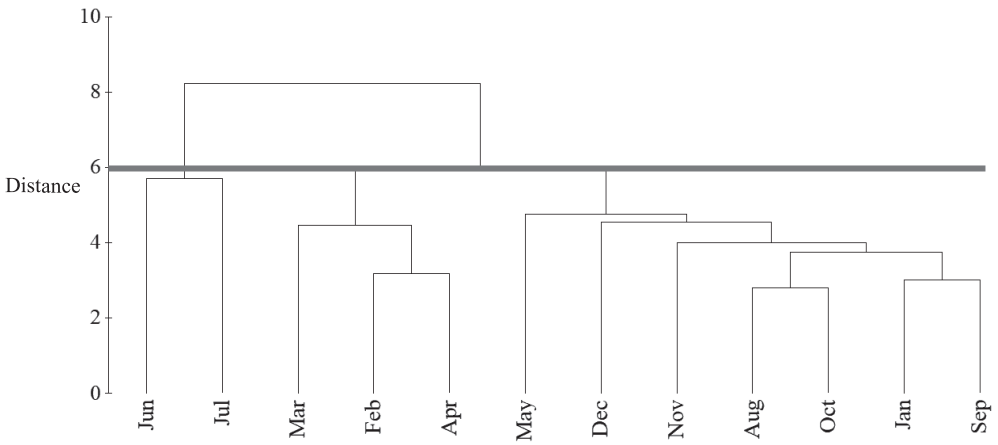

Fig. 2. Clustering surface water quality basing on months of the sampling.

Seasonal Change of Surface Water Quality

Physical Parameters

The average water temperature in 2021 ranges from 28.60±1.86ºC to 32.35±0.49ºC (Fig. 3). ANOVA analysis showed a statistically significant difference at 5% between the season change for the dry season and the rainy season ($p<0.05$). It can be seen that the temperature during the study period was within the tolerance limit of aquatic organisms [17]. The pH value in the rainy season had a statistically significant difference for the other two seasons ($p<0.05$). The highest pH value recorded in the dry season was 7.30±0.12 and the lowest in the rainy season was 7.02±0.07. In general, the pH did not fluctuate much and was within the allowable range of QCVN 08-MT:2015/BTNMT, column B1 (5.5-9.0). Electrical conductivity of water is the ability of water to conduct electric current and is also a measure of water salinity. The mean EC value between monitoring times ranged from 118.49±120.19 mS/m to 518.86±262.32 mS/m. EC value in the dry season had a statistically significant difference at 5% compared with the other two time points ($p<0.05$). According to [18], EC value in surface water should not exceed 1500 µS/cm. It can be seen that the surface water quality in the study area contained high salinity, which could flow to inland and seriously affect the freshwater aquatic ecosystem. The EC concentration in the dry season in the study area was 7.15 times higher than that that in the former study [19] in rivers and lakes in Hanoi, Vietnam. Fig. 2 shows that the average turbidity in 2021 had no statistically significant difference ($p>0.05$) and ranged from 41.87±11.34 NTU-225.30±90.93 NTU. In contrast, the highest average TSS concentrations was recorded in the dry season at 109.68±26.54 NTU and the lowest at the change of season was 69.13±22.45 NTU. TSS value in the dry season had a statistically significant difference compared with the other two periods (wet season and transitional period) ($p<0.05$). Turbidity is not specified in Vietnamese standards, meanwhile, TSS exceeded the allowable limit of QCVN 08-MT:2015/BTNMT, column B1 (50 mg/L) from 1.05-6.52 times. The high TSS value in the dry season may be partly due to the large amount of particulate matters in the rainy season (due to runoff and river bank erosion). In addition, wastewater, solid wastes also contribute to increasing TSS concentrations in water bodies [20]. The high turbidity and TSS concentrations in the study area were consistent with former studies [20-21].

DO, BOD, COD and TOC Parameters

The average dissolved oxygen concentration in June and July (seasonal change) had the lowest concentration of 2.68±0.20 mg/L and was significantly different from that in the dry season ($p<0.05$). Fig. 4 showed that the DO concentration at the time of the study was relatively low (less than 4 mg/L compared with QCVN) [22] indicating the occurrence of easily biodegradable organic matters in the water bodies. The average biochemical oxygen demand over the three monitoring times was also recorded to be low and there was no statistically significant difference between seasons ($p>0.05$). The lowest BOD value in the dry season was 2.14±0.43 mg/L and the highest in the changing season was 8.65±3.32 mg/L. Meanwhile, the average COD value in 2021 ranged from 10.19±1.59 mg/L to 72.15±13.65 mg/L. COD values in June and July had a statistically significant difference at 5% compared with the other two seasons ($p<0.05$). When compared with QCVN 08-MT:2015/BTNMT column B1, while the BOD was below the permissible limit of the regulation

