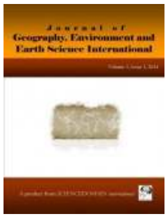

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Impacts of Urban Wastewater on Water Quality of the Lake at Rach Gia Bay in the Mekong Delta, Vietnam

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The Mekong Delta of Vietnam is facing impacts from climate change and sea level rise. Two extreme weather conditions – drought and flood – have occurred much more often recently. Faced with the challenges of drought, the government of Vietnam has an idea of constructing a super sea dyke (SSD)/barrage at Rach Gia Bay – Kien Giang province to create a fresh water lake that will provide water to water scarce regions in the Long Xuyen Quadrangle (LXQ) and especially, Ca Mau Peninsula (CMP). Three options for the SSD have been proposed: Option I: short route, 30 km, creating a small lake with a surface area of 357 km^2 and a volume of 609 million m^3; Option II: short route track, 31.8 km, creating a lake with a surface area of 425 km^2 and a volume of 795 million m^3; and Option III: long route, 47.5 km, forming a large lake with a surface area of 823 km^2, and a value of 2.58 billion m^3 in volume. Furthermore, each option includes at least a sluice gate and a navigation lock. The objective of this study was to assess the impacts of wastewater discharges on the water quality in the proposed barrage.

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Note: This paper was presented in SEAGA (Southeast Asian Geographers Association) International Conference 2014, Siem Reap, Cambodia (at Royal University of Phnom Penh), 25 - 28 November 2014.

Place of Study: Rach Gia City, Kien Giang province, Vietnam.
Methodology: Based on primary and secondary data for wastewater concentration estimates and the MIKE 21 FM model, water pollutant (TSS, BOD_5, COD, total nitrogen, total phosphorous) fate in the barrage under Option II (the consensus-based optimal option) was assessed.
Results: The results show that only considering the untreated wastewater from Rach Gia City would make the lake become a wastewater repository, especially for organic pollutants, as it will receive a total wastewater volume of 28,432 m^3/day from domestic sources and 16,711 m^3/day from industrial sources with a total load of TSS, BOD and COD being up to 25,482; 12,281; 21,074 kg/day, respectively. The MIKE 21 Flow Model FM was used to simulate and evaluate water quality of the lake considering different methods/modes of discharging treated wastewater into the lake. The results show that even though wastewater might be treated to meet the water quality standards of Vietnam (Class B), the lake still could become contaminated locally; different locations of treated wastewater discharge (e.g. 1 point or 5 points near the bank or even at the middle of the lake) do not help to ensure uniform water quality in all areas of the lake.
Conclusion: An optimal option proposed is to control water quality not only for Rach Gia City, but also for other rivers and canals which are flowing to the lake to improve the quality of water supply for different purposes.

Keywords: Climate change; wastewater; fresh water supply; pollutant load; water quality modeling; Rach Gia City; Vietnam.

1. INTRODUCTION

According to a recent World Bank study [1] Vietnam ranks among the top five developing countries that may be most impacted by climate change, especially due to sea level rise. Within Vietnam, the Mekong Delta region has been identified as being particularly susceptible to the impacts of extreme climate events and climate variability.

The Mekong Delta annually contributes about 22% to the national GDP, producing 55% of food production, providing more than 90% of rice exports, contributing 70% of fruits, 58% of seafood (of which 80% is shrimp) and 60% of fishery exports of the country [2]. The water resources of the Delta contribute substantially to such achievements. Water plays an important role in the socio- economic development, supporting a high potential for agriculture development, specifically for food production, aquaculture and fisheries, development of fruit gardens with high export value for the nation and enlarging the exchanges in the region and the world [3]. However, according to the Steering Committee of "Action Program to the Adaptation of Climate Change" of the Ministry of Agriculture and Rural Development of Vietnam [4], Vietnam is facing problems of water resources in the Mekong Delta due to climate change and sea level rise. The Committee noted in detail that:

- Due to the impact of global climate change, by the year 2070 the flow in the Mekong River in peak months will increase 40% in the upstream, and 19% in the downstream of Vietnam. Meanwhile, in the dry season, the flow will decrease about 24% in the upstream and 29% in the downstream of Vietnam [5].
- Sea level rise will cause salinity intrusion far inland and the sluices along the Delta rivers cannot get fresh water to the fields due to saline water of 4 g/L intruding up to 25 - 40 km from the river mouths. About 70% of the Mekong Delta area will be affected by salty water of about 4 g/L [5].
- Due to changes of the rainfall regime, together with urbanization and industrialization, the demand for water will increase, and many irrigation systems will not meet the requirement of water supply and drainage [5].
- If the temperature increases 1^{o}C, rice production will decrease 10%, which will seriously impact national food security, affecting tens of millions people [5].

