App. Envi. Res. 43(1) (2021): 14-27

Applied Environmental Research

Journal homepage : http://www.tci-thaijo.org/index.php/aer

Evaluating Water Quality Variation in the Vietnamese Mekong Delta Area Using Cluster and Discriminant Analysis

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Article History

Submitted: 27 May 2020/ Revision received: 31 July 2020/ Accepted: 7 August 2020/ Published online: 26 November 2020

Abstract

The study aims to assess spatial and temporal water quality variations in the upper reaches of the Vietnamese Mekong Delta. Thirty-one water monitoring samples of the two main rivers (Tien and Hau Rivers) and six canals flowing through An Giang Province were collected in the dry season (March) and the rainy season (September) from 2009 to 2019. Seven physicochemical parameters were analyzed including temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), orthophosphate ($P\text{-}PO_4^{3-}$), and coliforms. Water quality index (WQI), cluster analysis (CA), and discriminant analysis (DA) were applied to evaluate water quality, spatial and temporal variations, and seasonal discriminant water variables. WQI values (15–71) indicated surface water quality was very bad to medium in which the water quality in larger and in smaller rivers in the dry season was less polluted than that in the rainy season due to erosion and runoff water containing waste materials in the wet season. CA grouped the water quality in the dry and rainy seasons into four clusters mainly due to BOD and coliforms in the dry season; TSS and coliforms in the rainy season. Discriminant analysis revealed that DO, TSS, coliforms, temperature and BOD significantly contributed to seasonal variations in water quality. Therefore, water quality monitoring in the surveyed area could only focus on DO, TSS, coliforms, temperature and BOD to reduce monitoring cost.

Keywords: Water quality; Coliform; An Giang; Cluster analysis; Discriminant analysis; Water quality index

Introduction

An Giang Province, is located in the upstream of the Mekong Delta of south-western Vietnam, has contributed significantly into the general socio-economic development of the delta. The province is the first land area receiving water from the Mekong River at the northwest border with Cambodia divided into two main courses (known as the Tien and Hau Rivers). The total river flow is estimated annually at 13,650 $m^3\ s^{-1}$ with the distributary ratios at Tan Chau and Chau Doc of 80% and 20%, respectively [1]. In

https://doi.org/10.35762/AER.2021.43.1.2

addition to these two main rivers, the area also has many natural and artificial canals, which constitutes to the most intensive hydrological network in the Mekong Delta with a density of 0.72 km km^{-2} [2]. Surface water quality has thus relatively complicated.

Water quality is often influenced by natural sources (e.g., climate, surface runoff) and anthropogenic sources (e.g., discharge of wastewater, runoff from agricultural land, soil erosion and land use) [3–5]. These sources vary spatially because it is strongly depended on the different human activities among regions. Besides, the natural and anthropogenic impacts are very complex; water quality assessment hence requires a fundamental understanding of the change in physicochemical water properties by spatial and temporal [6]. For these purposes, surface water quality monitoring program has to be implemented annually. Subsequently, there is a huge data matrix generated during the long-term water quality monitoring, which has resulted in the difficulty and complexity of data storage, analysis and interpretation. Therefore, reducing the data size has drawn an interesting topic for many researchers. Data size reduction can be done by calculating the WQI, which has been successfully implemented in the classification and evaluation of water quality in several countries [7–10]. In addition, a number of previous studies have reduced initial analysis data using multivariate analysis techniques such as cluster analysis (CA), principal component analysis (PCA) and discriminant analysis (DA) [11–14].

The water quality index (WQI) is used to assess the combined effects of physical, chemical and biological parameters of water environment [15–18]. The index is a mathematical tool used to convert all data related to water quality characteristics into a single constant that represents the water quality level and can be widely used in the community. The combination of multivariate statistical techniques and WQI has been recommended in the previous study [19]. This combination allows classification of several water quality samples into clusters which could reflect the spatial and temporal variations of water quality [20]. Phung et al. (2015) [6] used the multivariate statistical techniques including cluster analysis, principal component analysis, and discriminant analysis to assess water quality by spatial and temporal in Can Tho City, Mekong Delta, Vietnam. In this present study, the CA and DA were applied to interpret changes in river water quality by temporal and spatial in An Giang Province, Vietnam. The results of this study could be used as referential information of the adjustment of water quality monitoring program in An Giang Province.

