Influence of Urban and Residential Areas on Surface Water Quality in the Vietnamese Mekong Delta Coastal Province

Nguyen Thanh Giao* and Nguyen Hong Thao Ly

***Abstract*—This study was conducted to assess the impact of residential and urban activities on surface water quality in Ben Tre province in 2021. Water quality data were collected in the dry and rainy seasons at 15 locations for evaluating the parameters of temperature, pH, dissolved oxygen (DO), salinity, turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium ($N\text{-}NH_4^+$), nitrate ($N\text{-}NO_3^-$), orthophosphate ($P\text{-}PO_4^{3-}$), iron (Fe), coliform using national technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT, A1) and surface water quality index (VN_WQI). Principal component analysis (PCA) and cluster analysis (CA) methods were used to evaluate sampling sites and identify key parameters and potential pollution sources. The results showed that TSS, BOD, COD, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe and coliform are pollutants significantly affect surface water quality in residential and urban areas. Salinity, nutrients, heavy metals and microorganisms had high values in the dry season, while turbidity, suspended solids, dissolved oxygen, and organic matter were higher in the rainy season. Water quality was assessed from moderate to very good indicated by VN_WQI index. PCA results revealed that five key factors explaining 87.2% of the variation and 12 main parameters (temperature, salinity, turbidity, TSS, DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, Fe and coliform) affecting water quality. CA results showed that the current monitoring locations can be reduced from 15 locations to 12 locations, which could save 20% of monitoring costs. Future study should focus on investigating concrete sources of water pollution for appropriate management measures.**

***Index Terms*—Water quality, residential area, organic pollution, Ben Tre province, coliform**

I. Introduction

The Mekong Delta is considered a region with rich surface water resources with a dense system of rivers, canals and canals widely distributed throughout the provinces in the region. This is both a source of water for domestic and production activities, as well as a place to receive waste from these activities. However, surface water in the Mekong Delta was locally polluted in industrial and agricultural areas [1]. Most of the surface water quality in rivers and canals in these areas has begun to exceed the allowable thresholds of Vietnamese standards, especially for organic matter, nutrients and micro-organisms [2, 3]. At present, the surface water environment in urban areas is also facing serious pollution due to urbanization process and excessive population growth. According to Hoan and Thong *et al*. [4], only 50% of domestic wastewater is treated properly before being discharged into the receiving source. Domestic wastewater from kitchens and bathrooms mainly contains biodegradable organic and inorganic nutrients as well as many types of bacteria and pathogens for humans. Therefore, when the pollutant load exceeds the load capacity of the receiving environment, it will lead to a decline in water quality and aquatic biodiversity. In addition, water pollution in urban areas also has a significant impact on people's health.

Ben Tre is one of the coastal provinces in the Mekong Delta. In order to promote socio-development, the demand for water for domestic, agricultural and industrial activities in the province is increasing rapidly. Along with this development, surface water quality in rivers and canals in the province is also seriously affected. Wastewaters arising from industrial, domestic and agricultural production have not been collected and treated thoroughly before being discharged into the environment [5]. This has resulted in surface water quality in Ben Tre province being heavily polluted by TSS and BOD [6, 7]. Therefore, surface water quality in socio-economic areas in the province should be closely monitored and monitored. The objective of this study is to assess surface water quality in cities and towns in Ben Tre province in space and time, based on multivariate statistical analysis methods and water quality index (WQI) index. Research results provide useful scientific information for environmental management agencies to control pollution and provide solutions to improve surface water quality in residential areas and urban areas.

II. Materials and Methods

A. Study Area

The Vietnamese Mekong Delta is the downstream region of the Mekong River basin before emptying into the East Sea, one of the largest and most fertile deltas in Southeast Asia. The area has a natural area of 39,194.6 km^2, located adjacent to the Southeast region, to the North by Cambodia, to the Southwest is the Gulf of Thailand and the Southeast is the East Sea. The Mekong Delta is considered to be the largest producer and exporter of food, foodstuffs, seafood and fruits in the country, contributing more than 53% of rice production, 65% of aquaculture production and about 75% fruit source for the whole country [8]. According to Ministry of Agriculture and Rural Development [9], the total annual flow potential of the Mekong Delta is about 400–500 billion m^3, with abundant surface water along with interlaced system of rivers and canals [9]. In which, the total exploitation of surface water for water supply is about 800,000 m^3/day/night, mainly serving urban areas. Water discharges on secondary canals and main rivers in the Mekong Delta range from 1–30 m^3/s and 400–6000 m^3/s, respectively, with the highest discharge in the rainy season [10]. The average water security

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in a year per 1 km^2 of area in the Mekong Delta is up to 14,700,103 m^3/km^2 and for one person is 31,560 m^3/person [11]. However, the area's surface water is receiving a large amount of wastewater from domestic and economic activities [12]. Specifically, the amount of domestic wastewater in the whole region is estimated at nearly 1,447 million m^3/day, and this is a source of waste with a very low rate of treatment that has been discharged into the receiving environment. Wastewater from industrial production in the region is estimated at 239,720 m^3/day. Medical wastewater is generated about 25,967 m^3/day with a properly treated rate of about 97.3% [12].

Ben Tre is a province located in the east of the Mekong Delta. The natural area is 2360.2 km^2, accounting for 5.84% of the area of the Mekong Delta. The province is also located in the tropical monsoon climate, creating two distinct seasons: the rainy season (May to November) and the dry season (December to April next year). The average annual temperature is from 26℃–27℃ and the average annual rainfall is 1250 mm–1500 mm. The average total surface water discharge of the province is 7512.3 m^3/s, distributed over four main tributaries: My Tho, Ba Lai, Ham Luong and Co Chien. In addition, there are important rivers and canals such as Ben Tre River, Cai Mon canal, Mo Cay canal, Mo Cay-Thom canal, Bang Cung canal, Ba Tri canal, Dong Xuan canal, Chet Say canal. These rivers play an important role for the people in the province such as providing fresh water for domestic use and agriculture, contributing to beautifying the landscape and regulating the climate. Currently, Ben Tre province is undergoing a strong urbanization process, with high population density in towns and towns and sparse in remote rural areas. In addition to Ben Tre city, which is the provincial capital—the largest urban center in the province, there are also two well-developed urban centers, namely Mo Cay town and Ba Tri town. On the other hand, Binh Dai town has a lot of potential to thrive in the future. These residential areas and urban areas are gradually being invested with social and technical infrastructure systems to serve the people in the province. The amount of domestic wastewater generated from urban areas in Ben Tre province in 2020 is 42,529 m^3/day. However, rapid urbanization while inadequate development of technical infrastructure has led to an increase in pollution load due to domestic wastewater in urban areas and residential areas. The sampling locations are shown in Fig. 1.

