Characteristics of Industrial Effluents in a Coastal Province of Vietnamese Mekong Delta

Nguyen Thanh Giao* and Nguyen Hong Thao Ly

***Abstract*—The study aims to assess the quality of industrial effluent in Bac Lieu province using multivariate statistical analysis. The effluent from wastewater treatments plants were collected at 12 locations with nine parameters including pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium ($N\text{-}NH_4^+$), chloride (Cl^-), total nitrogen (TN), total phosphorus (TP) and total coliforms. Effluent quality is compared with national technical regulations on industrial wastewater and seafood processing wastewater column B (QCVN 40:2011/BTNMT and QCVN 11-MT:2015/BTNMT, respectively). Principal component analysis (PCA) was performed to determine the important parameters affecting the quality of industrial wastewater effluent in the study area. The results showed that industrial wastewater effluent was high in organic matters, nutrients, microorganisms which exceeded the allowable limits of QCVN 40:2011/BTNMT and QCVN 11-MT:2015/ BTNMT. Correlation analysis showed that most industrial wastewater effluent parameters were closely correlated proving the treatment systems having problems in its operations. The results of PCA presented that pH, COD, BOD, TSS, TN, TP, $N\text{-}NH_4^+$ and total coliforms mainly affected industrial wastewater effluent. These parameters would negatively change surface water quality at the receiving water bodies. Improvement of wastewater treatment system efficiency is urgently needed to comply with discharge regulations and to protect precious surface water quality. The study' results provide useful information for local environmental managers to enhance management strategies to reach the environment sustainable goals in the locality development.**

***Index Terms*—Wastewater treatment plants, effluents, food processing facility, organic matters**

I. INTRODUCTION

At present, industrialization is considered the foundation of development strategies and contributes significantly to economic growth in the world in general and in Vietnam in particular. However, the speed of industrial expansion along with human activities has made the environment increasingly polluted and degraded water quality. Mao *et al*. [1] showed that about 28% of industrial wastewater is discharged directly into the receiving source without any treatment. As a result, many rivers in countries around the world are facing severe contamination due to the high levels of organic compounds and heavy metals [2, 3]. In Vietnam, as of early 2020, the country has 274 industrial parks in operation, of which 244 industrial parks have centralized wastewater treatment systems [4]. As can be seen that the level of water pollution in industrial parks and industrial clusters is very large if industrial wastewater is not treated appropriately. Many studies show that water quality in large cities such as Hanoi and Ho Chi Minh City is heavily polluted by industrial wastewater with concentrations of pollutants in the water higher than permitted standards [5, 6]. Meanwhile, in the Mekong Delta, only 44% of industrial parks have centralized wastewater treatment plants with a daily wastewater volume of about 47,000 m^3 [7]. Wastewater generated from industries can also cause serious health problems for humans and degrade surrounding ecosystems and water bodies [2]. Therefore, the continuous monitoring and evaluation of industrial wastewater before being discharged into the environment is very important. Common wastewater monitoring parameters include pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), ammonium ($N\text{-}NH_4^+$), coliform. Although the monitoring results may be representative for the characteristics of wastewater pollution, as a basis for developing standards to control pollutant concentrations, but there are certain limitations. On the other hand, multivariate statistical methods are found to be very useful tools for interpreting large and complex wastewater quality data sets as well as identifying potential sources and key parameters affecting wastewater characteristics [8, 9].

Bac Lieu is one of the coastal provinces in the Mekong Delta, located in the east of the Ca Mau peninsula. The province's economic growth rate is relatively high and is in the group of provinces with the highest growth rate in the region [10]. In which, industrial production is always at a good growth rate. In particular, the export seafood processing industry plays a key role with the total output in 2020 reaching 101,740 tons. The formation and development of industrial parks and industrial clusters have increased pressure on water resources in the province [11]. In addition, the treatment efficiency at some companies and industrial production facilities has not yet ensured the quality before being discharged into the environment [10]. This has had a significant impact on the water environment of Bac Lieu province, especially the water bodies near industrial production that are susceptible to physical, chemical and biological changes in the receiving water bodies [2]. Therefore, the objective of this study is to evaluate industrial wastewater after treatment and find out important parameters affecting wastewater in Bac Lieu province in 2020 based on principal component analysis (PCA). The results provide useful scientific information for environmental management agencies to come up with appropriate management measures in the future.

Manuscript received August 7, 2022; revised August 31, 2022; accepted September 6, 2022.

The authors are with College of Environment and Natural Resources, Can Tho University, Can Tho 900000, Vietnam (e-mail: thaoly.n08@gmail.com (N.H.T.L.).

