Assessment of surface water quality and some main rivers' capacity of receiving wastewater in Ca Mau province, Vietnam

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ABSTRACT

Surface water from rivers plays a significant role in socio-economic development in Ca Mau province. It supplies freshwater for agriculture and aquaculture. Faced with the pressures of development, surface water quality in Ca Mau province has been being at stake. The aim of this paper was to assess the water quality status and wastewater receiving capacity of the main rivers of Ca Mau province. The obtained results and calculated water quality index (WQI) indicated that almost surface water in Ca Mau province was heavily polluted and did not meet the irrigation purpose. Most rivers and canals in Ca Mau city were not able to receive any more contaminant loads of COD, BOD_5, N-NH_4^+, and P-PO_4^{3-}. To protect the water resource for sustainable development, consequently, it is important to propose water management solutions for the local government to regulate wastewater discharge into surface water bodies in Ca Mau province.

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1. Introduction

Ca Mau, located in the Mekong Delta region of Vietnam, is a coastal province in the southernmost part. This province has a total area of 5,221.2 km^2, a population of 1,229.6 thousand people, and a population density of 236 people/km^2 (GSO, 2018). Ca Mau province is a flat, low-lying area frequently flooded because of its low altitude of –1 to 3 m above sea level and the strong tidal variability of the East Sea and the Gulf of Thailand (Hong & San, 1993). This province is covered by a vast river and canal network, largely contributing to socio-economic development.

In recent years, the process of development and economic restructuring has brought great achievements in the local economy and residents' life quality (GSO, 2018). However, the province's socio-economic development process is continuing at a relatively high pace, which inevitably creates increasing pressures on natural resources and the environment (GSO, 2018). Poor industrial, agricultural and domestic wastewater treatment adds tremendous amounts of nutrients and organic carbon to receiving streams and estuaries, resulting in short-term oxygen loss, fish-killing, and algal bloom proliferation, and long-term creation of dead zones in streams (Reddy & DeLaune, 2008).

Rivers are significant water supply sources for agriculture and aquaculture in Ca Mau province, and particular attention should be paid to water quality and its changing patterns in these rivers. Assessment of water quality by measurement of the WQI is a conventional approach, simple to implement, cost-effective, and widely used in international and domestic studies for stating the general conditions of water quality (Tirkey et al. 2013; Yadav el al. 2015; Nguyen & Nguyen, 2018). Water quality index was designed to provide surface water classification requirements based on standard water characterization parameters (Bordalo et al., 2001; Cude, 2001; Jonnalagadda & Mhere, 2001). It is a clustering algorithm used to turn vast quantities of water characterization data into a single number that enables a casual reader to easily know the water quality status (Akoteyon et al., 2011; and Balan et al., 2012). In addition, the capacity of receiving wastewater of some main rivers and canals in Ca Mau city was determined. On these grounds, the management solutions were proposed to minimize impacts on surface water in Ca Mau province for sustainable development.

2. Materials and Methods

2.1. Monitoring data

To assess the surface water quality in Ca Mau province, water samples from 52 monitoring stations were collected from 2017 to 2018. The samples positions are presented in Table 1 and Figure 1. Each month, samples were taken one day; each day was taken twice - the highest tide peak and the lowest low tide. Water samples were taken midstream 30 cm above the water surface. These samples were grouped into six functional zones with several monitoring parameters presented in Table 2. In addition, the flow rate from the data of hydrological monitoring stations was also used to calculate the wastewater load capacity.

2.2. Method of calculating the WQI

The WQI was calculated according to the formula of VEA (2019) as follows:

$$WQI = \frac{WQI_I}{100} \times \frac{\left(\prod_{i=1}^{n} WQI_{II}\right)^{\frac{1}{n}}}{100} \times \frac{\left(\prod_{i=1}^{m} WQI_{III}\right)^{\frac{1}{m}}}{100} \times \left[\left(\frac{1}{k}\sum_{i=1}^{k} WQI_{IV}\right)^{2} \times \frac{1}{l}\sum_{i=1}^{lWQI_V}\right]^{\frac{1}{3}}$$

Where:

WQI_I: Calculated WQI value for pH parameter

WQI_{II}: Calculated WQI value for Aldrin, BHC, DDT_s, Heptachlor and Heptachlorepoxide

WQI_{III}: Calculated WQI value for As, Cd, Pb, Cr^{6+}, Cu, Zn and Hg

WQI_{IV}: Calculated WQI value for DO, BOD_5, COD, TOC, N-NH_4, N-NO_3, N-NO_2 and P-PO_4

WQI_V: Calculated WQI value total coliforms and *E.coli* parameter

In WQI method, values ranges from 0 – 100 and water qualities are classified as poisoned (< 10), heavily polluted (10 – 25), used for water transport (26 – 50), used for irrigation (51 – 75), used for domestic water supply after adequate treatments (76 – 90), or used for water supply (91 – 100).

2.3. Assessment of capacity of receiving wastewater

The formula for assessing the capacity of receiving wastewater was based on the Circular 76/2017/TT-BTNMT (MONRE, 2017), as follows:

$$L_{tn} = (L_{tđ} - L_{nn} - L_t) \times F_s$$

Where:

L_{tn} (kg/day) is the capacity of receiving the pollution load of water source

$L_{tđ}$ (kg/day) is the maximum pollution load of the water sources for pollutants under review

L_{nn} (kg/day) is the pollution load which is available in the receiving water sources

L_t (kg/day) is the pollution load in the waste source

F_s is the safety coefficient ($0.3 < F_s < 0.7$). The chosen Fs is 0.5 in this study

If L_{tn} is greater than 0, the water sources can still receive contaminants. If L_{tn} is less than or equal 0, it means the water sources are no longer able to receive contaminants.

$$L_{tđ} = C_{qc} \times Q_s \times 86.4$$

Where:

Q_s (m^3/s) is the instantaneous minimum flow measured at water quality monitoring sites

C_{qc} (mg/L) is the concentration limit values of pollutants under consideration specified in water quality standards to ensure the use of water resources (Column B1 of QCVN 08-MT:2015/BTNMT)

