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Analysis of Upstream Surface Water Quality Fluctuations of Vietnamese Mekong Delta Using Statistical Methods

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Abstract

This study was carried out to evaluate water quality, key water parameters and frequency of surface water monitoring in the upper part of Hau river in Vietnamese Mekong Delta using statistical approaches. The water quality data was collected at two locations including MH1 (upstream water entering Hau River in An Giang province) and MH2 (water in Hau river leaving An Giang province. Water quality data were collected in 2020 from January to November with a frequency of 4 times per month. Nine water quality parameters comprising temperature, pH, dissolved oxygen (DO), suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), nitrate (N-NO_3^-), orthophosphate (P-PO_4^{3-}) and coliform were used evaluate surface water quality. The national standard on surface water quality (QCVN 08-MT:2015/BTNMT, column A1, cluster analysis (CA) and Principal Component Analysis (PCA) were used to evaluate water quality, sampling frequency and key parameters influencing surface water quality in the study area. The results showed that surface water in Hau river belonging to An Giang province was polluted by DO, TSS, COD, BOD, P-PO_4^{3-} and coliform. June and August were the months with the highest level of water pollution. The water quality in the study area tended to be low in the dry season (March to June), but high in the rainy season (July to October). CA cluster reduced the sampling frequencies from 11 to 4, saving cost of monitoring by 63.63%. The PCA results showed that three potential sources which could explain 75.5% of the variation in water quality. Nine water parameters all caused affecting the changes of water quality. The study contributes to providing important information on surface water quality for the process of monitoring and planning water use for domestic purposes and conservation in Hau river area, An Giang province.

1. Introduction

Hau River is one of two main tributaries from the Mekong River flowing through Vietnam. The Hau River plays an important role in the daily life of people in the Mekong Delta, which is reflected in the supply of water for agricultural, industrial or aquaculture production activities [1-2]. In addition, the Hau river water is also used by people for daily living purposes [3]. According to [4], the Hau River is receiving wastewaters from direct and indirect causes such as domestic, agriculture, aquaculture, industry and tourism activities. Although there have been many studies on water quality in Hau river [3-6], there have not been any comparative studies on water quality changes at the upstream and downstream when flowing through An Giang province.

The study aimed at evaluating how surface water quality changes when flowing through An Giang territory and identifying key water parameters, monitoring frequency for future monitoring task. Surface water quality parameters were compared with national technical regulation on surface water quality (QCVN 08-MT:2015/BTNMT) [7]. The study used the methods of cluster analysis (CA) to group different sampling periods with the same water quality characteristics into the same group and vice versa. Principal Component Analysis (PCA) was used to identify the key water quality parameters influencing surface water quality and potential sources of pollution. As previously reported, CA and PCA are important tools in reducing the complexity of data sets, assessing the overall water quality, and determining the basic relationships of water quality parameters [8-9]. The research results could provide important scientific information on water quality changes in the Hau River and contribute to the management and planning of water use for domestic water supply and other activities. conservation on Hau river in An Giang province.

2. Materials and methods

2.1. Data collection

The study conducted to synthesize surface water monitoring data at two locations MH1 and MH2 described in detail in Table 1, sampling frequency was 4 times in a month from January to November 2020 from the Department of Natural Resources and Environment of An Giang province in 2020.

Table 1. Brief information of data collection

Site	Coordinates	Frequency	Brief description
MH1	536.280 1.211.554	12 times/year and 4 times/month	Tan Thanh Hamlet, Long Binh Town, An Phu District, Upstream of Hau River. Controlling the quality of water from Cambodia to the Hau River
MH2	581.014 1.141.993	12 times/year	My Thanh Ward, City. Long Xuyen, the end of Hau River is adjacent to Can Th. Controlling water quality of Hau river adjacent to Can Tho

Data was collected at two locations with 9 monitoring indicators including temperature (^oC), pH, dissolved oxygen (DO), suspended solids (TSS), chemical oxygen demand (COD), demand biological oxygen (BOD), nitrate ($N\text{-}NO_3^-$), orthorphosphate ($P\text{-}PO_4^{3-}$) and coliform. In which, temperature, pH and DO (mg/L) are measured values at the field, the rest TSS (mg/L), COD (mg/L), BOD (mg/L) , $N\text{-}NO_3^-$ (mg/L), $P\text{-}PO_4^{3-}$ (mg/L) and coliform (MPN/100mL) will be collected, stored and analyzed according to standard methods [10]. In this study, CA cluster analysis was used to group samples collected for surface water quality monitoring at each location. Observations with similar results were grouped together and presented as a dendrogram [8]. PCA core analysis helps to identify pollutant indicators, predict pollution sources, and contribute to the interpretation of fluctuations in baseline data [11]. The eigenvalue coefficient is an important value when looking at the results of the main sections, the larger the coefficient, the more significant it is to explain the variability [11]. The closer the absolute value of the weighted correlation coefficients (Loading) is to 1, the stronger the correlation between the main components and the water quality monitoring criteria (loading coefficient from 0.3-0.5 is a weak correlation, 0.5-0.75 is a moderate correlation, and greater than 0.75 is a strong correlation [11]. CA and PCA analysis were both performed through the Primer 5.0 for Window application (PRIMER-E Ltd, Plymouth, UK).