Methodology

1) Study area

Freshwater resources play crucial role in the socio-economic development of An Giang Province. The gross domestic product reached VND 39,274 million per capita in 2015 and increased VND 17,336 million per capita compared to that in 2010 [21]. The diversified agricultural structures have contributed significantly to promote the local economic development. An Giang is one of the two provinces with the highest rice area in Vietnam, accounted for 14.9% of the area and 41.1% of the rice production in the Mekong Delta [22–23]. In addition, expanding land under fruit trees has contributed to diversification in agricultural systems. An Giang is also one of the leading provinces in freshwater aquaculture production not only in the Mekong Delta but also the whole country. In 2018, the province's aquaculture output reached nearly 199 thousand tons with an increase of 8.26% over the same period in 2017. Besides the strengths of agriculture and fisheries, An Giang has also been promoting the development of industry and handicraft-industry sector focus on import and export activities. Currently, there are three international border gates including Khanh Binh (located in upstream of the Hau River), Vinh Xuong (located in upstream of the Tien River), and Tinh Bien (located near the Vinh Te Canal) in An Giang Province. Five industrial zones have been built along the major rivers such as Hau River, Tien River, Vinh Te Canal. The production value of handicraft-industry in 2018 reached VND 19,248 billion and increased by 8.1% over the same period last year. Due to the growth of industrial and agricultural activities and increase in population in the province, it has resulted in negative impacts on surface water quality where inappropriately treated waste-water was discharged into the environment. Therefore, the evaluation of water quality datasets for a 10-year period could help to find important water environment factors that affect surface water quality in An Giang Province.

2) Data collection

Thirty-one sampling stations along the main courses and tributaries were collected as follows: Hau River (7 stations, S1–S7), Tien River (6 stations, S8–S13), Vinh Te Canal (4 stations, S14–S17), Vinh Tre Canal (3 stations, S18–S20), Mac Can Dung Canal (2 stations, S21–S22), Tam Ngan Canal (3 stations, S23–S25), Rach Gia Canal (3 stations, S26–S28), and Ong Chuong Canal (3 stations, S29–S31). Map of study area and description of water quality monitoring stations are shown in Figure 1. At each location, a water sample was collected with the frequency of two times/year, in March (dry season) and September (rainy season). Datasets of the major river quality monitoring were collected from 2009 to 2019, while other tributaries were analyzed later from 2011 to 2019. WQI was calculated based on seven collected parameters including temperature (ºC), pH, dissolved oxygen (DO, mg L^{-1}); total suspended solids (TSS, mg L^{-1}), biochemical oxygen demand (BOD, mg L^{-1}), orthophosphate (P-PO_4^{3-}, mg L^{-1}) and coliforms (MPN 100 mL^{-1}). pH and DO parameters were measured on-site using ADWA AD11 pH (made by Romania) and DO 9142 DO meters (made by HANNA), while other parameters were properly stored and analyzed by standard methods [24].

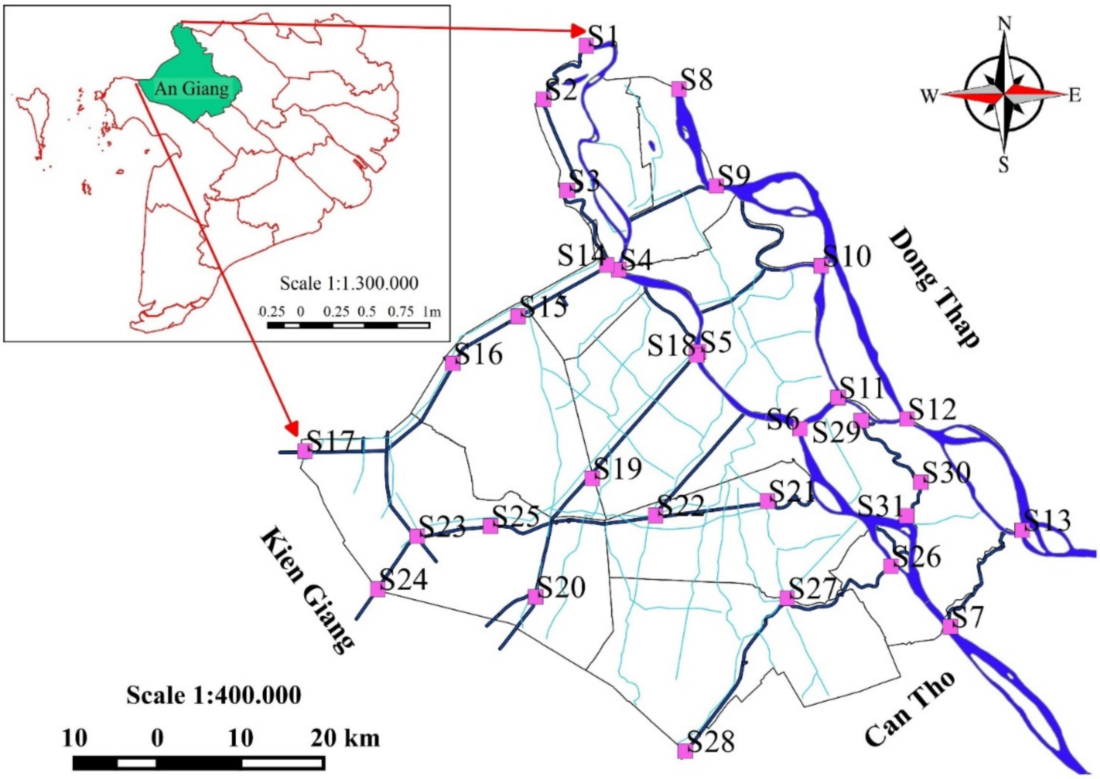

Figure 1 Location of river monitoring sites used in the study.