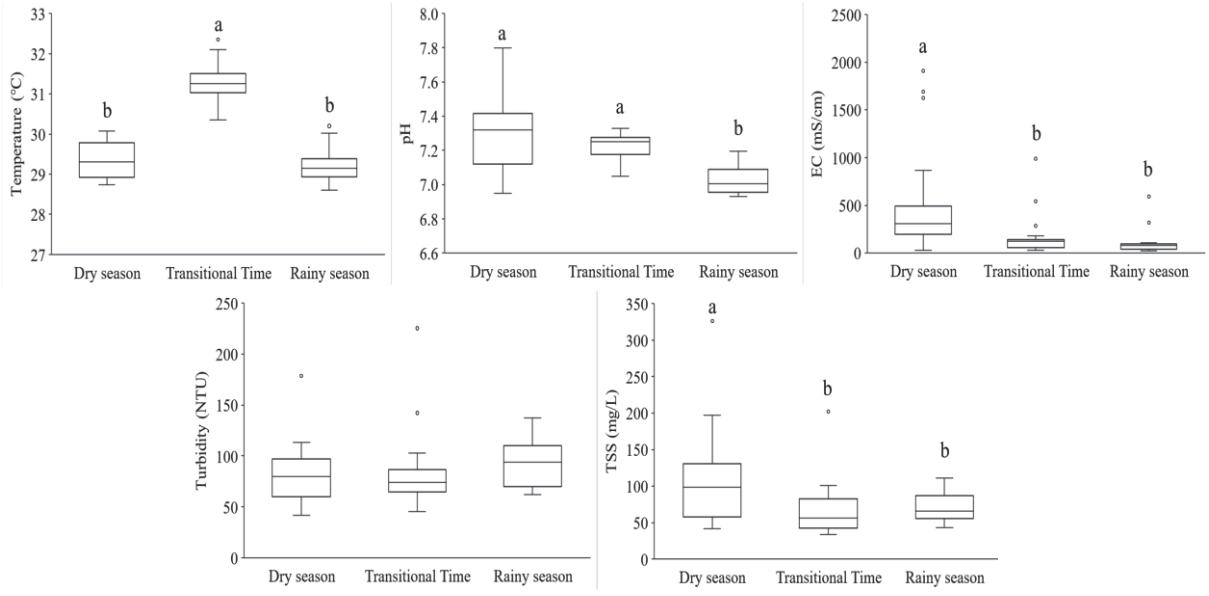

Fig. 3. Physical parameters of surface water in Soc Trang province in 2021.

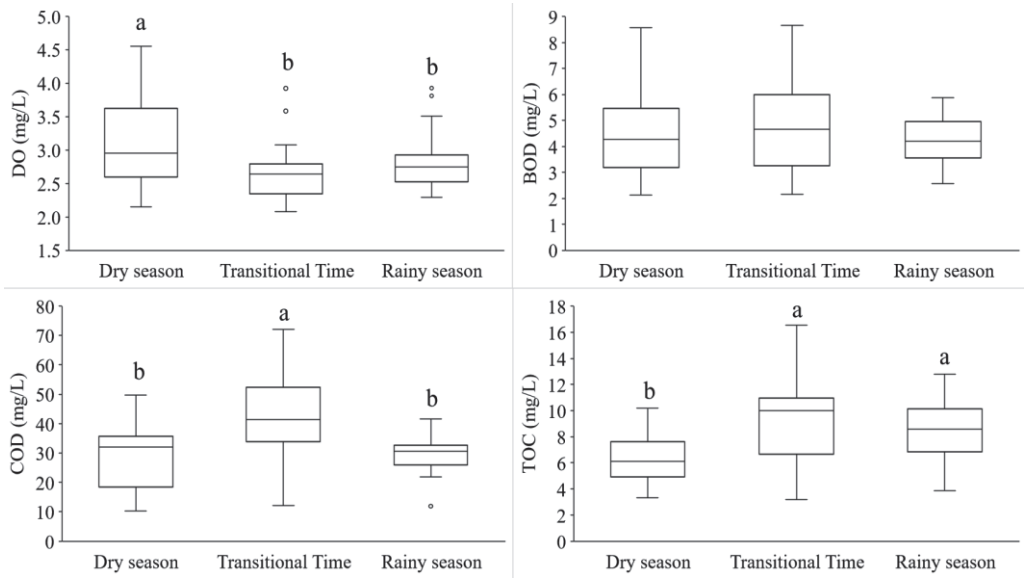

Fig. 4. DO, BOD, COD and TOC of surface water in Soc Trang province 2021.