3. Results and discussion

3.1. Variation of surface water quality in the study area

Temperature and pH: The monitoring results in Figure 1 show that the temperature at locations MH1 and MH2 fluctuates in the range of 28.425±1.14 °C to 33.3±0.31°C and 29.4±0.65 °C to 31.025±1.64 °C, respectively. The highest temperature at location MH1 is in May (33.3±0.31 °C) and the lowest is in October (28.425±1,14 °C). The research results of [5] show that the water temperature of the Hau River ranges from 27.1-32.0 0C, dropping low in September. Thus, at the MH2 location, the temperature is in the range of the general oscillation of the basin and the location of MH1 have a higher temperature background than that of the basin. Temperature fluctuations at location MH1 tend to increase from February to April and decrease towards the end of the year. The temperature at MH2 site is less volatile and tends to be equal. The difference in temperature at MH2 location between the highest month (31,025±1.64 °C) and the lowest (29.4±0.65 °C) is about 1.62 °C while the MH2 location has about 4,875 °C difference. Temperature fluctuations at location MH1 are somewhat larger than those at location MH2. The reason for this difference may be due to the fact that water has a function of temperature regulation [12], so during the flow process, it brings water from upstream to the location bordering Can Tho city, the temperature has dropped.

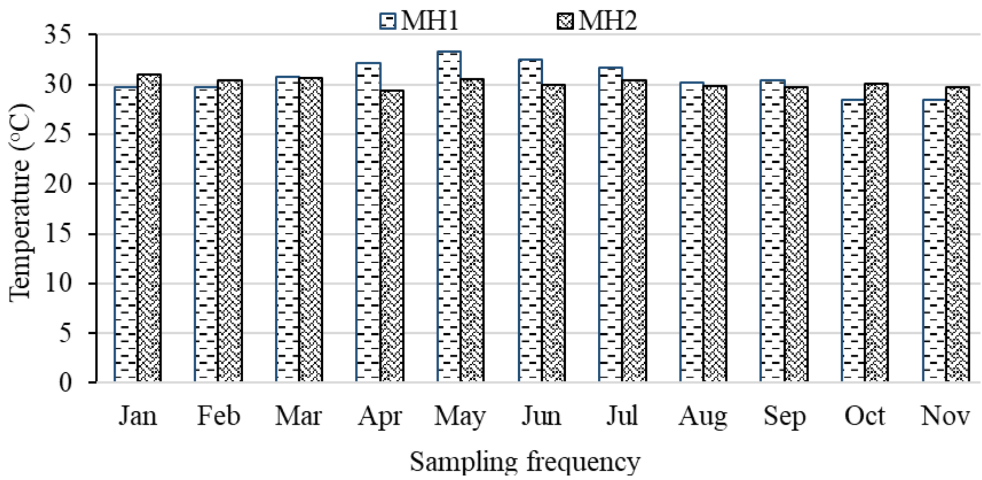

Figure 1. Spatial and temporal variation of temperature

Figure 2 shows, the results of the pH indicator at the MH1 site (blue line) ranged from 7.06±0.11 to 7.28±0.18 and the MH2 site (red line) had variable pH results. within the range of 7.12±0.11 to 7.26±0.07. Both positions have pH values within the allowable range according to column A1 QCVN 08-MT:2015/BTNMT. At location MH1, pH reached the highest result in January (7.28±0.18) and lowest in May (7.05±0.11), MH2 had the highest pH in March (7.26±0.07) and the lowest in October (7.12±0.11). There is no significant difference in pH between the two monitoring sites for surface water quality. The pH in the study area is equal and similar at the two monitoring locations for surface water quality (both lines are almost identical). The results of pH indicator do not have strong fluctuations, consistent with common conditions in the tropics [8].

