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Evaluating Current Water Quality Monitoring System on Hau River, Mekong Delta, Vietnam Using Multivariate Statistical Techniques

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Abstract

This study aims to assess the sampling sites and frequencies of sampling of the existing surface water quality monitoring on Hau River using multivariate analysis techniques. Principal Component Analysis (PCA) and Cluster Analysis (CA) were used to analyze the water quality monitoring data collected every month in 2018 from 8 sampling stations. Surface water quality parameters including pH, temperature, dissolved oxygen (DO), total suspended solids (TSS), nitrate ($N\text{-}NO_3^-$), phosphate ($P\text{-}PO_4^{3-}$), chemical oxygen demand (COD) and coliforms were used in the PCA and CA analyses. The findings indicated that the Hau River water quality was polluted by TSS, COD and coliforms in which COD was high in dry season, TSS was high in wet season and coliforms were high all year round. The PCA revealed that pH, temperature, DO, TSS, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, COD and coliforms influenced on the water quality, therefore, relevant for examination in the water samples. These water quality variables were affected by various polluting sources, for examples, runoff, human activities, and hydrological influence. Cluster analysis suggested that the current monitoring program could be reduced from 8 to 3-4 points and 12 to 3-4 times per year. This monitoring program could save the total budget for up to 42%. The findings of the present study could be useful to the policy maker especially to those who are dealing with surface water monitoring systems. The multivariate statistical techniques could be used to assess the surface water quality monitoring network.

Keywords: Cluster analysis; Hau River; Organic pollution, Principal component analysis; Water quality

Introduction

Hau River is the downstream part of the Mekong River that runs through Vietnamese territory in Khanh An commune, An Phu District, An Giang Province, flowing into South China sea through Tran De and Dinh An Mouths. It is about 250 km in length and the widest part of the river is approximately 4 km [1]. Its flow

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velocity is relative large from 1.0 to 2.98 m s^{-1}. According to water level monitoring for many years on the Hau River, the highest and lowest water level at Chau Doc Station were 4.91 m in 1937 and -0.68 m in 2005, respectively [2]. At Long Xuyen Station, the highest and lowest water level were 2.66 m in 1995 and -0.97 m in 2005, respectively [2]. This river flows in the northwest-southeast direction, partly influenced by the tidal regime in the eastern coastal area with an irregular semidiurnal tide having up and down twice a day with 2 peaks and 2 legs [3]. While the two tidal peaks differ slightly, the legs are much different; therefore, this will have the effect of bringing more water into the field. The total quantity of Hau River water flowing into the sea is about 200 billion m^3 a^{-1} (accounting for 41% per total water quantity of the Mekong River) [4]. Thus, Hau River plays an important role in daily life and different types of production for local people [5]. However, Hau River is also the place to receive waste directly from these activities which is directly and indirectly affects the water quality on the river, especially sources of waste from densely populated areas and intensive agricultural production [6]. Therefore, surface water quality in the region is largely influenced by both natural processes and by anthropogenic inputs [7]. This has generated great pressure on aquatic ecosystems [8], so it is therefore essential to prevent and control water pollution and to implement regular monitoring programs. Currently, many water quality monitoring points have been arranged along this river from the upstream of An Giang down to the East Sea. This arrangement by location and time is mainly based on the anthropogenic activities on both sides of the Hau River, but there is no scientific analysis method.

In recent years, multivariate analysis techniques including Cluster Analysis (CA) and Principal Component Analysis (PCA) have been widely applied to explain complex data sets with many factors and different sampling sites making it simpler, which helps to better assess water quality, and a range of other environmental issues. In particular, these methods could be used for the assessment of spatial and temporal variations of water quality, supporting the identification of pollution sources [9-13]. Moreover, many studies also concluded that these techniques have been used effectively in selecting water parameters for monitoring task [14-17]. It has been clearly showed that PCA and CA could be used to determine monitoring sites, parameters causing surface water quality changes in order to select appropriate monitoring indicators in establishing a network for monitoring surface water environment in a particular study area [9, 18]. This study was conducted to assess water quality in the Hau River based on 12-month water quality data at the 8 continuous monitoring sites. Spatial, temporal variation, and key water parameters influencing on water quality at the eight stations were also evaluated using CA and PCA. The findings from this study could effectively support the evaluation of the current sampling frequency, location, and parameter of water quality monitoring in Hau River, thus providing helpful information for water authorities in the study area.

