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Assessment of Surface Water Quality and Monitoring in Southern Vietnam Using Multicriteria Statistical Approaches

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Abstract

The study was conducted to analyze water quality fluctuations in the South of Vietnam using monitoring data at 58 locations, measured 8 times per year, analyzing 16 water quality indicators in 2020. The study has used national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT, column A1), water quality index (WQI), cluster analysis (CA), principal component analysis (PCA) and Entropy weighted methods to analyze surface water quality. The results showed that the water quality was contaminated with organics (low DO while TSS, BOD, COD was high), nutrients (mainly $N\text{-}NH_4^+$) and Fe. Pb at some locations exceeded the allowable limit. Cd, Hg and As were within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1. DO, TSS, BOD, COD, $N\text{-}NH_4^+$, Fe, EC, TDS, Cl^- were seasonally fluctuated. WQI classified water quality from bad to very good (WQI=42-100) due to the impact of hydrological conditions, navigation, wastewater and waste from industrial zones, and fishing ports. The findings presented that it is possible to reduce the 11 sampling locations of cluster 1-6, reduce the frequency of monitoring from 8 to 5 times per year, while still ensuring representativeness of water quality over time, reducing the monitoring costs by 56.5%. The PCA identified five major potential sources explaining 87.3% and 8 minor sources explaining only 12.7% of water quality variation. Temperature, pH, EC, DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, Fe, Cl^-, Pb need to be monitored, while adding indicators $P\text{-}PO_4^{3-}$, TP, TN, coliforms into the future monitoring program. The study shows that the medium and bad water quality are concentrated in Dong Nai, Ho Chi Minh City and Long An, so the relevant environmental management agencies needs to find solutions to improve the water quality in those areas. The current results can assist in decision-making related to environmental quality monitoring in the southern region of Vietnam.

1. Introduction

Water plays an important role for organisms and humans. Therefore, regular water quality monitoring is considered a top priority for all countries in the world [1, 2]. Monitoring water quality not only helps countries assess and predict pollution, but also provides information for planning sustainable use of water resources [3–5]. Vietnam conducts annual environmental monitoring of surface water, underground water and sea water in service of environmental management. The task of monitoring the water environment is assigned to the Ministry of Natural Resources and Environment and the People's Committees of 63 provinces and cities. Water environment monitoring is also carried out by production and business establishments in accordance with the current environmental protection law [6]. Physical, chemical and biological indicators are used in environmental monitoring in water bodies in Vietnam. The physical and chemical parameters include temperature, pH, total suspended solids (TSS), turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia ($N\text{-}NH_4^+$), orthophosphate ($P\text{-}PO_4^{3-}$), heavy metals (Fe, Al, Mn, Cr, Cd,...), chloride (Cl^-), sulfate (SO_4^{2-}), pesticides, antibiotics, and biological factors (E. coli, coliform) [7]. Monitoring results are evaluated using national technical regulations on surface water quality or using water quality and water quality index (WQI) [7–9]. These assessment methods are currently still simple, using only one or a few criteria included in the assessment of water quality, thus not fully exploiting the important information hidden in the very large dataset [5,9–11]. Currently, multivariate statistical methods are widely used in water quality assessment. Multivariate statistical methods can include all the water quality information in the calculation at the same time, thus extracting a lot of important information from the dataset [5, 11–14]. Multivariate statistical methods including cluster analysis (CA), principal component analysis (PCA) methods were used to assess the quality of rivers, lakes and groundwater water [10,13,15–19]. The water quality clustering analysis method is based on the similarity of water quality in space and time and can therefore be used to assess sampling locations and sampling frequencies [5, 9–11]. In addition, entropy weight was also used to measure the importance of key parameters in each cluster of CA analysis over time and to find out the key parameters causing the differences between clusters [15,20]. Meanwhile, the principal component analysis method extracts important information about the criteria affecting the water quality and the potential sources of pollution leading to water quality fluctuations, from which it can be used to identify representative indicators to assess water quality

[5,10,11,14,17,21]. The southern region of Vietnam is a dynamic economic zone with a high economic growth rate, with the largest industrial, business and service development activities in the country, where many industrial parks are concentrated industrial clusters and many handicraft production establishments of different sizes and industries are widely dispersed in the localities. The development of industrial zones and clusters is not synchronized with the technical infrastructure conditions on the environment; many industrial zones and clusters have not yet been invested in a centralized wastewater treatment system [4]. Along with the socio-economic development, the water quality of the river system is increasingly declining due to receiving domestic and industrial wastewater, a part of urban, industrial and hazardous solid waste, water from agricultural production with fertilizer and pesticide content [4,17,22]. Therefore, it is necessary to monitor water quality in areas affected by socio-economic development activities. This study uses multivariate statistical analysis to analyze water quality fluctuations using data at 58 monitoring locations in the southern region of Vietnam. The research results provide useful information for the southern environmental management agency in reviewing and re-evaluating the effectiveness of the surface water quality monitoring system.

2. Materials And Methods

2.1 Water sampling and analysis

The southern region consists of 21 provinces/cities, including two major key economic regions, the southern key economic zone and the Mekong River Delta, and two river basins, namely the Dong Nai River and the Mekong River. This is a dynamic economic region with high economic growth rate, with the largest industrial, business and service development activities in the country, where many industrial parks, industrial clusters and clusters are located. Many industrial and handicraft production establishments of different sizes and industries are widely dispersed in the localities. Monitoring of surface water environment in the South was carried out at 58 locations including Binh Duong (6 locations, BD1-BD6), Binh Phuoc (4 locations, BP1-BP4), Ba Ria-Vung Tau (3 locations, VT1-VT3), Dong Nai (15 positions, DN1-DN15), Ho Chi Minh City (12 locations, HCM1-HCM12), Long An (4 locations, LA1-LA4), Tay Ninh (5 positions, TN1-TN5), An Giang (5 positions, AG1-AG5), Tien Giang (2 positions, TG1-TG2), Dong Thap (DT1) and Ben Tre (BT1). The sampling location is shown in Fig. 1. Water samples were collected eight times a year (Apr-Dec) using 16 indicators to assess the water quality. Water samples were collected according to the instructions of TCVN 5998:1995 (ISO 5667-9: 1992) and the preservation method was carried out according to the instructions of TCVN 5998:1995 and TCVN 6663-3:2016 (ISO 5667-3:2012). The parameters of pH, temperature, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS) were measured on the spot using multi-parameters YSI 6820, Hach HQ40d, Turb 430T-WTW of the USA and Germany. The measurement methods were carried out by directly immersing the electrodes in water, waiting for stability, reading the corresponding measured values from the screen of the intrusment and recording in the sampling log sheet. Total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), ammonium ($N\text{-}NH_4^+$), nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$), iron (Fe), lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As) and chloride (Cl^-) were measured in the laboratory using standard methods [23]. The measurement methods and allowable limits of water quality indicators are presented in Table 1.

Table 1
Methods for water analysis and limit values

No.	Parameter	Unit	Analytical methods	Limit values*
1	Temp.	^oC	SMEWW 2550B:2017	-
2	pH	-	TCVN 6492:2011	6-8.5
3	EC	$mS\ cm^{-1}$	SMEWW 2510.B:2017	-
4	TDS	$mg\ L^{-1}$	SCEM_01	-
5	DO	$mg\ L^{-1}$	TCVN 12026:2018	≥ 6
6	TSS	$mg\ L^{-1}$	SMEWW 2540.D:2017	20
7	COD	$mg\ L^{-1}$	SMEWW 5220.C:2017	10
8	BOD	$mg\ L^{-1}$	SMEWW 5210.B:2017	4
9	$N\text{-}NH_4^+$	$mg\ L^{-1}$	TCVN 6179-1:1996	0.3
10	$N\text{-}NO_2^-$	$mg\ L^{-1}$	SMEWW 4500-NO_2^-.B:2017	0.05
11	$N\text{-}NO_3^-$	$mg\ L^{-1}$	SMEWW 4500-NO_3^-.E:2017	2
12	Fe	$mg\ L^{-1}$	SMEWW 3111.B:2017	0.5
13	Pb	$mg\ L^{-1}$	SMEWW 3113.B:2017	0.02
14	Cd	$mg\ L^{-1}$	SMEWW 3113.B:2017	0.005
15	As	$mg\ L^{-1}$	SMEWW 3114.C:2017	0.01
16	Cl^-	$mg\ L^{-1}$	SMEWW 4500-Cl^-.B:2017	250

* National technical regulation on surface water quality (QCVN 08-MT:2015/BTNMT), column A1 used for water supply [7].