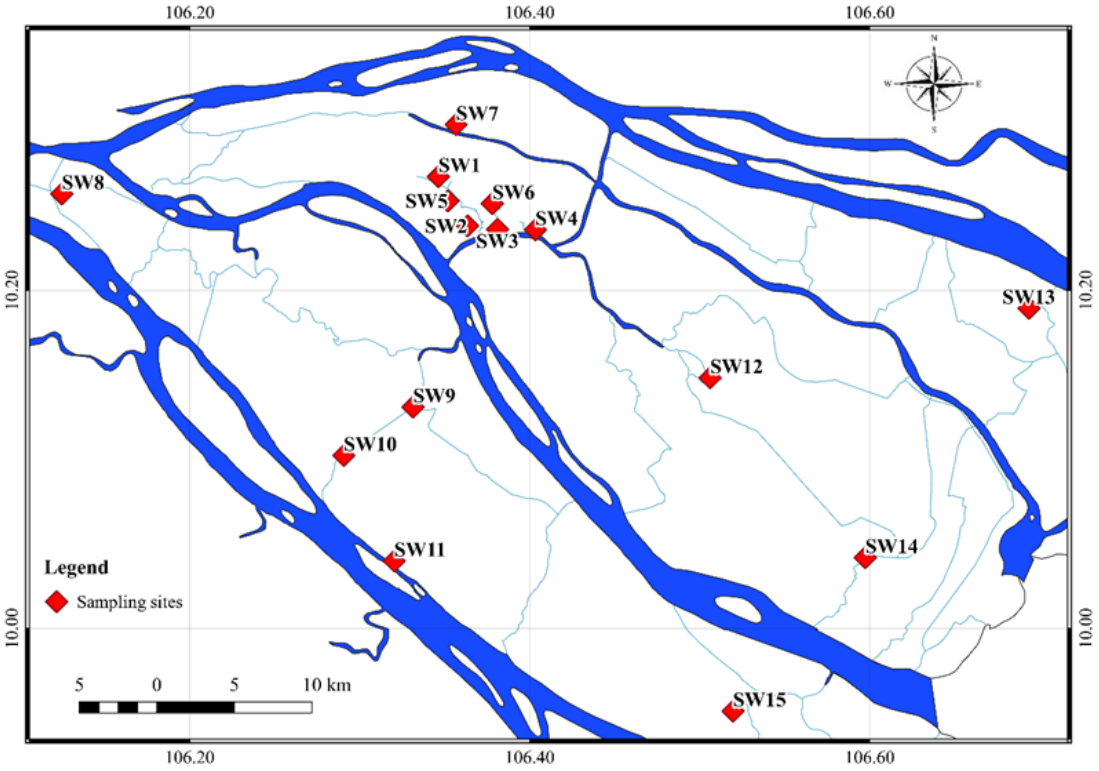

Fig. 1. Location of surface water sample collection in cities and towns in Ben Tre province.

B. Water Sampling and Analysis

Water quality monitoring data is collected from the Department of Natural Resources and Environment of Ben Tre province in 2021. Water samples were collected at 15 locations in rivers and canals in residential areas and urban areas in the province including: including Ben Tre City (SW1 to SW6), Mo Cay Nam District (SW9 to SW11), Chau Thanh, Cho Lach, Giong Trom, Binh Dai, Ba Tri, Thanh Phu districts with positions from SW7 to SW8 and from SW12 to SW15 with frequency four times/year (March, May, July and October). Surface water quality parameters include temperature, pH, dissolved oxygen (DO), salinity, turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium (N-NH_4^+), nitrate (N-NO_3^-), orthophosphate (P-PO_4^{3-}), iron (Fe), coliform are used to assess water quality and are input data for water quality assessment 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, DO,

salinity and turbidity were measured in the field while the remaining parameters were analyzed in the laboratory by standard methods [13]. The criteria, units, analytical methods and allowable limits are presented in Table I.

TABLE I: ANALYTICAL METHODS OF SURFACE WATER QUALITY PARAMETERS

No.	Parameter	Description	Unit	Analytical methods
1	pH	pH	-	TCVN 6492:2011
2	Temp.	Temperature	^{o}C	SMEWW 2550B:2017
3	Sal.	Salinity	‰	WTW Cond 3310
4	Turb.	Turbidity	NTU	TCVN 6184:2008
5	DO	Dissolved oxygen	mg/L	TCVN 7325:2016
6	BOD	Biological Oxygen Demand	mg/L	TCVN 6001-1:2008
7	COD	Chemical Oxygen Demand	mg/L	SMEWW 5220C:2017
8	TSS	Total Suspended solids	mg/L	TCVN 6625:2000
9	$N\text{-}NH_4^+$	Ammonium	mg/L	TCVN 6179-1:1996
10	$N\text{-}NO_3^-$	Nitrate	mg/L	TCVN 6180:1996
11	$P\text{-}PO_4^{3-}$	Orthophosphate	mg/L	TCVN 6202:2008
12	Fe	Iron	mg/L	TCVN 6177:1996
13	Coliform	Coliform	MPN/100mL	TCVN 6187-2:1996

C. Data Analysis

Surface water quality data was averaged before statistical analysis and compared with National Technical Regulation QCVN 08-MT:2015/BTNMT on surface water quality column A1 [14]. Cluster analysis (CA) and principal component analysis (PCA) were used in this study to evaluate sampling locations and determine the parameters that have the most influence on quality surface water in cities and towns in the study area. PCA and CA analysis were analyzed using Primer V5.2 for Windows license software (PRIMER-E Ltd, Plymouth, UK).

The WQI water quality index is calculated according to the guidance of [15] according to Eq. (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 colors will be shown based on the previous WQI results.

