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Spatiotemporal Variation of Coastal Water Quality in Kien Giang Province, Vietnam Using Multivariate Statistical Methods

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Abstract

The study was carried out to assess coastal water quality using multivariate statistics. The coastal water samples were collected in the dry season (March) and wet season (September) in 2020 at eight districts, 26 positions (KG1-KG26). The parameters of temperature (T), pH, salinity (Sal), total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD), ammonium nitrogen ($N\text{-}NH_4^+$), phosphate ($P\text{-}PO_4^{3-}$), Coliform, iron (Fe), and silicon dioxide (SiO_2) were used for coastal water quality assessment using national technical regulation on marine water quality (QCVN 10-MT:2015/BTNMT), cluster analysis (CA) and principal component analysis (PCA). The results showed that seawater was contaminated with organic (low DO and high TSS in some locations), microbiological, nutrient ($N\text{-}NH_4^+$), and metal (Fe). The sea water environmental indicators have seasonal fluctuations in which DO, COD, $N\text{-}NH_4^+$, TSS in the dry season tended to be higher than those in the rainy season. Coliform in dry season and rainy season were similar. The average value of iron in the rainy season was higher than that in the dry season. COD and SiO_2 were low and not regulated in QCVN 10-MT:2015/BTNMT. In the dry season water quality was classified into six clusters while in the rainy season it was classified into four clusters demonstrating spatial and temporal variation of sea water quality. Seawater in the dry season was affected by three main sources while in the rainy season it was only affected by two main sources. The main indicators affecting water quality in the study area including $N\text{-}NH_4^+$, Coliform, $P\text{-}PO_4^{3-}$, TSS, Fe, COD, SiO_2. Further studies need to investigate specific sources that contribute to water quality indicators in order to have a solution to better manage sea water quality in the study area.

1. Introduction

Kien Giang is one of 13 provinces of the Mekong Delta. Kien Giang has administrative boundaries: Adjacent to An Giang in the Northeast; Can Tho and Hau Giang in the east; Bac Lieu in the Southeast; and Ca Mau in the South; bordering Cambodia in the North with a border length of 56.8 km and the Gulf of Thailand in the West with a coastline of more than 200 km [1].

Kien Giang is a coastal province with a rich and diverse coastal mangrove ecosystem, with great potential for development of agriculture - forestry, fisheries and tourism. In addition, the province

has an economy with potential land, hills, minerals, primeval forests, sea and islands, and many rare animal species in the undersea forest [1]. Besides, Kien Giang also has a very important position and role in socio-economic development, trade exchange and national security. In the past period, the socio-economic development of the province has made strong strides, creating a turning point in the realization of industrialization and modernization of the economy and actively contributing to the process of economic development. common development of the region and the whole country, achieved many great achievements, contributing to improving people's quality of life [1]. Kien Giang is a coastal province with a potential economy in terms of land resources, hills, minerals, primeval forests, sea and islands, and many rare animal species in the undersea forest. Besides, there is also a very important position and role in socio-economic development, trade exchange and security and defense [2].

In recent times, the province's socio-economic development has made strong strides, creating a turning point in the implementation of industrialization and modernization of the economy and actively contributing to the development process. region and the whole country [1]. With the advantage and important development potential of the marine economy, the marine economy in recent years has contributed 75.6% to the province's GDP, the average annual growth rate of the marine economy is about 69% [1]. The environmental quality of seawater in Kien Giang province is also under pressure from pollution [2-3]. Firstly, pressure due to population growth and urban development in coastal areas. Secondly, the pressure due to maritime activities generates wastewater from ships and marine vehicles, shipbuilding and repairing factories, seaports, yards and warehouses. Thirdly, the pressure caused by fishing and aquaculture generates wastes arising from fishing activities and the crew's daily life if they are not treated and discharged directly into the sea. Fourth, pressure from coastal industrial development through policies to strongly develop coastal industrial parks and clusters. Tourism is also an activity that causes pressure on the environment due to the operation of hotels, motels and tourism services [1-3]. Kien Giang has conducted coastal water environment monitoring under the guidance of the Law on Environmental Protection of Vietnam [4]. The Ministry of Natural Resources and Environment has guided the assessment of sea water quality using each individual parameter [5]. However, this assessment does not fully reflect the information contained in the dataset [6]. Currently, multivariate statistical methods are commonly used to assess water quality [6-9]. Multivariate statistical methods can be used to identify sources of pollution, the main criteria affecting water quality, and water quality subclusters [6-11]. Therefore, the multivariate statistical method is very useful for analyzing environmental monitoring data.

This study was conducted to use cluster analysis method and principal component analysis method to analyze monitoring data of sea water environment quality in Kien Giang province. The results provide information on the current state of sea water environment quality, key influencing indicators, potential pollution sources, water quality subclusters, contributing to the management of sea water environment quality in Kien Giang province.

2. Materials and methods

Kien Giang, a province located in the southernmost position of the country, has the greatest potential for marine economic development in the Mekong Delta, with a total natural area of 6,346 km²; there are 09 administrative units at the coastal and island district level; including 07 districts, towns and coastal cities and 02 island districts (Phu Quoc, Kien Hai). Has a coastline of more than 200 km; The sea area is more than 63,290 km² (ten times larger than the mainland), with about 137 large and small floating islands/island, of which 43 are inhabited, is the sea, has national boundaries in the West Sea, bordering Cambodia, Thailand and Malaysia. In this study, the coastal water samples

were collected in the dry season (March) and wet season (September) in 2020 at eight districts including Rach Gia (KG1-KG2), Ha Tien (KG3-KG4), Kien Luong (KG5-KG7), Hon Dat (KG8-KG10), An Bien (KG11-KG12), An Minh (KG13-KG15), Kien Hai (KG16), and Phu Quoc (KG17-KG26). The map of the sampling sites is presented in Figure 1. Water samples were collected to analyze the parameters of temperature (T), pH, salinity (S), total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD), ammonium nitrogen ($N\text{-}NH_4^+$), phosphate ($P\text{-}PO_4^{3-}$), Coliform, iron (Fe), and silicon dioxide (SiO_2). T, pH, salinity, DO were measured in the field while COD, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Coliform, Fe, SiO_2 parameters were measured in the laboratory by standard methods [12]. Methods of field measurements and laboratory analysis are presented in Table 1.

