Determining Key Factors Affecting Surface Water Quality in Soc Trang Province, Vietnam

Nguyen Thanh Giao

***Abstract*—This study evaluates the quality and identify key variables influence on surface water quality in Soc Trang province, Vietnam. Water parameters of total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), orthophosphate (PO_4^{3-}-P), total nitrogen (TN) and total phosphorus (TP), turbidity (turb), pH; temperature (T), sulfate (SO_4^{2-}), electrical conductivity (EC), chloride (Cl^-), coliform, and iron (Fe) were used for the assessment. The findings revealed that most of the water parameters of TSS, DO, BOD, COD, TOC, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, Cl^-, Fe, and coliforms exceeded the limits of QCVN 08-MT:2015/BTNMT, column A2, B1. The water quality in Hau River was better than the other locations. Saline intrusion has become the concern for surface quality in the study area. PCA showed that five PCs explained 87.9% of the variation of surface water quality in the study area and the parameters including BOD, $N\text{-}NH_4^+$, TN, TOC, Cl^-, TSS, SO_4^{2-}, Fe and coliforms were the main variables influencing surface water quality in the study area. Potential sources of water pollution are saline intrusion, hydrological regime, runoff, agriculture, industry, and domestic activities.**

***Index Terms*—Organic matters, nutrients, principal component analysis, Soc Trang.**

I. Introduction

Water is one of the essential elements for all life activities on earth, making an extremely important contribution to human life, socio-economic development and ecological balance. Rivers are the main source of drinking water for urban and rural areas. Especially, people in rural areas and people with low income often use river water directly, however, fresh water is currently in a state of serious pollution and shortage. That is why water has become an urgent global problem. Currently, water resources are increasingly scarce, declining in both quantity and quality, accompanied by severe droughts and floods, while the demand for water is increasing. causing a water crisis and becoming an urgent global problem [1]. Vietnam in general and the Mekong River Delta in particular are located in the lower Mekong River with an abundant amount of alluvium every year suitable for agricultural development, with agricultural output accounting for more than 50% of the country. Therefore, this is an industry that has many impacts on surface water quality in the region. Agricultural wastewater is a matter of concern because it is difficult to control and originates from different sources, with no identifiable point of pollution originating from. That is the main cause affecting water resources in localities with a strong agricultural economy such as the Mekong Delta [2]. Wastewater from agricultural activities contains pesticides that are toxic to the environment and human health. In particular, people's lives in Mekong Delta area are still attached to river water sources, used as domestic water or used for aquaculture [3]. In addition, the water quality in the main rivers in the dry season is severely changed and degraded, such as surface water quality deteriorates, local salinization and acidification are increasingly complicated. on surface water quality in the Mekong Delta [4]. Therefore, the exploitation, rational use and protection of surface water resources in the Mekong Delta is becoming an extremely important task in the period of accelerating industrialization and modernization of the country.

Soc Trang is one of the coastal provinces of the Mekong Delta, which has many advantages due to its proximity to the sea. However, saline intrusion has affected the quality of surface water of rivers and canals in the province in recent years (especially in the dry season), causing many obstacles to people's life and production [3]. In addition, the status of pollutant discharge streams from agricultural, industrial, and daily life activities, etc., has affected the quality of surface water in rivers and canals in the province [3]. In order to effectively manage and protect the water environment, the monitoring of water quality assessment criteria is essential. These monitoring indicators will provide important information on water quality through which we can know the current state of water quality in the study area. Currently there are many analytical techniques such as multivariate analysis included cluster analysis, discriminant analysis, principal component analysis, which can help to extract important information thereby reducing the number of sampling points, sampling frequency or unnecessary sampling criteria avoid costly and improve monitoring efficiency [5]-[7]. This study aimed to identify key variables influencing on surface water quality. The results could be used for consideration of the water monitoring parameters.

II. Materials and Methods

A. Water Sampling and Analysis

In this study, water samples were collected at 19 sites in 2020 at the main rivers and canals in Soc Trang province (Table I). Water quality parameters were selected based on natural conditions and the socio-economic activities in the study area. The water variables included total suspended solids (TSS, mg/L), dissolved oxygen (DO, mg/L), biological oxygen demand (BOD, mg/L), chemical oxygen demand (COD, mg/L), total organic carbon (TOC, mg/L), nitrite ($N\text{-}NO_2^-$, mg/L), nitrate ($N\text{-}NO_3^-$, mg/L), ammonium

Manuscript received August 22, 2021, revised April 30, 2022.

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

doi: 10.18178/ijesd.2022.13.5.1385

($N\text{-}NH_4^+$, mg/L), orthophosphate ($P\text{-}PO_4^{3-}$, mg/L), total nitrogen (TN, mg/L) and total phosphorus (TP, mg/L), turbidity (NTU), pH; temperature (T, ^oC), sulfate (SO_4^{2-}, mg/L), electrical conductivity (EC, mS/cm), chloride (Cl^-, mg/L), coliform (MPN/100mL), and iron (Fe, mg/L). The water quality parameters including temperature, pH, turbidity, EC and DO were directly measured at the field while the remaining parameters were measured using the standard methods [8].