(15 mg/L), the COD exceeded the allowable threshold (30 mg/L) by 1.01-2.41 time. Although the BOD did not exceed the permissible value of column B1, it was still relatively high compared with the other studies in Ben Tre province, Long Xuyen Quadrangle [2, 23]. The BOD and COD sources could be from agricultural, industrial and human activities. TOC is the amount of organic carbon present in water. The presence of TOC concentrations in water significantly affects the human body when using surface water for domestic or drinking purposes [24]. The mean TOC concentration ranged from 3.19±0.81 mg/L to 16.55±2.19 mg/L. The highest and lowest TOC values were recorded at the change of season and had a statistically significant difference compared with the dry season ($p<0.05$). The concentration of TOC exceeded the allowable threshold of QCVN 08-MT:2015/BTNMT column B1 (4 mg/L) by 1.01-4.13 times. TOC in the current study area was found to be higher than that in the study former [25].

Nutritional Parameters

The results of the analysis of seasonal changes in nutritional parameters are shown in Fig. 5. It can be seen that most of the nutritional parameters in June and July (seasonal change) had the highest values, except for the nitrite with the highest concentration recorded in the rainy season. In which, three parameters including $N\text{-}NH_4^+$, $N\text{-}NO_2^-$ and TN had a statistically significant difference at 5% between the time of season change and the other two seasons ($p<0.05$).

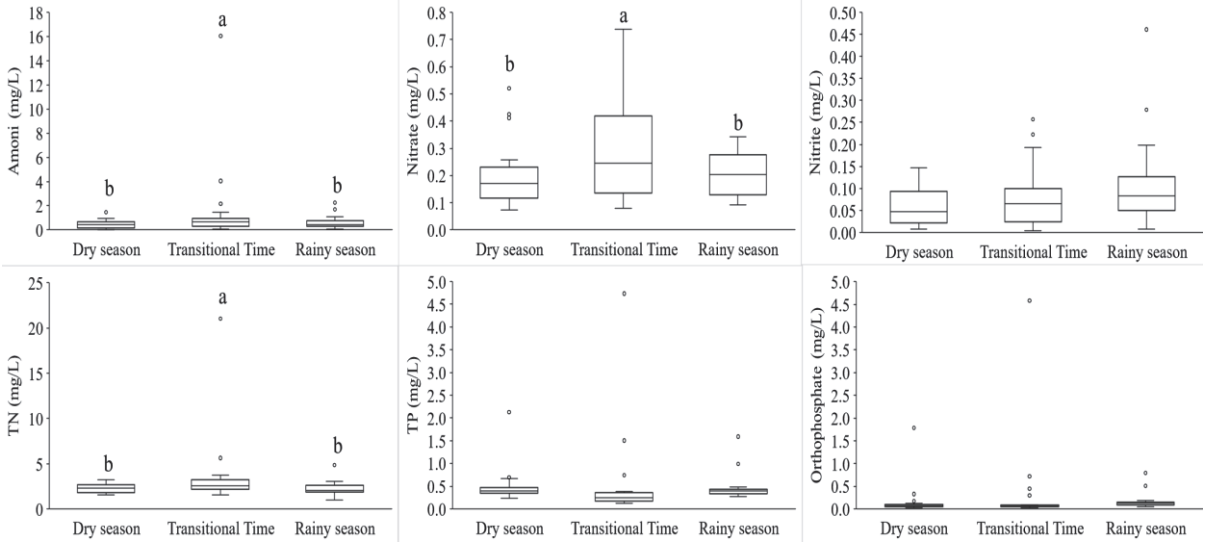

Fig. 5. Nutritional parameters of surface water in Soc Trang province 2021.

The concentrations of $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ in surface water were relatively high, ranging from 0.04±0.01 mg/L to 4.05±0.70 mg/L and from 0.01±0.00 mg/L to 0.46±0.66 mg/L, respectively. The concentration of $N\text{-}NH_4^+$ in the dry season and the rainy season was below the allowable threshold of QCVN 08-MT:2015/BTNMT column B1 (0.9 mg/L), while the $N\text{-}NO_2^-$ concentration at the study area was above the allowable threshold of the regulation (0.05 mg/L) from 1.20-2.22 times. Drasovean & Murariu [26] suggested that chemical forms of $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ could pollute and harm aquatic organisms. In contrast, the concentration of $N\text{-}NO_3^-$ in surface water was recorded quite low, ranging from 0.21±0.05 mg/L to 0.29±0.20 mg/L and within the allowable limit of QCVN 08-MT:2015/BTNMT column B1 (10 mg/L). The value of TN i n 2021 was relatively different between seasons, ranging from 1.57±0.40 mg/L-3.24±0.56 mg/L, 1.57±0.40 mg/L-21.05±12.52 mg/L and 1.01±0.24 mg/L-4.86±1.79 mg/L, respectively. The difference between TP and $P\text{-}PO_4^{3-}$ concentrations at different times of monitoring was low, ranging from 0.47±0.25 mg/L to 0.56±0.47 mg/L and 0.17±0.18 mg/L-0.36±0.49 mg/L, respectively. TN and TP were also not specified in Vietnamese standards, meanwhile, the value of $P\text{-}PO_4^{3-}$ at the time of season change exceeded the allowable limit of QCVN 08-MT:2015/BTNMT column B1 (0.3 mg/L). According to [27], the concentrations of nutrients in water depend a lot on the source directly discharged into the water source, when the nutrient concentration in the water is too high, it could affect the biological balance of the water and pollute the water source. Compared with the study of [25], the concentration of TN and TP in the current study area were much higher. The results revealed that surface water quality in Soc Trang province had a high level of nutrients that easily causes eutrophication.

