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SPATIAL AND TEMPORAL VARIABILITIES OF SURFACE WATER QUALITY IN URBAN AND RESIDENTIAL AREAS IN AN GIANG, VIETNAM

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Abstract – *This study aims to assess the surface water quality in both residential areas and urban areas in An Giang Province from 2011 to 2019. Thirteen locations were selected with eight water quality variables at each location; which were temperature, pH, nitrate ($NO_{3^-} - N$), total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD), coliforms, and total oil and grease were collected. Surface water quality data were compared with the Vietnamese standards. Cluster analysis (CA) and principal component analysis (PCA) were applied to determine the sampling locations and water variables affecting water quality in the residential and urban areas. The results showed that the parameters of temperature, pH, and $NO_{3^-} - N$ were within the allowable limits - while TSS, BOD, COD, coliforms, and total oil and grease exceeded the permitted limit. The results of CA indicated that 13 sampling points could be reduced to 8, saving nearly 40% of the water quality monitoring costs which could be provided the cost for water treatment of water bodies. PCA revealed that at least three sources of pollution could explain 83.7% of the water quality fluctuations. The main sources that affected surface water quality in residential and urban areas could be wastewater, solid wastes, stormwater runoff, and other hydrological factors. Further studies need to investigate and curb the sources of water pollution. It is urgently required to build a system of waste collection and treatment in this study area and at the same time raise public awareness about environmental protection.*

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I. INTRODUCTION

An Giang Province is adjacent to Cambodia in the southwest of Vietnam, with a total natural land area of 353,668.02 hectares. The provincial population was about 2 million people in 2019, of which the urban population accounted for 31.58% [1]. This province is a watershed area of the Mekong river, with two major tributaries, namely the Tien and Hau rivers, which annually supplies freshwater and contains huge amounts of sediment in the Vietnamese Mekong Delta. In addition, An Giang has many natural canals and hydrological networks with a density of 0.72 km/km^2, which is the most in the Mekong Delta [2]. This water source is used for several purposes and plays an important role in the development of agriculture, industry, daily life, transportation, and the ecological environment [3–5]. Due to the economic growth and residential area expansion, it has resulted in competition among different groups using the available water and the water quality deterioration [6].

II. BACKGROUND

An Giang Province includes 22 urban areas and 245 clusters and residential routes with the amount of wastewater generated about 300,000 m^3/day. night. Many urban areas and residential clusters do not have a complete drainage system and centralized wastewater treatment system. Thus, wastewater is primarily treated through septic tanks and then discharged directly to receiving sources [1]. The surface water quality in the study areas is facing severe pollution owing to the rapid growth of population and local industry and uncontrolled urbanization. Most of the waste generated in this area is discarded into nearby rivers, which has degraded the aesthetic, influenced human health and environmental quality. Several studies have shown a close relationship between water quality and activities in the urban area, which indicates that urban expansion is a major driving force in increasing non-point sources of water pollution [7–9]. Specifically, surface stormwater runoff from residential and urban areas has previously been linked to increased suspended solids, nutrients, altered temperature regimes, and lower dissolved oxygen levels [10–12]. In Vietnam, several studies have been implemented on surface water quality on Hau river and canals in An Giang Province [13–15] . However, many studies have not focused on spatial and temporal variations of water quality in residential and urban areas. This study was conducted to evaluate surface water quality in residential areas and urban areas in An Giang Province and determine sampling locations and key water variables influencing water quality using cluster analysis (CA) and principal component analysis (PCA). The research results could provide information on the impact of residential areas and urban areas on the surface water quality of An Giang Province and adjust the monitoring program in these areas.

III. MATERIALS AND METHODS

A. Data collection

Surface water samples were collected and stored in accordance with the guidance of TCVN 6663-6:2018 - Water Quality - Sampling, Part 6: Guidance on sampling of rivers and streams; TCVN 6663-3:2016 - Water quality - Sampling - Part 3: Preservation and handling of water samples, respectively. At each location, water samples were collected in the middle of the stream to a depth of 30 cm below the surface. These samples were stored at 4^{o}C and then transported to the laboratory. Each location collected about 2 liters of water to analyze water quality parameters. Water samples were collected at the locations on the rivers affected by residential and urban areas (Tan Chau, Cho Moi, My Luong, Chau Doc town, Cai Dau, Nui Sap, Tri Ton and An Phu urban area) in Tien river (ST1, ST2, ST3), Hau river (SH1, SH2, SH3, SH4), Phu Dat canal (PD), Long Xuyen canal (LX), Cai Son canal (CS), Cong Dong canal (CD), Tri Ton canal (TT), and Thay Ban canal (TB). Thus, there were 13 sampling sites with a frequency of 3 times per year (March, June, September) from 2011 to 2019. The description of sampling locations is shown in Figure 1.

Data were collected from the Department of Natural Resources and Environment of An Giang Province for nine years throughout 2011 to 2019. Water quality parameters included temperature, pH, nitrogen-nitrate ($NO_{3^-} - N$), total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD), coliform, and total oil and grease. Temperature and pH parameters were directly measured on-site using ADWA AD11 pH (made by Romania). TSS, BOD, COD, $NO_{3^-} - N$, coliform and total oil and grease were analyzed in the laboratory of the Center for Natural Resources and Environment Monitoring, An Giang by standard methods [16].