Clearly, climate change in the Mekong Delta is likely to impact water resources. Drought becomes more severe, water scarcer, and more polluted. Meanwhile, the demand for water is increasing, whether for intensive agriculture, recently expanding aquaculture, residential development, or for newly developed commercial and industrial enterprises [6].

To cope with these problems in the Mekong Delta, construction of a super sea-dike/sea wall (barrage) in Rach Gia Bay, Kien Giang province has been proposed, with 3 options as follows (Fig. 1):

- Option I: short route, 30.18 km, directly connected from Hon Dat to Xeo Quao, creating a small reservoir with a surface area of 357 km², a volume of 600 million m^3, and the deepest point being -2.64 m.
- Option II: short route, 31.8 km divided into two sections (Section 1: Hon Dat – Hon Tre: 15.54 km, deepest point -3.34 m; section 2: Hon Tre – Xeo Quao: 16.26 km, deepest point -4.39 m), with the track having a broken knee on Hon Tre. The surface area would be 425 km², and volume would be 820 million m^3.
- Option III: long route, 47.64 km, connecting from Hon Chong to Hon Tre (section 1) and from Hon Tre to Xeo Quao (section 2), forming a large reservoir with a surface area of 823 km², and 2.58 billion m^3 in volume.

There would be a sluice gate and navigation lock (-3.00 m) on each section of the dike with the width (B) ranging from 200 – 600 m.

Several workshops have been held to discuss this super sea dike. Most participants including scientists and local authorities prefer Option II, for the following reasons:

- Supporting tourism from the inland to Hon Tre
- Less impact on aquaculture
- Less impact on mangrove forest
- More feasible in terms of economic and technical considerations than Option III
- Positive adaptation response to climate change and sea level rise
- Supporting flood discharge to the sea.

However, one of the issues that everyone, from scientists to managers, worry about is the problem of water quality in the lake created by the dike, especially as impacted by wastewater from Rach Gia City.

Fig. 1. Three options of the Super Sea Dike

The question then becomes whether the lake created by the sea dike can become a source for clean, freshwater or not? Or will the lake become similar to Seamangeum Lake in Korea, where the water flows from rivers polluted by upstream agricultural activities have made the purpose of water supply a failure [7,8]. The problem is more serious in the context of the environment of Rach Gia.

The problem of water quality in the proposed lake is considered in this paper, specifically looking at the preferred Option II and with wastewater discharge from Rach Gia City and Tac Cau port.

2. MATERIALS AND METHODS

To evaluate water quality impacts for Option II, the following steps have been done:

- Data collection, survey and water quality monitoring in the area [9].
- Calculating pollution load and pollutant receiving capacity of the lake.

The pollutant load from domestic wastewater was calculated based on population, a pollution factor, capacity and the efficiency of primary treatment by septic tank before discharge into receiving waters [10,11]:

$$M_i = \frac{(N * G_i) - (\alpha * N * \eta_i * G_i)}{1.000} = \frac{(1- \alpha * \eta_i * N * G_i)}{1.000} \quad (1)$$

In which:

M_i – Pollution load of domestic waste needs tocalculate by pollutant i (kg/ day).
N – Population corresponding to the domestic wastewater (per capita).
G_i – Pollutant emission factor i (g/person/day)
α- Percentage of population using septic tanks to treat domestic wastewater locally.
ηi – Efficiency of treating pollutant i by septic tank.

According to the results of our surveys and monitoring, those factors are as shown in Table 1.

2.1 Mathematical Modeling

A two-dimensional numerical model was developed using the new generation *Mike21* flexible mesh software (MIKE 21 Flow Model FM – Hydrodynamic module and Transport module) to study the transport process of pollutants (BOD_5) to assess water quality in Rach Gia Bay, Kien Giang province – Mekong Delta, Vietnam.

MIKE 21 Flow Model FM is a new modeling system based on a flexible mesh approach. The modeling system has been developed for applications within oceanographic, coastal and estuarine environments [14].