2.2 Data analysis

Evaluation of water quality characteristics was performed based on the average value of each criterion of 8 sampling periods at 58 locations and presented in Boxplot form to describe the change over time of the water quality parameters. The Kolmogorov-Smirnov test was used to test the normal distribution at 5% significance level using SPSS version 20.0.0 (IBM Corp., Armonk, NY, USA). The WQI index is calculated based on parameters including temperature, pH, DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, As, Cd, Pb according to the guidance of Decision 1460/QD-TCMT dated November 12, 2019 of the Viet Nam Environment Administration on the issuance of a manual for calculating the water quality index [8]. The WQI parameter has a value from 0 to 100. In which, a value from 91–100 presents very good water quality that is considered good for domestic water supply purposes; a value of WQI from 76 to 90 shows good water quality suitable for use for domestic water supply but need suitable treatment measures; WQI value between 51–75 shows average water quality to be used for irrigation and other equivalent purposes; WQI values from 26 to 50 shows bad water quality used for navigation and other equivalent purposes; WQI values from 10 to 25 shows poor quality so the water is heavily tarnished, needing treatment measures, water with a WQI value < 10 is water of very heavy quality, contaminated water, and needs to be remedied and treated. Geographic information system software QGIS version 3.16 was used to present the spatial distribution of the WQI. In this study WQI was calculated using Microsoft Excel 2016.

Cluster analysis (CA) was used in grouping water quality by sampling location and by sampling frequency, using Euclidean distance [10]. CA results are presented as a tree structure. Sampling locations or times with similar water quality is grouped into the same group based on the D_{link}/D_{max} linkage distance [11]. The link distance between clusters is considered to have clustering significance when $D_{link/}D_{max}\times100 = 60$ [11]. The water quality characteristics of each cluster in cluster analysis acorrding to the sampling frequency were weighted using the entropy information method to rank importance according to the method of Li et al. (2016) [24]. The larger the H_i information coefficient, the lower the entropy weight and the smaller the impact on water quality [24]. The higher the weight of the water quality parameters, the greater the influence, and conversely, the smaller the weighted value of the parameter, the less significant the influence [24]. Principal component analysis (PCA) was used to identify potential sources of pollution and key indicators affecting water quality in the southern region of Vietnam. Potential sources affecting water quality are determined based on the Eigenvalue coefficient. If the Eigenvalues coefficient is greater than 1, the impact source is considered the main source, lower than 1 is the secondary source [21]. Meanwhile, the weighted correlation coefficient is used to determine the main indicators affecting water quality. The weighted correlation coefficient is divided into three levels of high, moderate and weak, respectively, with absolute values > 0.75, 0.75 – 0.50 and 0.50 – 0.30 [10]. The higher the correlation coefficient, the major contributor to water quality variability and therefore needs to be monitored [10]. CA and PCA were performed using Statgraphics Centurion version XVI software (Statgraphics Technologies Inc.,Virginia state, USA).

3. Results

3.1. Evaluating surface water quality in Southern Vietnam

The temperature between months ranged from 25.3 to 35.3 ^{0}C, with an average of 30.1 ^{0}C (Fig. 2) while between locations fluctuated between 28.6–31.4 ^{0}C.The pH ranged over time and space between 5.2-9.0 and 5.9–7.9, with an average of 7.1 (Fig. 2). The pH at some locations was slightly alkaline, has exceeded the allowable limit of column A [7], but is still within the allowable range of column B1. EC and TDS fluctuated greatly (Fig. 2). EC at the sampling periods and locations fluctuated from 14.5–59,200 mS cm^{-1} and 38–47,400 mS cm^{-1}, respectively, reaching the average value at 5,387 mS cm^{-1}. Moreover, TDS fluctuated over time and space were 8–34,300 mg L^{-1} and 16.5–26,071 mg L^{-1}, respectively, averaging at 2,823 mg L^{-1}.

Dissolved oxygen (DO) concentration also fluctuated greatly by months and sampling sites in the range of 0.2–10.8 mg L^{-1} and 0.6–7.8 mg L^{-1}, respectively, with an average value of 4.6 mg L^{-1}. DO in the study area is lower than the permissible limit of QCVN 08-MT:2015/BTNMT, column A1 [7]. DO has great volatility in April and July (Fig. 2). Besides that, BOD at 58 survey sites varied from 1.6 to 48.8 mg L^{-1} while BOD between months of sampling ranged from 0–79 mg L^{-1}. BOD in the rainy season months fluctuated more than that in the dry season months (Fig. 2). BOD at most locations exceeded the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 [7]. Similar to BOD, COD between months and between sampling sites ranged from 7.6–91.4 mg L^{-1} and 3 to 139 mg L^{-1}, with mean values at 17.5 mg L^{-1}. COD has exceeded the allowable limit (10 mg L^{-1}) of QCVN 08-MT:2015/BTNMT, column A1 [7]. TSS at sites and months fluctuated from 9.1-110.5 mg L^{-1} and 3-495 mg L^{-1}, respectively, with an average of 36.3 mg L^{-1}. TSS has seasonal variation in which the rainy season is usually higher than that in the dry season. TSS at most locations exceeded the allowable limit (20 mg L^{-1}).

The concentration of N-NH_4^+ between the months of sampling fluctuated in the range of 0.98–24.94 mg L^{-1} while between the sampling sites was in the range of 0.07–15.02 mg L^{-1}, reaching an average value of 0.98 mg L^{-1}. N-NH_4^+ in the study area has great fluctuations in space and time. Limit value of N-NH_4^+ according to QCVN 08-MT:2015/BTNMT, column A1 is 0.3 mg L^{-1} [7]. $N\text{-}NO_2^-$ in water fluctuated in space and time with concentrations of 0-0.34 mg L^{-1} and 0-0.69 mg L^{-1}, respectively, with an average of 0.03 mg L^{-1}. In locations with high concentration of $N\text{-}NH_4^+$ and low DO, the nitrite concentration accumulated and exceeded the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (0.05 mg L^{-1}) [7]. $N\text{-}NO_3^-$ between sampling months and sampling sites ranged from 0-3.65 mg $L^{-1}$and 0.06–1.98 mg L^{-1}, with mean values at 0.8 mg L^{-1}. $N\text{-}NO_3^-$ was highest in locations such as Cat Lai ferry terminal (Dong Nai), Ho Chi Minh City area, Tan Thanh wharf (Long An) and Vedan Port (Tay Ninh). $N\text{-}NO_3^-$ in April was significantly higher than that in other months. The fluctuation of $N\text{-}NO_3^-$ concentration depends on the concentration of $N\text{-}NH_4^+$ and DO. The limit value of $N\text{-}NO_3^-$ according to QCVN 08-MT:2015/BTNMT, column A1 is 2 mg L^{-1} [7], so only some positions at certain times exceed the allowed regulation.

The maximum Fe concentration at the locations was 4.4 mg L^{-1} and at the time of sampling was 16.1 mg L^{-1}, averaged at 1.8 mg L^{-1}, all exceeded the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (0.5 mg L^{-1}) [7]. Iron in the rainy season tended to be higher than in the dry season (Fig. 2). High Cl^- concentration is concentrated in the area near the sea of Ho Chi Minh City (HCM1, HCM10-12) with concentrations exceeding the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (250 mg L^{-1}) [7]. The remaining positions all have Cl- concentrations within the allowable limits. Chloride has a marked seasonal variation in which the dry season is higher than that in the rainy season. The trend of chloride fluctuations is similar to that of EC and TDS. High chloride concentrations lead to high EC and TDS (Fig. 2). Lead (Pb) in the study areas was within the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (0.02 mg L^{-1}) [7], except for some locations such as Ong Buong bridge (HCM5 in May), lower Tri An Dam (BD6 in June) and Be River estuary (BP4 in June) exceed the allowable limit. Cd and As at all locations through the sampling sessions were within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1 [7].