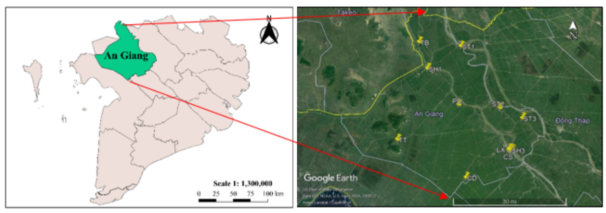

Fig. 1: Map of the sampling locations of water quality monitoring data

B. Data analysis

Water quality assessment (compared with standards)

The data sets were presented as Mean ± SD. The Shapiro-Wilk test was performed, which was used for a sample size (number of positions) less than 50. The data were then processed by IBM SPSS Statistics 20 analysis of variance (One-Way ANOVA) with Duncan test (p <0.05) (a standard normal distribution) or Kruskal-Wallis (a nonstandard normal distribution) to compare the difference of water parameters between the locations and years of observations.

Similarities of positions

Cluster analysis (CA) was used as an unsupervised pattern recognition technique that groups the sampling sites into clusters based on their similarities within a cluster and dissimilarities between different clusters. One of the most commonly used measurements to find the similarity of cases is the Euclidean distance based on Ward's methodology [17].

Identification of pollution sources

Principal component analysis (PCA) was employed to convert the individual parameters into a PC (principal component) through a linear combination of original variables. The PC gives information on the most important parameters, which depict an entire informational collection managing data that decrease with the least loss of unique information [18]. The importance of the PCs was sorted in descending order through its factor (Eigenvalues). Meanwhile, the most important parameters can identify the potential sources of pollution and water quality fluctuations using a correlation coefficient [19]. Correlation between principal components and initial data variables was discovered by the significant correlation coefficients (loading) [19]. The greater correlation coefficient is the more important indicator on water quality. Liu et al. suggest that the correlation coefficient is weak when the absolute value of the weighted correlation coefficient is between 0.3-0.5, average 0.5-0.75 and high when this coefficient is greater than 0.75 [20].

The average values of 8 water quality parameters for the period 2011 - 2019 at 13 locations were used in the CA and PCA. These analyses were performed using Primer 5.2 for Windows (PRIMER-E Ltd, Plymouth, UK), with input data being the average water quality parameters.

IV. RESULTS AND DISCUSSION

A. Spatial variations of surface water quality in residential and urban areas

The average values of water quality parameters in the areas were calculated using data spanning 9 years and are presented in Table 1. The Shapiro-Wilk test with Sig. = 0.05 = 0.93 (greater than 0.05) revealed that this distribution was standard (except COD and coliform). In the 2011-2019 period, the pH value was still within the limit [21] ranging from 6.6 ± 0.6 - 7.1 ± 0.4. There were statistically significant differences between ST1, SH3, SH4, and TT ($p < 0.05$). Ly and Giao [14] also reported that pH values in the canals in An Giang Province in 2006-2009 ranged from 6.9 - 7.1. Lien et al. [13] showed that the pH varied from 6.3 - 8.0 in the main rivers and tributaries of Hau river in 2016. In this study, the reason that can be explained for the differences between the study areas is mainly because of the differences in hydrological, geological, and soil characteristics in the study areas. The temperature value only had a statistically significant difference between ST2 and CD sites ($p < 0.05$). This result was consistent with the range of temperature fluctuations in the Mekong River, which was reported to range from 19.9 - 32.2^{o}C [22, 23] and in Tien river 25.1 - 32.1^{o}C [24].

The TSS concentration ranged from 42.6 ± 19.8 to 82.6 ± 43.1 mg/L, and there was a statistically significant difference between TB and SH4 sites ($p < 0.05$). All sampling sites exceeded the limit of the standard by 2.1 - 4.1 times. It can be seen in Figure 2 that the TSS concentration in the upstream area (TB) tended to be higher than those in the downstream (PD, LX, CS, CD, and TT). The TSS concentration depends on organic matter, soil, and alluvium and is directly related to the turbidity of the water; therefore, the large flow rate in the upstream area could cause an increase in TSS concentration in the water. Besides that, TSS concentrations in the Tien river (ST1-ST3) were recorded higher than that of the Hau river (SH1-SH4). It can be explained by the flow rate, water flow between the water bodies and the amounts of wastewater and solid wastes received [9]. According to the study of Giao [25], TSS concentration in aquaculture areas was 34.8 ± 10.6 - 44.6 ± 16.8 mg/L, while the concentration in the agricultural area ranged from 46 – 161 mg/L [26]. This can be reported that the TSS concentration in the residential area tends to be higher than that of aquaculture areas and lower than agricultural areas.