Table 1. Locations of samples for surface water quality analysis of Ca Mau province

No.	Coordinates*		Position
	X	Y	
NM-01	09°11'55.0"	105°10'45.2"	Tan Thanh Primary School, Ca Mau city
NM-02	09°10'37.7"	105°08'07.3"	Chua Ba fork, Ca Mau city
NM-03	09°10'27.2"	105°16'44.1"	Tac Van fork, Ca Mau city
NM-04	09°20'50.5"	105°05'17.5"	Xeo Ro fork, Thoi Binh District
NM-05	09°24'53.3"	104°58'07.8"	Khom 3 intersection, U Minh District
NM-06	09°20'35.5"	104°49'33.9"	Khanh Hoi estuary, U Minh District
NM-07	09°04'17.2"	104°58'09.5"	Tran Van Thoi town, Tran Van Thoi District
NM-08	08°56'23.5"	105°00'54.1"	Cai Nuoc fork, Cai Nuoc District
NM-09	08°51'31.7"	104°48'39.9"	Cai Doi Vam town, Phu Tan District
NM-10	08°48'40.5"	104°54'06.0"	Bay Hap estuary, Phu Tan District
NM-11	08°45'22.5"	104°59'28.7"	Tat Nam Can fork, Nam Can District
NM-12	08°42'55.7"	104°49'19.4"	Ong Trang estuary, Nam Can District
NM-13	08°37'16.5"	105°01'13.6"	Rach Goc estuary, Ngoc Hien District
NM-14	08°46'13.1"	105°12'07.8"	Bo De estuary, Ngoc Hien District
NM-15	08°49'32.9"	105°18'15.8"	Ho Gui estuary, Dam Doi District
NM-16	08°58'17.6"	105°19'12.0"	Tan Tien commune fork, Dam Doi District
NM-17	09°01'08.8"	105°24'57.5"	Ganh Hao estuary, Dam Doi District
NM-18	08°59'02.4"	105°12'28.7"	Dam Doi River fork, Dam Doi District
NM-19	08°36'26.5"	104°43'24.4"	Dat Mui restaurant pier, Ngoc Hien District
NM-20	08°57'57.6"	105°06'31.8"	Bay Hap canal, Dam Doi District
NM-21	09°10'13.4"	105°05'14.4"	Confluence of Ong Doc river and Luong The Tran canal, Tran Van Thoi District
NM-22	09°23'52.1"	105°08'29.5"	Ca Mau Sugar Enterprise, Thoi Binh District
NM-23	09°14'35.3"	105°03'51.8"	Gas-Power-Fertilizer Complex, U Minh District
NM-24	09°01'57.4"	104°49'01.7"	Doc estuary, Tran Van Thoi District
NM-25	08°45'41.3"	105°00'08.8"	New Port, Nam Can District
NM-26	09°23'55.3"	105°04'40.8"	Rach Nhum river, Khanh An IZ, U Minh District

*Coordinate system: VN-2000

Table 1. Locations of samples for surface water quality analysis of Ca Mau province (continued)

No.	Coordinates*		Position
	X	Y	
NM-27	08°46'38.1"	105°00'58.0"	Nam Can EZ, Nam Can District
NM-28	09°14'25.7"	104°49'47.7"	LFS, Tran Van Thoi District
NM-29	09°09'26.1"	105°09'21.0"	Minh Phu company, Ca Mau city
NM-30	09°22'03.7"	105°13'10.7"	Hung canal, Thoi Binh District
NM-31	09°02'16.3"	105°00'16.6"	Thi Tuong A Hamlet, Hung My Commune, Cai Nuoc District
NM-32	08°39'21.3"	105° 04'24.5"	Tan An Commune, Ngoc Hien District
NM-33	09°09'46.5"	105°13'17.3"	Quoc Viet company, Ca Mau city
NM-34	09°05'13.3"	105°00'20.2"	On Tu canal, Tran Van Thoi District
NM-35	09°02'46.5"	105°01'57.0"	Dai Loi company, Cai Nuoc District
NM-36	08°54'52.5"	104°52'42.6"	Xang Cong Da canal, Phu Tan District
NM-37	08°50'50.7"	105°07'57.4"	Canal 3, Nam Can District
NM-38	08°37'48.1"	105°01'57.8"	Khom 6 fishing port, Ngoc Hien District
NM-39	08°57'42.9"	105°07'22.4"	Lo Cai Nuoc – Tan Duyet, Dam Doi District
NM-40	09°08'10.4"	104°56'36.9"	Cu canal, Tran Van Thoi District
NM-41	09°17'33.2"	105°12'10.5"	Bach Ngu canal, Thoi Binh District
NM-42	09°18'41.7"	105°00'09.0"	Canal 29, U Minh District
NM-43	09°30'36.2"	105°00'50.1"	Hamlet 10, Bien Bach Commune, Thoi Binh District
NM-44	09°00'18.7"	104°53'48.6"	Thi Tuong Lagoon fork, Tran Van Thoi District
NM-45	09°11'51.6"	104°57'37.5"	U Minh Ha NP buffer zone, Tran Van Thoi District
NM-46	09°12'30.1"	104°57'37.9"	Contiguous area between buffer and core zone of U Minh Ha NP, Tran Van Thoi District
NM-47	09°13'24.7"	104°57'32.4"	U Minh Ha NP core zone, Tran Van Thoi District
NM-48	08°36'11.7"	104°49'21.2"	Mui Ca Mau NP buffer zone, Ngoc Hien District
NM-49	08°35'48.7"	104°47'46.5"	Contiguous area between buffer and core zone of Mui Ca Mau NP, Ngoc Hien District
NM-50	08°35'51.3"	104°46'37.3"	Mui Ca Mau NP core zone, Ngoc Hien District
NM-51	09°13'26.3"	104°57'33.5"	U Minh Ha NP, Tran Van Thoi District
NM-52	09°01'52.0"	105°05'17.1"	Landfill site, Tan Hoa Hamlet, Tan Hung Commune, Cai Nuoc District

*Coordinate system: VN-2000

Figure 1. Map of surface water sampling points in Ca Mau province with the water sampling points.