The calculation results of water quality index in the study area are presented in Fig. 3. Water quality index in Binh Duong (WQI = 95–100) and Binh Phuoc (WQI = 91–99), An Giang (WQI = 94–100), Tien Giang (WQI = 92), Ben Tre (WQI = 92), Dong Thap (WQI = 95) indicated that the water quality in these provinces was classified as very good. Water quality in Tay Ninh is classified as good with WQI ranging from 76–96. The water quality in Dong Nai varied greatly and was graded from moderate to very good (WQI = 66–100). Locations with medium water quality included DN11, DN12, DN14 and DN15. Water quality in the Ho Chi Minh City area was divided into three classes, class with bad water quality (HCM1-HCM3, HCM5-HCM7), medium (HCM4, HCM8-HCM11) and good (HCM12). Meanwhile, water quality in Long An was classified bad (LA1-LA2), moderate (LA3) and good (LA4).

3.2 Evaluating the sampling sites and frequencies of the surface water quality monitoring

Water quality in the South of Vietnam varies greatly. The results of water quality classification into 15 clusters (Fig. 4). The water quality characteristics in the identified clusters are presented in Table 3. Cluster 1 has 3 positions (BD1-2, BP1); which was the locations in Binh Duong and Binh Phuoc provinces. In cluster 1, TSS, $N\text{-}NH_4^+$, COD, Fe exceeded the limit values of QCVN 08-MT:2015/BTNMT, column A1. Cluster 2 has 6 positions (VT1, DN3-6); cluster 3 has 6 positions (DN7-8, TG1-2, DT1, BT1). Clusters 2 and 3 have parameters TSS, DO, COD, Fe that do not meet the requirements of the allowable limits. These clusters mainly belong to Dong Nai, Tien Giang, Dong Thap, Ben Tre, Ba Ria-Vung Tau provinces. Likewise, Cluster 4 has 3 positions (BD4,6, BP4); cluster 5 has 10 positions (BD5, BP2-3, VT2-3, DN1-2, DN9-11); cluster 6 has 5 positions (AG1-5). TSS and Fe indicators in cluster 4 (locations in Binh Duong and Binh Phuoc provinces) exceeded the allowable limit; while BOD, COD, $N\text{-}NH_4^+$, Fe in cluster 5 (including locations in Binh Duong, Binh Phuoc, Dong Nai, Ba Ria-Vung Tau) exceeded the allowable limits. Cluster 6 (mainly An Giang) has only TSS and Fe criteria that do not meet the requirements of QCVN 08-MT:2015/BTNMT, column A1.

Cluster 7 (DN12-15, HCM8-9); cluster 8 has 1 position (LA3); cluster 9 has 2 positions (HCM10-11); cluster 10 has 4 positions (HCM1-4); cluster 11 has 1 position (LA2); cluster 12 has 1 position (HCM5); cluster 13 has 3 positions (LA1, HCM6-7); cluster 14 has 1 position (HCM12) and cluster 15 has 6 positions (LA4, TN1-TN5). Clusters 7–13 (including Long An, Dong Nai and Ho Chi Minh City) have TSS, DO, BOD, COD, $N\text{-}NH_4^+$, Fe all exceeding the requirements of QCVN 08-MT:2015/BTNMT, column A1. Particularly for cluster 12–13, organic and nutrient pollution are very serious, possi-bly because these places received more pollutants from wastewater and waste than the other locations. In addition, lead in cluster 12 was detected at concentrations reaching the limit of QCVN 08-MT:2015/BTNMT, column A1 [7]. TSS, DO, BOD, COD, Fe, Cl^- of cluster 14 (1 location in Ho Chi Minh City) have exceeded the allowable limits. Meanwhile, DO, COD, $N\text{-}NO_2^-$ characterize water quality in cluster 15 (locations in Tay Ninh province, only one location in Long An province.

Table 3
Water quality in the identified clusters

Cluster	Temp	pH	TDS	EC	TSS	DO	BOD	COD
1	28.79	7.21	20.71	43.74	48.46	7.04	3.71	11.50
2	29.38	7.12	144.39	289.21	25.34	5.19	3.79	11.69
3	30.06	7.32	828.94	1715.43	58.80	5.09	3.73	13.69
4	29.74	7.21	31.84	71.28	27.75	6.28	2.29	9.63
5	30.37	7.22	36.59	83.46	17.95	6.03	4.43	12.88
6	30.16	7.76	96.92	220.95	38.15	6.60	2.78	9.00
7	30.23	6.46	57.97	129.47	20.82	2.68	6.71	17.73
8	29.75	6.39	204.10	442.61	33.25	1.35	11.25	27.00
9	30.90	6.14	1481.15	3066.95	19.01	3.09	6.76	19.38
10	29.67	6.92	1647.96	3417.95	50.41	1.68	8.07	21.82
11	30.48	7.07	3495.75	6861.75	73.38	1.92	11.75	30.50
12	29.15	7.16	607.88	1236.63	97.13	0.68	48.88	91.38
13	29.99	7.20	1143.55	2387.33	80.71	0.77	22.25	46.55
14	31.43	7.19	8304.88	16101.80	80.00	4.71	6.75	32.63
15	30.81	7.44	21829.30	40967.00	18.40	5.21	2.48	12.07
Limits	-	-	-	-	20	≥ 6	4	10
Cluster	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	$N\text{-}NO_2^-$	Fe	Pb	Cd	As	Cl^-
1	0.30	0.61	0.00	3.37	0	0	0	6.63
2	0.28	0.96	0.01	1.91	0	0	0	57.72
3	0.23	1.10	0.02	2.54	0	0	0	11.21
4	0.19	0.76	0.01	1.94	0.01	0	0	2.19
5	0.55	0.57	0.00	1.48	0	0	0	7.04
6	0.26	0.41	0.00	1.90	0	0	0	10.11
7	0.76	0.70	0.02	1.56	0	0	0	24.38
8	1.90	0.47	0.01	4.38	0	0	0	0.00
9	0.60	1.10	0.03	0.97	0	0	0	1466.65
10	1.06	1.48	0.06	1.67	0	0	0	104.79
11	1.68	1.98	0.34	1.95	0	0	0	0.00
12	15.02	0.06	0.02	1.90	0.02	0	0	0.00
13	5.34	0.34	0.02	2.69	0	0	0	0.00
14	0.17	1.18	0.03	3.36	0	0	0	6119.38

Cluster	Temp	pH	TDS	EC	TSS	DO	BOD	COD
15	0.14	0.87	0.10	0.32	0	0	0	0.00
Limits	0.3	2	0.05	0.5	0.02	0.005	0.001	250

Water quality according to sampling periods was classified into 5 clusters (Fig. 5). Cluster 1 includes April; cluster 2 includes May and June; cluster 3 includes July and August; cluster 4 includes September; and cluster 5 includes November and December. The results show that the water quality fluctuates greatly over time in which the water quality in the dry season months tended to be separate from the rainy season months. Pollution characteristics according to identified clusters are presented in Table 4. Cluster 1 was characterized by indicators in descending order N-NH_4^+ > EC = TDS > Fe > BOD; cluster 2 by TDS > EC > N-NH_4^+ > N-NO_2^- > TSS = Pb. Cluster 3 was characterized by EC = TDS > N-NH_4^+ > Cl^-. Cluster 4 was characterized by EC = TDS > Cl^- > N-NH_4^+ while cluster 5 was characterized by EC = TDS > N-NH_4^+ > Cl^-.

