# SURFACE WATER QUALITY IN A RURAL AREA OF HAU GIANG PROVINCE, VIETNAM

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ABSTRACT

This study investigates the surface water quality of rural areas in Hau Giang province, Vietnam using multivariate statistical analysis. Surface water samples were collected at 24 separate locations during the period from November 28 to December 3, 2019, and were measured for temperature (T), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium ($NH_4^+$-N), nitrite ($NO_2^-$-N), nitrate ($NO_3^-$-N), orthophosphate ($PO_4^{3-}$-P), Fe, As, Cd and coliform. Surface water quality was assessed using national technical regulations (QCVN 08-MT: 2015/BTNMT). The results showed that surface water in the study area was polluted with organic matter, nutrients, coliform, and Fe. BOD, COD, DO, TSS, $NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N, $PO_4^{3-}$-P are well correlated, which could be used to predict the concentration of correlated water parameters. Principal component analysis showed that 14 water quality variables affect surface water quality and therefore should be included and emphasized in monitoring programs. Water quality in the study area was divided into three groups with common pollution concerns of organic matter, microbes, and Fe. Particularly, group I had a high concentration of $NO_2^-$-N, while groups II and III had high coliform density. The findings highlight that surface water quality in the rural areas of Hau Giang province is heavily polluted and unsuitable for water supply. Urgent solutions are needed to protect water quality for local population usage needs.

**Keywords:** *Surface water pollution, coliform, rural, Hau Giang province, Vietnam.*

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## 1. INTRODUCTION

An essential component of life and the environment, water resources play a crucial role in a country's existence and sustainable development. In recent years, Vietnam's strong economic growth has led to this finite and important natural resource increasing at risk of pollution and depletion, especially surface water resources. The quality of surface water is influenced by both natural and human activities, including weather conditions, erosion conditions, hydrological characteristics, effects of climate change, precipitation, industrial activities, agricultural land use, wastewater discharge and water resource exploitation [1, 2]. Domestic, agricultural, industrial and aquaculture

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activities that generate an equivalent amount of wastewater directly or indirectly impact the water quality of ponds, lakes, rivers, streams, and receiving sources [1, 3].

The rural areas of Hau Giang province account for over 74.2% of the total population of 774,350. While the population density varies greatly between districts, towns, and cities. As rural production activities such as rice cultivation, husbandry and fisheries are not concentrated, it is challenging to implement and monitor environmental management solutions in general and waste management standards. Therefore, the surface water of rural areas is at high risk of pollution. Rural people in Hau Giang province depend much on surface water for daily activities, including water supply. Therefore, investigating the quality of this water is important for providing early warning for the human health of rural people.

In Vietnam, several studies on surface water quality assessment have been carried out. Truc *et al.* (2019) [4] studied the surface water quality of the Tien River flow through Tan Chau, An Giang province, to assess the water quality from upstream of the Mekong River affected by agricultural processing activities, hydropower projects and activities of the people. Moreover, Lien *et al.* (2016) [5] investigated the water quality of the main and tributary rivers of the Hau River, which is influenced by aquaculture and agricultural production. Surface water quality is often assessed using physio-chemical and biological factors, including temperature, pH, total suspended solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, nitrogen and phosphorus compounds, heavy metals, pesticides, *E. coli* and coliforms [6, 7, 8, 9]. In Vietnam, water quality is evaluated by comparing the measured values of parameters with the current national technical regulation on surface water quality. In addition, surface water quality is also evaluated using the water quality index (WQI). This study aims to assess surface water quality in the rural areas of Hau Giang province using multivariate statistical approaches, including Pearson's correlation, cluster analysis (CA), and principal component analysis (PCA). The study elaborates on the spatial variation of surface water quality, which helps design surface water quality monitoring systems in the rural areas of Hau Giang province and provides a more accurate overview of the state of surface water quality.

## 2. MATERIALS AND METHODS

### 2.1. Study area

Hau Giang province has administrative boundaries bordering Can Tho city to the North, Soc Trang province to the South, Kien Giang and Bac Lieu provinces to the West and Vinh Long and Song Hau provinces to the East (Figure 1). The province's natural area is 1,621.70 $km^2$, divided into eight administrative units. The geographical position of Hau Giang province shows that the section is influenced by both the East Sea tide and the West Sea tide regime. Therefore, the region is a water-bordered area and a water junction between the East and West Sea tides. Hau Giang province is interlaced rivers and canals with a total length of about 2,300 km. The topography is relatively flat, with gradually lower elevation from North to South and East to West, with three distinct regions. The tidal zone is bordered by the Hau river with an area of 19,200 ha, with a developing orchard, agriculture, forestry, and fishery economy. The tidal flood zone is adjacent to the tidal zone with an area of about 16,800 ha; here, rice cultivation with industrial and service potentials is thriving. The flooded area is deep in the inner field for diversified agricultural development.

