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Assessment of Surface Water Quality in the Hau Giang Province Using GIS and Statistical Approaches

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ABSTRACT

The study aimed to assess the surface water quality in the Hau Giang province in 2021 at 44 locations (with a frequency of 5 times per year) using Principal Component Analysis (PCA), Cluster Analysis (CA) and GIS. Surface water quality was compared with the national technical regulation on surface water quality (QCVN 08-MT:2015/BTNMT, column A1) and Water Quality Index (WQI). The results showed that the surface water quality parameters of total suspended solids, organic matters, nutrients, coliform, and Fe far exceeded the allowable limits, while the Cl^-, color, and CN^- parameters were within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1. The values of WQI showed that the water quality of the Hau Giang province ranged from poor to excellent. The water quality at the Vam Cai Dau and Hau River areas could only be exploited for water supply, but appropriate treatment is needed. CA divided the monitoring months into three distinct clusters and reduced the sampling sites from 44 to 33 locations, reducing 25% of monitoring cost per year. PCA revealed three main factors which could explain 69.0% of the variation in water quality. The water pollution sources were mainly industrial and agricultural discharges, domestic and urban activities, transportation activities, salinity, hydrological conditions and water runoff. The current findings provide useful information which support local environmental managers and water supply companies for safe and sustainable.

Keywords: GIS, multivariate statistical, water quality index, water supply.

INTRODUCTION

In recent years, Hau Giang has become one of the most economically developed provinces in the Mekong Delta. The province not only promotes the strengths of the agricultural economy (growing rice, orchards) but also develops in industry and construction with a GRDP of 5.32% in 2021 (DONRE, 2021). In addition, Hau Giang has a river network which is very convenient in developing freshwater aquaculture, serving waterway traffic and providing water supply for citizens. However, the impact of climate change and socio-economic development activities have degraded the water quality and limited surface water source for domestic use. Hence, assessing the water quality from rivers and canals is an important part of determining the areas acceptable for domestic water supply in the Hau Giang province.

Geographical Information System (GIS) is a useful tool for surface water quality mapping and essential for monitoring the water quality changes over a long period of time. (Ramaraju and Giridhar, 2015). Currently, many studies have utilized GIS for spatial assessment on water quality. Huy (2016) applied GIS for mapping surface water pollution in Cam Pha city, Quang Ninh province. Hoa and Long (2016) assessed the surface water quality of the Saigon River using GIS. Tuan et al. (2020) evaluated the salinity status during 2016–2017 in three provinces of Can Tho, Hau Giang and Soc Trang by GIS-based interpolation. However, there is quite a few studies using GIS to assess the surface water quality in the Hau Giang province and explore the spatial distribution of water quality parameters. In the present study, the surface water quality in the Hau Giang province was classified by water quality index (WQI) and

GIS. Moreover, multivariate statistical methods (CA and PCA) help to group and reduce the similar sampling sites to save cost and time monitoring as well as identify the key parameters affecting the surface water quality in the Hau Giang province in 2021. The research results provide useful information to assist environmental managers and water supply companies to secure a sustainable water supply.

METHODOLOGY

Study area

The Hau Giang province is located in the center of the Mekong Delta with a natural area of 160,058.69 km^2, accounting for about 4% of the area of the Mekong Delta and 0.4% of the total area of Vietnam. The North borders Can Tho City, the South borders Soc Trang Province, the East borders Hau River and Vinh Long Province, whereas the West borders Kien Giang and Bac Lieu Provinces. Hau Giang has 8 administrative units, including Vi Thanh city, Nga Bay city, Long My town, Phung Hiep district, Long My district, Vi Thuy district, Chau Thanh district, and Chau Thanh A district. The terrain is lower from north to south and from east to west. Similarly to other provinces in the Mekong Delta, Hau Giang has a tropical monsoon climate with rainy seasons (May to November) and dry seasons (December to April next year) distinct. The average annual temperature is 27°C, the average rainfall is about 1800 mm and the average humidity in the year is 82%. The Hau Giang province has a dense system of rivers and canals with 6 main rivers and canals including Cai Lon River, Vam Mai Dam, Xang Xa No Canal, Lai Hieu Canal, Quan Lo - Phung Hiep Canal and Xang Nang Mau Canal. Therefore, Hau Giang has a lot of potential to attract investors and is suitable for developing a tropical agricultural economy. With this development, the urban and rural environment of the Hau Giang province is increasingly polluted by industrial and agricultural discharges in the province. The sampling locations are shown in Figure 1.

Water sampling and analysis

Water quality monitoring data were collected from Hau Giang Department of Natural Resources and Environment in 2021. The water samples were collected at 44 locations including 5 locations in Vi Thanh city (NM01, NM02, NM03, NM04 and NM43), 4 locations in Nga Bay city (NM22, NM23, NM24 and NM52), 4 locations in Long My town (NM32, NM35, NM55 and NM56), 04 locations in Vi Thuy district (NM05, NM06, NM07 and NM08), 5 locations in Long My district (NM34, NM57, NM58, NM59 and NM62), 5 locations in Chau Thanh A district (NM09, NM10, NM11, NM12 and NM42), 7