Table 4
Weights of water quality parameters in the identified clusters

Parameters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Temp.	0.02	0.01	0.02	0.01	0.01
pH	0.02	0.01	0.00	0.00	0.01
TDS	0.16	0.17	0.22	0.24	0.23
TSS	0.06	0.08	0.06	0.05	0.07
EC	0.16	0.16	0.22	0.24	0.23
DO	0.02	0.01	0.01	0.01	0.02
BOD	0.09	0.05	0.05	0.04	0.07
COD	0.07	0.04	0.04	0.04	0.06
N-NH_4^+	0.19	0.15	0.14	0.13	0.15
N-NO_2^-	0.02	0.09	0.04	-	-
N-NO_3^-	0.05	0.04	0.02	0.02	0.03
Fe	0.11	0.04	0.04	0.04	0.02
Cl^-	0.02	0.07	0.13	0.17	0.12
Pb	-	0.08	-	-	-

3.3. Identifying key water parameters influencing water quality

The principal component analysis results show that water quality in the southern region of Vietnam is affected by many sources of pollution. In which, PC1-5 are considered the main source because it has an Eigenvalue > 1, explaining 87.3% of the variation in water quality. Meanwhile, the sources from PC6-13 as secondary explained only 12.7% of the variation (Table 5). The main PCs had weak correlations with the parameters of temperature, pH, TDS, EC, DO, BOD, COD, N-NH_4^+, N-

NO_2^-, Fe; had moderate correlations with pH, N-NH_4^+, N-NO_3^-, and a good correlation with Cl^-. Secondary PCs had moderate to good correlations with all parameters except Cl^- (Table 5).

The water quality indicators in the southern region are affected by many pollution sources. For example, temperature was affected weakly by three sources (PC2,5,6), and moderately by one source (PC7). pH was affected by 3 factors at weak level and 1 factor at medium level. EC and TDS were weakly affected by 2 factors and moderately affected by 1 factor. DO was weakly affected by PC1, 8, 9, and moderately by PC10. BOD was affected weakly by PC1 and strongly by PC12 while COD was weakly affected by PC1, PC12 but moderately affected by PC11. TSS was weakly affected by 1 factor, moderately affected by 3 factors (Table 5). N-NH_4^+ was moderately affected by PC11 but weakly affected by PC1, PC3, and PC12. Nitrate is moderately affected by PC3 but weakly affected by PC7 and PC9. N-NO_2^- was weakly affected by 4 factors, moderately affected by 1 factor. Fe was weakly affected by PC4, PC9 and moderately affected by PC7. Cl^- was strongly affected by PC7 and weakly affected by PC7.

Table 5
Potential polluting sources and key water parameters influencing surface water

PCs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Temp	-0.19	0.31	0.05	-0.23	0.44	0.40	0.55	-0.29	0.25	0.04	0.07	-0.01	0.00
pH	-0.16	-0.01	0.43	0.56	-0.05	0.40	-0.07	-0.15	-0.19	-0.50	0.02	0.00	0.00
TDS	-0.22	0.46	0.15	0.16	0.00	-0.42	-0.01	0.04	0.12	-0.02	0.01	0.02	0.71
EC	-0.22	0.46	0.14	0.17	0.00	-0.42	-0.01	0.04	0.12	-0.02	0.01	0.02	-0.71
TSS	-0.33	-0.25	0.24	0.26	0.11	0.23	-0.20	0.30	0.45	0.53	-0.13	0.04	0.00
DO	0.44	0.19	0.19	-0.06	-0.01	0.11	-0.09	0.07	0.18	-0.03	-0.05	0.82	0.00
BOD	0.43	0.23	0.12	-0.01	0.09	0.10	-0.09	0.10	0.19	-0.11	-0.68	-0.44	0.00
COD	0.32	0.05	-0.13	0.54	0.04	-0.07	0.13	-0.50	-0.18	0.53	-0.05	0.01	0.00
N-NH_4^+	0.42	0.17	0.30	-0.04	-0.04	0.11	-0.18	0.09	0.18	0.11	0.69	-0.37	0.00
N-NO_2^-	-0.07	0.16	-0.63	0.17	-0.21	0.21	-0.33	-0.23	0.50	-0.21	0.09	0.01	0.00
N-NO_3^-	-0.04	0.42	-0.27	0.14	-0.31	0.38	0.23	0.54	-0.33	0.19	0.01	0.00	0.00
Fe	0.24	-0.29	-0.18	0.40	0.18	-0.24	0.52	0.37	0.30	-0.27	0.13	-0.01	0.00
Cl^-	0.02	0.11	-0.25	0.11	0.78	0.02	-0.41	0.20	-0.28	-0.05	0.09	0.04	0.00
Eigen.	4.1	2.9	1.7	1.4	1.2	0.6	0.4	0.3	0.2	0.2	0.0	0.0	0.0
%Var.	31.8	22.4	13.2	10.5	9.3	4.6	3.1	2.1	1.5	1.2	0.2	0.0	0.0
C%Var.	31.8	54.2	67.4	77.9	87.3	91.8	95.0	97.1	98.6	99.8	100.0	100.0	100.0

4. Discussion

4.1. Evaluating surface water quality in Southern Vietnam

Temperature fluctuations are not large because water has the function of temperature regulation [1,25]. Temperature is in the range suitable for aquatic organisms [26]. The pH in the study areas is affected by wastewater and hydrological regime. pH in major rivers in the Mekong Delta is usually in the neutral range except for some coastal provinces where it is tested [1,19,25,27,28]. In addition, this has resulted that EC and TDS are high in estuary areas where brackish, saline water intrusion is possible. In addition, TDS and EC are also affected by inorganic substances present in wastewater or effluents discharged into receiving waters [1,4,22].

At many locations DO is very low due to the impact of wastewater containing organic compounds and $N\text{-}NH_4^+$ [22,29]. The fluctuations of DO are due to the presence of organic matters, the presence of algae, air diffusion and pH [4,26]. The results show that low DO while high BOD, COD, TSS revealed that surface water quality in the South of Vietnam has organic pollution, especially in Dong Nai area, Ho Chi Minh city and Long An where there are crowd industrial parks, and busy transport and fishing ports. Previous studies in the Mekong Delta also showed that the water was organically polluted and had seasonal fluctuations [1,19,27,28,30,31]. $N\text{-}NH_4^+$ is present in wastewater, domestic waste, agriculture, industry, and landfills [4,17,22,32]. High $N\text{-}NH_4^+$ is found in Dong Nai, Ho Chi Minh City and Long An areas where there are many industrial zones, and fishing ports. The findings show that water bodies are contaminated with nutrients, which can potentially lead to eutrophication of water environment [33]. Nutrient pollution is a water quality issue of concern in the Mekong Delta waters, mainly caused by wastewater from treatment systems and from agricultural production [4, 30,31].

Iron is present in the aquatic environment in the study area was predicted to be fromfrom natural sources (acid sulfate soils) or from industrial wastewater [4, 9,17,22,34]. The presence of Fe in surface waters is a common problem in the Mekong Delta [1,4,31]. And other heavy metals are often derived from agricultural and industrial wastewater [17,22,35,36].

The results show that water quality varies greatly according to sampling location, the most polluted locations are in Dong Nai, Ho Chi Minh City and Long An where there are many navigation activities, industrial zones, and fishing ports. DO, TSS, BOD, COD, $N\text{-}NH_4^+$, Fe, EC, TDS, Cl^- were seasonal fluctuations. The water quality in the southern part of Vietnam is contaminated with organic (low DO while TSS, BOD, and COD are high), nutrients (mainly $N\text{-}NH_4^+$) and Fe. Pb in some locations exceeded the permissible limit. Heavy metals such as Cd and As were within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1 [7]. This result is also consistent with previous studies on water quality in the Mekong Delta that have contaminated organic, Fe and nutrient, even microorganisms [1,4,9,19,25,27,30,31,37].

On the other hand, through the results of the WQI can be seen that the water quality from Dong Nai, Ho Chi Minh and Long An areas is worse than that in other areas. The reason may be that this area receives wastes from socio-economic development activities with inadequate and ineffective wastewater treatment systems [4,17,22,35]. Previous studies have shown that water quality in Dong Thap province was classified as bad to moderate; In places where water quality is affected by agricultural production, landfills, the water quality is bad, while in places with little impact, the water quality is good [32]. Water quality in large rivers is better than in tributaries [28,31,39,40].