The concentrations of BOD and COD fluctuated between 11 ± 7.0 - 30.6 ± 14.3 mg/L and 13.9 ± 5.5- 48.1 ± 22.9 mg/L, respectively,

Table 1: Surface water quality parameters in residential and urban areas of An Giang

Code	Temp. (°C)	pH	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	$N\text{-}NO_3^-$ (mg/L)	Oil and grease (mg/L)	Coliforms (MPN/100 mL)
ST1	$29.9^{ab}\pm1.3$	$7.1^{a}\pm0.4$	$71.7^{abc}\pm41.5$	$15.1^{c}\pm8.6$	$24.1^{b}\pm13.5$	$0.39^{ab}\pm0.4$	$1.74^{ab}\pm0.9$	1,019,089
ST2	$30.2^{a}\pm1.5$	$6.8^{ab}\pm0.4$	$71.7^{abc}\pm47.4$	$10.9^{c}\pm3.6$	$17.5^{b}\pm6.4$	$0.46^{ab}\pm0.3$	$1.29^{ab}\pm0.6$	143,983
ST3	$30.1^{ab}\pm1.6$	$7^{ab}\pm0.4$	$71^{abc}\pm43.9$	$13.4^{c}\pm7.1$	$24.1^{b}\pm19.6$	**$0.54^{ab}\pm0.6$**	$1.35^{ab}\pm0.7$	109,875
SH1	$30.1^{ab}\pm1.3$	$6.9^{ab}\pm0.3$	$47.3^{bc}\pm20.2$	$13.6^{c}\pm8.3$	$21.4^{b}\pm12.7$	$0.41^{ab}\pm0.3$	$1.12^{b}\pm0.6$	129,409
SH2	$29.8^{ab}\pm0.9$	$7^{ab}\pm0.3$	$54.3^{abc}\pm34.2$	$9.5^{c}\pm5.1$	$15^{b}\pm8.1$	$0.35^{ab}\pm0.3$	**$1.11^{b}\pm0.7$**	**39,796**
SH3	$29.7^{ab}\pm0.9$	$7.1^{a}\pm0.3$	$60.3^{abc}\pm29.3$	**$8.8^{c}\pm3.6$**	$13.9^{b}\pm5.5$	$0.41^{ab}\pm0.3$	$1.11^{b}\pm0.4$	279,029
SH4	$29.4^{ab}\pm1$	$7^{a}\pm0.3$	**$42.6^{c}\pm19.8$**	$14.4^{c}\pm7$	$23^{b}\pm11.1$	$0.32^{ab}\pm0.3$	$1.58^{ab}\pm1.2$	221,479
PD	$29.6^{ab}\pm1.4$	$6.9^{ab}\pm0.3$	$76.5^{ab}\pm41.7$	$24.7^{ab}\pm14.5$	$24.4^{b}\pm11.9$	$0.43^{ab}\pm0.4$	$2.44^{ab}\pm1.4$	1,253,826
LX	$29.7^{ab}\pm1.0$	$7^{ab}\pm0.3$	$57^{abc}\pm30.8$	$11^{c}\pm7.0$	$17.5^{b}\pm10.8$	$0.38^{ab}\pm0.2$	$1.23^{ab}\pm0.7$	247,675
CS	$29.5^{ab}\pm1.2$	$6.9^{ab}\pm0.4$	$62^{abc}\pm31.9$	**$30.6^{a}\pm14.3$**	**$48.1^{a}\pm22.9$**	**$0.13^{b}\pm0.1$**	**$2.78^{a}\pm1.6$**	902,613
CD	$29.1^{b}\pm1.4$	$6.8^{ab}\pm0.4$	$55.3^{abc}\pm17.1$	$16.9^{bc}\pm8.4$	$26.7^{b}\pm13.3$	$0.32^{ab}\pm0.4$	$2.33^{ab}\pm1.0$	363,591
TT	$29.3^{ab}\pm0.8$	$6.6^{b}\pm0.6$	$71.5^{abc}\pm24$	$28.2^{a}\pm14.4$	$44.8^{a}\pm23.4$	$0.22^{ab}\pm0.2$	$2.62^{a}\pm0.9$	353,511
TB	$29.6^{ab}\pm1.7$	$7^{ab}\pm0.3$	**$82.6^{a}\pm43.1$**	$16.3^{bc}\pm8.8$	$26.6^{b}\pm15.3$	$0.65^{a}\pm0.6$	$1.84^{ab}\pm1.1$	145,115
QCVN 08-MT:2015	-	6 – 8.5	20	4	10	2	0.3	2,500

Data were presented as Mean ± SD, n = 9. The values of the same column with different characters (a, b, c) were statistically different (p < 0.05).

and a high regulated concentration by QCVN 08-MT: 2015/BTNMT, a sign of organic matter contamination. There was a statistically significant difference in TT and CS compared to the locations in Hau and Tien rivers (SH1- SH4, ST1-ST3) ($p < 0.05$) for the concentrations of BOD and COD. It can be explained by TT and CS positions in tributaries, which have less dilution. While the water inflow is quite large on the Tien and Hau rivers, BOD and COD concentrations have been significantly diluted. Similar to TSS, BOD was also recorded higher than that of the aquaculture area (6.7 ± 1.5 - 10.7 ± 6.6 mg/L) [25] and agricultural cultivation (6 - 12 mg/L) [26]. The reason could be the effects of higher organic matters in domestic wastewater. In stark contrast to BOD and COD, the concentration of nitrate (0.65 ± 0.59 mg/L) at the lowest location (CS) was significantly different ($p < 0.05$) from the highest location (TB)- and this concentration was still within the permitted limit of QCVN 08-MT: 2015/BTNMT. In addition, compared to the studies of Tuan et al. [27] and Giao [28] on the water quality in canals influenced by the agricultural, aquacultural, and industrial areas of Soc Trang and Can Tho provinces, the concentrations of BOD, COD, and nitrate tended to be lower than found in this present study.