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

Where: WQI_I: Calculated WQI value for pH parameter; WQI_{IV}: Calculated WQI value for six parameters: DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$; WQI_V: Calculated WQI value for the Coliform.

Water quality is classified into six 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 tarnished) water is contaminated and needs remedial measures.

III. RESULTS AND DISCUSSION

A. Seasonal Variations of Surface Water Quality

The average pH value in 2021 is not significantly different between the dry season and the rainy season, ranging from 6.74 ±0.77–7.47 ±0.25 and 6.55 ±0.31–7.56 ±0.02, respectively (Fig. 2). The highest and lowest pH values were recorded in the rainy season with 7.56 ±0.02 and 6.55 ±0.31. Alkaline detergents and cleaning agents from human activities can cause the pH of water to rise [16]. The pH value is well compared with the study of [17] that pH in Can Tho River ranges from 6.7–7.3 and 6.4–7.2 in the dry and rainy seasons, respectively. However, the seasonal variation of pH in water in the present area tended to be lower than that of the Ray River basin having pH in the dry and in the rainy seasons fluctuating in the range of 6.8–8.1 and 6.8–8.2, respectively [18]. Similarly, pH in surface water recorded in Xuan Loc district, Dong Nai province also tends to be higher, ranging from 6.31–8.62 in the dry season and from 6.35–8.66 in the rainy season [19]. Meanwhile, the water temperature at the sampling locations ranged from 27.7 ±0.85–30.10 ±1.27 ℃ in the dry season and 27.35 ±0.64 – 29.75 ±0.07 ℃ in the rainy season. The highest temperature recorded in the dry season was 30.10 ±1.27 ℃ and the lowest in the rainy season was 27.35 ±0.64 ℃. The research results showed that the temperature has seasonal fluctuations in which the temperature in the rainy season tended to be lower than the temperature in the dry season. Similarly, low water temperature in wet season and high in dry season has been reported in several other studies [18, 20–24]. Research results show that the temperature in both seasons during the study period is suitable for aquatic species to grow. At the same time, the pH range does not fluctuate much and is within the allowable threshold of QCVN 08-MT:2015/BTNMT column A1 (6.0–8.5). Fig. 2 shows that the average turbidity in 2021 in the study area is quite big difference between the two seasons. In which, the turbidity content was recorded in the dry season about 12.65 ±4.68–64.24 ±8.90 NTU and in the rainy season about 10.02 ±2.31–154.39 ±96.89 NTU. High turbidity in the rainy season may be due to high rainfall leading to erosion on both sides of the river, and at the same time, overflowing water brings with it organic and inorganic pollutants and microorganisms [25]. Similarly, the highest and lowest mean TSS concentrations were recorded in the rainy season with values of 96.00 ±67.18 mg/L and 15.50 ±9.19 mg/L, respectively. Meanwhile, in the dry season, TSS content ranges from 37.25 ±10.25–93.00 ±4.24 mg/L. Former study also showed that TSS concentration is always higher in the rainy season due to the impact of rainwater

runoff and erosion [26]. The study of [27] attributed the significant difference in turbidity and TSS in water to stormwater runoff, plankton, and riverbank erosion. Other studies [18, 28, 29] found similar results that turbidity and TSS fluctuate seasonally, in which turbidity and TSS tend to be higher in the rainy season than in the dry season. Turbidity and TSS found in this study were higher than those of previous studies [18, 28, 29]. TSS concentration in the study area is much higher than that in surface water in residential area in Can Tho City (35.6 mg/L) [3] and other areas such as Binh Duong province (23.0±2.7–55.4±13.2 mg/L) [30], Dong Nai and Ba Ria Vung Tau (18–66.1 mg/L) [18]. In this study, TSS value exceeded the allowable limit of QCVN 08-MT:2015/BTNMT column A1 (20 mg/L) from 1.86–4.80 times. It can be seen that the high TSS content has degraded the water quality and increased the cost of water treatment. The salinity in water in the study area has a relatively large difference between the two seasons and the dry season tends to be higher than the rainy season. The salinity value ranges from 0.15±0.07–11.40±3.68‰ (dry season) and 0.00±0.00–8.45±6.58‰ (rainy season). This shows that saline intrusion and drought are significantly affecting water quality in residential areas and urban areas in Ben Tre province. According to Van and My [31], the salinity in the dry season is higher than in the rainy season due to the phenomenon of saline intrusion deeply encroaching into estuaries in Ben Tre province. In the study areas near other coastal estuaries, the salinity in the water tends to be higher and ranges from 23.5–28.9‰ [32]. High salinity can seriously affect aquatic life and people's daily activities [33], such as rice and shrimp farming [34].

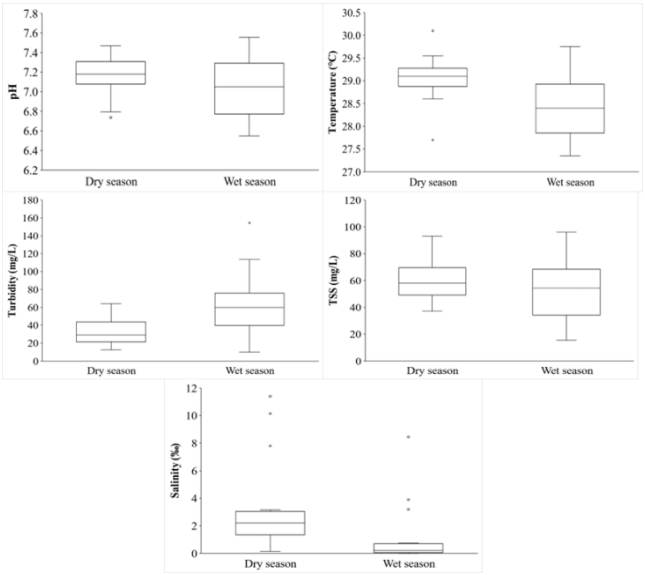

Fig. 2. Physical parameters of surface water in the study area.

