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Study of Fluctuation in Surface Water Quality in Can Tho Province (Mekong Delta, Vietnam)

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ABSTRACT

The research investigated changes in surface water quality (SWQ) in the canals and rivers of Can Tho province in the Mekong Delta in southern Vietnam. Surface water was sampled at 34 points through months of the end of the rainy and flood season (October 2023), the beginning of the dried season (December 2023), and the middle of the dried season (February 2024). The SWQ parameters were compared with limited values of the national technical standard on SWQ and the Vietnamese water quality index. We used principal component analysis (PCA) to find sources causing surface water pollution and cluster analysis (CA) to identify the similarities in SWQ parameters among sampling points. The research showed that Can Tho's average SWQ value ranged at a good level. The SWQ in the dry season is worse than in the rainy season. Pollution from suspended solids, organic matter, nutrients, and coliform was found in Can Tho's surface water. The PCA resulted in the three key sources of PCs 1, 2, and 3 being elucidated by 65.3% of SWQ changes. Twelve current monitoring parameters, including temperature, pH, dissolved oxygen, total suspended solids, total organic carbon, biological oxygen demand, chemical oxygen demand, ammonium, nitrite, nitrate, phosphate, and coliform, are influencing SWQ. It is suggested from the CA results that the 34 monitoring points could decrease to 30 points in the case of financial issues. The results are beneficial in reviewing the sampling points and monitoring parameters for SWQ in Can Tho.

Keywords: cluster analysis, monitoring, similarity, statistical approach, water surface.

INTRODUCTION

A central province in the Mekong Delta region – Can Tho – is located on the southern bank of Hau River (a tributary of the Mekong River). Millions of years ago, this region was established by the Mekong River's residue and the Pacific Ocean's movement. That is why its unique geography has abundant canals and rivers, including the Hau River and many sub-rivers. Annually, especially during the flood season, surface water receives an enormous alluvium volume from the Mekong River's upper parts, which is fertile for agricultural cultivation (Takemura et al., 2007). Additionally, Can Tho's surface water quality (SWQ) is critical for domestic water supply, aquaculture, aquatic animal life, etc. (Dinh et al., 2020). SWQ monitoring is a mandatory task in Vietnam. The SWQ monitoring brings forth information on the health of water bodies over time and the prediction of surface water pollution in the future (Sudriani et al., 2023). Annually, SWQ monitoring is the responsibility of the Ministry of Natural Resources and Environment (MONRE) and the Department of Natural Resources and Environment (DONRE) of Vietnam's provinces (MONRE, 2023). The SWQ reports conducted by MONRE and DONRE and former studies focused firmly on SWQ assessment by comparing with the Vietnamese National Technical Standard (VNTS) on SWQ and using the water quality index (WQI) (e.g., MONRE, 2021; Ha et al., 2021; Phu, 2019). However, these evaluation methodologies are too simple in that measured values of SWQ parameters are just compared to limited values regulated in the VNTS and ranged based on the WQI; in the meantime, the valuable information hidden in the extensive dataset has not been discovered yet (Giao, 2023; Thuan, 2022; Le et al., 2017).

In recent research, methodologies of multivariate statistical analysis are applied incrementally to the SWQ assessments (e.g., Thuan, 2022; Giao et al., 2021; Chounlamany et al., 2017). These methodologies consist of all the SWQ parameters in the calculation simultaneously, which helps assess the SWQ more distinctly from the extensive dataset (Thuan, 2022; Giao et al., 2021; Chounlamany et al., 2017). In there, principal component analysis (PCA) – a multivariate analysis technique – is applied to evaluate SWQ, determine polluted sources, and identify the significant factors causing changes in SWQ (Giao et al., 2023; Thuan, 2022; Zeinalzadeh, Rezaei, 2017). The methodologies of cluster analysis (CA) method is helpful to group sampling points in compliance with biophysical criteria to clarify how much difference in SWQ between water survey points (Hong et al., 2023; Chounlamany et al., 2017; Sahah et al., 2012).

The delta province of Can Tho belongs to the Asian monsoon area; thus, Can Tho's climate in the rainy season is distinguished from the sunny season. Besides, as a part of the Mekong River downstream, Can Tho obtains floodwater from the upstream of the Mekong River in the annual flood months. The SWQ in Can Tho changes seasonally; however, the profoundly deep understanding of seasonal changes in SWQ is limited. Previous research has affirmed the advantages of multivariate statistics exploited to analyze and assess SWQ monitoring data. Our study objectives are to evaluate seasonal changes in SWQ in canals and rivers in Can Tho and identify key factors that cause seasonal changes in SWQ using multivariate statistics.

MATERIALS AND METHODS

Water sampling and analysis

In Can Tho's monitoring program, they designed a survey of surface water samples in both the dried and rainy seasons with a frequency of six times a year. However, the sample collection frequency has been less than six due to financial issues in recent years. In this study, we focus on the interpretation of changes in SWQ at the end of the rainy season and flood season (October 2023), at the beginning of the dried season (December 2023), and at the middle of the dried season (February 2024). In detail, 34 points for monitoring were designed (Figure 1). The monitoring points consisted of at Ninh Kieu district (located at the center of Can Tho) with ten points from P1 to P10, at districts next to the center of Can Tho of Cai Rang district (P11–P14) and Binh Thuy district (P15 – P17), at rural districts in Can Tho of O Mon district (P18 – P22), Thot Not district (P23 – P25), Phong Dien district (P26 – P28), Thoi Lai district (P29 & P30), Co Do district (P31 & P32), and Vinh Thanh district (P33 and P34).