4.2 Evaluating the sampling sites and frequencies of the surface water quality monitoring

The rersults of cluster analysis is very consistent with the calculation results of the water quality index. This has also been reported in a previous study [28,38]. Clusters 1 to 6 have very good water quality, while clusters 7 to 14 are characterized by poor to moderate overall water quality, cluster 15 is characterized by good overall water quality. The results show that water quality varies greatly by sampling sites, mainly due to industrial production, agriculture, transportation, and marine economic activities. Previous studies have shown that locations with the same water quality, in the same water body, can be considered for reduction to save on monitoring costs [5,10,11,21]. This study proposes that monitoring sites from clusters 1 to 6 can be considered to reduce sampling sites because of similar water quality.

This study proposes to reduce the total number of monitoring points of cluster 1–6 by one third from 33 locations to 22 locations, reducing monitoring costs by about 19%. Or, these reduced 11 locations can be arranged in other areas to promptly detect water quality problems from which to have timely solutions.

For the cluster according to the sampling frequency, previous studies also found similar results that water quality was clustered by seasons [10,13,14,28,40]. The order of importance of the indicators changes with the seasons, showing that these indicators are affected by the observational periods. Clusters with similar water quality may consider reducing the sampling frequency. The results show that the sampling frequency could be reduced one for each Cluster II, Cluster III and Cluster V. Thus, this study recommends monitoring frequency from 8 to 5 times/year (Apr, Jun, Aug, Sept, Nov) depending on funding and human resources. This reduces monitoring costs by nearly 37.5%. Chounlamany et al. (2017) [10] also proposed to reduce the frequency of sampling for monitoring surface water quality based on the results of temporal cluster analysis.

4.3. Identifying key water parameters influencing water quality

In this study, the factor leading to the pH change may be due to the characteristics of wastewater and seawater [4,22]. EC, TDS, Cl^- are mainly affected by sources from saline intrusion, dissolved ions in wastewater [4,17,22]; organic substances from the discharge processes [29]; total suspended solids from riverbank erosion, plankton [1,4,25]; nutrients from hydrological factors, wastewater from domestic, agriculture and industry [17,22,35,36]; Fe was derived from natural and industrial wastewater [17,22,28,31] while other heavy metals (Pb, As, Cd) were derived from industrial waste [4,17]. The findings show that the parameters of temperature, pH, TDS, EC, DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, Fe, Cl^-, Pb need to be monitored while Hg, As, Cd may not need or reduce the frequency of monitoring because its concentrations is always at below the allowable level or below the detection limit. $N\text{-}NO_3^-$ may also not need to be monitored because it can be estimated from $N\text{-}NH_4^+$, $N\text{-}NO_2^-$ and DO. In addition, $N\text{-}NO_3^-$ is less harmful to the environment than that of $N\text{-}NH_4^+$, $N\text{-}NO_2^-$ in the study areas. EC and TDS have a close relationship with each other, so only one of these two indicators is selected for monitoring. In this study, the important water quality indicators such as $P\text{-}PO_4^{3-}$, TP, TN, and coliforms have not been observed, and need to be added to the future monitoring program for a more comprehensive assessment of surface water quality in the study area.

5. Conclusions

The results present that the water quality varies greatly according to the sampling locations, the most polluted locations are in Dong Nai, Ho Chi Minh City and Long An where there are many navigation activities, industrial parks, and fishing port. DO, TSS, BOD, COD, $N\text{-}NH_4^+$, Fe, EC, TDS, Cl^- have seasonal fluctuations. The water quality was contaminated with organic (DO was low while TSS, BOD, and COD were high), nutrients (mainly $N\text{-}NH_4^+$) and Fe. Pb at some locations exceeded the allowable limit. Heavy metals such as Cd, Hg and As are within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1. WQI shows that water quality is classified from bad to very good (WQI = 42–100), in which good water quality is concentrated in the areas of Binh Phuoc, An Giang, Tien Giang, Ben Tre, Dong Thap provinces while the average and bad water quality is concentrated in Dong Nai, Ho Chi Minh City, Long An. CA classifies water into 15 clusters in which clusters 1–6 have very good water quality, cluster 15 have good water quality, while clusters 7–14 have poor to moderate water quality. This study proposes to reduce the total number of monitoring points of cluster 1–6 by one third from 33 locations to 22 locations, reducing monitoring costs by about 19%. Water quality according to the sampling periods is classified into 5 clusters from which it is recommended that the frequency of monitoring be reduced from 8 to 5 times per year which helps to reduce monitoring costs by nearly 37.5%. The PCA results identified 5 major potential sources explaining 87.3% and 8 minor sources explaining only 12.7% of water quality variation. The parameters of temperature, pH, EC, DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, Fe, Cl^-, Pb need to be continuously monitored. $P\text{-}PO_4^{3-}$, TP, TN, coliforms need to be added to the future monitoring program to more comprehensively assess surface water quality in the study area. The study provides important scientific information that can support future surface water quality monitoring.

Declarations

Availability of Data and Materials

Not applicable

Competing interests

The authors declare they have no competing interests.

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Authors' contributions

Conceptualization, N.T.G. and H.T.H.N.; methodology, N.T.G.; software, H.T.H.N.; validation, N.T.G., H.T.H.N.; formal analysis, H.T.H.N.; investigation, N.T.G.; resources, N.T.G.; data cura-tion, N.T.G.; writing-original draft preparation, N.T.G. and H.T.H. N; writing-review and edit-ing, N.T.G;; visualization, H.T.H.N.; supervision, N.T.G.; project administration, N.T.G.; All au-thors have read and agreed to the published version of the manuscript..

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References

1. Mekong River Commission (MRC). Lower Mekong regional water quality monitoring report. ISSN: 1683-1489. MRC Technical Paper No.51; 2015.
2. Behmel S, Damour M, Ludwig R, Rodriguez MJ. Water quality monitoring strategies — A review and future perspectives. Science of The Total Environment. 2016;571:1312-29.
3. Turner S, Pangarre G, Mather RJ. Water governance: A current situation study in Laos, Cambodia, and Vietnam. Mekong Regional Water Dialogue. Switzerland IUCC; 2009.
4. Ministry of Natural Resources and Environment (MONRE). State of the National Environment in 2018-Water environment of river basins. 2018.
5. Mama A, Bodo W, Ghepdeu G, Ajonina G, Ndam J. Understanding seasonal and spatial variation of water quality parameters in mangrove estuary of the Nyong River using multivariate analysis (Cameroon Southern Atlantic Coast). Open Journal of Marine Science. 2021;11:103-128. doi: 10.4236/ojms.2021.113008.
6. Vietnam National Assembly. Law on Environmental Protection No. 77/2020/QH14 dated November 17, 2020, takes effect from January 1, 2022. 2020.
7. Ministry of Natural Resources and Environment (MONRE). National Technical Regulation on Surface Water Quality (QCVN 08-2015/BTNMT); Vietnam Environmental Protection Agency: Hanoi, Vietnam, 2015.
8. Vietnam Environment Administration (VEA). Decision 1460/QD-TCMT Dated November 12, 2019 on the Issuing of Technical Guide to Calculation and Disclosure Vietnam Water Quality Index (VN_WQI); Vietnam Environment Administration: Hanoi, Vietnam; 2019.