According to Hau Giang Statistical Yearbook (2018), the population in rural areas of the province does not fluctuate significantly from 573,462 - 583,848 people. However, the population has recently decreased, possibly due to the migration of people to urban areas in search of work. The population is related to resource use, domestic wastewater generation, and solid waste. Therefore, localities with higher population densities place more pressure on wastewater and solid waste management. Most of the wastewater from residential areas or communities is typically not collected or treated but solely passed or not through septic tanks and then discharged to infiltrate into the soil or discharged into ponds, ditches, rivers, and canals. There are many diverse types of production and husbandry activities in the area, including rice cultivation, livestock raising, aquaculture and the activities of craft villages and industries, creating a quantity of waste that contributes to environmental pollution.

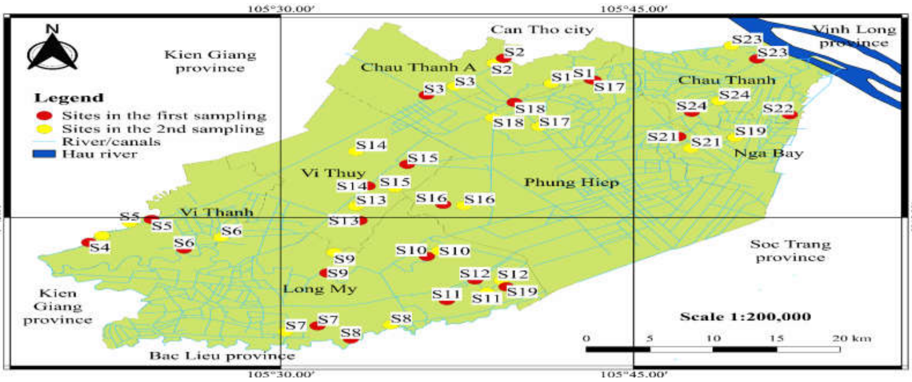


**Figure 1. Map of the sampling sites in the rural areas of Hau Giang province**

### 2.2. Water sampling and analysis

Water samples were collected at 24 locations (S1-S24) in Hau Giang province (HG1-HG8) in the dry season during the period from November 28 to December 3, 2019 (Figure 1).

The fields of HG1, HG2, HG3, HG4, HG5, HG6, HG7, and HG8 were Chau Thanh district, Chau Thanh A district, Vi Thanh city, Vi Thuy district, Long My district, Long My town, Nga Bay town, Phung Hiep district, respectively. The sampling sites were selected outside the towns or city centres with low population density. Fourteen parameters were checked to evaluate the quality of these water samples (Table 1). Water temperature, pH and dissolved oxygen (DO) were onsite detected while other parameters were analyzed as standard methods (Table 1). The limited values of surface water quality and methods for water quality analysis are presented in table 1.

Table 1. Analytical methods water quality parameters

| No. | Parameters | Unit | Analytical methods | QCVN 08-MT: 2015/BTNMT, Column A1 |
|---|---|---|---|---|
| 1 | Temperature | $^0C$ | SMEWW 2550B: 2012 | - |
| 2 | pH | - | TCVN 6492: 2011 | 6-8.5 |
| 3 | DO | mg/L | TCVN 7325: 2004 | ≥6 |
| 4 | BOD | mg/L | SMEWW 5210B: 2012 | 4 |
| 5 | COD | mg/L | SMEWW 5220B: 2012 | 10 |
| 6 | TSS | mg/L | TCVN 6625: 2000 | 20 |
| 7 | $NH_4^+$-N | mg/L | TCVN 6179-1: 1996 | 0.3 |
| 8 | $NO_2^-$-N | mg/L | TCVN 6178: 1996 | 0.05 |
| 9 | $NO_3^-$-N | mg/L | TCVN 6180: 1996 | 2 |
| 10 | $PO_4^{3-}$-P | mg/L | TCVN 6202: 2008 | 0.1 |
| 11 | Fe | mg/L | TCVN 6177: 1996 | 0.5 |
| 12 | As | µg/L | SMEWW 3114.C: 2012 | 10 |
| 13 | Cd | µg/L | SMEWW 3113.B: 2012 | 5 |
| 14 | Coliform | MPN/100 ml | TCVN 6187-2: 1996 | 2500 |