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

doi: 10.18178/ijesd.2023.14.2.1419

II. Materials and Methods

A. Study Area

Bac Lieu province is located on Ca Mau peninsula, in the Mekong Delta region with a natural area of 266,900.08 ha. The topography of the province is relatively flat and tends to slope from the coast to the inland, from the Northeast to the Southwest. The climate of the province lies in the tropical monsoon region, the rainy season from May to November and the dry season from December to April next year. The hydrological and hydrographic regime of the province is directly influenced by the East Sea tide, which is the irregular semi-diurnal tide, part of the tidal regime of the West Sea and the flood of the Mekong River. In recent years, industrial production—handicraft production in Bac Lieu province has had positive changes. Industrial production grew well, industrial production development index gradually increased over the years, production scale was expanded, technological lines have been improved, in addition, productivity and quality and competitiveness have also been improved. Currently, in Bac Lieu province, there are three industrial parks (Tra Kha, Lang Tram and Ninh Quoi industrial Parks) and four industrial clusters (Vinh My, Chu Chi, Vinh Loi and Hong Dan industrial clusters) in operation. In addition, there are many industrial and handicraft production establishments scattered in districts and towns throughout the province. These operate mainly in the field of seafood processing. The main products of the industry in Bac Lieu province such as frozen seafood, salt, beer, and electronics. In fact, waste sources from industrial zones are relatively large, while only a few industrial clusters have a centralized wastewater treatment system. Furthermore, most of the factories in industrial clusters have treated wastewater before discharging it into a nearby body of water, but the treatment efficiency is still not guaranteed. Industrial development activities would generate many types of waste and emissions that pollute the environment such as wastewater, exhaust gas, noise, domestic solid waste, industrial solid waste and hazardous waste [10]. The locations of the wastewater effluent collection are shown in Fig. 1.

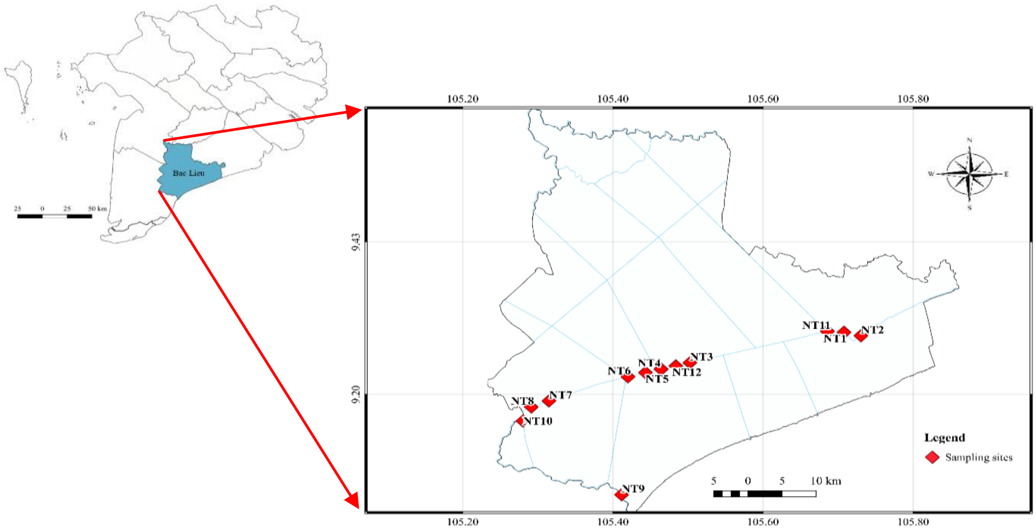

Fig. 1. Demonstration of wastewater effluent collection at the study area.

B. Wastewater Effluent Sampling and Analysis

Industrial wastewater effluent data were collected at twelve locations, including ten samples at seafood processing facilities (from NT1 to NT10) and two samples at industrial production facilities (NT11 and NT12) (Fig. 1). These sampling sites represent industrial activity, because seafood is the main industry in the study area. The effluent quality of industrial wastewater was assessed using nine parameters including pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium ($N\text{-}NH_4^+$), chloride (Cl^-), total nitrogen (TN), total phosphorus (TP) and total coliforms. These are important wastewater monitoring parameters according to Vietnamese standards on industrial wastewater and seafood processing wastewater. Wastewater effluent samples were collected and stored in accordance with current standards (TCVN 5999:1995; TCVN 6663-1:2011; TCVN 6663-3:2008-ISO 5667-3:2003). Parameters, units, analytical methods and allowable limits are presented in Table I.

TABLE I: Analytical Methods of Industrial Wastewater Effluent Parameters

No.	Parameter	Description	Unit	Analytical methods
1	pH	pH	-	TCVN 6492:2011
2	BOD	Biological Oxygen Demand	mg/L	SMEWW 5210B:2017
3	COD	Chemical Oxygen Demand	mg/L	SMEWW 5220C:2017
4	TSS	Total Suspended solids	mg/L	SMEWW 2540D:2017
5	$N\text{-}NH_4^+$	Ammonium	mg/L	SMEWW 4500 Cl-G:2017
6	Cl^-	Chloride	mg/L	SMEWW 4500P-B&E:2017
7	TN	Total Nitrogen	mg/L	TCVN 6638:2000
8	TP	Total Phosphorus	mg/L	Hach Method 8038
9	Total Coliforms	Total Coliforms	MPN/ 100ml	TCVN 6187-2:1996

C. Data Analysis

Industrial wastewater effluent parameters are compared with the National Technical Regulation on industrial wastewater (QCVN 40:2011/BTNMT) [12] and seafood processing wastewater (QCVN 11-MT:2015/BTNMT) column B [13]. The values of the pollution parameters in column B of the regulations are presented in Table II. The relationship and interdependence between the wastewater quality parameters are described through the Pearson correlation analytical method. Two parameters are positively correlated if the output value has a positive sign (+) and negatively correlated if the value has a negative sign (−). The closer the correlation coefficient is to 1, the stronger the relationship between those two parameters [14]. Correlation analysis was performed using the IBM SPSS Statistics 20 statistical software for Windows (IBM Corp., Armonk, NY, USA). Principal Component Analysis (PCA) is used to minimize a large number of variables while retaining as much information as possible [15]. In this study, PCA analysis was used to determine the parameters that have the most influencing on industrial wastewater effluent. PCA analysis was performed using the license software Primer V5.2 for Windows (PRIMER-E Ltd, Plymouth, UK).