86.4 is dimensional conversion cofficient from $(m^3)/s \times (mg/L)$ to (kg/day).

$$L_{nn} = Q_s \times C_{nn} \times 86.4$$

Where, C_{nn} (mg/L) is the maximum concentration value of the pollutants in the water sources before receiving wastewater based on monitoring data results.

$$L_t = Q_t \text{ x } C_t \text{ x } 86.4$$

Where, Q_t (m^3/s) is the maximum wastewater discharge of wastewater sources based on the discharge permits

C_t (mg/L) is the maximum concentration values of pollutants in wastewater based on the average value of 10 wastewater samples with a sampling frequency of 3 days/sample.

3. Results and Disscussion

3.1. Results and disscussion

3.1.1. Urban areas (residential areas, central markets, tourist areas)

In the urban areas (from NH-01 to NH-20), the pH values ranged from 7.00 to 8.11, and FOG concentrations ranged from 0.32 to 0.47 mg/L,

Table 2. Functional zones with monitoring parameters

No.	Functional zone	Sampling points	Monitoring parameters
1	Urban areas (residential areas, central markets, tourist areas)	NM-01 to NM-20	pH, Dissolved Oxygen (DO), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD5), $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe, Total Coliforms and Fat, Oil & Grease (FOG)
2	Industrial areas (IZs, factories outside IZs and LFS)	NM-21 to NM-28	pH, DO, TSS, COD, BOD_5, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe, As, Hg, Total Coliforms and FOG
3	Aquaculture and processing aquatic products areas	NM-29 to NM-39	pH, Cl^-, DO, TSS, COD, BOD_5, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe, Total Coliforms and FOG
4	Agricultural areas	NM-40 to NM-42	pH, DO, TSS, COD, BOD_5, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe, As, Hg, Total Coliforms, Plant protection products – Organic Phosphorus (Parathion, Malathion)
5	National parks and Thi Tuong Lagoon	NM-43 to NM-51	pH, DO, TSS, COD, BOD_5, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$ and Total Coliforms
6	Landfill site	NM-52	pH, DO, TSS, COD, BOD_5, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe, As, Hg, Cu, Total Coliforms and FOG

both of them met the requirement of irrigation purpose corresponding to Column B1 of QCVN 08-MT:2015/BTNMT (National technical regulation on surface water quality). The DO, TSS, COD, BOD_5, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Fe concentrations, and total Coliforms in the urban areas were presented in Figure 2. From 2017 to 2018, TTS concentrations at most sampling sites tended to decrease.

However, the TSS concentrations, ranging from 50 to 221 mg/L, still did not reach QCVN 08-MT:2015/BTNMT, column B1. The concentrations of Fe have tended to increase, and most of the sampling points (17/20 points) were not up to quality for irrigation purposes. Significantly at Tat Nam Can fork (NM-11), Ong Trang estuary (NM-12), and Tan Tien commune fork (NM-16), the Fe concentration was tremendous. Half of the sampling points in the urban areas had COD and BOD_5 concentrations that did not meet Column B1 of QCVN 08-MT:2015/BTNMT, but generally, these parameters did not significantly exceed the regulation. Previous study (Simeonov et al., 2003) also indicated that nutrients and metals occurred in surface water from the domestic activities. Total coliforms at most monitoring points (16/20 points) indicated that surface water in these areas could not be used for irrigation. Ammonium and phosphate concentrations at all sampling points in the urban regions met Column B1 of QCVN 08-MT:2015/BTNMT except at Chua Ba fork (NM-02). Concentrations of DO, COD, BOD_5, ammonium, and phosphates at the Chua Ba fork (NM-02) nearly doubled the water quality regulation used for irrigation because the Chua Ba fork received a large amount of wastewater from the market. In general, surface water in urban areas in Ca Mau province was polluted locally by organic matter, especially the section passing through Ca Mau city (NM-01 to NM-03), where residents are highly concentrated, but the domestic wastewater has not been treated and discharged directly into rivers and canals that is consistent with the study of Vo et al. (2015). Besides, the Ganh Hao canal (NM-17), which receives the chitin factory's wastewater, was also contaminated by organic matters.

3.1.2. Industrial areas

In the industrial areas (from NH-21 to NH-28), the pH values ranged from 6.78 to 7.88, and FOG concentrations were below 0.43 mg/L; both met Column B1 of QCVN 08-MT:2015/BTNMT. Concentrations of Hg and As at all sampling points in the area were slight or undetectable. The DO, TSS, COD, BOD_5, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$,

