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A Multivariate Statistical Analysis of Spatial and Temporal Variations in Surface Water Quality in Kien Giang Province, Vietnam

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ABSTRACT

In order to evaluate the changes in surface water quality in Kien Giang province, the study used discriminant analysis (DA) and principal component analysis (PCA). The 13 water quality indicators that were collected between years of 2019 and 2021 were T°, pH, DO, BOD_5, COD, TSS, N-NO_2^-, N-NO_3^-, N-NH_4^+, P-PO_4^{3-}, Fe_t, Cl^-, and Coliform. The federal government's criteria for surface and marine waterways are used to measure the water quality. The results show that the water quality in the study region is startling and exceeds the permitted limits established by national technical standards. In comparison to the rainy season, the dry season exhibited higher concentrations of N-NO_2^-, N-NO_3^-, and Cl^-. In both seasons, the study area's surface water quality can only be used for irrigation and drainage. Human activities in residential, agricultural, industrial, and saline intrusion areas are the main sources of contamination. The PCA suggests including eight indicators in the long-term monitoring program: T°, DO, BOD_5, COD, N-NO_2^-, N-NH_4^+, P-PO_4^{3-}, and Coliform because to their considerable impacts on the quality of surface water. TSS, N-NO_3^-, and Cl^- are a few more water body metrics that are affected by seasonal fluctuations. The most current scientific discoveries offer vital data that will help maintain the quality of the surface water along the coast, including Coliform, COD, N-NO_2^-, N-NH_4, and P-PO_4^{3-}. Seasonal variations affected other TSS, N-NO_3^-, and Cl^- characteristics of water bodies. The most recent findings provide critical scientific information for preserving the surface water quality in the coastal region.

Keywords: Discriminant Analysis, Kien Giang Province, Principal Component Analysis, Surface Water Quality, Temporal Variation

1.0 Introduction

Water is a necessary component for human survival and growth. People can use water as a natural resource for domestic, commercial, industrial, and agricultural uses [1](Trang, 2014). Still, these activities also significantly impact the surface water quality. The influence of natural elements, industrial regions, and agricultural practices are only a few of the factors that have been identified as affecting surface water quality in recent research [2, 3]. Hence, surface water quality faces severe pollution due to socioeconomic development, population growth, and uncontrolled urbanization. According to the MONRE report [4], the water supply in Vietnam is still polluted due to trash from cities, industrial regions, artisan villages, and growing populations. Water pollution affects human health, increasing the risk of infectious diseases, especially cancer from toxins, pesticide contamination, and heavy metal poisoning. Around 9,000 people die, and nearly 200,000 new cancer cases are identified yearly in Vietnam because of poor water supply and sanitation [5]. Therefore, evaluating the surface water quality is crucial. Additionally, it necessitates using the proper analytical tools to accurately and thoroughly assess the state of surface water quality.

Multivariate statistical analysis (MSA) is a widely used method that is thought to be able to examine large and complex data sets across a variety of fields [6]. For instance, MSA has been used to evaluate the surface water quality inside monitoring networks in several water bodies in Malaysia [7] in numerous studies carried out abroad, including in China [8]. Since then, Syria has offered efficient approaches to managing water quality [9]. Although MSA has not been used in Vietnam's surface water pollution, it has been used in other disciplines like psychology, economics, society, and engineering. For instance, the Mekong Delta's (MD) coastal provinces of Kien Giang have a sophisticated system of canals and two main sources of surface water: fresh and brackish. The province of Kien Giang's surface water quality has been significantly and intricately impacted by the socioeconomic development of the local population. The main factors affecting the water quality in the province of Kien Giang were identified, and regional and temporal changes in that quality were examined, using MSA.

2.0 MATERIALS & METHODOLOGY

2.1 Study area

The coastal province of Kien Giang is located to the southwest of the MD. The largest natural area is in the province, which makes up 6346.3 km^2, or 15.6% of the entire MD. Although relatively level, the geography deteriorates from the Northeast to the Southwest. The province suffers greatly from the buildup of rubbish from upstream regions, and because of its location at the entrance of the Mekong River and close to the Gulf of Thailand, it suffers greatly from sea level rise as well. The rainy season is lasts from May to November, and the dry season is lasts from December to April the following year, are both tropical monsoon seasons in Kien Giang. The annual rainfall ranged from 1593.4 to 2630.1 mm, and the average temperature is roughly 28.05°C. The hydrological cycle of the province is influenced by the Hau River, the regional rainfall cycle, and the tidal regime from the Gulf of Thailand. The rivers of Giang Thanh, Cai Lon, and Cai Be, as well as several the 1st grade canals that frequently branch off the Hau River and radiate into the 2nd and the 3rd grade canals that link to the interior area, make up the province's extensive waterway network, which spans 2054.93 km. The waterway system has a significant impact on the province's agricultural practices, soil characteristics, and water management [10].

2.2 Analysis and sampling of water

Information on water quality monitoring between 2019 and 2021 was collected from the Kien Giang Department of Natural Resources and Environment. Besides Kien Hai district, the estuaries, major rivers, and their tributaries in Kien Giang province, which consists of 14 districts and towns, were among the 49 monitoring stations where surface water samples were taken twice a year (in March and September) (Figure 1).

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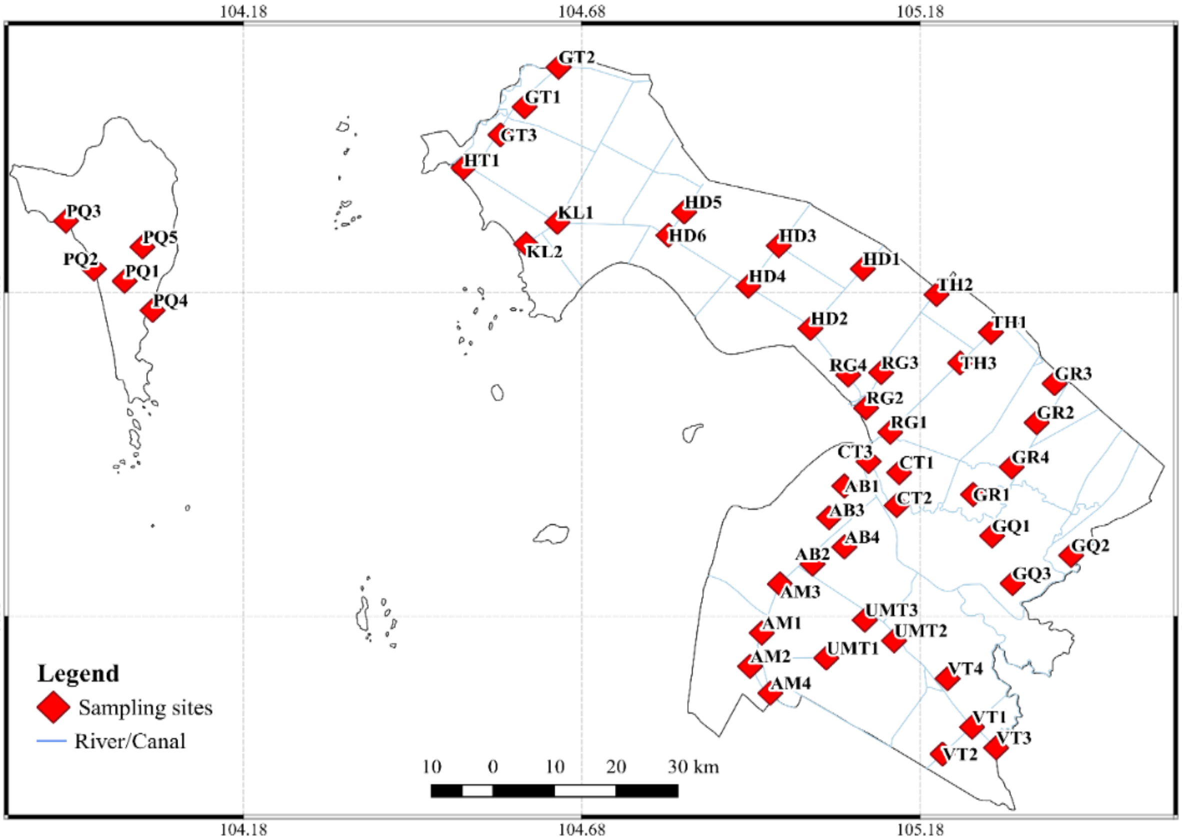

Fig.1 Sampling sites in Kien Giang province

In order to evaluate the water quality and give input data for MSA, orthophosphate ($P\text{-}PO_4^{3-}$), total iron (Fe_t), chloride (Cl^-), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), temperature (T^o), nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), total suspended solids (TSS), and Coliform were employed.

The recent technical national standards of TCVN 6663-6:2008, TCVN 6663-9:2008, and TCVN 6663-3:2016 were followed when collecting and storing water samples. While other parameters were examined in the laborator in accordance with accepted protocols of APHA [11]; parameters of T°, pH and DO were measured on-site. Table 1 contains a list of the analytical techniques used on the water sample.

Table 1: Analytical techniques for water quality

Parameters	Analytical methods	Technical national standards of	
		Surface water quality - A2 value [12]	Marine water quality [13]
T^o (^oC)	TCVN 4557:1988	-	-
pH	TCVN 6492:2011	6.0 - 8.5	6.5 - 8.5
DO (mg/L)	TCVN 7325:2004	≥ 5	≥ 5
BOD_5 (mg/L)	TCVN 6001-1:2008	6	-
COD (mg/L)	TCVN 6491:1999	15	-
TSS (mg/L)	TCVN 6625:2000	30	50
$N\text{-}NO_2^-$ (mg/L)	TCVN 6178:1996	0.05	-
$N\text{-}NO_3^-$ (mg/L)	TCVN 6190:1996	5	-
$N\text{-}NH_4^+$ (mg/L)	SMEWW 4500 NH_3-F 2017	0.3	0.1
$P\text{-}PO_4^{3-}$ (mg/L)	Hach DR 4000/5000 Method 8048	0.2	0.2

Fe_t (mg/L)	TCVN 6177:1996	1	0.5
Cl^- (mg/L)	TCVN 6194:1996	350	-
Coliform (MPN/100 mL)	TCVN 6197-2:1996	5000	1000

2.3 Data analysis

For this investigation, measurements of surface water quality were taken. The outcomes were contrasted with standards for surface and marine water quality.