TABLE II: LIMIT VALUES OF EFFLUENT QUALITY PARAMETERS OF INDUSTRIAL WASTEWATER AND SEAFOOD PROCESSING WASTEWATER

No.	Parameters	Limits	
		QCVN 40:2011/BTNMT	QCVN 11-MT:2015/BTNMT
1	pH	5.5–9.0	5.5–9.0
2	BOD	50	50
3	COD	150	150
4	TSS	100	100
5	$N\text{-}NH_4^+$	10	20
6	Cl^-	2	2
7	TN	40	60
8	TP	6	20
9	Total Coliforms	5000	5000

III. RESULTS AND DISCUSSION

A. Characteristics of Wastewater Effluent

The analysis results show that the pH value in industrial wastewater after treatment in the study area is slight acidic to alkaline, ranging from 6.80 to 8.63 with an average value of 7.99±0.49 (Fig. 2). This may be due to the presence of carbonates and bicarbonate in industrial wastewater. The lowest pH value was recorded at the NT8 position and the highest at the NT6 position. In general, the pH value in the study area is within the allowable range of QCVN 40:2011/BTNMT and QCVN 11-MT:2015/BTNMT, column B (5.5–9) [12, 13]. The results are also consistent with the study of Cristovao *et al*. [8] showed that the pH of seafood processing wastewater ranges from 5.6 to 9.6 with an average value of about 7.0. It can be seen that the pH in the study area is still within the tolerance limit of aquatic organisms [16].

Fig. 3 shows that the highest BOD concentration at the NT12 site was 80.00 mg/L and the lowest was found at the NT11 (10.50 mg/L). The mean value was 27.04±20.96 mg/L. When compared with the two standards QCVN 40:2011/BTNMT and QCVN 11-MT:2015/BTNMT column B [12, 13], BOD at both positions NT1 and NT12 exceeded the allowable threshold (50 mg/L) from 1.04 to 1.60 times. Wastewater from seafood processing industrial can be very high in BOD. According to Zulkipli *et al*. [17], the high concentrations of BOD reached 18,419 mg/L in seafood processing wastewater. A high BOD value indicates the presence of a large amount of organic matter in the wastewater. A greater concentration of organic components would use up a large amount of dissolved oxygen and increase the concentration of BOD in wastewater [18]. This can cause the surrounding water bodies to be contaminated with organic matters and reduce dissolved oxygen content, affecting the growth and development of aquatic lives. BOD content in industrial wastewater after treatment process in the study area is much lower than that in India (95–142 mg/L) and Hanoi (45–250 mg/L) areas [5, 19].

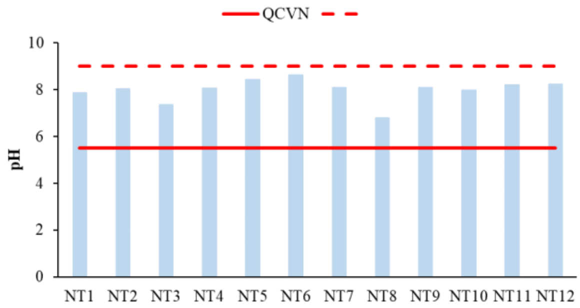

Fig. 2. pH value in industrial wastewater effluent.

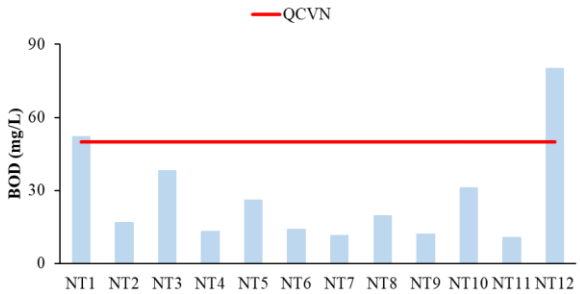

Fig. 3. BOD value in industrial wastewater effluent.

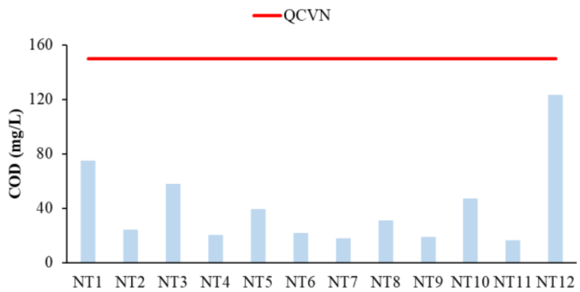

Fig. 4. COD value in industrial wastewater effluent.

COD concentration at the sampling sites varied relatively large, ranging from 16.00 to 122.60 mg/L and reaching an average value of 40.66±31.63 mg/L (Fig. 4). The highest COD concentration was found at the NT12 and the lowest was at the NT11. High concentration of suspended solids and organic substances in the wastewater at the location NT12 could be the aftermath of the industrial packaging production operations. In addition, the BOD concentration at the NT1 exceeded the allowable threshold, but the COD concentration was relatively low compared to that at the NT12. This shows that the wastewater in this area contains several biodegradable organic substances. However, the COD value in the study area is still within the allowable threshold (150 mg/L) of QCVN 40:2011/BTNMT and QCVN

11-MT:2015/BTNMT, column B [12, 13]. Compared with industrial wastewater effluent in Dong Thap province, the COD concentration in the study area is much lower (19–376 mg/L) [20].