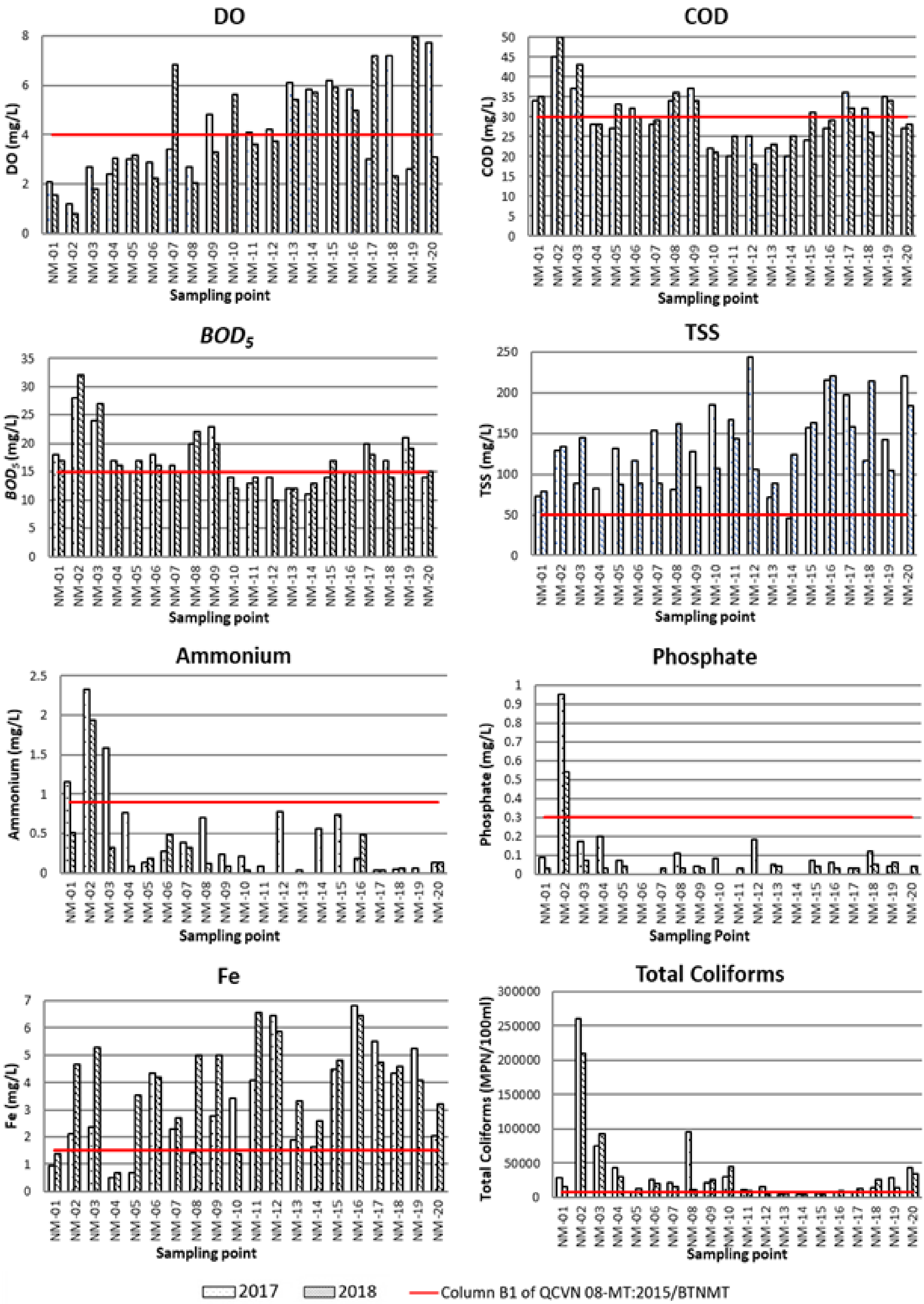

Figure 2. DO, TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-}, Fe concentrations and total coliforms in the urban areas.

Fe concentrations, and total Coliforms in the industrial areas were presented in Figure 3. From 2017 to 2018, TTS and Fe concentrations at almost sampling sites tended to increase and did not reach QCVN 08-MT:2015/BTNMT, column B1. DO, COD, and BOD5 concentrations indicated that surface water at Gas – Power – Fertilizer Complex (NM-23) and LFS (NM-28) was heavily polluted by organic matters because of fertilizers productions and Petrovietnam's activities. Ammonium concentrations at all sampling points in the industrial areas were up to quality for irrigation purposes except at Gas – Power – Fertilizer Complex (NM-23). All sampling points had phosphate concentrations that met Column B1 of QCVN 08-MT:2015/BTNMT, while total Coliforms did not satisfy the regulation. Effects of some water quality parameters especially total coliform and fecal coliform in surface water were analyzed and confirmed in waste water from industrial zones (Diviya and Solomon, 2016).

3.1.3. Aquaculture and aquatic products processing areas

In the aquaculture and aquatic products processing areas (from NH-29 to NH-39), the pH values ranged from 7.46 to 8.56, and FOG concentrations were below 0.47 mg/L, both of them met Column B1 of QCVN 08-MT:2015/BTNMT. Total Coliforms at almost sampling points (10/11) were huge, so water quality in these areas was only suitable for transport purposes. The DO, TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-}, Fe, and Chloride concentrations in the areas were presented in Figure 4. At almost sampling points (10/11), TSS concentrations did not reach the irrigation purposes. The discharge of wastewater from fisheries activities to the surface water increased the TSS concentration, and besides, TSS concentrations in the areas were affected by other factors such as silt content, tidal regime, transportation, . . . Chloride concentrations at all sampling points were very high and did not meet the irrigation purposes. DO, COD, BOD_5, N-NH_4^+, P-PO_4^{3-} concentrations indicated that surface water at Minh Phu company (NM-29) and Quoc Viet company (NM-33) was heavily polluted by organic matters. Because the large fisheries facilities are located in these areas, and the direct discharge without treatment into the canals and rivers is from small and unplanned fisheries companies.

3.1.4. Agricultural areas

The main types of agricultural production of Ca Mau province, such as rice, vegetables, short-day crops (corn, sugarcane, bananas, ...) were located in the farming areas (from NM-40 to NM-42). The pH values ranged from 7.21 to 8.56 that met Column B1 of QCVN 08-MT:2015/BTNMT. Concentrations of Hg, As, and organic phosphorus (plant protection products) at all sampling points in the agricultural area were undetectable. The TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-} concentrations and total Coliforms in the areas were presented in Figure 5. From 2017 to 2018, ammonium concentrations tended to increase while phosphate concentrations tended to decrease. All agricultural sampling points were lightly polluted by organic compounds. Nutrient emissions from agricultural activities have become the dominant source of nutrient loads to freshwater in the Netherlands. The research focused on nutrient emissions from agriculture, emphasizing nutrient loads to surface waters, and strategies and perspectives to reduce these emissions (Diederik et al., 1998).

3.1.5. National parks and Thi Tuong Lagoon

In the national parks and Thi Tuong Lagoon areas (from NM-43 to NM-51), the pH values ranged from 6.03 to 8.58 that met Column B1 of QCVN 08-MT:2015/BTNMT. The DO concentrations ranged from 0.59 to 4.98 mg/L; in canals in U Minh Ha NP, the DO concentrations were quite low due to the influence of vegetation decomposition in water. The TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-} concentrations and total Coliforms in the areas were presented in Figure 5. At all sampling points, the TSS concentrations were tremendous and did not reach the irrigation purposes. The total Coliforms at almost sampling points did not meet QCVN 08-MT:2015/BTNMT, Column B1 and tended to increase. The COD, BOD_5, N-NH_4^+, P-PO_4^{3-} concentrations tended to decrease and almost met the irrigation purposes except at U Minh Ha NP (NM-45, NM-46, and NM-47).