TABLE I: SURFACE WATER SAMPLING SITES IN THE STUDY AREA

Code	River	Longitude	Latitude
S1	Xang canal	105°57′51.67	9°36′51.29
S2	30/4 canal	105°58′36.63	9°36′21.90
S3	Maspero river	105°59′37.78	9°36′31.05
S4	Hau river	106°02′20.91	9°46′43.87
S5	Thanh Loi canal	105°59′57.78	9°33′20.29
S6	Co Co canal	105°56′25.15	9°25′37.56
S7	Vinh Chau canal	105°58′49.05	9°19′35.11
S8	Saintard river	106°02′13.52	9°37′25.72
S9	So 1 canal	105°59′10.60	9°46′08.93
S10	Ben Ba river	106°09′27.30	9°40′15.70
S11	Nhu Gia river	105°51′10.52	9°30′09.25
S12	Phu Loc canal	105°44′44.56	9°25′43.60
S13	Nga Nam canal	105°35′53.05	9°33′54.19
S14	Hau river	105°53′27.75	9°55′48.00
S15	Huynh Huu Nghia canal	105°48′39.19	9°38′10.13
S16	Lich Hoi Thuong canal	106°08′48.47	9°28′38.64
S17	Chau Thanh canal	105°37′21.35	9°37′59.23
S18	Long Phu canal	106°07′12.04	9°37′16.26
S19	Dinh river	106°01′21.47	9°36′13.28

B. Data Analysis

The water quality index was calculated to evaluate overall water quality in the water bodies by the following equation [9]:

$$WQI_{VN} = \frac{WQI_I}{100} \times \left(\frac{1}{k}\sum_{i=1}^{k} WQI_{II} \times WQI_{III}\right)^{\frac{1}{2}}$$

where WQI_I: calculation for pH; $WQII_{II}$: calculation for DO, BOD, COD, TOC, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$; WQI_{III}: calculation for coliforms.

Besides, the organic water pollution index (OWPI) was calculated through eight parameters based on the calculation of Bouderbala (2021) [10]. The arithmetic mean of eight parameters gives the level of organic water pollution, including pH, DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$. The weights of the parameters are detailed in the study by Bouderbala (2021) [10].

$$OWPI = \frac{1}{n}\sum_{i=1}^{n} \text{Weight of parameters } (pH + BOD + COD + NH_4^+ + NO_2^- + NO_3^- + PO_4^{3-})$$

The numerical values of OWPI are interpreted as from 1.0-1.9 represent very high, 2.0-2.9 (High), 3.0-3.9 (Moderate), 4.0-4.5 (Low) and 4.6-5.0 (Null).

TABLE II: CLASSIFICATION OF WATER QUALITY USING WQI_{VN}

Values	Water quality	Purposes of using water
91-100	Excellent	Domestic water supply
76-90	Good	Use for domestic water supply purposes but need appropriate treatment measures
51-75	Medium	Used for irrigation and other similar purposes
26-50	Fair	Used for navigation and other similar purposes
10-25	Poor	Heavy pollution, needing solutions in the future
<10	Very poor	Water was poisoned and needs remedy and treatment measures

Principal Component Analysis (PCA) was computed using the copyrighted software Primer 5.2 for Windows (PRIMER-E Ltd, Plymouth, UK). PCA is to reduce the initial variables that do not contribute significantly to intial dataset. Weighing factors are used to evaluate the correlation between PCs and original variables. The absolute values of weighing factors (WF) strongly correlated if WF > 0.75, moderately correled if 0.75 > WF > 0.5 and weakly correlated if 0.5 > WF > 0.3 [11]. The PCs with eigengene values of greater than 1 could be considered as signficant sources of water quality variation thus using for prediction of the water pollution sources.

III. RESULTS AND DISCUSSION

A. Surface Water Quality Variation

Oxygen compounds. DO in the water bodies in Soc Trang province ranged from 2.34 to 4.44 mg/L (Fig. 1). The two monitoring sites that usually have relatively high DO concentrations and meet the permissible standards at column B1 (DO>4 mg/L) [12] was Hau river. Some remaining locations such as Co Co canal, So 1 canal in Ke Sach town, Ben Ba river in Cu Lao Dung town also had high DO at the monitoring periods, approaching the limit value in column B1. DO at locations such as 30/4 canal, Maspero river, Vinh Chau canal, Huynh Huu Nghia canal, Chau Thanh canal usually have relatively low DO compared to other monitoring locations. The average DO concentration in the upstream water bodies of An Giang ranged from 4.0-5.2 mg/L [13], in the Hau River in 2016 it is 4.8±1.1-5.5±0.7 mg/L [14]. In canals of Soc Trang province, DO is lower than other studies, ranging from 1.7-6.17 mg/L [15], [16]. The BOD concentration varied from 3.58 to 8.80 mg/L (Fig. 1) in the monitoring periods in 2020, which was relatively low and did not exceed the allowable standard in column B1 (15 mg/L) [12]. Compared with others studies, BOD in water bodies in Soc Trang was higher than that of Hau river and An Giang provinces [13]; however, there was tended to decrease compared to 2019 in this study [15]. The origin of BOD can be due to waste from farming, livestock, landfill, domestic activities, and services that have discharged untreated waste into the surface water environment [17]-[19].