3) Data analysis

To assess the data set with several water quality monitoring parameters for the long-term period, the water quality index and the multivariate analysis (CA and DA) were applied, in which the WQI calculation was used to CA analysis and the average of the water quality parameters in the dry season and rainy season was the input source of the DA analysis. In this study, all calculations and analyses were performed using Microsoft Excel (Microsoft Office, 2016), IBM SPSS statistics for Windows, Version 20 (IBM Corp., Armonk, NY, USA), and PRIMER (PRIMER-E Ltd, Plymouth, UK) softwares.

3.1) Water quality index (WQI) analysis

The surface water quality assessment for different uses was conducted using the WQI according to the regulations of the Vietnam Environment Administration (2019) [18]. The analytical data are calculated and evaluated for the two seasons over the years at different positions by Eq. 1.

The WQI results show the level of water quality and the corresponding use purpose in a specific water body. The WQI ranges from 0 to 100 dividing water quality into five levels. Level 1 (indicated by Blue color, 100> WQI>91) is good water quality that could be used for purposes of water supply. Level 2 (Green, 90>WQI>76) is also used for water supply for domestic uses but suitable treatment measures are required. Level 3 (Yellow) is for irrigation and other similar purposes (75>WQI>51). Level 4 (Orange, 50>WQI >26) is the water suitable for transport and equivalent purposes while Level 5 (Red, 25>WQI>0) is considered to be heavily polluted water that proper treatment measures are urgently needed.

3.2) Cluster analysis (CA) and discriminant analysis (DA)

The water quality data were analysed using CA and DA. These two important methods aim to determine the similarity of water quality among the locations and figure out which parameters causing spatial and temporal variations, respectively.

The CA method is commonly employed to arrange and classify water quality at the survey sites in clusters based on the WQI values. Locations with high similarity in water quality are grouped together in one cluster, while others with different water quality are grouped into another cluster. This technique is constituted by the Ward algorithm [25] and the Euclidean distance measuring distances of water quality parameters between the locations. In this current work, CA was conducted using copyrighted software Primer 5.2 for Windows (PRIMER-E Ltd., Plymouth, UK).

$$WQI = \frac{WQI_{pH}}{100}\left[\frac{1}{3}\sum_{a=1}^{3} WQI_a . WQI_b . WQI_c\right]^{1/3} \quad \text{(Eq. 1)}$$

Where WQI_a is the calculated WQI value for three parameters (DO, BOD, $P\text{-}PO_4^{3-}$), WQI_b is the calculated WQI value for TSS, WQI_c is the calculated WQI value for coliforms, and WQI_{pH} is the calculated WQI value for pH (pH is in the range of 6–8.5).

Discriminant analysis (DA) is used to discriminate between groups, in which dependent and independent variables are categorical and quantitative attributes, respectively [26–27]. In this study, DA was used to evaluate and interpret the differences between clusters by spatial and seasonal through parameters using in WQI calculation [6, 28]. Basing on the original matrix variable, the DA technique builds up discriminate function (DF) for each group [11, 29]. The categorical-dependent values include spatial and temporal clusters, while the quantitative-independent variables are water quality monitoring parameters. This work was conducted using IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA).

Results and discussions

1) Water quality in the large rivers in An Giang Province

Tien and Hau Rivers are considered large rivers in An Giang Province. The water quality indexes calculated for Hau and Tien Rivers in upstream (S1 and S8 stations) to control/evaluate the water quality from Cambodia flowing into the Hau and Tien Rivers in the period 2009–2019. Besides that, the study evaluated the water quality at the end of Hau River belonging to An Giang Province before flowing through Can Tho City and at the end of Tien River before flowing to Dong Thap Province by the WQI calculation at S7 and S13 stations during the period of 2009–2019, and were presented in Figure 2. The mean WQI values in the upper section of Hau River ranged from 15–18 explaining that the river water was very bad quality. However, WQI in downstream of this river section were higher than those at the upstream in 2010, 2015, 2016 and 2018. The WQI values in the upper part of Tien River ranged from 15–71 classifying water quality from very bad to medium. In 2015, water quality in the upper parts of Hau River was relatively low (WQI=16) whereas that in the Tien River was recorded significantly higher (WQI=71). In contrast to Hau River, there was almost no change in water quality between upstream and downstream of Tien River. Tien River receive wastes and wastewaters from social economic activities from both An Giang and Dong Thap Provinces, especially agricultural cultivation in Dong Thap Muoi area which could be considered as the main causes influencing water quality in its downstream and upstream. In general, water quality in the upstream area tended to be lower than those in the downstream in Tien and Hau Rivers, which was also reported in the previous study [30]. Moreover, this fluctuation was also observed in the upper and lower reaches of the Mekong River when it flows through Thailand, Laos and Cambodia [20]. It can be concluded that water before flowing into Vietnam was polluted causing difficulty for water quality management in Vietnamese Mekong Delta. This leads to an urgent need in international collaboration in water management for the Mekong River.

