Spatial Variations of Surface Water Quality in Hau Giang Province, Vietnam Using Multivariate Statistical Techniques

Nguyen Thanh Giao*

College of Environment and Natural Resources, Can Tho University, Can Tho 900000, Vietnam

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*** Corresponding author:**
E-mail: ntgiao@ctu.edu.vn

ABSTRACT

This study assessed the surface water monitoring system in Hau Giang Province in 2019. The monitoring data for pH, temperature, total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+_N), nitrite (NO_2^-_N), nitrate (NO_3^-_N), orthophosphate (PO_4^{3-}_P), coliforms, and iron (Fe) were collected from the Department of Natural Resources and Environment, Hau Giang Province, Vietnam. The results were compared with the national technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT). Then, these parameters were used to determine the locations and parameters for water quality monitoring using multivariate analyses including cluster analysis (CA) and principal component analysis (PCA). The results indicated that the main concerns for the quality of water in the canal of Hau Giang Province were organic matter (high BOD and COD), nutrients (NH_4^+_N, NO_2^-_N, PO_4^{3-}_P), coliforms and iron. The CA results showed that 42 monitoring locations could be decreased to 26 locations, reducing monitoring costs by up to 32%. The PCA identified 12 sources of pollution, of which three main sources were PC1, PC2 and PC3 accounting for 75.6% of the variation in water quality. PCA findings showed that all the current water variables in the 2019 monitoring program were significant. The present study could help local environmental managers to reconsider the selected locations and parameters in the environmental monitoring program.

1. INTRODUCTION

Hau Giang Province is located in the sub-region of the Hau River in the Vietnamese Mekong Delta with an area of 160,058.69 ha and six main rivers (canals): Vam Mai Dam, Xa No Canal, Cai Lon Canal, Lai Hieu Canal, Quan Lo Phung Hiep, and Xang Nang Mau Canal. The province has a flat terrain and intertwined with interconnected river systems with a total length of approximately 2,300 km, predominantly, the Hau River along the Chau Thanh District with a length of about two km. The hydrological regime is mostly influenced by the Hau and Cai Lon Rivers. Along with the national development, Hau Giang Province has gradually shifted its economic structure towards industrialization and modernization combined with a strong urbanization process. Hau Giang can be considered as a province with mixed economic characteristics. In agriculture, rice cultivation plays a major role (rice fields (40%) as well as orchards (13%) and aquaculture, combined with urbanized and industrial agglomerations (German Aerospace Center, 2011). Agricultural farming can lead to accumulation of pesticides in water bodies causing exposure of humans and aquatic organisms (Toan et al., 2013). In addition, the terrain is low, sloping from the Northeast to the Southwest, and is influenced by the East and West Sea tides, so the saline intrusion situation is very serious and unpredictable, contributing to negative impacts in the water quality in the province (Hau Giang Department of Science and Technology, 2019). On the other hand, Hau Giang is also the province with predominantly acid sulphate soils; through soil erosion and runoff can cause high concentration of heavy metals (especially Fe and Al) in the surface water. Besides that, the rapid development of industrial area

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has increased the amount of wastes. This has put heavy pressure on the province's water environment. Therefore, the uncontrolled urbanization and economic development have posed many challenges to environmental issues, especially the water environment.

Water is very essential for life and various human activities. Hence, water quality monitoring has a crucial task to manage and maintain good water sources for socio-economic development. However, the choice of sampling locations, number of locations and analytical parameters in water quality monitoring is a difficult problem. Physicochemical and biological indicators are regularly selected to monitor the surface water quality in the Mekong Delta, Vietnam (Wilbers et al., 2014; Phung et al., 2015; Giao, 2019; Giao and Nhien, 2020). In particular, the physicochemical indicators mostly include temperature, pH, total suspended solids (TSS), turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+_N), orthophosphate (PO_4^{3-}_P), heavy metals (Fe, Al, Mn, Cr, Cd), chloride (Cl^-), sulfate (SO_4^{2-}), pesticides, and antibiotics. The biological indicators commonly used are *E. coli* and coliforms (MPN/100 mL) (Wilbers et al., 2014; Phung et al., 2015). These indicators can be preliminary information to assess the level of pollution and suitability of water for a specific purpose (Gebreyohannes, 2015). In Vietnam, selecting indicators and locations for a monitoring program are mainly based on funding and factors affecting water quality. For example, sampling locations are often divided into impact factors such as agriculture, aquaculture, residential/urban areas, tourism, industrial areas, etc. (MONRE, 2012). Multivariate analysis is globally used to assess water quality (Hosseinimarandi et al., 2014; Venkatramanan et al., 2014), such as a measure of fluctuations in the river and lake water quality (Cho et al., 2009; Chounlamany et al., 2017). Moreover, some previous studies have also used effective multivariate techniques to identify pollution sources and evaluate the monitoring network (Vega et al., 1998; Singh et al., 2005; Hosseinimarandi et al., 2014; Giao, 2020). Therefore, to achieve this goal the system of canals in Hau Giang was selected to conduct surface water quality assessment in Hau Giang Province, effectiveness of 42 locations and 12 environmental parameters in identifying the main sources of pollution in surface water quality monitoring program. The research results will be pivotal information to improve the surface water quality monitoring system in the province.

