Evaluating Surface Water Quality Using Multivariate Statistical Methods: A Case Study in a Province of the Mekong Delta, Vietnam

Nguyen Thanh Giao

Abstract—**This study aims to assess the quality, location and monitoring parameters of surface water quality in the water bodies of Vinh Long province using multivariate statistical methods. Water quality parameters including pH, temperature, turbidity, TSS, EC, DO, BOD, COD, NH_4^+-N, NO_3^--N, PO_4^{3-}-P, Cl^-, *E. coli*, coliform and Fe were used in the analysis. Cluster analysis (CA) was employed to analyze spatial variations of water quality, while principal component analysis (PCA) was used to identify key indicators affecting water quality. The findings showed that surface water quality in Vinh Long province was contaminated with organic matters (high BOD, COD and low DO), nutrients (NH_4^+-N, PO_4^{3-}-P), and microorganisms (*E. coli*, coliforms). The value of water quality health comprehensive was mainly evaluated at a "poor" to "medium" level. The CA results revealed that the water monitoring locations could be reduced from 63 to 48 locations, saving 23.8% of the total monitoring cost. PCA identified seven parameters that considerably influenced surface water due to four polluting water sources: runoff, residential areas, industrial and agricultural activities. Further studies need to identify specific sources and scales of water pollution for appropriate water management strategies.**

Index Terms—**CA, nutrients, surface water quality, organic pollution, PCA, microorganism.**

I. INTRODUCTION

Water is a precious resource that is extremely important for human life. Therefore, water sources must be guaranteed in both quantity and quality to meet the needs of consumers, sanitation, irrigation in agriculture and production. In recent decades, the human demand for water consumption is greatly increasing because of the pressure of an increase in population, living standards, and various complex production. Meanwhile, the threat is that water resources are increasingly limited. Surface water pollution is mainly caused by domestic wastewater, industrial wastewater, and partly from aquaculture wastewater [1], [2]. In addition, wastewater from rice cultivation containing pesticides and fertilizers contributes to polluted water sources. According to the regional planning project of Vinh Long province to 2030 with a vision for 2050, Vinh Long will be an agricultural center specializing in rice and fruit crops with the application of high technology. Moreover, it is also expected to be the center of multi-industry with the high-tech industry. Besides that, it is also a center of trade, eco-tourism in the river region, historical and cultural tourism at the regional level. In the face of economic development as well as the completion of planned goals, pressure on the environment has been put on it. Due to the limitation of water treatment plants in the area, the increasing amount of wastewater with complex compositions has polluted receiving sources, especially surface water. In addition, studies on surface water quality in Vinh Long province are scarce. Therefore, in the context of socio-economic development and climate change, it is necessary to assess and classify water quality in water bodies.

As a result of the aforementioned issues, the province's annual water quality monitoring system has been proposed in the national water quality monitoring program. However, most surface water quality assessment is mainly compared with the national technical regulation on surface water quality (QCVN 08-MT:2015/BTNMT); and based on the water quality index (WQI) [3], [4]. However, there are only a few studies that have applied in-depth evaluation methods like principal component analysis (PCA) and cluster analysis (CA). PCA and CA have been widely used in the spatiotemporal analysis of surface water quality in the world [5]-[7]. This study aimed to apply multivariate statistical methods in analyzing the water quality monitoring dataset of Vinh Long province. The results could improve the current assessment method of surface water quality in the study area.

II. MATERIALS AND METHODS

A. Site Description

Vinh Long province is located in the Mekong Delta region. The North and Northeast border Tien Giang and Ben Tre provinces, and the Northwest borders Dong Thap province. Tra Vinh province is adjacent to Vinh Long in the South, and its Southwest borders Hau Giang provinces, Soc Trang, and Can Tho City. Vinh Long province has an area of 1,525.73 km^2 with 1,050,241 people, including 8 administrative units (1 city, 1 town and 6 districts). Due to the topography of the floodplain at the mouth of the river, the sub-terrain of the province is in the form of a basin in the center of the province and gradually rises in two directions along the banks of the Tien, Hau, Mang Thit rivers and along major rivers and canals. It is located between the two largest rivers in the Mekong Delta, namely Tien and Hau rivers; thus, an interlaced network of rivers has facilitated a fairly complete natural water distribution system. Additionally, the large average annual rainfall has created favorable conditions for domestic and production activities. The water resources of Vinh Long province mainly rely on the continental surface water of 91 river and canal systems in the area. Surface water sources are relatively evenly distributed throughout the

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N. T. Giao is with College of Environment and Natural Resources, Can Tho University, Can Tho 900000, Vietnam (e-mail: ntgiao@ctu.edu.vn).