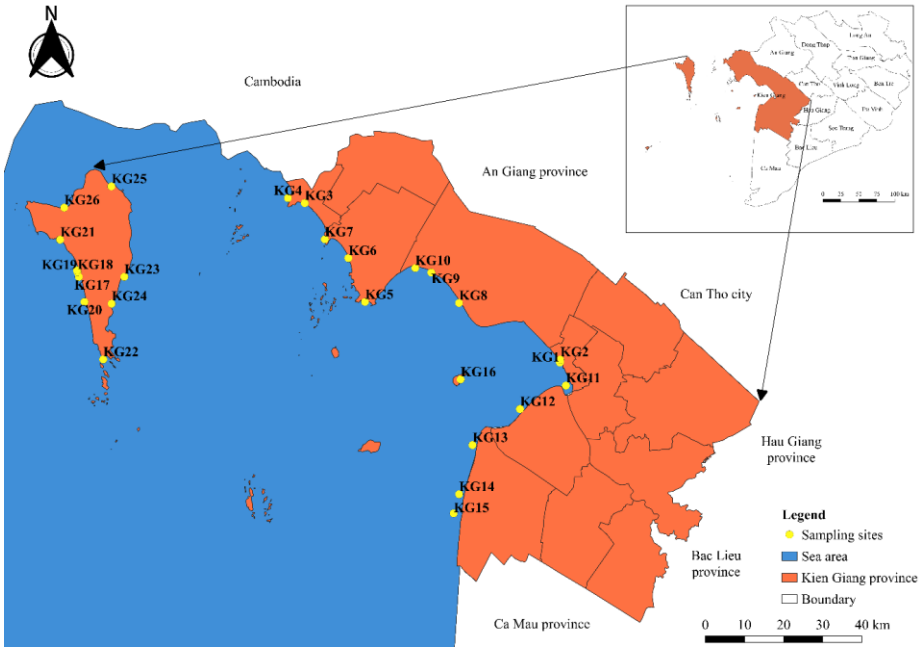

Figure 1. Map of the sampling sites

Surface water quality in the coastal area was assessed using national technical regulation on marine water quality (QCVN 10-MT:2015/BTNMT) [5] since the study areas are high salinity. The limit values of surface water quality are presented in Table 1. In addition, principal component analysis (PCA) and CA were used to identify potential polluting sources and key variables affecting water quality and classify surface water quality in the study areas. PCA and CA were performed using Primer Software Version 5.2.

Table 1. Analytical methods and limits of surface water quality

Variable		Unit	Analytical methods	Limit
Temp.	Temperature	^oC	TCVN 4557:1988	-
pH	pH		TCVN 6492:2011	6-5-8.5
Sal.	Salinity	‰	Salinometer	-
TSS	Total suspended solids	mg/L	SMEWW 2540B 2012	50
DO	Dissolved oxygen	mg/L	TCVN 7325:2004	≥ 5
COD	Chemical oxygen demand	mg/L	TCVN 6491:1999	-
$N\text{-}NH_4^+$	Ammonium	mg/L	SMEWW 4500 NH3 F 2012	0.1
$P\text{-}PO_4^{3-}$	Orthophosphate	mg/L	Hach DR 4000/5000 Method 8048	0.2
Coliform	Coliform	MPN/100 mL	TCVN 6197-2:1996	1000
Fe	Iron	mg/L	TCVN 6177:1996	0.5
SiO_2	Silicon dioxide	mg/L	Hach DR 4000/5000 Method 8195	-

3. Results and discussion

3.1. Evaluating surface water quality in the study area

The average temperature in coastal water in the dry season and the rainy season fluctuated between 28.0-32.0^{o}C and 27.1-29.7^{o}C, respectively (Figure 2). The seasonal variation between locations was low with the coefficients of variation between locations in the dry and rainy seasons being 3.31% and 3.43%, respectively. This temperature was in the range suitable for the growth of organisms in coastal waters [5].

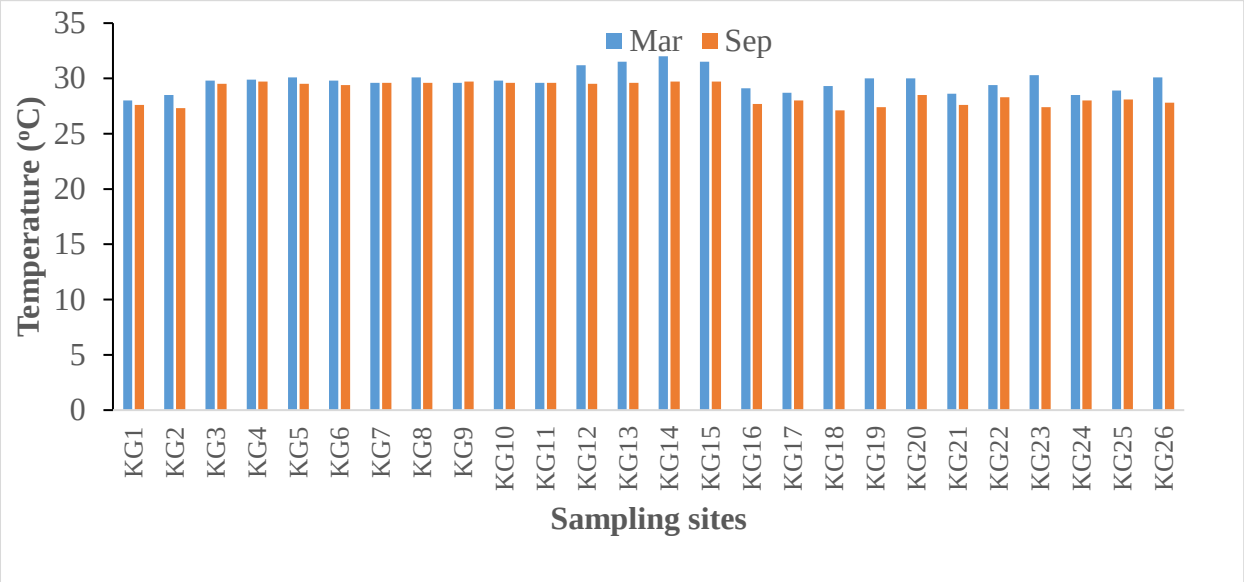

Figure 2. Temperature in surface water in coastal area

The average pH value in coastal water in the dry season and the rainy season fluctuated between 5.7-8.4 and 6.3-8.3, respectively (Figure 3). The variation of pH value in dry season (CV = 8.47%) was greater than that of pH in rainy season (CV=7.40%). The pH in coastal waters ranged from weak acid to alkaline. The pH in Kien Hai and Phu Quoc areas tended to be higher than that at other locations, even in the dry and rainy seasons.