The average dissolved oxygen content in 2021 ranges from 4.66±0.27–6.98±0.42 mg/L in the dry season and 3.89±0.91–7.34±0.59 mg/L in the rainy season (Fig. 3). It can be seen that the DO concentration in both seasons is still at a low threshold compared to the norm (below 6 mg/L) and the DO value in the rainy season tended to be higher than that in the dry season. Due to the relatively strong flow in the rainy season, it disturbs the water, causing more oxygen diffusion into the water [35]. The low DO content in surface water shows that the surface water quality in residential and urban areas in the study area has been organically polluted. Excessive organic waste concentrations have led to rapid microbial growth and depletion of dissolved oxygen [36]. In addition, the amount of garbage accumulated in the riverside in residential areas can also be a cause affecting the DO value in the water [16]. Low DO concentrations in water bodies as well as DO concentrations in water tend to be high during the rainy season, which has been reported in several studies. Specifically, DO concentration in Can Tho River fluctuates from 3.5–5.4 mg/L in the dry season and from 3.5–5.8 mg/L in the rainy season [17]. In the water bodies of Xuan Loc district, the DO concentration fluctuates between the dry season and the rainy season from 3.87±1.91 mg/L to 5.52±1.62 mg/L, respectively [19]. At Ba Lua and Bung canals, surface water is mainly affected by wastewater from the town where DO was recorded in the dry season is very low from 2.5±0.9–4.5±0.6 mg/L and increased in rainy season from 3.5±0.5–5.1±0.7 mg/L [30]. Similarly, in the La Buong river and canals in An Giang province, the DO concentrations recorded in the rainy season were also higher than those in the dry season [22, 29]. The average BOD concentration in the dry season and the rainy season did not differ much, ranging from 7.32±0.48–24.00±7.23 mg/L and 9.11±0.13–23.68±1.10 mg/L, respectively. The lowest and highest BOD values were recorded in the dry season, but through the analysis, it was found that the BOD concentration in the rainy season tended to be higher than that in the dry season. Similarly, COD values tended to be similar to BOD parameters (rainy season tends to be higher than dry season). This can be rainwater overflowing in the rainy season leading to wastes that then flow into canals and canals, increasing both oxygen and pollutant content simultaneously. The highest and lowest average COD concentrations recorded in the dry season were 43.22±11.13 mg/L and 13.23±0.45 mg/L, respectively. In the rainy season, the COD value ranges from 16.86±3.34–40.24±1.39 mg/L. The average value of BOD in both seasons was recorded at a very high concentration compared to QCVN 08-MT:2015/BTNMT column A1 (4 mg/L) which was 1.83 to 6.00 times higher than the limit. Meanwhile, the COD content in both seasons also exceeded the allowable threshold (10 mg/L) from 1.32 to 4.32 times higher than the norm. This result is also consistent with the study of [3], BOD and COD concentrations in residential areas in Can Tho City always had the highest values (11.4 mg/L and 18.8 mg/L, respectively). In the Ca Mau peninsula, the BOD and COD concentrations in surface water are influenced by residential areas and markets, respectively, were in the range of 16.5±5.3–16.9±7.1 mg/L and 29.2±9.2–29.9±11.5 mg/L, respectively [37]. At Ba Lua canal, Bung canal in the period of 2015–2017 where surface water quality is affected by residential areas, towns, BOD and COD concentrations were recorded in the range of 7.2±1.4–10.1±2.2 mg/L and 14.7±3.33–26.2±2.8 mg/L, respectively [30]. It can be seen that the pollution level of surface water in residential areas and urban areas in the study area is more heavily than that in residential areas in Can Tho City, Ca Mau Peninsula and Binh Duong province. However, in water bodies in An Giang province where influenced by urban areas, the average BOD and COD concentrations reaching 24.19±12.21 mg/L and 37.22±18.76, respectively [38] which were relatively higher than that in the present area. The high

content of organic matter in water significantly affects the growth and development of aquatic plants and animals in the water in the study area. According to Salah, AbdulGhafoor, and Abdalwahab [39] high levels of BOD and COD cause oxygen depletion, leading to suffocation of aquatic species.

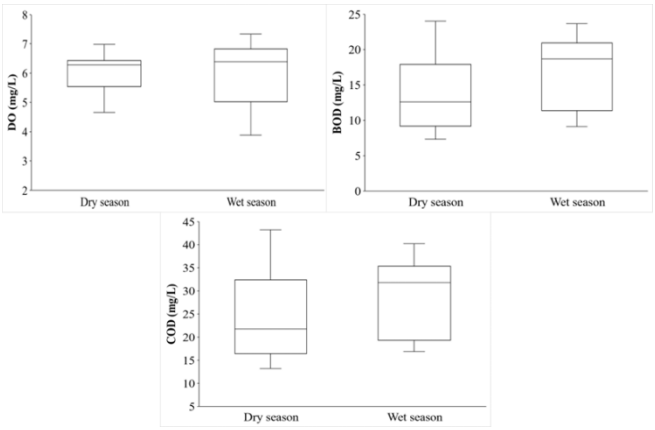

Fig. 3. Organic matter parameters in surface water in the study area.