In addition, the crucial parameter, the variation across seasons, was discovered using discriminant analysis (DA). In contrast, the province of Kien Giang used principal component analysis (PCA) to pinpoint the factors that significantly influenced the water quality. PCA was carried out using the IBM SPSS Statistics 20 tool, while DA was processed using Primer V5.2 software (PRIMER-E Ltd, Plymouth, UK).

3.0 RESULTS AND DISCUSSION

3.1 The variations in surface water quality in the province of Kien Giang

Figure 2 displays the average T^o findings for the research area. In the dry season, T^o ranges from 27.83 ± 0.64 to 30.37 ± 0.57℃, the lowest value recorded at site TH3 and the highest at site HT1. In the rainy season, the average T^o ranges from 28.43 ± 1.21 to 30.13 ± 0.72℃, the lowest value at site RG3 and the highest at site GR4, which has a negligible difference compared to the dry season. Temperature is essential in aquaculture activities as it directly affects DO demand, biological activity, and other parameters [14]. Aquatic species and related food chain organisms in aquatic ecosystems are susceptible to temperature. The most suitable temperature range for the development is from 25 to 35℃ [15]. The recorded temperature in this study does not affect the aquatic system. Water temperature in the study area has similar values to other water bodies in the MD [16, 17].

Figure 3 illustrates the notable variations in average pH between the two seasons, with readings ranging from 3.59 ± 0.18 (site KL2) to 7.34 ± 0.16 (site AM3) for rainy season and 6.03 ± 0.39 (site HD4) to 7.76 ± 0.88 (site GT2) for the others. The marine water quality guideline for aquaculture and aquatic conservation was set within values of 6.5 to 8.5, while the required range of surface water quality from 6.0 to 8.5. Even though only 27/49 sites had pH values that satisfied the requirements of marine water quality standards. The low pH readings at sites KL1, KL2, and GT1 during the rainy season may have been brought on by the excavation of ponds for aquaculture cultivation in the areas with acid-sulfate soil. As a result, during rainstorms, the acidity will disperse into bodies of water, reducing the pH of the water. A similar observations noting that aluminum sulfate from aquaculture ponds and rice fields was washed into nearby canals by rains, which led to low pH levels in several areas of the Kien Luong and Hon Dat districts [18]. As a result, it appears that the pH values at some monitoring locations are insufficient for the growth of fish and shrimp. If the pH is lower than four or higher than ten, fish and shrimp may grow slowly or even die. A high pH also makes it difficult to deliver water and lowers the sterilizing efficacy of chlorine. Contrarily, a low pH will cause metals and other things to corrode [19].

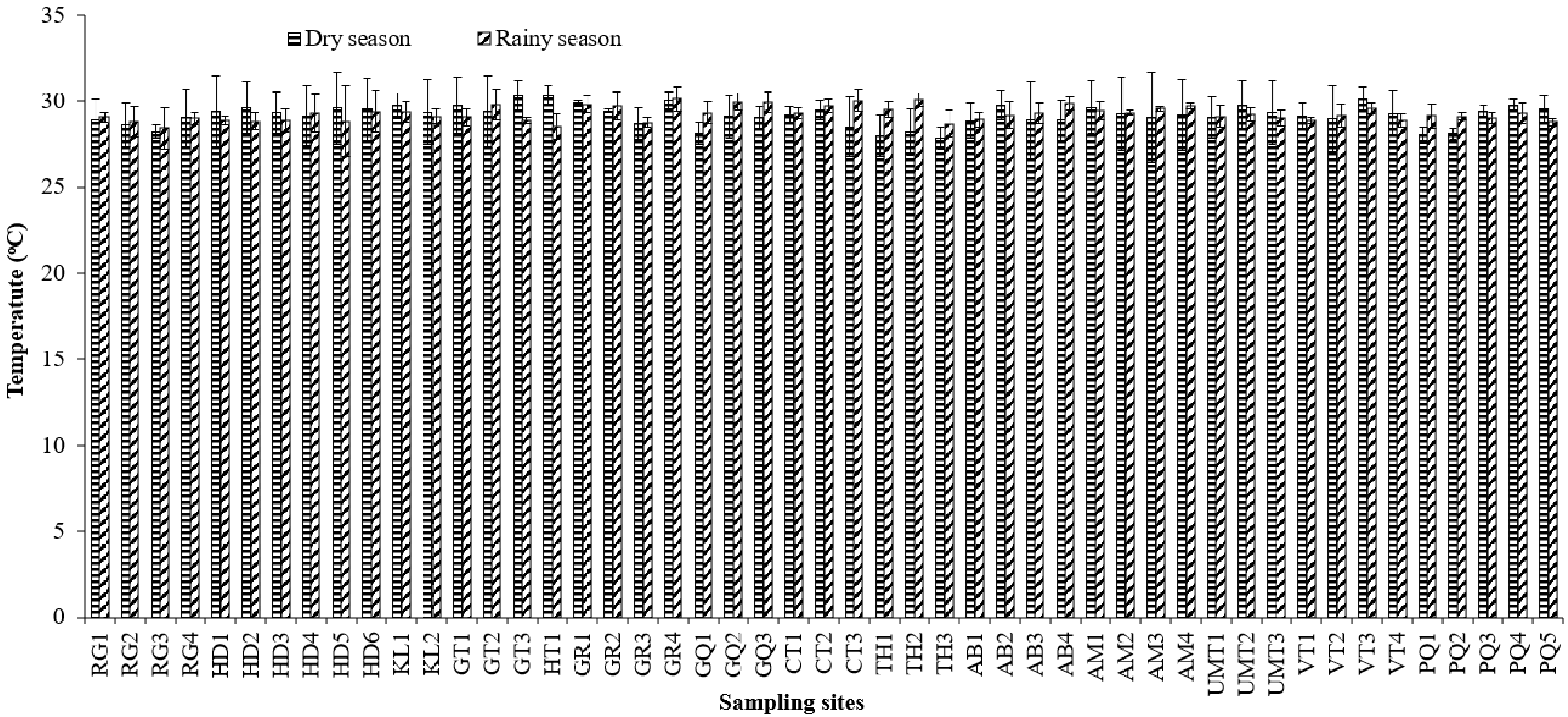

Fig.2 The seasonal average temperature in the study period

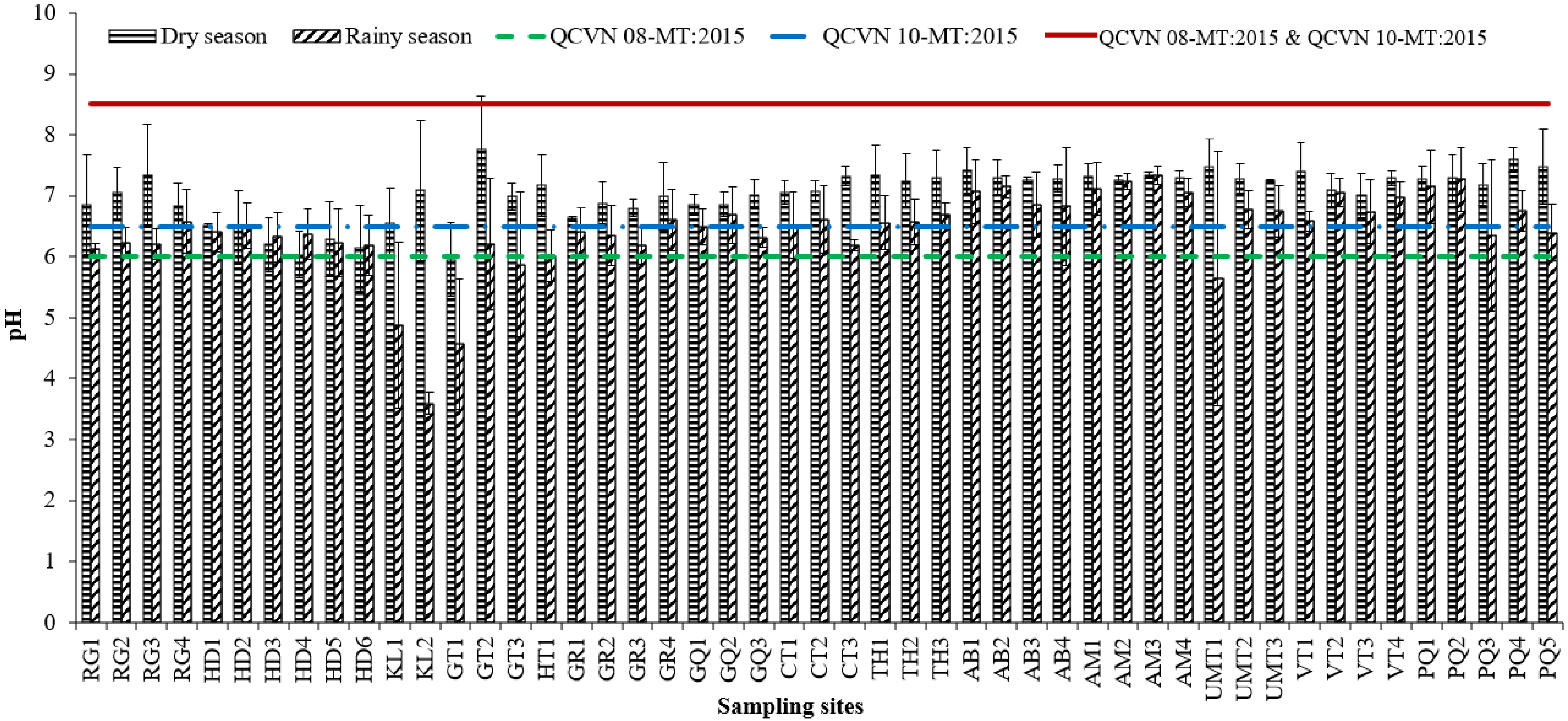

Fig.3 Seasonal average pH in the study period

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Figure 4 displays the average TSS results. The average TSS during the dry season ranges from 8.33 ± 2.31 to 64.33 ± 44.29 mg/L, with site PQ5 having the lowest value and site GR2 having the highest. The TSS concentration was 2.1 times greater in 25 of the 49 monitoring stations than the acceptable standard of surface water quality column A2 (30 mg/L). On the other hand, the permitted 50 mg/L of marine water quality standard was only exceeded by 2/49 points, or 1.3 times greater than the limits. During the rainy season, TSS concentrations range from 13.0 ± 11.36 to 84.33 ± 21.36 mg/L, with the lowest and highest values being recorded at sites PQ3 and VT2. The maximum value recorded at the 39/49 sampling locations during the rainy season was 2.8 times the surface water quality requirement (column A2). In comparison, 25/49 sampling points - with a maximum excess of 1.7 times - exceeded the permitted limit of marine water quality standards. In the canal network during the rainy season, there were higher TSS concentrations due to the amount of silt and suspended solids carried downstream by the river flow [20]. A study on the water quality of the main and tributary rivers of the Hau River found that the TSS concentration is higher during the rainy season than it is during the dry season due to upstream floods and solid water flows that transport a lot of sediment downstream [21].