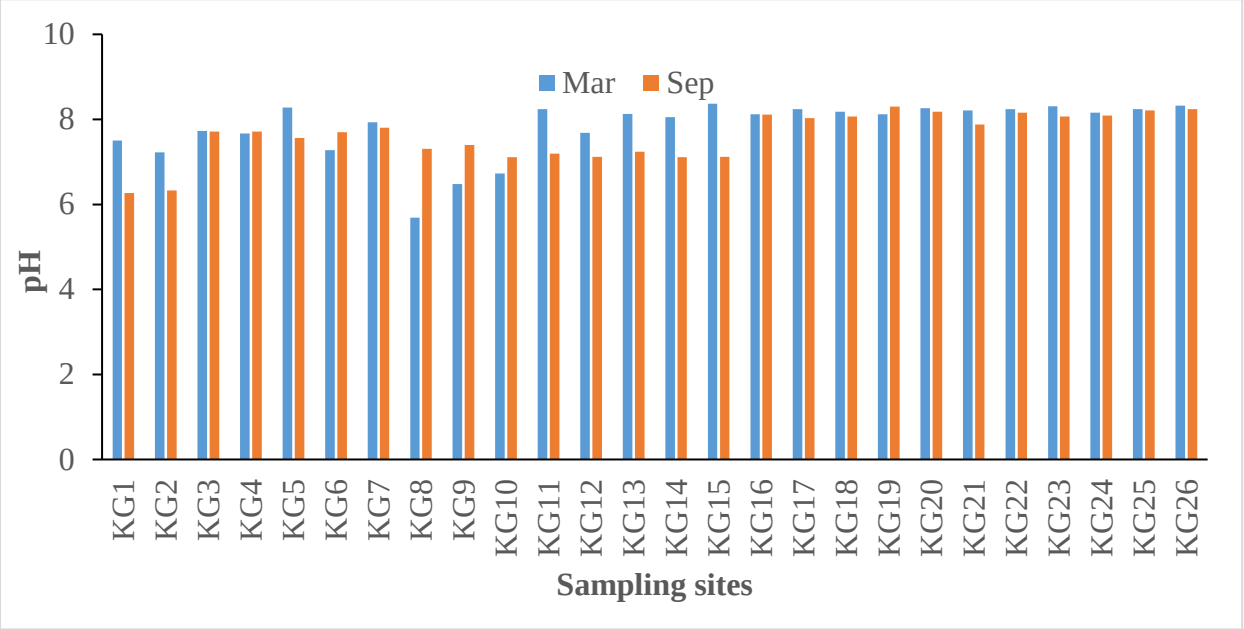

Figure 3. pH in surface water in coastal area

Salinity in coastal water in dry season and rainy season were in the range of 0.1-34.0 ‰ and 1.2-31.7 ‰, respectively (Figure 4). The variation of salinity in the dry season (CV = 39.2%) was lower than the value of salinity in the rainy season (CV = 42.0%). The lowest salinity was found in Rach Gia and the highest in Kien Hai and Phu Quoc. The salinity range in An Bien and An Minh fluctuated greatly between the dry season and the rainy season. The salinity at Ha Tien, Kien Luong, An Bien, Anh Minh, Kien Hai, Phu Quoc locations in the dry season was higher than that in the rainy season. However, the salinity in places like Rach Gia, Hon Dat in the rainy season was higher than that in the dry season.

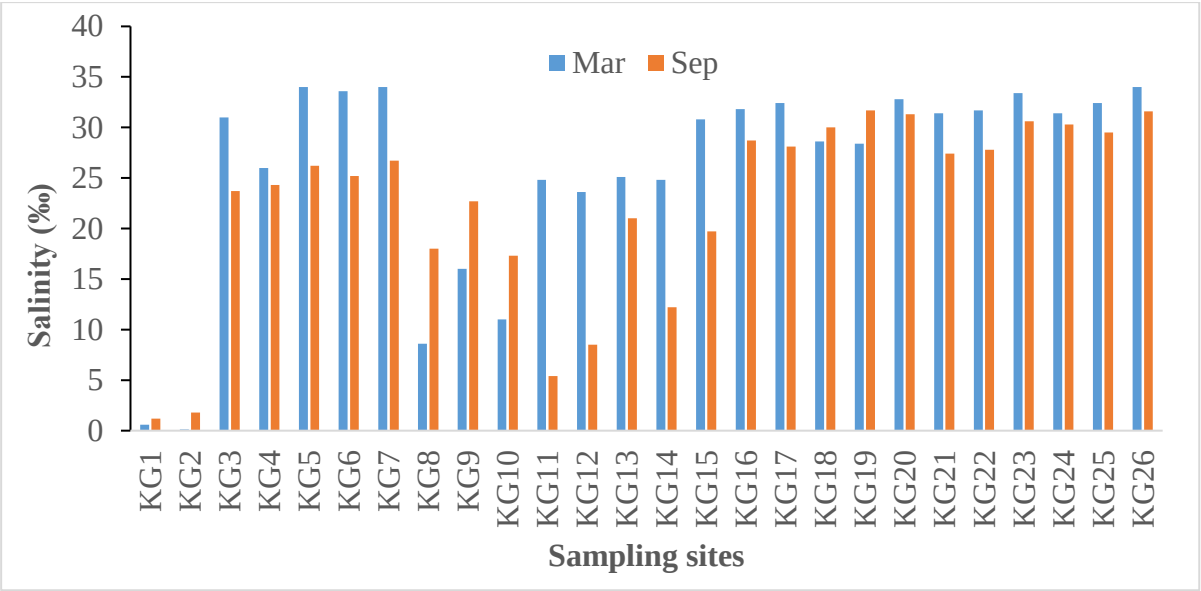

Figure 4. Salinity in surface water in coastal area

Total suspended solids (TSS) in coastal waters in the dry and rainy seasons ranged from 0-132 mg/L and 3-44 mg/L, respectively (Figure 5). TSS in the dry season and the rainy season fluctuated greatly

with coefficients of variation of 118% and 68.5%, respectively. TSS at positions KG2, KG6, KG10, KG12 in the dry season was higher than TSS at other locations. TSS at KG6, KG10 and KG12 exceeded the allowable limit (50 mg/L). TSS at sites KG16-KG26 was significantly higher than that at sites KG1 to KG15. TSS at KG25 and KG26 was lowest in both dry and rainy seasons. The average value of TSS in the study area in the dry season (29.9 mg/L) was significantly higher than in the rainy season (13.3 mg/L). The reason may be that phytoplankton grows better in the dry season, so TSS concentration in the dry season was higher than in the rainy season.

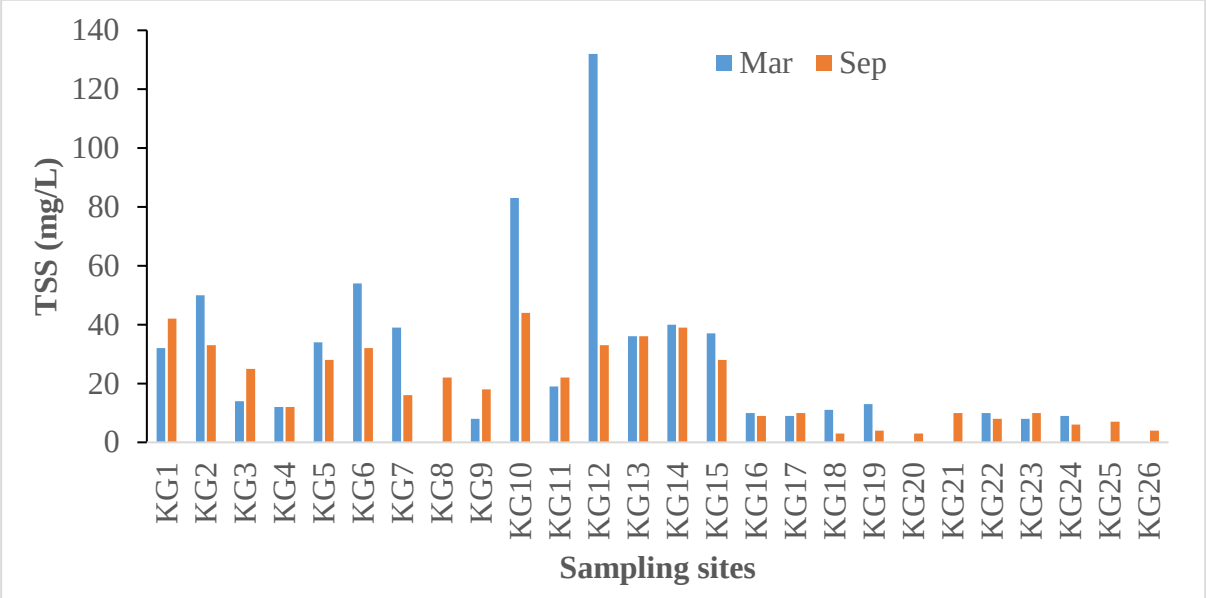

Figure 5. TSS in surface water in coastal area

Dissolved oxygen (DO) concentration in coastal water in dry season and rainy season fluctuated in the range of 3.7-6.1 mg/L (average 4.5 mg/L) and 4.1-7.4 mg/L (average 4.7 mg/L), respectively (Figure 6). The variation of DO in the dry season (CV = 11%) was lower than the value of DO in the rainy season (CV = 14%). The lowest DO was found at site KG14 (3.74 mg/L, dry season) and the highest at KG9 (7.40 mg/L, rainy season). The average DO value at the sampling sites in the districts was in the range of 4.1-4.8 mg/L in the dry season and 4.1-5.8 mg/L in the rainy season. DO at most locations was lower than the allowable limit of QCVN 10-MT:2015/BTNMT (≥ 5 mg/L).