The nutrients in surface water are one of the important parameters in the assessment of surface water quality. Excessive nutrient content will easily cause eutrophication, reducing dissolved oxygen and polluting aquatic ecosystems [4]. The results of the analysis of seasonal changes in nutritional parameters are shown in Fig. 4. It can be seen that most of the nutritional parameters are not significantly different between the dry season and the rainy season. In general, nutrient content in the dry season tends to be higher than in the rainy season. This may be because heavy rainfall has significantly diluted the pollutant concentration in the water, resulting in lower nutrient content compared to the dry season. The concentrations of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ in surface water are quite low, ranging from 0.06±0.09 to 4.09±0.06 mg/L and 0.20±0.11 to 1.00±0.98 mg/L, respectively. The highest and lowest concentrations of $N\text{-}NH_4^+$ were recorded in the rainy season with values of 4.09±0.06 mg/L and 0.06±0.09 mg/L, respectively. Meanwhile, the highest and lowest concentrations of $N\text{-}NO_3^-$ were recorded in the dry season with values of 1.00±0.98 mg/L and 0.20±0.11 mg/L. The concentration of $N\text{-}NH_4^+$ in both seasons exceeded the allowable threshold of QCVN 08-MT:2015/BTNMT column A1 (0.3 mg/L). According to Giao [7], in domestic wastewater up to 65% is $N\text{-}NH_4^+$ and the high concentration of $N\text{-}NH_4^+$ in surface water is capable of causing eutrophication of water sources [7]. This shows that surface water quality in residential and urban areas in the study area has been contaminated with nutrients. In contrast, the concentration of $N\text{-}NO_3^-$ at the time of the study was still below the allowable threshold of QCVN 08-MT:2015/BTNMT column A1 (2 mg/L). It can be seen that the nitrification process is unlikely to occur due to the influence of the high organic matter content, which depletes the dissolved oxygen content of the water, this result is similar to the study of [40]. Meanwhile, the average $P\text{-}PO_4^{3-}$ concentration in 2021 in the study area is quite high. The dry season ranges from 0.03±0.04–0.27±0.28 mg/L and the rainy season ranges from 0.09±0.02–0.43±0.46 mg/L. The value of $P\text{-}PO_4^{3-}$ in both seasons exceeded the allowable limit of QCVN 08-MT:2015/BTNMT column A1 (0.1 mg/L). The concentration of $P\text{-}PO_4^{3-}$ in surface water often indicates human impact on the environment from human and animal waste or washing powder in domestic wastewater [20]. Eutrophication with high concentrations of $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ and exceeding the allowable limit QCVN 08-MT/BTNMT (column A1) also occurs in many water bodies in the Mekong Delta when affected by the urban area. Specifically, the concentrations of $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ in water bodies in Ca Mau peninsula fluctuated in the range of 0.65±0.73–0.68±0.84 mg/L and 0.11±0.15–0.13±0.28 mg/L, respectively [37]. The concentration of $N\text{-}NH_4^+$ in the water bodies of An Giang province reached an average of 2.19±1.74 mg/L, 7.3 times higher than the the standard [38]. In the water bodies in Hau Giang province, the average concentrations of $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ fluctuated in the range of 0.4–0.5 mg/L and 0.3–0.4 mg/L, respectively [23]. Previous research also showed that the concentration of nutrient pollutants in surface water was highest in industrial and residential areas [4]. The results show that surface water quality in residential areas and urban areas in Ben Tre province has potential for eutrophication, affecting the biological balance of water and polluting water sources.

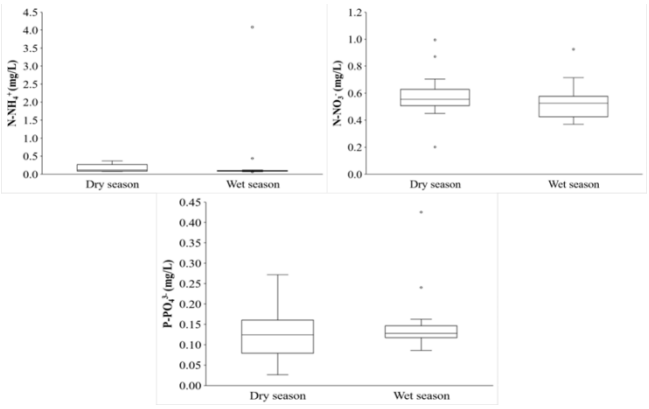

Fig. 4. Nutrient parameters in surface water in the study area.

The highest average iron content in 2021 was recorded in the dry season with a value of 1.32±0.26 mg/L and the lowest in the rainy season at 0.16±0.00 mg/L. Fe concentration in the dry season was higher than that in the rainy season (Fig. 5) and exceeded the allowable limit of QCVN 08-MT:2015/BTNMT column A1 (0.5 mg/L). Fe content in the dry season tends to be higher than in the rainy season. The main reason may be that Ben Tre province belongs to an ASS containing a lot of iron in nature. Compared with the previous studies, Fe concentration in the study area was lower than that in Soc Trang water bodies (0.3–3.75 mg/L) [41], Hau Giang water bodies (1.4–1.8 mg/L) [23] and Cau river (1.483±0.429–1.84±0.72 mg/L) [24] and residential areas in Can Tho City (0.46 mg/L) [3]. Rainfall and high air temperature would initiate releasing Fe in soil into surface water [42]. In addition, high Fe content in surface water can degrade water quality, increase feed water treatment costs, and significantly affect human health and the environment. The average coliform content at the time of the study had a large difference, ranging from 585.00±487.90–8350.00±1343.50 MPN/100 mL (dry season) to 695.00±77.78–6850.00±3464.82 MPN/100 mL. In general, the average coliform value in the dry season is higher than in

the rainy season. Compared with QCVN 08-MT:2015/BTNMT column A1 (2500 MPN/100 mL), the coliform content in both seasons exceeded the allowable limit many times, 2.74 times higher in the rainy season and 3.34 times in the dry season. According to Divya and Solomon [43], the presence of coliform in water originates from human and animal waste. Research by Viet, Chung, and Anh [5] also showed that surface water quality in Ben Tre province always has a very high coliform density (75000 MPN/100 mL). However, compared with the study of [17], coliform concentration in residential areas and urban areas in the study area was lower than that in Can Tho River (3448–27327 MPN/100 mL) [17]. Similarly, in water bodies in neighboring areas such as An Giang province, Ca Mau peninsula and Binh Duong province, surface water affected by residential and urban activities also has high coliform density [37, 38, 44]. The high concentration of coliform in surface water in the study area has increased the threat to the health of people in the province, especially in poor areas, lacking fresh water for daily life.

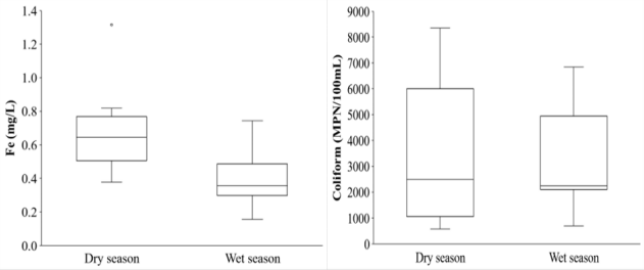

Fig. 5. Iron and coliform in surface water in the study area.