Materials and methods

1) Data collection and site description

All monitoring data on the Hau River was collected every month in 2018 by the Department of Natural Resources and Environment of An Giang and Hau Giang Provinces. Monitoring data of 8 sampling points along the river were collected in which two sites namely AG-1 and AG-2 were in the river segment belonging An Giang Province while the locations namely HG-1 to HG-6 belonging to Hau Giang Province. Brief description of all sampling points was provided in Table 1. Water quality parameters were temperature (ºC), pH, dissolved oxygen (DO, mg L^{-1}), total suspended solids (TSS, mg L^{-1}), nitrate (N-NO_3^-, mg L^{-1}), orthophosphate (P-

PO_4^{3-}, mg L^{-1}), chemical oxygen demand (COD, mg L^{-1}), and coliforms (MPN 100 mL^{-1}). Temperature, pH, and DO were directly onsite by using pH meter (HANNA HI 8424 - USA), and DO meter (HANNA HI 9146-04 - USA). The remaining water quality and quality control (TSS, COD, N-NO_3^-, P-PO_4^{3-}) were performed following the Standard methods for the Examination of Water and Wastewater (SMWW 2540, SMWW 5220, SMWW 4500-NO_3^-, SMWW 4500-PO_4^{3-}, respectively) [19].

2) Data analysis

In order to facilitate consistent evaluation of all multiple variables monitored during the different sampling points and time periods, two main methods used in this study were CA and PCA. In which, the CA was applied to group survey locations based on physical, chemical and biological criteria of surface water quality. The sampling points and times of sampling were grouped on the basis of similarities and dissimilarities of water quality using the Ward's method [20], using Euclidean distance representing the difference between the analytical values from the environmental samples [20]. The cluster analysis results were then presented in a dendrogram [21-22]. The PCA based on the correlation matrix was performed to understand the underlying relationship between the water quality variables of all monitoring stations, and to identify their characteristics. The PCA was used to reduce the complexity of original data with large amounts of information into new variables that were not uncorrelated and appear in descending order of importance, called Principal Component (PC) which are linear combination with the original variables.

Table 1 Location and characteristics of monitoring points

No.	Coding	Coordinates	Description of sites
1	AG-1	10° 57′ 19.797″N 105° 5′ 1.472″E	Hamlet 1, Long Binh Town, An Phu District. To control water quality from Cambodia to Hau River.
2	AG-2	10° 19′ 31.887″N 105° 29′ 40.922″E	Thoi Hoa Hamlet, My Thanh Ward, Long Xuyen City. To control water quality from the end of Hau River before flowing through Can Tho.
3	HG-1	9° 58′ 42.458″ N 105° 5′ 32.259″E	Hau River, the section from Mai Dam to Cai Con. To monitor impacts from waste sources to surface water quality on Hau River.
4	HG-2	9° 58′ 14.404″N 105° 5′ 59.418″E	Hau River, the section from Mai Dam to Cai Con. To monitor impacts from waste sources to surface water quality on Hau River.
5	HG-3	9° 57′ 44.228″ N 105° 6′ 32.251″E	Hau River, the section from Mai Dam to Cai Con Monitoring impacts from waste sources to surface water quality on Hau River.
6	HG-4	9° 57′ 16.163″ N 105° 7′ 7.582″E	Hau River, the section from Mai Dam to Cai Con. To monitor impacts from waste sources to surface water quality on Hau River.
7	HG-5	9° 56′ 47.871″ N 105° 7′ 45.702″E	Hau River, the section from Mai Dam to Cai Con. To monitor impacts from waste sources to surface water quality on Hau River.
8	HG-6	9° 56′ 15.136″ N 105° 8′ 30.183″E	Hau River, the section from Mai Dam to Cai Con. To monitor impacts from waste sources to surface water quality on Hau River.

Figure 1 Location of sampling points from An Giang to Hau Giang Provinces.

In classical PCA, the larger eigenvalue means that the PC has a greater contribution to explain the variation of the original data which is applied to identify the number of sources affecting the surface water quality in environmental monitoring [22]. The Varimax axis rotation method is defined by PCA, creating a new set of factors, in which each initial data variable will be classified into one factor and each factor will represent a small group of initial variables [22]. The correlation between the principal components and the initial data variables (water quality parameters) is expressed by weighing factors (loading) [22]. The absolute value of weighing factor is greater than 0.75, meaning that the close correlation between the main component and the water quality indicators, from 0.75 to 0.5 is the average correlation, and 0.5-0.3 is the weak correlation [23].