3.1.6. Landfill site

The pH value at the landfill site (NM-52) raged from 7.61 to 8.19, meeting Column B1 of QCVN 08-MT:2015/BTNMT. The As, Cu, and

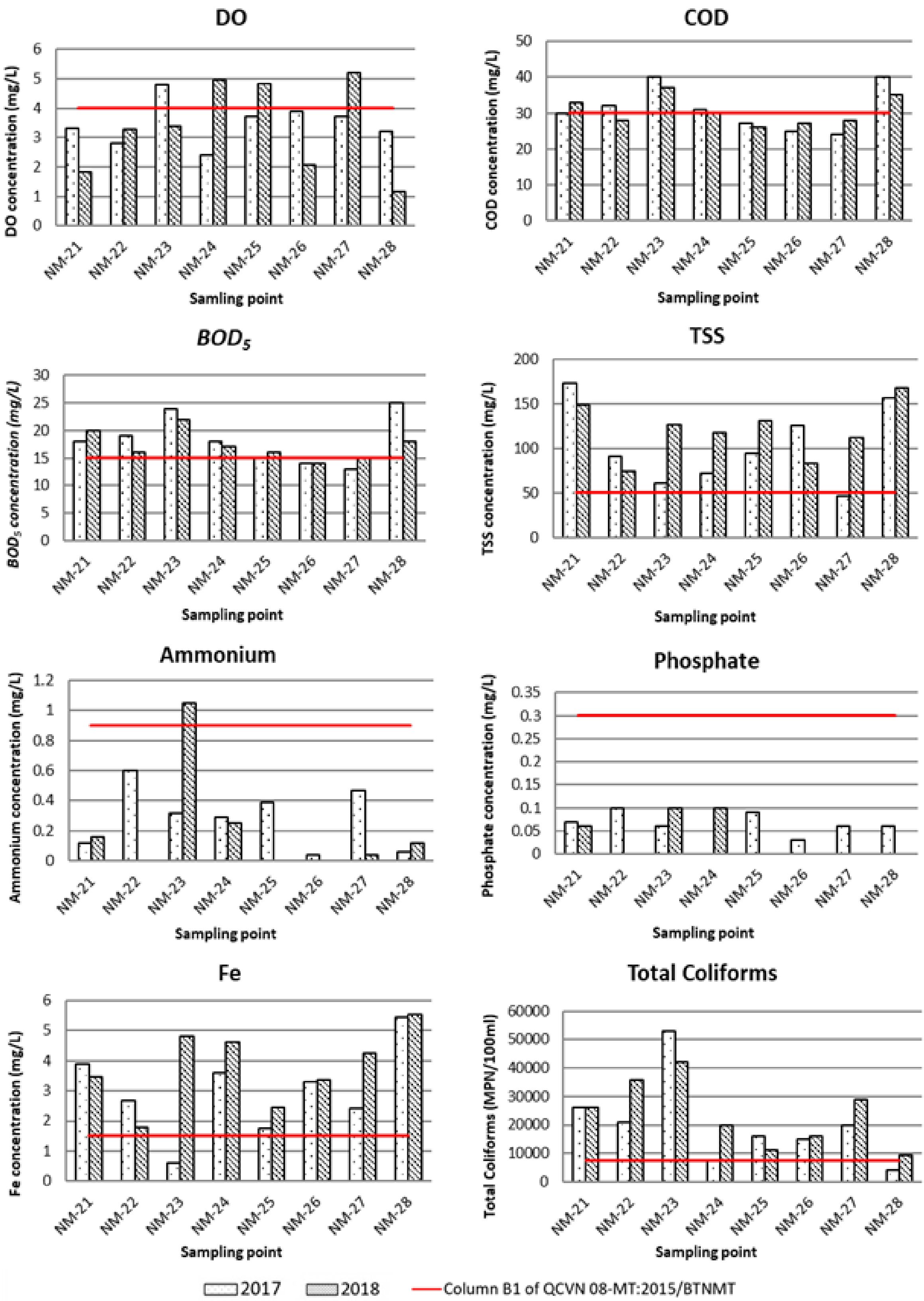

Figure 3. DO, TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-}, Fe concentrations and total coliforms in the industrial areas.