In the dry season, the average DO content ranges from 3.92 ± 0.37 to 4.95 ± 0.23 mg/L, while in the rainy season, it ranges from 3.85 ± 0.82 to 5.40 ± 1.16 mg/L (Figure 5). According to study done in the Can Tho river [20], this conclusion is consistent. In comparison to the dry season, the significant upstream water flows during the rainy season increase the likelihood of oxygen penetration into the water bodies. The DO measurements at sites KL2 and RG3 were the lowest in both seasons, while those at sites CT1 and RG4 were the highest. During the dry season, the DO readings at all 49 monitoring stations were greater above the permissible threshold of 5 mg/L for both marine and surface water quality. In contrast, only 4/49 points did so in the rainy season. Low DO levels (2 mg/L) will hinder the growth of aquatic organisms and result in fish death if fish are not used to low oxygen conditions [22]. Dissolved oxygen levels in the Hau River and its tributaries were lower than those in the study area when compared to a previous study [21]. This could be because wastewater from domestic, agricultural, and aquaculture activities is accessible; these sources are rich in organic matter and nutrients, which deplete dissolved oxygen and lower DO in the water.

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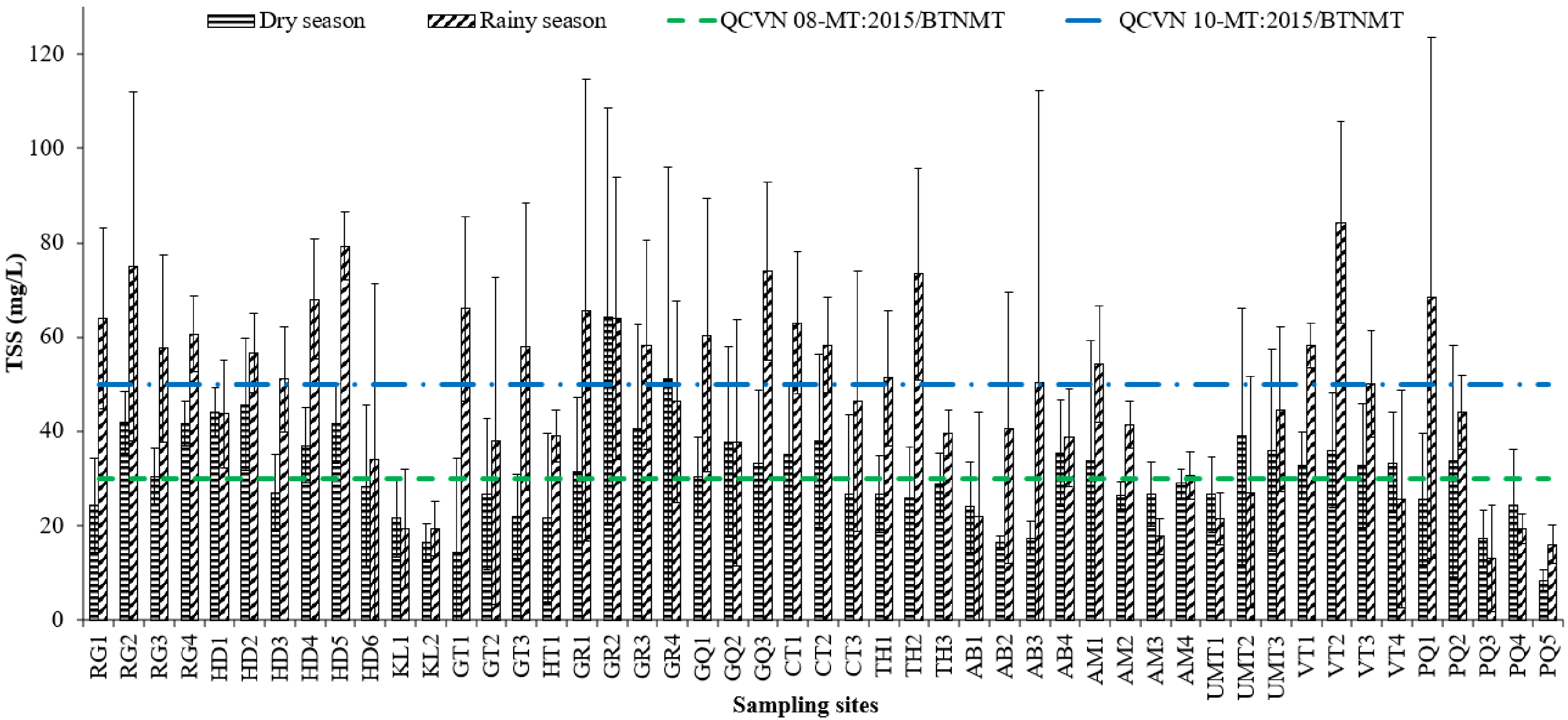

Fig.4 Seasonal average TSS in the study period

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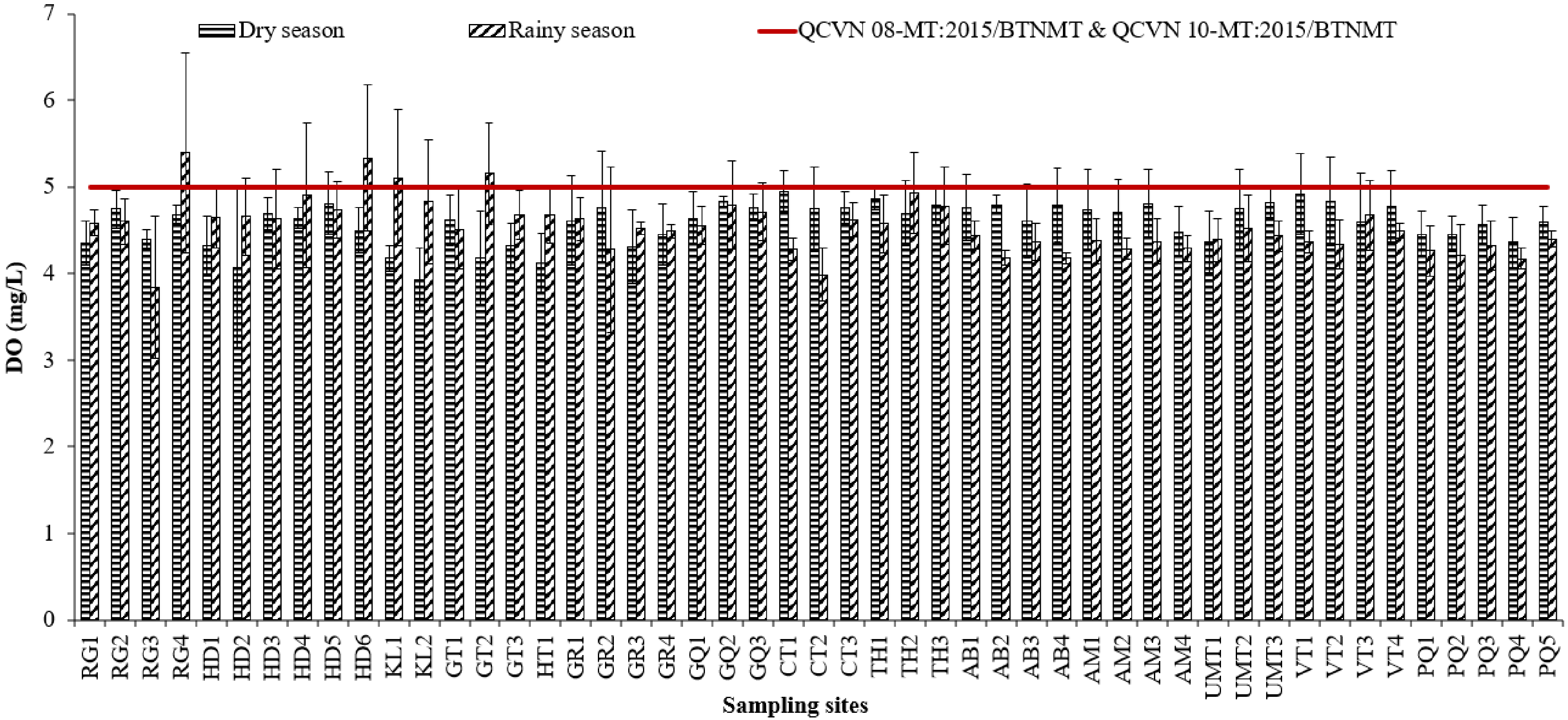

Fig.5 Seasonal average DO in the study period

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The variations in BOD_5 between sampling points in both seasons are depicted in Figure 6. The BOD_5 content ranged from 7.17 ± 2.57 mg/L (site PQ5) to 17.17 ± 7.29 mg/L (site CT2) during the dry season. The lowest value of the BOD_5 during the rainy season is at site PQ3 (8.6 ± 1.17 mg/L), and the highest value is at site AB4 (26.7 ± 19.04 mg/L). In all seasons, the average BOD_5 concentration was 2.80 to 4.45 times higher than the acceptable limit of surface water quality standard (column A2, 6.0 mg/L). Similar circumstances were observed in the Kien Luong and Hon Dat districts of Kien Giang; the BOD_5 is much higher than the permitted level, and the water quality is guaranteed to serve for irrigation but not for domestic use [18].