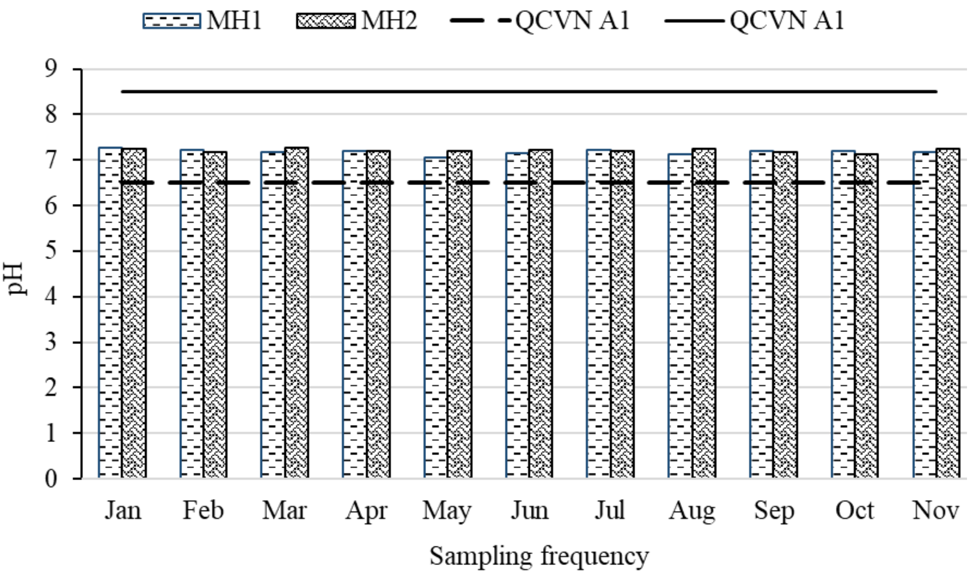

Figure 2. Spatial and temporal variation of pH

Dissolved oxygen: Figure 3 shows the variation of DO indicator in the study area in 2020. The results show that, DO at location MH1 fluctuates in the range of 3.4±0.5 mg/L to 6.38±1.31 mg/L and at MH2 is 4.85±0.84 mg/L to 5.63±0.39 mg/L. The result of monitoring DO indicator at location MH1 in June reached the highest value (6.38±1.31 mg/L) and was the only time when the DO value was within the allowable limit, the remaining time points at the two positions are not within the allowable threshold of column A1 QCVN 08-MT:2015/BTNMT. DO in rivers will depend on diffusion and the presence of phytoplankton as well as organic matter. In addition, DO can be used as an indicator for the presence of organic pollution [4]. Similar to the temperature indicator results, the DO value at location MH1 tends to increase gradually until May and June and decrease towards the end of the year. At position MH2 the DO value tends to be equal at the time of monitoring. In addition to April, May and June, the remaining DO content at location MH1 is lower than that of MH2. The cause may stem from the fact that there is a current that causes the diffusion of oxygen into the water, causing the difference between the two locations. This also explains the low DO in the study area at the upstream position (MH1) and high at the downstream position (MH2).

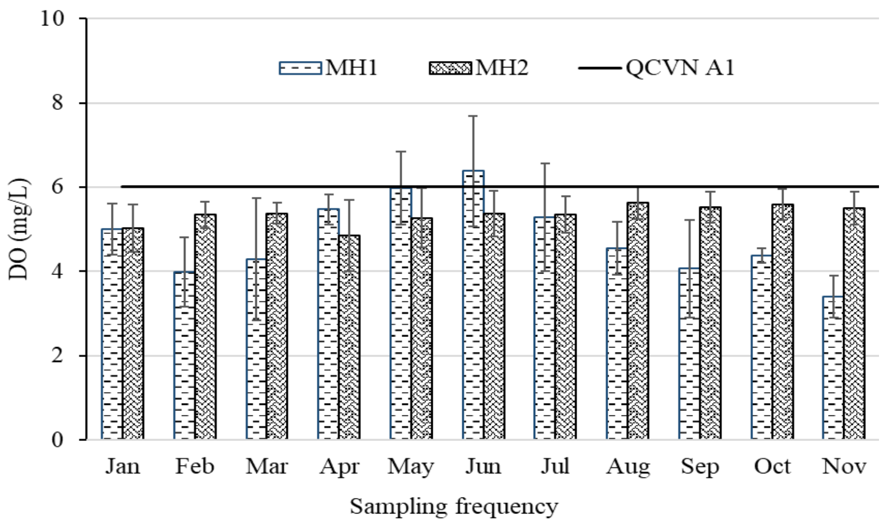

Figure 3. Spatial and temporal variation of DO

Total suspended solids: The results in Figure 4 shows the fluctuation of TSS value at location MH1 from 47±2.12 mg/L to 66.25±22.96 mg/L and MH2 from 46±2.24 mg/L to 55.75±5.97 mg/L. At all times of monitoring at both locations, TSS values exceeded the allowable limit (2 times higher than the allowable threshold) according to the National Technical Regulation on column surface water quality. A1. Compared with the research results of [3], on main rivers and tributaries of Hau river TSS ranges from 41.2±33.7 mg/L to 89.57±31.31 mg/L, TSS values in the study area are still much lower. The highest TSS values at MH1 site in August (66.25±22.96 mg/L) and MH2 site in July and August (55.75±2.59 mg/L and 55.75± 5.97 mg/L), the lowest TSS at MH2 was in April (47±2.12 mg/L) and MH2 was in April (46±2.24 mg/L). There is similarity in TSS values at both monitoring locations at monitoring times. Both positions tend to decrease TSS value from February to June, increase again in July and August, and gradually increase and decrease in the last months of the year. Although there is a decreasing trend, the TSS value is still higher than the allowable threshold for domestic water supply and conservation purposes. The cause of TSS in the study area reaching high values may be due to the amount of alluvium in the water from upstream and TSS in the upstream tends to be higher than downstream because of the flow rate and amount of alluvium contained in the water column [4,12]. At the same time, the high TSS value increases the cost of feed water treatment and is harmful to aquatic life in the study area [4].