Total Iron, Ions and Microorganisms

The highest average Fe concentration in 2021 was recorded in the rainy season with a value of 1.96±0.47 mg/L and the lowest in the changing seasons (June and July) at 1.73±0.44 mg/L. There was no statistically significant difference between seasons ($p>0.05$). Fe concentration at three time points exceeded the allowable limit when compared with QCVN 08-MT:2015/BTNMT column B1 (1.5 mg/L). This result is consistent with previous studies that Fe concentration tends to be higher in the rainy season [28]. Soc Trang province is an alkaline soil and there is a certain amount of iron. Therefore, during the rainy season, the precipitation eroded on both sides of the river can increase iron concentration. The study area borders the sea and is easily affected by saline intrusion, Cl^- concentration in 2021 was relatively high, ranging from 284.15±352.33 mg/L to 1437.37±897.20 mg/L.

The concentration of Cl^- in the dry season and the change of season exceeded the allowable limit of QCVN 08-MT:2015/BTNMT column B1 (350 mg/L) from 1.21 to 4.11 times. SO_4^{2-} concentration in surface water ranged from 12.88±10.73 mg/L to 507.43±204.67 mg/L and had an average value of 102.22±45.74 mg/L. SO_4^{2-} concentration in the dry season was statistically significant at 5% compared with the other two periods ($p<0.05$). SO_4^{2-} has not been specified in Vietnamese standards, but according to the standards of the World Health Organization (WHO), the concentration of SO_4^{2-} for drinking water is not more than 250 mg/L. The total oil and grease concentration in the water at the time of monitoring was low, ranging from 0.08±0.00 mg/L to 0.61±0.34 mg/L and did not exceed the allowable limit of QCVN 08-MT:2015/BTNMT column B1 (1 mg/L). The total oil and grease concentration in the dry season had a statistically significant difference compared with the other two times

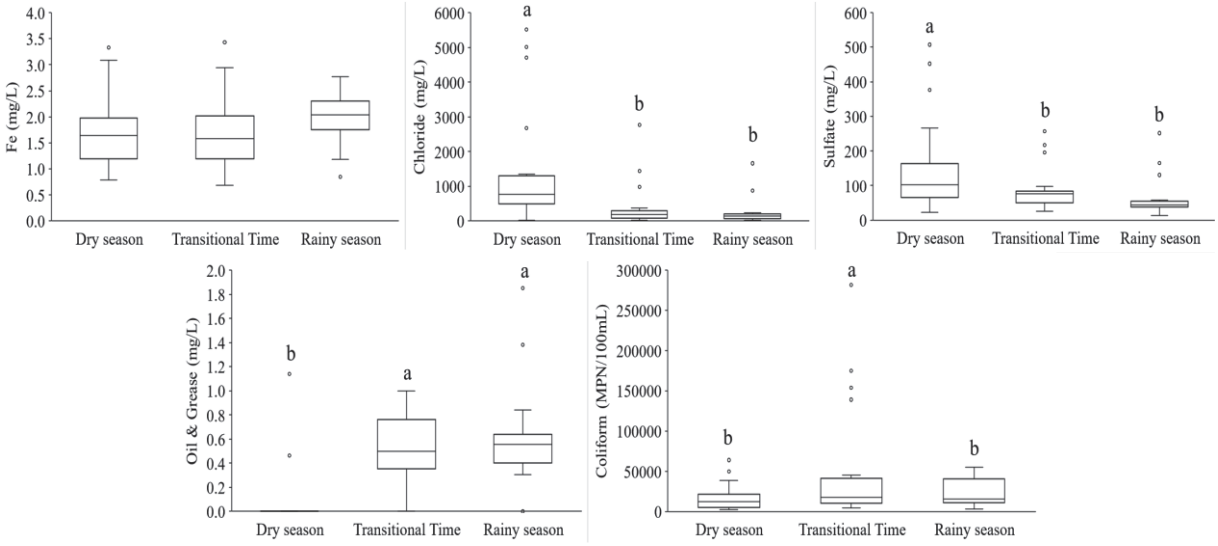

Fig. 6. Total iron, ions and microorganisms in Soc Trang province 2021.