The COD content was also generally very high and tended to increase throughout the rainy season (Figure 7). Sites CT3 and PQ5 had the highest (32.83 ± 8.10 mg/L) and lowest (14.33 ± 2.52 mg/L) COD contents throughout the dry season. During the rainy season, the lowest and highest values were at sites PQ3 and AB4, which had ranging from 17.92 ± 2.64 to 58.48 ± 47.39 mg/L. Except the average COD concentration in the site 49 exceeds the permissible limit of the surface water quality standard (column A2, 15 mg/L) by 2.2 to 3.9 times during the dry season. Organic matter has caused the water quality in the study region to degrade, which may have been brought on by the impact of waste and wastewater produced by commercial, residential, and public sector operations close to the study area's water bodies [23, 24]. This is indicated at monitoring locations in both seasons by low DO and high BOD_5 and COD levels. The high BOD_5 and COD concentration of wastewater from aquaculture activities such as shrimp farming, has a considerable impact on the quality of surface water as well [16, 25].

The average $N\text{-}NO_2^-$ concentration over the course of the dry season is obtained at site RG1 where it varies between a maximum of 0.56 ± 0.51 mg/L, and a minimum of 0 mg/L at eight other monitoring sites (Figure 8). After reviewing 49 monitoring sites, it was found that 31 of them had readings that were higher than the authorized level of the surface water quality standard (column A2, 0.05 mg/L), with the highest measurement coming in at 11.2 times. During the rainy season, the highest $N\text{-}NO_2^-$ measurement at site AM2 is 0.57 ± 0.51 mg/L, above the norm 11.4 times, while 16/49 monitoring points exceed the permissible limit. Aquaculture ponds can build high levels of $N\text{-}NO_2^-$ in the water body, which can poison fish and shrimp and reduce the productivity and quality of aquatic stocks [26].

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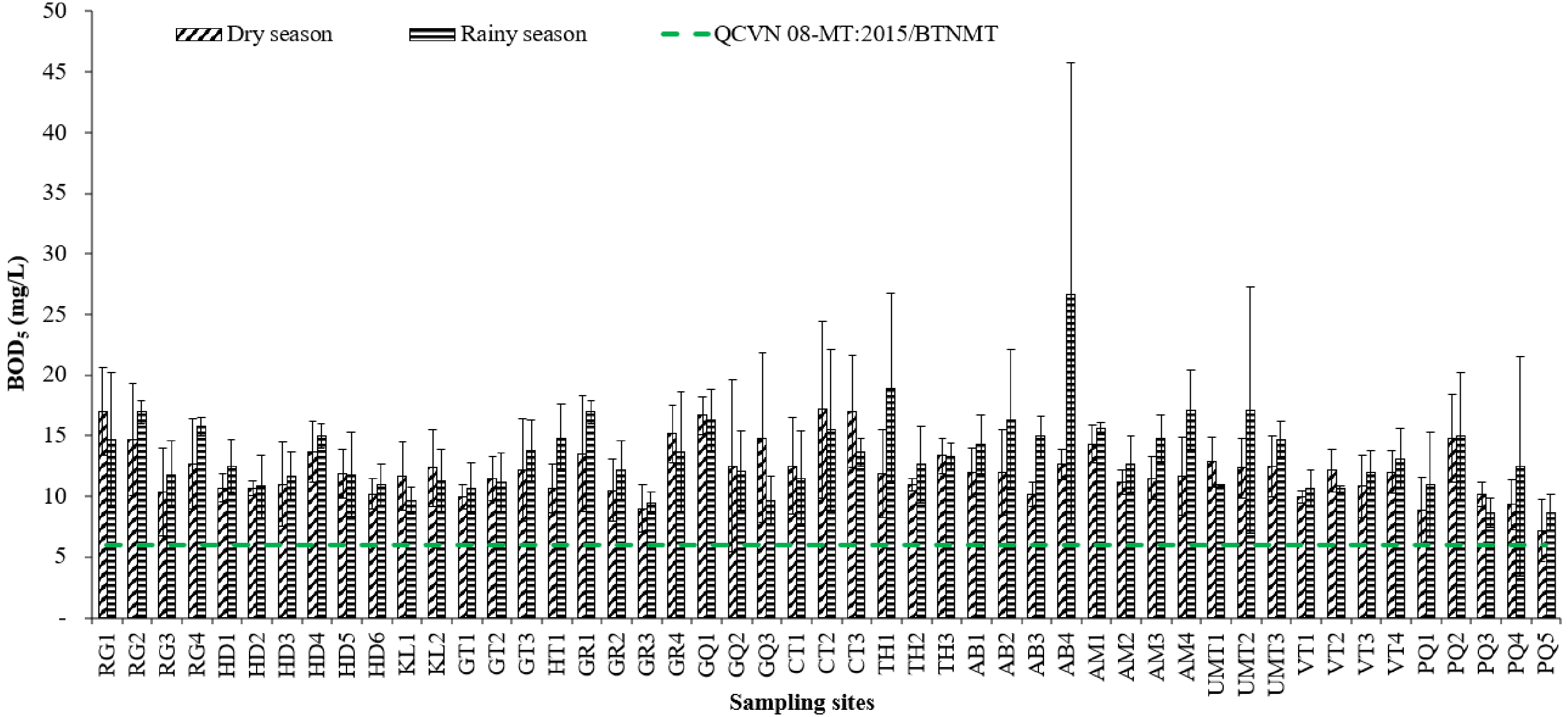