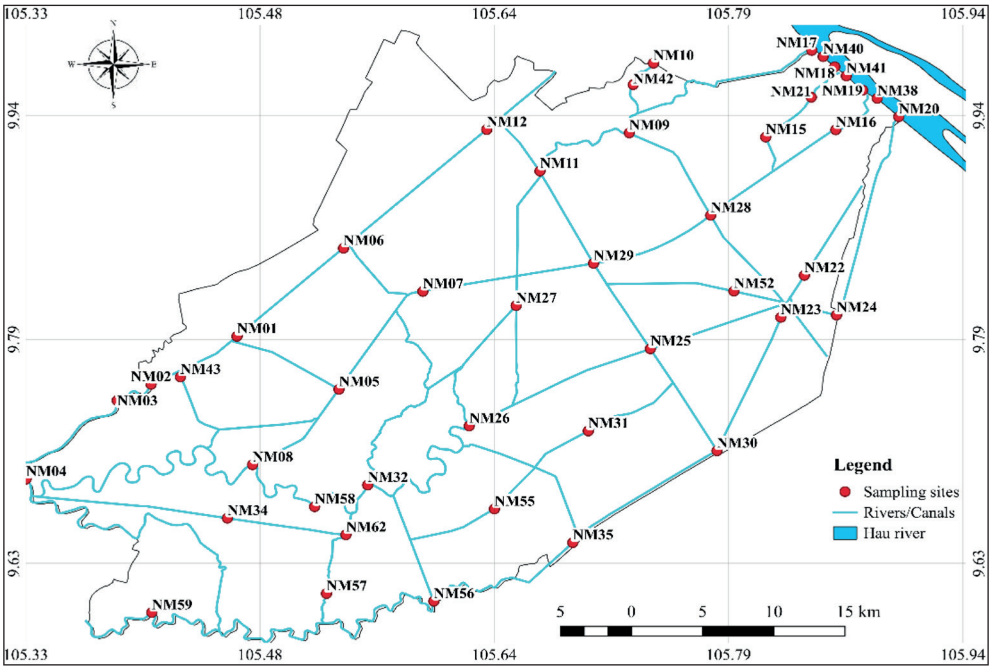

Figure 1. Sampling location in Hau Giang in 2021

locations in Phung Hiep district (NM25, NM26, NM27, NM28, NM29, NM30 and NM31) and 10 locations in Chau Thanh district (NM15, NM16, NM17, NM18, NM19, NM20, NM21, NM38, NM40, NM41) with a frequency of 5 times/year (April, May, June, October and November). The surface water quality parameters, including Temperature, pH, Dissolved Oxygen (DO), Color, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonium ($N\text{-}NH_4^+$), Nitrate ($N\text{-}NO_3^-$), Nitrite ($N\text{-}NO_2^-$), Orthophosphate ($P\text{-}PO_4^{3-}$), Chloride (Cl^-), Total Iron (Fe), Cyanide (CN^-) and Coliform, were used to assess the water quality and as input data in multivariate statistical analysis. The water samples collected and the preserved surface water samples comply with the current Vietnamese standards (TCVN 6663-6:2018; TCVN 6663-3:2016; TCVN 6663-3:2008-ISO 5667-3:2003; TCVN 8880:2011). The parameters of pH, temperature and DO were measured in the field while the remaining parameters were analyzed in the laboratory by using standard methods (APHA, 2012). The criteria, units, analytical methods and allowable limits are presented in Table 1.

Data analysis

The surface water quality data were averaged before statistical analysis and compared with National Technical Regulation on surface water quality QCVN 08-MT:2015/BTNMT, column A1 (MONRE, 2015). One-way analysis of variance (One-Way ANOVA) and Duncan's calculation at 5% significance level were used to compare the difference in surface water quality over time using the IBM SPSS 20.0 for Windows (IBM Corp., Armonk, NY, USA). Principal Component Analysis (PCA) and Cluster Analysis (CA) are used to minimize a large number of variables but retain as much information as possible (Singh et al., 2017). In this study, PCA was used to determine the parameters having the greatest effect on the water quality in the Hau Giang province, while CA analysis was used to group water quality at sampling locations and months by means of Ward method and Euclidean distance (Ibrahim, 2015). PCA and CA were analyzed using the license software Primer V5.2 for Windows (PRIMER-E Ltd, Plymouth, UK).

The WQI water quality index was calculated according to the guidance of the Vietnam Environment Administration (VEA, 2019) according to the formula (1) for 03 groups of parameters and was presented in the form of a map through the software QGIS version 3.16 (Open-Source Geospatial Foundation- OSGeo, Chicago, IL, USA). Then the colors will be shown based on the previous WQI results.

$$WQI = \frac{WQI_I}{100} \times \left[\left(\frac{1}{k}\sum_{i=1}^{k} WQI_{IV}\right)^2 \times \frac{1}{l}\sum_{i=1}^{l} WQI_V\right]^{\frac{1}{3}} \quad (1)$$

where: WQI_I – calculated WQI value for pH parameter; WQI_{IV} – WQI value calculated for 08 parameters: DO, BOD_5, COD, TOC, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$ and $P\text{-}PO_4^{3-}$; WQI_V – calculated WQI value for the coliform.

Table 1. Variables, analytical methods, and limits of surface water quality

Parameters	Meaning	Unit	Analytical methods	QCVN, A1
pH	pH	-	TCVN 6492:2011	6–8.5
Temp	Temperature	°C	SMEWW 2550B:2017	-
Color	Color	mg/l Pt	TCVN 6185:2008	-
DO	Dissolved oxygen	mg/l	TCVN 7325:2004	≥ 6
BOD	Biological oxygen demand	mg/l	TCVN 6001-1:2008	4
COD	Chemical oxygen demand	mg/l	SMEWW 5220C:2012	10
TSS	Total suspended solids	mg/l	TCVN 6625:2000	20
$N\text{-}NH^4+$	Ammonium	mg/l	TCVN 6179-1:1996	0.3
Fe	Iron	mg/l	TCVN 6177:1996	0.5
$N\text{-}NO^2-$	Nitrite	mg/l	TCVN 6178:1996	0.05
$N\text{-}NO^3-$	Nitrate	mg/l	TCVN 6180:1996	2
$P\text{-}PO_4^3-$	Phosphate	mg/l	TCVN 6202:2008	0.1
C^l-	Chloride	mg/l	TCVN 6194:1996	250
CN^-	Cyanide	mg/l	SMEWW4500-CN- C&E:2012	0.05
Coliform	Coliform	MPN / 100ml	TCVN 6187-2:1996	2500

Water quality is classified into 6 levels. Level 1 (WQI = 91-100, excellent) is used for domestic water supply purposes. Level 2 (WQI = 76–90, good) is used for domestic water supply purposes but needs appropriate treatment measures. Level 3 (WQI = 51–75, medium) is used for irrigation and other equivalent purposes. Level 4 (WQI = 26–50, bad) is used for navigation and other equivalent purposes. Level 5 (WQI = 10–25, poor) water is heavily polluted and needs future treatment measures. Level 6 (WQI < 10, highly polluted) is contaminated water which needs remedial measures.