The density of coliforms in Phu Dat canal (PD) was the highest (1,253,826 MPN/100mL) – this area receives wastewater from residential areas in Chau Phu District - while the coliform density in Hau river (SH2) was the lowest (39,796 MPN/100mL). It is also noted that the coliform density in water was significantly high at the

ST1 site (after the PD site); this may be influenced by transnational pollution sources [29]. Besides that, the concentration of oil and grease was relatively high at all monitoring locations, ranging from 1.11 ± 0.7 to 2.78 ± 1.6 mg/L. The result of ANOVA analysis showed a statistically significant difference between TT and CS sites compared to the other locations in Hau river (SH1 - SH3) ($p < 0.05$). The coliform density, oil and grease concentrations in the surface water at all locations exceeded the permitted limits of QCVN 08-MT: 2015/BTNMT. The results from this study were in accordance with the previous studies that the surface water in the Mekong delta of Vietnam have been persistently contaminated by coliforms [13, 14, 8, 30].

In the present study, the rivers mainly receive wastewater from trading, manufacturing and markets, and residential areas. The amount of wastewater that was not collected and treated may have resulted in high pollutants in the natural water source. Moreover, the results indicate that the residential and urban wastes have stronger effects on the tributary rivers than the main rivers (Tien and Hau rivers). It is because the tributaries have a small area, low turbulence, and low self-cleaning capability [1]. In short, the present study recorded that the river water quality was seriously contaminated by TSS, BOD, COD and coliforms, especifically at Cai Son (CS) and Phu Dat (PD). Furthermore, urban and residential activities have more negative impacts on surface water quality than agricultural and aquacultural activities.

B. Temporal variations of surface water quality in residential and urban areas

Yearly fluctuation of water quality in residential and urban areas

The average water quality at 13 locations on rivers and canals affected by residential areas and urban areas of An Giang in the period of 2011 - 2019 were presented in Table 3. Most of the monitoring parameters highly fluctuated and had a statistically significant difference (except for TSS, BOD, total o il and grease. This was shown using Kruskal-Wallis analysis ($p <0.05$); because the dataset does not have a standard normal distribution. The results are also recorded except for pH and N-NO_{3-}, the water quality exceeded the permissible limits of QCVN 08-MT:2015/BTNMT column A1 [21]. The temperature ranged from 28.9 ± 1.2°C to 30.7 ± 1.6°C, and the difference was statistically significant between years ($p < 0.05$). The pH values ranged from 6.3 ± 0.5 to 7.2 ± 0.2 which were within the permitted limits of QCVN 08-MT:2015/BTNMT (column A1) [15]. However, the pH value tended to increase over the years which could imply that residential and urban development have affected the chemical property of surface water. It is explained that domestic wastewater usually has dissolved minerals, alkali, and NaCl content due to the presence of detergents such as soap. The ranges of temperatures and pH are still suitable for aquatic organisms [30, 31].

The concentrations of COD, BOD, and TSS ranged from 16 ± 3.7 to 33.5 ± 11.1 mg/L, from 10.4 ± 2.9 to 22.4 ± 14.8 mg/L and 42.2 ± 17.4 to 95.3 ± 61.5 mg/L, respectively. In 2017, the concentrations of COD and BOD were the lowest. There were statistically significant differences between years for COD ($p <0.05$); however, no significant changes were observed for BOD ($p> 0.05$). Similarly, TSS concentration has not drastically changed over the years, although TSS concentration has increased temporally (2011-2018); however, it decreased remarkably in 2019. It is the result of flow blocking, which significantly reduces the sediment content to the Mekong Delta. The study of Ly and Giao [13] indicated that BOD and TSS concentrations in the surface water of An Giang Province during the period of 2009-2016 were relatively lower. The water quality was significantly influenced by the activities of residential and urban areas.

The concentration of nitrate from 2011 – 2019 ranged from 0.04 ± 0.0 - 1.08 ± 0.4 mg/L and tended to be high in the canals in An Giang Province in the period of 2009 – 2016 (0.31 to 0.58 mg/L) [8]. However, this variation was greatly dependent on the water flow rate, water volume, crop calendar, and sampling times, which were considered major factors in the variation of nitrate in river systems. Furthermore, oxygen demand in water to decompose organic matter of aquatic organisms can affect the conversion of N-NH4+ to $N\text{-}NO_{3-}$ via the nitrification process. The nitrate concentration values were not a serious problem in the current study; nevertheless, it still has an underlying risk of eutrophication [22, 30].

The lowest density of coliforms was in 2017 (31,572 MPN/100mL), and the highest value was in 2018 (1,071,733 MPN/100 mL). The coliform density exceeded the allowed limit standard set by QCVN 08-MT: 2015/BTNMT (column A1) [21] about 13 to 429 times. This density also recorded a significant increase in 2011 to 2019 compared to the period of 2009 to 2016 [8]. It means that the water quality in urban canals has a higher level of pollution than other canals.

Total oil and grease is an important indicator of surface water in the urban and residential areas. From 2011 to 2019, the total oil and grease ranged from 1.00 ± 0.53 mg/L (2017) to 2.67 ± 0.31 mg/L (2014) (Table 3), exceeding 2.0 to 4.2 times higher than the permissible limit of QCVN 08-MT:2015/BTNMT (column A1) [21]. In 2019, the total oil and grease was lower than the limit of detection.