at 5% ($p<0.05$). The average coliform concentration at the time of the study had a large difference, ranging from 17924.56±18678.07 MPN/100 mL to 23919.10±16100.88 MPN/100mL. The value of coliform in the dry season was significantly different from the other two times ($p<0.05$). When compared with studies in other provinces [3, 29] coliform values were quite high and exceeded the QCVN limit. 08-MT:2015/BTNMT column B1 (7500 MPN/100 mL) from 2.39 to 7.15 times. Surface water in most rivers and canals in Soc Trang province is seriously polluted from human and animal wastes and this situation has persisted for many years [4].

Correlation among Surface Water Parameters

The results of correlation analysis between 20 surface water quality parameters at 19 sampling locations in Soc Trang province in 2021 are shown in Table 2. It can be seen that temperature had a weak positive correlation with pH, EC, and COD, Cl^-, SO_4^{2-} and coliform and weakly negatively correlated with turbidity, $N\text{-}NO_3^-$ and Fe. The pH parameter was positively correlated with EC (r = 0.310), Cl^- (r = 0.286) and SO_4^{2-} (r = 0.338) and negatively correlated with turbidity, Fe and TOC. This result is in contrast with the study of [30] when pH is negatively correlated with chloride and SO_4^{2-}.

DO had a moderate to high negative correlation with parameters of BOD (r = -0.308), COD (r = -0.414), TOC (r = -0.529) and parameters $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $P\text{-}PO_4^{3-}$, TN, TP, Fe, coliform were weak. It showed that when the concentration of organic substances and nutrients in the water is high, the demand for oxygen increases, causing the DO concentration in the water to decrease [22]. EC conductivity had a moderate to high positive correlation with TSS (r = 0.508) and Cl^- (r = 0.994) parameters. This correlation is also recognized by the study of [31] with a high correlation. Meanwhile, turbidity had a good correlation with TSS (r = 0.712) and Fe (r = 0.720). This is consistent with previous study of [32] that turbidity is highly dependent on suspended solids in water. BOD had a good correlation with COD parameters (r = 0.464). At the same time, BOD and COD had weak to moderate correlation with $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $P\text{-}PO_4^{3-}$, TN, TP, coliform and TOC parameters. This represented organic matter pollution from domestic and agricultural wastes. TSS had a good correlation with Cl^- (r = 0.5), Fe (r = 0.672) and SO_4^{2-} (r = 0.471), indicating that salinity at estuaries had a significant influence on suspended solids, making suspended solids agglomerated. $N\text{-}NH_4^+$ had a good correlation with $P\text{-}PO_4^{3-}$ (r = 0.523), TN (r = 0.515), TP (r = 0.582), coliform (r = 0.365), TOC (r = 0.441) showing that the study area is affected mainly by agricultural activities and domestic waste from humans and animals. Cl^- has a high positive correlation with SO_4^{2-} (r = 0.909), which is related to salts dissolved in water in the study area. This correlation is also noted in the study of [33]. $N\text{-}NO_3^-$, $N\text{-}NO_2^-$, $P\text{-}PO_4^{3-}$ had a weak correlation with TOC. In addition, $P\text{-}PO_4^{3-}$ also had a high positive correlation with parameters of TN (r = 0.755), TP (r = 0.907), coliform (r = 0.331), showing that the study area organic matter pollution from sources of domestic waste, farming and agriculture. TN had a good correlation with TP (r = 0.712). At the same time, both TN and TP had a good correlation with coliform and TOC, indicating that the study area is susceptible to eutrophication. Correlation analysis showed that most of the surface water quality parameters of Soc Trang province in 2021 are related to each other. However,

Table 2. Correlation between surface water quality parameters.