RESULTS AND DISCUSSION

Spatial and temporal variability of water quality

Temporal variations of surface water quality

The water quality in the Hau Giang province through 5 monitoring periods of 15 water quality parameters was included in the cluster analysis. The results are presented in the form of a Dendrogram (Figure 2). The water quality can be represented by three temporal clusters at the Euclidean distance of 5. The first period included April, representing the dry season in the Hau Giang province. Cluster 2 includes May and June, corresponding to the rainy season in the study area. The third period includes October and November which are the last two months of the rainy season, representing the transition period to the dry season. Cluster 1 was clearly separated because of Fe and $P\text{-}PO_4^{3-}$ parameters (Table 2). Cluster 2 was the lowest concentration of pollutants between three clusters, characterized by the BOD, COD and $N\text{-}NO_2^-$ parameters with the values of 2.81, 1.98 and 1.56 respectively compared to QCVN 08-MT:2015/ BTNMT. Cluster 3 had the highest TSS and coliform content (2.74 and 3.81 times higher than the standard) compared to cluster 1 and cluster 2. The results showed that the frequency of water sampling in the Hau Giang province should be done at least three times, corresponding to three clusters of water quality monitoring.

Spatial variations of surface water quality

The cluster analysis used the average value of 15 water quality parameters at 44 monitoring locations in the Hau Giang province in 2021 (Figure 3). At the Euclidean distance of 3, the sampling sites were classified into 10 groups. Meanwhile, NM41 of cluster 1, NM04 of cluster 4, NM31 of cluster 5 and NM58 of cluster 6 need to be monitored independently in the future monitoring program. Cluster 2 and 9 both have two sampling sites, including NM38 and NM40 (cluster 2); NM23 and NM24 (cluster 9). The two monitoring sites in cluster 2 are located on the Hau River, so NM40 can be removed. In contrast, the two monitoring locations of cluster 9 which they are in the same group but in different rivers, the monitoring points are still selected for coming year monitoring. Similarly to cluster 9, cluster 3 has three similar positions including NM01, NM10 and NM26, all of which are retained for further monitoring. The sites from NM17 to NM21 in cluster 7 are located along the Hau River. In case the group has many monitoring points in the same area, it is possible to choose a representative location for the remaining locations. Thus, NM18 and NM20 were selected to monitor the water

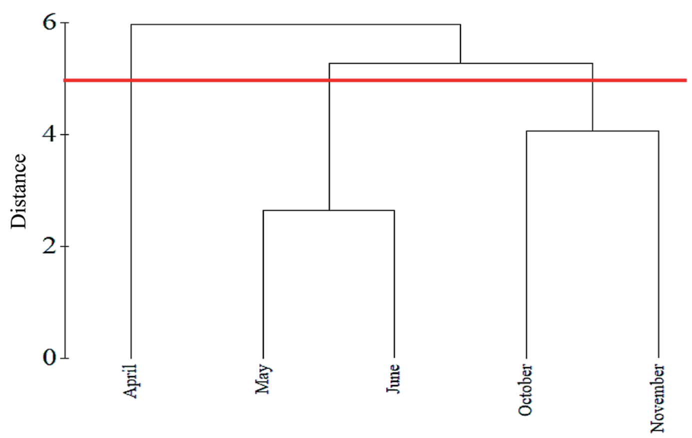

Figure 2. Clustering temporal similarities of monitoring periods

Table 2. Surface water quality in the identified clusters

Parameter	Unit	Cluster 1	Cluster 2	Cluster 3	QCVN, A1
pH	-	6.89	6.77	6.76	6-8.5
Temperature	°C	28.99	29.00	29.30	-
DO	mg/l	3.36	3.18	3.33	6
TSS	mg/l	48.26	38.53	54.72	20
Cl^-	mg/l	8.93	2.11	1.53	250
Color	mg/l Pt	0.00	0.89	0.88	-
$N\text{-}NH_4^+$	mg/l	0.23	0.40	0.19	0.3
$N\text{-}NO_2^-$	mg/l	0.06	0.08	0.05	0.05
$N\text{-}NO_3^-$	mg/l	0.46	0.58	0.45	2
$P\text{-}PO_4^{3-}$	mg/l	0.18	0.17	0.13	0.1
BOD	mg/l	9.02	11.23	9.93	4
COD	mg/l	15.23	19.75	17.17	10
CN^-	mg/l	0.00	0.00	0.00	0.05
Coliforms	mg/l	8179.55	8748.86	9522.73	2500
Fe	MPN/100ml	1.24	0.97	0.89	0.5

quality in the Hau River. Cluster 8 and cluster 10 consisted of 11 and 16 sampling sites with similar water quality, respectively. The number of sampling sites in cluster 8 can be reduced from 11 to 9 locations, including NM02, NM08, NM34, NM42, NM43, NM55, NM56, NM57 and NM59. Similarly, cluster 10 can be reduced to 12 positions including NM03, NM05, NM06, NM09, NM12, NM22, NM25, NM27, NM28, NM32, NM35 and NM52. The results could be utilized in reducing the sampling locations in the same rivers and canals. The total number of 44 positions in thr Hau Giang province in 2021 could be reduced to 33 locations, saving 25% of monitoring costs per year.

Temporal assessment of surface water quality in the Hau Giang province

From the CA results, the temporal variation of surface water quality is assessed by period 1 (April), period 2 (May and June) and period 3 (October and November). The parameter of temperature and pH did not have large fluctuations which was within the tolerance limit of aquatic organisms. The average values over 3 periods ranged from 28.99±0.23°C – 29.30±0.38°C and 6.76±0.23 – 6.89±0.09, respectively. ANOVA analysis showed a statistically significant difference in temperature and pH between period 1 and period 3 ($p<0.05$). The parameters of Cl^-, color and CN^- in the three periods were all very small