In general, water pollution in urban areas and population has tended to increase in recent years, and 2018 was the peak year of the recession over a period of 9 years. In 2019, water quality tended to be better, but most monitoring parameters still have not met QCVN 08-MT:2015/BTNMT. Besides, surface water quality has different pollution characteristics and properties over time. For example, in 2011 and 2012, surface water in residential and urban areas was seriously polluted by BOD and COD (Table 3). In 2018, the water environment was contaminated by BOD, COD, TSS, and coliforms.

Seasonal changes of water quality in residential and urban areas

The results of the Shapiro-Wilk test showed that the dataset has a standard normal distribution (Sig. = 0.11 – 0.72 > 0.05); therefore, a one - way ANOVA analysis (Duncan test) was applied to assess statistical differences between seasons. The variables of temperature, pH, total oil and grease, and coliforms were the highest in June and the lowest in September. The highest temperature was recorded at 30.1±1.1 ^{o}C (in June), and it was a significant difference (p<0.05) compared to that of September (29.1±1^{o}C). It was consistent with the former study that reported water temperature tended to decrease in September [13]. Changes in seasonal or daily water temperatures due to differences in regional activities may contribute to changes in surface water temperature [33]. The pH values had no significant change over time (6.8 ± 0.4 - 7 ± 0.4) and within the permitted limit of QCVN 08-MT: 2015/BTNMT, column A1 [21]. The values of pH in some water bodies were similar to this study, such as Hau river (6.3-8.0), Tien river (6.7-7.4), and canals in Can Tho (7.2-7.5) [13]. The total oil and grease, and coliforms in the water body ranged from 4.4 ± 0.62 to 4.88 ± 0.98 mg/L and from 117,421 to 648,382 MPN/100mL, respectively (Table 4). There was no statistically significant difference in total oil and grease concentrations between months (p > 0.05). The coliform density recorded in March tended to be lower than in June and higher than in September. Washing surfaces and overflows at the beginning of the rainy season have carried microbiological contaminants into the water source; this can be considered a cause of high coliform in June.

The content of TSS fluctuated in March, June, and September and ranged between 46.6 ± 20.9 to 82.5 ± 34.5 mg/L. There was a statistically significant difference between June and September (p<0.05). According to the research of Lien et al. [13] and Ut et al. [34], water quality was highly influenced by time as TSS in the rainy season is always higher than that in the dry season due to the impact of rainwater runoff and erosion. In addition, BOD and COD concentrations ranged from 14.7 ± 12 to 18 ± 15 mg/L, and from 23 ± 19.1 to 27.7 ± 23.6 mg/L, respectively. Therefore, BOD and COD concentrations were lower in the rainy season (June and September) than in the dry season (March). Seasonal variation of BOD indicators has also been reported in previous studies [13–15]. This could be because the pollutants were diluted in the rainy season. Moreover, the high level of TSS in the rainy season could reduce the DO content in the water, affecting the use of oxygen to decompose organic matter of microorganisms. Although there was a

Table 2: Water quality in residential and urban areas of An Giang through each year

Year	Temp. (°C)	pH	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	$N\text{-}NO_3^-$ (mg/L)	Oil and grease (mg/L)	Coliforms (MPN/100mL)
2011	29.6±1.4	6.3±0.5	42.2±17.4	19.1±9.7	33.5±11.1	0.85±0.2	2.36±1.4	469,412
2012	30.02±1.2	6.5±0.5	53.3±27.1	22.4±14.8	30.4±17.2	0.17±0.4	2.18±0.9	515,658
2013	29.8±1.1	7±0.6	55.3±33	16.8±10.4	30.1±23.7	0.61±0.4	2.32±0.6	133,966
2014	29.9±1.4	7±0.3	51.2±32.8	12.9±4.3	20.1±4.5	1.08±0.4	2.67±0.3	160,531
2015	29.3±1.2	7.1±0.2	67.6±40.4	13.4±7.8	18.2±5.2	0.31±0.1	1.97±1.4	404,518
2016	28.9±1.2	7.1±0.2	60±31.7	17.6±11.4	24.1±14.9	0.27±0.7	1.51±0.3	565,988
2017	30.7±1.6	7.1±0.4	88.4±29.2	10.4±2.9	16±3.7	0.07±0.1	1.0±0.5	31,572
2018	29.4±1.2	7.2±0.2	95.3±61.5	19.6±9.2	30.1±12.2	0.04±0.0	1.59±0.7	1,071,733
2019	29.6±0.8	7.1±0.3	57.1±21.1	15.7±6.2	24.1±9.7	0.06±0.1	0	252,846
Asymp. Sig.	0.01	0.00	0.09	0.30	0.00	0.00	0.20	0.00
QCVN 08-MT:2015	-	6 - 8.5	20	4	10	2	0.3	2,500

Data were presented as Mean ± SD, n = 13

Table 3: Water quality in residential areas and urban areas by seasons (months)

