Seasonal Variation and Key Variables Affecting Surface Water Quality in North Vam Nao Area, Vietnam

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***Abstract*—Surface water is essential to life, but it is seriously influenced by anthropogenic and natural impacts. Extraction of inside information (for examples sources and key variables influencing water quality) from monitoring data of surface water quality is a crucial task. This study was to intensively evaluate surface water quality in North Vam Nao using Principal Component Analysis (PCA) and Cluster Analysis (CA). The water quality parameters from seven locations during the period 2010–2022 including temperature, pH, total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO_3^--N), ammonium (NH_4^+-N), orthophosphate (PO_4^{3-}-P) and coliforms were collected. The results show that surface water quality is seasonally varied, except for pH. The PCA results predicted the main sources of water pollution were possibly hydrological conditions (rainfall, erosion) and human activities (domestic, agricultural and industrial activities). CA classified the water quality into three clusters for both dry and wet seasons. The common pollutants in both seasons were total suspended solids, organic matters, nutrients, and coliform. All the parameters temperature, pH, TSS, DO, BOD, COD, NH_4^+-N, NO_3^--N, PO_4^{3-}-P and coliform are key surface water parameters needed to be monitored. The results of the current study could be used for designing surface water monitoring at the study area.**

***Keywords*—cluster analysis, microorganism, North Vam Nao River, principal component analysis, surface water quality**

I. INTRODUCTION

Surface water pollution is one of the environmental problems that developing countries are facing [1]. This occurs when the amounts of pollutants discharged into the water body can no longer able to meet the needs of the natural ecosystem [2]. Water quality is significantly affected mainly by human activities (domestic, agricultural and industrial activities) and natural factors (riverbank erosion and climate change) [3, 4]. The discharge of untreated wastewater with high pollutant concentrations into water bodies aggravates the water pollution problem and reduces the self-cleaning ability of water [5]. Using contaminated water for a long time can be harmful to humans and the environment [5, 6].

In Vietnam, surface water quality is monitored using physical, chemical (temperature, pH, total suspended solids (TSS), turbidity, dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium (N-NH_4^+), orthophosphate (P-PO_4^{3-}), heavy metals (Fe, Al, Mn, Cr, Cd), chloride (Cl^-), sulfate (SO_4^{2-}), pesticides, antibiotics) and biological parameters (*Escherichia coli*, coliform (MPN/100mL) [7]. The monitoring data of surface water quality parameters are individually compared with those in the national technical regulation on surface water quality [7] and then used for calculation of water quality index for classification of water quality [8]. However, the methods used in Vietnam are simple and the inside information from the monitoring data is not completely mined. Currently, multivariate statistical methods including principal component analysis (PCA) and cluster analysis (CA) have been widely applied in surface water quality analysis since these methods could help in identifying potential pollution sources, key variables influencing water quality and grouping sites of surface water quality monitoring with similar water quality [9–11].

An Giang is the headwater province of the Mekong River, so the hydrological regime of the province depends on the water regime of the Mekong River. Furthermore, An Giang is the most vulnerable province to floods, causing damage to local life and economy. North Vam Nao is a flood control scheme for more than 24,000 hectares of agricultural land and serves the water demand for rural areas far away from Tien and Hau Rivers. The full-dike system in An Giang province is designed to control the flood water and this lead to the exchange of water between inside and outside is limited, thus polluting water [12]. For example, COD, NH_4^+-N, NO_2^--N and NO_3^--N concentration in surface water inside the full-dike system were significantly higher than those in outside the full-dike or semi-dike systems [13]. Surface water in North Vam Nao plays an important role in socio-economic development but its long-term assessment has not been performed. A few studies performed short-term assessment of the surface water quality of North Vam Nao [14, 15]. This study was carried out to evaluate long-term variations of surface water quality in North Vam Nao area in the period 2010–2022. Identification of potential pollution sources of surface water quality, key variable influencing surface water quality, clustering surface water quality in the study area would be performed using principal component analysis (PCA) and cluster analysis (CA). The findings of the current study could provide scientific information for future surface water monitoring and management.

II. MATERIALS AND METHODS

A. Description of the Study Area

An Giang is located in the west of the Mekong Delta of Vietnam. An Giang has two main topography types, including midland areas and seven low mountains. An Giang has abundant surface water and groundwater. The two main rivers (Tien and Hau Rivers) flow through the province with an average annual discharge of about 13,800 m^3/s. There are two

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seasons in a year, including the rainy season (from May to November) and the dry season (from December to April next year). The annual average temperature is about 27 °C, and the annual average rainfall is 1,400–1,500 mm. North Vam Nao flood control scheme was proposed to be built in 1985 in Phu Tan district of An Giang province. The main function is to reduce flood impact and protect production. With the flood control system, the area can produce 3 crops/year which could improve the living standards of the people in the area. However, surface water quality is greatly influenced [15].