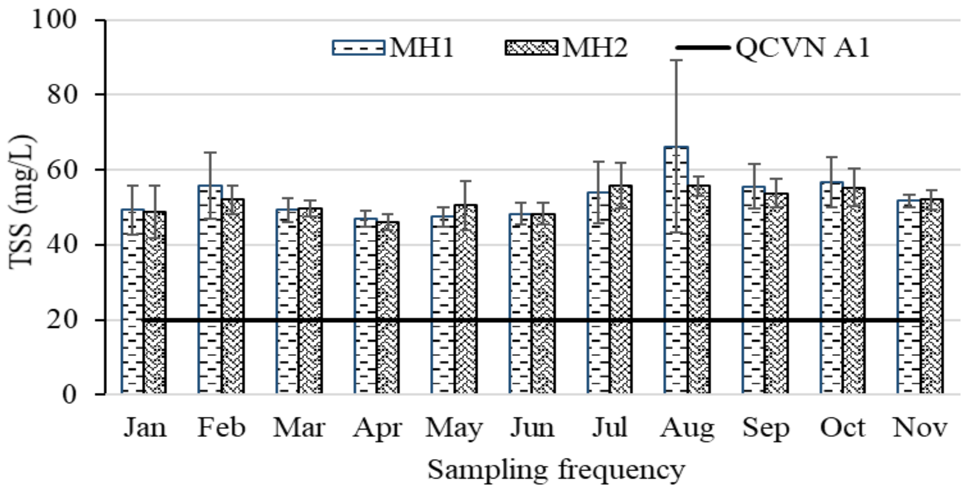

Figure 4. Spatial and temporal variation of TSS

Chemical oxygen demand: The variation of the COD indicator results (Figure 5) shows that the COD value ranges from 8.75±0.83 mg/L to 13.5±4.09 mg/L at MH1 and from 9±1.22 mg/L to 12.5±1.69 mg/L at the MH2 site. At all sampling times of both locations (MH1 and MH2), the COD value exceeded the allowable limit for column A1 QCVN 08-MT:2015/BTNMT. However, the COD results in the study area are still lower than the average COD (11.55-17.82 mg/L) in some main rivers and canals in Can Tho city [3]. High COD values may be associated with river activities [9]. At MH1 the lowest COD value was reached in April (8.75±0.83 mg/L), the highest in August (13.5±4.09 mg/L) and at MH2 the lowest COD was in June. (9±1.22 mg/L) and highest in August (12.5±1.69 mg/L). Both locations have similar fluctuations in COD value when both reach the highest COD value in August and tend to decrease from February to June, then increase again from July to the end of the year. The results of the COD indicator are consistent with the previous TSS and DO results in the study area.

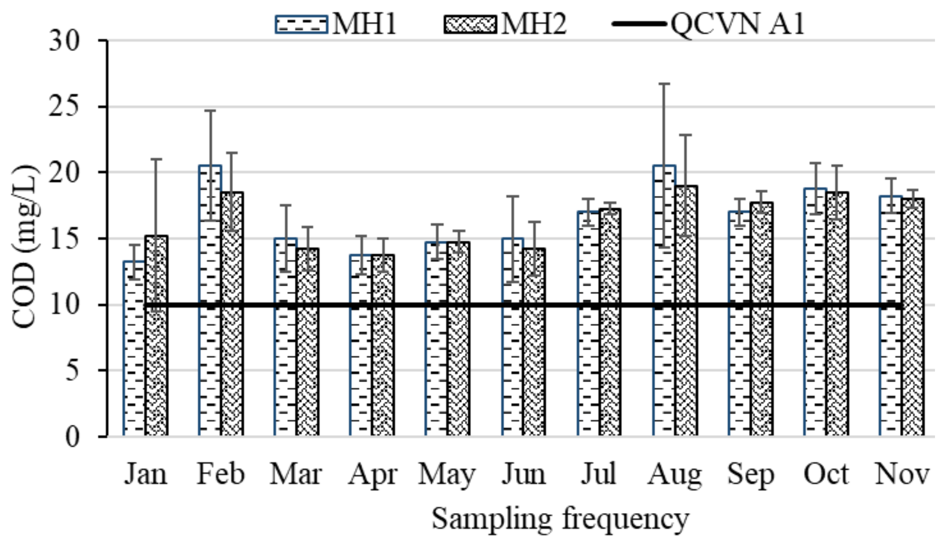

Figure 5. Spatial and temporal variation of COD

Biological oxygen demand: The results of Figure 6 show that there is a fluctuation of BOD at 2 monitoring locations. At location MH1, BOD fluctuates in the range of 8.75±0.83 to 13.5±4.09 mg/L, reaching the highest value in August and lowest in April. MH2 has BOD in the range. 9±1.22 to 12.5±2.69 mg/L, with the lowest BOD value in June and the highest in August. Similar to COD value, BOD value at all important time points All measurements exceed the allowable limit in column A1 of the National Technical Regulation on surface water quality. The origin of BOD can be due to service activities, farming activities, animal husbandry activities, garbage landfills and domestic activities that have created waste along with not going through the treatment process into the water environment pollution side [8-9]. BOD at both monitoring locations tended to be high in February and began to decrease gradually until April, then increased again and reached the highest value in August. According to the research results, the quality monitoring values. The amount of surface water at different times in 2020 of all three indicators TSS, COD and BOD has the same trend, exceeds the allowable limit and is consistent with the results of the DO indicator. This may indicate that the Hau River flowing through An Giang province may have been organically polluted. This is also a common problem of water bodies in the Mekong Delta [13].