The combination of Hydraulic one-dimensional and two-dimensional modeling has also been used to calculate the interaction between Rach Gia Bay and the Mekong Delta (Fig. 2).

Connections between the two-dimensional (2D) model and the one-dimensional (1D) model were done through the channel adjacent to the study area. The channels associated with the two-dimensional model will be linked via the channel ends connecting with the sea. For the link with the triangular grid in the two-dimensional model, each connection between the channels with the triangular grid was done by two or more points linked together.

The 1D-hydraulic calculation network has been set for the whole Mekong Delta from Kratie, Cambodia, to the East Sea with more than 2,500 branches of rivers and canals, 12,500 cross-sections and more than 2,500 structures.

Table 1. Factors for calculating pollution load of domestic and industrial wastewater [12]

No	Pollutant	Domestic wastewater			Pollutant concentration of industrial wastewater (mg/l)
		G_i (g/person.day)	η_i (%)	α (%)	
1	TSS	155 ÷ 208	65		115 ÷ 165
2	BOD_5	45 ÷ 60	50		85 ÷ 215
3	COD	82 ÷ 102	45	90*	135 ÷ 305
4	Total N	8 ÷ 13	70		61 ÷ 87
5	Total P	0.8 ÷ 4,5	75		4.5 ÷ 38,5

* *[13]*

The 2D-hydraulic calculation network has been set for the entire Bay of Rach Gia, with the grid in the range from 9E44’ to 10E14’ north latitude; and from 104E36’ to 105E07’ east longitude. The network is divided into 5,493 irregular triangular elements and 2,864 computation points.

For water discharge, the boundaries have been taken at Kratie, Tonle Sap Lake and East Vai Co River. For water level, the boundaries have been taken at the boundaries from Soai Rap mouth to Vinh Te mouth. At the Rach Gia Bay area, the boundaries are taken from the 2D model for the entire East Sea. Rainfall is ignored in the calculation process because very little or no rain occurs in the dry season. Besides, the boundaries inside the project area are calculated from the ability of water supply and drainage in the fields. Wave and wind conditions were obtained from the wave model results.

The suitable mesh has been developed for the study area, as shown in Fig. 3. The grid was computed in the range of 9°24’ to 10°19’ north latitude; from 104°4’ to 105°7’ east longitude. The seabed topography in the Rach Gia Bay area is shallow. For the area from Hon Tre inland, the elevation of the seabed is in the range from -4 to 0 m, for the area from Hon Tre to Hon Rai, the elevation ranges from -10 to – 4 m, and for the area from Hon Rai seaward, the elevation ranges from -14 to -10 m.

For the current condition, the network was divided into 7,235 grid irregular triangle elements and 3,911 calculation points. With the 2D model in the sea (including the area inside the dike - the reservoir - and outside the dike), the part inside the dike had a more detailed set up with the area of a grid being about 400,000 m^2, meanwhile for the part outside the dike the area of a grid was about 2,000,000 m^2.

For Option II, the network was divided into 10,214 irregular triangle elements and 5,478 calculation points. The area of the grid is divided between 400.000 m^2 (inside the dike) to 2,000,000 m^2. At the sluice gate, the area of the grid is about 5,000 m^2.

Since 2005 is the driest year in the Mekong Delta, it was used for the simulation of water demand for the year 2020 and also for the water quality.

Based on the satellite image for TSS, the boundaries on the sea were taken outside Hon Tre, where sea water was not impacted by the inland water and where the concentration of TSS was almost zero. The concentrations of other parameters were considered as a constant with the values of: BOD_5 = 2 mg/L, P = 0.2 mg/L, N = 1 mg/L.

The upstream boundaries were obtained from monitoring data in 2012. The input boundary of the 2D model at the estuaries was derived from simulated results of the ID model for the whole Mekong Delta. The initial conditions for the pollutants were also from monitoring data in 2012.

For pollutant dispersion, the TRANSPORT MODULE was used with scaled eddy viscosity formulation and scaling factor set at 1. The simulation time was from 2/1/2005 to 30/5/2005, with minimum time step of 0.1 sec and a maximum time step of 300 sec.