### 2.3. Data analysis

Data on surface water quality was assessed through comparison with the threshold values of national technical regulation QCVN 08-MT: 2015/BTNMT [11], column A1 (Table 1). Water quality index of Vietnam (VN_WQI) (1460/QD-TCMT dated November 12th, 2019) was used to evaluate the water quality for 8 units (H1-H8), including Group I (pH), Group III (As and Cd), Group 4 (DO, $BOD_5$, COD, N-$NH_4^+$, N-$NO_3^-$, N-$NO_2^-$ and P-$PO_4^{3-}$) and Group V (Coliform). Correlation analysis (Pearson) was used to describe the relationship and interdependence among the analyzed water quality variables. A positive correlation means that the two variables increase or decrease together, while the negative correlation is a decreasing variable and one increasing variable [8]. Water parameter values of greater than 0.5 show a statistically significant correlation ($p<0.05$) between the water quality indicators [12]. Correlation analysis was performed using the statistical software IBM SPSS 20.0 for Windows. Principal Component Analysis (PCA) was used to reduce the quantity of features from many variables to a smaller number of factors in order to select a small set of variables that are highly correlated with the main component. The PCA result produces a new set of variables called the major component or factor (PC). The eigenvalue coefficients were used to evaluate the main components. The larger this coefficient, the greater the major component that contributes to the explanation of the variation of the original data set. Correlation between the main component and the primary data variables is explained by the weighted correlation data [12]. An absolute value of the weighted correlation coefficient greater than 0.75 means that the correlation between the main component and the water quality parameter is strong, 0.5 - 0.75 is a moderate correlation and less than 0.5 is a weak correlation [13]. Cluster analysis (CA) was applied to the site group based on physical, chemical, and biological parameters of surface water quality. Sampling points were clustered on the basis of similarities. PCA and CA analysis were analyzed using Primer 5.2 for Windows software (PRIMER-E Ltd, Plymouth, UK).

## 3. RESULTS AND DISCUSSION

### 3.1. Evolution of surface water quality in rural Hau Giang province in 2019

#### *3.1.1. Water pH*

pH of surface water in rural areas of Hau Giang province ranged from 6.13 to 7.13 with an average of 6.54 ± 0.17 - 6.93 ± 0.17 (Table 2). Compared with the study results in the main river and tributaries of the Hau River, where the pH had a relatively higher value ranging from 6.3 to 8.0 with an average of 7.1 ± 0.32 [5]. In summary, the pH in the Hau Giang province study area, although lower than other study areas, is still within the permissible limit of column A1 of QCVN 08-MT: 2015/BTNMT. The results show that temperature and pH were in suitable ranges for aquatic life, fluctuating in water bodies in Hau Giang province, consistent with changes in the tropics [9].

#### *3.1.2. Oxygenation compounds*

DO in the rural Hau Giang province was seen to be relatively low, ranging from 0.17 to 4 mg/L with an average of 1.73 ± 0.94-3.72 ± 0.29 mg/L (Table 2). This low DO is due to the water environment with many organic substances that increase oxidation and oxygen consumption leading to oxygen depletion. Furthermore, the accumulation of organic humus in the areas affects the flow circulation and diffuses oxygen from the air into the water [15]. According to Lien *et al.* (2016) [5], wastewater from agricultural production, as well as domestic wastewater contains a lot of organic matter, so the decomposition of organic matter consumes dissolved oxygen, and DO is low. The results showed DO in rural areas of Hau Giang province have a value lower than the permissible limit for the column A1 of QCVN 08-MT: 2015/BTNMT, and the area shows signs of organic matter pollution.