Fig.6 Seasonal average BOD_5 in the study period

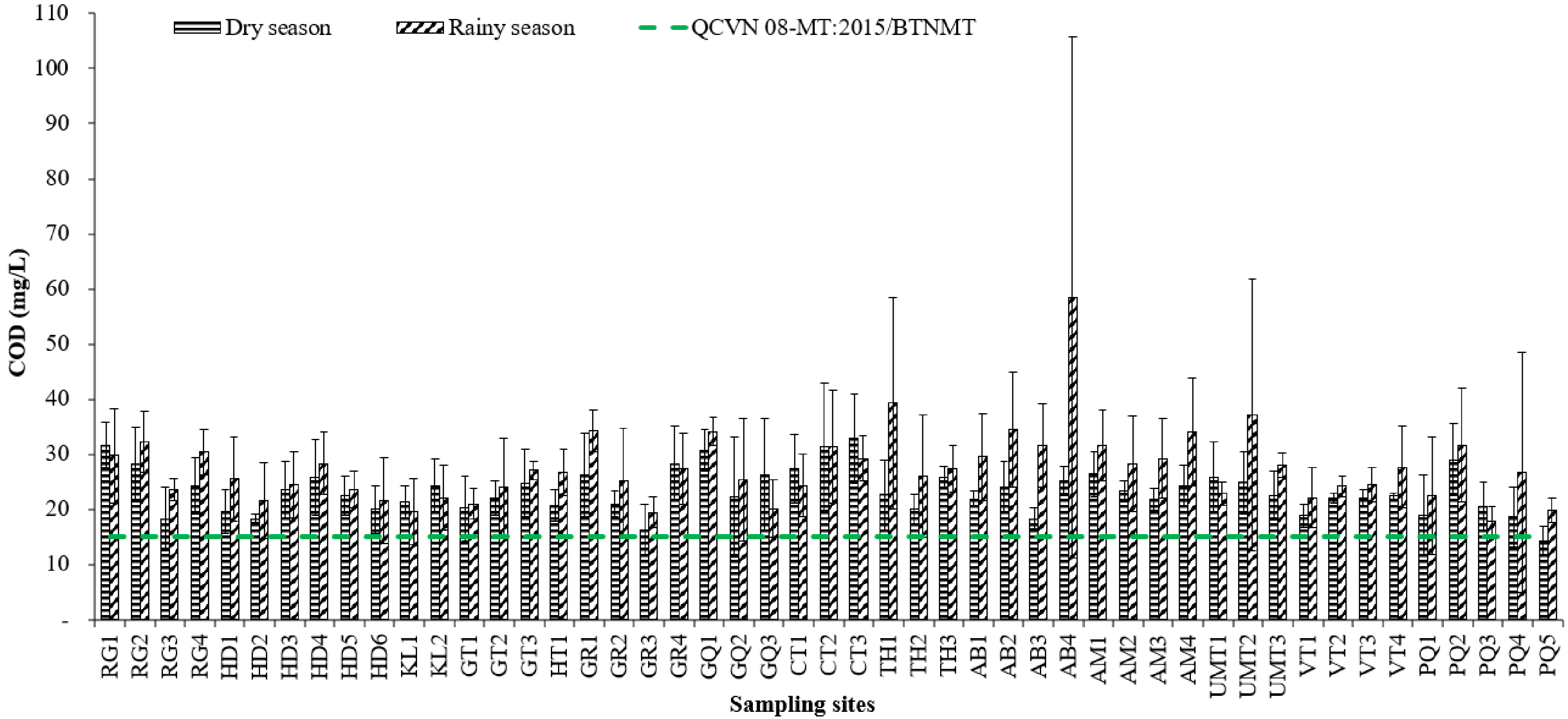

Fig.7 Seasonal average COD in the study period

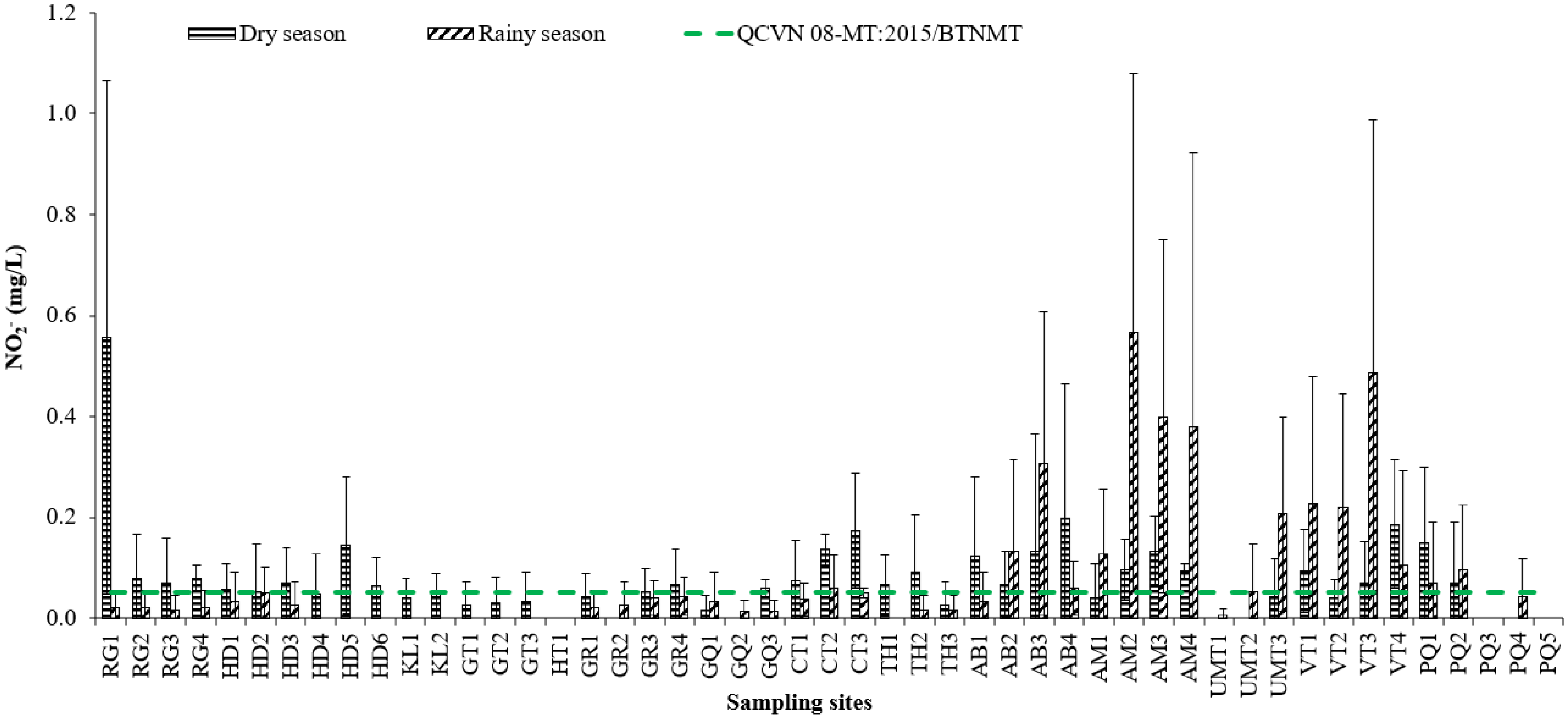

Fig.8 Seasonal average N-NO_2^- in the study period

Additionally, the average $N\text{-}NO_3^-$ concentration varies from 0.00 to 0.97 ± 0.03 mg/L and 0.00 to 0.53 ± 0.76 mg/L, during the rainy and dry seasons respectively (Figure 9). In the dry season at site HD5, and in the rainy season at site AB4, the greatest $N\text{-}NO_3^-$ levels were found. The $N\text{-}NO_3^-$ content at each monitoring site is below the 5.00 mg/L threshold value that is considered acceptable for surface water quality. The low $N\text{-}NO_3^-$ content reduces the amount of dissolved oxygen in the water body because of inadequate redox conditions or too high levels of organic matter [16].

The greatest $N\text{-}NH_4^+$ concentration value during the dry season is 1.78 ± 1.13 mg/L at site PQ1, while the lowest value is 0.00 mg/L (Figure 10). While 40 of the 49 monitoring points exceed the allowable value of marine water quality standard (0.1 mg/L), 20 of the 49 monitoring locations exceed the permitted thresholds of surface water quality (column A2, 0.3 mg/L). The $N\text{-}NH_4^+$ value peaked at site PQ2 at 0.96 ± 0.82 mg/L and site PQ5 at 0.08 ± 0.14 mg/L during the rainy season. While 33/49 monitoring points exceed the allowable value of the surface water quality standard, 48/49 monitoring points exceed the acceptable marine water quality standard threshold. Compared to the study on the Tien River at Tan Chau of An Giang, the region's $N\text{-}NH_4^+$ concentration has higher values because of its downstream location, where more nutrients collect from various activities [27].

The analytical data (Figure 11) show that there was a significant difference in $P\text{-}PO_4^{3-}$ concentration between the dry and rainy seasons, ranging from 0.00 to 0.19 ± 0.17 mg/L and from 0.00 to 0.41 ± 0.42 mg/L, respectively. The average $P\text{-}PO_4^{3-}$ concentration is frequently higher during the rainy season. The reason could be due to the dry season's reduced river water flow, which results in less dilution of domestic, industrial, and other effluents. According to a study on the river [21], the value of $P\text{-}PO_4^{3-}$ in the main and tributaries of the Hau River is lower in the dry season than in the rainy season. No points in the dry season had values more significant than the permissible thresholds of national standards [12, 13], while 12/49 points did so in the rainy season. Previous research has shown that nutrient concentrations in surface water is frequently low [28]. Contrarily, domestic, industrial, and agricultural wastewater includes chemicals and nutrients that are challenging to degrade [29]. As a result, the research area has comparatively high concentrations of N and P, demonstrating how eutrophication and human activity have negatively impacted to surface water quality.