Var.	Temp	pH	DO	EC	Tur	BOD	COD	TSS	$N\text{-}NH_4^+$	Clo	$N\text{-}NO_2^-$	$N\text{-}NO_3^-$	$P\text{-}PO_4^{3-}$	Fe	TN	TP	SO_4^{2-}	Coliform	TOC	O&G
Temp	1																			
pH	**0.199**	1																		
DO	-0.110	0.123	1																	
EC	**0.158**	**0.310**	0.075	1																
Tur	**-0.175**	**-0.141**	-0.082	0.112	1															
BOD	0.111	0.037	**-0.308**	-0.032	-0.107	1														
COD	**0.215**	-0.021	**-0.414**	**0.246**	0.091	**0.464**	1													
TSS	-0.098	0.074	0.093	**0.508**	**0.712**	-0.100	**0.142**	1												
$N\text{-}NH_4^+$	0.049	-0.039	**-0.385**	-0.042	-0.076	**0.520**	**0.441**	-0.086	1											
Clo	**0.153**	**0.286**	0.084	**0.994**	0.105	-0.046	**0.229**	**0.500**	-0.049	1										
$N\text{-}NO_2^-$	**-0.153**	-0.120	**-0.179**	-0.044	-0.008	**0.154**	0.025	-0.055	**0.171**	-0.043	1									
$N\text{-}NO_3^-$	0.060	0.047	**0.231**	-0.109	-0.047	**-0.175**	**-0.279**	-0.036	**-0.255**	-0.108	0.033	1								
$P\text{-}PO_4^{3-}$	-0.009	0.009	**-0.157**	-0.026	-0.095	**0.377**	**0.295**	-0.104	**0.523**	-0.034	0.008	-0.126	1							
Fe	**-0.155**	**-0.216**	**-0.185**	0.120	**0.720**	-0.033	**0.216**	**0.672**	0.119	0.122	0.098	**-0.168**	-0.037	1						
TN	0.113	-0.051	**-0.190**	0.048	-0.101	**0.330**	**0.443**	-0.064	**0.515**	0.037	0.096	-0.085	**0.755**	-0.002	1					
TP	-0.035	-0.014	**-0.163**	0.024	-0.011	**0.411**	**0.324**	-0.009	**0.582**	0.015	0.036	**-0.180**	**0.907**	0.071	**0.712**	1				
SO_4^{2-}	**0.185**	**0.338**	0.003	**0.923**	0.117	0.008	**0.291**	**0.471**	-0.024	**0.909**	-0.045	-0.075	-0.038	0.102	0.049	-0.002	1			
Coliform	**0.130**	0.012	**-0.236**	0.006	-0.091	**0.219**	**0.341**	-0.109	**0.365**	-0.015	-0.007	0.001	**0.331**	-0.040	**0.384**	**0.297**	-0.018	1		
TOC	0.080	**-0.223**	**-0.529**	-0.027	0.109	**0.319**	**0.568**	-0.100	**0.441**	-0.028	**0.300**	**-0.331**	**0.196**	**0.322**	**0.312**	**0.264**	0.017	**0.174**	1	
O&G	0.093	-0.067	0.093	-0.092	**-0.152**	0.020	-0.033	-0.116	0.000	-0.098	-0.017	-0.008	0.035	-0.101	0.093	0.027	-0.076	0.028	-0.015	1

Notes: Temp-Temperature, Tur-Turbidity, O&G-Oil & Grease

the correlation between water quality parameters was only moderate to weak. Therefore, it is possible that the water quality monitoring parameters are largely influenced by external factors.

Spatial Water Quality Variation by Water Quality Index

The surface water quality index for 2021 at 19 monitoring locations is shown in Fig. 7. The results showed that the WQI values at these monitoring points ranged from 21 to 84. Water quality was divided into four group from poor (red) to good (green). Fig. 4 also showed that there was no monitoring location with water quality in the very polluted group and the very good group in the province. The best water quality was recorded in Co Co market canal (M6) and Hau river - Nhon My commune (M4) with WQI values of 84 and 83 respectively. In addition, there were five locations with water quality in the group of bad quality including M8, M10, M13, M15 and M18 position and only two locations in the group with average water quality were M9 and M14. More than 52.63% of monitoring points had poor water quality. In which, the surface water quality at Xang canal (M1) and 30/4 canal (M2) had the lowest water quality compared to other monitoring locations, both positions had WQI value of 21. Water quality was poor in regions associated with concentrated socio-economic activities. As 30/4 canal is the place to receive wastewater from industrial activities, a part of people's domestic wastewater, so the water environment is polluted with organic and micro-organisms quite high. Vinh Chau town canal is also a section of canal flowing through the town center with dense population, thus receiving a lot of domestic waste water [4]. However, water quality in Soc Trang province in 2021 tended to be improved when studying the same site by Phong and Cuong [34].