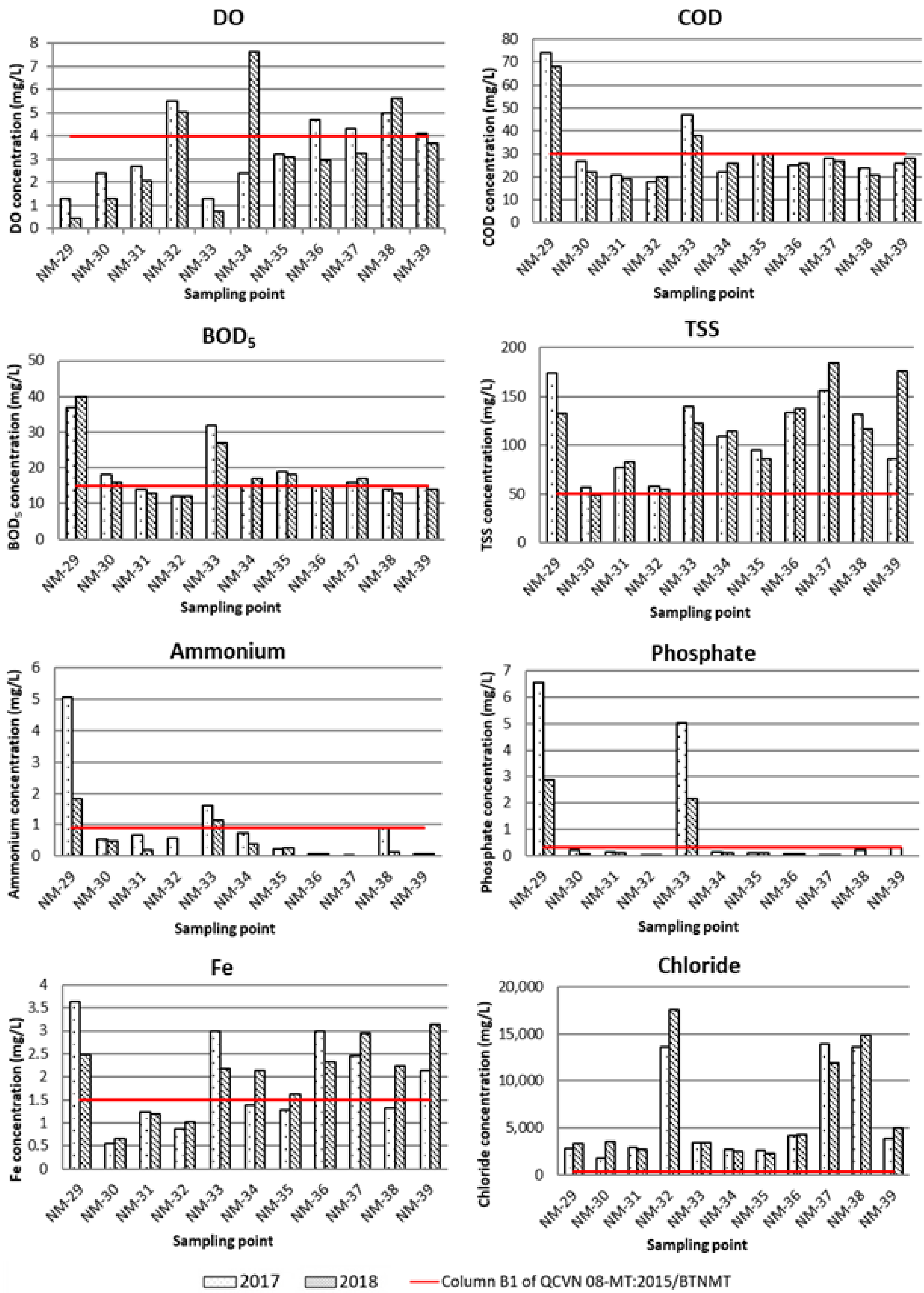

Figure 4. DO, TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-}, Fe and chloride concentrations in the fisheries areas.

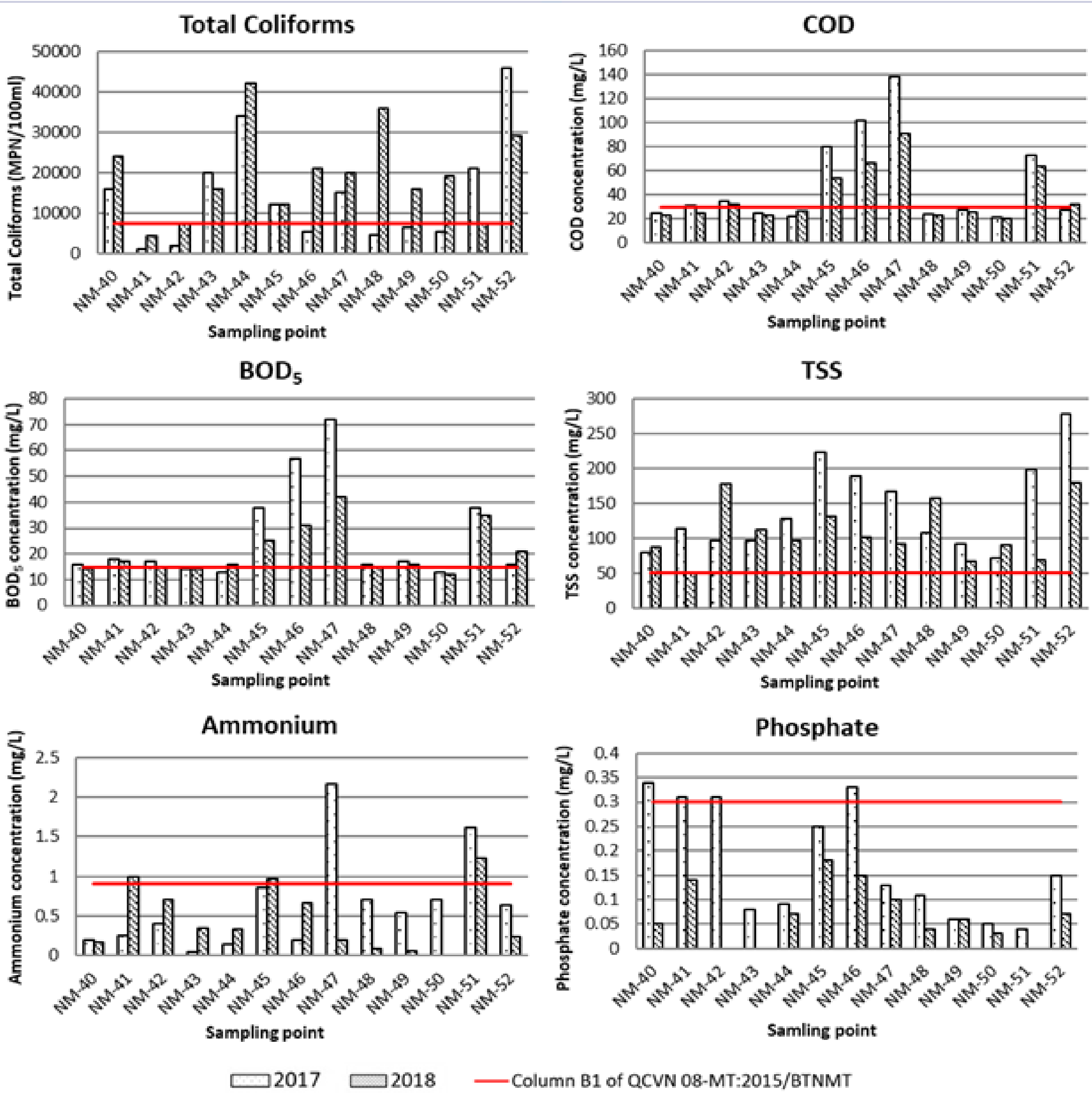

Figure 5. TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-} concentrations and total coliforms in the agricultural areas, the National Parks, Thi Tuong Lagoon and landfill site.