The mean WQI values over the years at five monitoring points in the Hau River and four points in Tien River were presented in Figure 3. The results showed that WQI values in Hau and Tien Rivers varied from 15–93 and 14–20 in the dry season, respectively. In rainy season, WQI values ranged from 4–16 indicating very bad water quality. WQI decreased significantly in the rainy season over the surveyed years. Increasing TSS and coliforms in the rainy season could be responsible for low WQI values reducing water quality. TSS is concerned since it is dependent on organic matter, soil, and silt originated from river bank erosion and runoff water [31–33]. Coliforms occurred in water environment is from overflowing water containing animal and human faeces [32–34]. In the rainy season, erosion and runoff water increased in the Vietnamese Mekong delta leading to the increasing of TSS and coliforms seriously reducing quality of water. Besides that, the average water quality index in the upstream of Hau river (S1 with WQI = 15–18 was lower than that at the downstream (S7 with WQI = 16–60). In Tien river, WQI was in the upstream (WQI = 17–71) was better than those at the middle (WQI = 9–17) and the downstream (WQI = 14–7). The results of WQI revealed that surface water quality in Tien and Hau Rivers flowing through An Giang province has been seriously polluted. Previous study reported that WQI in

Hau River belonging to Can Tho City and Hau Giang Province ranged from 67–88 [35] which was higher than those at An Giang section. This comparison indicates that Hau River in Vietnamese Mekong delta play a crucial role in purifying polluted water from the upper part of the Mekong River. The pollution sources affecting water quality in the rivers were previously reported by agricultural production, livestock and domestic activities [20, 36–37].

2) Water quality in the small rivers in An Giang province

The average water quality monitoring data in the dry season and rainy season at 18 locations of six tributaries belonging to An Giang Province was presented in Table 1. As can be seen that surface water quality was polluted by TSS, BOD, and coliforms in both dry and rainy seasons. The mean TSS concentration in the period of 2011–2019 in the dry and rainy seasons were ranged from 45.83 ± 12.31 to 84.3 ± 33.48 mg L^{-1} and 47.53 ± 23.49 to 99.19 ± 40.29 mg L^{-1}, respectively. These values were higher than the national technical regulation on surface water quality QCVN 08–MT:2015/BTNMT (TSS<20 mg L^{-1}) [38]. Similar to the trend of TSS, BOD concentrations at most locations exceeded the nation regulation (BOD<4 mg L^{-1}) ranged from 6.28 ± 1.92 to 9.26 ± 2.89 mg L^{-1} (in dry season) and 7.59 ± 2.88 to 10.19 ± 3.55 mg L^{-1} (in rainy season). It has been previously reported that water quality in some canals was contaminated by municipal and industrial wastewaters [10]. Coliforms was in the range of 4,793 ± 3,151 to 24,461 ± 52,299 MPN 100 mL^{-1} in dry season and 17,382 ± 13,138 to 29,041 ± 53,562 MPN 100 mL^{-1} in the rainy season. The higher of TSS and the lower of BOD and coliforms in the present study were comparable to water quality in the canals in Can Tho City during the period of 2008–2012 [6]. There are similarities in water quality small canals in the Mekong Delta Provinces [36, 39].

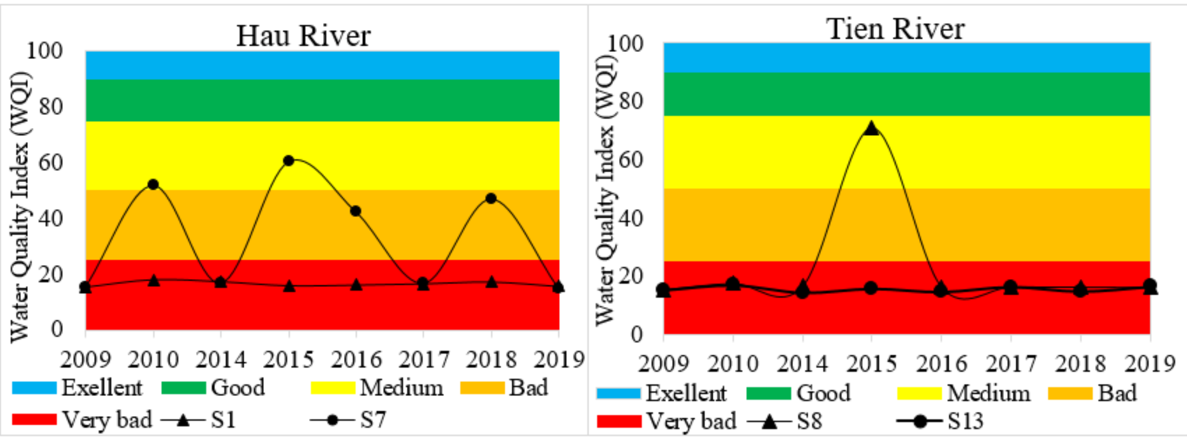

Figure 2 Surface water quality upstream and downstream in Hau and Tien Rivers in An Giang Province from 2009–2019.

