Variation of Surface Water Quality in Cu Lao Dung Island, Soc Trang Province, Vietnam

Nguyen Thanh Giao* and Le Thi Diem Mi

***Abstract*—The study aims to evaluate variation of surface water quality in canals in Cu Lao Dung district, Soc Trang province, Vietnam using multivariate statistical methods. Sixteen surface water samples with the parameters of pH, total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), NH_4^+-N, NO_2^--N, PO_4^{3-}-P, Cl^-, Fe, coliform were used for the assessment. The results showed that the surface water in the study area was contaminated with microorganisms, salinity and acidity, and nutrient. The concentrations of coliform, Cl^-, Fe, TSS and NO_2^--N were higher than the specified limits by 4.17, 2.04, 1.91, 1.28 and 1.10 times, respectively. The four principal components could explain up to 81.40% of the total variance of surface water quality. The main water pollution sources could be from natural (rainwater runoff, saltwater intrusion, erosion) and man-made activities from domestic and agricultural activities (livestock, aquaculture, cultivation), industry and navigation activities. Cluster analysis divided surface water quality into two groups by the difference in BOD, COD, NH_4^+-N, NO_2^--N, Fe, coliform and pH. Pearson correlation results demonstrated that only BOD or COD should be monitored since it is mutually predictable. Specific sources and its contribution should be further studied for effective surface water quality management in the study area.**

***Index Terms*—Surface water quality, Cu Lao Dung district, rainy season, microbial pollution**

I. INTRODUCTION

Water is one of the most important natural resources available in any economic structure, as it is the means of life and development for any society, and it is not possible to imagine the existence of life on the surface of the earth without the presence of water [1]. Aani *et al.* though three-quarter of the Earth's surface is covered by water, only about 1% is freshwater [2]. However, the process of industrialization, exploitation and unreasonable use of water resources by humans have created many challenges, especially in the aspect of surface water quality with increasing concentrations of pollutants in the receiving waters and make it unsuitable for various use purposes [2], [3]. Wurtsbaugh *et al.* [4] has shown that, agricultural, urban and industrial activities have dramatically increased aquatic nitrogen and phosphorus pollution leading to eutrophication with multiple problems, including hypoxic "dead zones" that reduce fish and shellfish production; harmful algal blooms that create taste and odor problems and threaten the safety of drinking water supplies and irrigation water for agriculture production In addition, according to Al-Taai [1], several diseases have been reported in humans related to the use of contaminated water such as cholera, typhoid, dysentery bacillus, infectious hepatitis giardia, schistosomiasis and nematode worm. Many previous studies have also shown that surface water pollution will seriously affect human health and aquatic ecosystems [5–7]. Therefore, the monitoring and evaluation of surface water quality is really necessary.

For the monitoring of surface water quality, physical, chemical and biological parameters are often selected [8]. The physical and chemical parameters including temperature, pH, total suspended solids (TSS), turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia (NH_4^+-N), orthophosphate (PO_4^{3-}-P), heavy metals (Fe, Al, Mn, Cr, Cd), chloride (Cl^-), sulfate (SO_4^{2-}), pesticides, antibiotics or biological factors such as E. coli, coliform (MPN/100 mL) [5, 9, 10]. In particular, in the research process, in order to identify sources of pollution, the main environmental indicators affecting surface water quality as well as find out monitoring locations with similar physical, chemical and biological characteristics, multivariate statistical analysis such as principal component analysis (PCA), cluster analysis (CA) and correlation analysis (Pearson) have been widely used [11–13]. According to Giao & Minh [14], using multivariate statistical analysis to assess surface water quality in Ben Tre Province, cluster analysis divided surface water quality into seven clusters, thus reducing eight sampling sites and two monitoring times of frequency, principal compoment analysis identified 13 observed water parameters significantly contribute to the variation in water quality. Similarly, in the study of Hong *et al.* [12], PCA results identified 14/17 surface water environmental parameters to be monitored, CA results showed that 34 monitoring locations can be reduced to 27 locations and DA indicated that the indicators of EC, SO_4^{2-} and Cl^- made the difference of the surface water quality between the wet and dry seasons [12]. The above studies have proved that multivariable statistical analysis is very useful in surface water quality assessment program, it is possible to design the monitoring network for spatial and temporal fluctuations optimally in the future, reducing the number of sampling stations, sample collection times and monitoring criterias, as well as related costs.

Cu Lao Dung is a coastal district in Soc Trang Province, surrounded by the Hau River and the East Sea along with a system of rivers and canals, which is a very important source of water and an input material for operating producing in the whole district. However, at present, the district's surface water is strongly affected by the continuous receipt of wastewater such as untreated domestic wastewater, agricultural production wastewater, or untreated wastewater that is not up to the standards. Rivers and canals can

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Nguyen Thanh Giao and Le Thi Diem Mi are with College of Environment and Natural Resources, Can Tho University, Vietnam.

*Correspondence: ntgiao@ctu.edu.vn (N.T.G.)