B. Water Sampling and Analysis

Water quality monitoring data were collected from An Giang Department of Natural Resources and Environment in the period 2010–2022 at 7 locations (S1-S7) (Fig. 1). In the period 2010–2021, the sampling months were divided into dry season (March) and rainy season (June and September). However, the sampling months in 2022 included January, March, and November (the dry season) and May, July, and September (the rainy season). The observed water quality parameters comprised temperature, pH, total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+-N), nitrate (NO_3^--N), orthophosphate (PO_4^{3-}-P) and coliform. The parameters of pH, temperature and DO were measured in the field, while the remaining parameters were analyzed in the laboratory by standard methods. Particularly, the parameters of TSS, BOD, COD, NH_4^+-N, NO_3^--N, PO_4^{3-}-P and coliform were analyzed in the laboratory using standard methods [16]. These collected water samples were analyzed at the Center for Monitoring and Engineering of Natural Resources and Environment of An Giang province, with the certificate of VIMCERT 138 (Decision No. 2857/QD-BTNMT). Temperature, pH and DO were directly measured by portable meters (ADWA AD11 pH meter and 9142 DO meter). TSS was filtered through filter papers and dried to a constant weight at 103–105 °C. The weight increase over the empty dish represents the total solids. BOD was determined by the 5-day BOD test method. The samples were poured into airtight bottles and incubated at room temperature for 5 days. The changes in dissolved oxygen were measured before and after incubation to compute BOD_5. The samples were analyzed using the closed reflux and titrimetric method to measure COD. The samples were refluxed with potassium dichromate and titrated with iron (II) ammonium sulfate. NH_4^+-N, NO_3^--N and PO_4^{3-}-P were analyzed by colorimetric methods at 640 nm, 410 nm and 880 nm, respectively. Finally, coliforms were determined by the multiple-tube (most probable number) method, which included detecting and counting coliform bacteria by culture in a liquid medium.

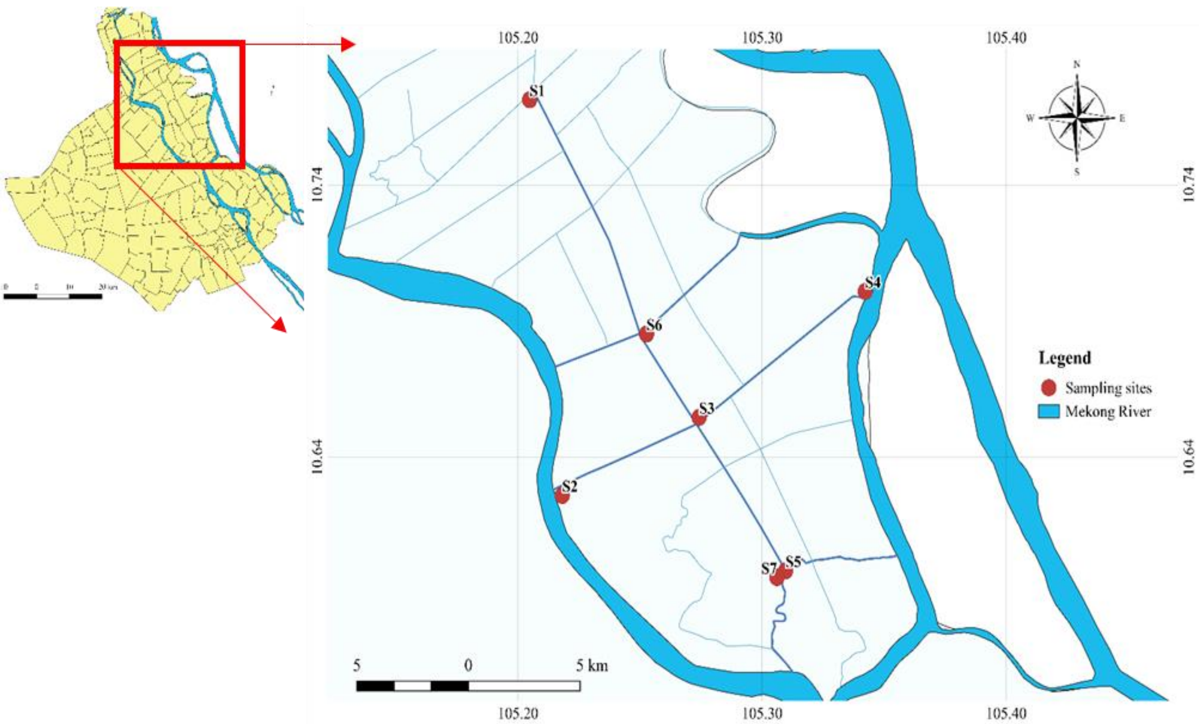

Fig. 1. Sampling sites in North Vam Nao.

C. Data Analysis

Surface water quality data were analyzed to determine values such as mean, standard deviation, maximum and minimum between dry and rainy seasons during 2010–2022. The water quality parameters were compared with QCVN 08-MT:2015/BTNMT National technical regulation on surface water quality [7].

Principal Component Analysis (PCA) was used to determine the main factors affecting surface water quality in North Vam Nao in the 2010–2022. The major trends in the data matrix provided important information that the simple descriptive statistical analysis cannot provide [17]. As a result, the main pollution sources have been identified based on the characteristics of the constituent elements [18–21]. Cluster Analysis (CA) was used to group the similar locations based on physical, chemical and biological characteristics in the water [22, 23]. PCA and CA were analyzed using the licensed software Primer V5.2 for Windows (PRIMER-E Ltd, Plymouth, UK).

III. Results and Discussion

A. Evolution of Surface Water Quality in the Study Area

1) Temperature and pH

The results showed that the temperature between dry and rainy season in the period 2010–2022 did not have a large fluctuation, and the temperature in the rainy season was higher than in the dry season. The temperature ranged from 27.24±0.65~31.08±0.73 ℃ (dry season) and 28.90±1.70~30.93±1.44 ℃ (rainy season), respectively (Fig. 2a). The temperature at the sampling sites was in the range of 28.65±1.18~30.35±1.31 ℃ and 29.01±1.14~30.13±1.11 ℃ in the dry season and rainy season, respectively (Fig. 2b). In general, the temperature in North Vam Nao was similar to that in the former studies [24–26]. The higher temperature in the rainy season than in the dry season may be due to the different sampling times between the two seasons. However, the temperature is considered suitable for aquatic organisms [27].