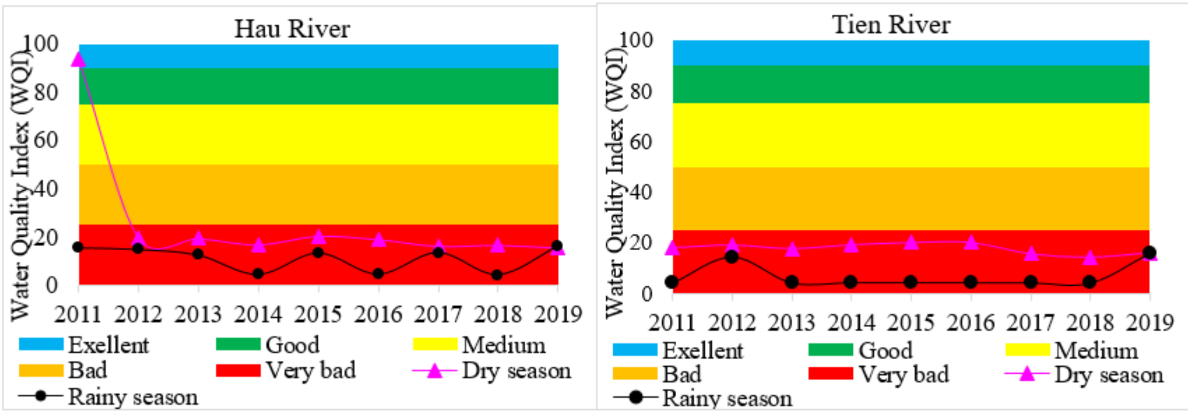

Figure 3 Temporal variation of water quality in Hau and Tien Rivers in An Giang Province.

Table 1 Water quality in the smaller rivers in An Giang Province

Season		Vinh Te Canal	Vinh Tre Canal	Mac Can Dung Canal	Tam Ngan Canal	Rach Gia Canal	Ong Chuong Canal
Dry	Temp	**30.01±0.99**	**29.54±0.91**	**30.14±0.91**	**30.32±1.2**	**29.4±1.46**	**30.17±1.31**
	pH	7.09±0.31	6.97±0.32	6.98±0.23	6.93±0.28	6.97±0.29	6.91±0.35
	DO	4.06±0.67	4.17±1.01	4.02±0.78	3.87±0.83	4.02±0.84	4.35±0.98
	TSS	**45.83±12.31**	**53.41±19.29**	**53.94±19.45**	**84.3±33.48**	**59.56±23.16**	**51.17±21.98**
	BOD_5	**7.53±2.36**	**7.7±1.46**	**6.28±1.92**	**9.26±2.89**	**7.15±2.67**	**6.85±1.89**
	$P\text{-}PO_4^{3-}$	0.13±0.1	0.18±0.14	0.17±0.15	0.13±0.11	0.17±0.11	0.19±0.23
	Coliforms	**8,753±6,518**	**4,793±3,151**	**7,241±5,810**	**24,461±52,299**	**13,219±14,434**	**15,784±23,814**
Rainy	Temp	29.41±0.53	29.52±1.24	29.51±1.85	29.8±1.22	29.49±0.95	28.66±0.74
	pH	6.94±0.26	6.98±0.27	6.85±0.3	6.86±0.21	7.01±0.25	6.97±0.35
	DO	5.12±0.59	5.08±0.68	4.91±0.49	5.09±0.64	5.24±0.64	5.28±0.9
	TSS	**47.53±23.49**	**72.52±22.81**	**58.28±19.54**	**57.85±22.87**	**58.37±23.22**	**99.19±40.29**
	BOD_5	**8.25±2.64**	**10.19±3.55**	**10.06±4.63**	**9.19±1.87**	**9.33±3.18**	**7.59±2.88**
	$P\text{-}PO_4^{3-}$	0.14±0.2	0.13±0.13	0.18±0.24	0.11±0.12	0.15±0.09	0.09±0.08
	Coliforms	**19,539±26,866**	**29,041±53,562**	**20,742±25,951**	**22,830±27,262**	**17,382±13,138**	**17,466±19,557**

The WQI ranging from 13 to 85 indicated that water quality of the tributaries was from very bad to medium in the dry season during 2011–2019 (Table 2). In this season, the highest WQI values were observed in Vinh Tre Canal (WQI: 14–74, WQI_{mean} = 61) and the lowest were found at the Tam Ngan Canal (WQI: 4–76, WQI_{mean} = 37). In the rainy season, the surface water quality also was very bad in the most canals with WQI values ranged from 4 to 84. The mean WQI in the rainy season was generally lower than that in the dry season. This result was consistent with the previous discussion that water quality in the rainy season was worse than that in the dry season. Overflow water could be the main reason for the difference [31–34]. The lower water quality in the rainy season could influence on water supply [28].