2. METHODOLOGY

2.1 Data collection

Data were collected at 42 sampling sites representing the surface water quality in Hau Giang Province in 2019. Thirty six of the monitoring sites were on canals: Xa No Canal (from XN1 to XN7), Vinh Vien Market (VVM8), Xang Nang Mau Canal (from NM9 to NM13), Cai Dau Canal (CD14, CD15), Vam Cai Cui (CC16), Vam Mai Dam (MD17), Cai Con Canal (CCO18, CCO19, CCO20), Cai Lon Canal (CL21, CL22), Cua Ga Canal (CG23), Lai Hieu Canal (LH24, LH25), Bung Tau Canal (BT26), Mang Ca Canal (MC27), Xeo Mon Canal (XM28), Kinh Cung Market (KCM29), Ba Lang River (BL30, BL31, BL32), Tan Phu Thanh Industrial Zone Port (KCN33), Hau Giang 3 Canal (HG34, HG35), and Xeo Xu Canal (XX36). The remaining sampling sites were located on the Hau River section flowing through the province (SH37, SH38, SH39, SH40, SH41, and SH42). All of the canals, Xa No Canal, Xang Nang Mau Canal, Cai Con Canal, Vam Cai Cui, Ba Lang River, Cai Dau Canal, and Vam Mai Dam, connected to the Hau River. The location map of monitoring data collection is shown in Figure 1.

Surface water samples were determined in March (end of dry season), May (onset of rainy season), August (end of rainy season) and October (onset of dry season) at 42 sampling sites. Water samples were collected in accordance with the guide of Vietnam Environment Administration (2018)-Guidance on sampling of rivers and streams. The samples were collected in the middle of the river/ canal flow (depending on the width of the canals) with a depth of about 30 cm below the surface water. At each site, three samples were mixed to obtain a pooled sample representing the site. A 2-liter sample bottle with a cap was rinsed at least three times with the same water source before collecting sample. Particularly, microbiological analysis samples were taken in a glass bottle which has been sterilized at 175°C for 2 h. A total of 12 indicators were analyzed to assess water quality: pH, temperature, TSS (mg/L), DO (mg/L), BOD (mg/L), COD (mg/L), NH_4^+_N (mg/L), NO_2^-_N (mg/L), NO_3^-_N (mg/L), PO_4^{3-}_P (mg/L), Fe (mg/L), and coliforms (MPN/100 mL). pH, temperature, and DO parameters were measured in-situ by pH meter (HANNA HI 8224, Rumani) and DO meter (Milwaukee SM 600, Rumani). The remaining water quality indicators were properly preserved and analyzed at the laboratory of the Provincial Center for Natural Resources and Environment Monitoring Hau Giang Province by Standard methods (APHA, 1998).

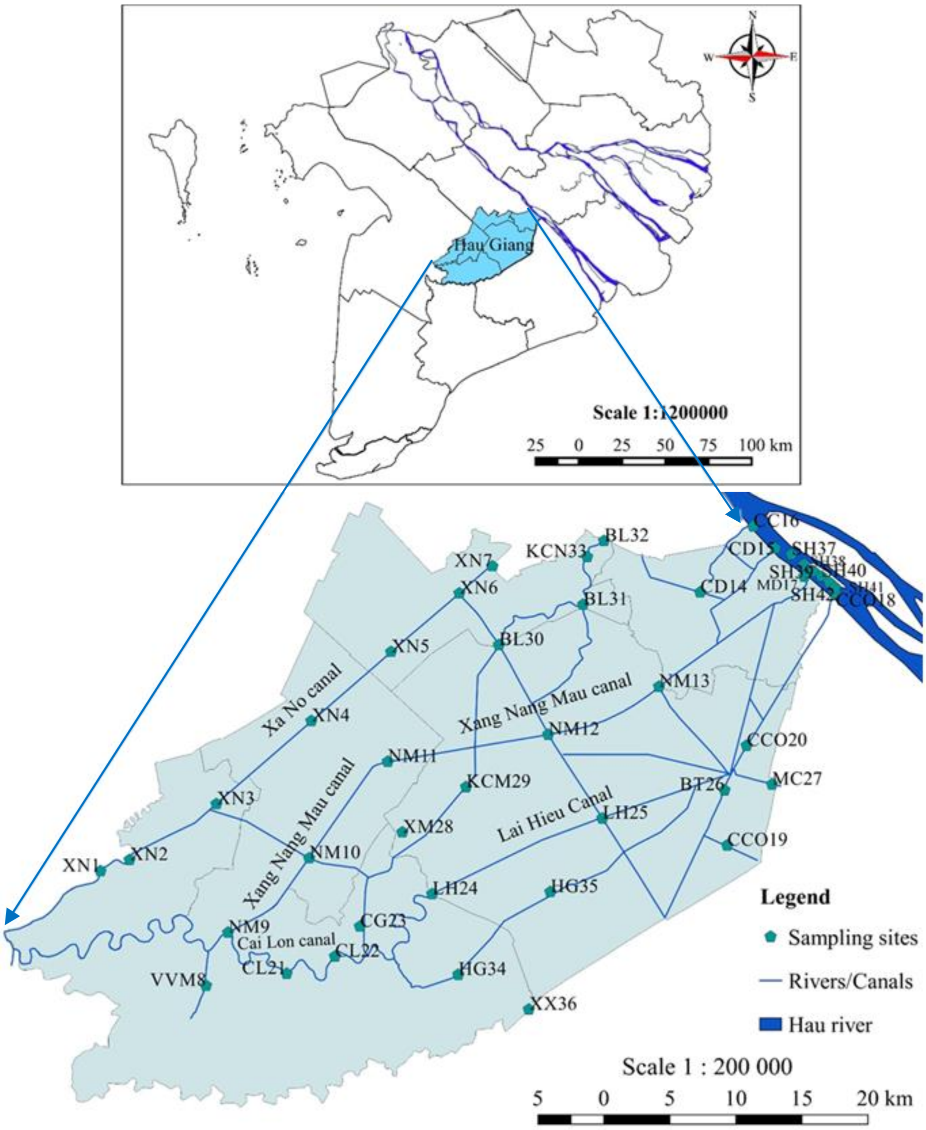

Figure 1. Water monitoring networks in Hau Giang Province

Cluster analysis (CA) is widely used to group water sources by spatio-temporal distribution (Feher et al., 2016; Chounlamany et al., 2017). Samples with similar pollution characteristics will be grouped into the same group, and different pollution properties will be classified into another group. In this study, cluster analysis was conducted by Ward's method (Salah et al., 2012) and presented in a dendrogram (Feher et al., 2016; Chounlamany et al., 2017). A dendrogram can help in determining the number of location groups which have similar characteristics. After identifying the location groups, the selection of effective sites to continue monitoring was based on two factors, the same group and the same river, because the survey of multiple locations on the same canal may not bring large fluctuations and is costly during periodic monitoring.