In the study area, the pH values were recorded within the allowable limit of QCVN 08-MT:2015/BTNMT (Fig. 3a, b). The pH value mainly fluctuates around the neutral range (pH = 7). Specifically, the range of pH in the dry and rainy season were 7.06±0.21~7.19±0.10 and 7.06±0.21~7.16±0.15, respectively. The variation of pH in this study has the same trend with the previous studies [4, 23].

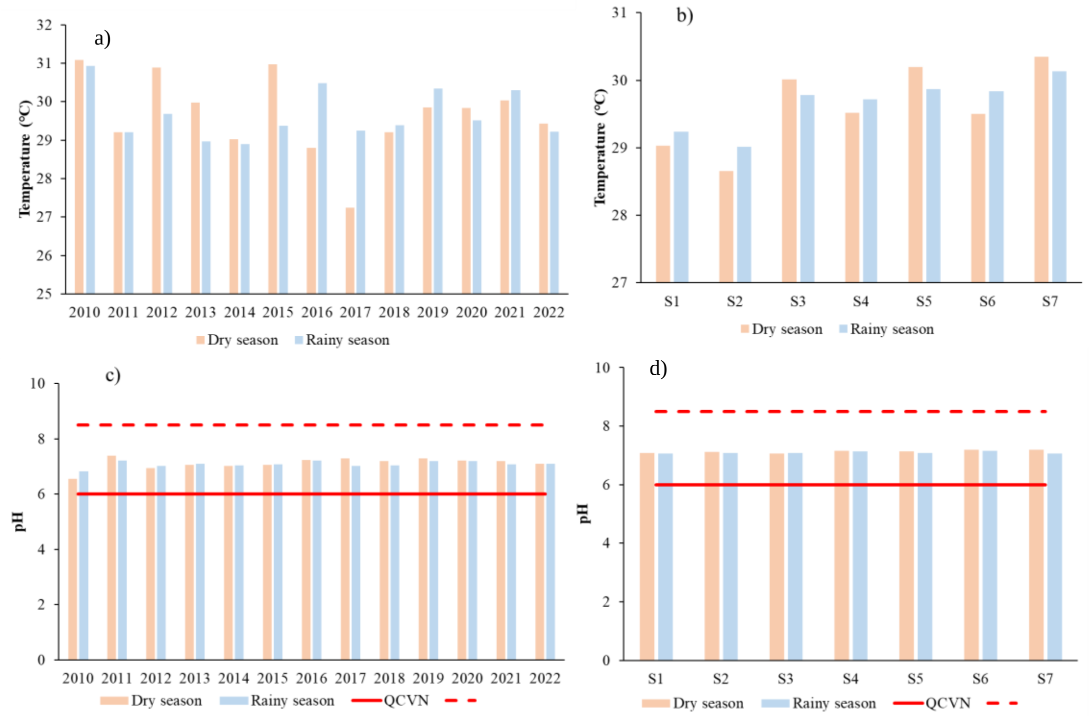

Fig. 2. Seasonal and spatial variation in the temperature (a, b) and pH (c, d).

2) Total suspended solids (TSS)

During the period 2010–2022, TSS concentrations in this study area all exceeded the allowable limit of the national standard on surface water quality QCVN 08-MT:2015/BTNMT, column A1 (20 mg/L) (Fig. 3a,b). The concentrations of TSS were in the range of 27.40±14.84~116.57±17.49 mg/L and 30.20±8.39~96.14±70.30 mg/L in dry and rainy season, respectively. The TSS concentrations tend to be higher in the rainy season than in the dry season, except 2017. This fluctuating trend has been recorded in many previous studies, both Vietnam and other countries studies [28–32]. Especially, some other studies also show that TSS in water bodies in An Giang province has exceeded the allowable limit [14, 25, 33]. The high TSS concentration not only has a strong impact on human activities and aquatic life in that area, but can also transport pollutants such as microorganisms, pesticides, etc. to other water bodies [34, 35]. In addition, TSS also causes difficulties and increases costs for water treatment [34].

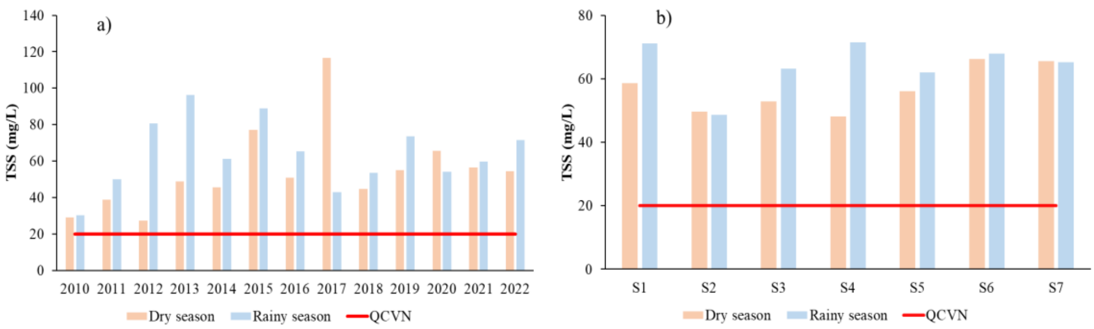

Fig. 3. Seasonal (a) and spatial (b) variation in TSS.