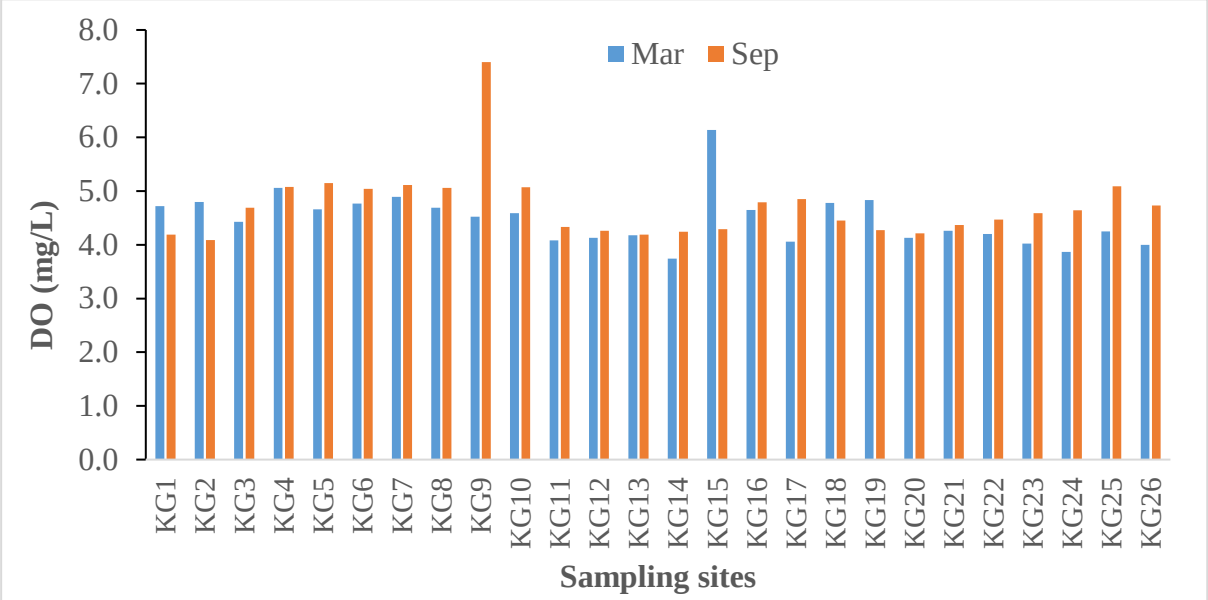

Figure 6. DO in surface water in coastal area

The chemical oxygen demand (COD) in coastal water in the dry season and the rainy season fluctuated between 3.8-26.4 mg/L (average 11.3 mg/L) and 0-21.1 mg/L (average 8.4 mg/L), respectively (Figure 7). The fluctuation of chemical oxygen demand in the dry season (CV = 52.4%) was lower than the value of chemical oxygen demand in the rainy season (CV = 73.1%). The lowest chemical oxygen demand was found at KG16-KG26 while higher COD was found at sites from KG1-KG15. The results showed that the impact of coastal economic activities on COD is very large. COD in dry season tended to be higher than COD in rainy season. This may be due to the presence of phytoplankton. In addition, it is possible that traffic and fishing activities take place more in the dry season, leading to different levels of impact on sea water quality. The average value of COD in Kien Hai, Phu Quoc was the lowest compared to COD in water bodies in other districts. The average COD value at the study sites in the dry season and the rainy season was 5.6-19.5 mg/L and 1.5-16.4 mg/L, respectively. COD at most locations was relatively low. COD is not specified in QCVN 10-MT:2015/BTNMT.

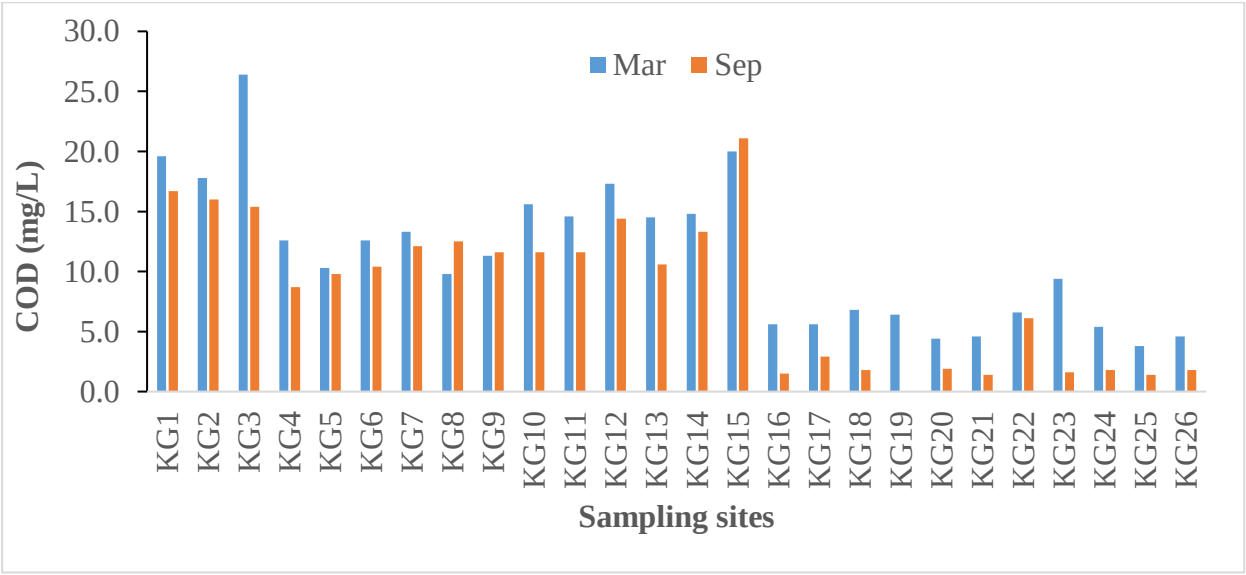

Figure 7. COD in surface water in coastal area

Ammonium ($N\text{-}NH_4^+$) in coastal water in dry season and rainy season fluctuated in the range of 0.0-13.8 mg/L (average 1.1 mg/L) and 0.0-1.5 mg/L (average 0.2 mg/L), respectively. L) (Figure 8). The volatility of ammonium during the dry season (CV = 295%) was significantly higher than that of the ammonium during the rainy season (CV=154%). The highest ammonium was found at KG8-KG10 during the dry season. $N\text{-}NH_4^+$ in dry season tended to be higher than $N\text{-}NH_4^+$ in rainy season. The average value of $N\text{-}NH_4^+$ in Rach Gia, Ha Tien and especially Hon Dat in the dry season was higher than in the rest of the locations and in the rainy season. $N\text{-}NH_4^+$ at most locations was higher than the limit value of QCVN 10-MT:2015/BTNMT (0.1 mg/L).