Water quality was highly fluctuated during the period of 2011 – 2019. The best water quality was recorded in 2012 while the worst one was detected in 2014 and 2015 among the canals in the surveyed areas. More specifically, the water quality index tended to increase in the Vinh Te, Mac Can Dung and Ong Chuong Canals in 2012 followed by a sharp decrease until 2015. Furthermore, after increasing in 2016 and 2017, the WQI in these canals decreased in 2018 and 2019. In contrast, the WQI had a tendency of being decreased continuously in the period (2011–2015), before increasing in 2016 and 2017. For the WQI in Tam Ngan canal tended to fluctuate similarly to that Vinh Tre Canal. According to the statistics of General Statistics Office of Vietnam [40], the gross domestic product (GDP) was about 5.43% (2011), 4.00% (2012), 4.89% (2013), 5.06% (2014), 6.03% (2015), 5.48% (2016), 5.10% (2017) and 7.38% (2018). This could imply that the variation of WQI values in the rivers were closely related to the change of GDP or social-economic activities. In both seasons, water quality in the surveyed areas was assessed to be very bad due to the high densities of coliforms. Tam Ngan Canal water quality was further contaminated with TSS in the dry season of 2011, 2017 and 2018. In addition, TSS was also recorded high in the rainy season at the Ong Chuong Canal in 2011, 2014 and 2015. Previous studies reported that high TSS in the rainy season could be due to runoff water containing wastes from anthropogenic activities and river water flow disturbances [10, 30].

According to the study of Giao [35], WQI values of the canals ranged from 51–89, which were higher than the results of the current study. It can be explained by the low distributary ratio of Hau River in the upstream (approximately 20% of the total river flow); after receiving water from Tien River through Bac Vam Nao Stream, the average flow of Hau River is doubled from 2,650 $m^3 s^{-1}$ to 6,600 $m^3 s^{-1}$ [41]. This could partially explain the water quality in the downstream of Hau River (at the point adjacent to Can Tho City) and the canals in Can Tho City tended to be better due to good mixing of the water column. Moreover, the water quality in the smaller rivers (the tributaries) was better than that of Hau and Tien Rivers in An Giang Province, as opposed to the previous study in Can Tho City [35].

Table 2 Seasonal water quality fluctuation in the tributaries

Year	Canal	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dry	Vinh Te Canal	68	75	60	14	17	17	55	66	72
	Vinh Tre Canal	14	72	61	70	73	68	51	63	74
	Mac Can Dung Canal	53	83	16	15	14	75	56	81	65
	Tam Ngan Canal	18	58	68	4	15	59	18	18	76
	Rach Gia Canal	58	73	13	16	13	16	67	16	80
	Ong Chuong Canal	48	85	14	17	17	16	50	77	77
Rainy	Vinh Te Canal	76	84	73	14	18	16	62	13	17
	Vinh Tre Canal	69	76	64	4	14	67	4	13	16
	Mac Can Dung Canal	65	74	82	13	15	15	42	50	15
	Tam Ngan Canal	72	71	77	14	16	14	13	14	16
	Rach Gia Canal	68	19	16	16	15	62	14	13	16
	Ong Chuong Canal	18	71	4	20	17	14	41	14	15
Average	Vinh Te Canal	72	80	67	14	18	17	59	40	45
	Vinh Tre Canal	42	74	63	37	44	68	28	38	45
	Mac Can Dung Canal	59	79	49	14	15	45	49	66	40
	Tam Ngan Canal	45	65	73	9	16	37	16	16	46
	Rach Gia Canal	63	46	15	16	14	39	41	15	48
	Ong Chuong Canal	33	78	9	19	17	15	46	46	46

3) Spatial variation of water quality for the period 2009–2019

Cluster analysis was applied to determine spatial variations of water quality in the rivers belonging to An Giang Province using the mean values of WQI by year and by river. The CA results revealed that water quality in An Giang Province could be divided into four clusters in the dry season (Figure 4) and the rainy season (Figure 5). In the dry season, the large rivers (Tien and Hau Rivers) were grouped into cluster 3 (Euclidean distance = 5.42) which represented very bad water quality. Cluster 1 included Rach Gia Canal, Mac Can Dung Canal, Vinh Te Canal and Ong Chuong Canal (Euclidean distance = 5.99). Meanwhile, cluster 2 and cluster 4 comprised Tam Ngan canal and Vinh Tre Canal, respectively. Clusters 1 and 2 corresponded to bad water quality. Cluster 4 was characterized by the largest Euclidean distance to Cluster 1, which corresponded to the highest annual mean WQI (better water quality). It showed the difference of the Vinh Tre Canal compared to other canals in the dry season, where the WQI values were higher through the survey periods.