3) Oxygen demand

The results showed that the concentrations of DO, BOD and COD exceeded the allowable limits of QCVN 08-MT: 2015/BTNMT, column A1 (Fig. 4). It can be seen that the surface water in North Vam Nao was contaminated with organic matters. The organic matters could be originated from human activities [36, 37]. DO did not change significantly over the years from 2010 to 2022, ranging from 3.21±1.74~6.53±0.88 mg/L (Fig. 4a). DO concentration tended to be higher than in the rainy season.

The DO concentrations at the monitoring sites ranged from 3.45±1.31~4.86±0.98 mg/L. The highest concentration was at S4 in two seasons (Fig. 4b). According to [26, 33], dissolved oxygen in water depends on temperature, decomposition processes of organic compounds and photosynthesis of aquatic plants. When DO concentration is too low, it is a favorable condition to generate odor-causing H_2S and reduce the self-cleaning ability of water bodies [24, 34]. Compared with DO at the sampling sites on Tien and Hau rivers outside the full-dike area (5.14–5.44 mg/L) [26], DO levels in the current study were low. Low DO indicates the water pollution at in North Vam Nao.

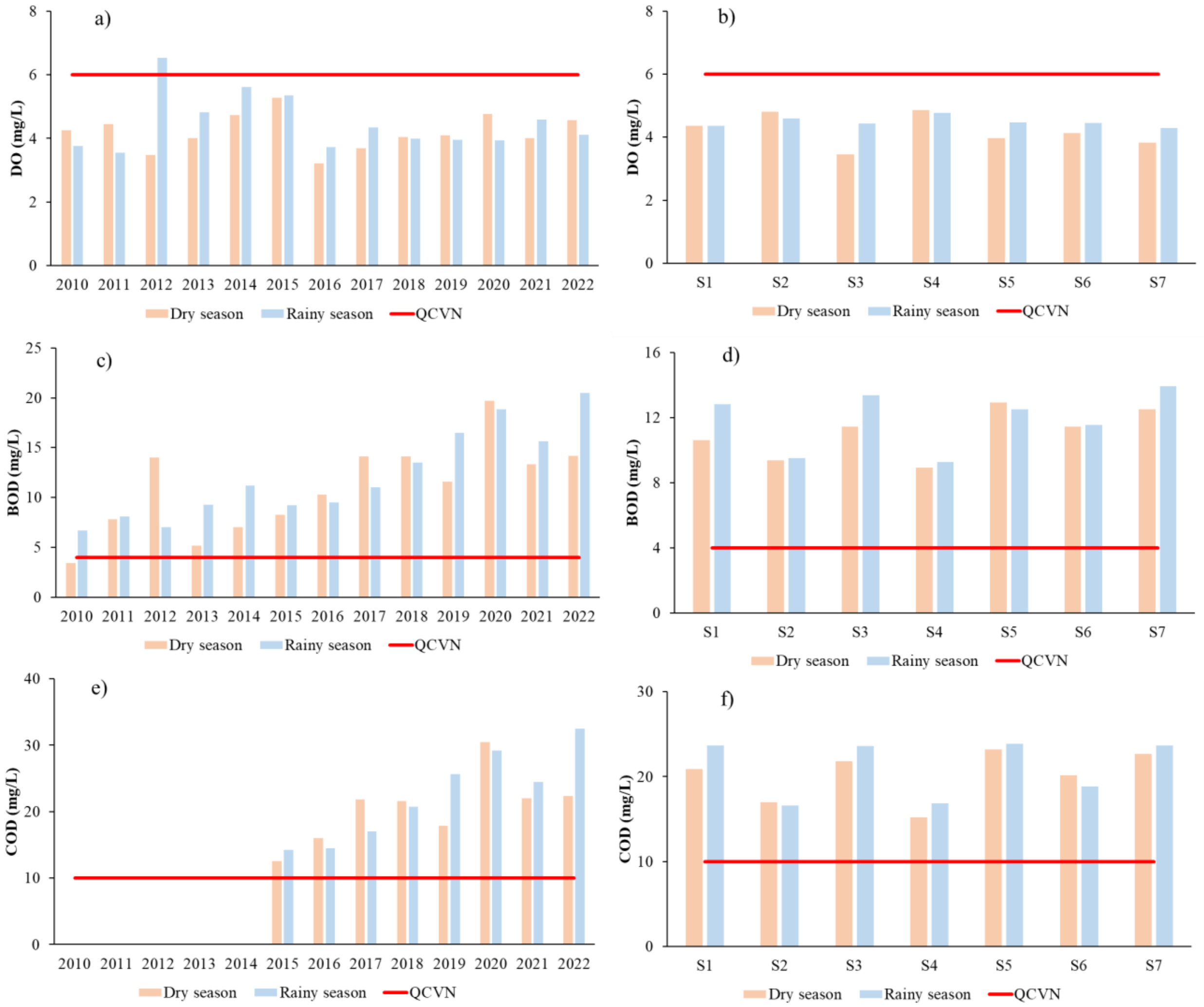

Fig. 4. Seasonal and spatial variation in the DO (a, b), BOD (c, d) and COD (e, f).