FOG concentrations were undetectable. The TSS, COD, BOD_5, N-NH_4^+, P-PO_4^{3-} concentrations and total Coliforms at the landfill site were presented in Figure 5. The COD and BOD5 concentrations tended to increase and did not reach the irrigation purpose, while the N-NH_4^+ and P-PO_4^{3-} concentrations tended to decrease and met the intent.

3.1.7. Water quality index values

The calculated WQI values at 52 sampling points in 2018 were presented in Figure 6. The WQI indicates that: Surface water at 05/52 monitoring stations (NM-02, NM-29, NM-33, NM-45, and NM-46) has been heavily polluted that requires timely remediation and recovery solutions; Surface water at 35/52 sampling points has been polluted, which need adequate treatment in the future; Water quality at 09/52 sampling points could be used for transportation; Only 03/52 sampling points (NM-13, NM-15, and NM-41) had water quality reaching the irrigation purpose. One of the main reasons for the low WQI in Ca Mau was the high total Coliforms at most monitoring points. In general, based on WQI, the sur-

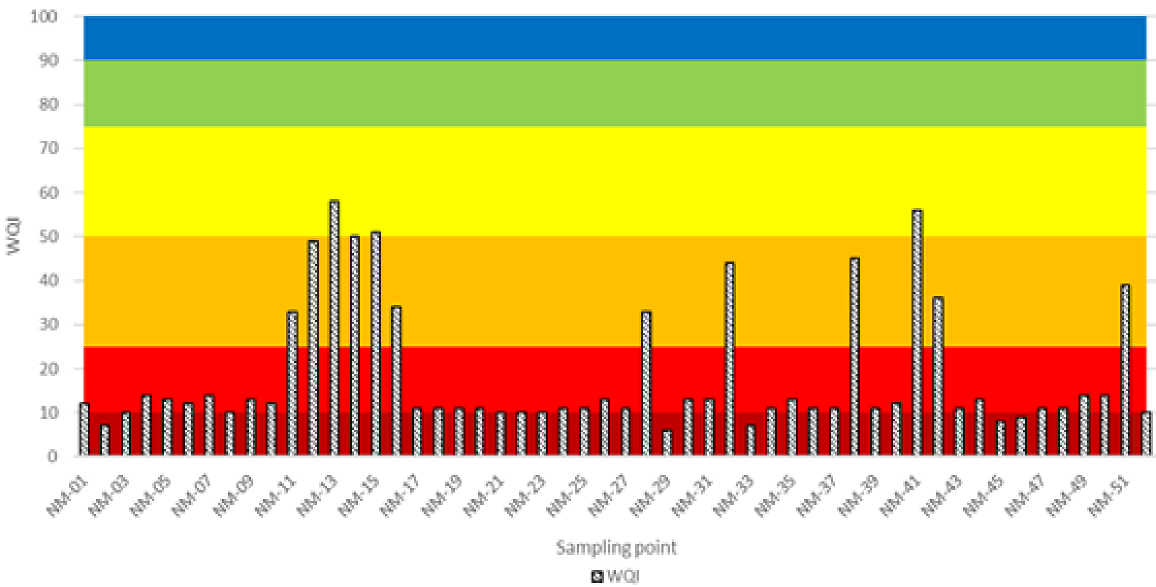

Figure 6. Water quality index of some major rivers in Ca Mau province in September 2018.

face water in Ca Mau province needs to be improved to achieve the irrigation purpose that is consistent with the study of Vo et al. (2015).

3.2. Assessing the capacity of receiving wastewater of some main rivers and canals in Ca Mau city

The main wastewater sources in Ca Mau city are domestic, industrial, and hospital wastewater. Wastewater discharge volume and receiving areas are presented in Table 3, Table 4, and Table 5. The wastewater parameters discharging to the main rivers and canals in Ca Mau city are shown in Table 6.

The capacity of receiving wastewater of 04 main rivers and canals in Ca Mau city was assessed through 04 pollution indicators: COD, BOD_5, N-NH_4^+ and P-PO_4^{3-} concentration (Table 7). All rivers and canals in Ca Mau city were not able to receive any more contaminant load of COD and BOD5. Almost rivers and canals could not acquire any more pollutant load of N-NH_4^+ and P-PO_4^{3-}, only Ca Mau river was able to receive wastewater with pollutant load of N-NH_4^+ and P-PO_4^{3-} is 273.75 and 130.60 kg/day. The calculated capacity of receiving wastewater reflects the actual situation of surface water quality in Ca Mau city, showing signs of severe decline. In the long term, to ensure the quality of water resources for irrigation, it is necessary to take adequate management solutions to protect water sources against the pressure of socio-economic development demands.

3.3. Management solutions proposals

From the analytical process above and for adequate protection and management of surface water sources in Ca Mau province, the synchronous implementation of solutions is urgently required, such as: (i) Investing in building centralized domestic wastewater collection and treatment systems, especially in Ca Mau city (corresponding to NM-01 to NM-03), to reduce the organic pollutants and total coliforms of domestic wastewater discharging to surface areas; (ii) Relocating the factories outside industrial zones (especially the aquatic products processing factories around NM-29 and NM-33, and in Ganh Hao river, corresponding to NM-17) into industrial parks and industrial clusters to collect and treat all industrial wastewater before discharging into the rivers; (iii) Tightening factories' wastewater treatment implementation, especially at Gas – Power – Fertilizer Complex (NM-23) and LFS (NM-28), to efficiently manage industrial wastewater discharge; (iv) Improving the capacity of receiving wastewater by periodically dredging to increase the flows of rivers and canals (Q_s); and (v) Determining the capacity of receiving wastewater of all rivers and canals throughout Ca Mau province to issue appropriate discharge permits to ensure the water quality.