Month	Temp. (°C)	pH	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	Nitrate (mg/L)	Oil and grease (mg/L)	Coliforms (MPN/100mL)
Mar (the end of dry seas on)	29.8^{ab}±1.3	7^{a}±0.4	61^{ab}±34.8	18^{a}±15	27.7^{a}±23.6	0.32^{a}±0.4	4.44^{a}±1.0	436,271
Jun (the beginning of the rainy season)	30.1^{a}±1.1	7^{a}±0.4	46.6^{b}±20.9	14.7^{a}±12	23^{a}±19.1	0.36^{a}±0.2	4.88^{a}±1.0	648,382
Sep (the end of rainy season)	29.1^{b}±1	6.8^{a}±0.4	82.5^{a}±34.5	16.7^{a}±13	24.8^{a}±17.6	0.48^{a}±0.3	4.4^{a}±0.6	117,421
QCVN 08-MT:2015	-	6.5 - 8.5	20	4	10	2	0.3	2,500

Data were presented as Mean ± SD, n = 9. The values of the same column with different characters (a, b, c) are statistically different ($p < 0.05$).

decrease in BOD and COD concentrations, these pollutants did not meet the permitted limits of QCVN 08-MT: 2015/BTNMT (column A1).

Meanwhile, nitrate concentration tended to increase from March (0.32 ± 0.37 mg/L) to September (0.48 ± 0.26 mg/L) (Table 4). This fluctuation was related to the crop calendar and the water flow in the rivers. Plants absorb only 50% of total applied nitrogen fertilizers and pesticides in the soils, and investment costs for fertilizers in winter-spring (March), summer-autumn (June) are often lower than for the later crops (Autumn-Winter - September). Therefore, this can make nitrogen accumulation in the soil higher and higher and increase pollutant leaching into the environment. It could directly affect neighboring water bodies with eutrophication. However, the nitrate values are still within the permitted limits of QCVN 08-MT: 2015/BTNMT (column A1) [21].

Generally, surface water quality in the residential and urban areas was seasonally dependent. In the dry season (March), water pollution is mainly due to high levels of BOD and COD. At the beginning of the rainy season (June), the indicators of the decline of organic matter (BOD and COD) may be due to the dilution of rainwater. Surface water in June was mainly polluted by coliforms and total oil and grease. Meanwhile, in the middle of the rainy season (September), surface water was heavily contaminated by TSS.

C. Clustering water quality in residential and urban areas

Water quality in residential and urban areas could be classified into five groups based on the red line, as presented in Figure 2. Group 1 consisted of four locations in Hau river (SH1-SH4) and Long Xuyen canal (LX), which were affected by wastewater from several business activities, residents, and markets. Group 2 consisted of three locations in Tien river (ST1-ST3) and one in Thay Ban canal (TB) affected by the wastewater of several business activities, residents, and wastewater from An Phu urban area discharging in Thay Ban Canal, directly affecting Hau river. Group 3 included only the locations on Phu Dat canal, which were affected by wastewater from several production, business and residential activities. Group 4 also had one location in Cong Dong canal, which receives wastewater from Nui Sap urban area. Group 5 included two locations on Cai Son river (CS), and Tri Ton canal (TT), where the results were mainly affected by wastewater from Long Xuyen City urban area and wastewater from Tri Ton urban area. Differences in water quality can be seen in large rivers such as Tien and Hau rivers and other small rivers under the impact of wastewater from residential and urban areas. It could imply that small rivers are at greater risk of contamination than larger rivers due to the concentration and limited dilution and waste flow into the receiving waters.

The results in Figure 2 showed that the CA technique is useful in the classification of river water in the study region, and the number of sampling sites and the associated monitoring costs could be reduced without missing much information [35]. In this study, the number of sampling locations could be minimized for cost-effective water quality monitoring by choosing representative locations from each cluster based on two conditions (the same river and the same group). Specifically, four sampling locations on the Hau river (Group 1) could be reduced to one sampling location. Three sampling locations in Tien river (Group 2) could be reduced to one sampling location. As a result, a total of thirteen sampling points can be reduced to 8 sampling points, saving nearly 40% of the total analysis cost for water quality monitoring in residential and urban areas.

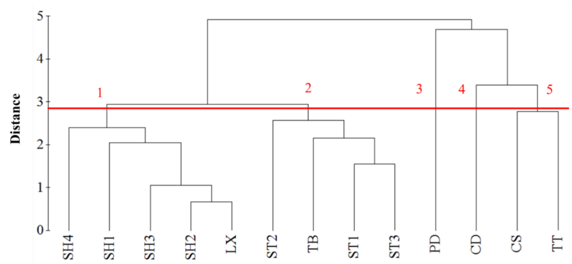

Fig. 2: Spatial variation of water quality in residential and urban areas

D. Key variables affecting water quality in residential and urban areas

The principal component analysis results using a set of eight water quality parameters for nine years with a frequency of three times a year were presented in Table 2.

Table 4: Key water parameters influenced by residential and urban areas

Variable	PC1	PC2	PC3	PC4	PC5
Temp	**0.3**	0.2	**0.4**	**0.5**	**-0.6**
pH	**0.3**	0.0	**-0.4**	**-0.6**	**-0.6**
TSS	-0.1	**0.7**	0.3	-0.2	0.0
N-NO_3^-	**0.3**	**0.5**	0.1	-0.2	**0.4**
BOD	**-0.5**	0.1	-0.0	0.0	-0.3
COD	**-0.5**	-0.0	0.3	-0.1	-0.3
Coliforms	-0.1	**0.5**	**-0.7**	**0.4**	-0.0
Oil and grease	**-0.5**	0.1	-0.1	-0.2	0.0
Eigenvalues	4.1	1.7	0.9	0.6	0.5
%Variation	51.5	21.3	10.9	7.4	6.6
Cu mulative %Variation	51.5	72.8	83.7	91.2	97.7