The analysis results showed that the TSS concentration at the wastewater treatment plant effluent in the study area ranged from 9.00 to 60.00 mg/L, with the average value being 21.58±14.65 mg/L (Fig. 5). Similar to the results of COD analysis, the highest TSS concentration was found at position NT12 with 60.00 mg/L. This result is well suited with the high BOD found at the same site. High TSS in effluent indicated that the settlement of the sludge in the treatment facility is now facing problem and it is needed to be improved. Meanwhile, positions NT4 and NT11 had the lowest TSS concentration of 9.00 mg/L. The concentrations of TSS at the monitoring positions did not exceed the permissible thresholds of QCVN 40:2011/BTNMT and QCVN 11-MT:2015/BTNMT, column B (100 mg/L) [12, 13]. High concentrations of TSS can reduce the transmission of light through water, thereby, slowing down the photosynthesis of aquatic plants. In addition, high TSS also increases the water surface temperature by absorbing heat from sunlight, thereby reducing the amount of dissolved oxygen in the water [2]. TSS concentration in the study area is also relatively low compared to the TSS concentration in industrial wastewater effluent in Dong Thap province (0–357 mg/L) and Hanoi (81–200 mg/L) [5, 21].

of plant and animal death in the water because of the disinfectant commonly used in wastewater treatment systems. In addition, Cl^- is essential for aquatic organisms to thrive, however high Cl^- concentrations can negatively impact aquatic ecosystems [21]. Besides, this parameter is used to disinfect wastewater before discharging into the receiving environment to minimize the spread of infectious diseases through the aquatic environment [22].

The TP content at the sampling sites ranged from 0.47 to 22.00 mg/L, reaching an average value of 11.00±8.38 mg/L (Fig. 7). The highest TP concentration was found at the NT2 site and the lowest was at the NT12. TP at 8 out of 12 locations exceeded the allowable threshold of QCVN 40:2011/BTNMT [12] (except NT6, NT9, NT11, NT12) (6 mg/L). Meanwhile, TP at the positions NT1 and NT2 exceeded the allowable threshold of QCVN 11-MT:2015/BTNMT (20 mg/L) [13]. This is because the positions NT1 and NT2 are from industrial seafood processing areas. The wastewater from seafood processing area contains high levels of organic matters, nutrients and grease [23]. High levels of TP in wastewater effluent would cause overgrowth of plants and algae in the surrounding water bodies. Then, the decomposition of this large the amount of plants and algae would reduce the dissolved oxygen content in the water body [2]. This shows that wastewater effluent from the seafood processing industry has a great influence on water quality.

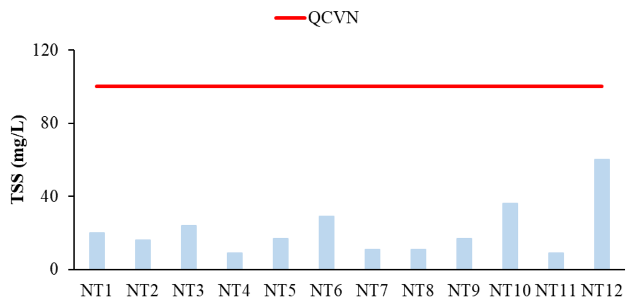

Fig. 5. TSS value in industrial wastewater effluent.

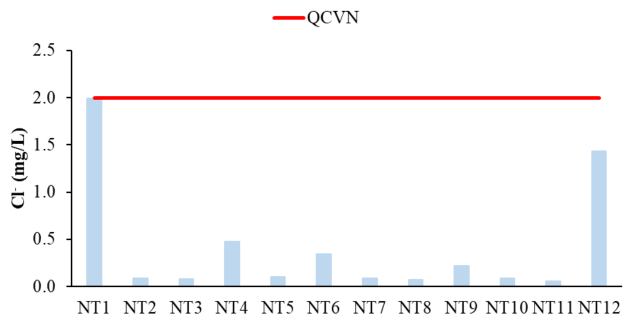

Fig. 6. Chloride in industrial wastewater effluent.

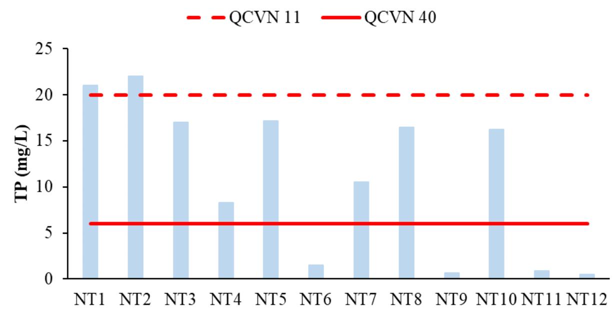

Fig. 7. TP in industrial wastewater effluent.

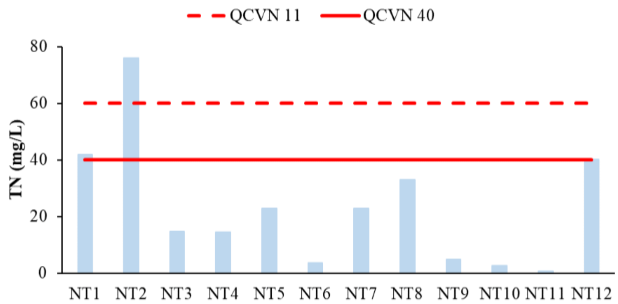

Fig. 8. TN in industrial wastewater effluent.