The research results show that water quality in residential areas and urban areas in Ben Tre province in 2021 has seasonal fluctuations. The concentrations of TSS, BOD, COD, N-NH_4^+, P-PO_4^{3-}, Fe and coliform exceeded the allowable threshold of QCVN 08-MT:2015/BTNMT, column A1, many times. In which, salinity, N-NO_3^-, N-NH_4^+, P-PO_4^{3-}, Fe and coliform values were higher in the dry season than in the rainy season. In contrast, the parameters of turbidity, TSS, DO, BOD, COD have higher values in the rainy season. This shows that the water quality in the study area in both seasons is not suitable for domestic water supply purposes and significantly affects the growth and development of aquatic plants and animals.

B. Spatial Variations of General Surface Water Quality in the Study Area

Fig. 6 shows surface water quality in cities and towns Ben Tre province from average (yellow) to very good (blue). The WQI values at these monitoring points ranged from 52 to 94. Fig. 6 also shows that none of the monitoring sites have bad water quality (26–50) to very heavy pollution (<10) in the province. In the dry season, the best water quality was recorded at locations SW4, SW8, SW9, SW10, SW11 and SW13 with VN_WQI values from 92 to 94. These locations are all located in urban speed districts urbanization is not high, not seriously affected by daily activities of people in the province (except SW4 in Ben Tre City). The remaining monitoring locations have moderate to good water quality, accounting for 40% and 20%, respectively. In the rainy season, it can be seen that the water quality at locations SW4, SW10 and SW11 decreases markedly. The water quality at these three locations changed from very good to good in the rainy season with VN_WQI values of 86, 84 and 79, respectively. Meanwhile, the water quality at three locations SW7, SW12 and SW14 has changed in the rainy season (from moderate to good). This shows that, at the time of rainy season, heavy rainfall leads to increased water flow in rivers and canals, diluting and reducing pollutant concentrations in these three locations. In addition, the results in Fig. 6 also show that the three locations SW1, SW3 and SW5 have average water quality in both seasons. All three locations are located in densely populated urban areas in Ben Tre City. The cause can be due to the accumulation of pollutants and because the runoff in the rainy season pulls pollutant material from the waste areas. In general, surface water quality in cities and towns in Ben Tre province in 2021 is still quite good, but water quality in locations in Ben Tre City is not suitable for domestic water supply purposes. Water quality in the study area tends to be improved compared to the same study by [6]. Using the WQI index to assess the water quality of the Saigon River—the section flowing through Thuan An town, the results showed that the surface water quality is relatively good with WQI fluctuating from 81–85 in the rainy season and surface water quality tended to improve in the rainy season [45]. In Ray River, WQI in the dry season was in the range of 18.88–95.54 while WQI was 4.23–83.73 in the rainy season [18]. As can be seen that the overall surface water quality in the current study area tended to be better than those in other study areas [37, 46, 47].

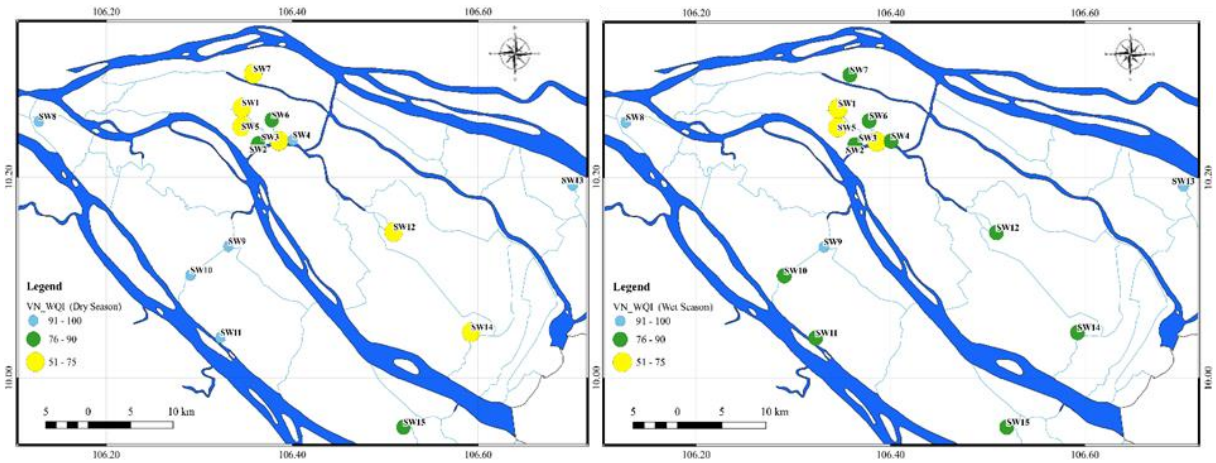

Fig. 6. Maps of water quality index in the study area.

C. Key Parameters Influencing Surface Water Quality in Urban and Residential Areas

The mean values of 13 water quality parameters at 15 sampling locations in rivers and canals flowing through cities and towns in Ben Tre province in 2021 were used in principal component analysis. The eigenvalues of each principal component are shown in Table II. As can be seen, the eigenvalue of each factor is sorted from large to small, and the eigenvalue from PC1 to PC5 is all greater than 1. Therefore, these PCs are considered to contain a lot of important information and it is used to assess the main sources of pollution to surface water quality [48]. These 5 PCs explain 87.2% of the variation in water quality with rates of 38.9%, 17.3%, 12.9%, 9.2% and 8.8%, respectively. While, the remaining PCs (from PC6 to PC11) are considered as secondary sources, explaining 12.8% of variation in surface water quality.