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contribute to an increase in the concentration of pollutants in the water environment. In addition, livestock production facilities in the district are small and have not yet invested in a waste treatment system, along with aquaculture activities accompanied by an increase in wastes such as sludge, food, excess feed, waste and wastewater from the ponds. The population of Cu Lao Dung district recorded about 58,304 people. According to Cong *et al.* [15], the amount of wastewater generated is about 62–75 L/person/day/night, so at the present time, the whole district will generate about 3,615–4,373 L of wastewater every day. In addition, the area of aquaculture in the district is estimated at 4,100 ha and about 12,140 cattle and poultry. Swine wastewater has the characteristics of BOD 873–1,690 mg/L, COD 1,794–3,871 mg/L and total phosphorus 131–512 mg/L [16]. Besides, it is estimated that if shrimp feed input is 100 kg, there will be 28 kg of protein (protein source) which adversely affects the aquatic environment as well as creates many nutrients for harmful microorganisms to develop [17]. In addition to impacts from man-made waste sources, due to the geographical location of the district near the sea, it is clearly affected by saline intrusion, saline water following inland rivers and canals such as Con Tron, Ben Ba, Khem Sau can penetrate very deep inside, causing the middle and tail of the isle to be severely affected [18]. In addition, the soil is acidic, which, through erosion and runoff, contributes to the formation of heavy metals, especially Fe and Al in surface water. From the above situation, the assessment of surface water quality in river and canals of Cu Lao Dung district was carried out to determine the variations of the surface water pollution and its pollution sources.

II. Materials and Methods

A. Description of the Study Area

Cu Lao Dung district is located at the end of Hau River, adjacent to Dinh An and Tran De sea estuaries. The interlaced system of canals divides the area into islets, creating a diversity of landscapes and fresh climates. The district has three ecological zones consisting of freshwater, brackish water and salt water suitable for the development of diverse agricultural systems. The district's surface water is strongly affected by the water of the Hau River and the tides of the East Sea. At the time of the tide, the canals in the district have almost run out of water, waste from markets, domestic activities, etc. aquaculture, animal husbandry and agricultural production activities in the area. Wastewater from impact sources in the area is not treated or only partially treated and then discharged directly into the receiving environment, contributing to the deterioration of surface water quality in the study area.

B. Description of Sampling Stations and Sampling Times

Surface water quality samples of Cu Lao Dung district, Soc Trang Province were collected in the rainy season (October) 2021 at 16 locations (S1-S16) presented in Fig. 1. In which, S1-Mieu canal and S2-Long An canal belong to An Thanh 1 commune; S3- Sau canal and S4-Dau La canal belong to An Thanh Tay commune; S5-Bung Binh canal and S6-Su canal belong to An Thanh Nam commune; S7- Ba Hum canal and S8-Trang canal belong to An Thanh 3 commune; S9-Thuy Loi canal and S10-Ong Tam canal belong to An Thanh 2 commune; S11-Day canal and S12-Xang canal belong to Dai An 1 commune; S13-Dinh Tru canal and S14-Ben Ba river belong to Cu Lao Dung town; S15-Long Dam canal and S16-Goc canal belong to An Thanh Dong commune. At each location, one water sample were collected early in the morning, so a total of 16 samples were collected throughout the study area.

Eleven water quality parameters including pH, organic matter (dissolved oxygen—DO, biochemical oxygen demand—BOD, chemical oxygen demand—COD), total suspended solids (TSS), inorganic nutrients (ammonium—NH_4^+-N, nitrite—NO_2^--N, orthophosphate – PO_4^{3-}-P), salinity (chloride—Cl^-), heavy metals (iron—Fe) and microorganisms (coliform) were used to assess water quality. The pH and DO parameters are measured directly in the field by the Sension6 pH meter. The remaining parameters including BOD, COD, TSS, NH_4^+-N, NO_2^--N, PO_4^{3-}-P, Cl^-, Fe and coliform were analyzed in the laboratory according to standard methods [19] (Table I). Surface water quality data collected from the Department of Natural Resources and Environment of Soc Trang Province.

C. Data Analysis

Surface water quality data was synthesized and analyzed to determine the mean, standard error, and range using IBM SPSS statistics for Windows, version 20.0 (IBM Corp., 2011). Assessment of surface water quality changes in the rainy season in 2021 by comparing with column B1 of QCVN 08-MT:2015/BTNMT, B1 means water quality used for irrigation or other uses with similar water qualiy requirements [20]. Besides, the average of the parameters exceeded the prescribed thresholds, comparing the difference with statistical significance ($p<0.05$) with the allowable limits of the standards (the analysis data is normal distribution). Determining the correlations, sources affecting surface water quality in the study area as well as grouping locations with similar physical, chemical and biological characteristics in water by multivariate statistical analysis such as correlation analysis, correlation (Pearson), principal component analysis (PCA) and cluster analysis (CA). The above statistical methods have been used in many studies of Barakat *et al.* [21], Karukuş [22], Mamun & An [23], Zhang *et al.* [13] and Hong *et al.* [12]. PCA and CA were performed using copyrighted software Primer 5.2 for Windows (PRIMER-E LTD., PLYMOUTH, UK). Correlation analysis were performed using SPSS statistics for Windows, version 20.0.

TABLE I: Sample Analysis Methods

No.	Parameters	Analytical methods
1	BOD	SMEWW 5520 D:2012/ TCVN 6001-1:2008
2	COD	HACH method 8000 (DR 5000)
3	TSS	TCVN 6625:2000
4	NH_4^+-N	US EPAMethod 350.2
5	NO_2^--N	SMEWW 4500-NO2.B:2012
5	PO_4^{3-}-P	SMEWW 4500-P.D:2012/ TCVN 6494-1:2011
6	Cl^-	SMEWW 4500-Cl-:B:2012/ TCVN 6494:1999
8	Fe	TCVN 6177:1996
9	Coliform	TCVN 6187-2:1996