The Cl^- concentration at the sampling sites in the study area varied considerably between the sampling sites, ranging from 0.05 to 1.99 mg/L (Fig. 6). The mean value is 0.42±0.63 mg/L. The highest Cl^- concentration was found at the position NT1 and the lowest Cl^- was found at the position NT11. The sampling locations all had Cl^- concentrations reaching the allowable limit of QCVN 40:2011/BTNMT and QCVN 11-MT:2015/BTNMT column B (2 mg/L) [12, 13]. The Cl^- parameter is often analyzed to exclude the possibility

The analysis results in Fig. 8 show that the TN concentration at the sampling sites ranges from 0.56 to 76.00 mg/L and had an average value of 23.16±22.00 mg/L. The lowest TN concentration was found at the position NT11 and the highest was found at the position NT2. When compared with QCVN 40:2011/BTNMT [12], TN concentrations at NT1, NT2 and NT12 exceeded the allowable limit (40 mg/L) from 1.01 to 1.90 times, while only TN at the position NT2 exceeded the allowable limit of QCVN

11-MT:2015/BTNMT (60 mg/L) [13]. Compared with the study of Long *et al*. [24], the concentration of TN in industrial wastewater effluent in the study area has a lower value (150–180 mg/L). TN is very important for both plants and animals in the water, but when the nutrient content of the wastewater is too high, it will cause eutrophication in the surrounding water bodies. At the same time, the formation of odorous gases such as NH_3, CH_4 and H_2S affects humans and aquatic species [25].

Similar to TN, N-NH_4^+ is one of the common forms of nitrogen in industrial wastewater, which can cause eutrophication and other environmental problems if not treated thoroughly. The effluent concentration of N-NH_4^+ at the wastewater treatment plant in the study area ranged from 0.04 to 25.20 mg/L and had an average value of 4.23±7.94 mg/L (Fig. 9). The highest concentration of N-NH_4^+ was found at the position NT2 site (25.20 mg/L) and the lowest concentration of N-NH_4^+ was found at NT6 and NT11, both at 0.04 mg/L. The concentrations of N-NH_4^+ at the positions NT2 and NT12 exceeded the permissible limit of QCVN 40:2011/BTNMT (10 mg/L) [13]. In addition, the concentration of N-NH_4^+ at the NT2 exceeded the permissible limit of QCVN 11-MT:2015/BTNMT (20 mg/L) [14]. The concentration of N-NH_4^+ in wastewater is too high, when discharged into the natural environment, it would transform into toxic substances that are dangerous to humans and inhibit the growth of plants and animals in the water [26]. Moreover, the presence of nitrogen, phosphorus and N-NH_4^+ is the causes of water quality impairment, which make the effluents high in BOD, COD values and influence on the oxygen balance [27].

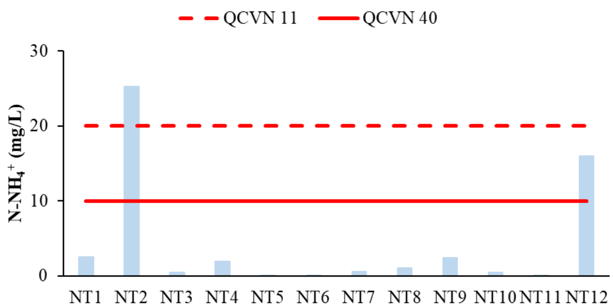

Fig. 9. N-NH_4^+ in industrial wastewater effluent.

Total coliforms concentrations at the sampling sites ranged from 1200 to 5300 MPN/100 mL, with the mean value being at 3991.67±1070.65 MPN/100 mL (Fig. 10). The highest value was found at the positions NT10 and NT12 with 5300 MPN/100 mL. The lowest coliform density was found at position NT11 (1200 MPN/100 mL). The coliform density at the positions NT10 and NT12 exceeded the allowable limit of QCVN 40:2011/BTNMT [12] and QCVN 11-MT:2015/BTNMT (5000 MPN/100 mL) [13]. This study found that coliform density in the effluent wastewater from the seafood processing industry was higher than that in other industries. This could be because food processing wastewater is rich in nutrients that supports rapid bacterial growth [27]. In addition, concentration of Cl^- in effluent at the two positions NT10 and NT12 was found to be relatively low. This shows that there may not be enough Cl^- dose for completely removal of bacteria in the effluents. Compared with the study of Giao [20], industrial wastewater in Dong Thap province had higher coliform density than that in the current study (930–24,000 MPN/100 mL). High levels of coliforms in effluent indicate the presence of human pathogens in wastewater and have the potential to contaminate natural water sources [22]. In general, industrial wastewater effluent in the study area has a content of BOD, TP, TN, N-NH_4^+ and total coliforms exceeding the allowable thresholds of QCVN 40:2011/BTNMT [12] and QCVN 11-MT:2015/BTNMT [13]. This shows that the wastewater treatment system in some industrial production facilities is still inefficiency in its operations. In particular, polluted effluent from seafood production and processing activities, when discharged into the receiving source, would cause several impacts on the aquatic ecosystem and human health.