The surface water was sampled and stored according to the guidelines of the VNTS on SWQ (QCVN 08-MT:2023/BTNMT) (MONRE, 2023). The SWQ parameters are listed in the VNTS, including temperature, pH, dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), total organic carbon (TOC), ammonium (NH_4^+-N), nitrite (NO_2^--N), phosphate (PO_4^{3-}-P), and coliform [MONRE, 2023]. TOC is rarely reported and was only analyzed in December 2023 and February 2024. Although nitrate (NO_3^-N) is not listed in QCVN 08-MT:2023/BTNMT, we also analyzed it to calculate the WQI. Temperature and COD were analyzed by standard methods for the examination of water and wastewater (SMEWW) of SMEWW 2550B:2017 and SMEWW 5220.C:2017, respectively, whereas pH, DO, TSS, BOD_5, NH_4^+-N, NO_2^--N, NO_3^--N, PO_4^{3-}–P, and coliforms were analyzed by the Vietnamese technical standards (TCVN) of TCVN 6492:2011, TCVN 12026:2018, TCVN 6625:2000, TCVN 6001-1:2008, TCVN 6179-1:1996, TCVN 6178:1996, TCVN 6180:1996, TCVN 6494-1:2011, and TCVN 6187-2:1996, respectively.

Data analysis

The VN-WQI - Vietnam water quality index - is calculated using Equation 1 according to the instructions of the Vietnam Environment Administration (VEA, 2019).

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

where: WQI_I was calculated for the pH parameter; WQI_{IV} was calculated for 08 parameters:

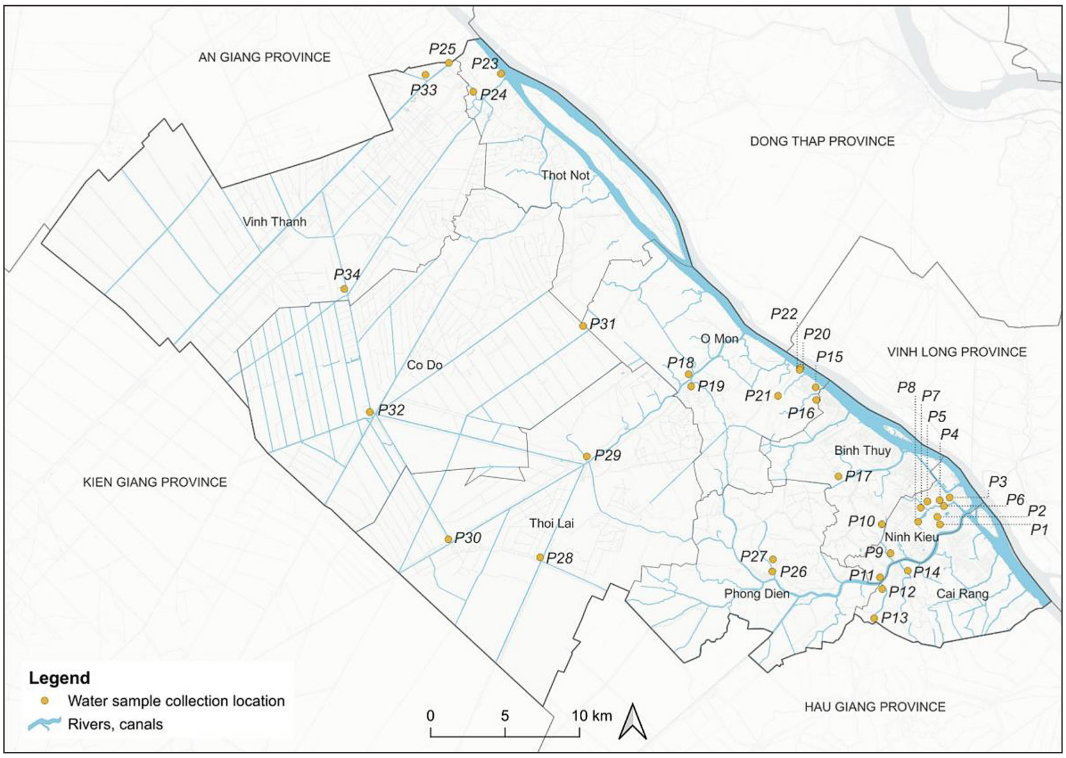

Figure 1. The map indicating the surface water monitoring points in Can Tho

DO, TOC, COD, BOD_5, PO_4^{3-}-P, NH_4^+-N, NO_3^--N, and NO_2^--N; WQI_V was calculated for the value of coliform.

The SWQ is divided into six levels. Level 1 with *WQI* from 91 to 100 ranged at a very good level, and water use for domestic water supply is proposed. Level 2 with *WQI* from 76 to 90 ranged at a good level, with water use for domestic water supply purposes after suitable treatments are proposed. Level 3 with *WQI* from 51 to 75, ranging at medium level, suggests that water for irrigation and other equivalents be used. Level 4 with *WQI* from 26 to 50 ranged at a bad level, where water is used for water transportation and another equivalent. Level 5 with *WQI* from 10 to 25 ranged at a poor level; polluted water is heavy and needs to be treated. Water is toxic and must be restored and treated that ranges at Level 6 ($WQI < 10$).

The values of SWQ parameters (pH, DO, TSS, BOD_5, COD, TOC, and coliform) were compared with the regulated values in the VNTS on SWQ of QCVN 08-MT:2023/BTNMT for column A – used for domestic water supply purposes after applying appropriate treatments, whereas values of NH_4^+-N and NO_2^--N were compared with the maximum limit values of parameters regulated by this VNTS that affecting health humans. In addition, we used SPSS 20.0 software (IBM Corp., USA) for performing a one-way analysis of the variance with Duncan Test to find out the significant differences (at 0.05 level; $p < 0.05$) for the mean values of SWQ parameters among the sampling times of the end of the rainy season, the beginning of the dried season, and the middle of the dried season.