**Table 2. Water quality in rural areas of Hau Giang province**

| Parameter | HG1 | HG2 | HG3 | HG4 | HG5 | HG6 | HG7 | HG8 | QCVN‡ |
|---|---|---|---|---|---|---|---|---|---|
| Temp. (°C) | 28.9±0.43 | 30.0±0.99 | 28.8±0.42 | 29.5±0.15 | 29.5±0.12 | 29.2±0.27 | 29.6±0.16 | 29.5±0.22 | - |
| pH | 6.93±0.17 | 6.54±0.33 | 6.54±0.17 | 6.61±0.25 | 6.67±0.24 | 6.37±0.26 | 6.56±0.33 | 6.76±0.21 | 6-8.5 |
| DO (mg/L) | 2.50±1.16 | 2.95±1.34 | 2.2±1.63 | 1.73±0.94 | 2.11±1.38 | 2.25±1.07 | 2.97±0.66 | 3.72±0.29 | ≥6 |
| BOD (mg/L) | 11.0±4.38 | 16.5±2.07 | 17.2±3.97 | 17.7±4.18 | 18.8±2.86 | 9.17±0.98 | 9.00±0.89 | 11.2±3.25 | 4 |
| COD (mg/L) | 20.0± 8.1 | 29.5±4.59 | 31.5±7.87 | 33.0±8.76 | 33.2±5.42 | 15.8±1.94 | 15.00±2.1 | 19.3±5.35 | 10 |
| TSS (mg/L) | 52.8±9.37 | 154±98.2 | 89.7±16.8 | 106±76.4 | 148±58.7 | 65.2±19.3 | 64.3±23.4 | 46.0±14.8 | 20 |
| $NH_4^+$-N (mg/L) | 0.31±0.31 | 0.83±0.33 | 1.29±0.25 | 0.70±0.21 | 0.79±0.32 | 0.50±0.33 | 0.27±0.26 | 0.32±0.17 | 0.3 |
| $NO_2^-$-N | 0.01±0.01 | 0.05±0.02 | 0.06±0.02 | 0.11±0.11 | 0.06±0.01 | 0.04±0.01 | 0.03±0.02 | 0.01±0.00 | 0.05 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (mg/L) | | | | | | | | | |
| $NO_3^-$-N (mg/L) | 0.21±0.05 | 0.38±014 | 0.27±0.12 | 0.39±0.15 | 0.38±0.17 | 0.20±0.07 | 0.21±0.09 | 0.1±0.03 | 2 |
| $PO_4^{3-}$-P (mg/L) | 0.1±0.02 | 0.15±0.06 | 0.17±0.01 | 0.19±0.09 | 0.17±0.1 | 0.09±0.01 | 0.12±0.05 | 0.07±0.01 | 0.1 |
| Fe (mg/L) | 1.13±0.32 | 2.11±0.65 | 2.21±0.46 | 1.87±0.39 | 1.90±0.14 | 2.42±0.79 | 1.3±0.47 | 0.87±0.39 | 0.5 |
| As (μg/L) | 2.31±0.16 | 3.74±2.34 | 3.46±0.67 | 2.52±0.58 | 2.27±0.06 | 1.69±0.60 | 1.96±0.01 | 2.21±0.39 | 10 |
| Cd (μg/L) | 0.12±0.00 | 0.12±0.01 | 0.14±0.06 | 0.12±0.00 | 0.12±0.00 | 1.41±3.16 | 0.12±0.00 | 0.12±0.00 | 5 |
| Coliform† | 28.6±19.2 | 45.7±52.5 | 44.2±34.7 | 20.3±14.5 | 28.2±32.6 | 60.0±37.0 | 13.7±68.8 | 57.8±57.4 | 2.5 |
| VN-WQI | 28 | 26 | 22 | 22 | 22 | 28 | 29 | 28 | - |

*"†" indicates the unit presented by $10^3$ MPN/100 mL; "ǂ" denotes the technical standard (QCVN 08-MT: 2015/BTNMT, A1 column)*

The BOD ranged from 7 to 25 mg/L, exceeding the permitted limit by 1.8-6.3 times (Table 2). The high BOD is consistent with low DO results. BOD in the study area exceeds column A1 of QCVN 08-MT: 2015/BTNMT. According to Nga and Thu [15], the source of organic pollution is the indiscriminate waste of the rural people, and the wastewater of households living and production activities in the area. The amount of organic humus has accumulated over time, increasingly obstructing the flow of water, which has reduced the ventilation and self-cleaning ability of the water bodies.

The COD ranged from 12 to 48 mg/L, averaging 15.00 ± 2.1-33.17 ± 5.42 mg/L (Table 2). The COD water quality in the Hau River was measured to be about 11.68 ± 3.76-13.54 ± 4.71 mg/L, while Ba Lua canal had a COD ranging from 14.7 ± 3.3 to 212.2 ± 37.4 mg/L, Phu Thinh commune (Hung Yen) has a COD of 152 mg/L [16]. If COD is <5 mg/L, the environment is classed as nutrient-poor, 20-30 mg/L is rich in nutrients and > 30 mg/L is polluted. In general, the COD in the study area exceeds the permissible limit of the standard of QCVN 08-MT: 2015/BTNMT, indicating that the water is organically polluted. The source of organic matter generation can be waste from farming, livestock, landfills, domestic activities, and services that discharge untreated waste into surface water [17, 18].

### *3.1.3. Total suspended solids*

Measured TSS ranged from 32 to 290 mg/L, exceeding the QCVN 08-MT: 2015/BTNMT, column A1 by a magnitude of 1.6 - 10.5 times (Table 2). This is consistent with the result of low DO, as a high amount of TSS can increase surface water temperature and reduce dissolved oxygen. In the main rivers and tributaries of the Hau River, TSS ranged from 41.2 ± 33.7 to 89.57 ± 31.31 mg/L [5], while on the canals of An Giang province in the period 2009 - 2016, TSS ranged from 25.0 ± 11.5 mg/L to 93.7 ± 28.3 mg/L [5]; In canals in Soc Trang province, TSS ranges from 16 to 176 mg/L [19]. TSS exceeding the standard may be due to the characteristics of water, sediment, and storm water runoff, in addition to the water flowing from agriculture, aquaculture, industry and human activities in the area. TSS increases the cost of water treatment and affects aquatic life. TSS is also a carrier that helps transport pollutants such as microorganisms, pesticides, and antibiotics, increasing exposure to adverse environmental factors.