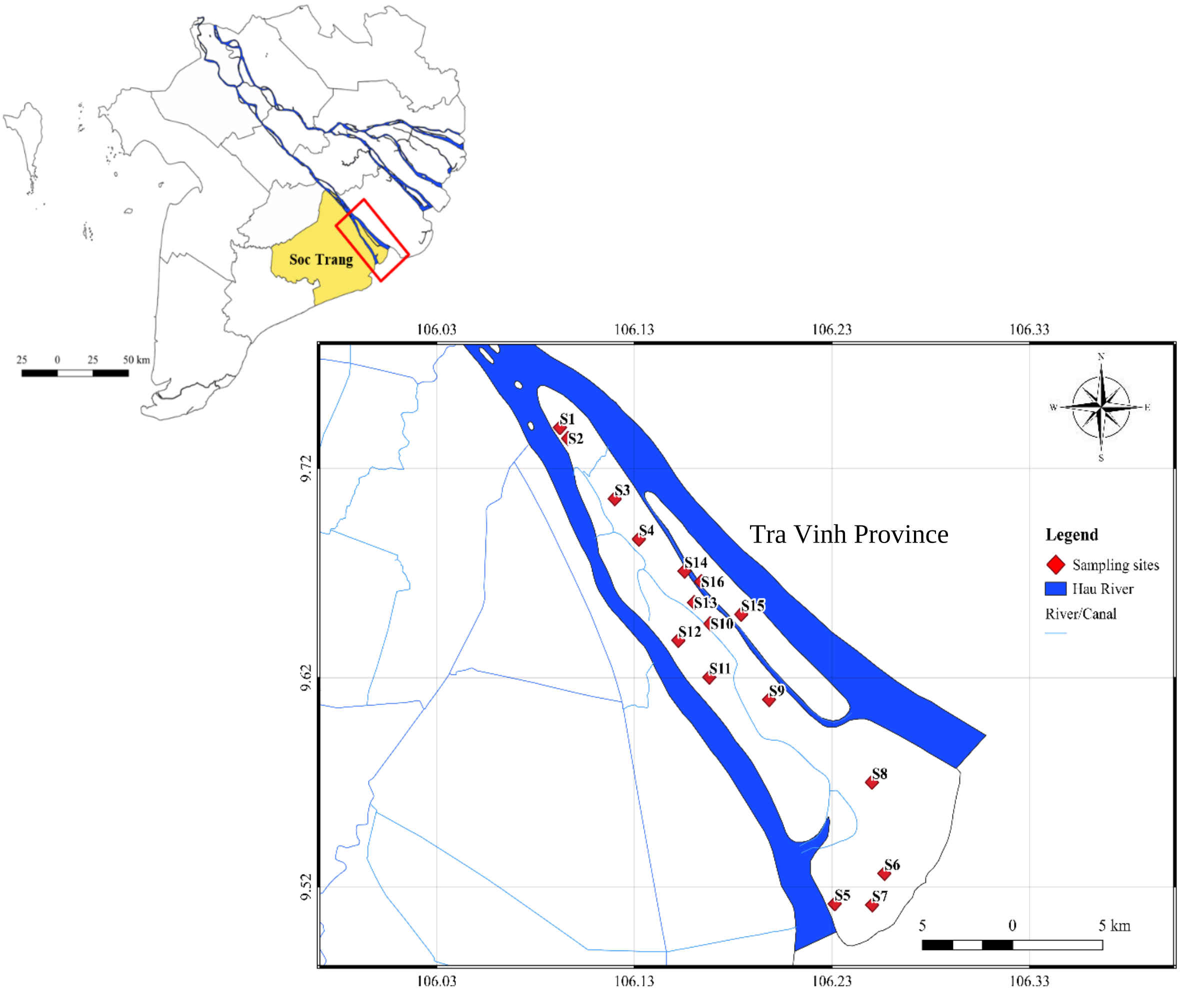

Fig. 1. Locations of water sampling in the Cu Lao Dung district, Soc Trang province.

III. Results and Discussion

A. Evolution of Surface Water Quality in the Study Area

1) pH and TSS

pH is the measure of hydrogen ion concentration or hydroxide ions concentrations in a solution [24]. The pH value of water at 16 monitoring locations at the time of the rainy season in 2021 is less volatile in the range of 6.70–7.50, reaching an average value of 7.09±0.24, corresponding to the lowest pH value at S10- Ong Tam canal and the highest at S12- Xang canal (Table II), showing that the surface water in the study area is neutral and weakly alkaline. The results of this study are consistent with the pH value in water in the rainy season on the Can Tho River, which fluctuates in the range of 6.40-7.20 [25]. Similarly, in the La Buong River area, the average pH in the water at the time of rainy season monitoring is also similar to 7.06±0.45 [26]. Besides, the research results are also consistent with some other studies in canals and canals of Hau River route [27, 28]. In addition, the result compares well with the study of Chinedu *et al.* [24] in water samples from Canaanland, Ota, Southwest Nigeria. However, in other study areas such as Tien Giang Province, Ain Zada Dam, Saraydüzü Dam Lake, pH value in water is higher than present study area [12, 29, 30]. In general, the pH value in surface water of Cu Lao Dung district is within the allowable range of column B1 of QCVN 08-MT:2015/BTNMT. However, in freshwater environment, if the pH is increased above 8 it will increase the toxicity of ammonia in water compared to lower pH [31].