Results and discussion

1) Surface water quality on the Hau River in 2018

The descriptive analyses of water quality variables were carried on eight parameters for twelve consecutive months in 2018 (Table 2). The temperature and pH ranged between 26.8 to 29.4°C and 6.7 to 7.1, respectively. The DO content and COD varied between 5.29 to 5.56 mg L^{-1} and 11.68 to 13.54 mg L^{-1}, respectively. There was no difference in DO and COD between the upstream and downstream locations. The pH, temperature and DO values at the study sites were suitable for the development of aquatic organisms [24-26]. Besides that, according to the study of Cat et al. [26], it was considered as rich in nutrients when the COD content ranges from 10 to 20 mg L^{-1}. In this study, COD values showed that water in the area was nutrient-rich. COD in the downstream locations tended to be higher than that of upstream indicating impact of social economic activities on the quality of surface water. The total suspended solid was relatively high between 41.16 to 48.67 mg L^{-1}. Runoff water from agriculture and anthropogenic activities could be the causes of high TSS concentration in the river. Concentration of nitrate (0.08 to 0.33 mg L^{-1}) and phosphate (0.04 to 0.10 mg L^{-1}) was relatively low. The nutrient concentrations were statistically significant difference between upstream and downstream sites ($p<0.05$). In natural surface water, the nitrate is usually less than 5 mg L^{-1} and orthophosphate is between 0.005 to 0.02 mg L^{-1} [27] which are higher than those found in this study. The nutrients concentrations found in the present study also were lower than those reported the previous study in Hau River in 2016 that nitrate and orthophosphate concentrations were approximate 0.11 mg L^{-1} and 0.1 mg L^{-1}, respectively [5]. The denisties of coliforms varied in the range of 1,346 - 86,338 MPN 100 mL^{-1}. In addition, the concentration of coliforms on Hau River belonging to An Giang Province tended to be higher than that of Hau Giang Province (Table 2), this result was also consistent with the previous study of Dien et al. [28].

All in all, most of the parameters have not statistically significant differences (except TSS, coliforms, nitrate and orthophosphate) among the sampling locations ($p<0.05$). The results indicated these parameters were in accordance with the national technical regulation on surface water quality (QCVN: 08-MT: 2015/ BTNMT) [29] except for total suspended solids and coliforms. Due to the presence of TSS and coliforms, the quality of surface water resources on Hau River is no longer suitable for domestic purposes but can only be used for irrigation or aquaculture.

Table 2 Water quality of the Hau River in 2018

Parameter	Unit	AG-1	AG-2	HG-1	HG-2	QCVN*
pH	-	6.7±0.65[a]	7.12±0.14[a]	6.95±0.29[ab]	7.02±0.28[a]	6-8.5
Temperature	°C	26.85±3.61[b]	29.84±1.11[a]	29.35±1.38[a]	29.27±1.33[a]	-
DO	mg L^{-1}	5.49±0.68[a]	5.29±0.33[a]	5.52±0.54[a]	5.55±0.65[a]	≥ 5
TSS	mg L^{-1}	**48.67±9.07[a]**	**46.88±8.07[ab]**	**42.71±32.65[b]**	**44.71±34.35[ab]**	30
Nitrate	mg L^{-1}	0.08±0.05[b]	0.08±0.06[b]	0.26±0.19[a]	0.31±0.19[a]	5
Phosphate	mg L^{-1}	0.04±0.03[b]	0.05±0.03[b]	0.1±0.05[a]	0.1±0.05[a]	0.2
COD	mg L^{-1}	11.77±1.35[a]	11.73±1.25[a]	13.54±4.72[a]	12.92±5.41[a]	15
Coliforms	MPN 100 mL^{-1}	**86,338±1,023[a]**	**31,835±4,138[b]**	1,778±983[b]	2,111±2,425[b]	5,000
Parameter	**Unit**	**HG-3**	**HG-4**	**HG-5**	**HG-6**	**QCVN***
pH	-	7.05±0.25[a]	7.03±0.27[a]	7.06±0.27[a]	7.07±0.27[a]	6-8.5
Temperature	°C	29.03±1.38[a]	29.1±1.3[a]	29.18±1.4[a]	29.21±1.36[a]	-
DO	mg L^{-1}	5.53±0.59[a]	5.53±0.6[a]	5.56±0.56[a]	5.54±0.62[a]	≥ 5
TSS	mg L^{-1}	**43.29±36.77[ab]**	**44.38±36.06[ab]**	**44.27±35.1[ab]**	**41.16±35.81[ab]**	30
Nitrate	mg L^{-1}	0.33±0.16[a]	0.29±0.18[a]	0.25±0.16[a]	0.3±0.19[a]	5
Phosphate	mg L^{-1}	0.11±0.05[a]	0.1±0.05[a]	0.1±0.06[a]	0.1±0.04[a]	0.2
COD	mg L^{-1}	13.3±3.77[a]	12.15±4[a]	11.68±3.76[a]	12.01±3.39[a]	15
Coliforms	MPN 100 mL^{-1}	1,346±915[b]	2,126±1,741[b]	1,947±1,742[b]	1,555±1,519[b]	5,000