*3.1.4. Nutrients*

$NH_4^+$-N ranged from 0.06 to 1.65 mg/L, with an average of 0.27 ± 0.26 - 1.29 ± 0.25 mg/L (Table 2). Chau Thanh A district and Nga Bay town had two sampling points with $NH_4^+$-N exceeding the allowed limit. Chau Thanh district had three points exceeding the permissible limit, while Phung Hiep District had four points exceeding the standard, while the remaining four areas all had six points exceeding the allowed limit in column A1 of QCVN 08-MT: 2015/BTNMT. The results indicated that $NH_4^+$-N is a serious problem of water quality in the study area. The $NH_4^+$-N value specified in QCVN 08-MT: 2015/BTNMT in columns A1 and A2 is 0.3 mg/L for domestic water supply and 0.9 mg/L for columns B1 and B2 used for irrigation and navigation purposes. $NH_4^+$-N is present in water due to the product of the decomposition of organic substances (especially proteins). The ammonium in the nitrogen cycle in nature or the water is contaminated with domestic wastewater and agricultural wastewater. Nitrite oxidises haemoglobin in red blood cells to form methemoglobin that cannot transport oxygen in the blood. Nitrite is toxic to aquatic organisms at a concentration of 0.1 mg/L and causes brown blood when the nitrite concentrations are about 0.5 mg/L. The results showed that the $NO_2^-$-N concentration ranged from 0.005 to 0.247 mg/L with an average of 0.01 ± 0.01-0.11 Ơ 0.11 mg/L (Table 3). $NO_2^-$-N concentration in the study area were relatively high, especially in Long Phu commune, Long My town, which had a very high $NO_2^-$-N, exceeding 4.6-4.9 times compared with the QCVN 08-MT: 2015/BTNMT.

Nitrate is the end product of the mineralization of nitrogen-containing organic substances and is one of the most easily absorbed forms of protein by plants and is not toxic to aquatic organisms. But too high concentrations of nitrate in water environments affect aquatic animals. $NO_3^-$-N in the study area ranged from 0.07 to 0.6 mg/L with the average ranging from 0.1 ± 0.03 to 0.39 ± 0.15 mg/L (Table 2). $NO_3^-$-N concentration in rural areas of Hau Giang province in 2019 was still within the permissible limit of column A1 of QCVN 08-MT: 2015/BTNMT. $PO_4^{3-}$-P concentrations in the study area ranged from 0.05 to 0.33 mg/L with an average of 0.07 ± 0.01-0.19 ± 0.09 mg/L (Table 2). The results showed that there were 28/48 monitoring points exceeding the allowable limit by 1.1-3.3 times when compared with the column A1 of QCVN 08-MT: 2015/BTNMT. The localities with very high $PO_4^{3-}$-P concentration were Hoa Luu commune - Vi Thanh city (exceedence1.4-2.6 times), Long Phu commune - Long My town (exceedance 2.7-3.2 times). $PO_4^{3-}$-P in the canals in Soc Trang province was measured to be 0.05-0.90 mg/L [19], and in the Tien River, a section flows through Tan Chau (An Giang) 0.02-8 mg/L [4]. In some locations, the high concentration of $PO_4^{3-}$- P is due to the excessive number of organic fertilizers, pesticides, livestock farming activities, and household detergents [4]. Binh *et al.* (2020) [20] revealed that nutrient oxyanions were affected by seasons, of which higher concentrations were identified in the dry season. This result is in line with the current study.

*3.1.5. Heavy metals (Fe, As, Cd)*

Fe concentration in rural areas of Hau Giang province in 2019 had values ranging from 0.54 to 3.49 mg/L, exceeding 1.08-6.98 times the permitted limit, with the average value fluctuating from 1.3 ± 0.47 to 2.42 ± 0.79 mg/L (Table 2). The concentration of As in the study area was in the range of 0.98-7.03 µg/L with the average ranging from 1.69 ± 0.60 to 3.74 ± 2.34 µg/L (Table 2). This value of As in the study area was still within the permissible limit for column A1 of QCVN 08-MT: 2015/BTNMT. Cd value was in the range of 0.12-7.86 µg/L, with the average ranging from 0.12 to 1.41 µg/L (Table 2). Cd value was also still within the permissible limit of column A1 of QCVN 08-MT: 2015/BTNMT.