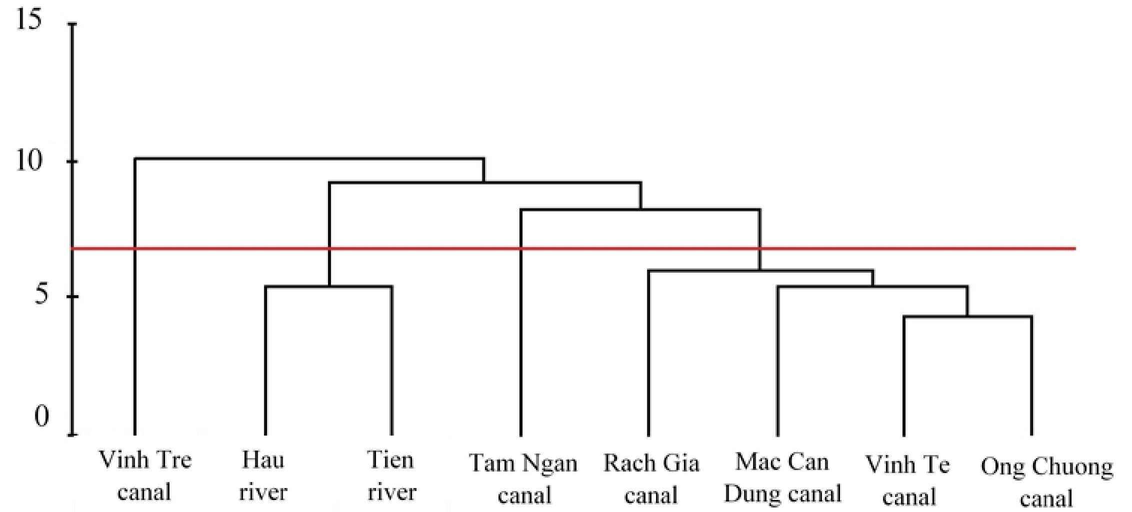

Figure 4 Clustering the water quality of the rivers in An Giang Province in the dry season.

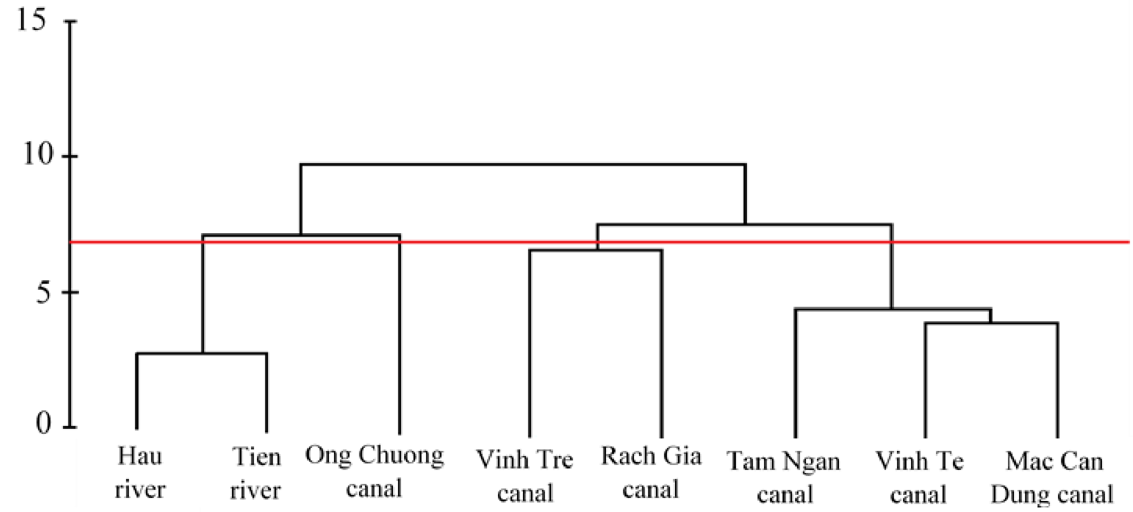

Figure 5 Clustering the water quality of the rivers in An Giang Province in the rainy season.

In the rainy season, water quality in the surveyed areas could be divided into four clusters. Cluster 4 had the highest pollution level compared to the remaining clusters including Tien and Hau Rivers (Euclidean distance = 2.71). Cluster 1 was formed by the Vinh Te, Mac Can Dung and Tam Ngan Canals (Euclidean distance = 4.4) corresponding to bad water quality. While cluster 3 consisted of the Vinh Tre and Rach Gia Canals (Euclidean distance = 6.49), Cluster 2 was only formed by the Ong Chuong Canal. Water quality in the cluster 2 and 3 having the water quality better than that in cluster 1. However, the Ong Chuong Canal has Euclidean distance quite close to Cluster 1 (about 7.11). It means that the water quality at Cluster 1 and Cluster 2 is almost similar in the rainy season. Water quality in Vinh Tre Canal fluctuated significantly by season; for example, in the dry season, this canal had the lowest level of water pollution, but in the rainy season, the level of water pollution was classified as medium. Vinh Tre canal has been influenced by the geographical position (deep in the interior field) and impacted by various canals such as Mac Can Dung, Tam Ngan and Hau Rivers. Therefore, Vinh Tre Canal was significantly affected by season compared to other canals in An Giang Province. The size of the rivers, volume and flow, runoff, and human activities could be main factors responsible for the difference in water quality among the rivers in the study areas. Further study should focus on the main causes for each river to solve the water quality problems.

The similarities and dissimilarities in water quality were more clearly distinguished in the rainy season than in the dry season (Figure 4 and Figure 5). Overall, CA analysis clearly explained the spatial differentiation based on WQI values. It should be noted that CA provided good results for the evaluation of spatial variations in water quality, but the analysis does not often provide a convincing explanation for the changes of water quality [42]. It is suggested that CA should be used in combination with discriminant analysis to figure out reasonable reasons for the differences in water quality by seasons.