In our study, we applied the methods of Feher et al. (2016) for PCA. Shortly, the PCA creates groups of SWQ variables from the original datasets named variables of the principal component (PC). The PCs are tightly associated with each other, which will be seen at increasing levels of importance. A pivot method of Varimax is applied in PCA. Every variable of initial data is allocated a factor, and every factor will appear for a minor group of initial variables. Through PCA, sources that caused changes in surface water quality were identified. The CA was conducted following the methods of Salah et al. (2012). We applied CA to group the sampling points by the physicochemical parameters. The sampling points with similar characteristics of SWQ were grouped, and those with different characteristics separated from others, resulting in a tree data structure (Hong et al., 2023; Chounlamany et al., 2017; Sahae al., 2012). Monitoring points and parameters for SWQ would be suggested through CA. Our study used Primer 5.2 software for Windows (PRIMER-E Ltd, UK) to run PCA and CA.

RESULTS AND DISCUSSIONS

The SWQ fluctuations

The seasonal fluctuations of SWQ

The average temperature value was 28.6 ± 1.3 °C, fluctuating from 26.1 to 31.3 °C (Figure 2a). The temperature in February (30.1 ± 0.6 °C) was significantly higher than that in October (28.0 ± 0.7 °C) and December (27.8 ± 0.8 °C); however, there was an insignificant difference between October and December. The water temperature was related to the air temperature, and variations of surveyed surface water temperature were due to the reduced air temperature in the rainy months and the increased air temperature in the dried months. In southern Vietnam, the air temperature in February is always higher than in December and October, so there is a higher water temperature in February. There were fluctuations in water temperature during the sampling months; however, they were within a suitable temperature range for aquatic animals (20–32 °C) (Mutea et al., 2021).

The average pH value reached 7.2 ± 0.1, while the lowest was 6.8 and the highest was 7.5 (Figure 2a). It met with the regulated value range (6–8.5) of the VNTS. The insignificant differences in pH values between months were found (7.2 ± 0.1, 7.2 ± 0.1, and 7.2 ± 0.2 for October, December, and February, respectively). The little changes in surface water pH values in Can Tho were well met with the surface water's pH value range of the Hau River's tributary and main rivers (e.g., the study of Giao et al., (2023) on SWQ in An Giang province – located at upstream of Hau River, the study of Thuan et al. (2022) on SWQ in Hau Giang province – located at downstream of Hau River, and the study of Mutea et al., (2021) on SWQ for aquaculture in Hau River). The surface water pH values in Can Tho were suitable for aquaculture (7–9; Boyd, 1998), and this finding is similar to the research of Mutea et al., (2021).

The average DO value was 4.2 ± 0.2 mg/L, and DO values varied lightly with 3.8–4.9 mg/L (Figure 2b). The DO in October (4.4 ± 0.2 mg/L) was significantly higher than that in December (4.2 ± 0.1 mg/L) and February (4.2 ± 0.1 mg/L), but the significant difference in DO values between December and February was not detected. Generally, DO values met the limit value of the VNTS (≥ 6 mg/L), and such results were also found in the Hau River's main and tributary rivers (Giao et al., 2023; Thuan et al., 2022; Mutea et al., 2021). The appropriate oxygen demand for aquatic organisms is 5–7 mg/L. Oxygen availability in water depends on many factors, such as temperature, solubility, nutrient availability, decomposition of organic compounds, photosynthesis of aquatic plants, etc. (Serajuddin et al., 2019; Boyd, 1998). The DO depletion in water bodies in Can Tho can be due to the decomposition of organic compounds and high temperatures (Mutea et al., 2021). The high amount of organic matter can come from organic waste from domestic activities and untreated sewage from industrial activities.

The TSS values for average, lowest, and highest were 28.0 ± 12.9 mg/L, 10.0 mg/L, and 81.0 mg/L, respectively (Figure 2b), approximately 1.9 times higher than the value of the VNTS (15

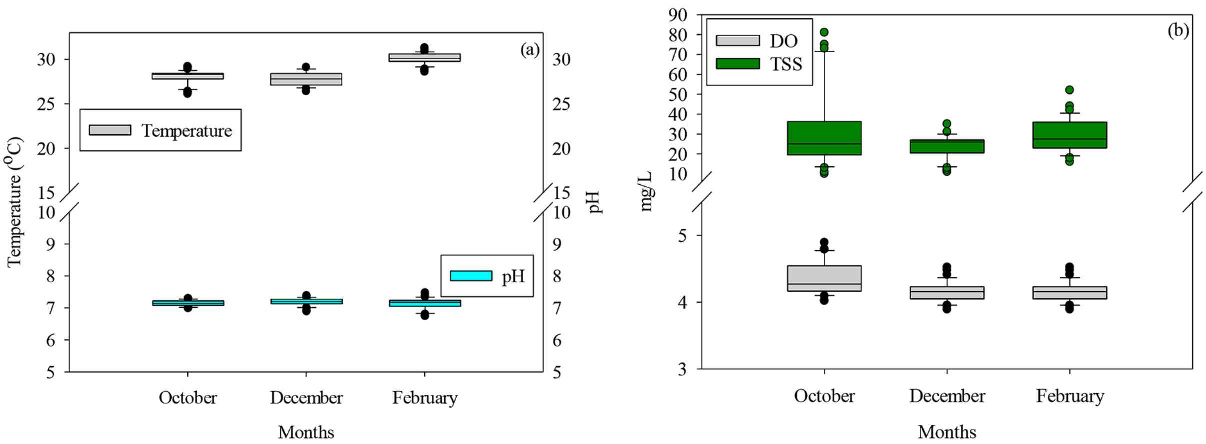

Figure 2. Values of temperature and pH (a), and DO and TSS (b) over months

mg/L). The TSS values between October (31.1 ± 19.3 mg/L) and December (24.4 ± 5.8 mg/L) differed significantly, but the differences between October and February (29.4 ± 8.3 mg/L) and between December and February were insignificant. The research on surface water in the Hau River's main and tributary rivers also showed large fluctuations in TSS values (Giao et al., 2023; Thuan et al., 2022; Mutea et al., 2021). High concentrations of TSS can be runoff by rainfall, riverbank erosion, high content of alluvial, and phytoplankton density in water (Adjovu et al., 2023; Giao, 2023; MONRE, 2021). In the flood season (August–November), alluvium is transported from the Mekong River upstream to the Hau River downstream. Thus, alluvium transportation and runoff by rainfall could be the main factors influencing the high TSS concentrations in October (in the flood and rainy season).