With a large dataset, many previous studies considered the PCs with eigen values $\geq$ 1 to be significant [36]. Therefore, the results showed that there were two main components that contributed to 72.8% of the variation in water quality of the study area. In particular, PC1 explained 51.5% of the fluctuations, weak correlation with parameters such as temperature (0.3), pH (0.3), nitrate (0.3), BOD (-0.5), COD (0.5) and total oil and grease (0.5). The PC2 component explained 21.3% of water quality fluctuations through TSS (0.7), nitrate (0.5), and coliforms (0.5). However, in some instances, it also depends on the measured parameters to retain the PCs; the eigenvalues <1 are acceptable for interpretation of the structure. Thus, PC3 was retained to account for variation in water quality by sub-sources. In particular, PC3 recorded significant contributions of coliform (0.7), temperature (0.4), pH (0.4), which has a higher coliform loading coefficient than PC2.

Moreover, the pH, temperature, TSS and COD were affected by at least two polluting sources including PC1 and PC3 (weak). TSS and coliforms were affected by PC2 (average) and PC3 (weak). Nitrate was weakly affected by PC1 and PC2 sources; BOD, oil and grease were weakly affected by one source of PC1. The pH, temperature, and TSS often represent the hydrological regime of water bodies, weather, and riverbank erosion in the study area [37]. COD, BOD, total oil and grease are often in the composition of domestic waste, about 52% organic matter, 48% inorganic, and other ingredients; high nitrate values can be found to be caused by runoffs since the fixed nitrogen content in the soil is usually quite high.

It is recognized that the main sources that affect surface water quality in residential areas and urban areas may be the domestic waste, stormwater runoff, and hydrological factors. Future studies need to investigate the sources of environmental pollution in urban and industrial areas, so proper solutions can be proposed to curb the pollution problem.

V. CONCLUSION

Water quality in residential and urban areas has been heavily polluted due to TSS, COD, BOD, total oil and grease and coliform during the period of 2011 to 2019. Water quality in the study areas was spatially, temporally and seasonally dependent. The small rivers such as Phu Dat and Cai Son suffered more pollution than the larger rivers such as Tien and Hau rivers. Surface water in 2011 and 2012 has very high BOD and COD levels, and water in 2018 has a high concentration of BOD, COD, TSS, and coliforms. BOD and COD tend to be high in the dry season; meanwhile, temperature, pH, TSS, nitrate, total oil and grease, and coliform concentrations increase during the rainy season. The results of cluster analysis show that 13 sampling points can be reduced to 8 sampling points, saving nearly 40% of the water quality monitoring cost. The money saved can be used to treat the parameters that have been contaminated to keep the water source able to serve many different purposes. PCA analysis showed that there were three main pollution sources that accounted for 83.7% of water quality fluctuations. The main sources that deteriorate surface water quality in residential and urban areas can be domestic waste, stormwater runoff, and hydrological factors. Further studies need to investigate the source of the pollution to these areas, and appropriate measures can be proposed to prevent further water pollution.

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REFERENCES

[1] People's Committee of An Giang Province. *Environmental Status Report in An Giang Province 2019*; 2019.

[2] Son N.T, Thang N.P. Potentials for developing agritourism in An Giang Province. *Journal of Ho Chi Minh City University of Science*. 2014;63: 82–89.

[3] Tuan LA, Wyseure G, Viet LH, Haest PJ. Water Quality Management forIrrigation in the Mekong river Delta, Vietnam. *International Conference on Agricultural Engineering*. Leuven. Belgium. 2004.

[4] Herbst S, Benedikter S, Koester U, Phan N, Berger C, Rechenburg A, Kistemann T. Perceptions of Water, Sanitation and Health: a Case Study from the Mekong Delta, Vietnam. *Water Science & Technology*. 2009;60(3): 699–707.

[5] Garschagen M, Diez JR, Nhan DK, Kraas F. Socio-Economic Development in the Mekong Delta: Between the Prospects for Progress and the Realms of Reality. In: Renaud F, Kuenzer C (eds). *The Mekong Delta System. Springer Environmental Science and Engineering*. Springer; 2012.

[6] Nhan DK, Be NV, Trung NH. Water use and competition in the mekong Delta. In *Chalenges to sustainable development in the Mekong delta: regional and national policy issues and research needs*. Sumernet; 2007. 143–188.

[7] Feng H, Han XF, Zhang WG, Yu LZ. A preliminary study of heavy metal contamination in Yangtze river intertidal zone due to urbanization. *Marine Pollution Bulletin*. 2004;49: 910–915

[8] Yin ZY, Walcott S, Kaplan B, Cao J, Lin WQ, Chen MJ, Liu DS, Ning YM. An analysis of the relationship between spatial patterns of water quality and urban development in Shanghai, China. *Environment and Urban Systems*. 2005;29: 97–221.

[9] Z. Tang Z, Engel BA, Pijanowski BC, Lim KJ. Forecasting land use change and its environmental impact at a watershed scale. *Journal of Environmental Management*. 2005;76: 35–45.

[10] Herb WR, Janke B, Mohseni O, Stefan HG. Thermal pollution of streams by runoff from paved surfaces. *Hydrological Process*. 2008;22(7): 987–999.