9. Giao NT, Nhien HTH, Anh PK., Ni DV. Classification of water quality in low lying area in Vietnamese Mekong Delta using set pair analysis method and vietnamese water quality index. Environ. Monit. Assess. 2021;193:1-16.
10. Chounlamany V, Tanchuling MA, Inoue T. Spatial and temporal variation of water quality of a segment of Marikina River using multivariate statistical methods. Water Science and Technology. 2017;76:1510-22.
11. Thu T, Le H, Zeunert S, Lorenz M, Meon G. Multivariate statistical assessment of a polluted river under nitrification inhibition in the tropics. Environmental Science and Pollution Research. 2017;24:13845–62.
12. Oketola A, Adekolurejo S, Osibanjo O. Water quality assessment of river Ogun using multivariate statistical techniques. Journal of Environmental Protection. 2013;4:466-79. doi: 10.4236/jep.2013.45055.
13. Badillo-Camacho J, Reynaga-Delgado E, Barcelo-Quintal I, Valle P, López-Chuken U, et al. Water Quality Assessment of a Tropical Mexican Lake Using Multivariate Statistical Techniques. Journal of Environmental Protection. 2015;6: 215-24. doi: 10.4236/jep.2015.63022.
14. Zoltan H, Mirjana H, Kristian P. Assessment of spatial and temporal water quality distribution of Lake Ludas, Serbia. Environmental Science and Pollution Research. 2021;1-33.
15. Li P, Qian H, Wu J. Application of set pair analysis method based on entropy weight in groundwater quality assessment - a case study in Dongsheng City, Northwest China. E-Journal of Chemistry. 2011;8:851-8. doi: 10.1155/2011/879683.
16. Islam M, Lenz O, Azad A, Ara M, Rahman M, Hassan N. Assessment of spatio-temporal variations in water quality of Shailmari River, Khulna (Bangladesh) using multivariate statistical techniques. Journal of Geoscience and Environment Protection. 2017;5:1-26. doi: 10.4236/gep.2017.51001.
17. Ojok W, Wasswa J, Ntambi, E. Assessment of seasonal variation in water quality in river rwizi using multivariate statistical techniques, Mbarara Municipality, Uganda. Journal of Water Resource and Protection. 2017;9:83-97. doi: 10.4236/jwarp.2017.91007.
18. Miao TS, Lu WX, Luo JM, Guo JY. Application of set pair analysis and uncertainty analysis in groundwater pollution assessment and prediction: a case study of a typical molybdenum mining area in central Jilin province, China. Environmental Earth Sciences. 2019;78:323. doi: 10.1007/s12665-019-8326-9.
19. Giao NT, Minh QV. Evaluating surface water quality and water monitoring variables in Tien River, Vietnamese Mekong Delta. Jurnal Teknologi. 2021;83: 29-36.
20. Singh KR, Dutta R, Kalamdhad AS, Kumar B. Information entropy as a tool in surface water quality assessment. Environmental Earth Sciences. 2019;78:15. doi: 10.1007/s12665-018-7998-x.
21. Shrestha, S., Kazama, F. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environmental Modelling and Software. 2007;22:464-75.
22. Atwebembeire J, Andama M, Yatuha J, Lejju JB, Rugunda GK, Bazira J. The physico-chemical quality of effluents of selected sewage treatment plants draining into river rwizi, Mbarara Municipality, Uganda. Journal of Water Resource and Protection. 2019;11:20-36. doi: 10.4236/jwarp.2019.111002.
23. APHA; AWWA; WEF. Standard Methods of for the Examination of Water and Wastewater, 22nd ed.; American Public Health Association: Washington, DC, USA; 2012.
24. Li C, Sun L, Jia J, Cai Y, Wang X. Risk assessment of water pollution sources based on an integrated k-means clustering and set pair analysis method in the region of Shiyan, China. Science of the Total Environment. 2016;557–558:307–316. doi: 10.1016/j.scitotenv.2016.03.069
25. Ongley ED. Chapter 12: Water Quality of the Lower Mekong River. In The Mekong: Biophysical Environment of an International;. Academic press: Montreal, QC, Canada; 2009.
26. Boyd CE. Water quality for pond Aquaculture. Department of Fisheries and Allied Aquacultures. Auburn University, Alabama 36849 USA; 1998. 37 pp

27. Giao NT. Evaluating current water quality monitoring system on Hau River, Mekong Delta, Vietnam using multivariate statistical techniques. Applied Environmental Research. 2020;42:14-25. doi: 10.35762/AER.2020.42.1.2.
28. Giao NT, Trinh LTK, Nhien HTH. Coastal water quality assessment in Bac Lieu province, Vietnam. Journal of Energy Technology and Environment. 2021;3:31-43.
29. Barakat A, Baghdadi ME, Rais J, Aghezzaf B, Slassi M. Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. International Soil and Water Conservation Research. 2016;4:284-92.
30. Ly NHT, Giao NT. Surface water quality in canals in An Giang province, Viet Nam, from 2009 to 2016. J. Vietnam. Environ. 2018;10:113-9.
31. Tuan DDA, Thu BA, Trung NH. Assessing quality of surface water for urban water supply source for Soc Trang City. Sci. J. Can Tho Univ. 2019;4A:61–70.
32. Nhien NT, Giao NT. Environmental quality of soil, water and sediment at Dong Thang landfill, Can Tho city, Viet Nam. Applied Environmental Research. 2019; 41:73-83.
33. Boyd CE, Green BW. Water quality monitoring in shrimp farming areas: an example from Honduras, Shrimp Farming and the Environment. The World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment; Auburn: USA; 2002.
34. Du LV, Giao NT, Dan TH. The variation of water quality in three land use types in U Minh Ha National Park, Ca Mau province, Vietnam using multivariate statistical approaches. Water. 2021;13:1-15.
35. Bolstad PV, Swank WT. Cumulative impacts of land-use on water quality in a southern Appalachian watershed. Journal of the American Water Resources Association. 1997;33:519-33.
36. Khadija D, Hicham A, Rida A, Hicham E, Nordine N, Najlaa F. Surface water quality assessment in the semi-arid area by a combination of heavy metal pollution indices and statistical approaches for sustainable management. Environmental Challenges. 2021;5:1-12.
37. Chea R, Grenouillet G, Lek S. Evidence of water quality degradation in Lower Mekong Basin revealed by self-organizing map. PLOS ONE. 2016. doi: 10.1371/journal.pone.0145527.
38. Giao NT. Application of multivariate statistical techniques in determining surface water quality monitoring sites at Bung Binh Thien reservoir, An Giang, Vietnam. Journal of Science on Natural Resources and Environment. 2020;33:57-67.
39. Giao NT. Surface water quality at the branches adjacent to Hau river in Can Tho city. Sci. Technol. J. Agric. Rural Dev. 2020;15:79–86.
40. Giao NT, Nhien HTH. Application of gis and multi-criteria statistical techniques in assessing water quality in the coastal province of Vietnamese Mekong Delta. Applied Environmental Research. 2021;43:17-33.