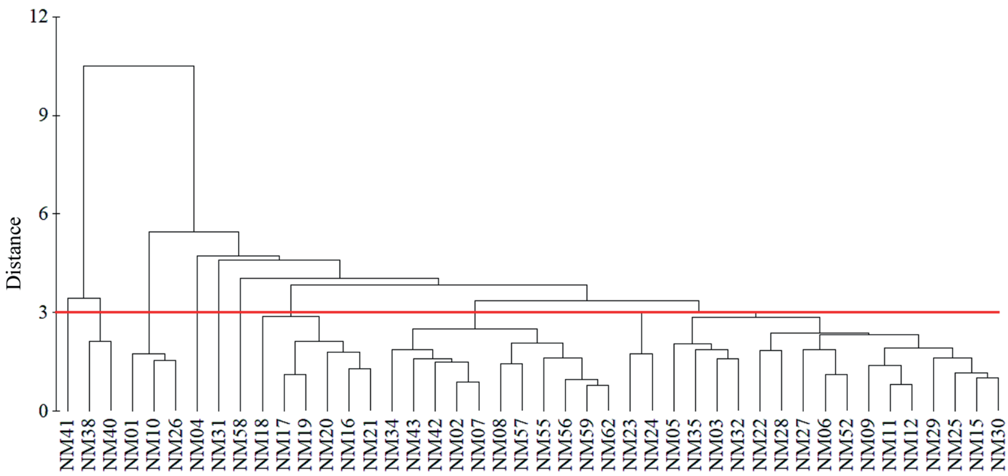

Figure 3. Clustering locations of surface water quality

values or below the detection threshold. Meanwhile, Cl^- and CN^- are within the allowable limits of QCVN 08-MT:2015/BTNMT column A1 (250 mg/L and 0.05 mg/L). The Cl^-, color and CN^- parameters had no statistically significant difference over 3 periods ($p>0.05$).

The results of the surface water quality analysis in the Hau Giang province of the remaining 10 parameters compared with QCVN 08-MT:2015/BTNMT column A1 are presented in the form of a histogram (Figure 4). DO and $N\text{-}NO_3^-$ concentration between three periods are within the limit of QCVN 08-MT:2015/BTNMT (6 mg/L and 2 mg/L), ranging from 3.18±0.86 mg/L to 3.36±0.70 mg/L and 0.45±0.17 mg/L to 0.58±0.15 mg/L. The $N\text{-}NO_3^-$ levels were statistically significant between period 2 compared to period 1 and period 3, while there was no statistically significant difference for the DO value over three periods ($p>0.05$). The surface water quality in most provinces in the Mekong Delta has low DO content, which is not really suitable for aquatic life (Nguyen Thanh Tam et al., 2022; Tuan et al., 2020). The average TSS concentration in period 3 with 100% of sampling sites exceeded the allowable limit from 2.74 times when compared with QCVN 08-MT:2015/BTNMT (20 mg/L) with an average value of 54.72±11.47 mg/L. Similarly to the TSS value, BOD and COD have quite high pollution frequency. The BOD levels in three periods had 100% of sampling sites exceeding the prescribed limit of QCVN 08-MT:2015/BTNMT (4 mg/L) (9.02±2.89 – 11.23±2.08 mg/L). Meanwhile, the COD content only in period 2 had 100% sampling locations exceeding the limit of QCVN 08-MT:2015/BTNMT column A1 (10 mg/L) with an average value of 19.75±4.23 mg/L. The parameters of TSS, BOD and COD are statistically significant ($p<0.05$) over three periods. In general, the TSS and BOD concentrations tend to increase gradually at the end of the rainy season (October and November). The water quality in the Hau Giang province is still polluted by organic matters, suspended solids and BOD and COD concentrations are higher than in 2019 (7.30±3.90-8.30±3.40 mg/L and 12.0±7.10-12.80±8.90 mg/L) (Giao, 2020). The $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ contents in period 2 both had a relatively high occurrence frequency of 45% and 77% respectively, exceeding the allowable limit of QCVN 08-MT:2015/BTNMT column A1 (0.3 mg/L and 0.05 mg/L). The average values of $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ ranged from 0.19±0.18 – 0.40±0.34 mg/L and 0.05±0.05 – 0.08±0.04 mg/L, respectively. The concentrations of $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ in the second period were statistically significant, compared to the first period and third period ($p<0.05$). Compared with the study by Nguyen Thanh Tam et al. (2022), the $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ levels were lower in the study area (0.56 mg/L and 0.55 mg/L). However, the presence of $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ indicates contaminated water and is toxic to aquatic organisms (Drasovean and Murariu, 2021). The frequency of sampling locations exceeding the limit of QCVN 08-MT:2015/BTNMT column A1 of parameter $P\text{-}PO_4^{3-}$ in three periods was 86%, 93% and 68% (0.1 mg/L) respectively, ranging from 0.13±0.04 to 0.18±0.06 mg/L. Periods 1 and 2 have a statistically significant difference compared with period 3 ($p<0.05$). $P\text{-}PO_4^{3-}$ is also considered an important parameter in assessing the water quality for water supply