The average COD concentration at the monitoring sites ranged from 17.9 to 46.1 mg/L. The value of lowest recorded in Hau river and the highest value in Vinh Chau canal. Some monitoring sites have relatively high concentrations and exceed the allowable limits of surface water quality standards at column B1 (30 mg/L) [12] in monitoring periods, including Xang canal, 30/4 canal, Thanh Loi canal, Vinh Chau canal. According to a previous study by [20], [21], the average COD in Soc Trang province was significantly higher than in Can Tho city and Hau Giang province. The average TOC in 2020 at monitoring locations ranged from 3.31 to 12.8 mg/L (Fig. 1). Compared with column A1 of surface

water quality standard (4 mg/L) [12], TOC has only met the allowable standards in Hau river; while the remaining positions have recorded exceeding the allowed standards. TOC concentration the highest value in the Vinh Chau canal; this can be explained by aquaculture activities that have affected TOC content in water bodies.

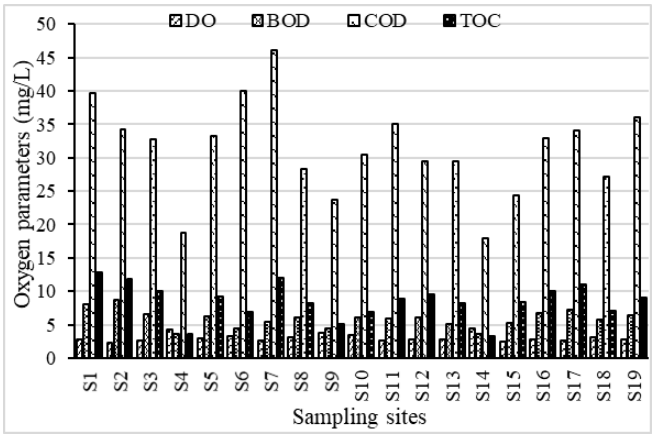

Fig. 1. Oxygen compounds in surface water.

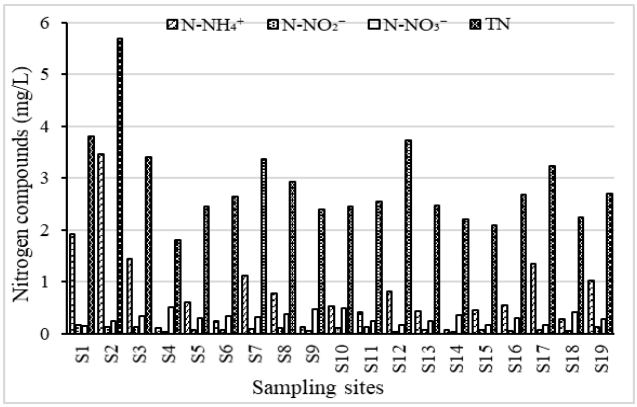

Fig. 2. Nitrogen compounds in surface water.

Nitrogen compounds. Ammonium ranged from 0.07 to 3.46 mg/L (Fig. 2) and exceeded the allowed standards at locations such as Xang canal, 30/4 canal, Maspero river, Vinh Chau canal, Chau Thanh canal, and Dinh river, in which the highest concentration was recorded at 30/4 canal during the 10th monitoring period. The remaining locations have relatively low ammonium levels during monitoring periods and do not exceed the allowed standards in column B1 (0.9 mg/L) [12]. Hau river and So 1 canal of Ke Sach town, the ammonium concentration met the allowable standard in column A2 (0.3 mg/L) [12]. The previous study showed that ammonium concentrations in Cai San River ranged from 0.29-0.90 mg/L [22] and 0.07-0.81 mg/L in Xa No canal [23]; it was shown that the $N\text{-}NH_4^+$ content was lower than in the present study. Nevertheless, according to Tuan et al (2019) [15], the 30/4 channel in Soc Trang province 2012-2018 ranged from 0.35-4.14 mg/L; This has shown that the ammonium content in the study area has tended to decrease. The concentration of $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ at the monitoring sites ranged from 0.020 to 0.163 mg/L and 0.153 to 0.158 mg/L, respectively. Compared with column B of Vietnam standard on surface water quality [12], both nitrite and nitrate concentrations were within the allowable limits. Total nitrogen at the study sites ranged from 1.81 to 5.68 mg/L (Fig. 2); it can be seen that most forms of nitrogen exist in organic form. Zeinalzadeh and Rezaei (2017) [24] found that total nitrogen ranged from 1.3±1.8 - 3.0±1.3 mg/L in the river. According to Boyd and Green (2002) [25] to minimize the possibility of eutrophication of water sources, total nitrogen should not exceed 3 mg/L. When TN is higher than 1.7 mg/L, the possibility of eutrophication of water is very high [16].