Within the VNTS sets the proper levels for BOD_5 concentration at 4 mg/L, COD concentration at 10 mg/L, and TOC concentration at 4 mg/L. The average values of BOD_5, COD, and TOC in this study were found to be 6.1 ± 2.2 mg/L (3.0–10.3 mg/L), 12.0 ± 3.1 mg/L (6.1–24.7 mg/L), and 5.1 ± 2.0 mg/L (1.8–11.7 mg/L), respectively (Figure 3a). These levels were slightly above what was allowed. The BOD_5 concentration and COD concentration in February (8.2 ± 2.0 mg/L and 14.2 ± 3.5 mg/L for BOD_5 and COD, respectively) were significantly higher compared with ones in October (5.3 ± 1.7 mg/L and 10.7 ± 2.5 mg/L for BOD_5, COD, respectively) and December (4.8 ± 0.9 mg/L and 11.1 ± 1.6 mg/L for BOD_5 and COD, respectively); however, there were no significant differences in BOD_5 concentration and COD concentration between October and December. The TOC concentration in February (5.6 ± 1.5 mg/L) was also significantly higher than in December (4.6 ± 2.5 mg/L). High organic matter in surface water is different sources of aquaculture activities, waste from domestic and industrial activities, agricultural runoff, aquatic plant and animal decay, etc. (Riyadh et al., 2024; Xenopoulos et al., 2021). The high organic matter in February can be explained by some sampling points received industrial and municipal wastewater in combination with low water exchanges due to low water volume in water bodies in the dried months. The results showed that much

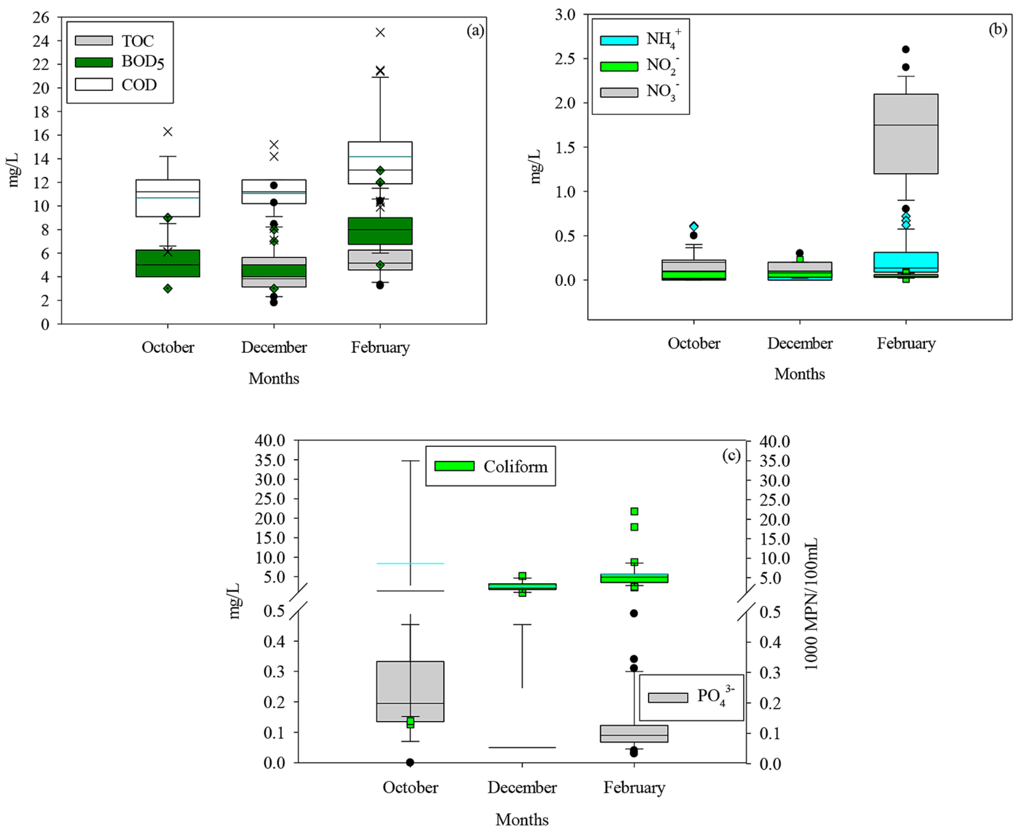

Figure 3. Values over months of TOC, BOD_5, and COD (a), NH_4^+-N, NO_2^--N, and NO_3^- (b), and PO_4^{3-} and coliform (c)

organic matter was contaminating the surface water in Can Tho, so visible SWQ improvement is necessary by managing wastewater sources. Recent research on SWQ in the main and tributary rivers of the Hau River has found high levels of organic pollution (Giao et al., 2023; Thuan et al., 2022; Mutea et al., 2021). This pollution could harm people who use the water, aquaculture, and the health of river ecosystems.