TSS concentration in 16 surface water samples monitored in canals and canals of Cu Lao Dung district in October 2021 largely fluctuated from 21.50–136.10 mg/L with an average value of 63.78±37.55 mg/L, the lowest and highest at S11-Day canal and S5-Bung Binh canal, respectively (Table II). Compared with the TSS concentration in surface water in Ke Sach district, there are similarities, fluctuating from 24.13±10.45–186.13±100.82 mg/L and high TSS concentration mainly due to erosion, alluvial, rainwater runoff and other activities [32]. According to the research of Giao *et al.* [33], in Cai Rang district, Can Tho city, TSS presence in surface water during the rainy season was lower than in the present study, only ranging from 17.30±0.30–64.23±2.68 mg/L. In addition, in other water bodies on Can Tho River, Hau River,, Keban Dam Reservoir and Sanh Lake, TSS concentration in the study area is higher [25, 28, 34, 35]. In general, the mean TSS value on the canal system of Cu Lao Dung district has exceeded the allowable limit for column B1 of QCVN 08-MT:2015/BTNMT and is 1.28 times higher, but with this concentration the different is not statistical significance with the limit of the standard (p > 0.05). The results also showed that, in 16 observed surface water samples, 10 water samples appeared with TSS concentration higher than the standard, accounting for 62.50% of the total. According to Ty *et al.* [8], TSS content is high in the rainy season, because rainwater has washed away mud and dissolved organic matter into the water, causing disturbance to the bottom layer. In addition, according to Phu *et al.* [36], the high concentration of suspended solids in the water is also affected by navigation activities, wastes from agricultural production and aquaculture. High TSS concentration in water is an extremely important cause of water quality deterioration, higher water treatment costs, reduced aquatic resources, adverse effects on aquatic life and toxic binding harmful [37–39].

TABLE II: SUMMARY OF SURFACE WATER QUALITY

No.	Parameters	Unit	Mean ±SD	Min	Max	QCVN 08-MT:2015/BTNMT, B1
1	**pH**	-	7.09 ±0.24	6.70	7.50	5.5–9
2	**DO**	mg/L	2.56 ±0.39	2.05	3.35	≥4
3	**BOD**	mg/L	3.398 ±1.35	1.57	6.23	15
4	**COD**	mg/L	22.85 ±9.57	11.00	49.30	30
5	**TSS**	mg/L	63.78 ±37.55	21.50	136.10	50
6	**NH_4^+-N**	mg/L	0.59 ±0.35	0.142	1.37	0.9
7	**NO_2^--N**	mg/L	0.055 ±0.05	0.007	0.21	0.05
8	**PO_4^{3-}-P**	mg/L	0.02 ±0.02	0	0.064	0.3
9	**Cl^-**	mg/L	713.95 ±562.02	156.10	1.685.70	350
10	**Fe**	mg/L	2.87 ±1.85	0.98	7.46	1.5
11	**Coliform**	MPN/100 mL	31,237.50 ±33,295.68	2,100	93,000	7,500

2) Organic matters (DO, BOD, COD)

The DO concentration in all monitored water samples is lower than the threshold specified in column B1 of QCVN 08-MT:2015/BTNMT. The DO value in water in the study area fluctuates in the range of 2.05–3.35 mg/L, the average value is 2.56 ±0.39 mg/L, respectively the lowest at S2-Long An canal and the highest at S5-Bung Binh canal (Table II). According to Sarda & Sadgir [40], the low dissolved oxygen concentration could be due to increased turbidity and suspended matter in the water, which is consistent with the high TSS results in the study area water. In addition, DO is also used to oxidize organic substances and DO less than 3 indicates a polluted environment [8]. The DO concentration in water in canals of Cu Lao Dung district is consistent with the results of some other studies in Ke Sach Province and the Tunggak River [32], [41], influenced by agricultural production wastes, industry, aquaculture, animal husbandry and domestic wastewater [27]. This result is within the range (DO = 0–5 mg/L) recorded in the Mekong Delta [42]. However, in some other water bodies, the DO concentration recorded was higher than in the present study area. Specifically, the DO concentration recorded in the La Buong River (Dong Nai Province) ranged from 5.684 ±1.69–6.198 ±1.118 mg/L [26] and Saraydüzü Dam Lake, DO values ranged from 10.26–14.48 mg/L [30]. Similarly, DO concentration recorded in Ray River is also higher than the results of the present study (4.4–7.6 in the rainy season) [43]. The range of dissolved oxygen recorded from 4.8–8.2 mg/L indicates that the water is of good quality and is suitable for the reproductive development of fish [40]. Thus, low DO concentration at monitoring points will affect aquatic ecosystems and reduce the self-cleaning capacity of water [32].

The BOD concentration at 16 monitoring locations ranged from 1.57–6.23 mg/L with the average value reaching 3,398 ±1.35 mg/L, the lowest at S7-Ba Hum canal and the highest at S15-Long Dam canal. With this value, the BOD in the water in canals and canals of Cu Lao Dung district is still within the allowable limit for column B1 QCVN 08-MT:2015/BTNMT, there is no sign of organic matter pollution. It can be seen that the BOD concentration in the study area is much lower than that of polluted water bodies such as in Can Tho City, Dong Nai Province and U Minh Ha National Park with BOD values obtained from 10–185 mg/L,18.76–35.50 mg/L and 49.13–61.73 mg/L, respectively [44–46]. According to Sarda & Sadgir[40], the discharge of untreated urban and domestic waste into the receiving waters increases the organic matter concentration. Besides, according to Giao *et al.* [32], also suggested that the high concentration of BOD in water originates from human activities, agricultural production activities and other sources of waste rich in organic matter in the area. Similar to BOD, the average COD concentration in the water in the study area is still within the allowable limit for column B1 of QCVN 08-MT:2015/BTNMT, showing that the water bodies of Cu Lao Dung district still have no signs of organic pollution. COD concentrations at 16 monitoring locations ranged from 11–49.30 mg/L, the average value reached 22.85 ±9.57 mg/L, continued to be the lowest and highest at S7-Ba Hum canal and S15-Long Dam canal. This result indicates that, at site S15-Long Dam canal has the highest level of organic pollution among all studied sites. Although, the average COD concentration is still within the allowable limit of QCVN 08-MT:2015/BTNMT, but there are still two locations (S14-Ben Ba river, S15-Long Dam canal) with COD concentration exceeding the standard from 1.11–1.64 times.