Phosphorus compounds. The average orthophosphate content in 2020 varied from 0.033 (Ben Ba river) to 0.813 mg/L (30/4 canal) (Fig. 3). The result of the monitoring shows that the orthophosphate was high and exceeded the allowed standards (0.3 mg/L) [12] at locations such as Xang canal, 30/4 canal. In addition, locations such as the Maspero river, Thanh Loi canal, Chau Thanh canal also had orthophosphate concentrations exceeding the standard in some monitoring periods. The remaining monitoring sites have relatively low orthophosphate and did not exceed the allowable standards in column A1 (0.2 mg/L) [12]. Dissolved phosphorus values in the infield canals and Hau river of An Giang province ranged from 0.02 to 0.47 mg/L [13], 0.04-0.11 mg/L in the Hau river (An Giang-Hau Giang section) [20], 0.05-0.9 mg/L in canals of Soc Trang province [15] showed that PO_4^{3-}-P in surface water environment in the Mekong Delta exceeded the limit value of the regulation (0.1 mg/L) [12]. Total phosphorus ranged from 0.26 to 1.29 mg/L (Fig. 3), which is very high compared to orthophosphate. According to Boyd and Green (2002) [25], the content of TP greater than 0.1 mg/L, eutrophication is likely to occur. The average TP at the survey sites was higher than 0.1 mg/L, which revealed that the water quality at these locations is likely to be eutrophic. From the data of nutrients, it is shown that the surface water environment in Soc Trang has a high risk of causing eutrophication when the environmental conditions are suitable. The origin of phosphorus can be due to fertilizers, detergents due to farming, livestock and industrial activities [26].

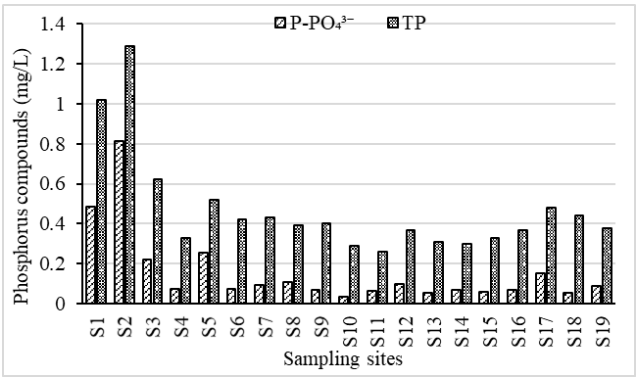

Fig. 3. Phosphorus compounds in surface water.

Suspended matters. The average TSS concentration at the monitoring sites ranged from 39.9 to 193.5 mg/L (Fig. 4), the lowest and highest concentration were found at 30/4 canal and Co Co canal, in turn. More than 80% of the monitoring sites have the average TSS content in 2020 exceeding the allowed standard in column B1 [12]. In which the highest level is at Co Co canal, which has exceeded about 3.9 times. In main rivers and tributaries of Hau river TSS ranged from 41.2±33.7 to 89.57±31.31 mg/L [14], in canals of An Giang province TSS ranging from 25.0 ± 11.5 mg/L to 93.7 ± 28.3 mg/L [13]. Besides that, TSS ranged from 16-176 mg/L in canals of Soc Trang province in 2012-2018 [15] and 32.8±6.4

to 101.8±40.9 mg/L (Hau Giang province) [21]. This result illustrated that all the river water has been contaminated with TSS and tended to be increase in the study area in 2020. Turbidity has a positive correlation with suspended solids (Fig. 4). Turbidity in the water bodies of Soc Trang province is also very high, ranging from 48.3 to 105.7 NTU.

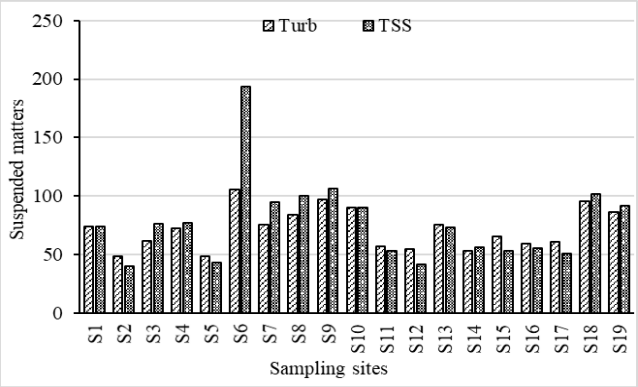

Fig. 4. Suspended matters in the surface water.