Table II presents the load factors of the main 5 PCs for 15 water quality parameters in the form of a bar graph. According to Islam and Lenz *et al*. [49], the absolute value of the load factor greater than 0.75 means that there is a strong correlation between the main component and the water quality parameter, from 0.75 to 0.50 is the average correlation and less than 0.5 is the weak correlation. PC1 explains the fluctuations of DO (0.373), BOD (−0.374), COD (−0.384), N-NO_3^- (−0.343) and coliform (−0.302) parameters at a weak correlation. The load factor of PC1 has shown that these PCs are mainly influenced by organic matter, nitrogenous nutrients, and excreta from humans and animals. The results showed that organic matter, nutrient and microbiological pollution are the main potential factors affecting water quality in cities and towns in the study area. PC2 has a weak to moderate positive correlation for temperature (0.338), salinity (0.521) and a weak negative correlation with turbidity (−0.445) and Fe (−0.430), which is affected by natural elements, salinity and heavy metals. Natural factors often significantly affect the self-cleaning process of rivers and canals and the exchange of oxygen in the water. PC3 explains the variation of temperature (−0.373), turbidity (0.382), BOD (0.311), N-NH_4^+ (−0.421), P-PO_4^{3-} (−0.327) and Fe (−0.404) to a similar extent. important. This source represents a mixed source consisting of natural elements, organic matter, nutrients and heavy metals. PC4 has a weak positive correlation with turbidity (0.375), P-PO_4^{3-} (0.418) and a weak to moderate negative correlation with Fe (−0.356) and coliform (−0.587). This source includes phosphorus-containing nutrients and microorganisms. PC5 explains the change of temperature (−0.413) at a weak level and TSS (−0.646) at a moderate level, influenced by natural factors and rainwater runoff with polluted matters.

From the PCA results, the sources of surface water quality pollution in cities and towns in Ben Tre province can occur including hydrological factors, organic matter, nutrients, heavy metals, microorganism, etc. and rainwater overflowing with polluted matter. It can be seen that principal component analysis has identified potential pollution sources that significantly affect surface water quality in Ben Tre province. According to several studies by [27, 37], PC correlates with coliform demonstrating the influence of microorganisms from human and warm-blooded animal waste. While organic pollutants such as BOD, COD, and nutrients N-NH_4^+, N-NO_3^-, P-PO_4^{3-}, are reported to be strongly associated with domestic wastewater, industrial, urban and agricultural [4, 17, 37, 44, 50, 51]. Salinity in coastal areas is mainly influenced by seawater intrusion, seawater can penetrate deep into the field through rivers and canals, leading to salinization of water sources [52]. At the same time, the high Fe concentration in the water is thought to be influenced by the alkaline soil characteristics in the study area, the soil leaching process has created the Fe content in the water [10].

This study found that the parameters such as temperature, salinity, turbidity, TSS, DO, BOD, COD, N-NH_4^+, N-NO_3^-, P-PO_4^{3-}, Fe and coliform all affect the surface quality in the areas of cities and towns in Ben Tre province in 2021. These parameters should be monitored in the future.

TABLE II: KEY VARIABLES AND SOURCES OF INFLUENCE ON SURFACE WATER QUALITY

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
pH	0.277	0.290	0.024	−0.141	0.292	0.617	0.112
Temp.	0.236	**0.338**	**−0.373**	0.058	**−0.413**	−0.103	0.156
DO	**0.373**	−0.100	−0.059	0.259	−0.221	0.298	0.145
Sal.	0.132	**0.521**	0.197	0.082	−0.216	−0.374	0.306
Tur.	0.086	**−0.445**	**0.382**	**0.375**	−0.118	−0.072	0.155
TSS	0.221	−0.206	0.123	−0.170	**−0.646**	0.347	−0.129
BOD	**−0.374**	0.127	**0.311**	0.070	−0.245	0.064	0.064
COD	**−0.384**	0.107	0.297	0.082	−0.219	0.075	0.041
N-NH_4^+	−0.271	0.213	**−0.421**	0.273	−0.191	0.063	−0.252
N-NO_3^-	**−0.343**	−0.046	−0.144	0.017	0.064	0.291	**0.778**
P-PO_4^{3-}	−0.292	−0.123	**−0.327**	**0.418**	−0.036	0.226	−0.176
Fe	−0.017	**−0.430**	**−0.404**	**−0.356**	−0.157	−0.280	0.285
Coliform	**−0.302**	0.069	0.059	**−0.587**	−0.204	0.161	−0.147
Eigenvalues	5.06	2.25	1.67	1.2	1.14	0.68	0.47
%Variation	38.9	17.3	12.9	9.2	8.8	5.2	3.6
%Cum.Variation	38.9	56.2	69.1	78.4	87.2	92.4	96

D. Clustering Surface Water Quality in Urban and Residential Areas

The results of cluster analysis were evaluated by 13 water quality parameters at 15 sampling locations in rivers and canals flowing through cities and towns in Ben Tre province in 2021. Fig. 7 shows the collection locations. The sample is divided into 5 separate clusters at Euclidean = 3. Cluster I and cluster III have only one position, respectively, at SW13 and SW1. Cluster II includes 5 locations, SW2, SW4, SW6, SW8 and SW9. Meanwhile, cluster IV includes 06 positions, namely SW3, SW5, SW7, SW11, SW12 and SW14. Finally, two positions SW10 and SW15 belong to cluster V. Table III shows that in all clusters, TSS, BOD and COD concentrations exceed the allowable limits. However, the difference between clusters may be because cluster I has a relatively lower concentration of pollutants than the rest of the clusters. At the same time, the VN_WQI index also showed that cluster I has very good water quality and has the highest VN_WQI value (VN_WQI = 93). Cluster II also has the content of P-PO_4^{3-} and Fe exceeding the standard (1.64 times and 1.21 times higher, respectively). This shows that, in addition to being affected by organic substances and suspended solids, cluster II is also affected by nutrients containing phosphorus and heavy metals. However, surface water quality in this cluster is still at a good level with VN_WQI value of 90. For cluster V, TSS content is the highest compared to other clusters (3.32 times higher than the norm), at the same time. also had a coliform content 1.04 times higher than the standard. Similar to cluster II, surface water quality in cluster V is very good with VN_WQI value of 92. Cluster III is considered a cluster with very high concentrations of organic, nutritional and microbiological pollution, higher than other clusters. and 5.62 times, 3.94 times, 7.41 times, 2.92 times and 2.40 times higher than the limits). The water quality in this cluster is average with VN_WQI value of 57. Concentration of pollutants in cluster IV is similar to cluster II, but cluster IV appears to have very high coliform content, 2.13 times higher than that in cluster IV. In general, water quality in cluster IV is still good but still worse than cluster I, cluster II and cluster V (VN_WQI = 74).