*3.1.6. Coliform*

The coliform density in rural Hau Giang province in 2019 ranged from 9,300 to 150,000 MPN/100 mL, exceeding the limit threshold by 3.72-60 times (Table 2). Former studies have also previously reported high densities of coliform in surface waters. In the Can Tho River in 2010-2014, coliform density was from 3,448 to 27,327 MPN/100 mL [21]. Coliform density in the study area was high and exceeded the permissible limit in column A1 of QCVN 08-MT: 2015/BTNMT. The water source was polluted with microorganisms, and surface water must be properly treated before use. The presence of coliforms shows that the environment is receiving secretions from humans and animals (livestock, poultry, and aquaculture in Hau Giang province).

*3.1.7. VN_WQI index*

Table 2 shows that VN_WQI indexes varied between 22 and 29. It means that the water quality ranged between poor and very poor. Higher pollution was identified in sites HG3, HG4, and HG5, where VN_WQI was below 25 (very poor), recommended suitable water treatment methods for further use. While the VN_WQI of HG1, HG2, HG6, HG7 and HG8 fluctuated from 26 to 28. The water quality was poor and appropriate for waterway transportation and other analogous purposes.

**3.2. Correlation between surface water quality variables**

Correlation analysis (Pearson) was used to describe the positive and negative relationships and interdependence between the analyzed criteria (Figure 2). BOD correlated positively with COD, TSS, $NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N, $PO_4^{3-}$-P with correlations of (0.992), (0.663), (0.563), (0.565), (0.725) and (0.667). COD was also correlated with TSS (0.659), $NH_4^+$-N (0.579), $NO_2^-$-N (0.588), $NO_3^-$-N (0.738) and $PO_4^{3-}$-P (0.683). TSS was found to be positively correlated with $NH_4^+$-N (0.531), $NO_2^-$-N (0.611), $NO_3^-$-N (0.761) and $PO_4^{3-}$-P (0.715). Moreover, the nitrogen and phosphorus compounds were positively correlated. Specifically, $NH_4^+$-N correlates with $PO_4^{3-}$-P with a high correlation (0.606); $NO_2^-$-N correlated positively with $NO_3^-$-N (0.564) and $PO_4^{3-}$-P (0.744); $NO_3^-$-N is positively correlated with $PO_4^{3-}$-P (0.708). In general, organic matter and nutrients in surface water were positively correlated and can help predict the correlated pollutants, thereby reducing the number of analysis criteria to save time and money.