Figures

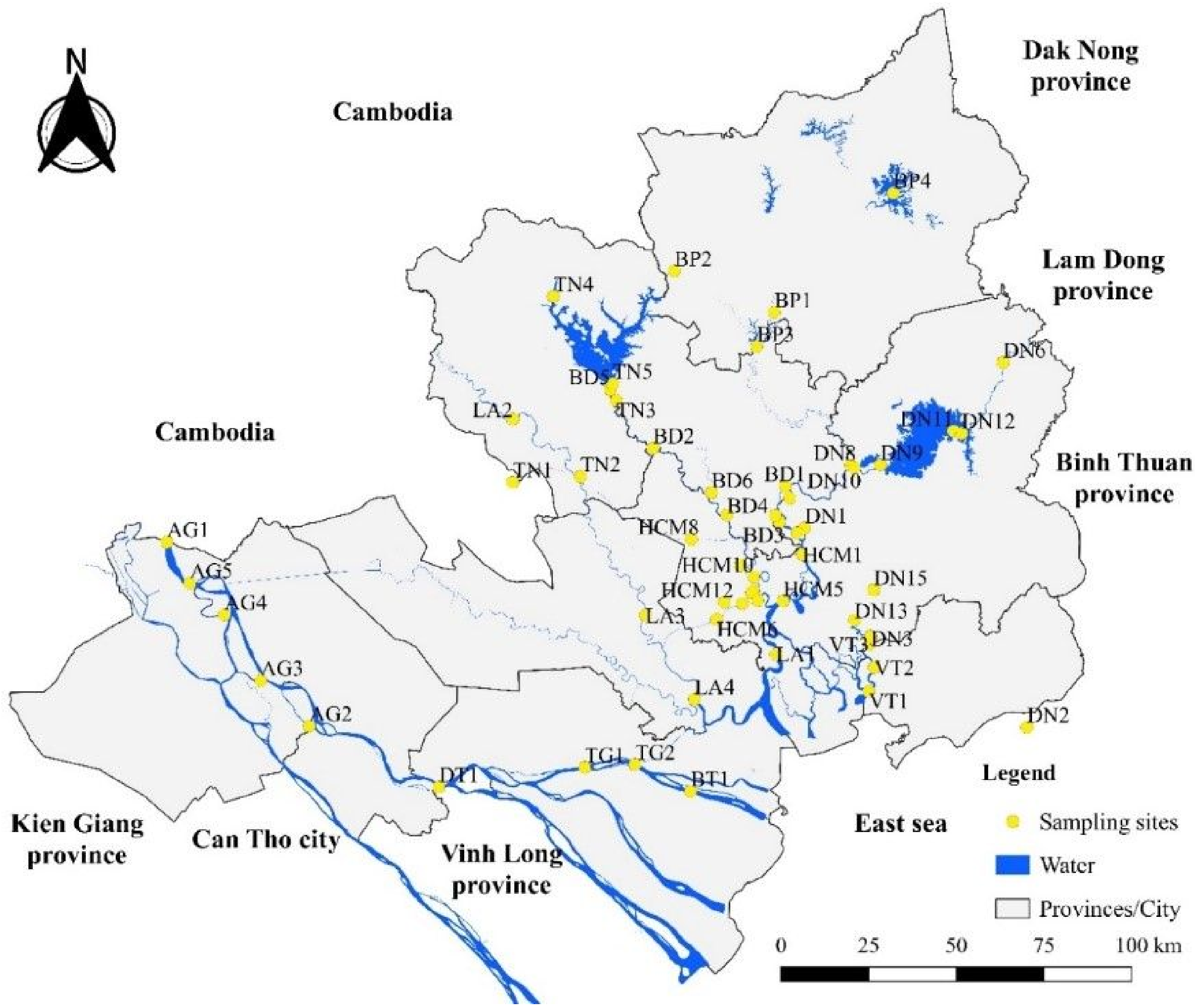

Figure 1

Map of the sampling locations

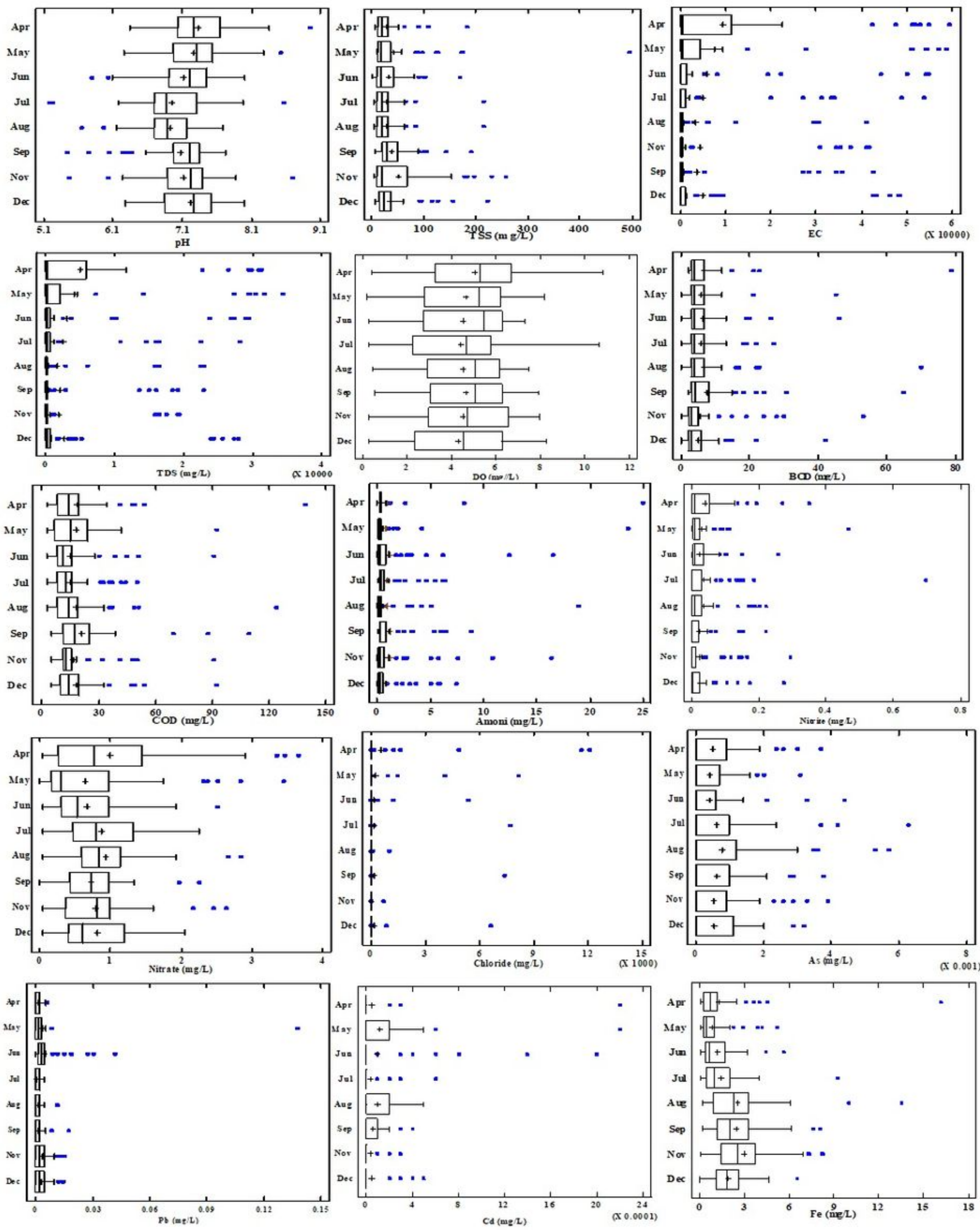

Figure 2

Characteristics of surface water quality in Southern Vietnam

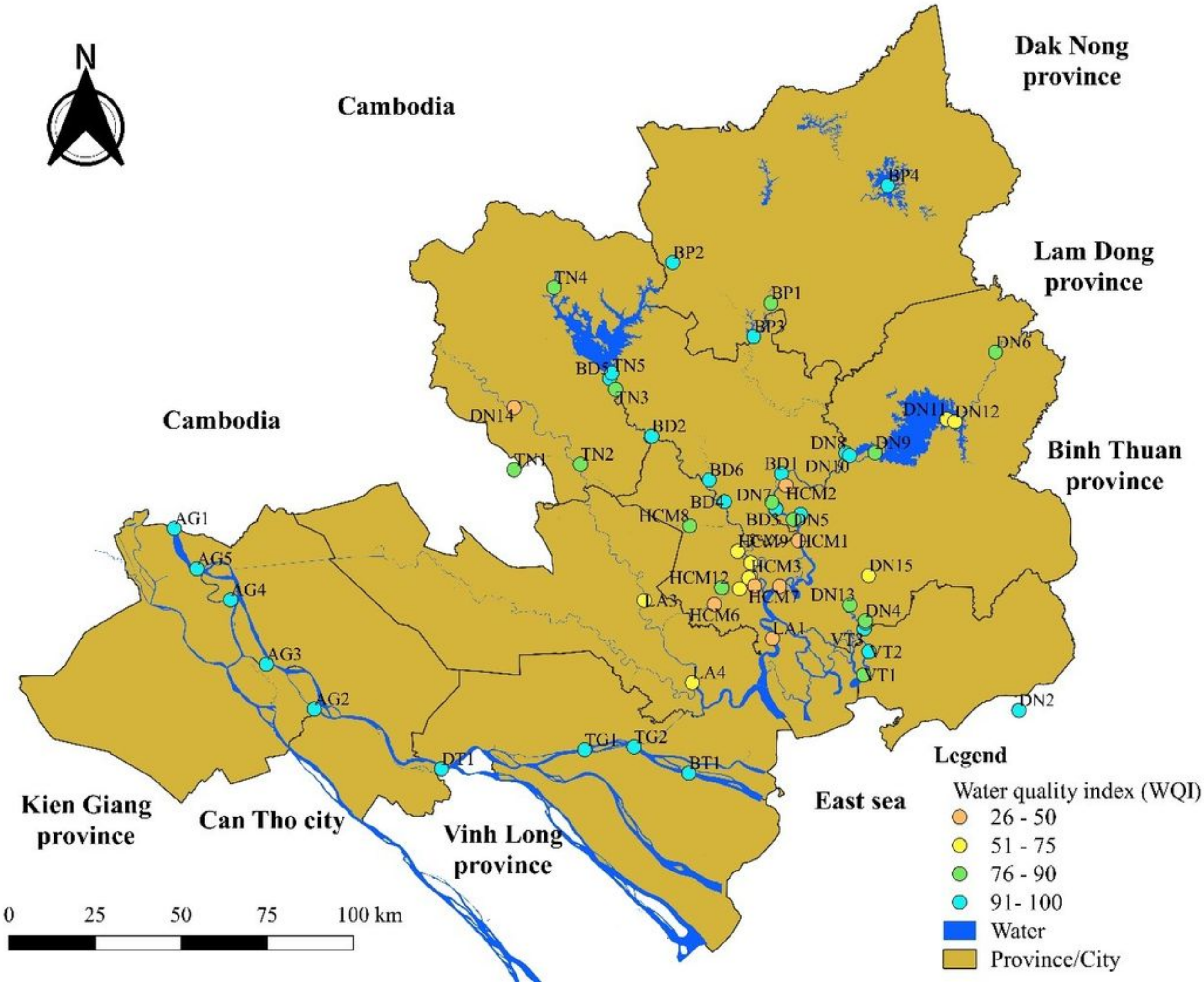

Figure 3