Principal Component Analysis (PCA) is used to extract important information from the original dataset (Feher et al., 2016; Chounlamany et al., 2017). The axis rotation method performed in PCA is Varimax. Each of the original variables will be classified as one principal component (PC) and each PC is a linear combination of the original variables (Feher et al., 2016). The purpose of the PCA is to reduce the initial variables that do not contribute significantly to data variability. The correlation between PCs and original variables were exhibited by weighing factors (loading)

(Feher et al., 2016). The absolute values of weighing factors (WF) have a strong correlation between PCs and parameters when WF>0.75, average (0.75> WF>0.5) and weak (0.5>WF>0.3) (Liu et al., 2003). Both CA and PCA analyses were computed using the copyrighted software Primer 5.2 for Windows (PRIMER-E Ltd, Plymouth, UK).

3. RESULTS AND DISCUSSION

3.1 Surface water quality in Hau Giang Province in 2019

Surface water quality in Hau Giang Province in 2019 was summarized in Figure 2. It can be seen that the average value of pH and temperature at the sampling sites during the year did not have large fluctuations. pH measured on-sites ranged from 6.8±0.0 to 7.1±0.3 and the annual average was about 7±0.1, which was within permitted limits of QCVN 08-MT: 2015/BTNMT (Table 1). Previous studies showed that the surface water pH in An Giang, Can Tho and Soc Trang also fluctuated in the neutral range (Lien et al., 2016; Ly and Giao, 2018; Tuan et al., 2019; Giao, 2020). Temperature varied from 28.6±0.2°C to 29.6±0.9°C, averaging at 29.4±0.38°C and within the permitted limits of WHO (2008) (<40°C). In addition, the temperature on Hau River ranged from 28.9±0.4°C to 29±0.5°C in 2019, which was lower than the temperature in the Hau Giang River. On the other hands, the temperature on Hau Giang Rivers and canals were similar to the in-field canals of An Giang Province ranging from 28.1±0.9°C to 31.3±2.0°C (Ly and Giao, 2018).