In general, the concentration of BOD and COD in the water in the study area has not shown any signs of organic pollution, is still within the allowable threshold of column B1 QCVN 08-MT:2015/BTNMT. The results also show that the low DO in the study area may be largely influenced by the high concentration of TSS in the water and low DO diffusion.

3) Nutrients (NH_4^+-N, NO_2^--N, PO_4^{3-}-P)

The average concentration of NH_4^+-N in all surface water samples in the study area reached 0.59 ±0.35 mg/L, ranging from 0.142 to 1.37 mg/L, respectively, the lowest and the highest at S5-Bung Binh canal and S9-Thuy Loi canal in the study area (Table II). Similarly, Tien Giang Province, the NH_4^+-N concentration fluctuates in the range of 0.14±0.04–0.84±0.19 mg/L [12]. In canal 30/4 in Soc Trang Province, NH_4^+-N concentration is higher than that in canals in Cu Lao Dung district, ranging from 0.35–4.15 mg/L, because it is located near Soc Trang City which may be affected by domestic and production wastewater in the area [47]. In addition, in some other water bodies, the concentration of NH_4^+-N has reflected the pollution level, causing eutrophication [3, 48, 49]. According to Nga & Thu [44], NH_4^+-N concentration greater than 5 mg/L indicated that the water is very dirty and some aquatic plants such as water hyacinth and udu will thrive in the water body. The concentration of NH_4^+-N formed in water is mainly from the farming system that uses a lot of nitrogen fertilizers and the wastewater treatment process is not guaranteed in the study area, however, the average value of NH_4^+-N content is still within the allowable limit for column B1 of QCVN 08-MT:2015/BTNMT. The research results also showed that there were three surface water samples with NH_4^+-N concentration exceeding the prescribed threshold, accounting for 18.75% of the total. Besides, the nitrogen content found in natural surface water sources is in the range of <0.2 mg/L (NH_4^+-N), < 5mg/L (NO_3^--N), thus the concentration of NH_4^+-N in the canals of Cu Lao Dung district needs more attention in the future [50].

NO_2^--N is extremely toxic to aquatic life, but usually only exists in trace amounts in most natural freshwater systems because it is rapidly oxidized to nitrate. The conversion process is influenced by several factors including pH, temperature and DO, the number of nitrifying bacteria and the presence of inhibitory compounds [40]. The results of analysis of NO_2^--N concentration in 16 water samples in the study area ranged from 0.007–0.21 mg/L, respectively the lowest and highest at S13-Dinh Tru canal and S15-Long Dam canal with the average value of 0.055±0.05 mg/L (Table II). In the Gradinari surface water, the nitrite concentration was higher than that of the present study area, ranging from 0.48–0.59 mg/L, mainly arising from agricultural intensification [51]. Similarly, in Dong Thap Province, NO_2^--N concentration in the water from of 1.14±0.39–3.00±0.83 mg/L, higher than the present study area và water containing NO_2^--N is of great concern because it can cause methmoglobinemia or blue-skin disease due to limited oxygen transport in the bloodstream [52]. However, compared with the results reported by Ty *et al.* [8], the concentration of NO_2^--N in the canals of Cu Lao Dung district was higher than that of the water sample in Bung Binh Thien with 0.01±0.01 mg/L. In some other studies, it was also shown that the NO_2^--N concentration in canals in Cu Lao Dung district was higher [30, 43]. In general, the average value of NO_2^--N content in the study area has exceeded the allowable limit for column B1 of QCVN 08-MT:2015/BTNMT by 1.10 times. In addition, the research results also show that, in 16 monitored water samples, 7 water samples exceeded the prescribed threshold, accounting for 43.75% of the total. High levels of NO_2^--N present in water and exceeding standards may be due to insufficient oxygen in the water to convert to nitrate, so they exist in the nitrite state. This shows that the aquatic environment lacks oxygen and can be toxic to aquatic life [50].

The concentration of PO_4^{3-}-P in water samples on the canal system of Cu Lao Dung district fluctuates in the range of 0–0.064 mg/L with an average value of 0.02±0.02 mg/L, the lowest at S4-Dau La canal and highest at S2-Long An canal (Table II). Concentrations of PO_4^{3-}-P in Hau River and inland canals of Hau Giang Province ranged from 0.1±0.02–0.36±0.26 mg/L, higher than the current study area [50]. High concentrations of PO_4^{3-}-P present in surface water were also detected in many places in Tien Giang and An Giang Provinces [12, 28]. Similarly, according to the study of Dung *et al.* [26], assessment surface water quality in La Buong River, the concentration of PO_4^{3-}-P has exceeded the allowable limit of the standard, ranging from 0.451±0.285–0.461±0.222. The natural breakdown of rocks and minerals, agricultural discharges, erosion and sedimentation, through the input of operations are non-point sources, while point sources are domestic and industrial wastewater that contribute to increased PO_4^{3-}-P content in water [53]. Besides, according to Barakat *et al.* [21] reports that the sources of PO_4^{3-}-P formation in the aquatic environment are agricultural wastewater, livestock waste, domestic and industrial waste. An earlier study by Jarvie *et al.* [54], showed that point (effluent) rather than diffuse (agricultural) sources of phosphorus provide the most significant risk for river eutrophication. The high presence of PO_4^{3-}-P in water can promote the growth of algae and aquatic plants leading to eutrophication of aquatic ecosystems [39]. Research results show that the concentration of PO_4^{3-}-P in the water in the study area is still within the allowable limit for column B1 QCVN 08-MT:2015/BTNMT

4) Chloride (Cl^-) and heavy metal (Fe)