Note: * National technical regulation on surface water quality (QCVN: 08-MT: 2015/BTNMT). Different letters [a, b, c, d] indicates significantly different at significance level of 5%.

The mean values of every water quality parameter were calculated based on the data collected at 8 sampling sites. Table 3 showed that the temporal fluctuation of water quality parameters was relatively large and there were differences between months of the year for most parameters (except coliform). COD in the dry season (December, January, and February) was higher than the permissible level regulated in QCVN: 08-MT: 2015/BTNMT [29]. The COD concentration indicated that the water in Hau River was organically polluted since the high COD was often used as a solid indicator of organic waste concentration in water [7, 32]. TSS tended to be high in the rainy season (June to November) in the study area. The concentration of coliforms was at high level throughout the year and over the permissible limit (QCVN: 08-MT: 2015/BTNMT) [29]. The high level of coliforms in water indicated effect of wastes derived from human and animal feces [33-34]. TSS exceeded the standard is most likely due to the characteristics of water, which was considerable alluvial content along with storm water runoff and erosion on the Hau River during the rainy season [36]. According to the previous research, the surface water quality in the Mekong Delta was contaminated by organic matter, suspended solids, and microorganisms [5, 36-37] in line with the results in this study.

2) Key water quality parameters effecting Hau's surface water quality

The mean value of each water quality parameter at eight sampling stations was used in the principal component analysis. The results of the analysis were presented in Table 4. There were seven factors that contributed to the overall interpretation of the change in surface water quality in the Hau River from An Giang to Hau Giang province, but only PC1 and PC2 largely contributed by 63.8% and 23.8%, respectively. Meanwhile, PC3, PC4, PC5, PC6 and PC7 had moderate contributions by 8.8%, 2.5%, 0.8%, 0.2%, and 0.1%, respectively.

As reported by Shrestha and Kazama [11], the PC with eigenvalue greater than 1 considered significantly. In the present study, the eigenvalues of PC3-PC7 were much smaller than 1 (0.07, 0.01 and 0.01, in turn), which could be ignored. However, PC3 and PC4 were still retained for discussion since these PCs were highly correlated with COD (0.896) and TSS (-0.906), respectively. PC1 was weakly contributed by TSS (positive), nitrate and phosphate (negative), and coliforms (positive). pH and temperature (negative), and dissolved oxygen (positive) were moderately correlated to the PC2. PC3 and PC4 were strongly correlated by COD (positive) and TSS (negative), respectively. From these values, it can be seen that the change in surface water quality in the study area is relatively complicated due to two major sources (PC1 and PC2) and two other minor sources (PC3 to PC4). PC1 potentially represents a mixture of both natural sources (such as agricultural runoff) and artificial sources (such as livestock and human activities) causing water pollution. In contrast, at the PC2, the source affecting water quality is mainly due to hydrological factors (pH, temperature and DO). PC3 had a high positive correlation with COD by 0.896, which could mean that it represents the source of impact related to organic matter originating from human activities or other sources of wastewater [9]. All in all, the possible polluting sources including agricultural runoff, livestock and human activities (domestic and urban waste generation), and hydrological factors result in affecting water quality parameters leading to the fluctuation of surface water quality in the Hau River from An Giang to Hau Giang Provinces. The previous studies have indicated that a number of sources affecting water quality in the Mekong Delta include overflow rainwater, agricultural production, livestock, aquaculture, residential and urban areas, industry and tourism [2, 36].