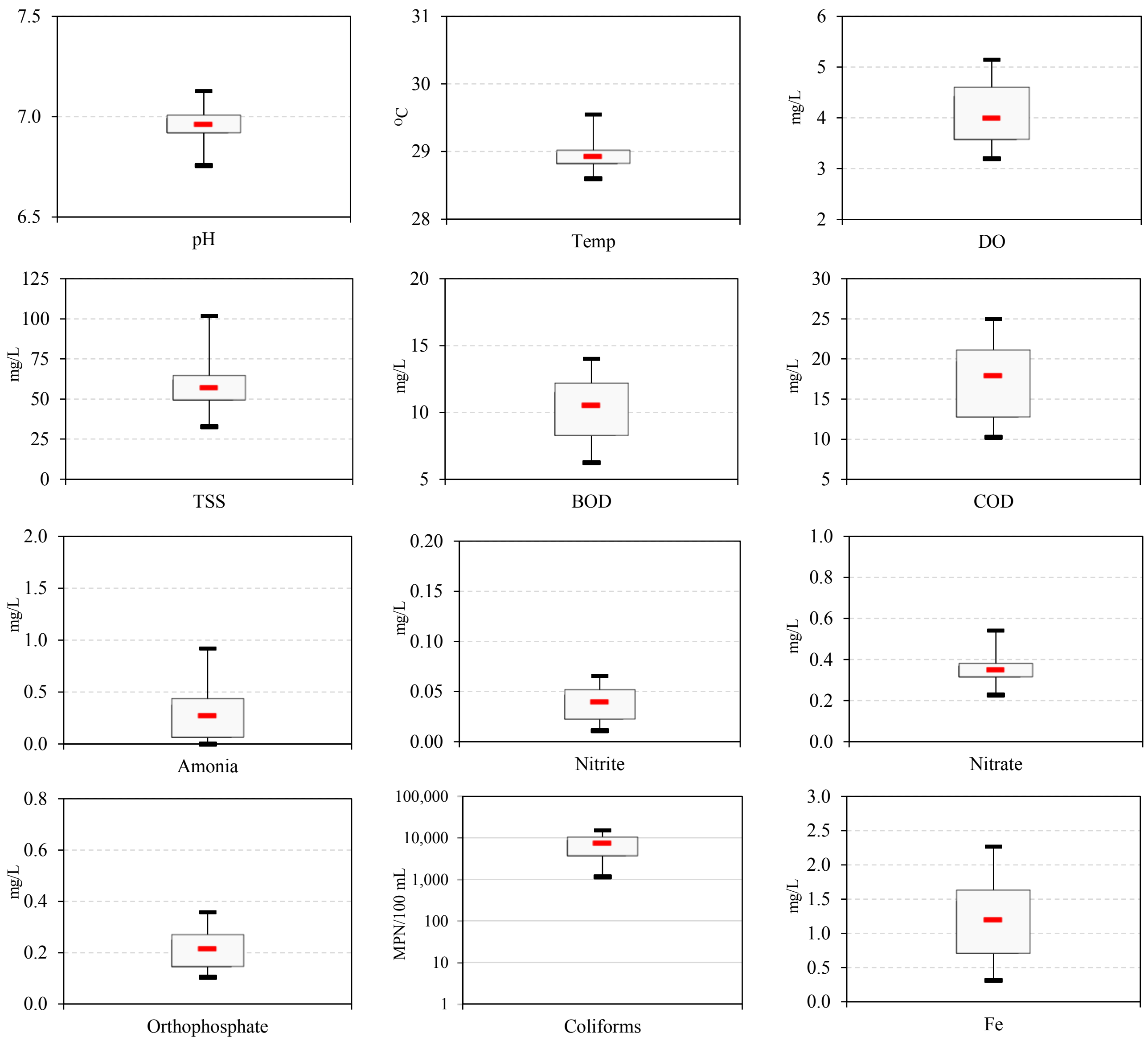

Figure 2. Physisco-chemical, biological characteristics of water quality in Hau Giang in 2019

The mean of TSS concentration in Hau Giang Province in 2019 was 57±22.6 mg/L ranging from 32.8±6.4 to 101.8±40.9 mg/L. In particular, the average TSS concentration in Hau River and in-field canals varied from 34.8±22.6 to 50.8±26.6 mg/L and 32.8±6.4 to 101.8±40.9 mg/L, respectively; this indicated that the water quality in Hau River was less polluted by TSS than those of the canals in Hau Giang Province. The high TSS concentration was due to rainwater runoff, erosion and the presence of phytoplankton in the environment (MONRE, 2012; Giao and Nhien, 2020). The concentration of TSS in Hau River in 2016 was higher than the current study (51.5±31.37 mg/L) (Lien et al., 2016); however, this concentration tended to be similar in 2018 (Giao, 2020). In the in-field canals of An Giang Province, TSS was recorded between 25.0-93.7 mg/L in the period from 2009-2016 (Ly and Giao, 2018). Meanwhile, in the canals of Soc Trang Province, TSS ranged from 16-176 mg/L (Tuan et al., 2019). Thus, TSS concentration in the surface water in Hau Giang was higher than that in canals in An Giang and lower than that in canals in Soc Trang. This may be because Soc Trang is a coastal province, heavily influenced by mudflats and estuaries. According to Akan et al. (2008) and Gebreyohannes et al. (2015), the concentrations of TSS in the canals in Hau Giang Province in 2019 can be comparable to wastewater (TSS concentration is less than 100 mg/L).

The DO value on the in-field canal in the current study was relatively large ranging from 3.2±0.1-5.2±0.8 mg/L and in Hau River ranged from 4.6±0.2-4.7±0.1 mg/L, the annual average was 4.0±0.3 mg/L, there may be negative effects on aquatic ecosystem life (Gebreyohannes et al., 2015). DO concentration in the canals had a tendency of being lower than in Hau River, because the concentration of DO depends on the air diffusion into the water, turbulence in rivers, the presence of biodegradable organic matters and the photosynthesis of phytoplankton (Giao and Nhien, 2020). DO concentration in Soc Trang Canals was 1.7 to 6.2 mg/L (Tuan et al., 2019); in the in-field canals of An Giang was in the range of 4.9-5.5 mg/L in the period from 2009-2016 (Ly and Giao, 2018). DO concentration in the canals in Hau Giang Province was similar to that in Soc Trang and An Giang Canals.

In Hau River, concentrations of BOD and COD were in the ranges of 7.3±3.9-8.3±3.4 mg/L and 12±7.1-12.8±8.9 mg/L, respectively. The concentrations of BOD and COD in the in-field canals were 6.3±0.5-14±4.5 mg/L and 14±4.5-25±8.9 mg/L, respectively. This indicated that the water quality in the canals and Hau River was organically polluted and the pollution level in the infield canals tended to be higher. Some previous studies have also concluded that the canals in the Mekong Delta have been organically polluted. For example, the period of 8 years from 2009-2016 in An Giang Province, BOD concentration in the canals ranged from 4.7±2.3-12.3±9.2 mg/L (Ly and Giao, 2018); BOD and COD values in canals locating in Soc Trang Province were 2.2-22.4 and 6.0-44.9 mg/L, respectively (Tuan et al., 2019); and COD value on Hau River was in the range of 10.4±1.2-16.5±4.1 mg/L (Giao, 2020). This can be explained by the influence of socio-economic activities such as agriculture, industry, services, residential and urban areas (MONRE, 2012; Zeinalzadeh and Rezaei, 2017).