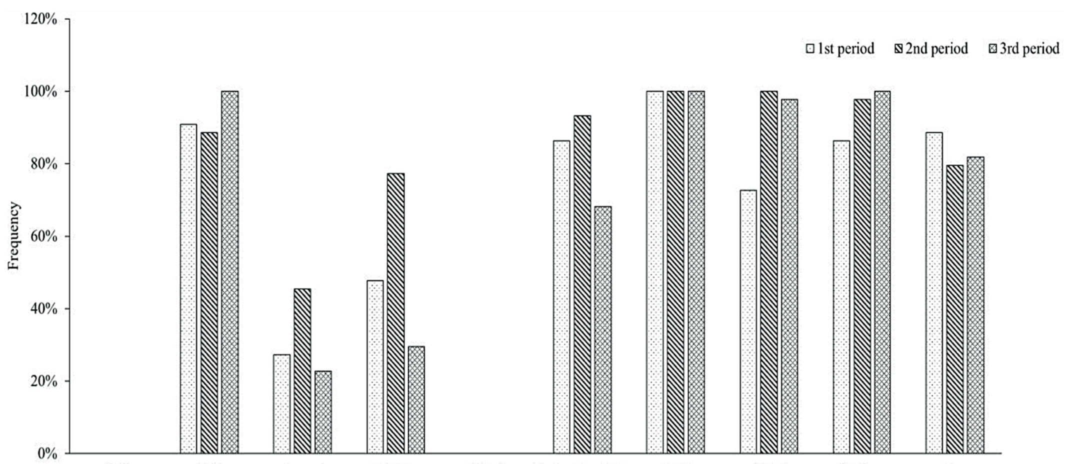

Figure 4. Frequency of parameters in the Hau Giang province in 2021

purposes in Mekong Delta. The sources of $P\text{-}PO_4^{3-}$ in the water environment are agricultural fertilizers, industrial and domestic wastes (Barakat et al., 2016). Generally, the water quality in study area has the potential for eutrophication. The coliform concentration in period 3 had 100% of the sampling sites, exceeding the permitted limit from 3.81 times when compared with QCVN 08-MT:2015/BTNMT column A1 (2500 MPN/100mL) with the average value of 9522.73±5207.55 MPN/100 mL. There was no statistically significant difference at the 5% level over three periods ($p>0.05$). Previous studies have shown that the surface water in the Mekong Delta has been seriously polluted from human and animal uses (Giau et al., 2019; Tuan et al., 2020). Fe in period 1 had 89% of sampling locations exceeding the allowable limit of QCVN 08-MT:2015/BTNMT column A1 (0.5 mg/L) and significantly different from the other two periods ($p<0.05$). The Hau Giang province is located on an alkaline soil containing a lot of iron, so the water environment also has a high iron content. However, high iron levels can increase the water treatment costs and affect people's health when using this water source for domestic water supply (Hasan et al., 2021). It can be seen that the water quality in the study area is only suitable for a living when appropriate treatment technologies are applied.

Spatial assessment of surface water quality in the Hau Giang province

Spatial variation of water quality index

The surface water quality index (VN_WQI) in the Hau Giang province in 2021 at 44 monitoring locations are shown in Figure 5. The results show that VN_WQI values range from 23 to 96 over three periods. Water quality is divided into 5 groups from poor (red) to excellent (blue). Figure 5 also shows that there are no sampling sites with water quality in the highly polluted group all three periods in the province. In the first period, there are two locations (NM01 and NM06) belonging to the group of poor water quality with a VN_WQI value of 25. The monitoring locations have a VN_WQI value from 26 to 75, accounting for 68.18% belonging to the group with a water quality from 26 to 75 (from bad to medium). The quality group from good to excellent all accounted for 13.64%, including positions NM15, NM17, NM18, NM21, NM57, NM58 (with a VN_WQI value from 76 to 90) and NM19, NM20, NM31,

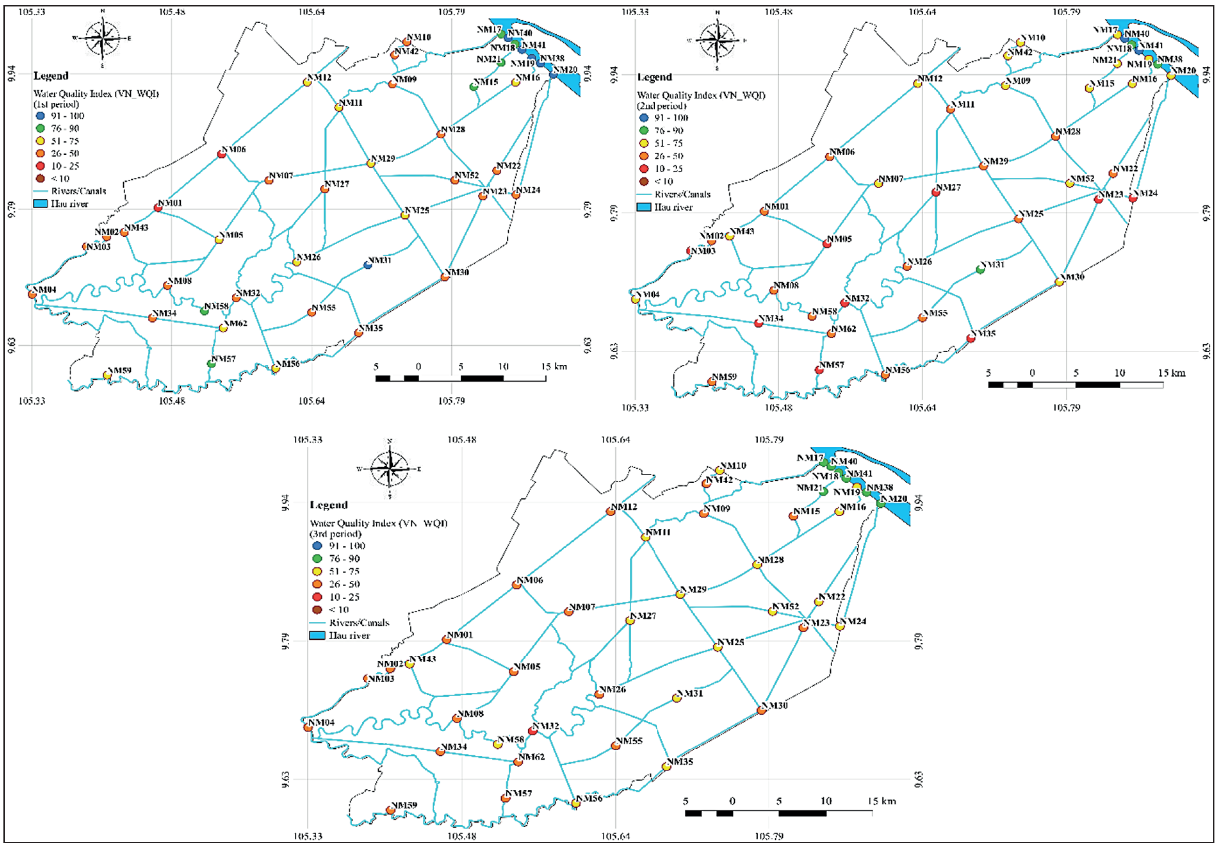

Figure 5. Map of surface water quality index in the Hau Giang province in 2021

NM38, NM40, NM41 (with a VN_WQI value from 91 to 100). In the second period, there are 9 monitoring locations belonging to the group of poor water quality (20.45%). Similarly to period 1, the group of poor to medium water quality accounted for 68.18%, corresponding to 15 locations in each group. Only 5 positions, including NM18, NM31, NM38, NM40 and NM41 belong to the quality group from good to excellent with values of 78, 81, 87, 92 and 92, respectively. In the third period, only NM32 has a VN_WQI value of 24 in the group of poor water quality. The group of bad to medium water quality in this period accounted for 81.82%. The group of good water quality (from 76 to 90) recorded in 7 locations, including NM17, NM18, NM20, NM21, NM38, NM40 and NM41 (15.91%). None of the positions in the third period were in the excellent quality (from 91 to 100). It can be seen that the water quality in period 2 is more polluted than in period 1 and period 3. Four locations, i.e. NM18, NM38, NM40 and NM41, have better water quality than the remaining locations over three periods. Therefore, these areas are suitable for domestic water supply purposes, but treatment measures must still be taken. The water quality of the Hau Giang province in 2021 has better than the water quality of the An Giang province (Giao and Nhien, 2021) and the Bac Lieu province (Huynh Phu, 2021).