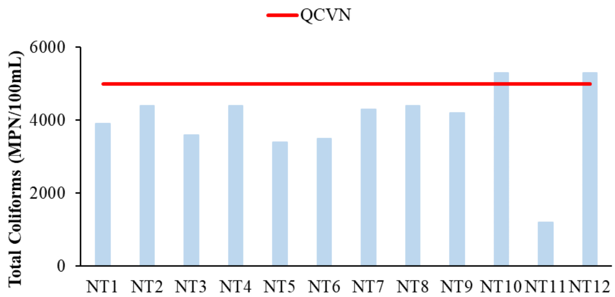

Fig. 10. Coliforms in industrial wastewater effluent.

A. *Correlation of Effluent Quality Parameters*

The results of correlation analysis between nine industrial wastewater parameters at 12 sampling locations in the study area in 2020 are shown in Table III. There is a strong positive relationship between BOD and COD (r = 0.99). In industrial wastewater, both of these parameters serve as standard measurements for organic compounds. However, the COD parameter would be used more often because COD measures everything chemically oxidized and includes oxidation of biological compounds (BOD). The study of Bacalla *et al*. [28] also suggested that the ratio of BOD and COD is significant. In addition, COD and BOD also had a strong positive correlation with TSS (r = 0.83 and r = 0.81) and Cl^- (r = 0.73 and r = 0.75). This shows that a large part of the particulate organic matter in wastewater is biodegradable [8]. In addition, TN has a strong positive correlation with N-NH_4^+ (r = 0.82). Both parameters are the most common nitrogen forms in wastewater, which can cause eutrophication and other environmental problems if not treated thoroughly [29]. Correlation analysis shows that most of the effluent parameters in the study area have a close relationship. Based on the correlation analysis, it is possible to reduce the number of industrial wastewater effluent monitoring parameters in the study area. For example, only BOD or COD is selected for the monitoring since it can be predicted via correlation coefficient.

TABLE III: CORRELATION BETWEEN INDUSTRIAL WASTEWATER EFFLUENT PARAMETERS

Parameters	pH	COD	BOD	TSS	Cl^-	TP	TN	$N\text{-}NH_4^+$	Coliform
pH	1								
COD	−0.06	1							
BOD	−0.05	**0.99**	1						
TSS	0.22	**0.83**	**0.81**	1					
Cl^-	0.10	**0.73**	**0.75**	0.45	1				
TP	−0.46	0.03	0.06	−0.25	0.00	1			
TN	−0.19	0.30	0.32	0.07	0.32	0.55	1		
$N\text{-}NH_4^+$	0.10	0.31	0.31	0.33	0.19	0.15	**0.82**	1	
Coliform	−0.17	0.41	0.41	0.50	0.23	0.23	0.34	0.35	1

B. *Key Parameters Influencing Wastewater Effluent*

The results of the principal component analysis are presented in Fig. 11 and Fig. 12. It can be seen that there are eight factors that could explain 100% of the variations of industrial effluent quality in the study area. Fig. 11 shows that the eigenvalue of each factor is sorted from large to small and there is a clear change of slope from the first eigenvalue to the second. Because PC1 has contributed significantly to the explanation of 43.7% of the variations of industrial effluent. In addition, PC2 and PC3 could explain the changes of industrial effluents by 22.7% and 13.5%, respectively. These PCs all had eigenvalues greater than 1, so they are considered as the main sources affecting industrial effluent in the study area. PC4 – PC8 are considered secondary sources, explaining the remaining 20.0% and had eigenvalues much less than 1. However, PC4 has a strong correlation with total coliforms, so it should be kept to explain the variation in effluent quality in the study area. The PC1 was characterized for organic matters (COD and BOD) and suspended solids (TSS) pollution of treated industrial wastewater with a positive and weak correlation. This result is also consistent with the study of Praus [30] that wastewater is mainly affected by BOD, COD and TSS. PC2 had a weak negative correlation with pH (−0.404) and a weak to moderate positive correlation with TP (0.575) and TN (0.496). In addition, Fig. 12a also shows positive loading factors for pH, COD, BOD, TSS, Cl^- and negative loading factors for TN, TP, $N\text{-}NH_4^+$ and total coliforms. Fig. 12b shows that PC3 had a moderate negative correlation with pH (−0.618) and $N\text{-}NH_4^+$ (−0.600). Research by Cristovao *et al*. [8] and Nadella & Sen [9] also show that pH is one of the important parameters contributing to the variation of wastewater quality. Meanwhile, PC4 was strongly correlated with total coliforms (0.716), which represents microbial contamination in industrial effluent. Both PC3 and PC4 show relatively little contribution of COD, BOD and TP with loading factors less than 0.3. From these results, it can be seen that pH, COD, BOD, TSS, TN, TP, $N\text{-}NH_4^+$ and total coliforms are the most important parameters affecting industrial wastewater effluent. These parameters would significantly influence on surface water quality at the receiving water bodies. In addition, based on the above correlation analysis results, parameters such as BOD and $N\text{-}NH_4^+$ may not need to be included in the monitoring program.

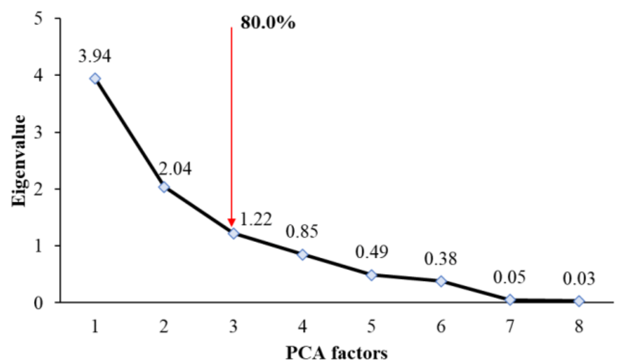

Fig. 11. Scree-plot of PCA.