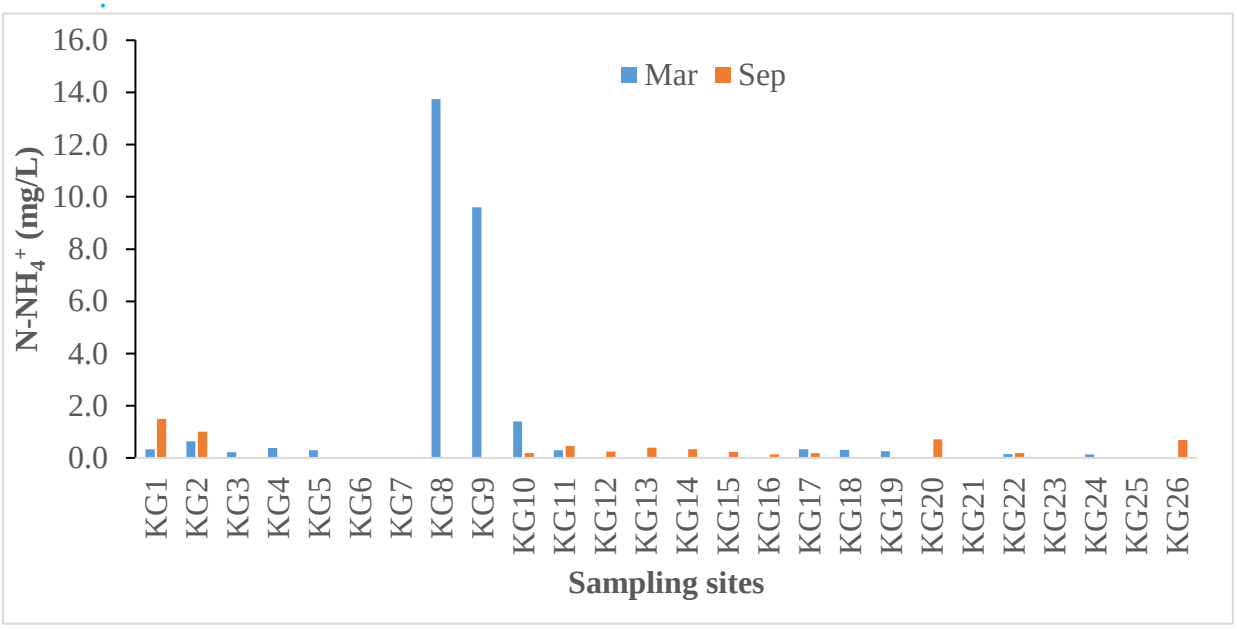

Figure 8. $N\text{-}NH_4^+$ in surface water in coastal area

Orthophosphate in coastal water in dry season and rainy season fluctuated in the range of 0-0.3 mg/L and 0-0.6 mg/L, respectively (Figure 9). Orthophosphate was found only at the KG1, KG2 and KG12 positions. Orthophosphate at site KG1 (rainy season and dry season) and at site KG2 (rainy season) were higher than the allowable limit of QCVN 10-MT:2015/BTNMT (0.2 mg/L). Orthophosphate at all remaining sites was below detection threshold (Figure 9).

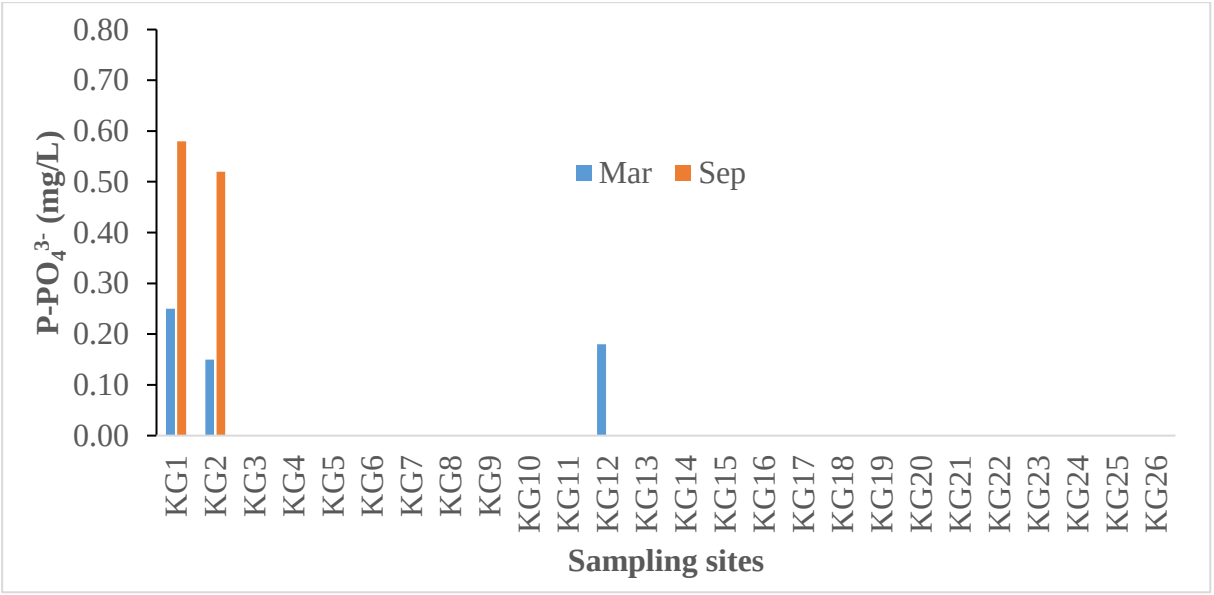

Figure 9. P-PO_4^{3-} in surface water in coastal area

Coliforms in coastal waters in the dry and rainy seasons ranged from 9-93000 MPN/100 mL and 7-93000 MPN/100 mL, respectively (Figure 10). The variation of coliform was very large even in the dry season (CV = 303.8%) and in the rainy season (CV = 303.9%). The lowest coliform was found in Kien Hai and Phu Quoc areas and the highest in Rach Gia. The average values of coliform in the dry and rainy seasons were similar. Coliforms at sites from KG1-KG15 were significantly higher than those at sites KG16-KG26. The average density of coliforms in the water bodies of Rach Gia, Ha Tien (dry season), Kien Luong (dry season), Hon Dat, An Bien, An Minh (rainy season) has exceeded the permitted limit of QCVN 10-MT:2015/BTNMT (1000 MPN/100 mL). The results showed that many areas have been contaminated with microorganisms.