Spatial variability of water quality parameters in the Hau Giang province in 2021

The spatial distribution map of 10 water quality parameters in the study area is shown in Figures 6 and 7. The spatial distribution was performed to consider the change in concentration of water quality parameters at 44 sampling sites. The lowest value is represented in light red color and the highest value is represented in dark red color for 10 different water quality parameters. Figure 6 shows that high DO values (3.67–4.66 mg/L) as well as low BOD and COD values (6.40–8.55 mg/L and 10.60–14.95 mg/L) were recorded in the area near the Hau River (from NM17 to NM21). It can be seen that the water quality in this area is not as heavily polluted by organic contaminants as other locations in the inner province. The sampling sites with high BOD and COD concentrations are often located near industrial zones (such as NM02 - Vi Thanh Sugar Factory), agricultural production

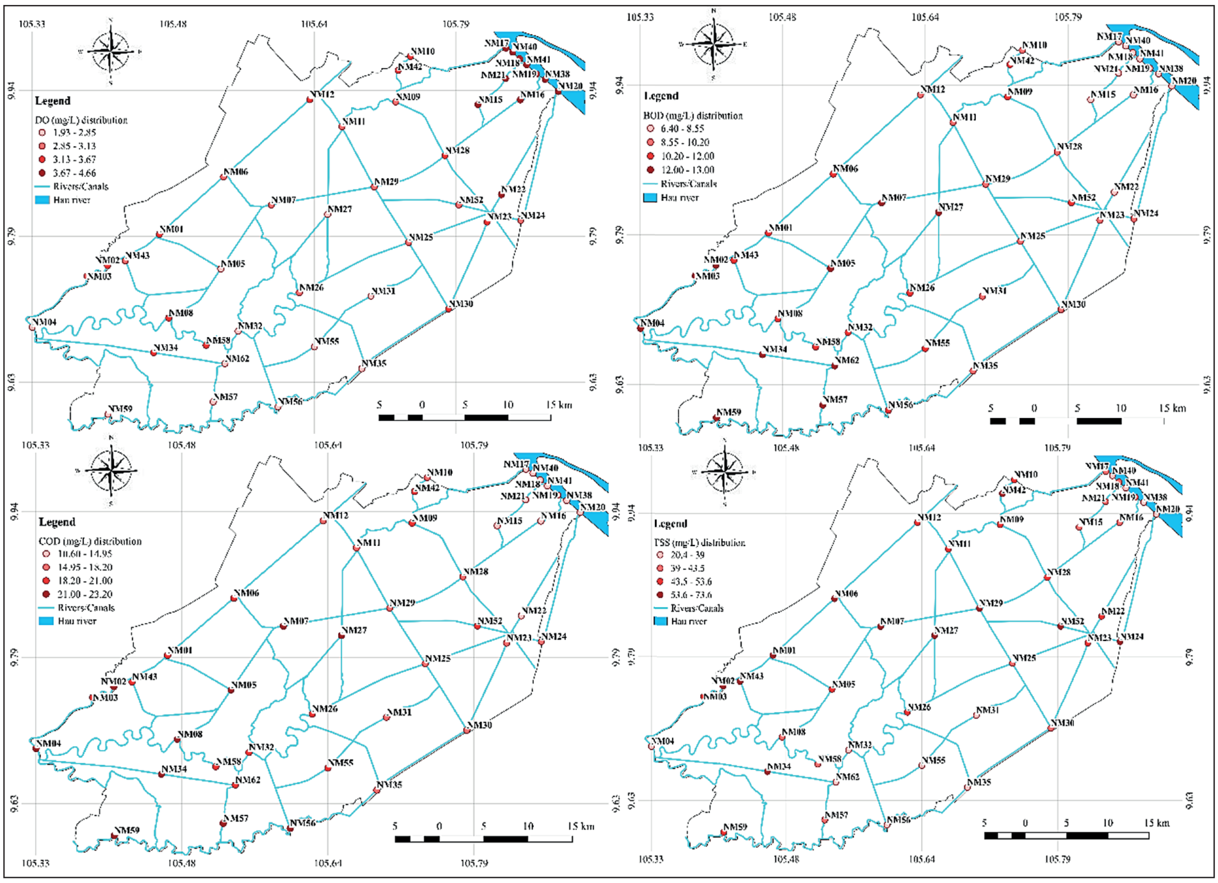

Figure 6. Spatial distribution map of DO, BOD, COD and TSS

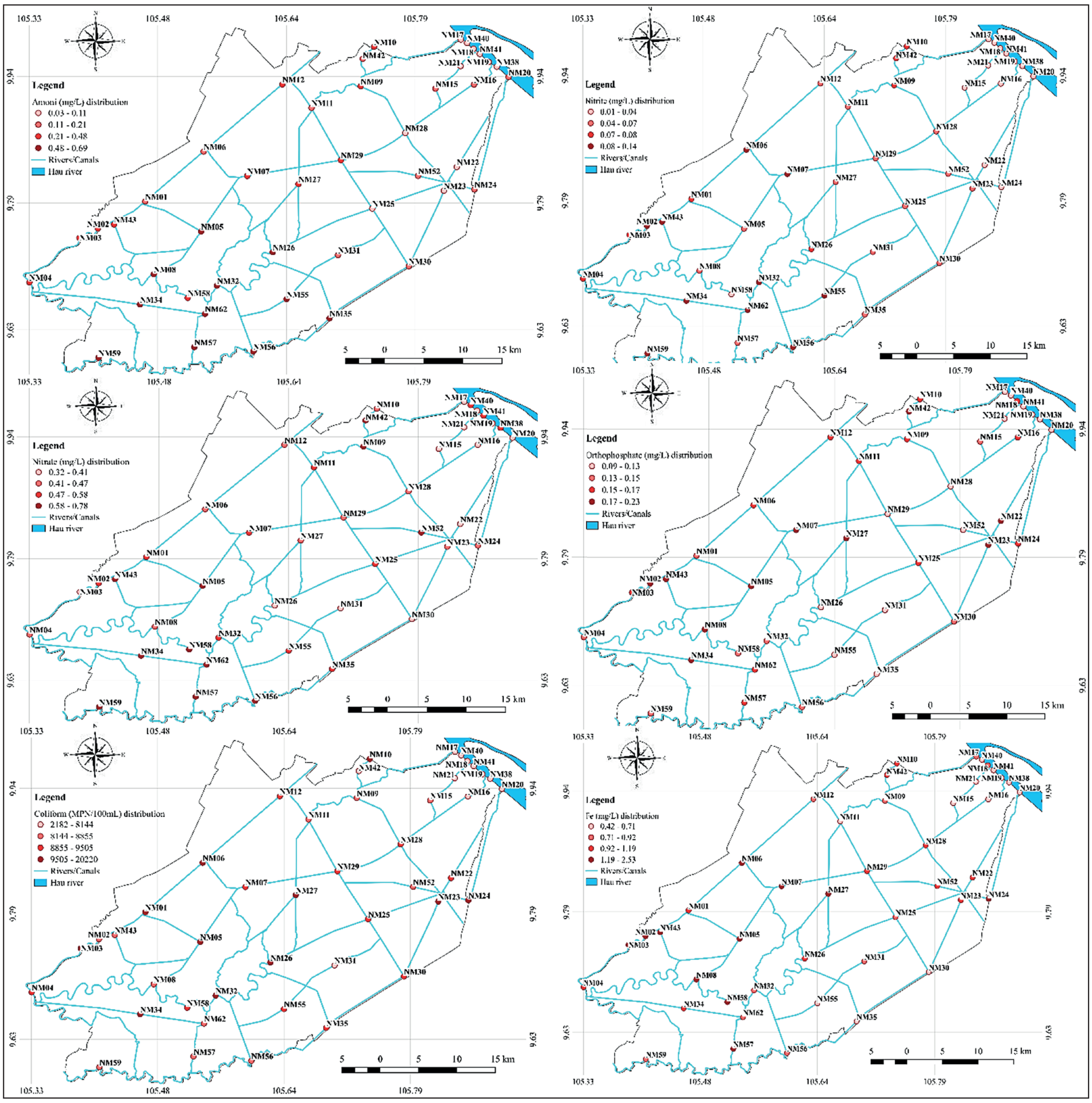

Figure 7. Spatial distribution map of nutrients, coliform and Fe

activities, urban areas, and at the intersection rivers or adjacent provinces. High TSS concentrations (53.6–73.6 mg/L) are common in the areas affected by harbor areas (such as locations NM29, NM42 and NM52), industrial activity (NM43) and agricultural activities (NM06 and NM07).

The spatial distribution of nutrients (N-NH_4^+, N-NO_2^-, N-NO_3^- and P-PO_4^{3-}) is usually concentrated in agricultural areas (livestock, growing rice), such as NM06 and NM07; the high population density areas (residential areas, markets), such as NM05, NM08 and