Key Parameters Affecting Surface Water Quality and Seasonal Variation

PCA analysis results identified seven factors explaining 94.9% variation in surface water quality in Soc Trang province in 2021 (Table 3). In which, five main factors including PC1, PC2, PC3, PC4, PC5 explained 88.8% of the change in water quality with the rates of 37.4%, 26.2%, 11.0%, 8.6% and 5.7%, respectively. As can be seen, the eigenvalue coefficients from PC1 to PC5 were all greater than 1, so these PCs were used to evaluate the main sources of pollution to surface water quality. Table 2 showed that PC1 explained the fluctuations of DO (0.308), $N\text{-}NH_4^+$ (-0.323), $N\text{-}NO_2^-$ (-0.306) and TN (-0.334) parameters at a weak level. This source includes most nitrogen-containing nutrients that can be affected by agricultural waste, especially fertilizers. This result is consistent with the study of [35] that nutrient pollution is one of the main potential factors affecting surface water quality. PC2 explained the fluctuations of EC (0.390), TSS (0.361), Cl^- (0.391) and SO_4^{2-} (0.401) parameters as weakly correlated. This source is mainly influenced by suspended solids and salinity in the water. PC3 had a weak correlation with pH (0.316), $N\text{-}NO_3^-$ (0.382), $P\text{-}PO_4^{3-}$ (0.321), Fe (-0.320) and TP (0.307), was affected by nutrients and heavy metals can be affected by agricultural, domestic and industrial waste sources. PC4 had a moderate correlation with temperature (0.564) and a weak correlation with turbidity (-0.437), TSS (-0.341) and Fe (-0.348), influenced by industrial activities and rainwater run overflow with suspended matter. PC5 explained the change of turbidity parameters (-0.370) at a weak level and with total grease parameter (0.559) at medium level, which could be affected by wastewater from industrial and domestic activities in the study area. From the PCA results, it shows the parameters of temperature, pH, DO, EC, TSS, turbidity, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$, $P\text{-}PO_4^{3-}$, TN, TP, Cl^-, SO_4^{2-}, Fe and

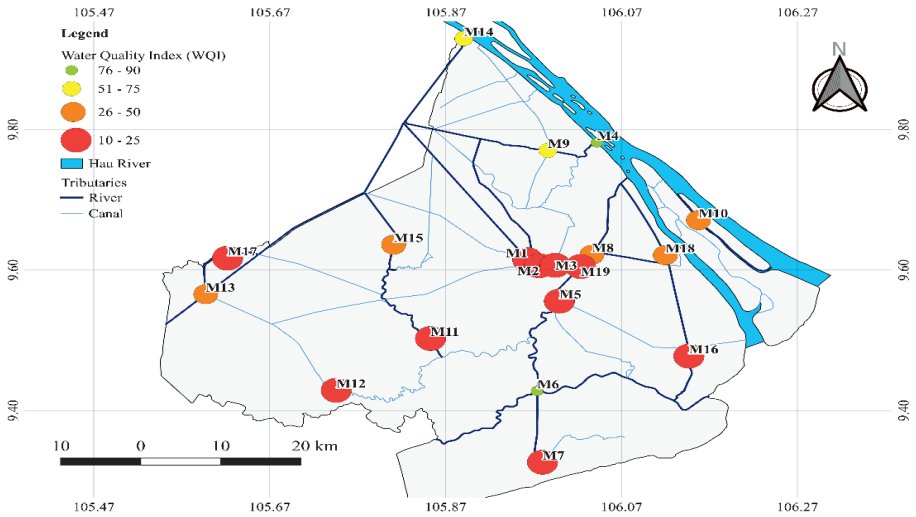

Fig. 7. Map of surface water quality index at sampling locations.

Table 3. Key parameters affecting surface water quality in Soc Trang province in 2021.

Parameters	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Temp	-0.001	0.247	-0.027	0.564	-0.170	0.092	-0.027
pH	0.178	0.118	0.316	0.024	-0.256	-0.641	-0.067
DO	0.308	-0.119	0.223	-0.083	0.065	0.026	-0.087
EC	-0.008	0.390	0.226	0.079	0.258	-0.014	0.033
Tur	0.073	0.296	-0.021	-0.437	-0.370	0.046	-0.025
BOD	-0.299	-0.005	-0.068	-0.131	-0.183	-0.274	0.478
COD	-0.274	0.255	-0.095	0.050	0.086	-0.074	0.358
TSS	0.082	0.361	0.084	-0.341	-0.123	0.067	-0.173
$N\text{-}NH^{4}+$	-0.323	-0.092	0.218	-0.060	0.013	0.001	-0.327
Cl^{-}	-0.001	0.391	0.219	0.080	0.267	-0.013	0.007
$N\text{-}NO^{2}$-	-0.306	-0.047	0.068	-0.069	-0.258	-0.091	0.184
$N\text{-}NO^{3}$-	0.235	-0.118	0.382	-0.153	0.008	0.055	0.542
$P\text{-}PO^{43}$-	-0.283	-0.132	0.321	-0.143	0.131	0.086	-0.040
Fe	-0.054	0.292	-0.320	-0.348	-0.118	0.116	-0.160
TN	-0.334	-0.076	0.205	-0.084	0.041	0.059	-0.140
TP	-0.294	-0.100	0.307	-0.163	0.107	0.083	-0.132
SO_4^{2-}	-0.011	0.401	0.189	0.053	0.248	0.030	0.063
Coliforms	-0.265	0.068	-0.003	0.243	-0.212	-0.376	-0.255
TOC	-0.297	0.096	-0.269	-0.002	0.200	0.111	0.156
Oil	0.069	-0.077	-0.286	-0.260	0.559	-0.543	-0.084
Eigenvalues	7.47	5.23	2.20	1.72	1.13	0.84	0.37
%Variation	37.4	26.2	11.0	8.6	5.7	4.2	1.9
Cum.%Variation	37.4	63.5	74.6	83.2	88.8	93.0	94.9