Ionic compounds. The average chloride ranged from 78.4 to 5,402 mg/L (Fig. 5), the lowest value in Hau river and the highest value in Co Co canal. Due to the influence of saline intrusion, chloride in the first 6 months of the year exceeded the permitted standards in column B1 (350 mg/L) [12] at many monitoring locations (except for Phu Loc canal, Nga Nam canal, Huynh Huu Nghia canal and Hau river). In the remaining monitoring periods, chloride concentration has tended to decrease with relatively low values and did not exceed the allowed standards [12]. Sulfate concentrations in surface water ranged from 36.3 to 641.7 mg/L while electrical conductivity is in the range of 43.8-1737.2 mS/cm (Fig. 5).

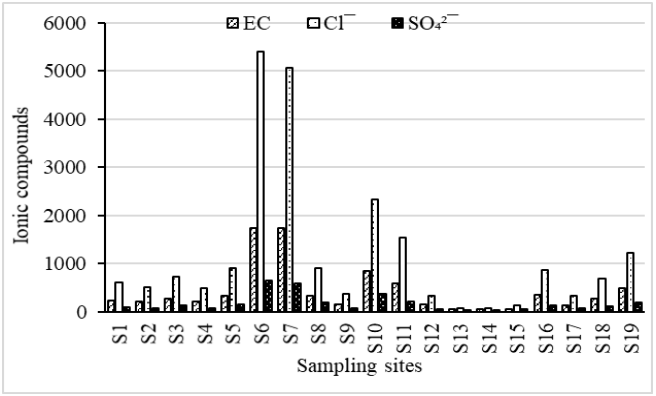

Fig. 5. Ionic compounds in the surface water.

Other water quality parameters. The average pH value at surface water monitoring sites ranged from 6.89 to 7.19 (Fig. 6). There was insignificant difference in pH value between the monitoring locations. The values of pH fluctuated within the allowable range of the standard (5.5-9) [12]. The average total Fe concentration at monitoring locations ranged from 0.73 to 2.02 mg/L, the highest and lowest value were in Co Co canal and Hau river, respectively. Total Fe concentration in some locations have relatively high and exceeded the permission standards such as Maspero River, Co Co canal, Saintard river, Canal So 1 in Ke Sach town, Nhu Gia river and Dinh river. In Soc Trang, the content of Fe in surface water varied 0.30-3.75 mg/L in 2012-2018 [15]; there has been a downward trend in 2020. The presence of iron degrades water quality, incurs treatment costs and poses health risks to humans and the environment [21]. The total oil and grease in surface water at monitoring locations is quite low, most of which have values that do not exceed the allowed standards, the highest concentration was recorded in Hau river with a value of 0.98 mg/L. Two observations in the first 6 months of 2020 recorded total oil and grease concentration at monitoring locations almost below the detection threshold of the analytical method.

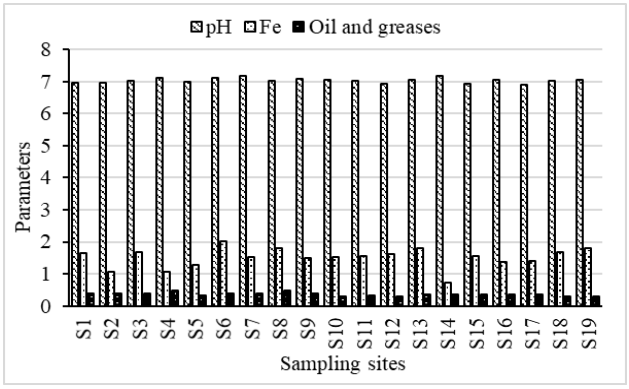

Fig. 6. pH, Fe and oil & grease in surface water.

The water temperature was stable with a value from 29 to 29.9°C. The density of microorganisms was ranged from 1500-79,000 MPN/100mL (Fig. 7); the results showed that the water environment was contaminated with microorganisms. More than 50% of monitoring sites have microbiological density exceeding the allowed standards [12]. Some locations have relatively low concentrations of coliforms and meet permissible standards, including Co Co canal, Hau river, So 1 canal in Ke Sach town, and Nga Nam canal. The previous study by Ly and Giao (2018) [13] showed that coliform in surface water of An Giang province in the period 2009-2016 exceeded the allowable limit 2.14-7.02 times. In canals of Soc Trang province, coliform also exceeded from 1 to 36 times in 2012-2018 [15]. The density of coliforms in Hau Giang province varied widely from 1156.3±500 to 15,275±15244.8 MPN/100mL [21]. The coliform data revealed that the river water was serious contamination with fecal microorganisms. The sources of coliform contamination are from human and animal wastes, especially the fecal materials [27], [28].