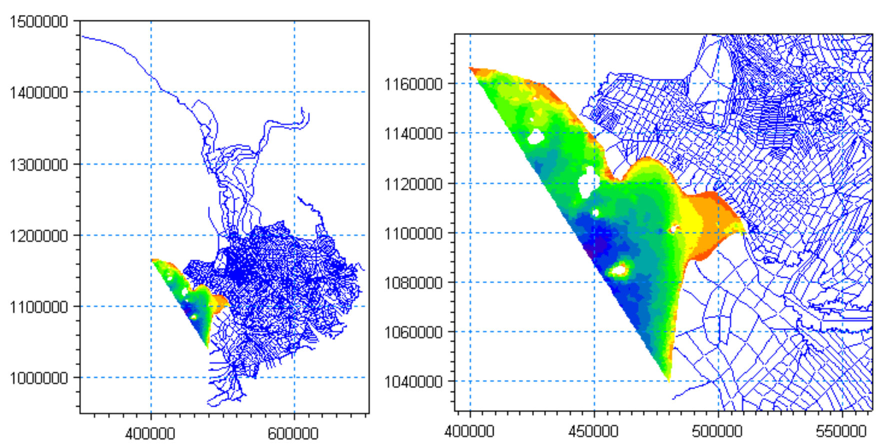

Fig. 2. Hydro-dynamic network combination of 1D and 2D

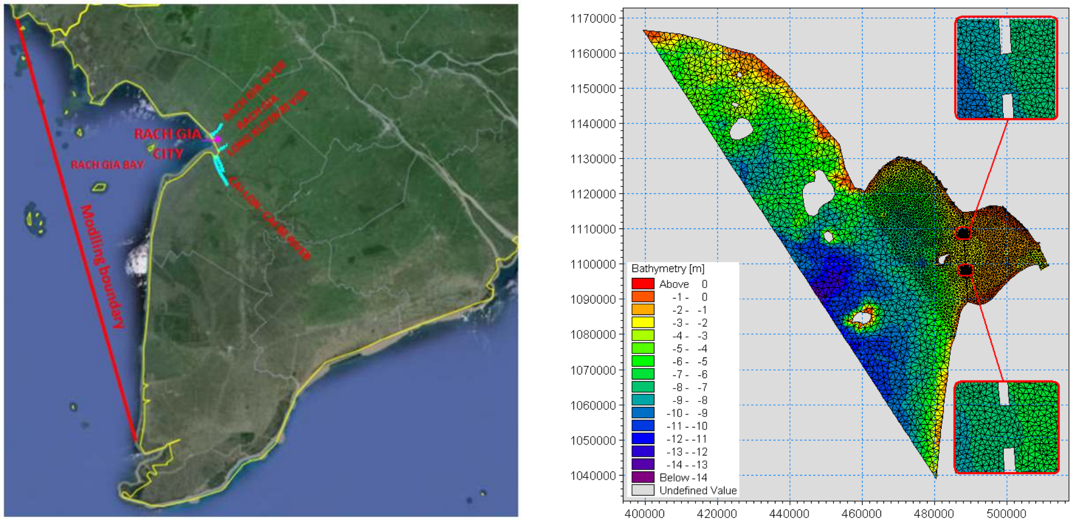

Fig. 3. Modeling boundary and computational mesh

3. RESULTS AND DISCUSSION

3.1 Status of Wastewater Discharge in Rach Gia City – Kien Giang Province

In general, most of surface water in the City is polluted due to wastewater discharges from industry, enterprises, production facilities, business and homes, which is untreated and discharged directly into the rivers/canals. Many parameters such as BOD_5, COD, NH_4^+, total N, total P have values many time higher than standards allow.

Currently, *domestic wastewater* from residential areas concentrated along the river and canals systems in the region is not going through treatment systems, but is discharged directly into canals (Fig. 4). At present, the population in Rach Gia City is about 235,050 inhabitants [13] which would produce up to 25,385 m^3/day of waste discharge to the rivers/canals. According to the City planning, by 2020 the population will increase to 263,260 inhabitants [13] which would produce up to 28,432 m^3/day of waste discharge to the rivers/canals.

Untreated wastewater from *industry* or from manufacturing facilities is mostly also discharged directly into rivers or canals causing contamination of surface and ground water (Fig. 5). The operation of wastewater treatment systems is just only to cosmetically deal with the law but is not effective.

For example, at Tac Cau port, there are 16 companies operating in the field of seafood processing, for which 13 companies have wastewater treatment systems/plants, but only 8 are in good operation, the remaining 5 plants have been degraded, damaged and are irregularly operated.