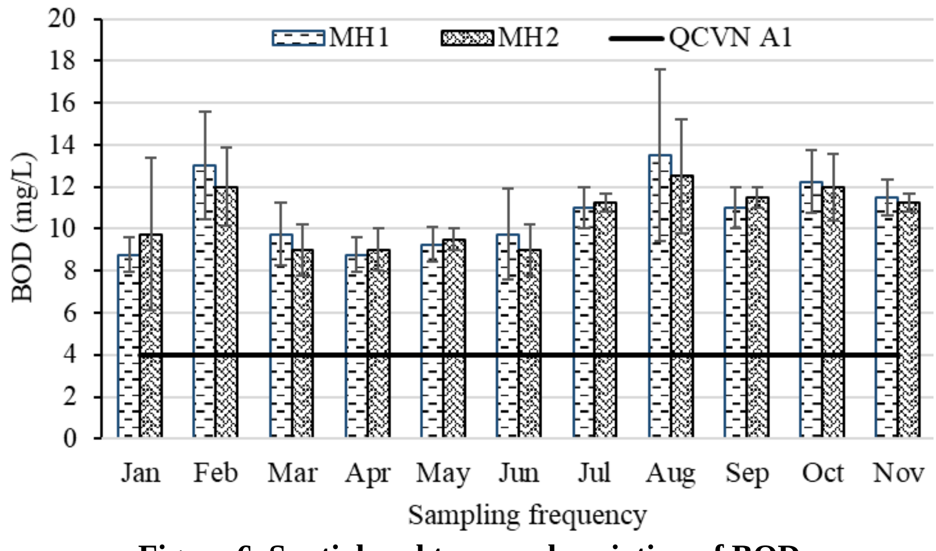

Figure 6. Spatial and temporal variation of BOD

Nitrate: The results of Figure 7 show that, at both positions MH1 and MH2 at all times of monitoring $N\text{-}NO_3^-$, the values of $N\text{-}NO_3^-$ do not exceed the threshold limit according to column A1 QCVN 08- MT:2015/BTNMT. At position MH1, $N\text{-}NO_3^-$ fluctuates between 0.068±0.03 mg/L to 0.163±0.15 mg/L and reaches the highest value in February, the lowest value in June. MH2 has $N\text{-}NO_3^-$ highest in January and lowest in April, ranging from 0.089±0.02 mg/L to 0.248±0.19 mg/L. According to research by [3], $N\text{-}NO_3^-$ in Hau river ranges from 0.002 mg/L to 0.395 mg/L and canals in An Giang $N\text{-}NO_3^-$ is at 0.31 ± 0.3 mg/L to 0.58 ± 0.64 mg/L [5]. Compared with the above studies, the $N\text{-}NO_3^-$ value in the study area is still lower than that of other places with the same water body. Position MH1, $N\text{-}NO_3^-$ tended to increase and decrease continuously over time of observation. At position MH2 the $N\text{-}NO_3^-$ value reached the highest in January, then gradually decreased to September, increased high in October and gradually decreased the following month. $N\text{-}NO_3^-$ in the upstream location has a lower value than other places in the same basin, indicating that there may have been impacts from agricultural production activities and people's daily activities, especially densely populated areas lead to high domestic $N\text{-}NO_3^-$ values [3-6].