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province and water sources of water supply stations in the area are mainly taken from surface water of major rivers such as Tien River, Hau river, Co Chien river and Mang Thit river. Vinh Long has favorable conditions for agricultural production, which is considered a great strength to develop the provincial economy. Vinh Long has always been one of the leading provinces in the country in attracting investment through reasonable and open policies. Under the process of industrialization and modernization in the province, a significant number of wastes have been generated and then potentially pollute the surface water environment. Therefore, monitoring and evaluating surface water quality are important tasks for environmental managers.

B. Water Sampling and Analysis

The 63 water monitoring sites (denoted NM01-NM63) were collected in urban areas, densely populated areas, central market areas, industrial parks, and handicraft villages. There were five background monitoring locations (NM01, NM24, NM40, NM41 and NM54) and 58 impact monitoring sites (Fig. 1). Surface water samples were monitored three times/year, namely in March, June and September. Fifteen water quality variables including pH, temperature (^oC), turbidity, total suspended solids (TSS), electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+-N), nitrate (NO_3^--N), orthophosphate (PO_4^{3-}-P), chloride (Cl^-), *E. coli*, coliforms and iron (Fe) were analyzed. pH, temperature, turbidity, EC and DO were measured directly in the field while TSS, BOD, COD, NH_4^+-N, NO_3^--N, PO_4^{3-}-P, Cl^-, *E. coli*, coliforms and Fe were analyzed in the laboratory by standard methods [8].

C. Data Analysis

The comprehensive water quality health assessment method (ETI) was used to assess the water quality status and zone for the studied water bodies.

$$ETI_{total} = \frac{1}{n} \times \sum_{i=1}^{n} C_i = \frac{C_{physicochemical} + C_{nutrients} + C_{microbiology}}{3} \quad (1)$$

$$C_{physicochemical} = \frac{C_{pH} + C_{TSS} + C_{DO} + C_{BOD} + C_{COD} + C_{Fe} + C_{Cl^-}}{7} \quad (2)$$

$$C_{nutrients} = \frac{C_{NH_4^+-N} + C_{NO_3^--N} + C_{PO_4^{3-}-P}}{3} \quad (3)$$

$$C_{microbiology} = \frac{C_{E.coli} + C_{Coliform}}{2} \quad (4)$$

The score of each water quality parameter is calculated by equation (5) and (6).

$$C_{DO} = \frac{Measured - Threshold}{Expectation - Threshold} \quad (5)$$

For the remaining parameters,

$$C_{parameters} = \frac{Threshold - Measured}{Threshold - Expectation} \quad (6)$$

where, ETI_{total} is the comprehensive evaluation value of water quality and health; C_i is the normalized value of physicochemical parameter group, nutritional parameter group and different biological parameter groups, and n is the number of parameter groups. The expected value and threshold of the parameters are determined according to the national technical regulation on surface water quality columns A1 and B1 [9].

The level of water quality health of water bodies is divided into 5 levels, including very poor (0-0.2), poor (0.2-0.4), medium (0.4-0.6), good (0.6-0.8) and excellent (0.8-1.0) [10], [11].

The individual parameters of surface water quality were compared with the national technical regulation on surface water quality QCVN 08-MT:2015/BTNBMT, column A1 [9]. Principal Component Analysis (PCA) was used to reduce the complexity of the original data set from a large number of variables to a smaller number of factors. The results of PCA generate a new set of variables called principal components or principal factors (PCs) [12]. The eigenvalue coefficient is considered a measure of the importance of the principal component [13]. The absolute value of the significant correlation coefficient greater than 0.75 means a strong correlation between the main component and the water quality parameter, from 0.5-0.75 is the average correlation and less than 0.5 is the weak correlation [14]. Cluster analysis (CA) was used to group monitoring locations into classes (clusters) on the basis of similarity in water quality among sites using the Ward's method [15], [16]. CA results were presented by a dendrogram that visually presents the internal relationships between variations of surface water parameters. PCA and CA were performed using Primer 5.2 software for Windows (PRIMER-E Ltd, Plymouth, UK).