Table 3 Spatial variation of water quality on the Hau River in 2018

Parameter	Unit	T1	T2	T3	T4	T5	T6	QCVN*
pH	-	7.08±0.87^{abc}	7.31±0.09^{a}	7.17±0.07^{ab}	7.21±0.09^{a}	7.23±0.04^{a}	7.19±0.13^{ab}	6-8.5
Temp	°C	27.73±2.66^{c}	27.43±2.1^{c}	28.79±2.24^{abc}	29.91±2.25^{ab}	30.68±2.29^{a}	29.19±1.25^{abc}	-
DO	mg L^{-1}	**4.85±0.26^{de}**	**4.98±0.14^{de}**	5.96±0.16^{b}	6.37±0.42^{a}	5.83±0.28^{b}	5.71±0.37^{bc}	≥ 5
TSS	mg L^{-1}	24.22±10.66^{c}	27.13±14.29^{c}	24.91±8.19^{c}	24.88±8.14^{c}	24.88±10.77^{c}	**44.47±6.72^{b}**	30
Nitrate	mg L^{-1}	0.14±0.18^{cde}	0.24±0.08^{bcd}	0.02±0.04^{e}	0.09±0.01^{de}	0.23±0.15^{bcd}	0.21±0.04^{bcd}	5
Phosphate	mg L^{-1}	0.05±0.02^{d}	0.07±0.01^{cd}	0.15±0.04^{a}	0.07±0.02^{cd}	0.07±0^{d}	0.09±0.03^{bcd}	0.2
COD	mg L^{-1}	**16.5±4.11^{a}**	**15.63±3.27^{ab}**	14.52±1.98^{ab}	10.38±1.16^{de}	13.03±4.56^{bcd}	10.88±1.48^{cde}	15
Coliforms	MPN 100 mL^{-1}	**30,411±83,187^{a}**	2,411±1,029^{a}	**30,851±8,292^{a}**	**37,756±93,515^{a}**	**9,856±15,377^{a}**	**35,583±63,636^{a}**	5,000
pH	-	6.74±0.22^{e}	6.75±0.1^{d}	6.88±0.06^{bcd}	6.82±0.19^{cd}	6.85±0.22^{cd}	6.78±0.2^{cd}	6-8.5
Temp	°C	28.33±0.73^{bc}	28.08±1.43^{bc}	28.21±1.2^{bc}	30.47±0.34^{a}	29.75±0.65^{ab}	29.18±1.46^{abc}	-
DO	mg L^{-1}	5.45±0.38^{c}	5.73±0.49^{bc}	5.72±0.3^{bc}	5.64±0.3^{bc}	5.08±0.28^{d}	**4.7±0.23^{e}**	≥ 5
TSS	mg L^{-1}	**94.38±26.18^{a}**	**82.09±15.89^{a}**	**88.78±23.38^{a}**	**29.94±12.31^{bc}**	**30.77±13.12^{bc}**	**37.66±13.49^{bc}**	30
Nitrate	mg L^{-1}	0.28±0.16^{bc}	0.33±0.21^{ab}	0.23±0.13^{bcd}	0.29±0.17^{bc}	0.26±0.12^{bc}	0.48±0.27^{a}	5
Phosphate	mg L^{-1}	0.13±0.07^{ab}	0.14±0.07^{a}	0.11±0.07^{abc}	0.05±0.02^{d}	0.05±0.02^{d}	0.06±0.04^{d}	0.2
COD	mg L^{-1}	9.92±2.23^{e}	7.88±1.46^{e}	12.88±1.48^{bcd}	13.66±4.26^{abc}	14.24±1.61^{ab}	9.16±1.62^{e}	15
Coliforms	MPN 100mL-^{1}	**9,926±15,258^{a}**	**15,443±23,586^{a}**	**7,127±12,504^{a}**	**7,641±4,809^{a}**	3,817±5,842^{a}	2,734±3,432^{a}	5,000

Note: *National technical regulation on surface water quality (QCVN: 08-MT: 2015/BTNMT). Different letters $^{a, b, c, d}$ indicates significantly different at significance level of 5%

Table 4 Principal component analysis for water quality on Hau River in 2018

Parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7
pH	-0.296	**-0.518**	-0.158	-0.180	**-0.453**	0.290	**-0.521**
Temperature	-0.305	**-0.508**	0.135	-0.071	**0.515**	-0.390	-0.138
DO	-0.234	**0.567**	-0.356	-0.182	0.360	-0.036	**-0.574**
TSS	**0.403**	-0.042	0.102	**-0.906**	0.047	-0.006	0.048
Nitrate	**-0.412**	0.221	-0.087	-0.215	**-0.535**	**-0.625**	0.202
Phosphate	**-0.429**	0.153	-0.086	-0.187	0.008	**0.601**	0.352
COD	-0.250	0.244	**0.896**	-0.038	-0.053	0.095	-0.228
Coliforms	**0.431**	0.137	0.050	0.160	-0.330	-0.035	-0.401
Eigenvalues	5.11	1.90	0.71	0.20	0.07	0.01	0.01
Variation (%)	63.8	23.8	8.8	2.5	0.8	0.2	0.1
CumVariation (%)	63.8	87.6	96.5	98.9	99.7	99.9	100