The average concentration of NH_4^+_N, NO_2^-_N and NO_3^-_N compounds in the year 2019 had the average concentrations of 0.27±0.16, 0.04±0.017, and 0.35±0.20 mg/L, respectively. Specifically, the concentration of NH_4^+_N in Hau River and the in-field canals in Hau Giang Province fluctuated from 0±0-0.1±0 mg/L and 0±0-0.92±0.56 mg/L, respectively. NH_4^+_N concentration in surface water in Soc Trang ranged from 0.02 to 4.15 mg/L (Tuan et al., 2019), which was higher than that of Hau Giang Province. Besides that, NO_2^-_N concentration was in the range of 0.011±0.006-0.066±0.049 mg/L (in-field canals) and 0.011±0.007-0.017±0.009 mg/L (Hau River). The NO_2^-_N concentrations in the canals in Hau Giang Province were much lower than those of NO_2^-_N (0.001-0.56 mg/L) in the canals in Soc Trang Province (Tuan et al., 2019). This showed that the water environment was lacking oxygen and could be toxic to aquatic life, consistent with the low DO value in the above discussion. In addition, NO_3^-_N concentrations in the canals in An Giang Province ranged from 0.03 to 1.76 mg/L in the period from 2009 and 2016 (Ly and Giao, 2018). Meanwhile, NO_3^-_N concentration in the canals in Soc Trang Province varied from 0.05 to 1.14 mg/L (Tuan et al., 2019). The concentration of NO_3^-_N in the canals in Hau Giang Province in 2019 (0.23±0.05-0.54±0.44 mg/L) did not differ from the concentrations recorded in An Giang and Soc Trang Provinces. In Hau River, NO_3^-_N concentration was recorded in the range of 0.34±0.15-0.38±0.13 mg/L, which tended to be higher than those in 2018. The difference between the research results and the current study can be a result of oxidation of organic debris, human and animal wastes (DWAF, 1996). From the above discussion, the levels of NH_4^+_N, NO_2^-_N and NO_3^-_N in the in-field canals had the tendency of being higher in Hau River. However, according to DWAF (1996) and Boyd and Green (2002), the nitrogen concentrations found in natural surface water sources range from <0.2 mg/L (N-NH_4^+), <<5 mg/L (N-NO_3^-). Thus, nitrate concentration was not an important environmental issue in Hau Giang Province, but NH_4^+_N concentration in the in-field canals should be paid more attention.

Orthophosphate concentration ranged from 0.1±0.02-0.36±0.26 mg/L. The average was 0.23±0.07 mg/L (in-field canals) and 0.1±0.05-0.23±0.26 mg/L (Hau River) with 0.13±0.05 mg/L the mean concentration. It can be seen that the orthophosphate concentration in Hau River was lower than in the canals in Hau Giang Province. On the other hand, the PO_4^{3-}_P concentration in the canals was reported ranging from 0-0.9 mg/L in Soc Trang Province (Tuan et al., 2019) and the mean concentration of 0.16±0.12 mg/L in An Giang province (Ly and Giao, 2018), which were lower than the in-field canals of Hau Giang Province in the current study. The sources of orthophosphate in the water environment are agricultural runoff, livestock, domestic and industrial wastes (Barakat et al., 2016).

Coliforms densities ranged from 1,156.3±500 to 1,657.5±612.6 MPN/100 mL in Hau River and 3,225±1,913.8 to 15,275±15,244.8 MPN/100 mL in the in-field canals; the densities of coliform in Hau River was significantly lower than that in the in-field canals. In addition, it can be recognized that coliforms were a problem that needs more attention in the canals in Hau Giang Province than in Hau Rivers. Coliforms were detected in An Giang, Soc Trang Provinces, and Hau River with the fluctuation of 2,260-155,000 MPN/100 mL, 2,300-89,000 MPN/100 mL, and 1,346±915-2,126±1,741 MPN/100 mL, respectively (Ly and Giao, 2018; Tuan et al., 2019; Giao, 2020). This indicated that the densities of coliforms in the in-field canals in Hau Giang Province were lower than those in An Giang and Soc Trang Provinces, which could mean that water quality was less polluted by fecal materials. The origin of coliforms can be from human and animal feces (Bolstad and Swank, 1997; UNICEF, 2008).

The average iron concentration was 1.2±0.6 mg/L in 2019 ranging from 0.3±0.1-0.47±0.2 mg/L (Hau River) and 0.50±0.2-2.26±0.5 (in-field canals). Due to acid sulfate soil property, it has resulted in the release of iron into surface water leading to aesthetic issues, disposal costs, and human health. In Soc Trang, the iron concentration in surface water ranges from 0.30-3.75 mg/L (Tuan et al., 2019), tended to higer than that in the canals in Hau Giang Province. In addition to the geographical conditions, human activities (e.g., washing acidic soil, intensive agricultural production) are responsible for the iron-contaminated water.

Table 1 illustrates the limit values of surface water quality parameters that are regulated in Vietnam. The limits are applied to assess and manage surface water quality and provide a basis for appropriate protection and use of water resources. All in all, the mean values of the monitoring indicators were greater than the national technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT), with the exception of nitrogen compounds and pH (Table 1). Although the nitrogen concentration in the water was in accordance with the permitted standard, the surface water environment is facing the risk of eutrophication due to the higher concentration of dissolved phosphorus (Li and Liao, 2003). Thus, it could be implied that artificial activities such as rainwater runoff, industrial and agricultural cultivation, acid sulfate soil washing exert an adverse impact on water quality in the province. The water quality in the canals in Hau Giang fields tended to be more polluted than that in Hau River. For example, the density of coliforms and Fe in Hau River were within limits regulated by QCVN 08-MT: 2015/BTNMT, while the coliform densities and Fe concentrations on the in-field canals of Hau Giang exceeded the limits at all sampling sites.

Table 1. Limited value of surface water quality parameters

Parameter	Units	Limit values	
		QCVN*A1	QCVN*A2
pH	-	6-8.5	6-8.5
Temperature	°C	-	-
TSS	mg/L	20	30
DO	mg/L	≥6	≥5
BOD	mg/L	4	6
COD	mg/L	10	15
NH_4^+-N	mg/L	0.3	0.3
NO_2^--N	mg/L	0.05	0.05
NO_3^--N	mg/L	2	5
PO_4^{3-}-P	mg/L	0.1	0.2
Coliforms	MPN/100 mL	2,500	5,000
Fe	mg/L	0.5	1

*National technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT); A1 means water quality used for domestic purposes (after normal treatment has been applied), conservation of aquatic plants and animals and other purposes; A2 is used for domestic purposes but treatment technology must be applied.