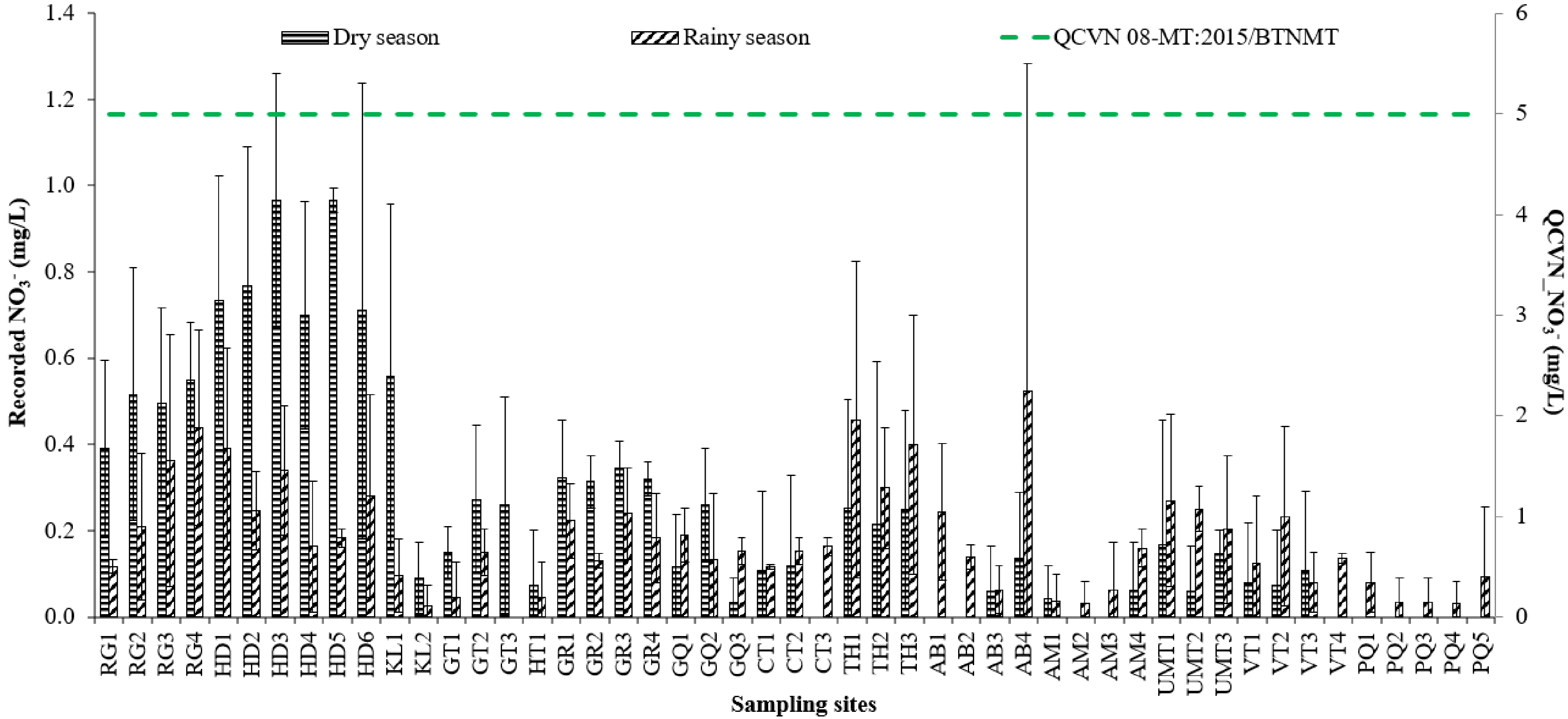

Fig.9 Seasonal average N-NO_3^- in the study period

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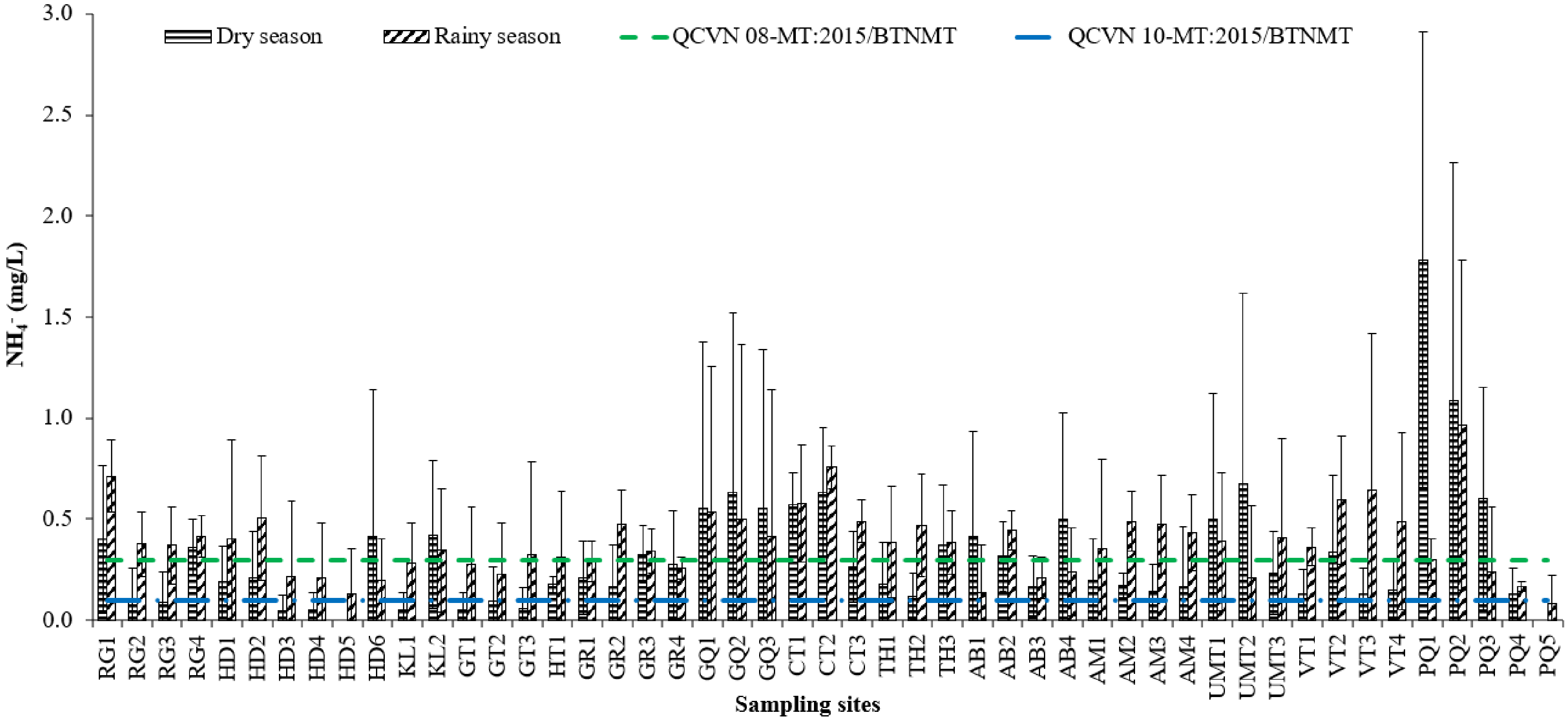

Fig.10 Seasonal average N-NH_4^+ in the study period

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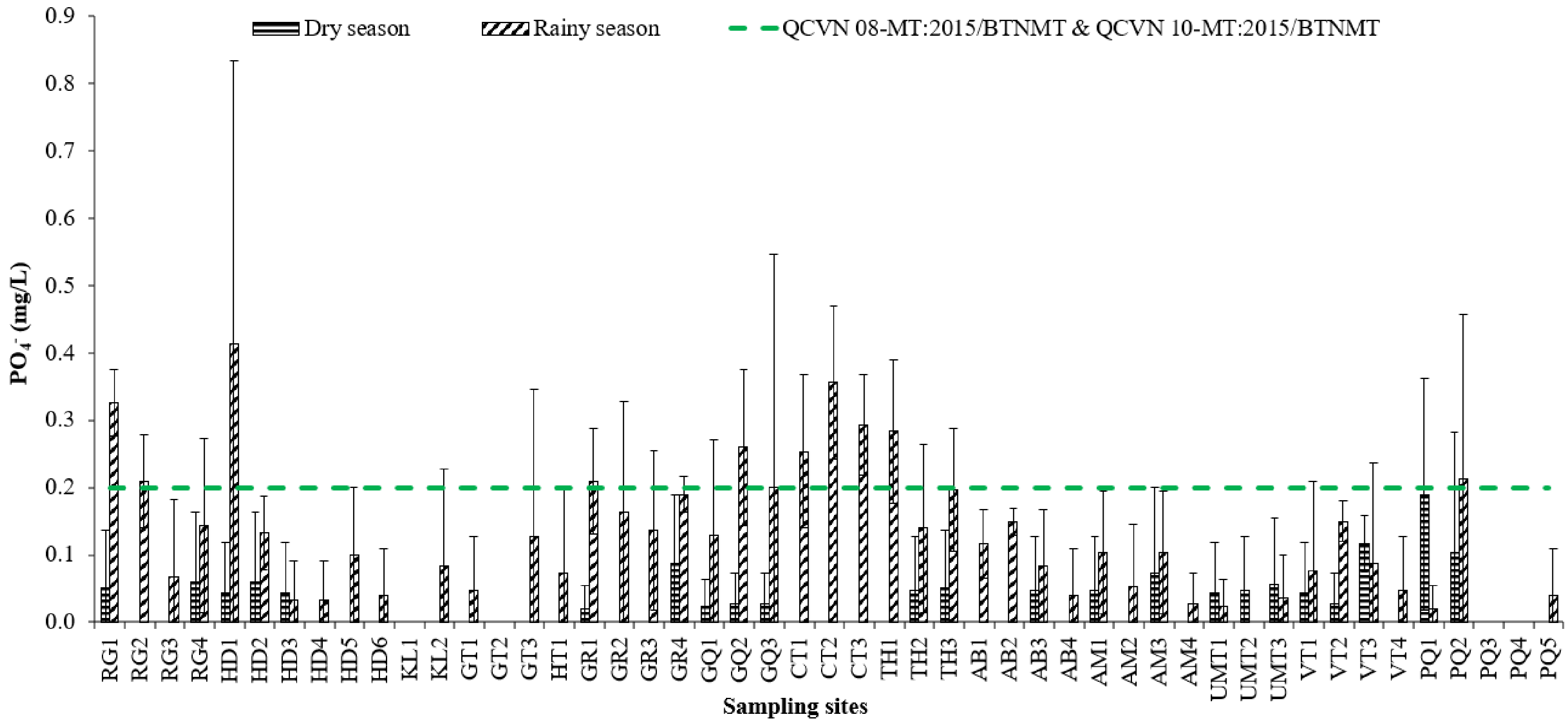

Fig.11 Seasonal average P-PO_4^{3-} in the study period

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The results on the average Fe_t content in the research area are shown in Figure 12. The Fe_t content differs significantly between the two monitoring periods and is higher during the rainy than during the dry season. During the rainy season, alum is washed from the soil and into water bodies, which results in a tendency for increasing Fe_t concentration [18]. As a result, surface water has a greater Fe_t level during the rainy season. The greatest Fe_t concentration was discovered at site GR1, where dry season values were 1.99 ± 0.8 mg/L and rainy season values were 3.02 ± 0.79 mg/L. Sites PQ5 (0.08 ± 0.09 mg/L during the dry season) and PQ1 (0.47 ± 0.51 mg/L during the rainy season) had the lowest Fe_t values. In the dry season, 33/49 points exceed the legal limit of 0.5 mg/L while 18/49 points exceed the A2 permitted level of 1.0 mg/L by 1.99 to 3.98 times [12]. 48/49 points are 6.04 times above the marine water quality norm, while 38/49 points are over the surface water quality level (column A2) during the rainy season. The growth of aquatic plants and the carbon, nitrogen, and phosphorus cycles in the aquatic environment will be impacted by high Fe_t concentrations in the water [30]. Agricultural activities and washed alum have harmed the water bodies, increasing the Fe_t value in the aquatic environment [31].

Figure 13 shows that the average Cl^- concentration in the study area varies significantly depending on the season, with the dry season having a higher value than the rainy season. Site PQ4 had the highest Cl^- content during the dry season, measuring 15244.33 ± 1823.15 mg/L, and site HD2 had the lowest, measuring 24.0 ± 3.00 mg/L. With the highest value being 43.55 times the limit, 31/49 monitoring points are above the A2 acceptable limit of 350 mg/L [12]. Site VT2 had the highest Cl^- value of 2680.00 ± 3115.27 mg/L, while site GR1 had the lowest value of 11.67 ± 10.116 mg/L during the rainy season. As a result, 20/49 monitoring sites had values more significant than the benchmark, with the highest value being 7.65 times higher. High levels of Cl^- in water can contaminate surface water, harm aquatic life, and even leach into the groundwater, lowering the quality of drinking water [32]. Due to the similar saline intrusion condition, coastal districts including Kien Luong, Giang Thanh, An Bien, An Minh, Vinh Thuan, and Phu Quoc all have high Cl^- concentrations.