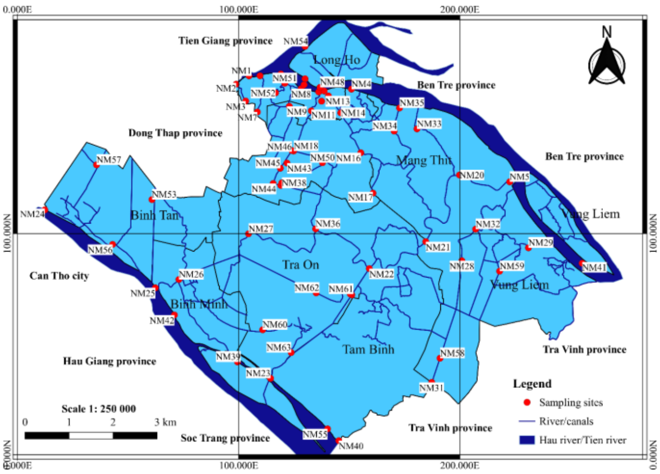

Fig. 1. Map of surface water monitoring locations.

III. RESULTS AND DISCUSSION

A. Variation of Surface Water Quality

The pH value at 63 monitoring locations for surface water fluctuated in the range of 7.08±0.43-7.94±0.23, with an annual average of 7.50±0.37 (Table I). The lowest value was found at NM21, and the highest one was at NM09. pH was still within the allowable limit of QCVN 08-MT:2015/BTNMT column A1. The pH value was recorded in the range of 7.2-7.9, with an average of around 7.6 in 2016 [17]. This showed that the pH value did not change much compared to 2016. Compared with other water bodies, previous research showed that pH ranged between 6.9-7.1 in canals of An Giang province [18], 6.3-8.0 in Hau river [19], and 6.8±0.0 to 7.1±0.3 in water bodies in Hau Giang province [20]. In general, the pH in the study areas is similar and within the allowable limit for column A1 of QCVN 08-MT:2015/BTNMT. The pH value is also in the tolerant range of aquatic organisms [21]. The temperature in the study area varied in the range of 28.30±2.71-31.43±2.71°C, with an average annual average of 30.13±0.95°C (Table I). NM49 and NM56 were found with the lowest and highest temperature, respectively. Water temperature in the Hau river ranges from 27.1-32.0 °C [19]-[21] and in the Mekong River is from 19.9-32.2°C [22], [23]. Water temperature tends to decrease in the rainy season [19]. However, this fluctuation is not large [18] since water has the function of temperature regulation. This temperature range is suitable for the growth of aquatic organisms [11], [24].

Turbidity was from 26.10±19.33-95.70±34.50 NTU with the average at 52.61±28.53 NTU (Table I). The lowest and highest values were detected in NM15 and NM62, respectively. According to Nhien and Giao (2019) [25], the turbidity in the water in rivers and canals of the Mekong Delta only varied from 3.25-59.17 NTU. There is no regulation on turbidity in the national technical regulation. However, when the turbidity is high, it will lead to high TSS in water [20], which is costly in treating water supply, reducing the biological productivity of the water bodies [21], [24]. The mean TSS in surface water monitoring locations varied from 22.67±5.86-49.67±8.50 mg/L (Table I). TSS concentration at all monitoring locations exceeded 1.13-2.48 times the allowable limit of QCVN 08-MT:2015/BTNMT column A1. TSS ranged from 32.8±6.4 to 101.8±40.9 mg/L in water bodies of Hau Giang province [20], varied from 16-176 mg/L in canals of Soc Trang province [26], and ranged from 41.2±33.7 to 89.57±31.31 mg/L in Hau river [19]. The cause of high TSS is due to algae, riverbank erosion, rainwater overflow containing organic matters. TSS increases the cost of water treatment and also influences the natural development of aquatic organisms. In addition, it is a carrier to transport pollutants such as microorganisms, pesticides, antibiotics to many different water bodies, which in turn increases the possibility of human exposure to adverse environmental factors. Electrical conductivity (EC) in water bodies ranged from 16.00±7.94 to 51.40±11.66 mS/m (Table I). The locations with high EC values were found in the residential areas, industrial parks, central markets as well as fishing villages and rice farming in the inland areas.

TABLE I: SUMMARY MEAN WATER QUALITY IN THE STUDY AREA

Parameters	Unit	Min	Max	Mean
pH	-	7.1	7.9	7.5
Temp.	°C	28.3	31.4	30.1
Turb.	NTU	26.1	95.7	52.6
TSS	mg/L	22.7	49.7	35.5
EC	mS/m	16.0	51.4	27.0
DO	mg/L	4.1	6.1	5.0
BOD	mg/L	4.4	8.5	6.0
COD	mg/L	7.9	18.2	12.5
NH_4^+-N	mg/L	0.2	0.6	0.3
NO_3^--N	mg/L	0.1	0.7	0.4
PO_4^{3-}-P	mg/L	0.2	0.9	0.6
Cl^-	mg/L	0.0	284.7	12.3
E. Coli	MPN/ 100mL	23.7	82.0	54.6
Coliform	MPN/ 100mL	2400	17467	5073
Fe	mg/L	0.2	0.7	0.4