Table 3. The domestic wastewater discharge volume and receiving areas in Ca Mau city

No.	Wastewater receiving areas	Number of households	Discharge volume (m^3/day)
1	Ca Mau river	5,655	2,714.4
2	Quan Lo – Phung Hiep canal	7,421	3,562.4
3	Ca Mau – Bac Lieu canal	8,115	3,895.2
4	Ganh Hao river	4,251	2,040.0
	Total:		12,212

Table 4. The industrial wastewater discharge volume and receiving areas in Ca Mau city

No.	Wastewater receiving areas	Number of factories	Discharge volume (m^3/day)
1	Ca Mau – Bac Lieu canal	09	3,891
2	Ganh Hao river	09	5,960
	Total:		9,851

Table 5. The hospital wastewater discharge volume and receiving areas in Ca Mau city

No.	Wastewater receiving areas	Number of hospitals	Discharge volume (m^3/day)
1	Ca Mau – Bac Lieu canal	04	525
2	Ca Mau river	02	60
3	Quan Lo – Phung Hiep canal	02	35
	Total:		620

Table 6. The maximum concentration values of wastewater discharging to the main rivers and canals in Ca Mau city

No.	Parameter	Maximum concentration values of wastewater C_t (mg/L)			
		Quan Lo – Phung Hiep canal	Ca Mau – Bac Lieu canal	Ca Mau river	Ganh Hao river
1	BOD_5	59.0	124.9	86.0	303.0
2	COD	-	300.1	197.0	764.0
3	$N\text{-}NH_4^+$	31.6	11.7	16.0	27.9
4	$P\text{-}PO_4^{3-}$	1.0	1.6	1.1	0.7

Table 7. The capacity of receiving wastewater of some main rivers in Ca Mau city

No.	Parameter	Capacity of receiving wastewater L_{tn} (kg/day)			
		Quan Lo – Phung Hiep canal	Ca Mau – Bac Lieu canal	Ca Mau river	Ganh Hao river
1	BOD_5	-122.28	-7,810.60	-6,951.72	-28,059.50
2	COD	-43.20	-5,587.40	-7,477.28	-42,429.83
3	$N\text{-}NH_4^+$	-53.18	-227.55	273.75	-1,148.23
4	$P\text{-}PO_4^{3-}$	0.48	-1,129.03	130.60	-2,743.73

4. Conclusions

The river and canal system in Ca Mau province play a particularly important role in the socio-economic development of the province. Facing development pressures, surface water quality in Ca Mau province is being seriously threatened, especially in Ca Mau city. Surface water quality was polluted by organic matters, nutrients, and microorganisms, only meeting transportation purposes. According to the calculated WQI, most of the rivers and canals in Ca Mau were heavily polluted and need to be treated in the future. Most rivers and canals in Ca Mau city could no longer receive more BOD5 and COD in wastewater, the capacity to receive N-NH_4^+ and P-PO_4^{3-} was no longer or very low. Proposed solutions need to be applied to improve the surface water quality in Ca Mau province.

Conflict of interest

The authors declare no conflict of interest.

References

Akoteyon, I. S., Omotayo, A. O., Soladoye, O., & Olaoye, H. O. (2011). Determination of water quality index and suitability of urban river for municipal water supply in Lagos, Nigeria. *European Journal of Scientific Research* 54(2), 263–271.

Balan, I. N., Shivakumar, M., & Kumar, P. D. M. (2012). An assessment of groundwater quality using water quality index in Chennai, Tamil Nadu, India. *Chronicles of Young Scientists* 3(2), 146–150.

Bordalo, A. A., Nilsumranchi, W., & Chalermwat, K. (2001). Water quality and uses of the Bangpakong river (Eastern Thailand). *Water Research* 35, 3535-3642.

Cude, C. (2001). Oregon water quality index: a tool for evaluating water quality management effectiveness. *Journal of the American Water Resources Association* 37, 125-137.

Diederik, T.V.M., Auke, B., & Paul, C. M. B. (1998). Agricultural nutrient losses to surface water in the Netherlands: Impact, strategies, and perspectives. *Journal of Environmental Quality* 27 (1) 4-11.

Divya, A. H., & Solomon, P.A. (2016). Effects of some water quality parameters especially total coliform and fecal coliform in surface water of Chalakudy river. *Procedia Technology* 24, 631-638.

GSO (General Statistics Office). (2018). *Statistical summary book of Vietnam 2018*. Ha Noi, Vietnam: Statistical Publishing House.

Hong, P. N., & San, H. T. (1993). *Mangroves in Vietnam*. Bangkok, Thailand: IUCN (The International Union for Conservation of Nature and Natural Resources).

Jonnalagadda, S. B., & Mhere, G. (2001). Water quality of the Odzi river in the eastern highlands of Zimbabwe. *Water Research* 35, 2371-2376.

MONRE (Vietnam Ministry of Natural Resources and Environment). (2017). *Circular 76/2017/TT-BTNMT: Regulate principles of assessing the capacity of receiving waste water of rivers and lakes*. Ha Noi, Vietnam.

MONRE (Vietnam Ministry of Natural Resources and Environment). (2015). *QCVN 08-MT: 2015/BTNMT: Vietnam National technical regulation on surface water quality*. Ha Noi, Vietnam.

Nguyen, T. T., & Nguyen, T. L. (2018). Evaluating water quality and recommending measures to control the pollution of sai gon river section flowing through Thu Dau Mot city. *Thu Dau Mot University Journal of Science* 2(37), 32-39.

Reddy, K. R., & DeLaune, R. D. (2008). *Biogeochemistry of wetlands science and applications*. Boca Ratón, USA: CRC Press.

Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M., & Kouimtzis, T. (2003). Assessment of the surface water quality in Northern Greece. *Water Research* 37(17), 4119-4124.

Tirkey, P., Bhattacharya, T., & Chakraborty, S. (2013). Water quality indices - important tools for water quality assessment: A review. *International Journal of Advances in Chemistry* 1(1), 15-29.

Vo, D. L., Huynh, L. T., & Vo, D. Q. (2015). Assessment of surface water in Ca Mau province. *Science and Technology Journal of Agriculture and Rural Development* 3-4, 124-130.

Yadav, K. K., Gupta, N., Kumar, V., Sharma, S., & Arya, S. (2015). Water quality assessment of Pahuj River using water quality index at Unnao Balaji, M.P., India. *International Journal of Sciences: Basic and Applied Research* 19(1), 241–250.