Extensive surveys are needed to accurately identify the contribution of the sources of pollution to propose proper measures to eliminate contamination of surface water. This study only performed PCA analysis for eight parameters, so the explanation of the analytical results may be not fully represented the actual water quality parameters that could influence on overall water quality in Hau River. This could also mean that the selection of current water quality monitoring indicators for water environment in Hau River may be reconsidered. For examples some other water quality variable including the flow velocity, discharge, depth, turbidity, electrical conductivity, phytoplankton, biological oxygen demand, ammonia, nitrite, and sulfate should be collected for PCA analysis prior to making the final decision for inclusion of the water parameters in monitoring task.

3) Assessment of water quality monitoring by stations

The cluster analysis used averaged values of water quality parameters at eight different monitoring points in the Hau river crossing An Giang and Hau Giang provinces. The grouping result was shown in Figure 2. It could be seen from the figure that the sampling sites could be divided into three separate groups by the red line (with a distance of 4) including Group I (AG-1), Group II (AG-2) and Group III (HG-1 to HG-6). This separation is due to the presence of higher concentration of TSS and coliforms in AG-1 and AG2 (Table 2) indicating high variation of water quality in the upstream (of An Giang Province). It could be also seen that water flowing from Cambodia readily polluted before entering Vietnamese's water. The sampling locations could possibly be classified into four groups (Group I (AG-1), Group II (AG-2), Group III (HG-1, HG-2, and HG-3), Group IV (HG-4, HG-5, and HG-6) by the blue line (with a distance of 1.8) which could enable us to observe more detail of water quality variation in Hau Giang area. There could be a significant source of pollutants affecting the water quality at the position between Group III and IV. Thermal power plant and paper manufacturer could be possibly the sources of pollutants. However, field investigation should be conducted to search for polluting sources resulting in the difference in water quality. Based on the grouping of water quality presenting in the Figure 2, the number of monitoring points on the Hau River could be reduced from 8 locations to 3 - 4 locations (AG-1, AG-2, HG-1 or HG-2 or HG-3, HG-4 or HG-5 or HG-6). However, more monitoring stations are needed to make the application of multivariate statistics more reliable.

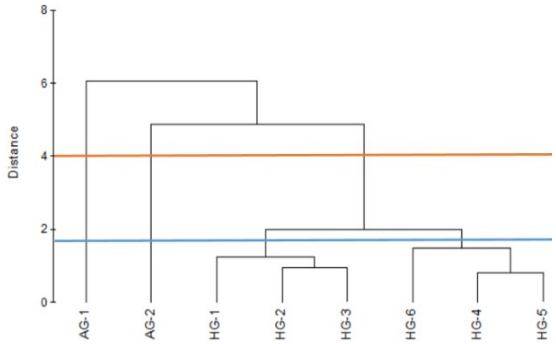

Figure 2 Clustering monitoring sites in Hau River in 2018.

4) Assessment of temporal water quality monitoring

In assessing the monitoring frequency at the study sites, the cluster analysis was conducted using surface water quality data for 12 months in 2018. The results were shown in Figure 3. Temporal variation of quality of water in Hau River could be separated into three groups by the red line (with Euclidean distance of approximate 4), which were Group I (January), Group II (February to June), and Group III (July to December). However, it can also be classified into four groups by the blue line (with the Euclidean distance of around 3) including Group I (January), Group II (February to June), Group III (July to September), and Group IV (October to December). In this way, during the rainy season, from July to December, the water quality is greatly changed indicating highly seasonally dependent of the water environment in Hau River.

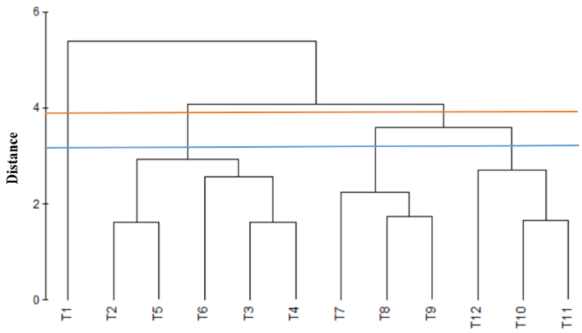

Figure 3 Clustering monthly water quality in Hau River in 2018.