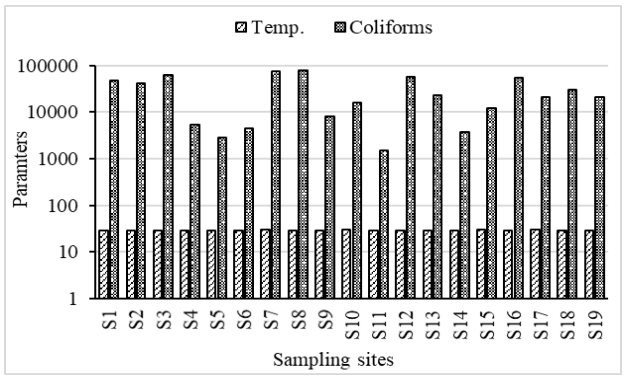

Fig. 7. Temperature and coliform in surface water.

B. Surface Water Quality Variation Using WQI

The values of WQI were presented in Fig. 8. Two positions

(S4, S14) were classified as good water quality (WQI = 83-87). Five out of 19 positions (WQI = 51-74) had moderate water quality, and 12 out of 19 positions (WQI = 28-48) were found to be fair water quality. The spatial distribution of water quality in Figure 8 can be seen that the lowest water quality was concentrated in residential areas and near aquaculture areas. This was also recorded in the previous study of Giao *et al*. [29].

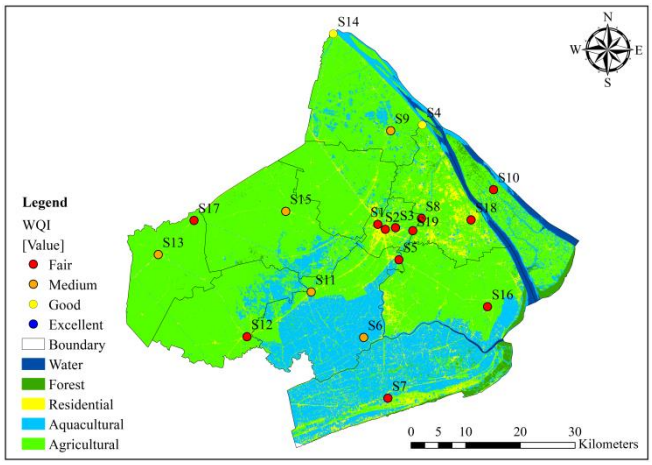

Fig. 8. Overall water quality (WQI).

Organic matters, nutrients, and microorganisms could be the most influencing on water quality index calculation for the rivers/canals in Soc Trang province. Specifically, the organic water pollution index was recorded at a high level at positions S1 and S2; meanwhile, S14 was determined to be low. In summary, the water quality in the study area is assessed as unsuitable for water supply. More attention should be paid on controlling quality of surface water in the study area.

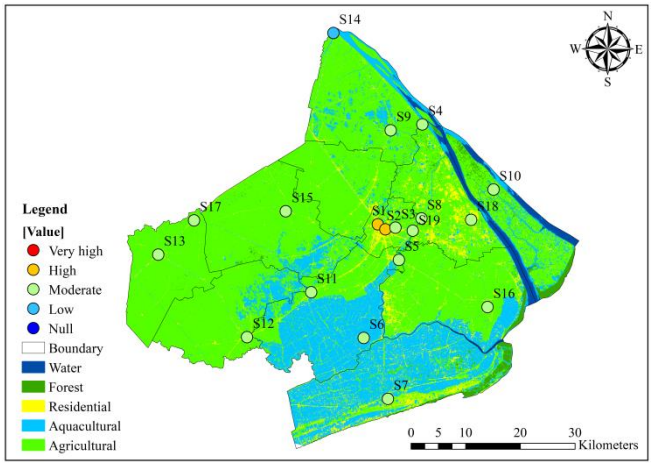

Fig. 9. Spatial distribution of organic water pollution index.

C. Key Variables Influencing Surface Water Quality

The results of principal analysis showed that five PCs explained 87.9% of the variation of surface water quality in the study area. PC1, PC2, PC3, PC4, PC5 explained 38.4%, 24.9%, 11.8%, 7.4% and 5.3%, respectively. PC1 was a weakly correlated with BOD (-0.337), N-NH_4^+ (-0.331), TN (-0.315) and TOC (-0.319). PC1 could be from the mixed sources of water pollution. PC2 also had weakly positive correlation with EC (0.415), COD (0.346), Cl^-(0.414), sulfate (0.417) representing the sources from saline intrusion. PC3 was negatively correlated with temperature (-0.386) while positively correlated with N-NO_3^- (0.334) and oil and grease (0.475). This PC3 could represent the sources of water pollution from human activities that release the oil and grease. PC4 was positively correlated with temperature (0.357) and negatively correlated with turbidity (-0.389) and iron (-0.534). The PC4 was from natural condition, for example river bank erosion, runoff, and acid sulfate soil. PC5 was weakly and negatively correlated with turbidity while moderately positively correlated with coliforms. The PC5 could be the sources of water pollution from human and animal excretes resulting in abundance of coliforms in the water environment. It is predicted that the water quality parameters including BOD, N-NH_4^+, TN, TOC, Cl^-, TSS, SO_4^{2-}, Fe and coliforms are the main variables determining surface water quality in the study area. These parameters should be included in the monitoring task.