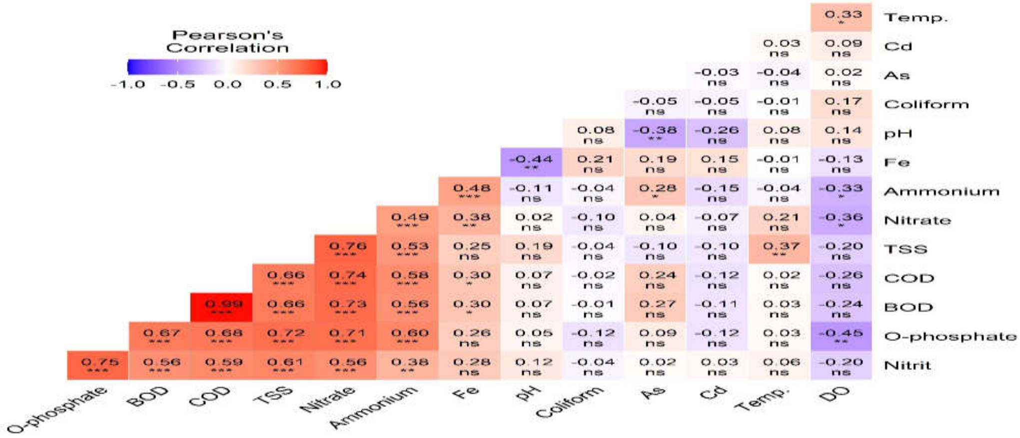


**Figure 2. Pearson correlation heat map between surface water quality variables**

*"ns", P≥ 0.05; "*", P<0.05; "**", P<0.01; "***", P<0.001.*

**3.3. Key parameters affecting surface water quality**

The principal component analysis (PCA) results showed that four main factors explained 92.7% of the variation in surface water quality in the study area of rural Hau Giang province (Table 3). As reported by Shrestha and Kazama (2007) [22], a PC with eigenvalues values greater than 1 is considered significant. PC1 accounts for 50.9% of the total variation in the data. PC1 is affected by positive coefficients that correlate weakly with indicators BOD (0.348), COD (0.349), TSS (0.32), $NH_4^+$-N (0.305), $NO_2^-$-N (0.32), $NO_3^-$-N (0.35) and $PO_4^{3-}$-P (0.359). The results are similar to those reported by [5], in which the variables pH, $NO_3$-N, TN, TP and COD were highly correlated, and the nutrient content and organic matter existed in the water. This is also consistent with the results of the correlation analysis discussed in the previous section. PC1 can be the decentralized source of impacts due to the daily domestic wastewater of households, farming activities, fertilization, animal husbandry and aquaculture in the area. PC2 explained 19.5% of the total variation of the obtained data, which correlated weakly with pH (0.496), Fe (-0.452), coliform (-0.342), and the average correlation with Cd (-0.554). PC2 is mainly affected by industrial production and trade villages and waste excreted from humans and animals. Furthermore, PC3 explained 12% of the variation in surface water quality. PC3 is affected by a positive coefficient with a weak correlation to temperature (0.341), As (0.453), and coliform (0.481), which had an average correlation with DO (0.511), affected by industrial activities, human and animal waste.

According to Nga *et al.* (2005) [15], this appears in areas with many suspended materials, and agricultural and industrial wastewater. PC4 explains 10.4% of the variation in surface water quality within the study area, at a high correlation with temperature (0.7) affected by natural environmental conditions and a weak correlation with $NH_4^+$-N (0.365). The PCA results show that the 14 initially selected indicators all have a significant impact on surface water quality and should therefore be included in a periodic monitoring program to monitor the changes in surface water quality. However, it can be possible to select BOD or COD to represent organic matter; among the nitrogen species, $NH_4^+$-N should be selected since $NO_2^-$-N and $NO_3^-$-N could be predicted using the relationship among $NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N and DO. The possible polluting sources of water quality in the study area come from domestic activities, cultivation, husbandry, fisheries, industrial production, and hydrology.

**Table 3. Key variables influencing water quality in the rural areas of Hau Giang province**

| Variable | PC1 | PC2 | PC3 | PC4 |
|---|---|---|---|---|
| Temp. | 0.077 | 0.122 | 0.341 | -0.700 |
| pH | -0.074 | 0.496 | -0.125 | 0.257 |
| DO | -0.245 | 0.187 | 0.511 | -0.094 |
| BOD | 0.348 | 0.125 | 0.076 | 0.136 |
| COD | 0.349 | 0.12 | 0.052 | 0.163 |
| TSS | 0.320 | 0.043 | 0.209 | -0.237 |
| $NH_4^+$-N | 0.305 | -0.142 | 0.170 | 0.365 |
| $NO_2^-$-N | 0.32 | -0.095 | -0.231 | -0.145 |
| $NO_3^-$-N | 0.35 | 0.049 | -0.063 | -0.219 |
| $PO_4^{3-}$-P | 0.359 | 0.070 | -0.152 | -0.014 |
| Fe | 0.241 | -0.452 | 0.028 | -0.017 |
| As | 0.238 | 0.089 | 0.453 | 0.237 |
| Cd | -0.106 | -0.554 | -0.095 | -0.101 |
| Coliform | -0.1 | -0.342 | 0.481 | 0.253 |
| Eigenvalues | 7.12 | 2.72 | 1.68 | 1.45 |
| %Variation | 50.9 | 19.5 | 12 | 10.4 |
| Cum. %Variation | 50.9 | 70.3 | 82.3 | 92.7 |

### 3.4. Spatial variation of surface water quality in rural areas of Hau Giang province

The results of cluster analysis (CA) in rural Hau Giang province in 2019 showed that water quality was divided into three clusters (Figure 3). Cluster I consist of 4 sampling sites (S10, S13, S14, S19), Cluster II includes 10 sampling sites (S2, S4, S8, S9, S15, S16, S17, S18, S23, S24), and group III includes the remaining 10 sampling locations (S1, S3, S5, S6, S7, S11, S12, S20, S21, S22).

All three groups showed water sources polluted with organic matter, microorganisms and heavy metals (Table 4). However, Cluster I showed the presence of $NO_2^-$-N in the water in concentrations exceeding the permitted standard by1.2 times. Whereas Clusters II and III, although located in a large branch, the density of coliform in Cluster II is relatively higher than that of Cluster III (2.66 times), and higher than that in the standard by 24.51 times.