The results showed that the Cl^- concentration in 16 water samples belonging to the canals of Cu Lao Dung district fluctuated relatively large in the range of 156,10–1,685.70 mg/L with an average content of 713.95±562, 02 mg/L, the highest at S6-Su canal and the highest value 10.8 times the lowest value (Table II). Another study in Ke Sach district, the concentration of Cl^- in the water was lower without any sign of salinity, only ranging from 11.40±2.15–34.48±6.59 mg/L [32]. It can be seen that in the same Province, receiving different amounts of waste as well as geographical location will affect the Cl^- contamination in the water. According to the study of Truc *et al.* [55], surface water quality of Tien River flowing through Tan Chau River had Cl^- content ranging from 2.1–19.4 mg/L, with this value lower than the results recorded in canals of Cu Lao Dung district. Similarly, compared with other study areas at The Keban Dam Reservoir and Saraydüzü Dam Lake the concentration of Cl^- in the water in the canals of the study area tended to be higher [30, 34]. According to Sarda & Sadgir [40], high chloride content in water samples can be attributed to wastewater pollution and municipal waste, as well as naturally occurring in marine waters. According to Madhav *et al.* [39], ion exchange processes, precipitation, runoff water in agriculture, untreated wastewater from industries, sewage waste are sources of Cl^- in the water. Excessive Cl^- content imparts a salty taste to the water and individuals sensitive to Cl^- may experience a laxative [56]. It also contributes to the corrosion of many metals, including man-made structures such as dams [39]. In summary, the average concentration of Cl^- in surface water in the rainy season in 2021 in the study area has exceeded the allowable limit for column B1 of QCVN 08-MT: 2015/BTNMT, 2.04 times higher than the limit mainly affected by wastewater and saline intrusion from the sea. Too much soluble salts such as chloride in irrigation water can change the osmotic pressure in the roots, affect agricultural soils, reduce yield and hinder plant growth [57, 58].

The average concentration of iron in surface water in the study area of Cu Lao Dung district reached 2.87±1.85 mg/L, ranging from 0.98–7.46 mg/L and was highly concentrated in S8-Trang canal. The presence of high Fe content in all monitoring sites reflects a severely contaminated area. Part of this may be due to the acidic soil that leads to the release of iron into surface water, besides human activities such as intensive agricultural production [50]. Compared with the research results of Tam *et al.* [59] and Giao [50], the Fe content in these areas is lower, only fluctuating in the range of 0.46–0.70 mg/L and 0.3±0.1–2.26±0.5, respectively. In addition, according to the study of Phung *et al.* [60], Fe concertration in the samples water from Can Tho City also tended to be lower, only ranged from 0.37–0.84 mg/L. On the other hand, water samples in Dong Nai River and Hong River recorded high Fe content and exceeded the allowable limit many times [61, 62], similar to the study results. And of the eight heavy metals monitored in the Ganga river, Fe was found to have the highest concentration in water [63]. Compared with Vietnamese standards show that the concentration of Fe in water in the rainy season in 2021 in the survey area has exceeded the allowable limit for column B1 of QCVN 08-MT: 2015/BTNMT, 1.91 times higher than the standard. According to Zahra *et al.* [64] reported that, high Fe content causes serious plant morphological and physiological disorders, including reduced germination rate, inhibition of enzyme activities, nutritional imbalance, damage to membranes and chloroplast structure in plants. Typically in rice, iron poisoning reduced oxidation in the rhizosphere, the entire rice root surface is covered with dark brown to black color, the roots cannot develop and affected the crop yield (average from 13-30%), in many cases rice yield is reduced by 100% [65].

5) Coliform

The coliform density in water in the canals of Cu Lao Dung district fluctuated relatively large in the range of 2,100–93,000 MPN/100 mL with an average of 31,237.50±33,295.68 MPN/100 mL and the highest coliform content at some monitoring locations including S3-Sau canal, S4-Dau La canal and S8-Trang canal (Table II). The average coliform presence in surface water in the rainy season in 2021 in the study area exceeded the allowable limit for column B1 of QCVN 08-MT:2015/BTNMT and 4.17 times higher than the standard. Microbial contamination is high, indicating that the water source has received a large amount of waste originating from humans and warm-blooded animals. Poor sanitation system, waste from livestock and aquaculture activities that is not thoroughly treated or is not treated and discharged directly into the receiving environment are considered as the main causes of serious coliform contamination in the study area [39, 66]. According to the studies of Servais *et al.* (2007) and Ouattara *et al.* (2011) also pointed out that, high coliform density in river water is directly affected by human activities: point discharge sources (domestic and industrial wastewater) and emission sources (washed out from agricultural land and grazing land) as well as environmental factors such as temperature, pH, nutrient content, turbidity, salinity, hydrological regime [67]. This pollution also occurs in many water bodies in Vietnam. Specifically, the highest concentration of coliform recorded at surface water monitoring sites in Soc Trang Province was 89,832 MPN/100 mL [47]. In the study of Dung *et al.* [26], coliform concentration in sample waters in the La Buong River ranged from 11,496.54 MPN/100 mL to 14,485.22 MPN/100 mL. Besides, in the some canals in Thuan An City such as Ba Lua canal, Bung canal, D canal and Cat stream, the recorded coliform content was very high, ranging from 3,700-15,000,000 MPN/100 mL [68]. In the studied water bodies in Xuan Loc district, similar results were also recorded [45].