4) Seasonal variations in surface water quality

Discriminant analysis (DA) was applied to determine the level of discriminant functions (DFs) and the most important parameters that influences seasonal change in water quality. Table 3 illustrated the discriminant parameters that affect on water quality during the dry and rainy seasons. Three DFs were found to discriminate water quality in the dry season and the rainy season. For the dry season, the results of Wilk's Lamda analysis showed that there were significant discriminants between two DFs ($p<0.05$), with 100% discriminant among clusters where DF1, DF2 and DF3 accounted for 82.7%, 15.4% and 1.9%, respectively. TSS, BOD and coliforms were the important parameters contributing to the fluctuation of water quality, assigned 54.2% of cases correctly. Besides that, 69.8% of the discriminant was explained by DF1, 27.4% by DF2 and 2.8% by DF3 in the rainy season. Although DF1 and DF2 has an Eigenvalue <1; however, the coliform and TSS parameters were the significant contributors to the fluctuation of water quality in the rainy season, which was retained. Seven discriminant parameters gave 61.1% of correct assignations. Coliform and TSS were mainly responsible for discriminating water quality at the surveyed locations during the rainy season.

Water variables that caused seasonal changes of water quality were presented in Table 4. Wilks' Lambda (0.678) and significance level ($p=0.00<0.05$) indicated the good results of the discriminant analysis (Table 4). The DA results showed that DO, TSS, coliforms, temperature, BOD significantly contributed to the changes in water quality between seasons in which DO and TSS were the most vital parameters for the seasonal discriminant. It means that these two parameters accounted for most of the seasonal variations in water quality. Seasonal changes of TSS have also been recorded in a number of previous studies [20]. However, in the study of Phung et al. (2015) [6] on the canals in Can Tho City, the seasonal change was caused by pH and $N\text{-}NO_2^-$ which is completely different from the results of the current study. It could be roughly explained by the different water quality characteristics of each area [39]. DA analysis could assist in significantly reducing the size of the monitoring data set and requires only a few parameters that are primarily responsible for spatial and temporal changes in water quality. The results of the present study showed that water quality monitoring in An Giang Province should only focus on the water variables including DO, TSS, coliforms, temperature and BOD to be able to assess changes in water quality and pollution characteristics of each season. In addition, this can help to reduce monitoring cost by only evaluating five parameters instead of seven parameters.

Table 3 Water variables resulting spatially different in water quality in the dry and rainy seasons

DFs	Dry season			Rainy season		
	1	2	3	1	2	3
BOD	**-0.619**	0.607	0.081	-0.026	0.278	**0.541**
TSS	**0.539**	0.301	-0.231	0.150	**-0.700**	0.205
$P\text{-}PO_4^{3-}$	-0.108	0.463	-0.464	-0.138	0.239	0.113
DO	0.288	0.122	0.058	0.268	-0.213	0.149
Coliform	**0.599**	0.603	-0.076	**0.707**	-0.109	-0.301
Temperature	0.063	0.395	0.748	0.324	0.443	-0.007
pH	0.063	0.395	0.748	0.325	-0.177	0.678
Eigenvalue	1.085	0.203	0.025	0.767	0.301	0.031
% of variance	82.7	15.4	1.9	69.8	27.4	2.8
Cum %	82.7	98.1	100.0	69.8	97.2	100.0
Wilks' Lambda	0.389	0.811	0.976	0.422	0.745	0.97
Sig.	0.000	0.183	0.805	0.000	0.083	0.846

Table 4 Water variables resulting seasonally different in water quality

DFs	DO	TSS	Coliform	Temp	BOD	pH
1	0.750	0.549	0.162	-0.426	0.381	-0.147
$P\text{-}PO_4^{3-}$	**Eigenvalue**	**% of Variance**	**Cum %**	**Wilks' Lambda**	**Sig.**	
-0.073	0.476	100	100	0.678	0.00	

Conclusion

Surface water quality in An Giang Province in the period of 2009–2019 ranged from very bad to good based on water quality index. The upstream water quality of Hau River was very bad, and it tended to be improved in the lower part. There was no significant difference in water quality between the upper and lower parts of Tien River. It was found that water quality in smaller rivers was less polluted than that in the larger rivers as Tien and Hau Rivers. Water quality in the dry season was better than that in the rainy season, the most obviously observed in 2019. A significant increase in TSS and coliform concentration has resulted in water pollution. The CA grouped the water quality in the dry and rainy seasons into four clusters which was highly matched with WQI values.

The main parameters responsible for the clustering including BOD and coliforms in the dry season; TSS and coliforms in the rainy season. Discriminant analysis revealed that DO, TSS, coliforms, temperature and BOD significantly contributed to seasonal variations in water quality. The results of the present study showed that water quality monitoring in An Giang Province could only focus on DO, TSS, coliforms, temperature and BOD, thus reducing the monitoring cost.

Conflict of Interest: The authors declare that they have no conflict of interest

Acknowledgements

The authors would like to thank the Department of Natural Resources and Environment, An Giang Province, Vietnam for providing water monitoring data period 2009–2019. All opinions expressed in this paper represent the scientific and personal views of the authors and do not necessarily reflect the views of the data provider.

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