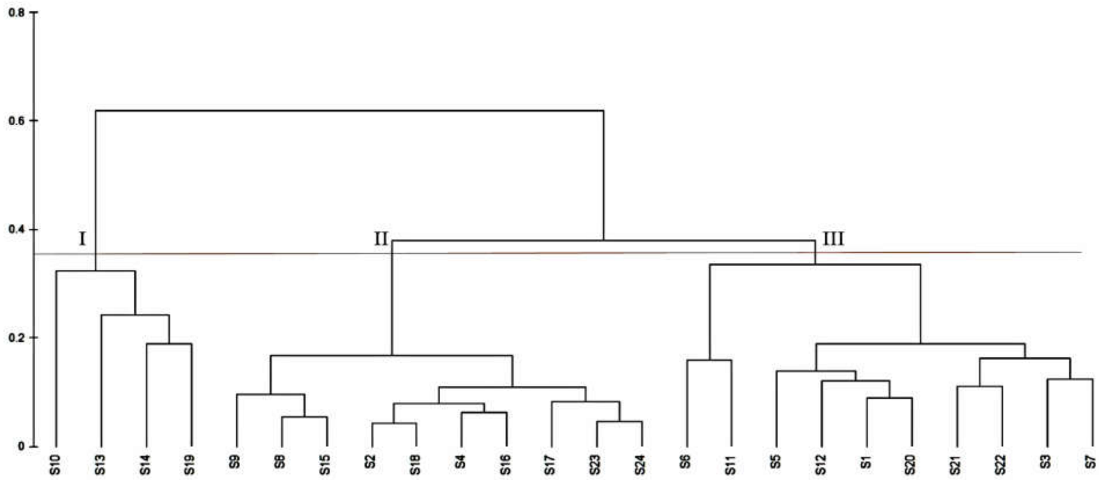


**Figure 3. Spatial variation of surface water quality**

**Table 4. Characteristics of water quality in the group**

| Parameter | Units | Cluster | | | |
|---|---|---|---|---|---|
| | | Cluster I | Cluster II | Cluster III | QCVN |
| Temp | °C | 29.46 | 29.34 | 29.39 | - |
| pH | - | 6.69 | 6.66 | 6.58 | 6-8.5 |
| DO | mg/L | 1.84 | 3.02 | 2.37 | ≥6 |
| BOD | mg/L | 16.25 | 12.70 | 13.95 | 4 |
| COD | mg/L | 28.74 | 22.48 | 25.39 | 10 |
| TSS | mg/L | 123.50 | 72.00 | 96.25 | 20 |
| $NH_4^+$-N | mg/L | 0.69 | 0.65 | 0.57 | 0.3 |
| $NO_2^-$-N | mg/L | 0.06 | 0.04 | 0.05 | 0.05 |
| $NO_3^-$-N | mg/L | 0.33 | 0.21 | 0.30 | 2 |
| $PO_4^{3-}$-P | mg/L | 0.18 | 0.11 | 0.13 | 0.1 |
| Fe | mg/L | 1.55 | 1.93 | 1.59 | 0.5 |
| As | µg/L | 2.23 | 2.40 | 2.76 | 10 |
| Cd | µg/L | 0.12 | 0.51 | 0.13 | 5 |
| Coliform | MPN/100mL | *12975.00* | *61280.00* | *23075.00* | 2500 |

## 4. CONCLUSIONS

This study on the surface water quality in the rural areas of Hau Giang province showed that the pH, $NO_3^-$-N, As and Cd were within the allowable limits, while the indicators $NO_2^-$-N, $PO_4^{3-}$-P, $NH_4^+$-N exceeded the corresponding permitted thresholds of QCVN 08-MT: 2015/BTNMT, column A1. DO was below the allowable threshold, while BOD, COD, TSS, Fe, and coliform at all sampling locations exceeded the permitted threshold limits. The results show that the surface water environment in the study area is polluted with organic matter, nutrients, microorganisms, and Fe. The parameters of organic matter (BOD, COD, DO, TSS), and nutrients ($NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N, $PO_4^{3-}$-P) were positively correlated and can be used for prediction of the correlated water pollutants and, thus reduce water sample analysis criteria. PCA results showed that all water quality parameters need to be monitored. The cluster analysis results divided the surface water quality in the study area into three clusters with common pollution problems, including organic matter, microbes, and Fe. The pollution of Cluster I was characterized by high $NO_2^{-}$N, while Clusters II and III were characterized by coliform. The sources of surface water pollution are mainly from daily activities, cultivation, animal husbandry, fisheries, industrial production, soil conditions and the hydrological regime. The results of the current study provide important information on the current state of surface water quality, serving as a scientific basis for establishing a much-needed water monitoring network.

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**AUTHOR CONTRIBUTIONS**

*All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by Nguyen Van Cong, Huynh Van Thao, Huynh Cong Khanh. The first draft of the manuscript was written by Nguyen Thanh Giao and authors commented on the previous versions of the manuscript. All authors read and approved the final version.*

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