The finding suggested that sampling frequency in Hau River could be reduced from sampling 12 times per year to 3-4 times per year basing on the clustering results. It is clearly showed that cluster analysis could be used to propose options for water quality monitoring frequency which could help in saving cost of monitoring duty.

Conclusion

This study demonstrated that surface water quality in Hau River from An Giang to Hau Giang Province was contaminated with coliforms and total suspended solids. COD was high in the dry season, TSS was high in a rainy season, whereas coliforms were high in all year round. This has resulted in an adverse effect on using water for local people such as domestic water supply. PCA demonstrated that pH, temperature, DO, TSS, N-NO_3^-, P-PO_4^{3-}, COD, and coliforms affected the surface water quality at the sampling stations, therefore, these parameters are relevant for indicating status of water quality. There were at least two major sources of pollutants impacting water quality in Hau River that was explained by PC1 and PC2. The PC1 source resulted in high TSS, N-NO_3^-, P-PO_4^{3-}, and coliform while the PC2 source caused variation in pH, temperature, and DO. These two PCs could be caused by agricultural runoff, livestock farming, human activities (PC1), and hydrological influence (PC2). Cluster analysis suggested that it is possible to reduce the number of monitoring points from 8 to 3-4 points with a frequency of 3-4 times per year. However, this is only an initial result, more data should be considered (both in space and time) in order to have more reliable conclusion. To sum up, multivariate statistical techniques could be used to design and evaluate surface water environmental monitoring network.

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References

[1] Hung, L.M., Hoang, T.B. The erosion of river system in Mekong Delta and contribution of science and technology to the prevention and mitigation of damage. Journal of Science and Technology, 2017, 9. (In Vietnamese)

[2] People's Committee of An Giang Province. Report on the state of environment in five years (2011 -2015) of An Giang Province, 2015, 181.

[3] Tuan, L.A. The tidal and the transmission of the tidal into the Mekong River in Characteristics of methodology - Hydraulic regional area of Mekong River. Can Tho University, 2004, 18.

[4] Thanh, T.N. The report on assessment of the status of water resources and water resources programs, projects in the area of provinces and cities: Can Tho, Vinh Long and Dong Thap. National Center for planning and investigation of water resources, 2016.

[5] Lien, N.T.K., Huy, L.Q., Oanh, D.T.H., Phu, T.Q., Ut, V.N. Water quality in mainstream and tributaries of Hau River. Can Tho University Journal of Science, 2016, 43, 68-79.

[6] Mekong River Commission. Annual water quality data assessment report. MRC Technical Paper, 2013.

[7] Kazi, T.G., Arain, M.B., Jamali, M.K., Jalbani, N., Afridi, H.I., Sarfraz, R.A., Shah, A.Q. Assessment of water quality of polluted lake using multivariate statistical techniques: A case study. Ecotoxicology and Environmental Safety, 2009, 72 (2), 301-309.

[8] Herrera-Silveira, J.A., Morales-Ojeda, S.M. Evaluation of the health status of a coastal ecosystem in southeast Mexico: assessment of water quality, phytoplankton and submerged aquatic vegetation. Marine Pollution Bulletin, 2009, 59, 79-86.

[9] Zeinalzadeh, K., Rezaei, E. Determining spatial and temporal changes of surface water quality using principal component analysis. Journal of Hydrology: Regional Studies, 2017, 3, 1-10.

[10] Ouyang, Y. Evaluation of river water quality monitoring stations by principal component analysis. Water Research, 2005, 39, 2621-2635.

[11] Shrestha, S., Kazama, F. Assessment of surface water quality using multivariate statistical techniques: a case study of the Fuji river basin, Japan. Environmental Modelling & Software, 2007, 22, 464-475.

[12] Bouza-Deaño, R., Ternero-Rodríguez, M., Fernández-Espinosa, A.J. Trend study and assessment of surface water quality in the Ebro River (Spain). Journal of Hydrology, 2008, 361, 227-239.

[13] Omo-Irabor, O.O., Olobaniyi, S.B., Oduyemi, K., Akunna, J. Surface and groundwater quality assessment using multivariate analytical methods: A case study of the western Niger Delta, Nigeria. Physics and Chemistry of the Earth, 2008, 33, 663-673.