3.2 Assessment of water quality monitoring locations in Hau Giang Province in 2019

The average value of each water quality monitoring indicator was used as input data to group water quality by the sampling location. To optimize the monitoring locations, the sampling sites that were within the same group and in the same river can be reduced. For example, if a group has 3 sites located in the same canal, one of the three sites can be selected for monitoring. Besides that, if they are in the same group but in different rivers, the monitoring points are still selected for the coming year monitoring.

The results of cluster analysis showed that 42 locations of surface water sampling in Hau Giang Province were classified into nine groups denoted from 1 to 9 (Figure 3), in which group 9 represented the lowest pollution level and group 1 was the highest pollution level. The XM28, KCM29, and HG35 sites in groups 2, 4, and 8 were found to be less similar than the other sampling sites and belonging to different canals that are surely remained for monitoring. In the case of a group with multiple monitoring points in the same area, one representative location can be selected for the remaining positions.

Particularly, group 1, including XN5, XN6, and XN7 points on Xa No Canal, have similar data, hence, it is possible to choose one of these points to monitor water quality in this area. Group 3 consisted of 6 locations belonging to 3 areas such as Xa No Canal (XN2, XN3, XN4), Nang Mau Canal (NM10, NM11), and Vinh Vien Market (VVM8). Among the sampling points in the group 3, only one sampling point per river was chosen to collect water samples. XN1, XN3, XN4 and NM10, NM11 sites were located in Xa No and Xang Nang Mau Canals, respectively. Therefore, only one location is selected in each canal. On the other hand, the VVM8 site was in a separate canal; thus, this location was retained for monitoring. Similarly, the number of sampling locations in groups 5, 6, 7 and 9 can be reduced from 8 to 6, 3 to 2, 8 to 6, and 11 to 5 locations (Figure 3). Thus, the total number of 42 locations could be reduced to 26 locations but still ensuring the accuracy of the monitoring process, resulting in a 32% reduction in the total cost of monitoring. In one case, 26 sampling locations that could be selected to monitor the water quality in Hau Giang Province is shown in Figure 4. In this case, the external locations which border between Can Tho city, Soc Trang and Kien Giang Provinces were given the priority to be selected so that they can assess the water input and output of the area. Previous studies have also shown that the application of CA in grouping water quality by sampling location would help reduce the number of sampling locations and therefore significantly diminish costs (Feher et al., 2016; Chounlamany et al., 2017; Giao, 2020).

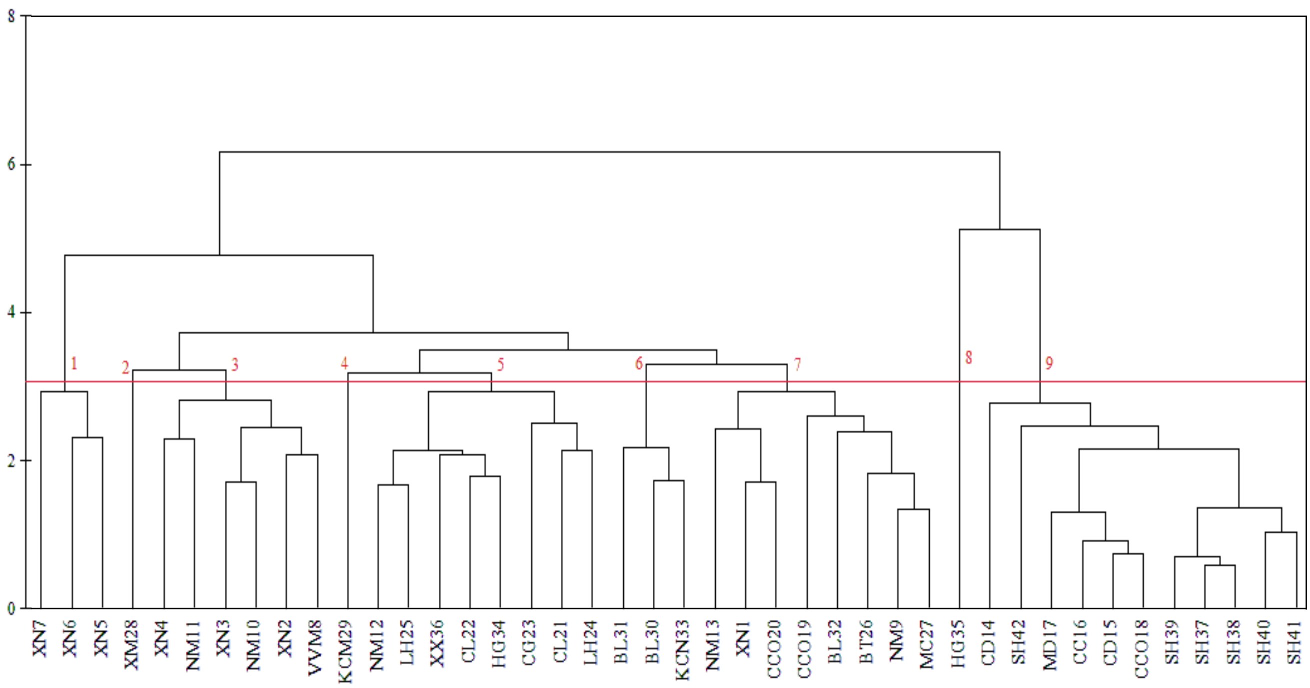

Figure 3. Spatial variations of surface water quality in Hau Giang Province in 2019