TABLE III: KEY WATER QUALITY PARAMETERS IDENTIFIED USING PCA

Variables	PC1	PC2	PC3	PC4	PC5
Temp	0.098	0.060	-0.386	0.357	-0.180
pH	0.233	0.129	0.266	0.235	0.222
DO	0.283	-0.111	0.295	0.101	-0.130
EC	0.060	0.415	0.025	0.257	0.035
Turb	0.176	0.257	0.069	-0.389	-0.303
BOD	-0.337	0.022	-0.039	-0.071	-0.093
COD	-0.192	0.346	-0.104	0.110	0.050
TSS	0.165	0.330	0.156	-0.232	-0.211
N-NH_4^+	-0.331	0.023	0.183	0.098	-0.114
Cl^-	0.063	0.414	0.028	0.254	0.024
N-NO_2^-	-0.241	0.169	0.042	-0.143	-0.235
N-NO_3^-	0.249	0.040	0.334	-0.036	-0.063
P-PO_4^{3-}	-0.296	-0.043	0.290	0.124	-0.261
Fe	-0.013	0.289	-0.233	-0.534	-0.022
TN	-0.315	0.050	0.184	0.115	-0.001
TP	-0.293	0.000	0.299	0.049	-0.269
SO_4^{2-}	0.071	0.417	0.017	0.216	0.004
Coliforms	-0.176	0.123	0.100	-0.177	0.658
TOC	-0.319	0.139	-0.152	0.014	0.173
Oil and grease	0.004	0.032	0.457	-0.167	0.277
Eig. val.	7.69	4.99	2.36	1.48	1.06
%var.	38.4	24.9	11.8	7.4	5.3
Cum.%var.	38.4	63.4	75.2	82.5	87.9

IV. CONCLUSIONS

The results of the study showed that water quality was concerned by suspended solids, organic matters, nutrients, and microorganisms and salinity intrusion. Most of the water parameters including TSS, DO, BOD, COD, TOC, N-NH_4^+, N-NO_2^-, Cl^-, Fe, and coliforms were exceeded the permissible values. However, the findings also showed that the water quality at two locations in Hau River was better than the other locations. Hau river's water can be considered for exploiting surface water for water supply of Soc Trang city, but it is necessary to apply appropriate treatment technology. Besides, saline intrusion has affected the quality of surface water of rivers and canals in the province, especially in the dry season, causing obstacles to life and production. The results of PCA showed that five PCs explained 87.9% of the variation of surface water quality in the study area. It is predicted that the water quality parameters including BOD, N-NH_4^+, TN, TOC, Cl^-, TSS, SO_4^{2-}, Fe and coliforms were the main variables determining surface water quality in the study area. These parameters should be included in the future monitoring task. Sources of pollution can include natural (salt intrusion, hydrological regime, runoff) and human activities

(agriculture, industry, and domestic activities). It can be seen that the water quality is not guaranteed for the purposes of domestic water supply, aquatic conservation and often only meets the purposes of irrigation.

ACKNOWLEDGMENT

The author would like to express our sincere gratitude toward the Department of Natural Resources and Environment Soc Trang province for data provision. The scientific and personal views presented in this paper do not necessarily reflect the views of the data provider.

CONFLICT OF INTEREST

The author declares no conflict of interest.