DO in surface water was in the range of 4.14±1.03-6.10±0.15 mg/L, with an average of 4.98±0.65 mg/L (Table I). In the study area, most of the monitoring locations with DO was below the prescribed threshold, and only 2 out of 63 locations met the limit of QCVN 08-MT: 2015/BTNMT, column A1. However, the content of DO tends to improve compared to 2016 [17]. The average of DO in water bodies of Hau Giang province was 4.0±0.3 mg/L [20], and that ranged 1.7-6.17 mg/L in Soc Trang province) [26], and 4.0-5.2 mg/L in An Giang province [18]. It can be seen that the DO content in the water bodies of Vinh Long province is relatively better than that of Hau Giang, Soc Trang and An Giang. The DO concentration in rivers mainly depends on diffusion, phytoplankton, and organic matters. Low oxygen in water bodies can lead to a decrease in the biodiversity of water bodies. According to Boyd (1998) [24], the suitable DO in water is 5-7 (mg/L). It can be seen that the average DO of all locations is not in this suitable range. BOD concentration in the study area ranged from 4.35±0.32 to 8.50±1.36 mg/L, with an average of 6.03±1.11 mg/L (Table I). BOD concentration in the study area exceeded the expected value of QCVN 08-MT:2015/BTNMT column A1 from 1.09-2.13 times. Previous research also showed that most of the water bodies in the Mekong Delta with BOD exceeded the permissible limit [18]-[20], [26]. High BOD in surface water can pose many risks when used as supply water because carbon compounds can combine with chlorine during the disinfection phase to produce hazardous compounds and result in health effects [27]. Like TSS, organic pollution due to high BOD in water bodies is prevalent in the Mekong Delta. The origin of BOD can be from farming, livestock, landfill, domestic activities, and services that have discharged untreated wastes into the surface water environment [23], [28]. COD was varied from 7.92±0.43-18.20±2.76 mg/L (the mean value was 12.47±2.45 mg/L). 55 out of 63 the monitoring positions had COD exceeded the expected value of QCVN 08-MT:2015/BTNMT from 1.04-1.82 times. The average COD in some main rivers and canals in Can Tho city and Hau Giang exceeded QCVN 08-MT:2015/BTNMT column A1 (10 mg/L) [20], [29]. DO, BOD and COD data in the water bodies indicated the organic pollution is the concern for water quality in the study area.

The average concentrations of NH_4^+-N and NO_3^--N were 0.33±0.10 and 0.37±0.15 mg/L, respectively (Table I). More than 50% of the monitoring sites (35/63) with NH_4^+-N exceeded the expected value of QCVN 08-MT:2015/BTNMT column A1 from 1.03-1.93 times. This result is similar to previous studies that reported surface water quality in the Mekong Delta is contaminated with ammonia [20], [26]. However, the concentration of NO_3^--N in the study area was still within the expected value of QCVN 08-MT:2015/BTNMT, column A1. Nitrate content in Vinh Long province was only recorded in the range of 0.18 - 0.48 mg/L in 2016 [17]; that is, nitrate content has tended to increase. Studies on surface water quality show that NO_3^--N concentration in Hau river ranged from 0.002-0.395 mg/L [19], 0.05-0.14 mg/L in canals of Soc Trang province [26], 0.35±0.20 mg/L in canals in Hau Giang province [20]. The NO_3^--N concentrations ranged 0.2-1.0 mg/L, with an average greater than 0.7, which is suitable for aquatic life but potentially causes eutrophication [22], [24].

The concentration of PO_4^{3-}-P fluctuated between 0.16±0.02 and 0.89±0.03 mg/L, averaged at 0.61±0.19 mg/L (Table I). The origin of phosphorus can be from fertilizers and detergents due to farming, livestock and industrial activities [30]. Dissolved phosphorus values in the infield canals and Hau river of An Giang province ranged from 0.02 to 0.47 mg/L [18], 0.05-0.9 mg/L (Soc Trang province) [26]; it can be seen that PO_4^{3-}-P in water bodies of Vinh Long province was higher than in the other provinces. Phosphate content in the current study is lower than in 2016 [17], but this content was still recorded above the expected value of QCVN 08-MT:2015/BTNMT, column A1. There is a potential risk of eutrophication if nitrate concentration increases.