The average values of NH_4^+-N, NO_2^--N, and NO_3^--N were 0.12 ± 0.17 mg/L (0.00–0.72 mg/L), 0.06 ± 0.05 mg/L (0.00–0.23 mg/L), and 0.66 ± 0.76 mg/L (0.10–2.60 mg/L) (Figure 3b). The ammonium concentration was lower than one of 0.3 mg/L in the VNTS; however, the nitrite concentration was slightly higher than the limit of 0.05 mg/L in the VNTS. Nitrite is toxic for aquatic organisms (Kroupova et al., 2016) and humans (Fan, 2011); therefore, it is necessary to manage nitrogen-nutrient sources and treat nitrites carefully for domestic water supply. The values of NH_4^+-N, NO_2^--N, and NO_3^--N in February (0.22 ± 0.19 mg/L, 0.04 ± 0.02 mg/L, and 1.74 ± 0.53 mg/L for NH_4^+-N, NO_2^--N, and NO_3^--N, respectively) were significantly higher than that in October (0.09 ± 0.17 mg/L, 0.05 ± 0.05 mg/L, and 0.20 ± 0.12 mg/L for NH_4^+-N, NO_2^--N, and NO_3^--N, respectively) and December (0.05 ± 0.06 mg/L, 0.09 ± 0.06 mg/L, and 0.15 ± 0.06 mg/L for NH_4^+-N, NO_2^--N, and NO_3^--N, respectively); however, a significant differences between October and December were not found. The lower concentration of inorganic nitrogen in October and December can be explained by the contribution of dilution due to precipitation, especially in the rainy season, and the large water volume from upstream flowing to Can Tho. The higher nitrate concentration compared to ammonium and nitrite indicated nitrate accumulation by nitrification in running water waterbodies (Malagó et al., 2019). The high nitrogen in the rivers and canals may be due to rich nitrogen sources from aquaculture, rice farming, and domestic and industrial wastes (Thuan, 2022; Mutea et al., 2021).

Boyd (1998) reported that phosphate concentrations of 0.005–0.02 mg/L are suitable for aquaculture. The average PO_4^{3-}-P concentration was 0.19 ± 0.22 mg/L, which differed slightly from 0.00 - 0.75 mg/L (Figure 3c). The surface water in Can Tho contaminated by dissolved phosphorus was detected based on the PO_4^{3-}-P results. The high phosphate in the water bodies may be due to sources of phosphorus from rice farming and domestic and industrial wastes (Badamasi et al., 2019). The PO_4^{3-}-P concentration in October (0.28 ± 0.23 mg/L) was significantly higher than in December (0.16 ± 0.23 mg/L) and February (0.12 ± 0.10 mg/L), whereas it is not found a significant difference between December and February. It is plausible to assume that the dilution process causes lower PO_4^{3-}-P values in the rainy months than in the dried months. The results showed the inverse results as unexpected and that unidentified sources contributed to higher PO_4^{3-}-P values in the rainy months.

The average coliform density was 5,694 ± 9,171 MPN/100mL, and coliform density fluctuated largely from 130 MPN/100mL to 46,000 MPN/100mL (Figure 3c). Can Tho's rivers and canals have coliform density five times higher than the allowable value of 1,000 MPN/100mL in the VNTS. Such high coliform density in Can Tho's water bodies was detected in Hau River's main and tributary rivers (Giao et al., 2023; Thuan et al., 2022)]. The primary sources of high coliform are the disposal of wastes from livestock and the discharge of domestic wastewater into water bodies. It is noted that the water surface in Can must be re-treated carefully before being used for domestic water supply.

The VN-WQI in Can Tho at 34 sampling points are shown in Figure 4, and values of VN-WQI varied in the range of 24–96 (81 ± 14). VN-WQI in December (87 ± 14) was significantly higher than in October (77 ± 25) and February (75 ± 16). In general, SWQ in Can Tho ranges at a good level. The canal and rivers in Can Tho have received water exchanges with Hau River, which has a large water volume; therefore, SWQ in Can Tho is still good. However, SWQ at each sampling point differs, which is discussed in detail in the section below.

We also ran the correlation between 34 sampling points and 12 variables of SWQ along rivers and canals in Can Tho, shown in Table 1. According to the findings, coliform density decreased as temperature increased, and coliform density increased with increased phosphate concentration. It implies that coliform density will be low during the dry season, and we need to control phosphate disposal in water bodies to reduce the development of coliform bacteria. It found that pH had significant negative correlations with TSS, BOD_5, and COD. This study also found a significant positive correlation between BOD_5 and COD. The evidence for nitrification through relations among