The BOD concentration fluctuated in the range between 3.40±0.55~19.71±6.02 mg/L and 6.70±9.84~20.50±7.45 mg/L in the two seasons. The BOD levels peaked in the rainy season and gradually increased over the years, exceeding the allowable limit of QCVN 08-MT:2015/BTNMT (Fig. 4c). The seasonal variation of BOD at sampling sites ranges from 8.91±4.70 to 13.94±6.94 mg/L. The highest concentration was at S7 in the rainy season (Fig. 4d). Compared with the BOD concentration in the full dike in My Luong town, the concentration in the study area is relatively higher [12]. The BOD concentration over the years exceeded the limit by 1.29–5.13 times (over the years) and 2.23–3.48 times (over the sampling sites). The BOD was found high is consistent with the low DO in water bodies. The organic matters could consume oxygen resulting in dissolved oxygen [38].

Similarly, COD concentration also tended to increase gradually over the study period, showing increasing organic pollution in North Vam Nao. The highest concentration of COD was 30.43±9.05 mg/L in the dry season (2020). In the rainy season, the highest COD concentration was 32.50±11.61 mg/L (in 2022) (Fig. 4e). The COD concentration at the locations ranged from 15.17±5.23 to 23.88±10.28 mg/L with the high COD concentration was at S5 in the two seasons (Fig. 4f). In this study, DO concentration in water was low while BOD and COD were high. The previous studies also found a negative relationship between DO and BOD, COD [22]. The COD concentration in the study area has exceeded the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (10 mg/L) by 1.26–3.25 times (over the years) and 1.52–2.39 times (over the sampling sites). Many studies have shown that the concentration of COD in the Mekong Delta water bodies exceeds the limit indicating the surface water is seriously polluted by organic matters [39, 40].

4) Nutrients

The NH_4^+-N concentrations fluctuates strongly between the two seasons (Fig. 5a,b). The highest concentrations in the dry and rainy seasons were 0.98±0.08 mg/L in 2017 and 0.85±0.65 mg/L in 2020 (Fig. 5a), respectively. The spatial variation of NH_4^+-N ranged from 0.39±0.46 to 0.76±0.49 mg/L, with the highest at S7 in the rainy season. The NH_4^+-N concentration of this study was lower than that in other rivers and canals [26, 40, 41]. Domestic, agricultural and industrial wastewater are sources generation of NH_4^+-N [6, 31, 40-44]. Especially the excessive use of fertilizers and pesticides in agriculture activities [26, 42, 43].

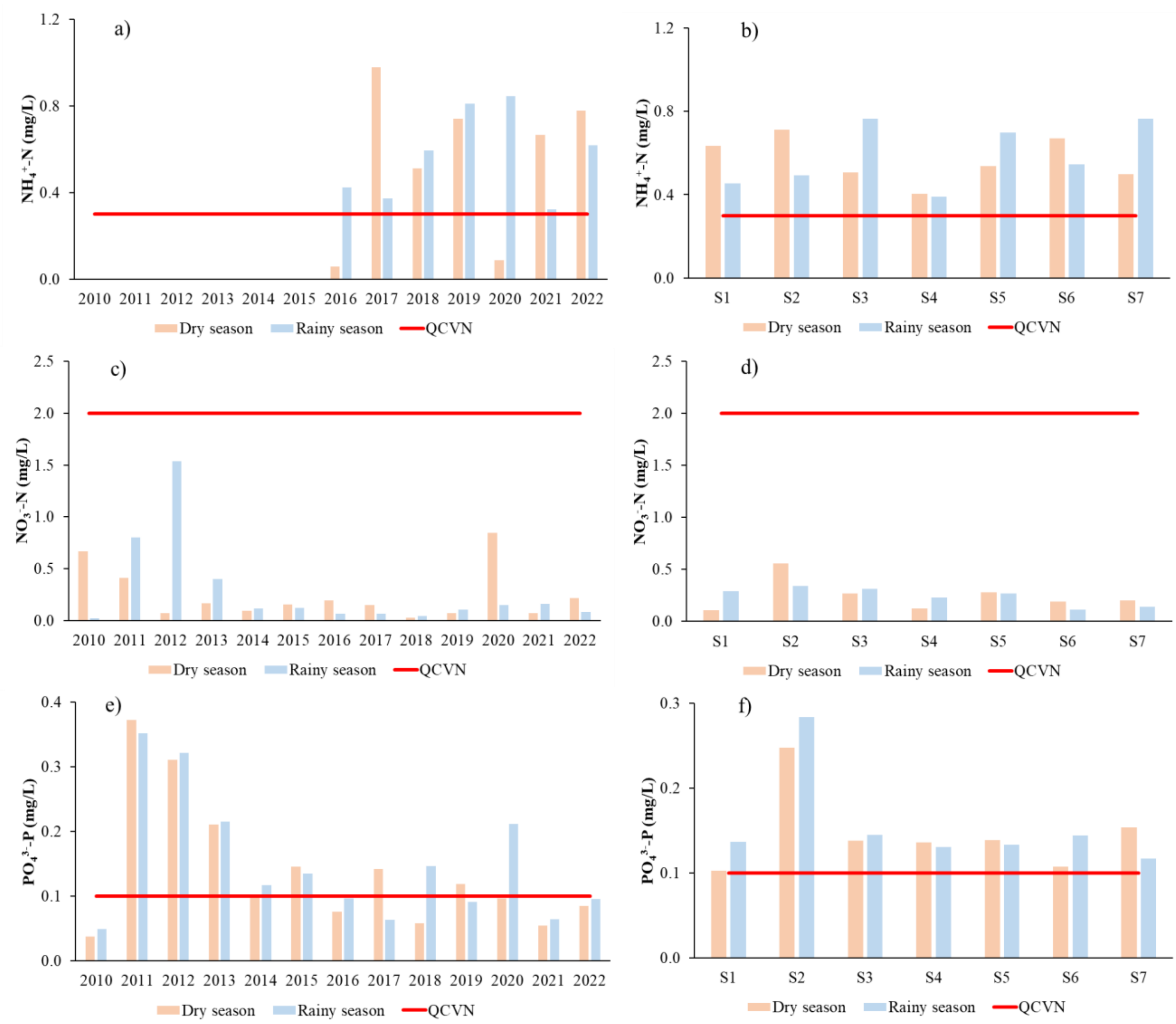

Fig. 5. Seasonal and spatial variation in the NH_4^+-N (a, b), NO_3^--N (c, d) and PO_4^{3-}-P (e, f).