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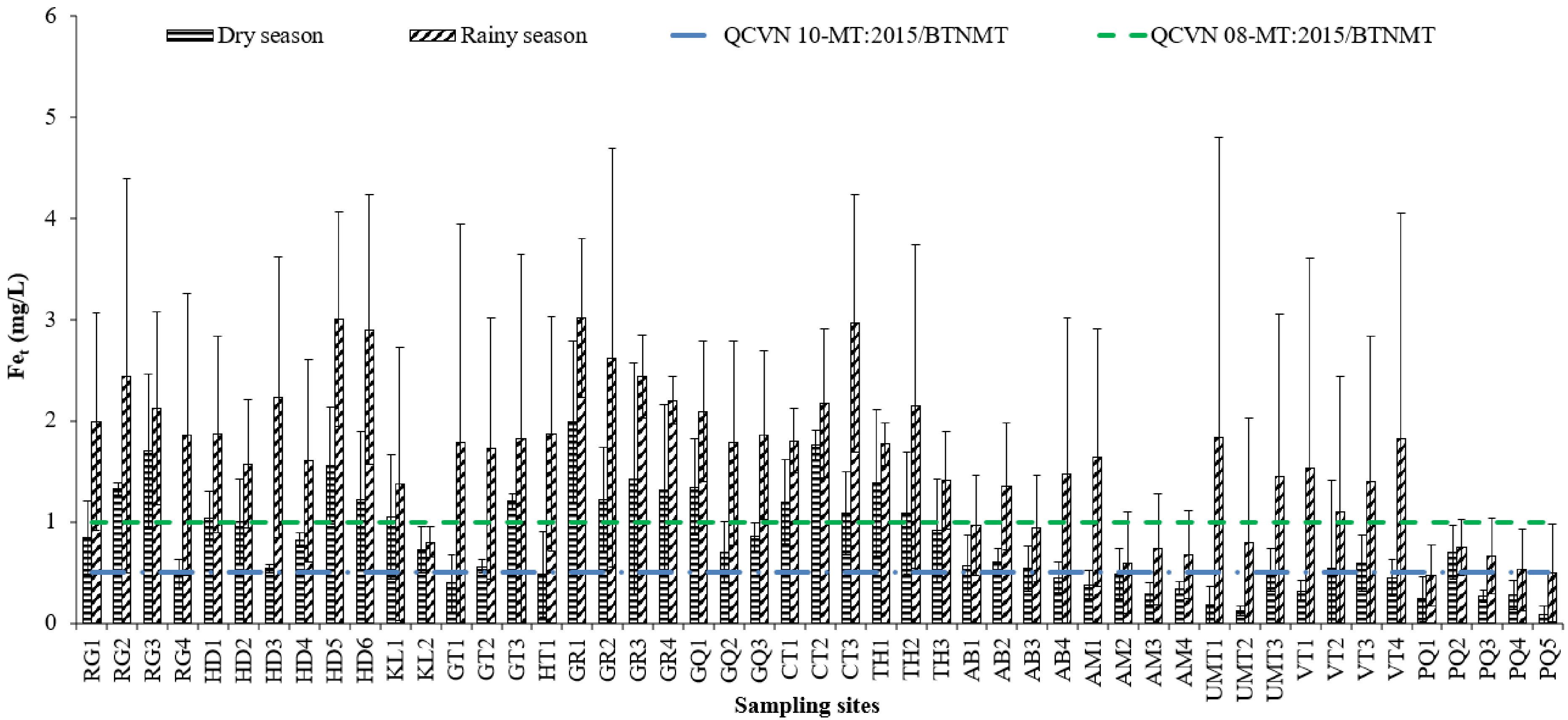

Fig.12 Seasonal average Fe_t in the study period

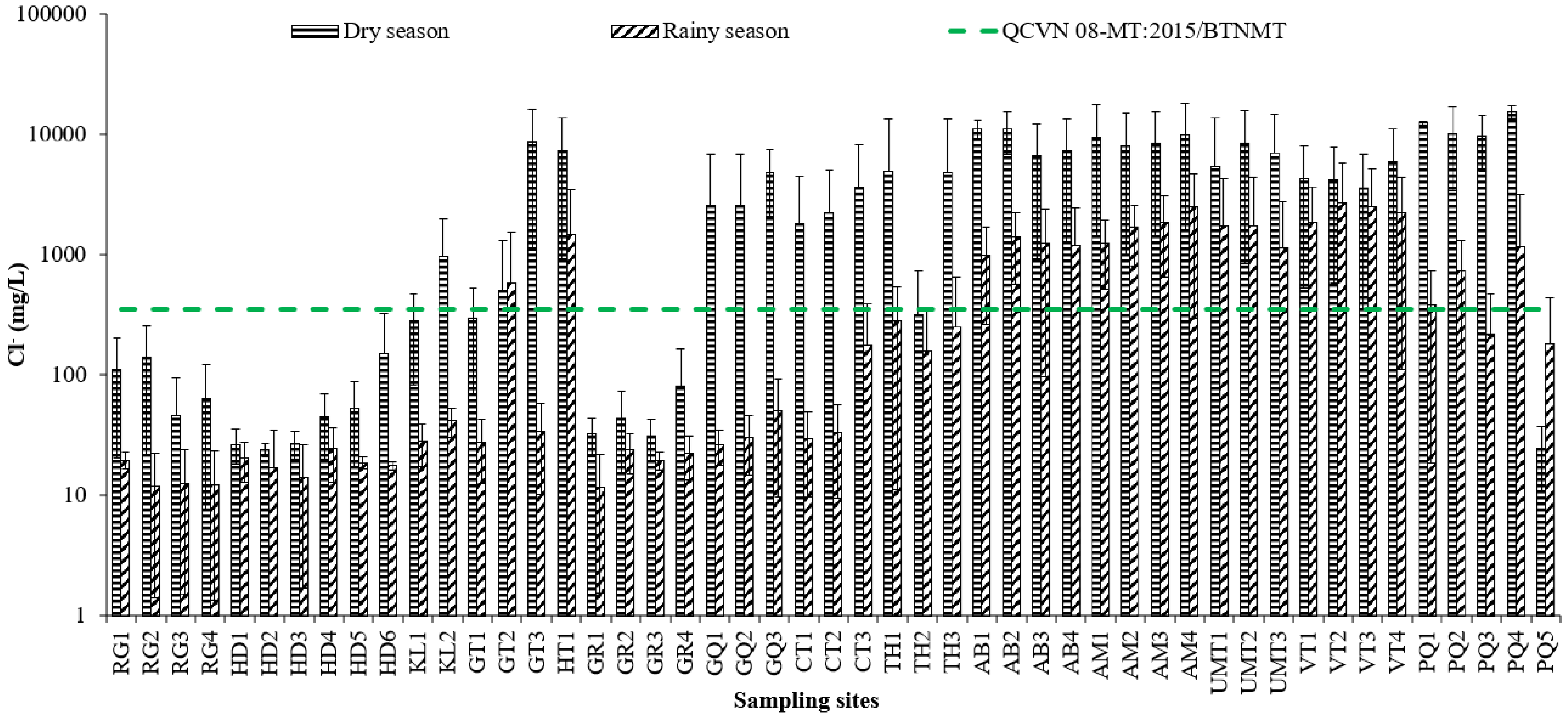

Fig.13 Seasonal average Cl^- in the study period

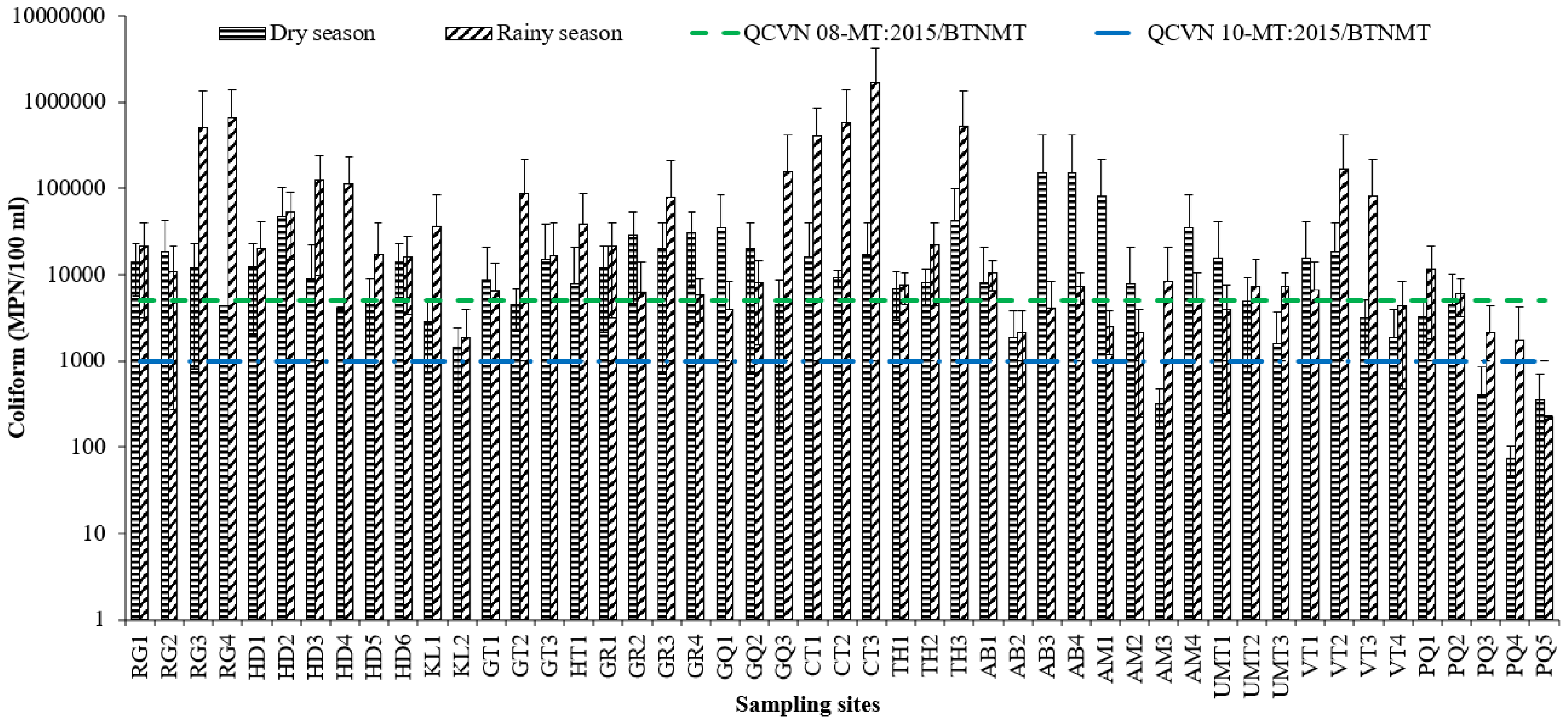

Fig.14 Seasonal average Coliform in the study period

The examination results of the usual Coliform content in the research region are shown in Figure 14. Between site AB4 to site PQ4, Coliform values ranged from 73.33 ± 28.87 MPN/100 mL during the dry season. While 32/49 monitoring points exceeded the permissible threshold of surface water quality standard (column A2, 5000 MPN/100 mL), 45/49 monitoring points exceeded the permitted barrier of marine water quality (1000 MPN/100 mL). Sites CT3 and PQ5 showed the highest and lowest Coliform concentrations of 1693666.67 ± 2526511.49 MPN/100 mL, 223.33 ± 11.55 MPN/100 mL, respectively throughout the rainy season. Therefore, according to national standards [12, 13], 38/49 and 48/49 sites are ineligible for Coliform permission. Coliform levels commonly exceed the allowable limit when domestic wastewater from residential areas is discharged into rivers, according to previous studies in the Mekong Delta [20, 31].