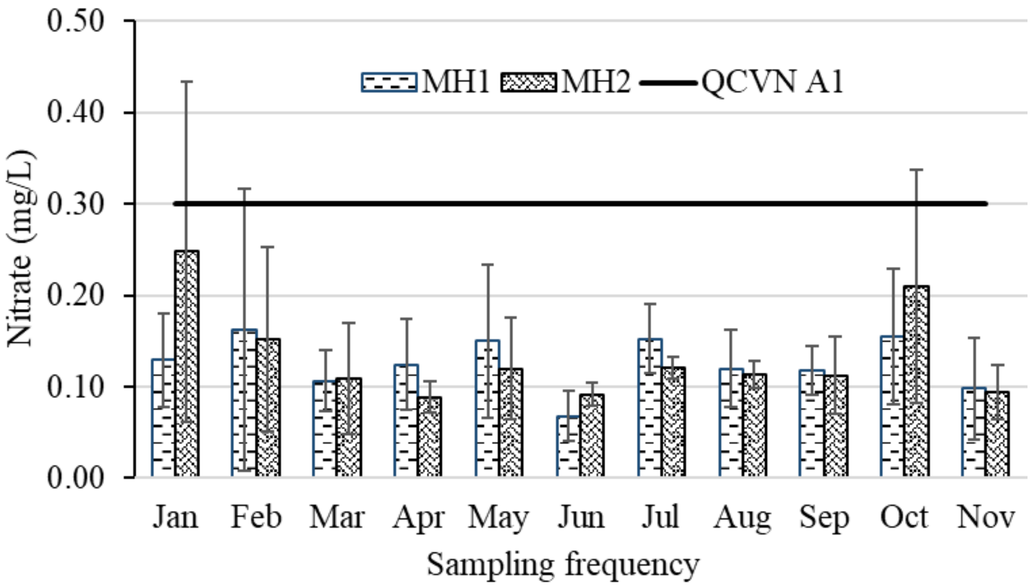

Figure 7. Spatial and temporal variation of nitrate

Orthophosphate: $P\text{-}PO_4^{3-}$ at the study area (Figure 8) has a difference between the two sites but it is not significant. Specifically, at MH1 $P\text{-}PO_4^{3-}$ ranged from 0.024±0.02 mg/L to 0.25±0.06 mg/L and at MH2 $P\text{-}PO_4^{3-}$ ranged from 0.06±0.01 mg/L - 0.33 ±0.5 mg/L. In a previous study by [5], the $P\text{-}PO_4^{3-}$ value in Song Hau area ranged from 0.02 mg/L to 0.47 mg/L. This shows that the results of $P\text{-}PO_4^{3-}$ in the study area are lower than before. However, at location MH1 at the monitoring times in April, July, August, September and January, July, August, September at MH2 exceeded the allowable limit according to column A1 QCVN 08-MT:2015/BTNMT. $P\text{-}PO_4^{3-}$ at MH2 was unusually high in January and August, at MH1 site $P\text{-}PO_4^{3-}$ reached high values in August and September. Both locations had high $P\text{-}PO_4^{3-}$ values in August. In the January monitoring period, $P\text{-}PO_4^{3-}$ at the two monitoring locations has a huge difference. When the upstream position (MH1) reaches the smallest value, the MH2 position reaches the highest value. The reason may be that in the process of flowing to the upstream, the Hau River has suffered a large amount of wastewater from washing powder or fertilizer from aquaculture, farming, people's living and industrial activities [4]. High $P\text{-}PO_4^{3-}$ can lead to eutrophication in the water, which affects aquatic life.

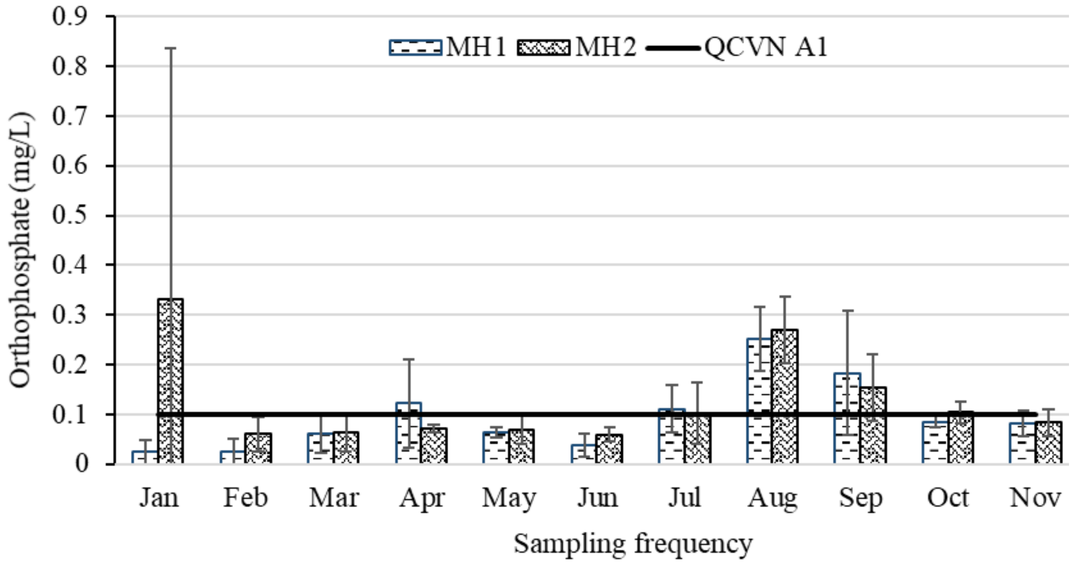

Figure 8. Spatial and temporal variation of orthophosphate

Coliforms: As the results of Figure 9 showed, coliform at two monitoring locations on the Hau River at all monitoring times exceeded the allowable limit and was many times higher than column A1 QCVN 08-MT:2015/BTNMT. The presence of coliform in the study area shows that the water source has gradually become polluted with organic substances originating from human and animal waste [15]. At MH1, coliform ranged from 4800±1701.14 MPN/100mL to 28750±10034.32 MPN/100mL reaching the maximum value in September and the smallest value in June. Coliform at MH2 site reached its maximum value in August, the lowest in January and ranges from 6700±1385.64 MPN/100mL to 21325±14434.92 MPN/100mL. Coliforms at two locations tend to be low in the first months of the year and reach high values from July to the end of the year. The results of coliform monitoring indicators in the study area also have the same results with the previous study of Tuan et al., (2019), when coliform was 1 to 36 times higher than QCVN in Soc Trang canals or studied of [5] with coliform values in surface water of An Giang province exceeding the allowable limit of 2.14-7.02 times in the period of 2009-2016.