Currently, the industrial area for the City is only about 60 ha, with the wastewater being about 4,096 m3/day.

Fig. 4. Current status of waste discharge in Rach Gia City

Fig. 5. Current status of industrial wastewater discharge

As planned, by 2020, the industrial land use will increase to about 310 ha [13], and produce a wastewater discharge to receiving waters of up to 16,711 m^3/day.

3.2 Pollution Load and Barrage Capability of Receiving Pollutants

From equation (1) and Table 1, the pollution load of domestic and industrial wastewater has been calculated for the current condition (Table 2), for the year 2020 without treatment (Table 3) and with treatment (Table 4).

It is clear that the main source of pollutants is domestic wastewater. It also means that much of the pollutant loading is organic matter, including the food processing industry source.

With this pollution load the lake will exceed its capacity to receive pollutants, which means the water will have lost the capacity of self - purification if untreated domestic and industrial wastewater dump into the lake, especially for organic pollutants and total suspended solids (TSS). This will make the reservoir become a wastewater repository, especially for organic pollutants. Research from Long and Phuong [12] showed that the lake is still capable of receiving water pollution if wastewater has been treated to meet at least class B of Vietnam environmental regulations QCVN 14: 2008 and QCVN40:2011 before being discharged into the lake.

Table 2. Total pollution load of domestic and industrial wastewater – current condition

Pollutant	Total pollution load		
	M_{min} (kg/day.night)	M_{av} (kg/day.night)	M_{max} (kg/day.night)
TSS	15,589	18,276	20,963
BOD_5	6,164	7,399	8,634
COD	12,019	13,765	15,510
Total nitrogen (TN)	945	1,215	1,486
Total phosphorous (TP)	79	290	501

Table 3. Total pollution load of domestic and industrial wastewater – condition by the year 2020 without treatment

Pollutant	Total pollution load		
	M_{min} (kg/day.night)	M_{av} (kg/day.night)	M_{max} (kg/day.night)
TSS	18,856	22,169	25,482
BOD_5	7,936	10,109	12,281
COD	15,100	18,087	21,074
Total nitrogen (TN)	1,798	2,260	2,720
Total phosphorous (TP)	143	586	1,028

Table 4. Total pollution load of domestic and industrial wastewater – condition by the year 2020 with treatment

No	Pollutant	Standard of Vietnam*		Pollution load (kg/day.night)		
		QCVN14:2008 class B (mg/l)	QCVN40:2011 class B (mg/l)	Domestic	Industry	Total
1	TSS	100	100	2,843	1,671	4,514
2	BOD_5	50	50	1,422	836	2,258
3	COD	N/A	100	N/A	1.671	N/A
4	TN	50	30	1,422	501	1,923
5	TP	10	6	284	100	384

**Source: [15,6]*

3.3 Methods / Modes for Treated Wastewater Discharge into the Lake

Fig. 6 shows the current status of water quality in the Rach Gia Bay. According to the National technical regulation on coastal water quality [16], water quality at the coastal area of the Bay is contaminated with organic matter, especially at the Rach Gia City area. This situation occurs even though the Bay has received a considerable volume of water from the upstream rivers and canals (Cai Lon, Cai Be, Rach Gia Rivers and Cai San canal) to push the pollutants away to the sea.

According to the People's Committee of Rach Gia City, the risk of wastewater contamination from Rach Gia City will be solved by construction of a wastewater treatment plant (WWTP) near the bank of the lake (barrage). The collecting system along the lake will conduct wastewater to the WWTP.

Should the SSD be built as Option II, and the baseline concentration of BOD_5 of the Cai Lon, Cai Be Rivers, Cai San canal and Rach Gia mouth is about 9 mg/l as at present, the question remains: How will the wastewater discharge location (site) from the City impact the water quality of the lake? Can a uniformly good water quality be achieved?

Simulation results are shown in Fig. 7, where wastewater has been treated to class B then discharged into the lake at 1 point near the bank (case 1); Fig. 8 for the same case but wastewater discharged into the lake at 5 points near the bank (case 2); and Fig. 9 for treated wastewater discharged into the lake at 1 point but 8.5 km out from the bank (case 3).