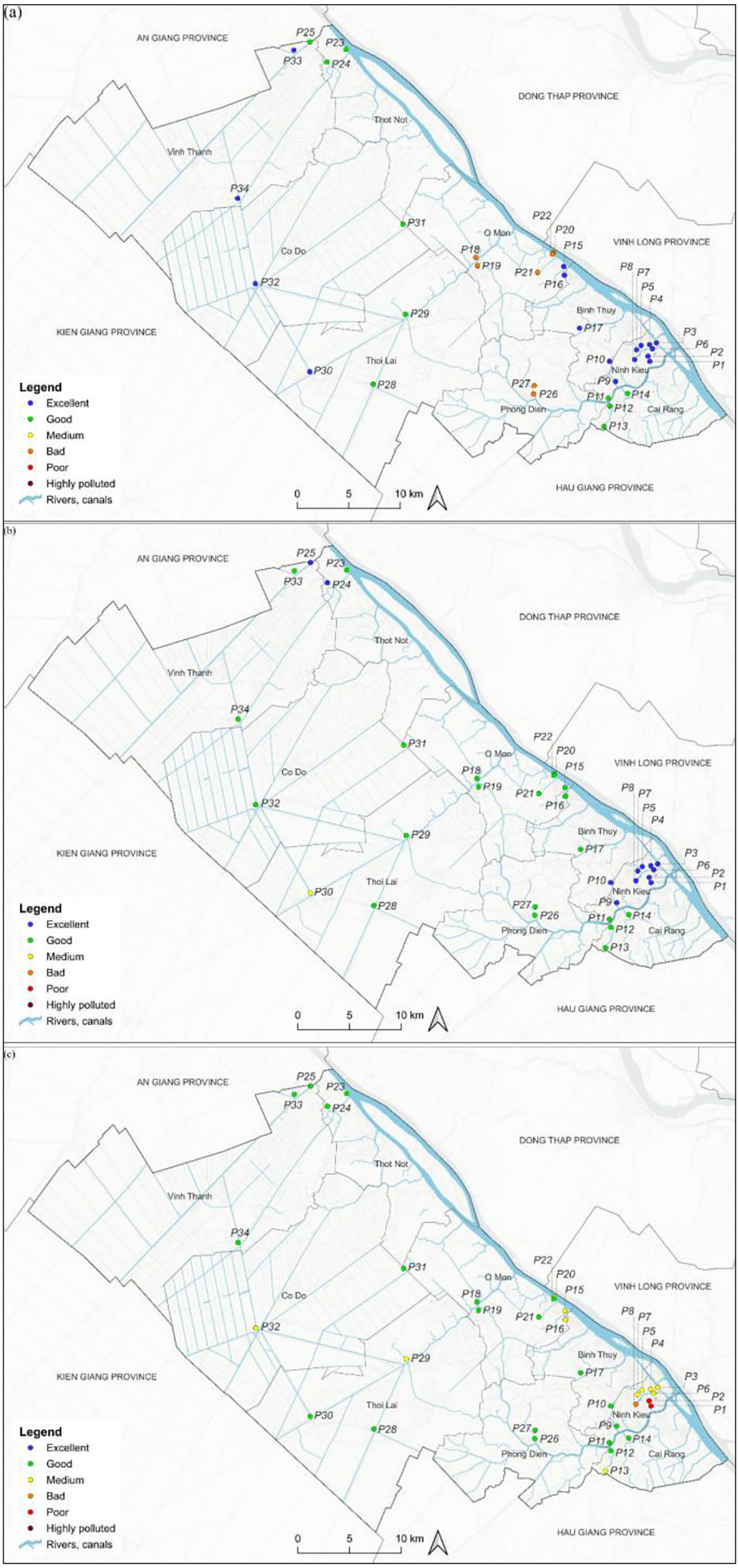

Figure 4. The VN-WQI at sampling points in October (a), December (b), and February (c)

Table 1. The correlation among SWQ parameters

Parameters	Temperature	pH	DO	TSS	BOD_5	COD	TOC	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}
pH	0.099										
DO	-0.053	0.122									
TSS	-0.013	**-.355***	0.064								
BOD_5	-0.048	**-.543****	-0.109	0.062							
COD	0.082	**-.541****	-0.053	0.116	**.890****						
TOC	0.124	0.079	0.123	-0.082	-0.02	-0.056					
NH_4^+	0.185	-0.189	-0.261	0.044	0.311	0.311	-0.139				
NO_2^-	-0.02	-0.039	0.134	0.196	**-.426***	**-.361***	-0.17	-0.249			
NO_3^-	0.016	-0.251	-0.098	0.091	0.154	**.394***	-0.248	0.069	0.268		
PO_4^{3-}	-0.259	-0.129	-0.307	0.017	-0.22	-0.264	-0.315	0.151	**.589****	0.337	
Coliform	**-.594****	-0.322	-0.332	-0.02	0.097	-0.001	-0.048	-0.161	-0.052	0.047	**.471****

Note: * Significant correlation at the level of 0.05; ** Significant correlation at the level of 0.01

NH_4^+, NO_2^-, and NO_3^- was not found. Significant negative correlations between BOD_5 COD and NO_2^- were found, and potential reasons for these relations still need to be discovered. Organic matter and nutrients from the same sources brought into water bodies may be a rationale for the significantly positive correlation between COD and NO_3^-. Such an explanation may be applied to the case of the significant positive correlation between PO_4^{3-} and NO_2^-.

The spatial fluctuations

In the case of October, the cluster indicated by the red line was divided into five groups at a similarity of 90% (Figure 5). The similarity on SWQ for all sampling points in the rainy season month was low at 39%. Regarding December, the cluster was grouped into three groups at a similarity of 90% (Figure 5). The similarity on SWQ for all sampling points at the beginning of the dried season was high at 83%. For February, the cluster was split into three groups at a similarity of 90% (Figure 5). The similarity on SWQ for all sampling points in the dry season was 71%. It can be assumed that dilution factors caused by precipitation and water sources from upstream flowing Can Tho in the flooded and rainy seasons caused significant differences in SWQ among sampling points. In December, there was a high similarity in SWQ among sampling points and insignificant