NM34; the intersection rivers or adjacent provinces, such as NM26, NM32, NM35, NM56, NM59 and NM62; industrial areas, such as NM02 and NM23 - Vi Thanh and Phung Hiep sugar factories. The monitoring sites with high coliform content (9505 – 20220 MPN/100mL) are distributed in market and residential areas (such as NM26, NM27 and NM34) and at the intersection rivers or adjacent provinces (such as NM10 - adjacent to Can Tho city, NM23 and NM24 - adjacent to Soc Trang province, NM01, NM05 and NM32). The distribution of Fe in the study area is more stable than that of other parameters. Because the Hau Giang province is an alkaline soil containing a lot of iron. In general, the locations with the iron content from 1.19 to 2.53 mg/L are usually located in the southeast of the province, especially in the developed industrial and agricultural activities (NM02, NM57 and NM58) and in landfill sites

(NM27 and NM28). It can be seen that the water quality in the areas along the Hau River will be more suitable for domestic water supply purposes.

Key water quality parameters affecting the Hau Giang province surface water quality in 2021

The eigenvalues of each principal component are shown in the form of a Scree Plot in Figure 8. It can be seen that the eigenvalues are sorted from large to small and there is a significant change in slope after the third principal component. The first three principal components with eigenvalue > 1 should be kept, which explained 69.0% of variation in water quality. Figure 9 presents the factor loadings of these 3 PCs for 14 parameters as a column graph. Factors loading are classified as strong, average and weak with absolute values greater than 0.75, from 0.75 to 0.50 and from 0.50