[11] Freeman PL, Schorr MS. Influence of watershed urbanization on fine sediment and macroinvertebrate assemblage characteristics in tennessee ridge and valley streams. *Journal of Freshwater Ecology*. 2004;19(3): 353–362.

[12] Reale JK, Van Horn DJ, Condon KE, Dahm CN. The effects of catastrophic wildfire on water quality along a river continuum. *Freshwater Science*. 2015;34(4): 1426–1442.

[13] Lien NTK, Huy LQ, Oanh DTH, Phu TQ, Ut VN. Water quality in mainstream and tributaries of Hau river. *Can Tho University Journal of Science*. 2016;43: 68–79.

[14] Ly NHT, Giao NT. Surface water quality in canals in An Giang Province, Vietnam, from 2009 to 2016. *Journal of Vietnamese Environment*. 2018;10(2): 113–119.

[15] Giao NT. Evaluating current water quality monitoring system on Hau river, Mekong delta, Vietnam using multivariate statistical technique. *Journal of Applied Environmental Research*. 2020;42(1): 14–25.

[16] APHA, AWWA, WEF. *Standard methods of for the Examnination of Water and Wastewwater*. 23^{rd} edition. American Public Health Association: Washington, DC, USA; 2017.

[17] Willet P. Recent trends in hierarchic document clustering: A critical review. *Information Processing & Management*. 1988;24(5): 577–597.

[18] Helena R, Pardo M, Vega E, Barrado JM, Fernández L. Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga river, Spain) by principal component analysis. *Water Research*. 2000;34(3): 807–816.

[19] Feher IC, Zaharie M, Oprean I. Spatial and seasonal variation of organic pollutants in surface water using multi-variate statistical techniques. *Water Science and Technology*. 2016 74: 1726–1735.

[20] Liu CW, Lin KH, Kuo YM. Application of factor analysis in the assessment of groundwater quality in a Black-foot disease area in Taiwan. *Science of the Total Environment*. 2003;313(1-3): 77–89.

[21] Ministry of Environment and Natural Resources. *National technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT)*; 2015.

[22] Ongley ED. Chapter 12: Water Quality of the Lower Mekong river. In: Campbell, I.C.(ed.). *The Mekong: Biophysical Environment of an International river Basin*. Montreal QC, Canada: Academic Press; 2009.

[23] Mekong river Commission. *Annual water quality data assessment report*. MRC Technical Paper; 2015

[24] Truc DT, Phat PH, Nam NDG, Toan PV, Tri VPD. The water surface quality of Tien river in the area of Tan Chau District, An Giang Province. *Journal of Science Can Tho University*. 2019;55: 53–60.

[25] Giao NT. Surface Water Quality in Aquacultural Areas in An Giang Province, Vietnam. *International Journal of Environment, Agriculture and Biotechnology*. 2020;5(4): 1054–1061.

[26] Giao NT, Ai TTM, Nhien HTH. Evaluation of current water use situation and water quality in Tan Thanh Commune, Thoi Lai District, Can Tho City. *Journal of Natural Resources and Environment*. 2020;30: 11–30.

[27] Tuan DDA, Thu BA, Trung NH. Assessing quality of surface water for urban water supply source for Soc Trang City. *Scientific Journal of Can Tho University*. 2019;4A: 61–70.

[28] Giao NT. Surface water quality in the tributaries adjacent to the Hau river in Can Tho City. *Journal of Agriculture and Rural Development*. 2020.

[29] Giao NT and Nhien HTH. Evaluating Water Quality Variation in the Vietnamese Mekong Delta Area Using Cluster and Discriminant Analysis. *Applied Environmental Research*. 2021;43(1): 14–27.

[30] Boyd CE. *Water quality for pond Aquaculture*. Department of Fisheries and Allied Aquacultures. Auburn University: Alabama, USA; 1998.

[31] Phu TQ, Ut VN. *Water quality for pond aquaculture*. Can Tho University; 2006.

[32] An Giang Statistics Office. *An Giang Statistical Yearbook*. Statistical Publishing House; 2019.

[33] Gebreyohannes F, Gebrekidan A, Hedera A, Estifanos S. Investigations of Physico-Chemical Parameters and its Pollution Implications of Elala river, Mekelle, Tigray, Ethiopia. *Momona Ethiopian Journal of Science (MEJS)*. 2015;7(2): 240–257.

[34] Ut VN, Loan NB, Giang HT, Oanh DTH, Lien NTK, Quoc NB, Ngoan NV, Hoa AV, Tu PTC. *Study on measures to limit the growth of Limnoperna fortunei living on Cipangopaludina lecithoides in Cho Lach District, Ben Tre*. Final report on ministerial-level projects; 2013.

[35] Fataei E and Shiralipoor S. Evaluation of Surface Water Quality Using Cluster Analysis: A Case Study. *World Journal of Fish and Marine Sciences*. 2011;3: 366–370.

[36] Chowdhury S, Zahrani M. Water quality change in dam reservoir and shallow aquifer: analysis on trend, seasonal variability and data reduction. *Environmental Monitoring and Assessment*. 2014;186(10): 6127–6143.

[37] Giao NT. Spatial variations of surface water quality in Hau Giang province, Vietnam using multivariate statistical techniques. *Environment and Natural Resources Journal*. 2020;18(4): 400–410.