The seasonal variation of NO_3^--N over the years (0.03±0.01~1.54±0.29 mg/L) and over locations (0.11±0.09~0.56±0.87 mg/L) still within the allowable limit of QCVN 03-MT:2015/BTNMT (2 mg/L) (Fig. 5c,d). In the period 2011–2014, NO_3^--N was the relatively high and it was found that nitrate concentration in the rainy season was a significantly higher than that in the dry season. In contrast, the concentration of NO_3^--N was higher in the dry season in the period of 2015–2022. The presence of NO_3^--N in water originates from domestic wastewater and the decomposition processes of nitrogen compounds [42–45].

The seasonal variation of PO_4^{3-}-P in the study area mostly exceeded the allowable limit of QCVN 03-MT:2015/BTNMT (0.1 mg/L) (Fig. 5e, f), ranging from 0.04±0.01~0.37±0.19 mg/L (over the years) and 0.10±0.08~0.28±0.32 mg/L (over the sampling sites). The concentration of PO_4^{3-}-P tended to be high in the rainy season. According to [31], the source of phosphate is the decomposition of organic (plant or animal), agricultural activities, and industrial wastewater. The high PO_4^{3-}-P concentration can lead to eutrophication of surface water [23, 46]. The findings showed that nitrate concentration is not an important environmental problem in North Vam Nao, whereas NH_4^+-N and PO_4^{3-}-P were potential causes of eutrophic water.

5) Coliform

The evaluation results show that the surface water quality in the study area was heavily contaminated with microorganisms. The density of coliform has far exceeded the allowable value of QCVN 08-MT:2015/BTNMT (Fig. 6a,b). The temporal variation of coliform density ranged from 398±312 MPN/100 mL to 191,307±268,370 MPN/100 mL. Fig. 6a shows that the lowest and highest values of coliform were in 2010 and in 2018, respectively. According to the spatial variation, the range of coliform density was 7,000±7,274~49,524±197,040 MPN/100 mL (Fig. 6b). The coliform density in rainy season tended to be higher than that in dry season (Fig. 6a,b). Many previous studies have also shown that coliform density was high in other water bodies of the Mekong Delta [25, 40].

Human and animal excreta are the main sources of coliforms [6, 47]. In addition, rainwater overflow is also a contributing cause to the increase of coliform density [48, 49]. The presence of high coliform density leads to water quality degraded, no longer safe for human activities as well as conservation of aquatic animals.

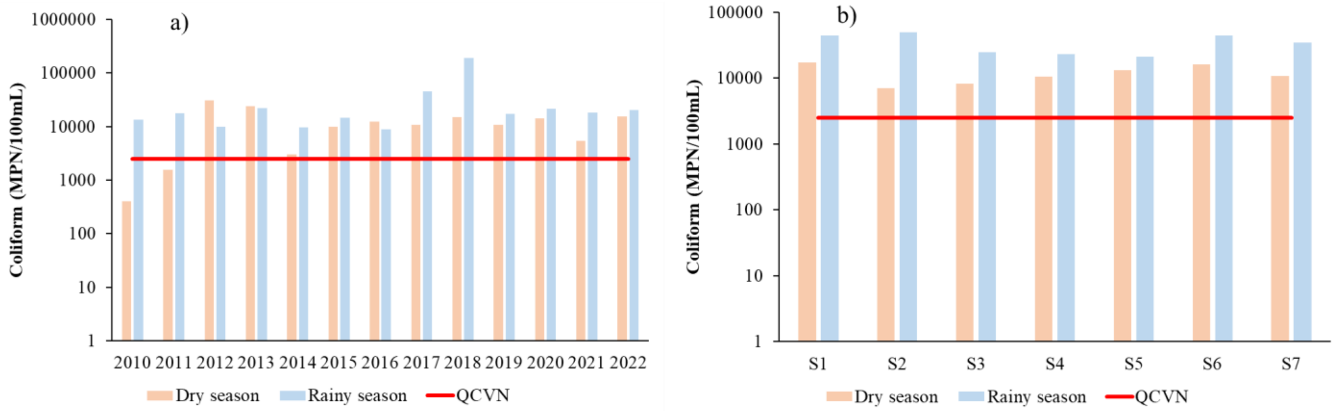

Fig. 6. Seasonal (a) and spatial (b) variation in the coliform.

B. Key Parameters Affecting North Vam Nao's Surface Water Quality

The result of the principal component analysis is presented in Table 1. Both the dry season and the rainy season have 04 main potential sources of pollution (PC). These PCs were defined based on the criterion of Eigenvalues coefficients greater than 1 [50–52]. Factors loading are classified as strong, average and weak if absolute values greater than 0.75, from 0.75 to 0.50 and from 0.50 to 0.30, respectively [19]. The results show that the variation of surface water quality in the dry season and the rainy season in the study area was explained by 97.1% and 97.6%, respectively.