REFERENCES

[1] D. T. Loi and D. Q. Khai, "Management of water resources and tasks for work tasks for scientific research, training in economics and management," *Journal of Irrigation Science and Technology*, 2012, vol. 8, pp. 1-10.
[2] N. T. M. Linh, N. V. Be, V. P. D. Tri, M. T. Ha, and P. L. M. Duyen, "Agro-ecological zoning based on surface water resources dynamics in the Soc Trang province," *Can Tho University Journal of Science*, 2014, vol. 30, pp. 84–93.
[3] Department of Natural Resources and Environment in Soc Trang (DoNRE), "Report on environmental status of Soc Trang province in 2017," Department of Natural Resources and Environment in Soc Trang, 2017, pp. 1-181.
[4] N. H. Trung and V. P. D. Tri, "Chapter 10: Possible impacts of seawater intrusion and strategies for water management in coastal areas in the Vietnamese Mekong Delta in the context of climate change," *Coastal Disasters and Climate Change in Vietnam*, Elsevier Inc., New York, 2012, pp. 219-232.
[5] I. C. Feher, M. Zaharie, and I. Oprean, "Spatial and seasonal variation of organic pollutants in surface water using multivariate statistical techniques," *Water Science & Technology*, 2016, vol. 74, pp. 1726-1735.
[6] M. Varol, "Spatio-temporal changes in surface water quality and sediment phosphorus concentration of a large reservoir in Turkey," *Environmental Pollution*, 2020, p. 259.
[7] N. T. Giao, "Evaluating current water quality monitoring system on Hau River, Mekong Delta, Vietnam using multivariate statistical techniques," *Applied Environmental Research*, 2020, vol. 42, no. 1, pp. 14-25.
[8] American Public Health Association (APHA), "Standard methods for the examination of water and wastewater, 20th edition," American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA, 1998.
[9] Vietnam Environment Administration (VEA), "Decision 1460/QD-TCMT dated November 12, 2019 on the issuing of technical guide to calculation and disclosure Vietnam water quality index (VN_WQI)," Hanoi, Vietnam, VEA, 2019.
[10] A. Bouderbala, "Index methods for the assessment of surface water quality: the case study of Oued Fodda dam, in the Northwest of Algeria," *Environ Dev Sustain*, 2021, vol. 23, pp. 13340–13363.
[11] C. W. Liu, K. H. Lin, and Y. M. Kuo, "Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan," *Science of the Total Environment*, 2003, pp. 77–89.
[12] Ministry of Environment and Natural Resources (MoNRE), "National technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT)," Ministry of Natural Resources and Environment (MONRE), Hanoi, Vietnam, 2015.
[13] N. H. T. Ly and N. T. Giao, "Surface water quality in canals in An Giang province, Viet Nam, from 2009 to 2016," *Journal of Vietnamese Environment*, 2018, vol. 10, no. 2, pp. 113-119.
[14] N. T. K. Lien, L. Q. Huy, D. T. H. Oanh, T. Q. Phu, and V. N. Ut, "Water quality in mainstream and tributaries of Hau River," *Can Tho University Journal of Science*, 2016, vol. 43, pp. 68-79. (In Vietnamese).
[15] D. D. A. Tuan, B. A. Thu, and N. H. Trung, "Assessing quality of surface water for urban water supply source for Soc Trang City," *Tạp chí Khoa học Đại học Cần Thơ*, 2019, pp. 61-70. (In Vietnamese).
[16] E. D. Ongley, "Chapter 12: Water quality of the lower Mekong River," in Campbell, I.C. (ed.): *The Mekong: Biophysical Environment of An International*.
[17] Mekong River Commission (MRC), "Lower Mekong regional water quality monitoring report," MRC Technical Paper No.51.
[18] R. Chea, G. Grenouillet, and S. Lek, "Evidence of water quality degradation in lower Mekong Basin revealed by self-organizing map," *PLOS ONE/DOL*, 10.1371/journal.pone.0145527.
[19] H. T. H. Nhien and N. T. Giao, "Environmental soil, water, and sediment quality of Dong Thang landfill in Can Tho city, Vietnam," *Applied Environmental Research*, 2019, vol. 41, no. 2, pp. 73-83.
[20] N. T. B. Thao, "Evaluation of changes in surface water quality in some main rivers and canals in Can Tho city," Can Tho University, Graduate thesis.
[21] N. T. Giao, "Spatial variations of surface water quality in Hau Giang Province, Vietnam using multivariate statistical techniques," *Environment and Natural Resources*, 2020, vol. 18, no. 4, pp. 400-410.
[22] T. T. Toan and N. T. N. Tran, "Survey on changes in phytoplankton species composition according to surface water quality in Cai San river," Can Tho University, 2019, Graduation thesis.
[23] D. T. Lam, "Assessment of surface water quality on Xang Xa No Canal in Hau Giang province," Can Tho University, 2016, Master's thesis in Natural Resources Management and Environment.
[24] K. Zeinalzadeh and E. Rezaei, "Determining spatial and temporal changes of surface water quality using principal component analysis," *Journal of Hydrology: Regional Studies*, 2017, vol. 13, pp. 1-10.
[25] C. E. Boyd and B. W. Green, "Water quality monitoring in shrimp farming areas: An example from honduras, shrimp farming and the environment," The World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment, Auburn: USA.
[26] A. Barakat, M. E. Baghdadi, J. Rais, B. Aghezzaf, M. Slassi, "Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques," *International Soil and Water Conservation Research*, 2016, vol. 4, no. 4, pp. 284-292.
[27] P. V. Bolstad and W. T. Swank, "Cumulative impacts of landuse on water quality in a southern Appalachian watershed," *J. Am. Water Resour. Assoc.*, 1998, vol. 33, no. 3, pp. 519–533.
[28] United Nations Children's Fund (UNICEF), *Handbook on Water Quality*, New York, UNICEF, 2008.
[29] N. T. Giao, N. V. Cong, and H. T. H. Nhien, "Using remote sensing and multivariate statistics in analyzing the relationship between land use pattern and water quality in Tien Giang province, Vietnam," *Water*, 2021, vol. 13, no. 8, 1093.

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