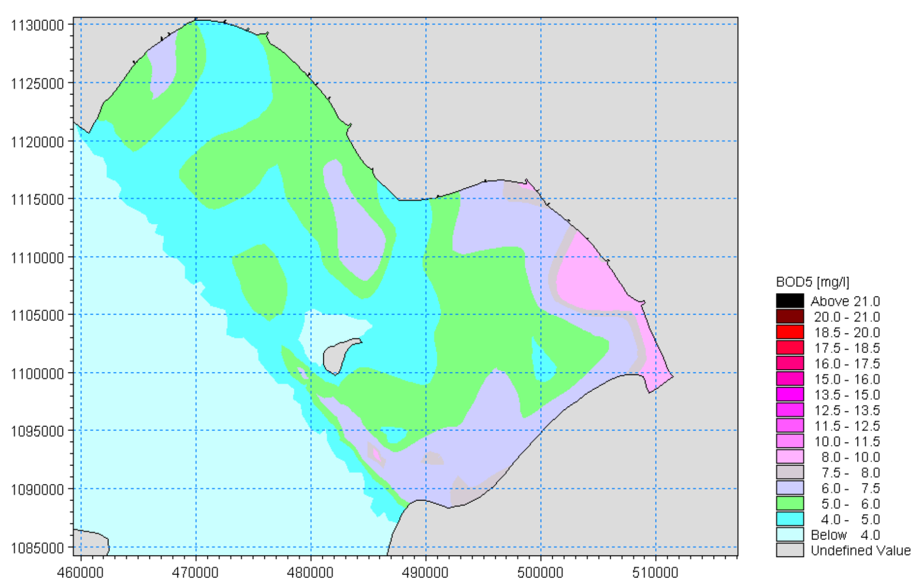

Fig. 6. Current status of water quality in the Rach Gia Bay (dry season 2012)