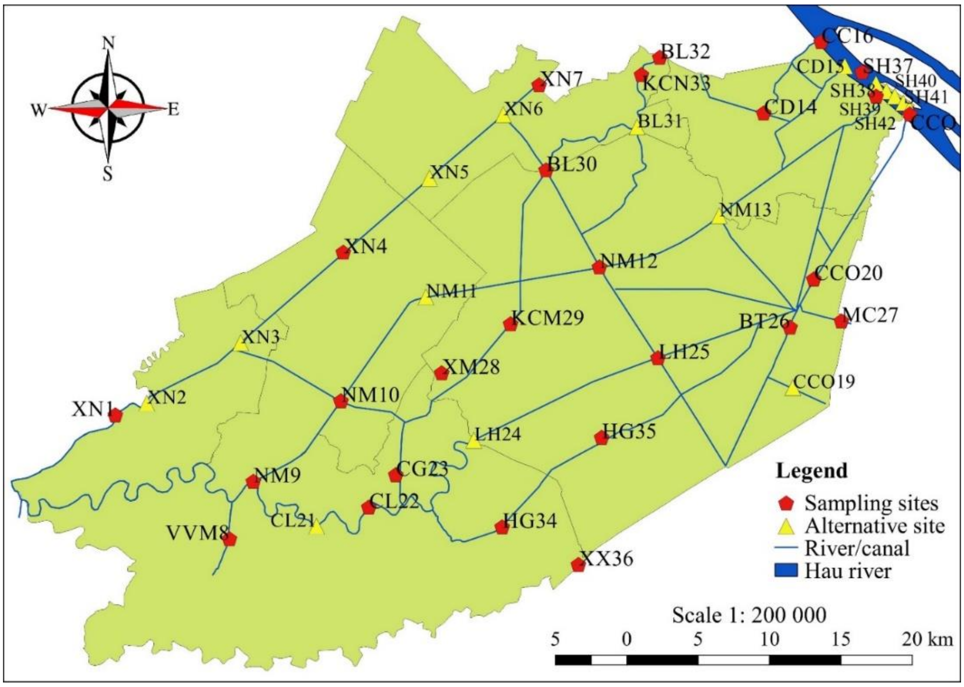

Figure 4. The recommended sampling sites after performing cluster analysis (Note: XN7 or XN5 or XN6; XN4 or XN2 or XN3; NM10 or NM11; NM9 or NM13; CL22 or CL21; LH25 or LH24; BL32 or BL31; CCO20 or CCO19; CD14 or CD15; SH37 or SH38 or SH39 or SH40 or SH41 or SH42)

3.3 Identification of water quality monitoring parameters

Table 2 presents the results of PCA, sources of pollution and water quality indicators showing the impact of pollution sources. Regarding pollution sources, the results of PCA demonstrated that there were 12 pollution sources. The main sources included PC1, PC2, and PC3 with their eigenvalue values greater than 1 (Shrestha and Kazama, 2007), which was responsible for 75.6% of the variation in water quality. Meanwhile, sources from PC4 to PC12 were subsidiary sources contributing 24.4% to the variation in water quality of Hau Giang Province.

PC1 could be considered as a non-point source explaining 52.5% of the variation in water quality data since there was a weak correlation (from 0.313 to 0.356) between PC1 and the water monitoring parameters (e.g., TSS, DO, BOD, COD, NH_4^+_N, NO_2^-_N, NO_3^-_N, PO_4^{3-}_P, and Fe). Hence, some non-point sources were typical in Hau Giang such as flows from agricultural areas, markets, and the sources of pollution by the riparian population. Besides that, Hau Giang has an inter-water transport road of Can Tho-Hau Giang Province (Xa No Canal, Ba Lang Canal). Therefore, this can also be considered as a non-point source that significantly affected the water quality in the study area.

The pH and temperature were mainly explained by PC2, PC3, and PC4 which represent weather (the amount of light reaching the water bodies), hydrological regime (water depth, volume, flow), and buffering capacity of water in the acidic water environment. Besides, it can be seen that coliform values at PC1, PC2, PC3, and PC4 did not contribute significantly to the explanation of water quality pollution. Nevertheless, the coliform value at PC1 was asymptotic to 0.3, which was weakly correlated. This indicated that coliform was not the main parameter influenced on PC1. The correlation of PC5 and PC8 to TSS were positively and negatively correlated by 0.500 and -0.514, respectively. Two possible sources causing high TSS were storm runoff and riverbank erosion (Giao, 2020).

Dissolved oxygen concentration was inversely correlated with PC8 (-0.514), PC10 (-0.490) and PC11 (-0.362) affected by many factors such as temperature, air diffusion, presence of aquatic plants and organic matter (Galal-Gorchev et al., 1993; Kazi et al., 2009; Chounlamany et al., 2017). Both BOD and COD were explained by PC12 with correlation coefficients of 0.693 and -0.707, respectively. These parameters were good indicators for organically polluted environments (Siwiec et al., 2018); therefore, it is reasonable to have the same origin. The sources of organic pollution possibly were human activities such as urban-residential, services and tourism, industrial production and agriculture (Zeinalzadeh and Rezaei, 2017).