E. coli at the monitoring locations varied from 23.67±8.33 to 82.00±11.14 MPN/100 mL exceeding the expected value of QCVN 08-MT:2015/BTNMT, column A1 by 1.18-4 times. Similarly, the density of coliforms in surface water was in the range of 2,400±200-17,466.67±23,846.45 MPN/100 mL, averaged at 5,073.02±3279.62 MPN/100 mL (Table I). Coliforms in the study area exceeded the expected value of QCVN 08-MT:2015/BTNMT, column A1 up to 6.99 times. Previous studies also showed that surface water quality in the Mekong Delta has been contaminated with microorganisms [3], [18], [20],]26]. The sources of coliform contamination are from human and animal wastes, especially the fecal matters [31]. The presence of *E. Coli* and coliforms indicated that surface water quality in the study area was microbially polluted.

Cl^- was detected only at 4 monitoring locations NM28, NM31, NM40 and NM41, ranging from 0 to 284.67±39.72 mg/L, with an average of 12.32±49.80 mg/L (Table I). The site NM41 had signs of saline intrusion with Cl^- concentration exceeded the expected value of QCVN 08-MT:2015/BTNMT, column A1. Fe concentration at 63 monitoring sites was averaged at 0.38±0.99 mg/L (Table I). 6 out of 63 positions with Fe concentration exceeded the expected value of QCVN 08-MT:2015/BTNMT, column A1 from 1.12-1.34 times. In Soc Trang province, the measured Fe content in surface water was 0.3-3.75 mg/L [26], and in the canals of Hau Giang the concentration of Fe was 1.2±0.6 mg/L [20]. The presence of iron degrades water quality, incurs treatment costs and poses health risks to humans and the environment [20]. The cause of Fe pollution is due to the geographical conditions in the Mekong River Delta, which is acid sulfate soil, and farming activities have resulted in soil disturbance leading to Fe-contaminated water.

B. Comprehensive Water Quality Assessment

The value of ETI showed that the water quality in the study area ranged from very poor to excellent, but mostly fell in poor and medium (Fig. 2). The highest value recorded was 0.96, and the lowest was 0.07. As can be seen from Fig. 2, the medium water quality was concentrated in the northern region (Vinh Long city). Meanwhile, the poor water quality was recorded scattered in the inland area where agricultural activities and riverside population were observed. The level of water quality pollution was mainly affected by NH_4^+-N, PO_4^{3-}-P and *E. coli*. This can be deduced that the control of nutrients and *E. coli* should be a priority for water quality management in the water bodies.

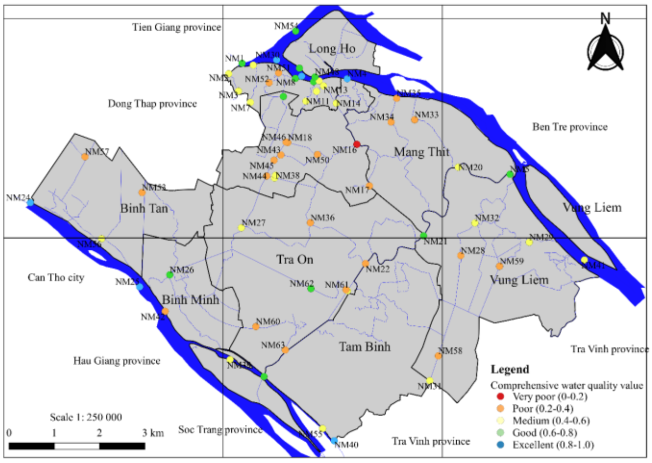

Fig. 2. Spatial distribution of the ETI results in the study area.

C. Key Parameters Affecting Surface Water Quality

PCA results showed that 10 PCs explained 92.50% of the variation in surface water quality in the study area (Table II). According to Shrestha and Kazama (2007) [32], PCs with eigenvalues greater than 1 are considered significant. Based on the results, there were four sources of water pollution corresponding to the first four PCs. PC1 had weak correlation with BOD (-0.356), COD (-0.338), NH_4^+-N (-0.337), NO_3^--N (-0.327), PO_4^{3-}-P (-0.326) and *E. coli* (-0.351). This shows that the correlation of organic and nutritional indicators is related to population factors, industrial facilities, services and livestock activities [33]. PC2 was weakly correlated with turbidity (-0.437), TSS (0.358), BOD (-0.321), COD (-0.351) and Fe (0.371). Nhan and Nhan (2014) [33] reported that aquaculture and rice production are the two causes of the positive correlation of TSS and Fe with PC2. PC3, PC4 appeared to correlate with Cl^- at moderate and weak correlation, respectively (Table II). These two main components have been reported to be related to salinity in water because the salinity has tended to propagate into the infield of water bodies in Vinh Long since 2016 [34]. PC5 has an eigenvalue of only 0.96, but it moderately correlates with temperature (-0.744). PC6 is weakly correlated with EC, BOD, and Cl^-, and moderately correlated with coliforms and Fe. PC7 was weakly correlated with pH, temperature, DO, nitrate and coliforms. PC8 was weakly correlated with EC, nitrate and coliforms. PC9 was weakly correlated with NO_3^--N and moderately correlated with pH and turbidity. PC10 had relatively small eigenvalues, but this PC had a relatively high correlation with TSS (0.564). Key water parameters that had an important influence on surface water quality were Cl^-, temperature, Fe, turbidity and TSS. Nutrients and microorganisms also exceeded the allowable limits.