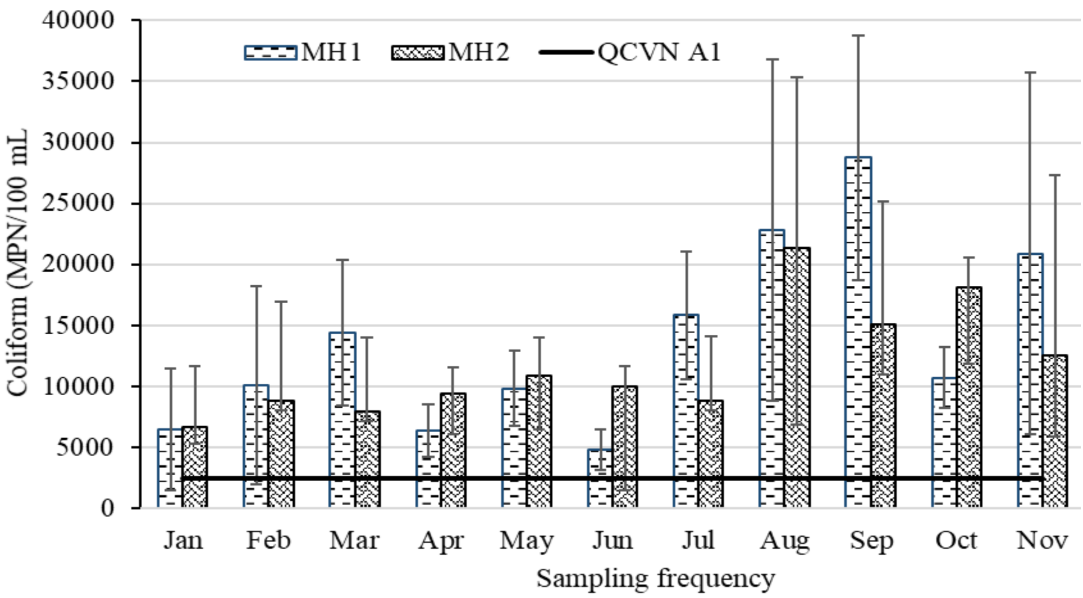

Figure 9. Spatial and temporal variation of coliform

3.2. Analysis of sampling frequency of surface water quality

At the Euclidean similarity level close to 3 (red line), 11 months of sampling on the Hau River in An Giang province were classified into 4 main groups. January is classified into group N1, possibly because this month has abnormally high and low concentrations of environmental monitoring indicators at both locations MH1 and MH2. Group N2 includes August, September and November and group N4 includes February, April, and June. The reason why group N2 includes the months of August, September and November may be due to the high value of the monitoring indicators of these months. Compared with the rest of the time, especially August and September. In Group N4 including the months of February, April and June, the trend is opposite compared to the group of N2, N4 with the months usually reaching values at different locations. monitoring indicators are at a low level and there is a similarity in the level of difference between the two monitoring locations. The remaining months are classified into group N3 (March, May, July and October). PCA analysis helps to reduce the number of sampling months from 11 months to 4 main months including January, August (or November, September), October (or one of the months of March, May, and July) and February (or April, June). The monitoring grouping helps to reduce the cost of monitoring by 63.63% (reduced from 11 months to 4 months).

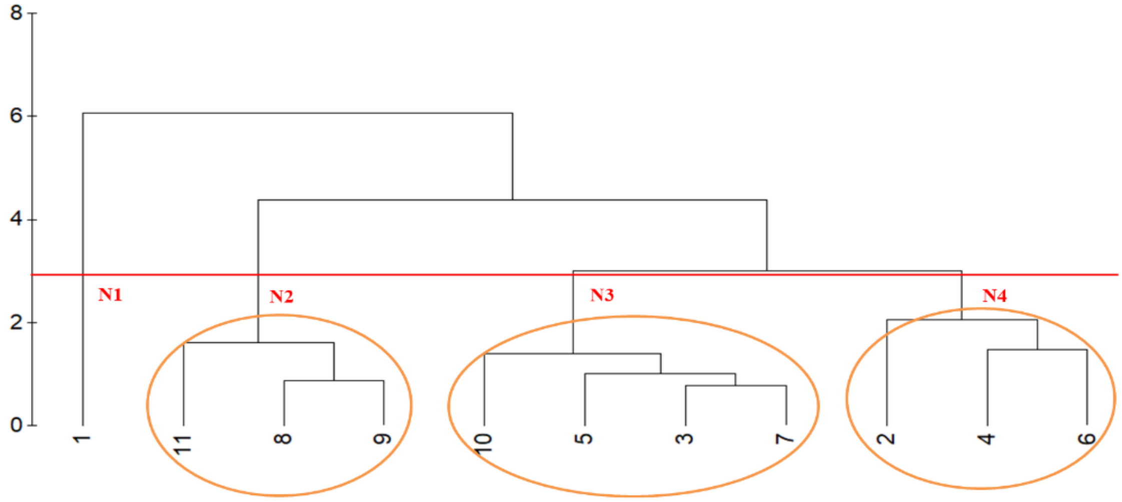

Figure 10. Clustering the sampling frequency of surface water quality

CA analysis results have divided the sampling times into 4 groups, and each group represents the water quality at a certain time of monitoring. The average values of the parameters are presented in Table 2, N1 only has January, so no SD value is recorded. Through the results in Table 2, it shows that in the N1 group, there is pollution of DO, TSS, COD, BOD, P-PO_4^{3-} and coliform criteria. In which, TSS and coliform were recorded as the two most heavily polluted indicators. Typical pollution at N2 includes DO, TSS, COD, BOD and coliform, which is less than 1 monitoring indicator compared to N1, but the coliform indicator at this time is the most polluted when reaching a very high value (20229 ±3057 MPN/100 mL). Groups N3 and N4 have the same pollution characteristics including pH, DO, TSS, COD, BOD and coliform criteria. The values of each indicator in groups N3 and N4 tend to be low, although pollution still occurs, but at a slight level. Indicator N-NO_3^- which appeared in all 4 groups, but did not exceed the allowable threshold according to QCVN 08-MT:2015/BTNMT.