B. Correlation and Origin of Water Pollution Parameters

According to Baraket *et al.* [21], correlation analysis aims to evaluate the relationship between water environment variables, a correlation coefficient near -1 or 1 means a strongest or negative or positive relationship between two variables and its value closet to 0 means no linear relationship between them at a significant level of $p < 0.05$. The results of the correlation analysis between surface water quality parameters in the canals of Cu Lao Dung district are detailed in Table III. The results show that pH is negatively correlated with TSS and Cl^- with coefficients are (−0.641) and (−0.629), respectively. The analysis also shows that DO and TSS have a close positive relationship, correlated at the significance level ($p < 0.01$) with a correlation coefficient of 0.717. For the parameters indicating organic pollution, BOD and COD are strongly correlated (0.818), similar results were obtained by Mamun & An) [23] and Tam *et al.* [59]. The correlation between them, indicating that most organic materials were rapidly biodegradable [21, 52]. This result proves that they have the same origin, and the results also show that when monitoring can use one indicator of BOD or COD for general assessment of water quality [59, 69]. In addition, BOD also appeared to be negatively correlated with PO_4^{3-}-P (r = –0,540). COD has a strong negative and positive correlation with TSS (−0.587) and NO_2^--N (0.666), respectively. TSS and NH_4^+-N have a close relationship with Cl^- with correlation coefficients of 0.610 and 0.535, respectively. Particularly, NH_4^+-N also appeared to have a positive correlation with Fe (0.623) at a significant level ($p < 0.01$). Thereby, it is found that the relationships formed between the surface water quality parameters are moderate to closely correlated.

TABLE III: CORRELATION BETWEEN SURFACE WATER QUALITY PARAMETERS IN CU LAO DUNG DISTRICT

Parameter	pH	DO	BOD	COD	TSS	NH_4^+-N	NO_2^--N	PO_4^{3-}-P	Cl^-	Fe	Coliform
pH	**1**										
DO	−0.282	**1**									
BOD	0.184	−0.324	**1**								
COD	0.462	−0.315	**0.818****	**1**							
TSS	**−0.641****	**0.717****	−0.418	**−0.587***	**1**						
NH_4^+-N	-0.418	0.095	−0.183	-0.183	0.187	**1**					
NO_2^--N	0.183	−0.021	0.461	**0.666****	−0.121	0.235	**1**				
PO_4^{3-}-P	-0.069	0.274	**−0.540***	−0.411	0.414	−0.148	−0.375	**1**			
Cl^-	**−0.629****	0.393	−0.224	−0.365	**0.610***	**0.535***	0.261	−0.166	**1**		
Fe	−0.457	−0.106	0.044	0.105	0.004	**0.623****	0.377	−0.394	0.460	**1**	
Coliform	0.224	0.027	−0.015	0.137	−0.283	0,173	−0.006	−0.267	−0.124	−0.001	**1**

**. Correlation at the significance level 1%; *. Correlation at the significance level 5%.

The study also conducted PCA analysis to determine the main sources and factors affecting surface water quality in the rainy season in 2021 in canals in the study area. The scree plot was used to determine the number of PCs to be retained (Fig. 2). An eigenvalue of 1 or greater is considered significant while variables with eigenvalues lower than 1, were removed due to their low significance [11, 12, 22]. In the present study, the scree plot (Fig. 2) showed a pronounced change of slope after the fourth eigenvalue; four principal components were retained to explain the variability of the dataset. According to Liu *et al.* [70], classified the factor loadings as 'strong', 'moderate', and 'weak' where the absolute loading values are greater than 0.75, between 0.75 and 0.50 and between 0.50 and 0.30, respectively. The four main components identified explain up to 81.40% of the total variance of the baseline water quality variables (Table IV). Specifically, PC1, PC2, PC3 and PC4 explain 34.60%, 24.80%, 11.90% and 10% of the total variance, respectively. In the first major component (PC1), a combination of physical factors (pH, TSS), organic pollutants (DO, BOD, COD) and salinity factors (Cl^-). This is considered the main component with the greatest contribution to the change in surface water quality in the study area, affected by natural factors, salinization and human activities (such as biological waste water activities), runoff water from agricultural production activities, industrial wastewater and navigation activities in the area). In the study of Mamun & An [23], poined out that the major sources of COD, BOD are industrial effluent and domestic sewage, representing organic contamination in sewage [13]. In addition, accroding to Liu *et al.* [71], the high concentration of Cl^- may be the results of sewage discharge or the leaching of saline residues in soil. The second major component (PC2), a set of substances indicating nutrient contamination (NH_4^+-N, NO_2^--N, PO_4^{3-}-P), salinity (Cl^-) and acidic contamination (Fe). PC2 reflects water sources that can be affected by wastewater rich in nutrients and detergents in domestic and industrial activities, along with intensive farming activities in agriculture. PC3 and PC4 co-express the origin of coliform formation in water derived from human and animal feces [52]. Point sources can come from aquaculture waste, livestock farms and poor-quality septic tanks in the study area. For non-point sources formed from livestock and poultry grazing on uncontrolled fields as well as small-scale livestock households that do not have a proper waste treatment system. It can be seen that the observed parameters all contribute to the change in water quality in the study area, focusing on a weak correlation, only DO, Fe and coliform have an average correlation. This is consistent with low DO, high Fe and coliform that do not reach the limit of the regulation. According to Karroum *et al.* [11], the results of PCA analyses identified the potential contamination sources of El Abid and Ahen çal Rivers, this contamination is due to a mixed source including natural processes and anthropogenic activities with the discharging untreated rural waste into surface water system constitutes the major point anthropogenic contamination source and the non-point source which also contributes immensely to water contamination is manure and livestock. In another study at Oum Er Pbia River, principal component analysis helped in identifying sources causing the degradation of water quality with the main cause being related to pollutant loads from diffuse (non-point) sources due to weathering of mineral and soil and from urban wastewater discharge [21].