D. Spatial Variation of Surface Water Quality

Cluster analysis results are presented in Fig. 3. Surface water quality in the study area was divided into 11 groups. Groups 1, 2, 3, 4, 7, 10 represented a distinct characteristic position. Group 1 had one location at NM16 at the confluence of the Long Ho river, which receives wastes from the market area. Group 2 was at NM62 - Kenh Xang bridge where wastes were received from inland areas. Group 3 was at

NM40 on Hau river in the border area between Vinh Long - Tra Vinh - Soc Trang. Group 4 was the location at NM28 at Bung Truong river where wastewater was received from Hieu Phung market area. Group 7 was the location at NM15, the monitoring point at the head of the river near Mau Than bridge, where wastes were received from the market area nearby. Group 10 was the NM37 Mang Thit river where wastes were received from Tam Binh market. Water quality in these locations was different from the rest; thus, they are retained for future monitoring.

TABLE II: MAIN COMPONENTS AFFECTING SURFACE WATER QUALITY IN THE STUDY AREA

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
pH	0.203	-0.033	-0.464	-0.236	-0.129	0.037	0.412	0.123	-0.520	0.281
Temp.	-0.092	0.145	-0.050	-0.416	-0.744	-0.214	-0.326	0.163	0.150	-0.088
Turb.	-0.118	-0.437	0.254	-0.324	0.131	0.156	-0.219	0.218	-0.538	-0.316
TSS	-0.246	0.358	-0.020	-0.285	0.282	-0.041	-0.270	0.219	-0.127	0.564
EC	-0.195	-0.189	0.229	0.445	-0.246	0.340	-0.082	0.489	0.034	0.409
DO	0.186	0.162	-0.402	-0.015	0.281	0.375	-0.473	0.278	0.136	-0.323
BOD	-0.356	-0.321	-0.262	-0.029	-0.030	-0.036	0.007	-0.103	0.175	-0.005
COD	-0.338	-0.351	-0.292	-0.020	0.000	-0.058	0.005	-0.021	0.154	0.020
NH_4^+-N	-0.337	-0.217	-0.220	-0.123	0.019	0.290	0.150	-0.061	0.136	-0.011
NO_3^--N	-0.327	0.044	0.146	0.169	0.026	-0.172	-0.370	-0.459	0.380	0.049
PO_4^{3-}-P	-0.326	0.297	-0.046	-0.070	0.207	0.136	0.119	-0.095	0.134	0.017
Cl^-	0.023	0.016	0.501	-0.468	0.007	0.399	0.239	-0.106	0.220	0.029
E. Coli	-0.351	0.226	-0.016	-0.190	0.104	-0.082	0.175	0.088	-0.004	-0.141
Coliforms	-0.283	0.211	0.125	0.187	0.057	-0.308	0.325	0.492	-0.093	-0.395
Fe	-0.179	0.371	-0.105	0.218	-0.366	0.523	0.076	-0.225	-0.299	-0.210
Eigenvalues	4.08	1.93	1.70	1.29	0.96	0.87	0.78	0.62	0.50	0.44
%Variation	32.00	12.90	11.30	8.60	6.40	5.80	5.20	4.20	3.30	2.90
Cum.%Var	32.00	44.90	56.20	64.80	71.10	76.90	82.10	86.30	89.60	92.50