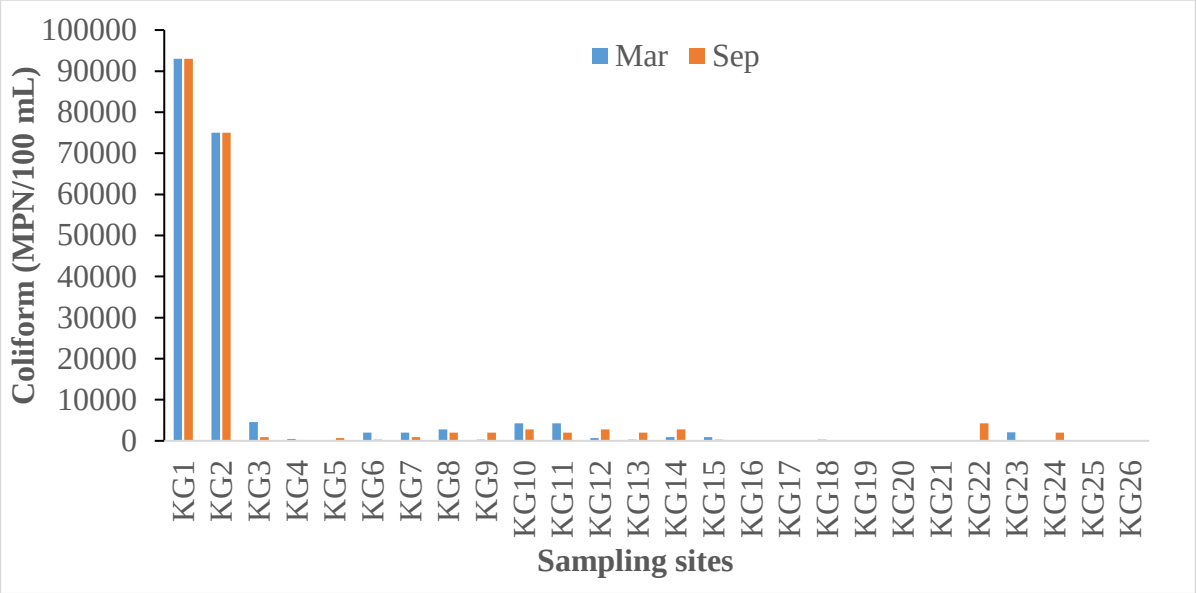

Figure 10. Coliform in surface water in coastal area

Iron (Fe) in coastal water in the dry season and the rainy season fluctuated in the range of 0.0-2.7 mg/L and 0.0-1.4 mg/L, respectively (Figure 11). The volatility of iron in the dry season (CV = 157%) was higher than the value of iron in the rainy season (CV = 89%). The iron in seawater at the KG1-KG15 position was significantly higher than the iron at the KG16-KG26 position. Iron in Kien Hai and Phu Quoc is lower than in other districts. The average value of iron in the rainy season (0.5 mg/L) was higher than that in the dry season (0.3 mg/L). Fe in most locations KG1-KG15 in the rainy season exceeded the allowable limit of QCVN 10-MT:2015/BTNMT (0.5 mg/L).

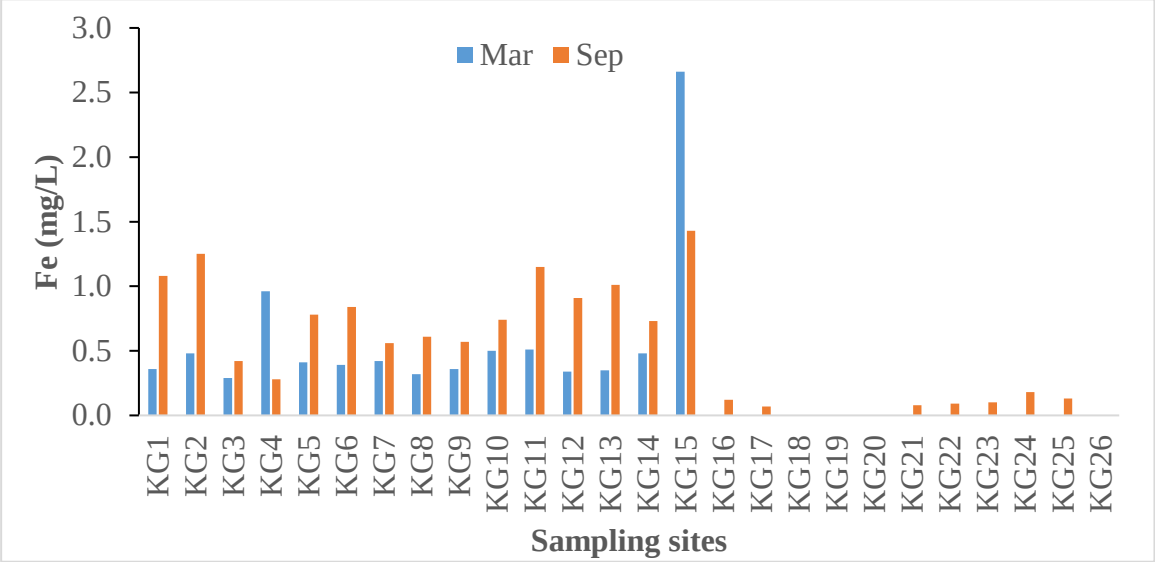

Figure 11. Fe in surface water in coastal area

SiO_2 in coastal water in dry season and rainy season fluctuated between 1.0-12.0 mg/L (average 4.5 mg/L) and 1.0-18.0 mg/L (average 4.7 mg/L) (Figure 12). The volatility of SiO_2 in the dry season (CV = 66%) was lower than the value of SiO_2 in the rainy season (CV=87%). The lowest SiO_2 was found in Kien Hai and Phu Quoc and the highest in Rach Gia, Hon Dat, An Bien and An Minh areas. SiO_2 is not regulated in QCVN 10-MT:2015/BTNMT.

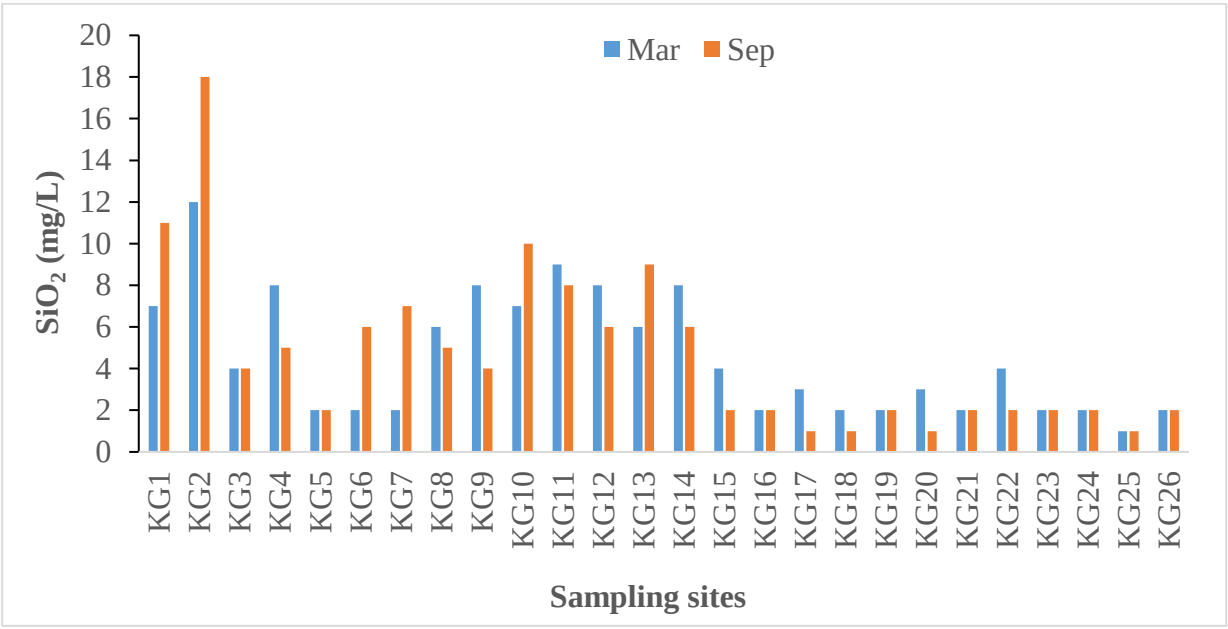

Figure 12. SiO_2 in surface water in coastal area

3.2 Spatial variation of surface water quality in the study area

The classification of coastal water quality in Kien Giang province by dry season and rainy season is presented in Figure 12 and Figure 13. Coastal water quality in the dry season was classified into six clusters (Figure 12). Cluster 2 includes positions from KG1-KG6 and the typical pollution indicators of the cluster are DO, $N\text{-}NH_4^+$, coliform and Fe (Table 2). TSS of cluster 1 has not