In the dry season, PC1, PC2, PC3 and PC4 contribute 46.10%, 21.40%, 17.50% and 12.20%, respectively, to surface water quality variation. In which, PC1 is the most important factor with the weak correlation of parameters temperature, TSS, DO, BOD, COD and PO_4^{3-}-P. The components in this PC show possible sources of waste from domestic, industrial and agricultural activities [53]. Pollution sources in the rainy season are similar to the dry season. The results of PCA show that PC1 is the most important factor (47.10%) contributed by temperature, DO, BOD, COD, NH_4^+-N and PO_4^{3-}-P. This source of pollution has the characteristics of domestic and agricultural waste [17, 20, 21, 52]. Temperature is directly affected by the characteristics of the water body and the disturbance process [34]. PC2 also significantly explains the variation (27.30%) of water quality in the rainy season with moderate contribution of pH (−0.501) and weak contribution of TSS (−0.403), NO_3^--N (0.383) and PO_4^{3-}-P (0.320). The contribution of these parameters indicates that pollution can be caused by domestic, agricultural and flow conditions (erosion and disturbance). PC3 with the contribution of Coliform (strong), DO and NO_3^--N (weak) explained 13.2% of the variation in water quality. This source of pollution is clearly characterized by excretory and agricultural wastes. PC4 accounts for 10% of the total variation in water quality. It can be a source of pollution from agricultural activities and hydrological conditions due to the significant contribution of temperature, TSS and NH_4^+-N [23].

In addition, surface water overflow, flow disturbance, river bank erosion is also likely to contribute greatly to TSS pollution source [34]. Similar to many previous studies, the negative correlation between DO and BOD, COD, temperature parameters was also recorded in this PC [34, 54, 55]. PC2 was contributed mainly by DO, NO_3^--N, PO_4^{3-}-P and coliform. The results show that the nutrient parameters represent for materials and fertilizers in agriculture [34]. Meanwhile, the source of microbiological pollution is from excretory waste [6, 47, 56]. Similarly, PC3 and PC4 are also predicted to have pollution sources from agricultural activities and hydrological factors such as rainfall, runoff, erosion. Because the factor loading values of the component parameters all contribute at a significant level. Specifically, the parameters of temperature, TSS, NH_4^+-N and NO_3^--N have weak to strong contributions to PC3. Meanwhile, PC4 is explained by two parameters, pH and PO_4^{3-}-P.

PCA results show that all monitoring parameters have significant contributions to water quality variation in the study area. In particular, TSS and nutrient parameters (NH_4^+-N, NO_3^--N, PO_4^{3-}-P) appeared in most of the identified pollution sources. Therefore, the important factors affecting water quality variation in the study area can be hydrological conditions, domestic, industrial and agricultural wastes. However, to ensure that water quality is suitable for many different uses, it is necessary to continue to comprehensively monitor all parameters including temperature, pH, TSS, DO, BOD, COD, NH_4^+-N, NO_3^--N, PO_4^{3-}-P and Coliform.

Table 1. Key Variables influencing water quality in the dry and rainy season

Variable	Dry season				Rainy season			
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Temp	**−0.362**	0.255	**0.325**	−0.230	**−0.360**	−0.285	0.064	**0.385**
pH	−0.092	−0.279	−0.024	**-0.805**	0.145	**−0.501**	−0.157	0.238
TSS	**−0.356**	−0.142	**−0.355**	−0.284	−0.213	**−0.403**	−0.048	**−0.577**
DO	**0.362**	**−0.369**	0.005	−0.159	**0.343**	−0.283	**0.410**	0.037
BOD	**−0.403**	0.270	−0.155	−0.103	**−0.425**	0.197	−0.129	−0.073
COD	**−0.390**	0.288	−0.204	0.128	**−0.405**	0.232	0.077	−0.229
NH_4^+-N	0.110	−0.030	**−0.727**	0.105	**−0.352**	0.213	0.115	**0.512**
NO_3^--N	0.292	**0.429**	**−0.308**	−0.161	0.194	**0.383**	**0.492**	−0.256
PO_4^{3-}-P	**0.354**	**0.353**	−0.134	**−0.303**	**0.369**	**0.320**	−0.092	0.256
Coliform	−0.256	**−0.485**	−0.248	0.195	0.208	0.195	**−0.718**	−0.095
Eigenvalues	4.61	2.14	1.75	1.22	4.71	2.73	1.32	1.00
%Variation	46.1	21.4	17.5	12.2	47.1	27.3	13.2	10.0
Cum.%Variation	46.1	67.5	84.9	97.1	47.1	74.4	87.6	97.6

C. Temporal Variations of North Vam Nao's Surface Water Quality

The result of cluster analysis is presented in Fig. 7. As can be seen that surface water quality in the dry and wet seasons over the period of 10 years was divided into three clusters. In the dry season, Cluster I has 04 locations including S1, S4, S5 and S6. Cluster II includes only S2. Cluster III includes S3 and S7. Similar to the dry season, Cluster II of the rainy season also has only S2. Cluster I includes S3, S4 and S5, Cluster III includes S1, S6 and S7. All clusters in both rainy and dry seasons had concentrations of DO, BOD, COD, TSS, NH_4^+-N, PO_4^{3-}-P and Coliform higher than the limits of QCVN 08-MT: 2015/BTNMT. Two parameters of pH and NO_3^--N were within the allowable limits of the national standard.