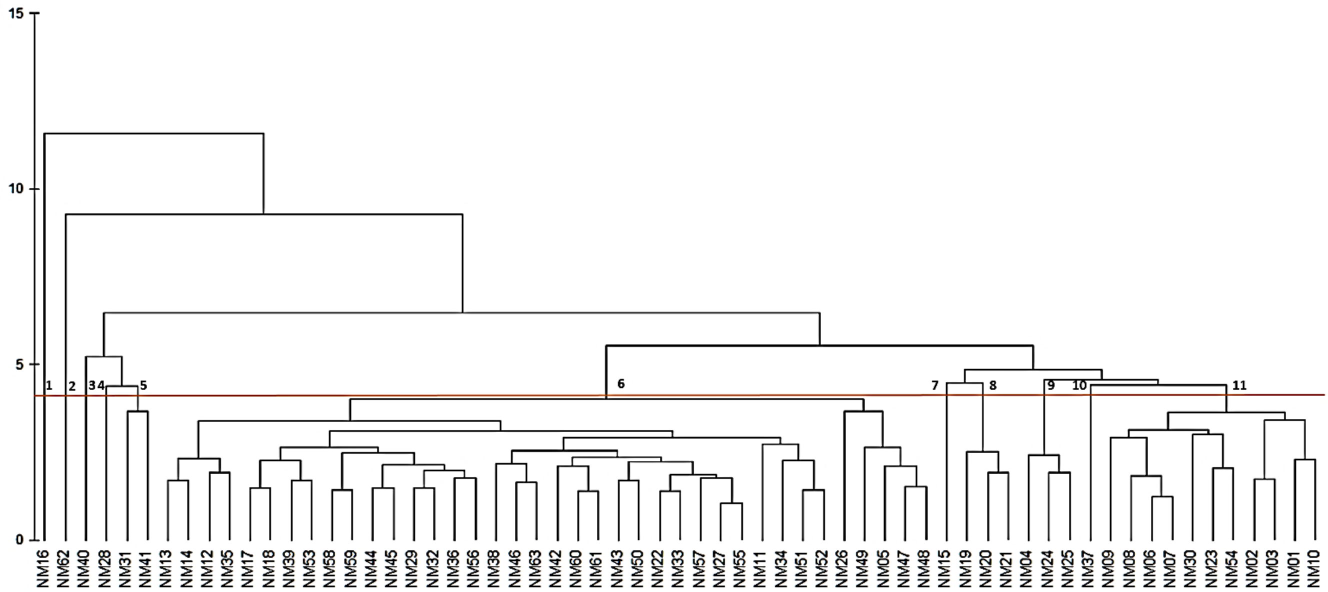

Fig. 3. Surface water quality classification using cluster analysis.

Group 5 included NM31 and NM41 with similar surface water quality, although these points are located on two different rivers, Tra Ngoa River and Co Chien River.

Group 6 included 38 locations; in which, NM05 (Mang Thit River - bordering Co Chien River), NM11 (Cau Vong River), NM17 (An Hiep river), NM18 (Ong Me Nho river), NM26 (Cai Von river), NM27 (Ba Cang river), NM33 (Thay Cai Canal), NM36 (Cai Ngang River), NM38 (River near Long Phu Bridge), NM56, NM57, NM58, NM59, NM60, NM63 were recorded in different rivers. In addition, the locations that were affected by waste sources in the market area and located on the same river in group 6, including NM12, NM13 and NM14 (Long Ho River), NM22 and NM61 (Mang Thit river), NM29 and NM32 (Vung Liem River), NM34 and NM35 (Hoa My River). On the other hand, NM43, NM46 and NM50 are all located on Hoa Loc River and are affected by wastewater from residential areas and industrial zones. Meanwhile, the water quality of Ba Lang River (NM44 and NM45), Co Chien River (NM47 and NM48) and Tien River (NM49) are all affected by wastes from residential areas - fish farming. Finally, NM51 and NM52 (Cai Con river) and NM53 (Nha Man river) were affected by both residential - market areas. Although NM39, NM42 and NM55 are located on Hau river, they are also different impacts. Certain sites in the same river with similar water quality could be considered for eliminating from the monitoring system. Thus, Group 6 from 38 initial monitoring positions can be reduced to 26 positions.

Group 8, 9 included 3 locations for each NM19, NM20, NM21; NM04, NM24, NM25, respectively. Group 11 included 11 positions NM01, NM02 and NM03 (Cai Da River), NM06 and NM07 (Cai Doi River), NM08 and NM09

(Cai Cam River), NM10, NM23, NM30, NM54. In group 11, 11 monitoring positions could be reduced to 8 positions. Finally, cluster analysis revealed that the number of sampling locations could be reduced from 63 to 48 sites. The newly recommended locations for future water monitoring are presented in Fig. 4.