total grease affect the surface water quality of Soc Trang province in 2021 and should be included in the monitoring program. Thus, the surface water in the province is affected by many sources such as domestic wastewater, wastewater from industrial and agricultural activities, salinity and rainwater runoff leading to suspended matter. The study of [35, 36] also revealed agricultural activities, erosion, domestic and industrial discharges are fundamental causes of water pollution.

Discriminant analysis (DA) was applied to determine the level of discriminant functions (DFs) and the most important parameters affecting the change of water quality between dry season, seasonal change and rainy season as shown in Table 4. The results showed that DF1 and DF2 could distinguish surface water quality at three time points. Wilk's Lambda analysis showed that there was a significant difference between the dry season, the transitional season and the rainy season (Sig. = 0.000<0.05) with an accuracy rate of 100%. DF1 and DF2 had rates of 63.9% and 36.1% respectively. It was shown that TOC, TSS, coliform, DO, temperature, pH, EC, Cl^{-}, SO_4^{2-}, COD were important parameters contributing significantly to the change of water quality between the seasons. These 10 parameters had an accurate discrimination rate of 85.1%. Seasonal changes of TSS, COD, pH parameters have also been noted by previous studies [16, 37]. DA analysis showed that a few key parameters responsible for temporal changes in surface water quality. The results could be helpful in considering reduction of the size of the dataset during monitoring surface water quality in Soc Trang province.

Conclusions

The study showed that the surface water quality of Soc Trang province in 2021 was contaminated with organic and micro-organisms. The CA analysis divided the monitoring months into three clusters representing the dry season, the transition and the rainy season. ANOVA analysis showed that the seasonal difference in water quality was statistically significant at 5% and the water quality values at the season change tended to be

Table 4. Values of variables leading to different seasonal water quality.

Discriminant Functions (DFs)	DF1	DF2
TOC	**0.307**	-0.138
TSS	-0.231	0.205
Coliform	**0.219**	0.141
DO	**-0.211**	0.086
Oil and grease	0.187	-0.131
$N\text{-}NH_4^+$	0.180	0.107
pH	-0.141	**0.615**
Temperature	0.361	0.443
EC	-0.308	0.401
Cl^-	-0.301	0.376
SO_4^{2-}	-0.215	0.359
COD	0.289	0.321
TN	0.174	0.187
BOD	0.009	0.178
$N\text{-}NO_2^-$	0.037	-0.128
$N\text{-}NO_3^-$	0.124	0.125
Fe	0.000	-0.123
Turbidity	0.017	-0.111
$P\text{-}PO_4^{3-}$	0.088	0.103
TP	0.020	0.058
Eigenvalue	1.183	0.668
% of variation	63.9	36.1
Cum %	63.9	100.0
Wilks' Lambda	0.275	0.600
Sig.	0.000	0.000

higher than that of the other two time points. Almost parameters exceeded the allowable limits of QCVN 08-MT:2015/BTNMT, column B1. Pearson correlation presented that turbidity had a good correlation with TSS; organic compounds were well intercorrelated; nitrogen and phosphorus compounds correlated well with coliform and TOC. The WQI ranked the water quality from poor to good. Water quality was poor mainly in areas associated with concentrated socio-economic activities. PCA indicated five main factors explaining 88.8% of the variation in water quality. The parameters of temperature, pH, DO, EC, TSS, turbidity, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$, $P\text{-}PO_4^{3-}$, TN, TP, Cl^-, SO_4^{2-}, Fe and total grease affected the surface water quality. Pollution sources in the province could be mainly from domestic wastewater, wastewater from industrial and agricultural production activities, salinity and runoff. Ten parameters caused the difference between time points including TOC, TSS, coliform, DO, temperature, pH, EC, Cl^-, SO_4^{2-} and COD by discriminant analysis. The results provide scientific information to support environmental management agencies in Soc Trang province and neighboring coastal provinces in reviewing the surface water monitoring system, thereby having solutions to manage and improve the quality of coastal water environment.

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Conflict of Interest

The authors declare no conflict of interest.

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