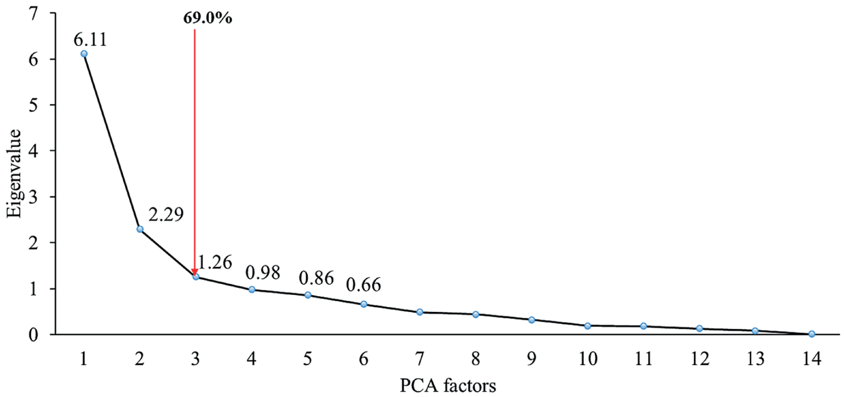

Figure 8. The scree plot of eigenvalues

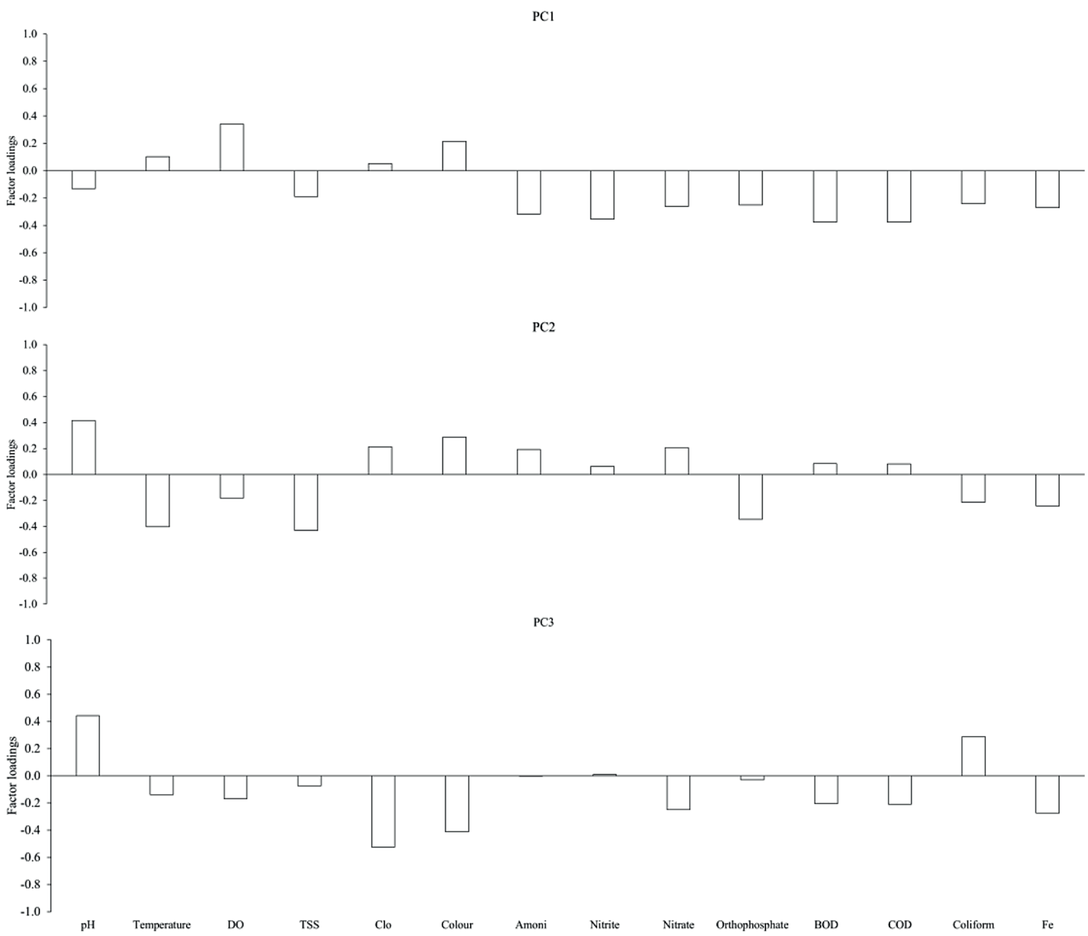

Figure 9. Factor loadings of PCA on 14 water quality parameters

to 0.30 respectively (Barakat et al., 2016). PC1 explained 43.7% of the variation of DO (0.341), $N-NH_4^+$ (-0.316), $N-NO_2^-$ (-0.355), BOD (-0.376) and COD (-0.377), which was weakly correlated. This source includes organic pollution that consume oxygen, nutrients, which may be related to the influences by domestic wastewater, agricultural wastes and industrial activities. According to Yang et al. (2020), nutrient pollution and organic pollution are the main potential factors affecting surface water quality. PC2 was weakly correlated by pH (0.417), temperature (-0.401), TSS (-0.429) and $P-PO_4^{3-}$ (-0.344), explaining 16.4% of the variation. This source is mainly influenced by hydrological conditions, transportation activities, stormwater runoff and agricultural activities. PC3 (9.0% of the variation) was contributed by pH (0.441), color (-0.411) and Cl^- (-0.525) from weak to moderate. This source is mainly influenced by salinity (Cl^-). The water quality indicators should be accounted in the water monitoring program, including pH, temperature, color, DO, TSS, BOD, COD, $N-NH_4^+$, $N-NO_2^-$, $P-PO_4^{3-}$ and Cl^-. The water quality in the study area was influenced by industrial, agricultural and domestic activities, transportation activities, salinity, hydrological conditions and stormwater runoff.

CONCLUSIONS

The study demonstrated that the surface water quality in the Hau Giang province in 2021 is contaminated with organic and micro-organisms. CA divided the monitoring months into three clusters including period 1 (April), period 2 (May and June) and period 3 (October and November). In addition, it was possible to reduce the sampling sites from 44 to 33 locations and save 25% of the monitoring cost. The parameters of TSS, BOD, COD, $N-NH_4^+$, $N-NO_2^-$, $P-PO_4^{3-}$, coliform and Fe exceeded the allowable limit of the regulation many times, while the parameters of Cl^-, color and CN^- are within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1. VN_WQI showed that the water quality in the Hau Giang province ranges from poor to excellent. The Vam Cai Dau and Hau River areas were suitable for domestic water supply purposes, but appropriate treatment measures are required. The spatial distribution showed that most of the pollution factors distributed in industrial, agricultural and residential areas, landfills, harbor areas and at the intersection rivers or adjacent provinces. The results of PCA revealed three main factors explaining 69.0% of the water quality variation leading to water pollution. The quality of surface water in the Hau Giang province is influenced by industrial and agricultural activities, domestic activities, transportation activities, salinity, hydrological conditions and stormwater runoff. The current results showed that GIS could be useful in spatial distribution and monitoring the surface water quality change detection.

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