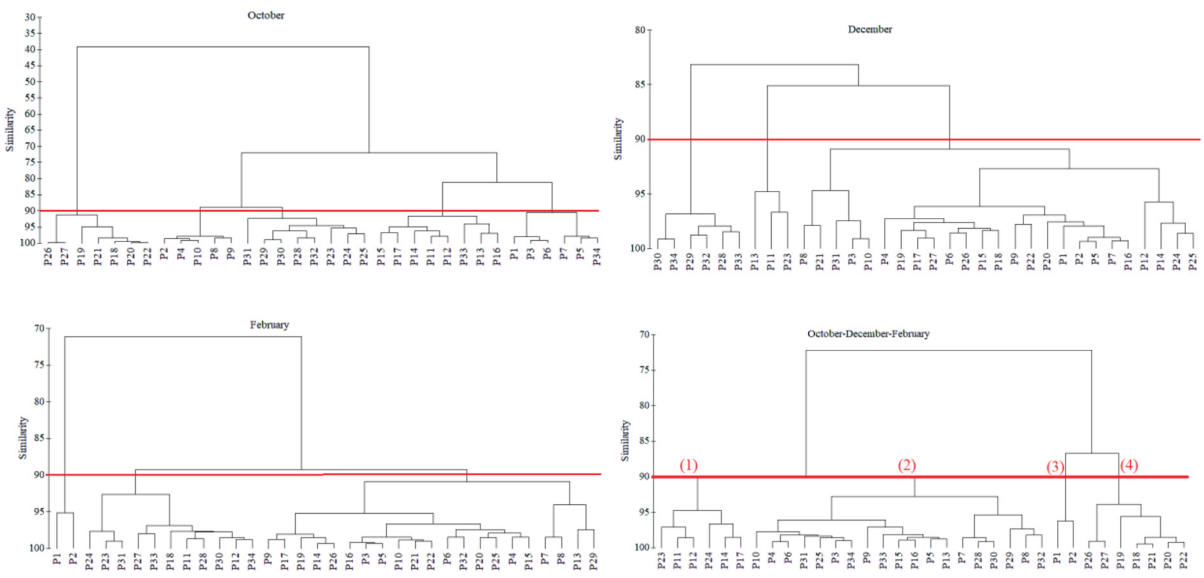

Figure 5. The similarity SWQ among sampling points

differences in almost all SWQ parameters between October and December, and it is reasonable to suggest that the monitoring in December can be cut out if it lacks budget.

A calculation for average values of SWQ parameters in October, December, and February showed that the cluster could be divided into four groups at a similarity of 90% (Figure 5). The similarity on SWQ for all sampling points was relatively high, at 72%. The SWQ at sampling points in group 4 was worst based on the VN-WQI value (Table 2), which ranged at a medium level. The sampling points in group 4 showed SWQ with very high pollution from coliform. The sources of pollution can come from waste from the industrial sections (P19–P21) and domestic wastewater and animals (P18, P19, P26, and P47) located at canals past rural residential areas). The SWQ at sampling points in group 3 ranged at a medium level (Table 2). The SWQ at sampling points in group 3 was figured out by high organic and nutrient contaminant, suspended solids, and coliform density. The source of high organic and nutrient pollution and coliform density can be too many wastes from domestic wastes in city residential areas (P1 and P2). The SWQ at sampling points in groups 1 and 2 ranged at a good level. Sampling points in group 1 are located at rivers that are directly tributaries of the Hau River (P11, P12, and P14); therefore, water at these points is mainly diluted with water in the Hau River, resulting in SWQ still being good. The SWQ at the remaining sampling points in groups 1 and 2 may be due to the minor effects of waste from domestic and industrial activities, leading to poor water quality. If there is a need to cut back on sampling points because of budget issues, points located in the same rivers or canals and having a high similarity of SWQ over 98% quality should be removed. These points include P20 or P22 (similarity = 99.3%), P4 or P6 (similarity = 99.1%), P26 or P27 (similarity = 99.1%), and P15 or P16 (similarity = 98.9%).

Identification of main factors influencing SWQ

The PCA of the SWQ dataset in Can Tho consisted of 34 monitoring points with 12 monitored parameters, which were assessed based on specific eigenvalues (EV). More than one EV value was selected to assess the discriminant between the variables of SWQ parameters [Boyacioglu and Boyacioglu, 2008]. Figure 6 showed that 3 PCs contributed significantly to explaining 65.3% of SWQ fluctuation in Can Tho.

PC1-PC3 described the fluctuation of SWQ with different proportions of 41.7%, 14.1%, and 9.5%, respectively. Factors loading is categorized as weak, moderate, and strong, with values of 0.30–0.50, 0.50–0.75, and over 0.75, respectively (Barakat et al., 2016). The PC1 found that changes in BOD_5, COD, NH_4^+-N, NO_3^--N, and coliforms were strongly corrected. Temperature, pH, and TSS were moderately corrected, and DO and NO_2^--N were also moderately corrected. The contribution of SWQ parameters to PCs is shown in Figure 7. The PC1 found organic and nutrient pollutants that came from human activities in wastewater from aquaculture, farming, and household and industrial activities (Giao, 2023; Thuan, 2022; Mutea et al., 2021). Organic and nutrient contaminants are usually the main potential influences on SWQ (Yang et al., 2020). Additionally, the source of alluvial transportation, hydrological conditions, and runoff by rainfall can be the main factors in changes in suspended solids, whereas seasonal changes cause temperature fluctuations (Thuan, 2022; Mutea et al., 2021). Temperature, pH, NO_2^--N, and NO_3^--N were weakly correlated with the PC2 and only moderately correlated with DO, TOC, and PO_4^{3-}-P. According to Thuan (2022) and Mutea et al. (2021), anthropogenic-related sources are the main factors influencing organic and nutrient pollution. The weak correlation for pH, TSS, and PO_4^{3-}-P and the moderate correlation for NO_2^--N were seen in PCs. Alluvial transportation and rainfall runoff are

Table 2. The SWQ parameters in the clusters observed

Group	pH	DO	TSS	BOD_5	COD	TOC	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}	Coliform	WQI
1	7.2	4.2	26.1	5.8	11.7	3.35	0.11	0.09	0.67	0.22	2991	83.7
2	7.2	4.3	27.3	6.1	12.0	3.42	0.14	0.05	0.64	0.14	3363	84.3
3	7.0	4.1	**30.3**	**8.5**	**15.5**	3.05	**0.26**	0.04	**0.90**	0.21	**7870**	70.0
4	7.1	4.2	28.8	6.0	11.5	3.34	0.07	0.07	0.66	0.28	**14581**	64.6