3.2 Key parameters affecting surface water quality

The results of the PCA analysis for the median value of 13 water quality metrics at 49 monitoring sites are shown in Table 2.

Table 2. Key parameters influencing water quality in the period 2019 - 2021

Parameters	Dry season					Rainy season			
	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4
T°	-0.107	-0.303	0.227	0.316	-0.170	-0.038	-0.243	-0.045	0.789
pH	0.429	0.067	0.195	-0.102	-0.054	-0.337	-0.244	-0.090	-0.148
TSS	-0.258	0.196	-0.264	-0.327	-0.385	0.205	-0.253	-0.255	-0.225
DO	0.067	0.222	0.163	-0.579	-0.300	0.306	0.083	0.194	0.444
BOD	-0.105	0.536	0.237	0.212	-0.075	-0.193	-0.439	0.360	0.007
COD	-0.066	0.526	0.250	0.260	-0.110	-0.225	-0.440	0.353	0.018
$N\text{-}NO_2^-$	-0.009	0.322	0.007	0.133	0.631	-0.430	-0.004	-0.251	0.165
$N\text{-}NO_3^-$	-0.474	-0.074	-0.251	-0.022	0.139	0.138	-0.314	0.368	-0.244
$N\text{-}NH_4^+$	0.267	0.270	-0.466	0.175	-0.122	-0.083	-0.263	-0.530	-0.003
Fe_t	-0.399	0.195	0.033	-0.037	-0.094	0.396	-0.244	-0.022	0.040
$P\text{-}PO_4^{3-}$	0.190	0.149	-0.636	0.094	-0.005	0.191	-0.384	-0.332	-0.071
Cl^-	0.473	0.010	0.084	0.025	-0.107	-0.474	0.042	-0.034	0.046
Coliform	0.055	0.102	0.048	-0.524	0.510	0.180	-0.217	-0.204	0.108
Eigenvalue	3.15	2.65	1.47	1.16	1.06	3.16	2.82	1.79	1.07
% variation	24.3	20.4	11.3	8.9	8.2	24.3	21.7	13.8	8.2
% cum. variation	24.3	44.6	56	64.1	73.1	24.3	46	59.8	68

With percentage fluctuations of 24.3%, 20.4%, 11.3%, 8.9%, and 8.2%, the results for the dry season showed that 5 major components (PC1 to PC5) explained 73.1% of the change in water quality. Each PCA's eigenvalue greater than 1.0 contains important data [33]. pH (0.429), $N\text{-}NO_3^-$ (-0.474), Fe_t (-0.399), and Cl^- (0.473) had weak correlations with PC1. Agriculture-related activities, alum contamination, and saline intrusion all impact this source. The potential alum layer has been impacted by agricultural farming activities such as plowing the soil and increasing the Fe_t concentration [34]. Additionally, according to study [31], Cl^- is a reliable indicator for highly salinized environments impacted by saline intrusion. In contrast to BOD_5 (0.536) and COD (0.526), PC2 describes the variance of T° (-0.303) and $N\text{-}NO_2^-$ (0.322) with a weak correlation. BOD_5 and COD indicate of an organic matter-polluted environment, while PC2 is where domestic, agricultural, and industrial output pollution comes from. Because excess fertilizers can drift down canals and increase the concentrations of $P\text{-}PO_4^{3-}$ and $N\text{-}NH_4^+$, PC3 has a moderate correlation with $P\text{-}PO_4^{3-}$ (-0.636) and a weak correlation with $N\text{-}NH_4^+$ (-0.466), demonstrating that agricultural activities can be the source of pollution [29]. T° (0.316) and TSS (-0.327) have little correlation with DO (-0.579) and Coliform (-0.524), both of which can be influenced by human and animal excretion [35]. $N\text{-}NO_2^-$ (0.631) and Coliform (0.510) contribute to PC5, while TSS (-0.385) and DO (-0.300) have weak correlations that can be impacted by agricultural operations, human and animal excretions, and other factors [29, 35].

PCA results explain the shift in water quality in Kien Giang province during the rainy season, which reveals 4 primary components (PC1 to PC4) with variations of 24.3%, 21.7%, 13.8%, and 8.2%, respectively. PC1 explains the changes of the following parameters with weak correlations: pH (-0.337), DO (0.306), $N\text{-}NO_2^-$ (-0.430), Fe_t (0.396), and Cl^- (-0.474). Similarly to results in the dry season, agricultural operations, alum washing, and seawater intrusion are the key factors affecting PC1. PC2 provides a poor correlation explanation for the variations of BOD_5 (-0.439), COD (-0.440), $N\text{-}NO_3^-$ (-0.314), and $P\text{-}PO_4^{3-}$ (-0.384), which are influenced by production activities in both agricultural and urban areas. PC3 exhibits a moderate connection with $N\text{-}NH_4^+$ (-0.530) but a poor correlation with BOD_5 (0.360), COD (0.353), $N\text{-}NO_3^-$ (0.368), and $P\text{-}PO_4^{3-}$ (-0.332). According to previous studies [24, 29], urban population, tourism services, agricultural production, and aquaculture are vital human activities contributing to this pollution source. A high connection with T° (0.789), controlled mainly by natural causes, but a weak association with DO (0.444), explains the unpredictability of water quality data.

The PCA results for both seasons show that a variety of factors including seawater intrusion, animal and human excretions, and main wastewater from household and agricultural processes, have an effect on the surface water quality in the study area. The main elements influencing surface water quality during the dry season are DO, BOD_5, COD, $P\text{-}PO_4^{3-}$, $N\text{-}NO_2^-$, and Coliform. However, during the rainy season, T° and $N\text{-}NH_4^+$ are the main factors affecting the surface water quality. The monitoring program for the province of Kien Giang's surface water quality must therefore contain the aforementioned components.

3.3 Key parameters affecting seasonal variation

The results of the DA between the dry and rainy seasons in the study area from 2019 to 2021 are shown in Table 3. The findings provide a discriminant function (DF1) that can distinguish between dry and rainy seasons in terms of water quality, with an Eigenvalue of 0.929. Wilk's Lambda analysis, which showed a 100% accuracy rate (Sig. = 0.000 < 0.05), revealed that the dry and rainy seasons were considerably different from one another. The Canonical correlation coefficient is equal to 0.4816, or $(0.694)^2$, shows 48.16% of the variance for the dependent variable. The normalization coefficient in statistical analysis contributes more to the function's discriminant ability the larger its absolute value, claimed by Pinto [36]. Table 3 lists the values of the variables that affect seasonal water quality.

DFs	1
T°	-0.015
pH	0.489
TSS	-0.289
DO	0.116

BOD_5	0.561
COD	-0.801
$N\text{-}NO_2^-$	-0.251
$N\text{-}NO_3^-$	0.605
$N\text{-}NH_4^+$	0.105
Fe_t	-0.157
$P\text{-}PO_4^{3-}$	-0.350
Cl^-	0.515
Coliform	-0.117
Eigenvalue	0.929
% of variation	100.0
Cum. %	100.0
Canonical Correlation	0.694
Wilks' Lambda	0.518
Sig.	0.000

The results also showed that the measurements of BOD_5, COD, $N\text{-}NO_3^-$, and Cl^- had a significant differences in water quality between the two seasons. Monitoring sites with higher contaminations during the rainy season have higher BOD_5, COD, and $N\text{-}NO_3^-$ concentrations than sites with higher contaminations during the dry season. The DA results support this notion, which was previously mentioned. The variation affects how the water quality varies throughout the season of the year. The concentration levels at the sampling sites such fluctuate over the dry and rainy seasons, similar to Cl^-. This discrepancy shows that during the dry season, saline instrusion has migrated deeper inland. The earlier studies [36, 37] reported BOD_5, COD, and $N\text{-}NO_3^-$ are also essential elements for evaluating seasonal water quality.

In contrast to this study, [38] showed that additional factors that affect seasonal water quality include pH and $N\text{-}NO_2^-$. It can be because of distinct regional variations in water quality. Therefore, the metrics BOD_5, COD, $N\text{-}NO_3^-$, and Cl^- must be included in the program for assessing the quality of the surface water in the province of Kien Giang.

4.0 CONCLUSION

According to the study, the province of Kien Giang's surface water quality decreased between 2019 and 2021 as a result of Coliform, iron, suspended particles, nutrients, and organic matter. The quality of the water is also impacted by saline intrusion. The surface water quality in the research area is unsuitable for the domestic water supply and the growth of aquatic species since the majority of water quality parameters are beyond the authorized limits of the national standard of surface water quality (column A2) and the national standard of marine water quality. In the study area, the concentrations of $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, and Cl^- were higher during the dry season than during the rainy season. On the other hand, during the more frequency rainy period, the levels of TSS, BOD_5, COD, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe_t, and Coliform increased.

While 68% of the change in surface water quality during the rainy season is attributed to four PCs, the change during the dry season is attributed to five PCs. The influences of T°, DO, BOD_5, COD, $N\text{-}NO_2^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, and Coliform have a significant impact on the surface water quality in Kien Giang province. The DA results demonstrate that the four significant parameters of BOD_5, COD, Cl^-, and $N\text{-}NO_3^-$ can explain the changes between the two seasons. For these measurements, the discrimination accuracy rating is a perfect of 100. In the study area, saline intrusion, domestic, agricultural, and industrial activities are the main sources of contamination. The study provides crucial data on the surface water environment in the province of Kien Giang for analysis and monitoring.

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