Table 2. Mean values of water parameters in the identified clusters

Parameter	Unit	QCVN A1	N1	N2	N3	N4
Temp	^{0}C	-	30.36	29.73±0.54	24.58±1.09	23.01±0.6
pH	-	6.5-8.5	7.27	7.2±0.02	5.75±0.04	5.39±0.01
DO	mg/L	6	5.01	4.78±0.32	4.15±0.35	3.92±0.61

TSS	mg/L	20	49.00	55.83±4.68	41.88±3.61	37.16±3.85
COD	mg/L	10	14.25	18.42±1.21	13.03±1.94	11.97±3.1
BOD	mg/L	4	9.25	11.88±0.98	8.4±1.36	7.69±1.96
N-NO_3^-	mg/L	0.3	0.19	0.11±0.01	0.11±0.03	0.09±0.04
P-PO_4^{3-}	mg/L	0.1	0.18	0.17±0.09	0.07±0.02	0.05±0.03
Coliform	MPN/100 mL	2500	6587	20229±3057	9655±1752	6181±1094

3.3 Key parameters influencing on surface water quality

The results of Table 2 show that there are 3 main factors explaining 75.5% of the variation of water quality in the study area. PC1, PC2 and PC3 are the main factors explaining the change with the proportions of 43.8%, 17.5% and 14.3%, respectively. Eigenvalues are considered as a measure the importance of factors. An eigenvalue greater than or equal to 1 is considered significant (Liu et al., 2003). The main factors (PC1-PC3) all have eigenvalues greater than 1. Other factors contribute but are insignificant. PC1 explains for 4 factors including TSS (-0.452), COD (-0.461), BOD (-0.467) and coliform (-0.376) all at weak correlation. The cause of the influence of this source can be from the amount of alluvium in the water, agricultural production activities, wastewater from livestock activities and people's daily life when microorganisms appear in the area. materials from animal and human waste. For PC2, temperature (0.576) and pH (-0.508) have a moderate correlation, only DO (0.443) has a weak correlation. This source has a temperature and pH that can be affected by natural factors and DO is affected by organic pollution in the water. PC3 has an average correlation with all 3 factors including pH (-0.543), N-NO_3^- (-0.620) and P-PO_4^{3-} (-0.513). The causes of the influence of the above factors may come from the effects of natural factors and wastewater from agricultural activities.

Table 3. Key parameters affecting surface water quality

Parameters	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Temp	0,287	0,576	0,029	-0,125	0,041	-0,715	0,126	-0,198
pH	0,000	-0,508	-0,543	-0,075	-0,448	-0,453	-0,170	-0,074
DO	0,275	0,443	-0,021	0,058	-0,659	0,310	-0,423	0,119
TSS	-0,452	0,145	0,075	0,035	-0,207	-0,262	0,213	0,777
COD	-0,461	0,112	0,098	0,294	-0,181	-0,059	0,002	-0,452
BOD	-0,467	0,119	0,089	0,270	-0,204	-0,023	0,025	-0,304
N-NO_3^-	-0,106	0,283	-0,620	0,432	0,451	0,012	-0,337	0,142
P-PO_4^{3-}	-0,233	0,289	-0,513	-0,544	-0,074	0,321	0,416	-0,143
Coliform	-0,376	0,046	0,179	-0,577	0,191	-0,107	-0,666	-0,020

The results of PCA analysis showed that all 9 monitoring parameters including temperature, pH, DO, TSS, COD, BOD, N-NO_3^-, P-PO_4^{3-} and coliform all affected the surface water quality of the river. Post-colonial area of An Giang province with PCs representing each pollution source. The identified causes of pollution may be due to natural factors, agricultural production process, wastewater from livestock, daily activities of people in the area. In addition, due to the amount of alluvium in the water pouring from the upstream, the overflowing rain also brings many pollutants into the Hau River, causing the surface water quality indicators here to be changed and causing changes in the surface water quality.

4. Conclusion

Water quality in Hau river segment belonging to An Giang province in 2020 is facing pollution. There are six out of nine water indicators including DO, TSS, COD, BOD, P-PO_4^{3-} and coliform exceeded the allowable limits of column A1 QCVN 08-MT:2015/BTNMT. TSS and coliform and two indicators with the heaviest pollution in the study area. Along with the low DO, high TSS, BOD and COD indicators show that the water environment in Hau River is heavily organically polluted. The indicator P-PO_4^{3-} occurs at a slight level of pollution. The presence of coliform at high levels indicates that a lot of untreated human and animal waste is discharged directly into the Hau River. The water quality at two locations MH1 and MH2 is similar, there is not much difference, excepting temperature and DO. Water quality in June and August were lower compared to the other months. The CA results showed that the frequencies of surface water quality could be reduced from 11 to 4 times per year, reducing monitoring cost by 63.63%. DO, TSS, COD, BOD and coliform are typical pollution indicators in all four groups. The results from the PCA analysis showed that 75.5% of the variation in water quality in the Hau River area of An Giang province could be explained by three main factors. The monitoring parameters including temperature, pH, DO, TSS, COD, BOD, N-NO_3^-, P-PO_4^{3-} and coliform are the main indicators causing influence on surface water quality. The causes of pollution sources can come from natural processes, waste from agricultural production, animal husbandry, aquaculture, wastewater from industry and in the daily life of human activities.

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