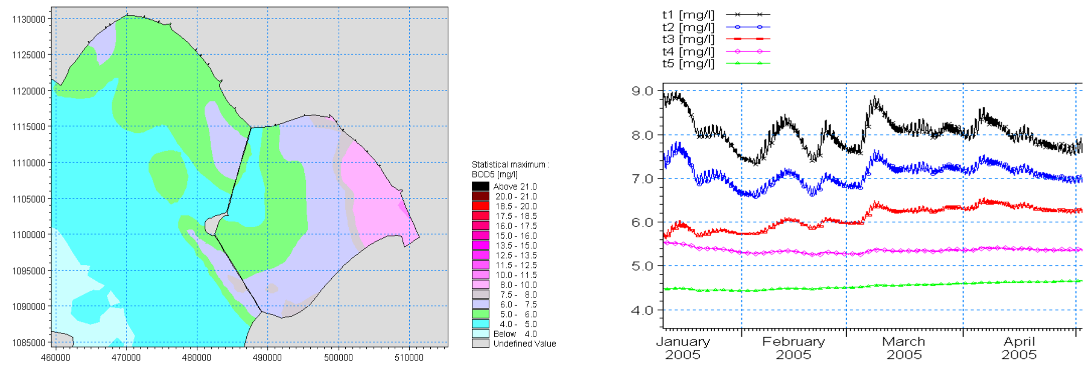

Fig. 7. Treated wastewater discharged into the lake at 1 point near the bank

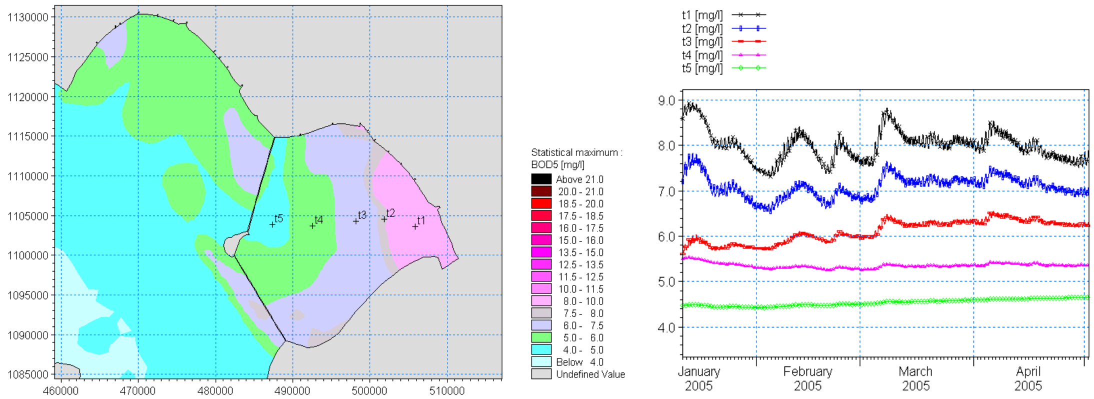

Fig. 8. Treated wastewater discharged into the lake at 5 points along the bank

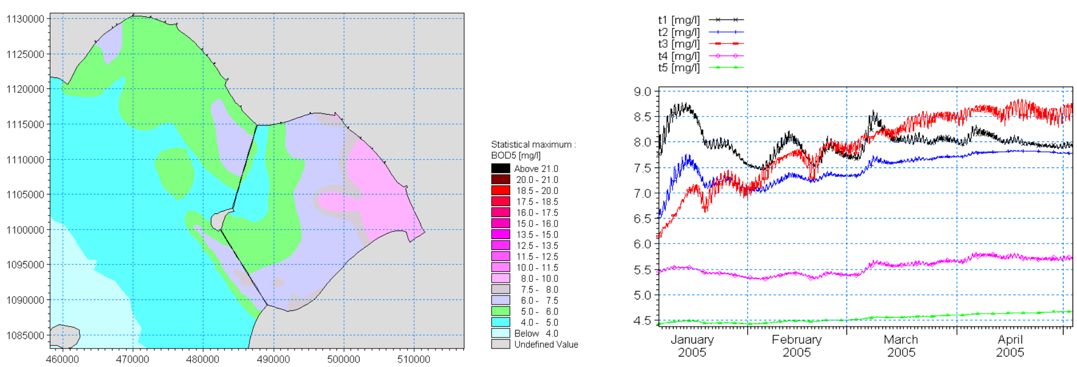

Fig. 9. Treated wastewater discharged into the lake at 1 point far from the bank

Locations t1, t2, t3, t4, and t5 are different extraction points as shown in Fig. 8. For case 1 and case 2, the results are almost the same, although the concentration of BOD_5 under the single discharge point scenario is a bit higher (Fig. 10). In the case 3, even though the discharge point is nearly at the middle of the lake (8.5 km out from the bank), the distribution of pollutants in the lake is not much improved. But, the pollutant levels at t3 are greater because this site is right at the discharge point; moreover this case makes the water quality at t4 and t5 worse.

Considering the three treated wastewater discharge location options into the lake, a uniform good water quality cannot be achieved.

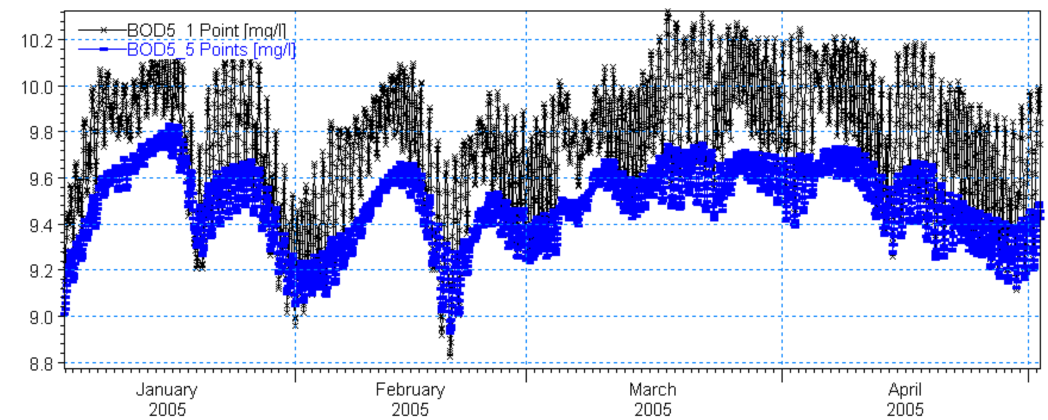

Fig. 10. Comparison of BOD5 at discharge point of case 1 and case 2

According to the National technical regulation on surface water quality [17] with the limited value of BOD_5 for different use purposes as in Table 5, only the water at area t5 (about 20 km from the bank), can be used for domestic water supply. The area at t4 (from the bank, about 13.8 km for the case discharge at 1 and 5 points; and about 16.5 km for the case the discharge point is at the middle of the lake) also can be used for domestic water supply but there would have to be appropriate treatment technologies. The water in the areas at t3, t2 and t1 could be used only for irrigation and navigation. At these three areas, water quality is also not good for aquatic life [18].