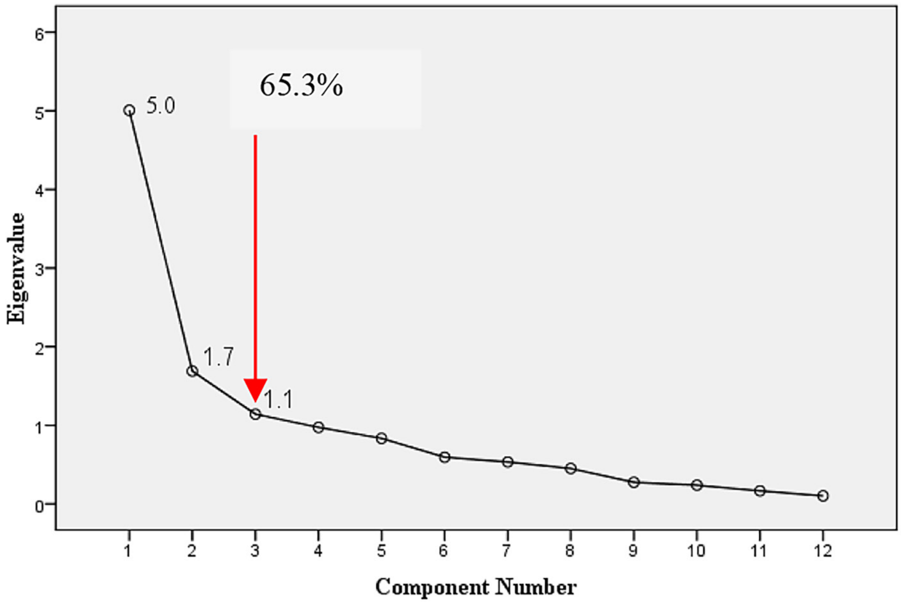

Figure 6. The scree plot of the EV

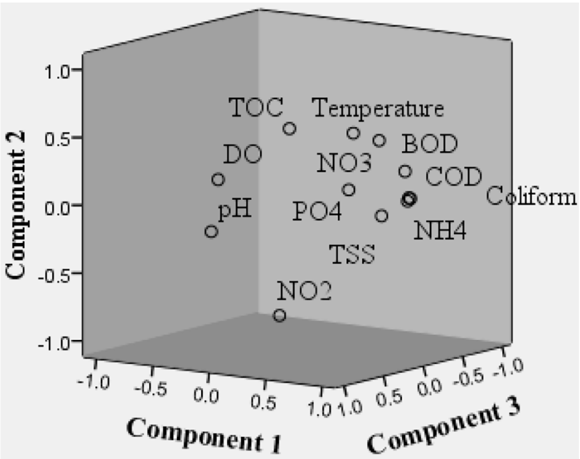

Figure 7. The component plot

primarily responsible for changes in suspended solids, whereas domestic wastewater and agricultural wastes are responsible for changes in phosphorus (Giao, 2023; Mutea et al., 2021). According to the PCA results, all SWQ parameters were subject to PC influence (Table 3). Additionally, SWQ parameters with correlations from medium to strong are suggested to be included in the monitoring parameters [Chounlamany et al., 2017]. The results of this investigation illustrated that twelve SWQ parameters in the current water monitoring program in Can Tho need to be used to continue because they affect SWQ in Can Tho. Nitrate and phosphate are parameters listed in the VNTS on SWQ but not in the updated QCVN 08-MT: 2023/BTNMT. Human health is affected when using water with a high nitrate concentration (Kroupova et al., 2016); as a consequence, nitrate and phosphate should be SWQ parameters for monitoring because of the effects of SWQ, which is evidenced in our study. In short, natural factors from seasonal changes, alluvial transportation, runoff by rainfall, and anthropogenic factors from industrial, agricultural, and domestic activities influenced the SWQ in Can Tho. To solve issues of water surface pollution in Can Tho in the future, the local authorities should have priority strategies to reduce contaminants from agricultural, industrial, and domestic activities.

CONCLUSIONS

Our study's results reflected that Can Tho's surface water was polluted with suspended solids, nitrogen nutrients, organic matter, and coliforms. The key sources of alluvial transportation, runoff by rainwater, and wastes from agriculture, residential areas, and industrial zones are suggested to cause SWQ pollution. The SWQ in canals and rivers in Can Tho in the dried season is significantly worse than in the rainy and flood season. The PCA resulted that all SWQ parameters in this survey, including pH, temperature, TSS, DO, COD, BOD_5, TOC, PO_4^{3-}, NH_4^+, NO_2^-, NO_3^-, and coliform, which contributed as the main indicators affecting SWQ in Can Tho, which interpreted 65.3% of SWQ fluctuation. The key factors of alluvial transportation,

Table 3. The key parameters influencing SWQ

SWQ parameters	PC1	PC2	PC3
Temperature	**.696**	**.495**	-.053
pH	**-.503**	**.360**	**.391**
DO	**-.353**	**.572**	.109
TSS	**.709**	.023	**.379**
BOD_5	**.899**	.049	.051
COD	**.827**	-.147	.166
TOC	.186	**.522**	-.226
NH_4^+	**.824**	-.169	.121
NO_2^-	**-.302**	**-.378**	**.709**
NO_3^-	**.817**	**.316**	-.071
PO_4^{3-}	.096	**-.613**	**-.465**
Coliform	**.816**	-.211	.097

runoff by rainwater, and dilution by rainwater and upstream water caused seasonal changes in SWQ between the dried season and the rainy and flood season. Further research can be concentrated on the identification of practical solutions for much better management of water surface pollution areas.

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