Table 2. Principal component analysis for surface water quality monitoring data

Parameters	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
pH	0.088	-0.256	**0.731**	**-0.521**	-0.004	-0.021	0.106	-0.169	0.137	0.234	0.084	-0.006
Temperature	0.037	**0.606**	-0.250	**-0.473**	-0.112	0.342	-0.099	-0.172	0.342	0.183	-0.160	-0.012
TSS	**-0.313**	0.192	-0.126	-0.099	**0.500**	-0.347	0.067	**-0.514**	-0.357	0.254	0.090	0.016
DO	**0.344**	-0.178	-0.060	-0.096	-0.138	-0.182	-0.294	**-0.568**	-0.039	**-0.490**	**-0.362**	0.054
BOD	**-0.354**	-0.053	0.157	0.283	-0.181	0.363	0.093	-0.276	0.002	0.083	-0.176	**0.693**
COD	**-0.356**	-0.059	0.143	0.283	-0.191	0.312	0.009	-0.357	0.050	-0.001	-0.051	**-0.707**
NH_4^+-N	**-0.321**	-0.213	0.027	0.037	**0.507**	-0.064	**-0.443**	0.147	**0.542**	-0.020	-0.277	0.013
NO_2^--N	**-0.336**	0.162	0.051	0.165	0.167	-0.263	**0.634**	0.089	0.218	-0.506	-0.223	-0.017
NO_3^--N	**-0.318**	-0.172	**0.539**	**-0.433**	-0.031	0.064	-0.321	0.105	-0.202	**-0.376**	0.119	0.029
PO_4^{3-}-P	**-0.318**	-0.172	-0.049	**-0.433**	-0.031	0.246	-0.172	0.304	**-0.584**	-0.082	**-0.380**	-0.066
Coliforms	-0.298	0.157	0.080	0.027	**-0.584**	**-0.597**	-0.314	0.094	0.035	0.253	-0.094	0.016
Fe	**-0.342**	-0.167	-0.189	-0.282	-0.146	0.077	-0.224	-0.095	0.095	**-0.363**	**0.708**	0.108
Eigenvalue	6.30	1.70	1.08	0.88	0.54	0.46	0.31	0.24	0.21	0.19	0.10	0.01
%Variation	52.5	14.2	9.0	7.4	4.5	3.8	2.6	2.0	1.7	1.6	0.8	0.1
Cum.%var.	52.5	66.7	75.6	83.0	87.4	91.2	93.8	95.8	97.5	99.1	99.9	100.0

Note: Bold values indicate weak, moderate and strong correlation between PCs and original variables

PC1, PC5, PC7, and PC9 were correlated with the fluctuations of NH_4^+_N by -0.321, 0.507, -0.443, and 0.542, respectively. This could mean that there were many sources of NH_4^+_N release such as fertilizer application, biodegradation of organic matters, and natural factors that affect these two processes (Zeinalzadeh and Rezaei, 2017).

NO_2^-_N had a moderate correlation with PC7 (0.634), however NO_2^-_N was formed mainly due to the effect of microorganisms in the presence of NH_4^+_N and DO (Giao et al., 2017). PCA results also showed that NO_3^-_N had a weak relationship with PC3 (0.539), PC4 (-0.433), and PC10 (-0.376) impling that the source of NO_3^-_N in water environment is quite a diversity including agricultural fertilizers and the presence of NH_4^+_N metabolites under aerobic conditions. Previous research has shown that the presence of NO_3^-_N in river water was greatly influenced by human activities (Zeinalzadeh and Rezaei, 2017). PO_4^{3-}_P had a weak relationship with PC4 (-0.433), PC9 (-0.584), and PC11 (-0.380). It could mean that there were many factors leading to the fluctuation of orthophosphate concentration in the surface water environment in Hau Giang Province such as fertilizers, washing powders, and the decomposition of wastes and plant and animal residues (Bolstad and Swank, 1997; Barakat et al., 2016; Zeinalzadeh and Rezaei, 2017; Chounlamany et al., 2017). The major sources of the presence of coliforms in surface water in Hau Giang Province were PC5 (-0.584) and PC6 (-0.597). These sources might be from humans and animals through excretion that is not well-managed (Bolstad and Swank, 1997; UNICEF, 2008). Iron (Fe) was an important contribution by the PC11 source with a correlation coefficient of 0.708. Hau Giang is a heavy acid sulfate soil so this PC11 was a great source represents the natural conditions of the acid sulphate soils. In addition, PC10 also contributed weakly (-0.363) in explaining the fluctuation of iron concentration in the surface water environment of Hau Giang Province in 2019.

PCA results showed that all indicators (pH, temperature, TSS, DO, BOD, COD, NH_4^+_N, NO_2^-_N, NO_3^-_N, PO_4^{3-}_P, coliforms, and Fe) have significant impacts on surface water quality in Hau Giang Province. Thus, it is necessary to continue monitoring these water quality parameters in surface water monitoring program. However, NO_2^-_N might not be needed because they could be predicted by the concentration of NH_4^+_N, NO_3^-_N, and DO. The COD/BOD ratio ranged from 1.5-1.8 (averaged at 1.7), so it is possible to choose one of the two indicators for analysis and reduce cost savings. This is entirely appropriate under condition that the province has a limit of funding for environmental monitoring.

4. CONCLUSION

The water quality in Hau Giang Province in 2019 was assessed to be contaminated by organic matters, nutrients, coliforms, and iron. Most of the monitoring parameters were over the national standard (QCVN 08-MT: 2015/BTNMT). The Hau River section flowing through Hau Giang Province was less polluted than the other canals and rivers in the study. The CA results determined that it is highly possible to monitor 26 locations instead of the current 42 locations while ensuring representative for the water monitoring of the study area. This new monitoring program possibly saves monitoring costs by up to 32%. The PCA results demonstrated that there were 12 PCs contributing to the change in water quality in Hau Giang Province. In which, PC1, PC2, and PC3 were the three main sources explaining up to 75.6% of the water quality variation leading to water pollution. The results also showed that all the water quality parameters significantly influenced the surface water quality in Hau Giang Province in 2019. To reach cost efficiency, NO_2^-_N, and BOD or COD indicators are considered for reductions because it could be predicted by the concentrations of the other available related parameters. Subsequent studies will need to investigate specifically for each different source of pollution in different canals that facilitate appropriate management strategies to improve surface water quality in Hau Giang Province.

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