exceeded the allowed limit, but it is the cluster with the highest TSS. As can be seen, cluster 1 is the most polluted cluster of coastal areas in the dry season. Cluster 2 includes sites KG7 and KG8 with pollution characteristics due to N-NH_4^+, DO and coliform. N-NH_4^+ in cluster 2 was much higher than other clusters. Cluster 3 has only 1 position at KG18. Cluster 3 only has DO below the allowable limit and N-NH_4^+ above the allowable limit. Cluster 4 includes two positions KG14 and KG15. In this cluster, only Fe is above the allowable limit while the rest of the criteria are at the allowable level. However, TSS in cluster 4 is the highest compared to other clusters. Cluster 5 has only one KG21 site with pollution characteristics that only have a DO index lower than the allowable limit. Cluster 6 includes the remaining sites with pollution characteristics of low DO and high N-NH_4^+. Thus, in the dry season, seawater has indicators of DO, N-NH_4^+, Fe, coliform exceeding the allowable limits.

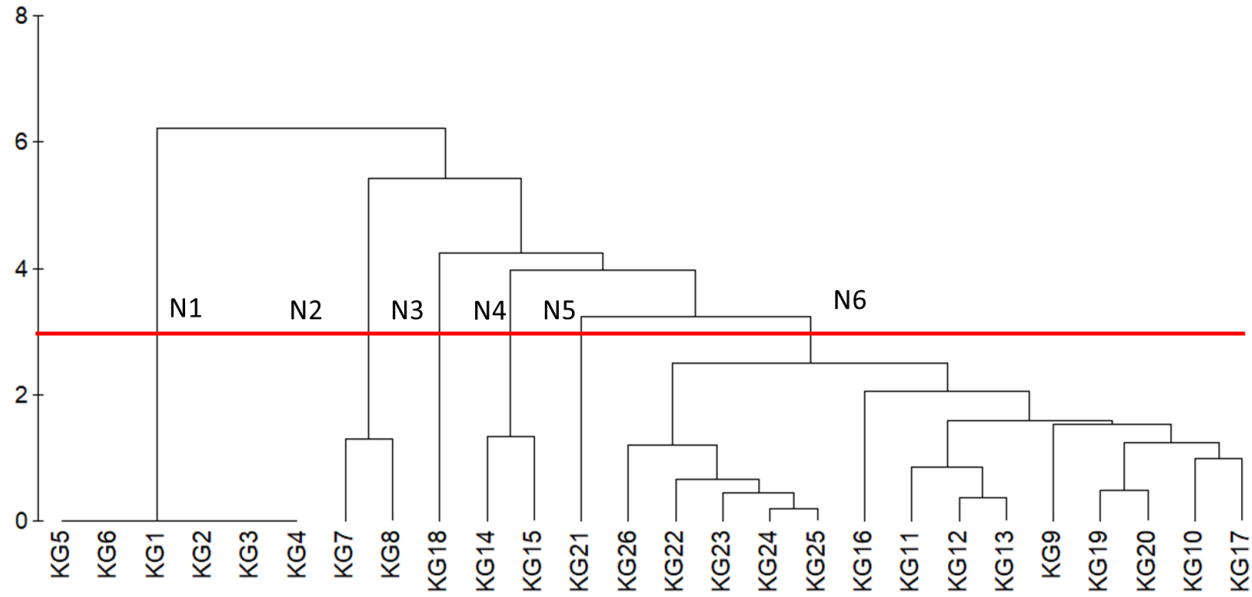

Figure 12. Spatial variation of surface water quality in dry season

Coastal water quality in the rainy season is classified into 4 clusters (Figure 13). Cluster 1 includes positions from KG1-KG6. This cluster is more polluted than other clusters because the indicators DO, N-NH_4^+, Fe, coliform all exceed the allowable limits. Cluster 2 includes 3 positions KG7-KG9, with the characteristic that coliform and Fe have exceeded the allowable limit. Cluster 3 includes 4 positions from KG23 to KG26. The water quality of cluster 3 is very clean, only the N-NH_4^+ indicator exceeds the allowable limit. Cluster 4 includes the remaining sites with pollution characteristics of coliform and N-NH_4^+. Similar to the dry season, the seawater in the rainy season has indicators of DO, N-NH_4^+, Fe, and coliform exceeding the allowable limits (Table 2). The results showed that water quality has large fluctuations in space and time.