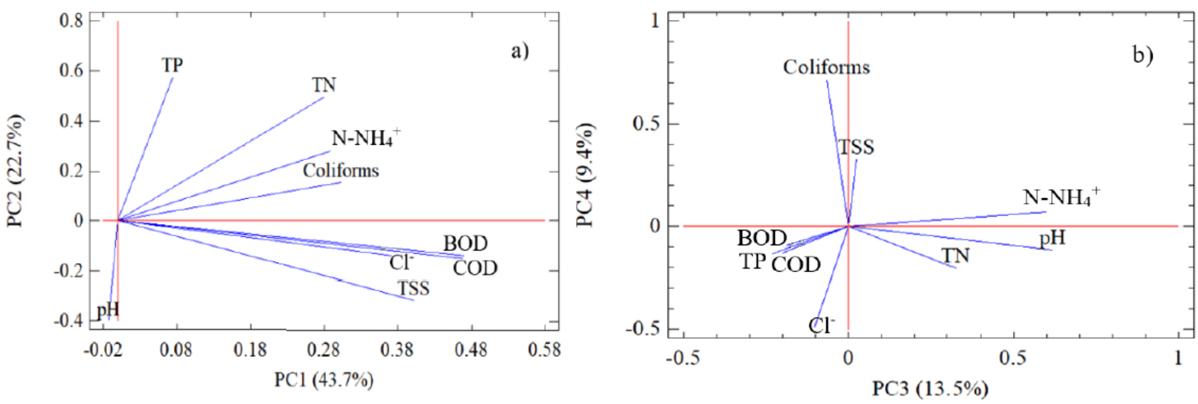

Fig. 12. PCA results (a) PC1 vs PC2; (b) PC3 vs PC4.

IV. Conclusions

The industrial wastewater effluent was high with organic matters, nutrients and microorganisms. The parameters of BOD, Cl^-, TP, TN, N-NH_4^+ and total coliforms exceeded the permissible limits of QCVN 40:2011/BTNMT and QCVN 11-MT:2015/BTNMT. The remaining parameters such as pH, COD, TSS are still within the allowable limits of the regulation. Pearson correlation analysis results show that COD had a good correlation with BOD and both have a good correlation with TSS, Cl^-. Meanwhile, nitrogen compounds are well correlated. The results of PCA analysis presented that three main component that explained 80.0% of the variation of industrial wastewater effluent. The parameters of pH, COD, BOD, TSS, TN, TP, N-NH_4^+ and total coliforms mainly affected industrial wastewater effluent in the study area. The results also showed that wastewater effluent from seafood production and processing activities could greatly affect aquatic ecosystems and degrades surface water quality in receiving waters. Wastewater treatment system is urgently needed to be improved to comply with discharge regulations and to protect precious surface water quality. Further studies should focus on investigating the problems in wastewater treatment processes and improving its operations. The results of the current study could provide scientific information for environmental managers to reinforce management strategies for future the environment sustainable goals.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nguyen Thanh Giao designed the research and methodologies; Nguyen Thanh Giao and Nguyen Hong Thao Ly conducted the research, analyzed the data and drafted the manuscript; Nguyen Thanh Giao revised and finalized the manuscript; all authors had approved the final version.

References

[1] G. Mao, Y. Han, X. Liu, J. Crittenden, N. Huang, and U. M. Ahmad, “Technology status and trends of industrial wastewater treatment: A patent analysis,” *Chemosphere*, vol. 288, no. 2, 132483, 2022.

[2] B. Firdissa, Y. Solomon, and T. Soromessa, “Assessment of the status of industrial waste water effluent for selected industries in Addis Ababa, Ethiopia,” *Journal of Natural Sciences Research*, vol. 6, no. 17, pp. 1–10, 2016.

[3] E. Assegide, T. Alamirew, H. Bayabil, Y. T. Dile, B. Tessema, and G. Zeleke, “Impacts of surface water quality in the Awash River basin, Ethiopia: A systematic review,” *Frontiers in Water*, vol. 3, pp. 15, 2022.

[4] D. H. Ha, L. T. T. Nga, and T. T. Q. Anh, “Evaluation of quality of industrial treated waste water and reuse potential for agriculture in Yen Binh industrial park, Dong Tien ward, Pho Yen town, Thai Nguyen province,” *IJARIIE*, vol. 7, no. 4, pp. 1443–1448, 2021.

[5] N. D. Dap, “Impacts of waste water from main factories on water quality of Tolich river, Hanoi,” *E3S Web of Conferences*, vol. 91, 2019.

[6] N. T. Danh, “A few solutions for improving the water quality of polluted rivers and canals in Vietnam: A case of Ho Chi Minh city,” in *Proc. International Scientific and Practical Conference on Sustainable Development of Regional Infrastructure*, 2021, pp. 10–15.

[7] L. Trinh, “Water pollution in the Mekong Delta: sources, present, future, ecological impacts and mitigation,” *International Water Forum*, Chungnam, Korea, 2017.

[8] R. O. Cristovao, V. M. S. Pinto, A. Goncalves, R. J. E. Martins, J. M. Loureiro, and R. A. R. Boaventura, “Fish canning industry wastewater variability assessment using multivariate statistical methods,” *Process Safety and Environmental Protection*, vol. 102, pp. 263–276, 2016.