[14] Kotti, M.E., Vlessidis, A.G., Thanasoulias, N.C., Evmiridis, N.P. Assessment of river water quality in northwestern Greece. Water Resources Management, 2005, 19, 77-94.

[15] Chau, K.W., Muttil, N. Data mining and multivariate statistical analysis for ecological system in coastal waters. Journal of Hydro-information, 2007, 9, 305-317.

[16] Nakano, T., Tayasu, I., Yamada, Y., Hosono, T., Igetaa, A., Hyodo, F., ..., Yachia, S. Effect of agriculture on water quality of Lake Biwa tributaries, Japan. Science Total Environment, 2008, 389, 132- 148.

[17] Hua, G.C., Luo, X.J., Guo, J.Y., Chen, S.J., Hong, C., Mai, B.X., Xu, M.Q. Organochlorine compounds and polycylic aromatic hydrocarbons in surface sediment from Baiyandian Lake, North China: concentrations, sources profiles and potential risk. Journal of Environmental Science China, 2010, 22, 176-183.

[18] Singh, K.P., Malik, A., Sinha, S. Water quality assessment and apportionment of pollution sources of Gomti River (India) using multivariate statistical techniques - A case study. Analytica Chimica Acta, 2005, 538(1-2), 355-374.

[19] American Public Health Association. Standard methods for the examination of water and wastewater, 20th Editions, Washington DC, USA, 1998.

[20] Salah, E.A.M., Turki, A.M., Othman, E.M.A. Assessment of water quality of Euphrates River using cluster analysis. Journal of Environmental Protection, 2012, 3, 1629-1633.

[21] Chounlamany, V., Tachuling, M.A., Inoue, T. Spatial and temporal variation of water quality of a segment of Marikina River using multivariate statistical analyses. Water Science and Technology, 2017, 76, 1510-1522.

[22] Feher, I.C., Zaharie, M., Oprean, I. Spatial and seasonal variation of organic pollutants in surface water using multivariate statistical techniques. Water Science and Technology, 2016, 74, 1726-1735.

[23] Liu, C.W., Lin, K.H., Kuo, Y.M. Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. Science of the Total Environment, 2003, 313, 1-3, 77-89.

[24] Boyd, C.E. Water quality for pond aquaculture. Research and Development Series, 1998, 37pp.

[25] Cat, L.V., Nhung, D.T.H., Cat, N.N. Aquaculture water quality and improvement measures. Scientific and Technical Publisher, Hanoi, 2006.

[26] Tien, T.M. Environmental monitoring. Vietnam National University Journal of Science, 2005.

[27] Boyd, C.E., Green, B.W. Water quality monitoring in shrimp farming areas: A n example from honduras, shrimp farming and the environment. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment, Auburn, USA, 2002, pp. 29.

[28] Dien, L.D., Lan, M.T., Hung, N.D. Status of water quality of canals on Tien and Hau River (2011-2012). Environment Magazine, 2013, 7.

[29] Ministry of Environment and Natural Resources. National technical regulation on surface water quality. QCVN 08-MT: 2015/BTNMT, 2015.

[30] Salve, B.S. and Hiware, C.J. Studies on water quality of Wanparakalpa Reservoir, Nagapur, near Parli Vaijnath, dist. Beed, Marathwada region. Journal of Aquatic Biology. 2006, 21(2), 113-117.

[31] Varol, M., Sen, B. Assessment of surface water quality using multivariate statistical techniques: A case study of Behrimaz Stream, Turkey. Environmental Monitoring and Assessment, 2009, 159, 543-553.

[32] Galal-Gorchev, H., Ozolins, G., Bonnefoy, G. Revision of the WHO guidelines for drinking water quality. Annalidell'Istituto Superiore di Sanità, 1993, 29, 335-345.

[33] Bolstad, P.V., Swank, W.T. Cumulative impacts of land use on water quality in a

southern Appalachian watershed. Journal of the American Water Resources Association, 1997, 33, 3, 519-533.

[34] UNICEF. Handbook on Water Quality. United Nations Children's Fund, New York, 2008.

[35] Boyd, C.E., Tucker, C.S. Water quality and pond soil analysis for aquaculture. Agricultural Experiment Station, Alabama, Auburn University, 1992.

[36] Ministry of Natural Resources and Environment. National State of Environment -Surface Water Quality, 2012.

[37] Ly, N.H.T., Giao, N.T. Surface water quality in canals in An Giang Province, Viet Nam, from 2009 to 2016. Journal of Vietnamese Environment, 2018, 10, 2, 113-119.