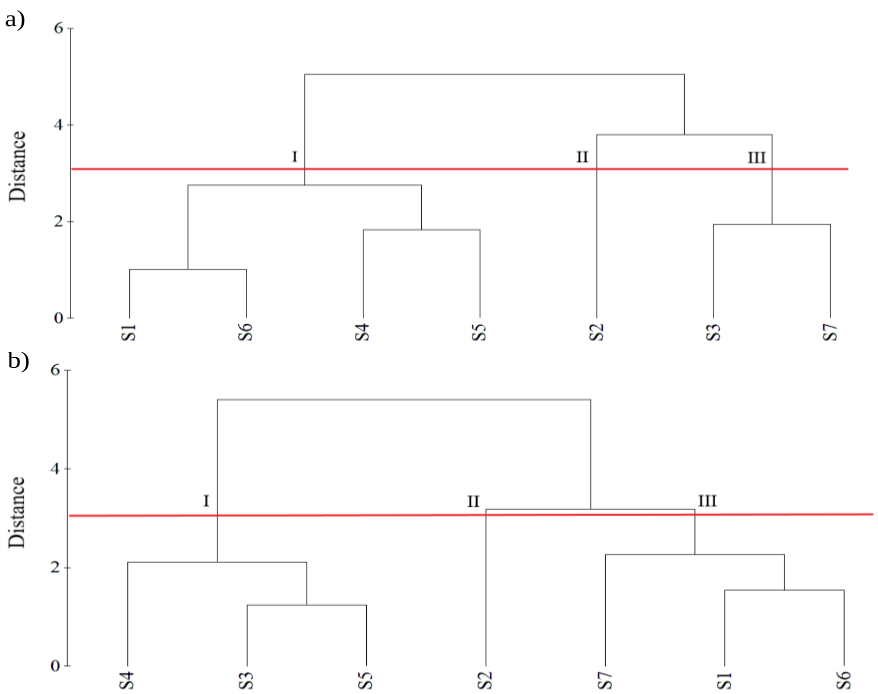

Fig. 7. Clustering surface water quality in Dry season (a) and Rainy season (b).

In the dry season, Cluster I, Cluster II and Cluster III are characterized by microbiological, nutritional and organic pollution, respectively (Table 2). Specifically, Cluster I had the highest density of coliform. Cluster II had the highest concentrations of NH_4^+-N and PO_4^{3-}-P. Finally, Cluster III had the highest concentrations of TSS, BOD, and COD and the lowest concentration of DO.

The research results show that the density of coliform in the rainy season was 2–7 times higher than in the dry season and far exceeds the allowable value of the national standard on surface water quality. The highest coliform density was recorded in Cluster II. Runoff in the rainy season increases the density of microorganisms and other suspended matter in the water [49, 56]. Pollution characteristics of Cluster I in the rainy season and Cluster III in the dry season are similar (Table 2). TSS, BOD and COD parameters had higher concentrations than other clusters.

Table 2. Values of water quality parameters in the identified clusters

Parameters	Dry season			Rainy season			QCVN 08-MT: 2015/BTNMT
	Cluster I	Cluster II	Cluster III	Cluster I	Cluster II	Cluster III	
Temp	29.56	28.65	30.18	29.74	29.01	29.79	-
pH	7.14	7.12	7.12	7.10	7.08	7.10	6-8.5
DO	4.33	4.81	3.64	4.37	4.59	4.56	6
BOD	10.97	9.36	**11.98**	**12.77**	9.50	11.72	4
COD	19.85	17.00	**22.25**	**22.06**	16.58	21.43	10
TSS	57.30	49.64	**59.22**	**68.08**	48.64	65.57	20
NH_4^+-N	0.56	**0.71**	0.50	0.59	0.49	**0.62**	0.3
NO_3^--N	0.18	0.56	0.24	0.18	0.34	0.27	2
PO_4^{3-}-P	0.12	**0.25**	0.15	0.13	**0.28**	0.14	0.1
Coliform	14,299.48	7,000.91	9,537.16	41,107.33	**49,524.09**	22,999.85	2,500

Based on the high concentrations of TSS, BOD, COD, NH_4^+-N, PO_4^{3-}-P and coliform, it can be seen that surface water quality in North Vam Nao area is contaminated with suspended solids, organic matter, nutrients and microbiology. The main sources of pollution can be human activities such as domestic, agricultural, industrial and hydrological conditions, rainwater runoff, riverbank erosion. All the parameters temperature, pH, TSS, DO, BOD, COD, NH_4^+-N, NO_3^--N, PO_4^{3-}-P and coliform are key surface water parameters needed to be monitored. The CA revealed that surface water quality at North Vam Nao is spatially varied. This information could be used for designing surface water monitoring locations at the study area.

IV. CONCLUSION

The quality of surface water in North Vam Nao was contaminated by total suspended solids, organic matters, nutrients and microbiology. The key variable influencing surface water quality included temperature, pH, TSS, DO, BOD, COD, NH_4^+-N, NO_3^--N, PO_4^{3-}-P and coliform. Surface water quality is highly spatially and temporally varied. Potential sources of water pollution could be from natural condition (hydrological regime) and anthropogenic activities (discharge of wastes from domestic, agricultural and industrial activities). Field surveys should be implemented to estimate the contributing sources of water pollution for future sustainable management of water sources in the study area.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

NXL conducted the research and analyzed the data; NXL wrote the paper; HVTM and NTG revised the manuscript; all authors had approved the final version.

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