TABLE IV: PRINCIPAL COMPONENT ANALYSIS RESULTS

Parameters	PC1	PC2	PC3	PC4
pH	**0.367**	0.237	−0.033	−0.290
DO	**−0.314**	0.013	0.299	**−0.591**
BOD	**0.364**	−0.207	**0.343**	0.064
COD	**0.431**	−0.187	0.271	−0.133
TSS	**−0.446**	−0.020	**0.329**	-0.143
NH_4^+-N	−0.189	**−0.406**	**−0.339**	−0.046
NO_2^--N	0.183	**−0.404**	**0.355**	−0.244
PO_4^{3-}-P	−0.235	**0.377**	0.144	0.024
Cl^-	**−0.328**	**−0.377**	0.101	−0.064
Fe	−0.065	**−0.501**	−0.189	0.239
Coliform	0.115	−0.049	**−0.550**	**−0.633**
Eigenvalues	3.81	2.73	1.31	1.10
% Variation	34.60	24.80	11.90	10.00
% Cumulative variation	34.60	59.40	71.40	81.40

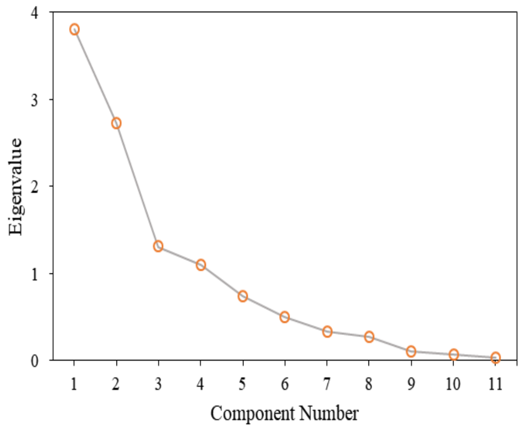

Fig. 2. Scree plot indicating significant principal components.

C. Clustering Surface Water Quality in the Study Area

CA analysis results from 16 monitoring locations in the canals of Cu Lao Dung district, based on the similarity in physical, chemical and biological characteristics of water, forming two groups of surface water quality (Fig. 3). Cluster I gathered most of the sites including S1, S2, S3, S4, S6, S7, S8, S9, S11, S12, S14, S15, S16 with average BOD content (3.45 mg/L), COD (23.96 mg/L), NH_4^+-N (0.624 mg/L), NO_2^--N (0.061 mg/L), Fe (2.92 mg/L), coliform (37,938.46 MPN/100 mL) and pH value (7.12) with higher nutrient, acidity and microbial contamination than those in Cluster II. Particularly for Cluster II, the set of three positions, S5, S10 and S13, had the lowest coliform content and was still within the allowable limit for column B1 of QCVN 08-MT:2015/BTNMT. Other researchers have successfully utilized the CA approach to identify similarities among sampling sites and track water quality programs [10, 12, 29, 46]. Specifically, in the study of Du *et al.* [46], CA analysis grouped 30 monitoring sites into four water quality groups, and at each group only one representative location was selected to monitor surface quality fluctuations. Another study by Phung *et al.* [60], cluster analysis grouped 38 different monitoring points into three groups of water quality representing areas affected by urban-rural activities, agricultural and industrial activities in the study area, and the results proved that it is only necessary to monitor water quality at eight stations.

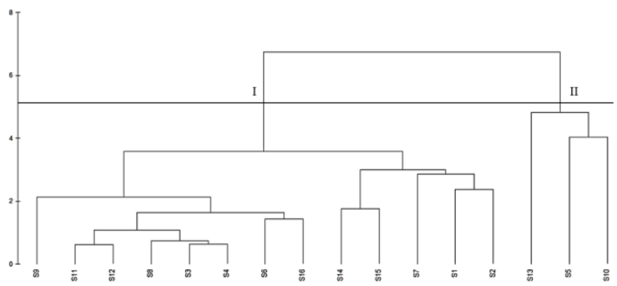

Fig. 3. Two groups of surface water quality in Cu Lao Dung district.

IV. Conclusions

The research results demonstrate that the surface water quality in the rainy season in 2021 in the study area is severely contaminated with microorganisms, salinity, and acidity, along with signs of nutrient pollution. The contents of coliform, Cl^-, Fe, NO_2^--N, TSS exceeded the allowable limits for column B1 of QCVN 08-MT:2015/BTNMT, surface water is not suitable for irrigation purposes for agricultural production in the area. Besides, NH_4^+-N exceeded the detection limit in natural surface waters is alarming about the level of nutrient pollution in the study area. The study results also showed that the indicators exceeding the prescribed threshold including coliform, Cl^-, Fe, TSS, NO_2^--N exceeded 4.17 times, 2.04 times, 1.91 times, 1.28 times and 1.10 times, respectively. Pearson analysis found mainly moderate to strong correlations of surface water environmental parameters. The results also show that, when assessing the quality of surface water contaminated by organic substances, it is only necessary to choose one of the two indicators, BOD or COD because they have a close correlation. Principal component analysis (PCA) formed at least four main sources affecting water quality in the study area, both natural and man-made. In particular, man-made activities include human activities such as waste water from daily life, agricultural production (livestock, aquaculture, farming), industrial activities and navigation. Natural causes of water pollution include rainwater runoff, saline intrusion, and erosion in the study area. Cluster analysis (CA) from 16 monitoring locations formed two groups of surface water quality based on the similarity in physical, chemical and biological characteristics of water. Local authorities need to investigate concrete sources of surface water pollution and appropriate measures to control pollution sources in the area are urgently needed. Especially, wastewater sources containing many microorganisms and saline intrusion need to be better controlled in the study area because currently the concentrations of colifrm and Cl^- pollutants have exceeded many times the standard. However, the present study only evaluated surface water quality in the rainy season, therefore, further research needs to determine the pollution in surface water in the dry season. It will provide a comprehensive picture of how polluted surface water is in the whole year, which may help to suggest reducing pollution and water utility of relevant activities in the case study.

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