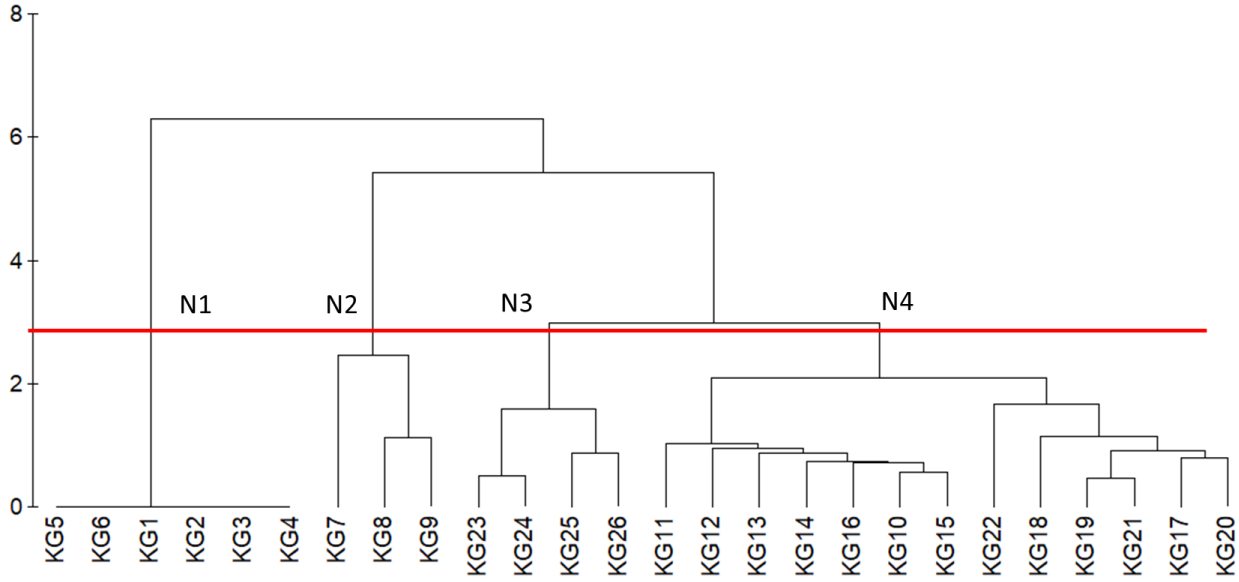

Figure 13. Spatial variation of surface water quality in wet season

Table 2. Values of water variables in the identified clusters

Variable	Dry season						Wet season				Limit
	N1	N2	N3	N4	N5	N6	N1	N2	N3	N4	
Temp.	29.4	29.9	29.3	31.8	28.6	29.8	28.83	29.63	27.83	28.64	-
pH	7.6	6.8	8.2	8.2	8.2	7.9	7.21	7.50	8.15	7.66	6-5-8.5
Sal.	20.9	21.3	28.6	27.8	31.4	27.8	17.07	22.47	30.50	22.24	-
TSS	32.7	19.5	11.0	**38.5**	0.0	24.1	28.67	18.67	6.75	19.15	50
DO	**4.7**	4.8	4.8	4.9	4.3	4.3	4.71	5.86	4.76	4.45	≥ 5
COD	16.6	11.6	6.8	17.4	4.6	8.9	12.83	12.07	1.65	7.55	-
$N\text{-}NH_4^+$	**0.3**	**6.9**	**0.3**	0.0	0.0	**0.9**	**0.42**	0.00	**0.17**	**0.23**	0.1
$P\text{-}PO_4^{3-}$	0.1	0.0	0.0	0.0	0.0	0.0	0.18	0.00	0.00	0.00	0.2
Coliform	**29196**	**2400**	280	900	9	882	**28348**	**1633**	550	**1312**	1000
Fe	**0.5**	0.4	0.0	**1.6**	0.0	0.1	**0.78**	**0.58**	0.10	0.49	0.5
SiO_2	5.8	4.0	2.0	6.0	2.0	4.2	7.67	5.33	1.75	4.00	-

3.3 Identifying key variables influencing water quality in the study area

The results show that coastal water quality in the dry season was influenced by three main components PC1-PC3, which explains 80.5% of water quality variation. The PC4-PC7 subcomponents explain 18.4% of the water quality variation (Table 3). PC1 caused slight fluctuations to the parameters of temperature, pH, DO, COD and SiO_2. PC2 had a weak effect on salinity parameters while moderate impact on $P\text{-}PO_4^{3-}$ and coliform. PC3 has a weak effect on TSS but a strong effect on Fe. PC5 mainly affects TSS and has little effect on coliform. PC6 has a weak effect on $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$ while having a significant effect on SiO_2. PC7 has a strong effect on COD and a weak effect on SiO_2. Thus, the main indicators affecting water quality in the dry season include $N\text{-}NH_4^+$, Coliform, $P\text{-}PO_4^{3-}$, TSS, Fe, COD, SiO_2 because the load coefficient fluctuates from medium to strong.

Table 3. Key variables influencing surface water quality in dry season

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Temp.	-0.411	0.154	-0.090	0.202	0.002	0.017	0.080
pH	-0.402	0.173	0.028	0.254	0.116	-0.017	0.149
Sal.	-0.265	0.468	0.213	0.208	0.057	0.117	-0.022
TSS	-0.267	-0.171	0.345	-0.140	-0.742	0.200	0.053
DO	-0.409	0.140	-0.097	0.099	0.150	0.214	0.116
COD	-0.387	-0.100	0.025	-0.198	0.029	-0.169	-0.865
$N\text{-}NH_4^+$	-0.041	0.017	-0.855	-0.025	-0.253	0.365	-0.095
$P\text{-}PO_4^{3-}$	-0.164	-0.556	0.136	0.169	-0.024	0.397	0.127
Coliform	-0.139	-0.548	-0.024	0.176	0.476	0.068	-0.022
Fe	-0.232	0.064	0.032	-0.848	0.297	0.197	0.264
SiO_2	-0.330	-0.235	-0.254	-0.064	-0.174	-0.733	0.334
E.val.	5.29	2.33	1.24	0.86	0.66	0.31	0.19
%Var.	48.1	21.2	11.2	7.9	6.0	2.8	1.7
C.%Var.	48.1	69.3	80.5	88.4	94.4	97.2	*98.9*

In the rainy season, only two main components PC1 and PC2 have major impacts on water quality, explaining 84.3% of water quality variation. The PC3-PC7 sub-sources explain 14.8% of the water quality variation. The parameters Fe, COD, SiO_2, TSS, salinity are the main indicators affecting water quality. The results show that water quality in the dry season fluctuated more than in the rainy season.

Table 4. Key variables influencing surface water quality in wet season

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Temp.	-0.341	-0.292	-0.114	0.007	0.025	-0.032	-0.283
pH	-0.309	-0.333	-0.236	0.025	0.026	-0.046	-0.280
Sal.	-0.091	-0.503	-0.309	-0.228	0.167	-0.002	0.659
TSS	-0.364	0.007	0.332	0.062	-0.166	-0.786	0.264
DO	-0.311	-0.324	-0.184	0.129	-0.070	0.129	-0.248
COD	-0.357	0.007	0.326	0.556	0.129	0.270	0.116
$N\text{-}NH_4^+$	-0.278	0.347	-0.159	-0.423	0.437	-0.252	-0.325
$P\text{-}PO_4^{3-}$	-0.238	0.399	-0.383	-0.056	0.125	0.168	0.373
Coliform	-0.236	0.376	-0.388	0.457	-0.047	-0.032	0.074
Fe	-0.338	0.031	0.511	-0.268	0.375	0.357	0.104
SiO_2	-0.346	0.155	0.042	-0.395	-0.757	0.264	0.033
E.val.	6.09	3.18	0.84	0.34	0.22	0.14	0.09
%Var.	55.4	28.9	7.6	3.1	2.0	1.3	0.8
C.%Var.	55.4	84.3	91.9	95.1	97.1	98.3	99.1

4. Conclusion

The results show that the sea water temperature was within the allowable limit and there was little seasonal variation. The pH in coastal waters ranges from weak acid to alkaline. The pH in Kien Hai and Phu Quoc areas tended to be higher than that at other locations, even in the dry and rainy seasons. The lowest salinity was found in Rach Gia and the highest in Kien Hai and Phu Quoc. Salinity fluctuations varied widely between sampling areas. TSS at some locations (KG6, KG10 and KG12) exceeded the allowable limit. DO at most locations was lower than the allowable limit of QCVN 10-MT:2015/BTNMT. COD at most locations was relatively low and not regulated in QCVN 10-MT:2015/BTNMT. The highest ammonium was found at KG8-KG10 during the dry season. DO, COD, $N\text{-}NH_4^+$, TSS in dry season tended to be higher than that in rainy season.

Orthophosphate was found only at the KG1, KG2 and KG12 positions. Orthophosphate at site KG1 (rainy season and dry season) and at site KG2 (rainy season) were higher than the allowable limit of QCVN 10-MT:2015/BTNMT. The lowest coliform was found in Kien Hai and Phu Quoc areas and the highest in Rach Gia. The average values of coliform in the dry and rainy seasons were similar. The findings showed that many areas have been contaminated with microorganisms. The average value of iron in the rainy season was higher than in the dry season. Fe in most locations KG1-KG15 in the rainy season exceeded the allowable limit of QCVN 10-MT:2015/BTNMT. The lowest SiO_2 was found in Kien Hai and Phu Quoc and the highest in Rach Gia, Hon Dat, An Bien and An Minh areas. SiO_2 was not regulated in QCVN 10-MT:2015/BTNMT. The results of cluster analysis showed that water quality fluctuated in space and time. In the dry season water quality was classified into six clusters while in the rainy season it was classified into four clusters. DO, $N\text{-}NH_4^+$, Fe, coliform in identified clusters in two seasons exceeded the allowable limit. PCA showed that seawater in the dry season was affected by three main sources while in the rainy season it was only affected by two main sources. The main indicators affecting water quality in the study area included $N\text{-}NH_4^+$, Coliform, $P\text{-}PO_4^{3-}$, TSS, Fe, COD, SiO_2. Further studies need to investigate specific sources contributing to water quality indicators in order to have a solution to better manage sea water quality in the study area.

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