CA is useful in classifying river water and can reduce the number of sampling sites and sampling frequency [53]. Sampling sites with the same conditions as being close to each other in terms of water quality and in the same water body can consider reducing the sampling location [54–58]. Therefore, surface water quality monitoring sites in cities and towns in Ben Tre province can be reduced from 15 locations to 12 locations. The positions that are not retained in the monitoring program include positions SW2 and SW6 of cluster II and SW5 of cluster IV. This could save up to 20% of monitoring costs per year.

E. Solutions to Surface Water Quality Management

In order to enhance the effectiveness of environmental protection of water sources in the study area, the main pollution sources have been identified that need specific solutions to limit the generation and increase of pollutants. Firstly, the group of policy solutions and local authorities need to improve the investigation and strictly handle the situation of discharge into the receiving environment without treatment. Second, the solution group improves capacity, provides professional training for local full-time officials in water resource management. Third, the group of technical solutions, it is necessary to invest in completing and improving urban infrastructure, wastewater and waste treatment systems in accordance with regulations. Typically, septic tank systems in residential areas and urban areas need to be invested and built according to standards. The rainwater system overflows to avoid stagnation, leading to other pollution sources into the water body. Dredging, clearing flows at some rainwater and wastewater collection routes in the area, and at the same time establishing a research team to deploy a system of mixing and air island in some seriously polluted canals in the area. province to increase dissolved oxygen content in water, helping to improve water quality. In addition, Ben Tre is a coastal province, affected by sea water intrusion, so local authorities need a solution to store fresh water in the dry season to avoid affecting people's water use needs. Fourth, the group of propaganda and education solutions to raise and change people's consciousness as well as awareness, through seminars and radio stations about the potential consequences of surface water pollution for human health and ecosystems, especially the lack of clean water will cause extremely serious consequences. This should be done on a regular basis and on a large scale.

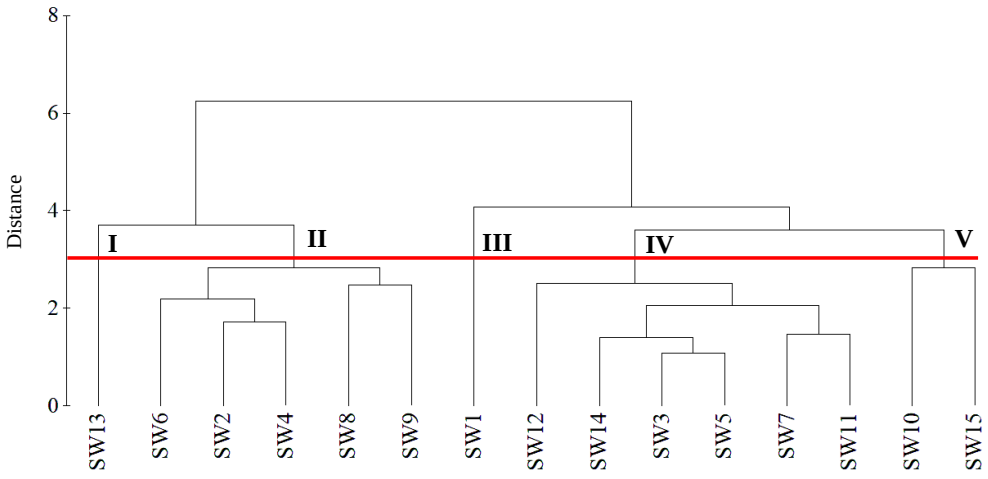

Fig. 7. Clustering surface water quality.

TABLE III: WATER QUALITY IN THE IDENTIFIED CLUSTERS

Variables	Clus. 1	Clus. 2	Clus. 3	Clus. 4	Clus. 5	QCVN
pH	7.38	7.00	6.82	7.12	7.32	6.0–8.5
Temp.	29.93	28.60	29.10	28.45	29.16	-
DO	6.93	6.31	4.69	5.53	6.67	6
Sal.	9.93	1.06	1.03	1.84	3.63	-
Tur.	32.25	66.25	16.64	42.67	43.86	-
TSS	**57.13**	**56.48**	**40.88**	**56.15**	**66.38**	20
BOD	**12.90**	**13.39**	**22.49**	**17.22**	**13.19**	4
COD	**21.71**	**23.71**	**39.44**	**29.80**	**23.05**	10
$N\text{-}NH_4^+$	0.18	0.13	2.22	0.12	0.19	0.3
$N\text{-}NO_3$–	0.47	0.53	0.79	0.58	0.48	2
$P\text{-}PO_4^{3}$–	0.08	**0.16**	**0.29**	**0.13**	0.08	0.1
Fe	0.35	**0.61**	**0.54**	**0.57**	0.34	0.5
Coliform	1142.50	1586.60	**6000.00**	**5312.50**	**2595.00**	2500
VN_WQI	93	90	**57**	**74**	92	81

IV. CONCLUSIONS

Surface water quality in cities and towns in Ben Tre province in 2021 has been polluted, manifested by parameters TSS, BOD, COD, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe and coliform exceeding the limits for permission of QCVN 08-MT:2015/BTNMT column A1. Concentrations of salinity, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe and coliform in the study area in the dry season were higher than in the rainy season. The remaining parameters such as turbidity, TSS, DO, BOD, COD have higher values during the rainy season. The VN_WQI index shows that the water quality in the study area ranges from moderate to very good. Surface water quality is only suitable for irrigation purposes in both dry and rainy seasons. Areas with a lower degree of urbanization have better water quality than the rest. The PCA analysis showed that the parameters of temperature, salinity, turbidity, TSS, DO, BOD, COD, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe and coliform significantly affected environmental quality. The water market flows through residential areas and urban areas in Ben Tre province. CA analysis results show that only 12/15 sampling locations need to be monitored, saving 20% of monitoring costs. Surface water quality in cities and towns in Ben Tre province is influenced by many different sources such as hydrological conditions, organic matter, nutrients, heavy metals, microorganisms and rainwater runoff. contaminated material. Further studies need to evaluate specifically for each source of pollution, in order to come up with effective strategies for surface water quality management in residential areas and urban areas.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Dr. Nguyen Thanh Giao designed the research and methodologies; Dr. Nguyen Thanh Giao and Ms. Nguyen Hong Thao Ly conducted the research, analyzed the data and drafted the manuscript; Dr. Nguyen Thanh Giao revised and finalized the manuscript; all authors had approved the final version.

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