[9] A. Nadella, and D. Sen, “Assessment of seasonal and spatial fluctuations in wastewater quality using multivariate statistical methods,” *Environmental Monitoring and Assessment*, vol. 194, no. 254, pp. 1–12, 2022.

[10] Department of Natural Resources and Environment of Bac Lieu province, *Report on Environmental Status of Bac Lieu Province in the Period*, pp. 337, 2020.

[11] H. Phu, “Research on zoning surface water quality according to the development of economic regions of Bac Lieu province,” *Hydrometeorology Magazine*, vol. 725, pp. 17–28, 2021.

[12] Ministry of Natural Resources and Environment, *QCVN 40:2011/BTNMT National Technical Regulation on Industrial Wastewater*, 2011.

[13] Ministry of Natural Resources and Environment, *QCVN 11-MT:2015/BTNMT National Technical Regulation on the Effluent of Aquatic Products Processing Industry*, 2015.

[14] C. Iticescu, L. P. Georgescu, G. Murariu, C. Topa, M. Timofti, V. Pintilie, and M. Arseni, “Lower danube water quality quantified through WQI and multivariate analysis,” *Water*, vol. 11, no. 6, p. 1305, 2019.

[15] T. Singh, A. Ghosh, and N. Khandelwal, “Dimensional reduction and feature selection: principal component analysis for data mining,” *Radiology*, vol. 285, no. 3, pp. 1055–1056, 2017.

[16] V. S. Kale, “Consequence of temperature, pH, turbidity and dissolved oxygen water quality parameters,” *International Advanced Research Journal in Science*, pp. 186–190, 2016.

[17] M. A. Zulkipli, J. A. Bakar, M. Bakar, R. M. S. R. Mohamed, and A. Al-Gheethi, “Optimization of fixed-bed sequencing bio-reactors using Jute Fibre for seafood processing wastewater treatment,” *The International Journal of Integrated Engineering*, vol. 13, no. 1, pp. 321–328, 2021.

[18] M. Z. Asghar, A. Arshad, L. Hong, M. Riaz, and M. Arfan, “Comparative assessment of physico-chemical parameters of waste water effluents from different industries in Lahore, Pakistan,” in *Proc. the International Academy of Ecology and Environmental Sciences*, vol. 8, no. 2, pp. 99–112, 2018.

[19] Z. Aslam, Y. M. Raina, and I. Mohiuddin, “Characterization of wastewater in Rajouri Town, Jammu and Kashmir, India,” *Journal of Engineering Research and Applications*, vol. 5, no. 10, pp. 69–79, 2015.

[20] N. T. Giao, “Characteristics of domestic and industrial wastewater effluent in Dong Thap province, Vietnam,” *Journal of Energy Technology and Environment*, vol. 3, no. 4, pp. 15–23, 2021.

[21] J. N. Okereke, O. I. Ogidi, and K. O. Obasi, “Environmental and health impact of industrial wastewater effluents in Nigeria — A review,” *International Journal of Advanced Research in Biological Sciences*, vol. 3, no. 6, pp. 55–67, 2016.

[22] S. Makuwa, M. Tlou, E. Fosso-Kankeu, and E. Green, “Evaluation of fecal coliform prevalence and physicochemical indicators in the effluent from a wastewater treatment plant in the North-West province, South Africa,” *International Journal of Environmental Research and Public Health*, vol. 17, no. 6381, pp. 1–13, 2020.

[23] P. Dhanke, S. Wagh, A. Patil, “Treatment of fish processing industry wastewater using hydrodynamic cavitational reactor with biodegradability improvement,” *Water Science & Technology*, vol. 80, no. 12, pp. 2310–2319, 2020.

[24] V. D. Long, N. C. Can, T. X. Minh, K. T. Tieng, and M. T. Anh, “Application of ecological technology to treat nutrients from tapioca processing wastewater,” *Journal of Science and Food*, vol. 19, no. 2, pp. 58–66, 2019.

[25] L. D. Hanh, N. X. Hai, T. T. Hong, N. H. Huan, P. H. Son, N. V. Linh, H. N. Hoang, P. A. Hung, and P. P. Hanh, “River water quality assessment related to odor pollution of some inner rivers in Hanoi city,” *Journal of Science*, Hanoi National University, pp. 147–155, 2016

[26] G. Salbitani, and S. Carfagna, “Ammonium utilization in microalgae: A sustainable method for wastewater treatment,” *Sustainability*, vol. 13, no. 2, 956, 2021.

[27] V. Venugopal, and A. Sasidharan, “Seafood industry effluents: environmental hazards, treatment and resource recovery,” *Journal of Environmental Chemical Engineering*, vol. 9, no. 2, 104758, 2020.

[28] L. L. Bacalla, A. J. Bantay, and D. J. Paug, “Correlational analysis of the effluent from the San Carlos Biopower, Inc. wastewater treatment plant,” *Journal of Science, Engineering and Technology*, vol. 9, pp. 12–20, 2021.

[29] W. E. Ndibize, M .N. Hossain, N. Hongyan, M. Salam, M. M. Mian, M. E. Sarker, and M. R. I. Shojib, “Ammonium-nitrogen removal from

aqueous solution using municipal green waste wood biochars," *Advances in Environmental Technology*, vol. 1, pp. 15–29, 2022.
[30] P. Praus, "Evaluation of biological wastewater treatment process using Mahalanobis distances in original and principal component space: a case study," *Applied Water Sciences*, vol. 8, no. 167, pp. 1–9, 2018.

Copyright © 2023 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (CC BY 4.0).