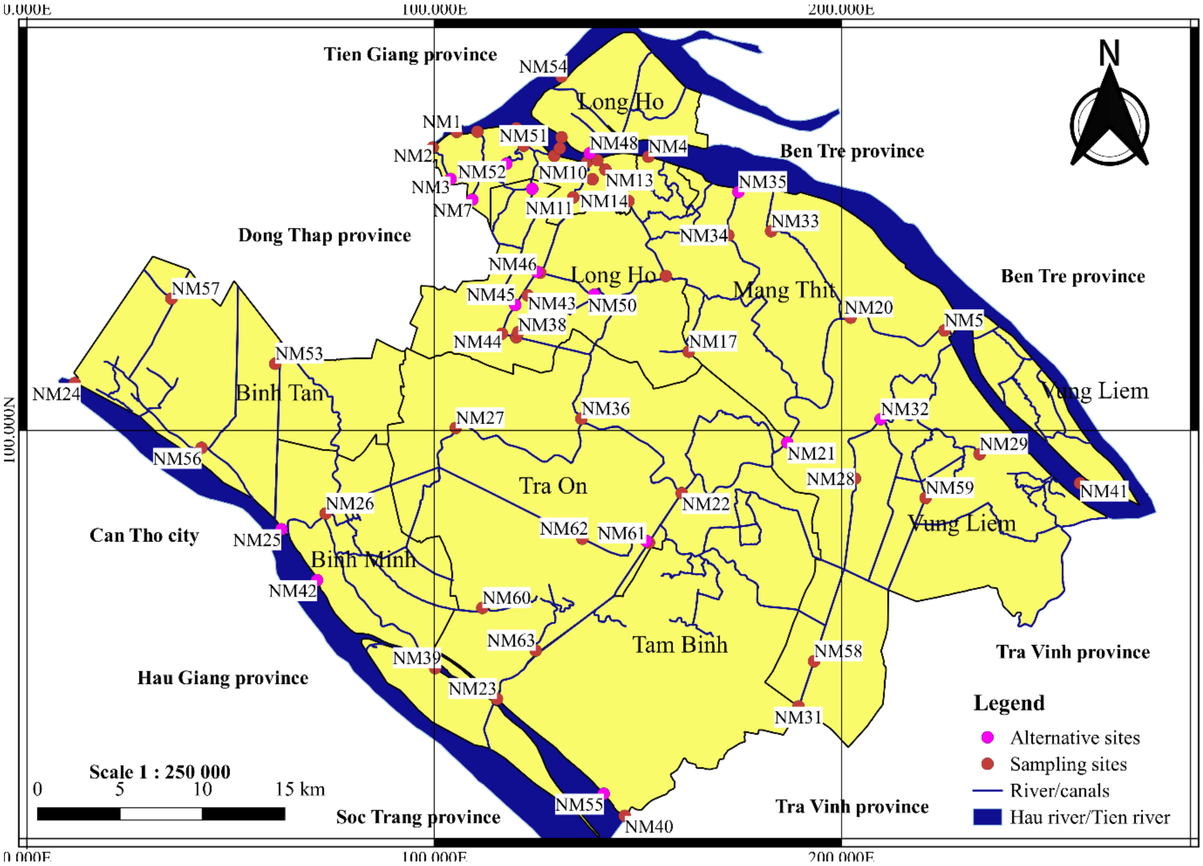

Fig. 4. Map of monitoring location for surface water quality after cluster analysis.

IV. Conclusions

The results showed that surface water quality in Vinh Long was polluted by suspended solids, organic matters, nutrients and microorganisms. BOD, COD, NH_4^+-N, PO_4^{3-}-P, *E. coli*, coliforms, TSS all exceeded the allowable thresholds of QCVN 08-MT:2015/BTNMT, column A1 at the majority of the monitoring positions. DO was below the specified threshold. Cl^- was very high at NM41 showing signs of saline intrusion. 6 out of 63 positions with Fe concentration exceeded the allowable limit by 1.12-1.34 times. pH, temperature and NO_3^--N were within the allowable limits. The comprehensive water quality is rated mainly poor to medium. PCA indicated 10 PCs explained 92.5% of the variation of surface water quality, in which four PCs were the main sources of water degradation, including runoff, residential areas, industrial and agricultural activities. CA revealed that the initial water monitoring sites could be reduced from 63 to 48, saving the monitoring cost by 23.8%. Future studies should investigate specific water-polluting sources for appropriate management strategies.

Conflict of Interest

The author declares no conflict of interest.

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Nguyen Thanh Giao was born in Can Tho city, Vietnam. Currently, he is a lecturer at the College of Environment and Natural Resources, Can Tho University, Vietnam. He received the MSc and PhD in environment management from Chulalongkorn University, Thailand in 2011 and 2017, respectively. In 2005, he received a BSc degree in environmental science, Can Tho University, Vietnam. His current research interests include water environment, human and ecological risk assessment.