If water quality of the boundary river/canal would be controlled well, the concentration of BOD_5 of the Cai Lon, Cai Be Rivers, Cai San canal and Rach Gia mouth could be improved to 5 mg/l and the baseline water quality of the lake would be improved by about 2 mg/l of BOD_5. The treated wastewater from Rach Gia City discharged into the lake then would not affect water supply purposes. There is quite uniform water quality in the lake in this case, except a small area at the discharge point (Fig. 11). This means water quality should be controlled not only for Rach Gia City, but also for other rivers, canals flowing to the lake to ensure good water

Table 5. Limited value for BOD_5

Parameter	Unit	Limited value			
		A		B	
		A1	A2	B1	B2
BOD_5 (20^oC)	mg/l	4	6	15	25

Note: A1 – Good use for domestic water supply and other purposes as A2, B1 and B2.
A2 – Used for water supply purposes but have to apply appropriate treatment technologies; conservation of aquatic plants, or other uses such as B1 and B2. B1 - Used for irrigation purposes or other uses that require the same water quality or other similar uses as type B2.
B2 - Navigation and other purposes with the requirement of low quality water

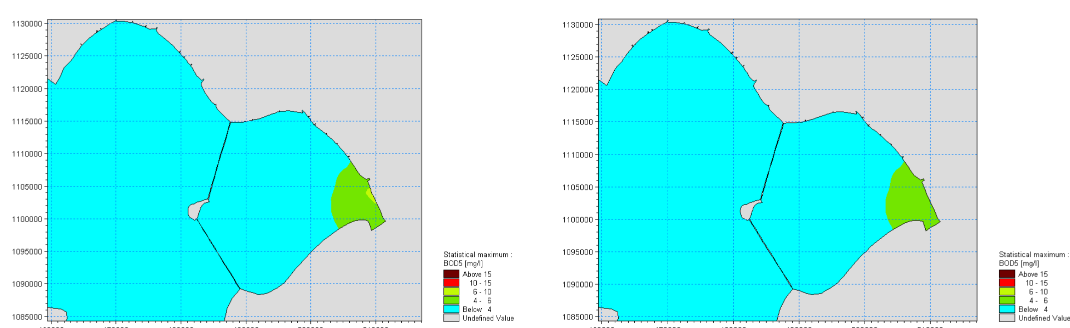

Fig. 11. Treated wastewater discharge into the lake in good baseline condition (on the right – discharge at one point; on the left – discharge at 5 points)

quality of the lake for different use purposes. This will avoid the situation that happened at Seamangeum Lake, Korea.

4. CONCLUSION

Currently, most of the surface water in Rach Gia City is contaminated with organic matter. The amount of domestic wastewater discharged to the receiving water is about 25,385 m^3/day.

By 2020 this amount will increase up to 28,432 m^3/day and together with 16,711 m^3/day of industrial wastewater, will be discharged to the receiving water if they are not treated.

The total load of TSS, BOD and COD will be up to 25,482; 12,281; 21,074 kg/day respectively. If wastewater has not been treated, this can make the lake become a wastewater repository, especially for organic pollutants.

Water quality at the coastal area of the Bay is contaminated with organic matter, especially at the Rach Gia City area.

Results of MIKE 21 Flow Model FM shows that:

- Even though the wastewater from Rach Gia City has been collected and treated to meet the discharge standard of Vietnam (level B), the water quality of the lake still would be contaminated in large areas.
- The discharge methods at one point, 5 points near the bank and even at 8.5 km out from the bank also do not help to make the water quality uniform in the lake.
- The water of the area near the bank - up to 13.8 km from the bank in the discharge at 1 or 5 points scenarios; and up to 16.5 km from the bank in the discharge point at the middle of the lake scenario - can only be used for irrigation and navigation.
- For domestic use, water should be taken from the area about 20 km from the bank; or at the area from about 13.8 km from the bank in the discharge at 1 or 5 points scenario; and about 16.5 km from the bank for the discharge point at the middle of the lake scenario, but in the latter cases appropriate treatment technologies have to be applied.
- Water quality should be controlled not only for Rach Gia City, but also for other rivers and canals flowing to the lake to ensure good water quality of the lake for different water use purposes. This means water quality of the upstream of the Cai Lon, Cai Be Rivers, Cai San canal and Rach Gia mouth should be controlled as well.

DISCLAIMER

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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