Distribution of WQI at the monitoring locations

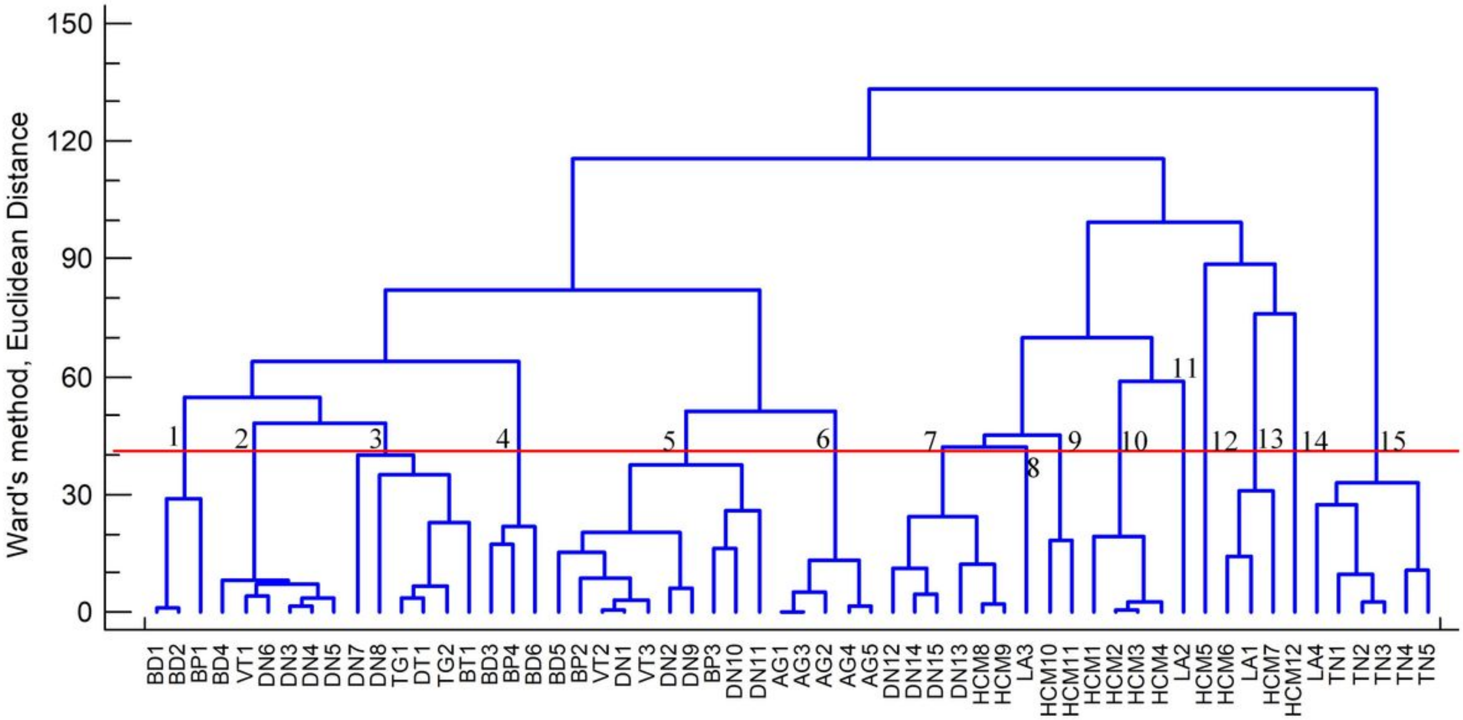

Figure 4

Clustering surface water quality by sampling locations

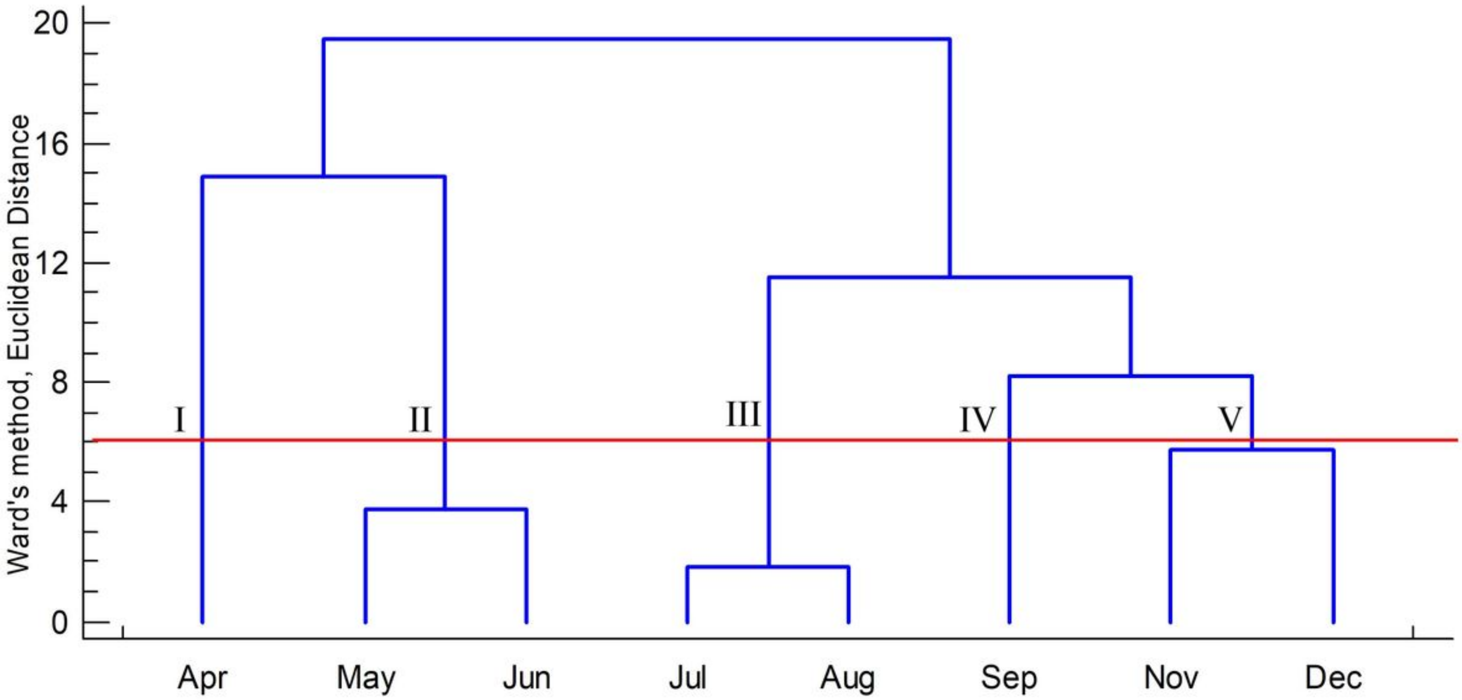

Figure 5

CA results according to the sampling frequency