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Research Article

Study to assess the impact of saltwater intrusion in Ho Chi Minh City under climate change conditions

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Abstract: The study on assessing the impacts of saline intrusion on water resources, from building a hydraulic model MIKE 11 including hydraulic model, rain model, and advection–dispersion module (HD + RR + AD) together with the calculation scenarios in consideration of climate change through the high scenarios RCP 8.5 and low scenarios RCP 4.5 in 2025, 2030 and 2050 are highlighted in the paper. In addition, the impacts of salinity, salinity margins on the constructions, and water resources through the cases with or without the saltwater prevention works are considered, thereby assessing the impact of salinity intrusion through scenarios and structural solutions for water resources in HCMC.

Keywords: Saline intrusion; Saline boundary; Saigon–Dong Nai River system; Climate change; Sea level rise; MIKE modeling.

1. Introduction

At present, the saline intrusion is a serious problem for many local governments in coastal areas, in the context of increasingly complex and unpredictable climate change, possibly resulting in the increasing risk of saline intrusion, impacting water resources [1–3]. The saline intrusion from the seas to the rivers is very widespread for the coastal plains, especially in the dry season [4–6]. The extent of saline intrusion depends on many natural factors such as topographical characteristics, flow regime from upstream, the tidal regime of estuary, changes in rainfall, temperature and evaporation, sea–level rise trend, or human activities such as groundwater extraction, change of land use, destruction of mangroves [7–11].

Ho Chi Minh City is surrounded by a very developed network of a total of 3,020 rivers and canals in a total length of 5,075km, including three main river systems, Dong Nai River, Saigon River, and Vam Co River [12]. With relatively flat terrain, the hydrological and hydraulic regimes are not only strongly influenced by the East Sea tide, but also clearly affected by the exploitation of terraces of reservoirs at the upstream at present and in the future (such as the reservoirs of Tri An, Dau Tieng, Thac Mo...) [13]. Despite several abundant water resources thanks to a dense network of rivers and streams, in recent years, water shortages are more and more seriously due to colonization and saline boundary (SB) moving deeply into the field as consequences of climate change. Accordingly, fresh water supply to the city is more and more challenging [14–16]. To deal with the above matter, the study of the saline intrusion on the main rivers of Ho Chi Minh City should be implemented in parallel with the assessment based on the climate change and sea–level rise scenarios in the future context for proper management and policies to ensure the sustainable socio–economic development. Currently, the modeling method is widely applied in simulating saltwater intrusion in many river systems [17–18]. Some case studies have used the HD, RR, and AD modules of the MIKE 11 model, all developed and supported by the Danish Hydraulic Institute (DHI) to model the effects of river flows and saltwater intrusion [8, 19]. After proper calibration and verification, the HD, RR, and AD modules of the MIKE 11 have been used to estimate the salt profile. Scenarios for salinity intrusion simulation were developed based on the Climate change and sea–level rise scenarios for Vietnam by MONRE [20]. Results of salinity intrusion computation for RCP4.5 and RCP8.5 scenarios up to 2050 are shown for some cross–sections in the main Sai Gon–Dong Nai River systems.

2. Materials and Methods

2.1. Description of the study site

Ho Chi Minh City is the largest metropolis in Vietnam and the main center for most economic activities, not only for the South region but for the whole country in general. It is also a hub for educational, scientific, cultural, and technological activities. The city currently has 24 administrative units, including 19 districts and 5 districts. Ho Chi Minh City has a complex natural drainage system, including many sewer lines discharging water into rivers and canals connecting each other. The main river system is the Dong Nai–Saigon River system in the east and the Vam Co River system in the west.

2.2. Calculation of rainfall-runoff model (MIKE NAM)

- Using Hydrometeorological data at measuring stations in the study area and surrounding areas, collected from the Southern Regional Hydrometeorological Station from January 1, 2017, to December 1, 2017:

+ Daily rainfall data at five stations on the Saigon–Dong Nai river system: Ta Lai, Tri An, Tan Son Hoa, Dong Ban, and Loc Ninh.

+ Evaporation data estimated by Blaney–Crridle method based on temperature data of the Tan Son Hoa station.

+ Average daily flow data to the Tri An and Dau Tieng Reservoirs.

- According to the river system, the river basins in the study area are divided into basins and sub–basins. The basins are demarcated based on the database of the digital elevation model (DEM) (30 m × 30 m). The sub–basins area is considered the basis for the calculation of mean precipitation by the Thiessen method. The precipitation means for each sub–basin corresponding to the rainfall stations will be used as input for the NAM model (Figure 1).

2.3. MIKE 11 model

+ Cross–section data: the section is defined in compliance with the national standard elevation on the topographic map of 1:10,000 scale as a basis for determining the location of the river section on the hydraulic diagram (Cross-sectional data are inherited from the topic of HCMC climate change response plan in 2020).

+ The network consists of 79 large and small tributaries, 674 cross–sections, 68 points of entry and exit. The maximum distance dx on the tributaries is 500–1000 m, and the smallest is 100–200 m.

+ The upstream boundary data are calculated from the NAM model with 5 stations, specifically the water level at Go Dau and Tan An corresponding to Tay Ninh and Long An basins, and discharge flows of Phuoc Hoa, Tri An, and The The Dau Tieng Reservoirs.

+ The downstream boundary data are the water level at 4 stations (Soai Rap, Dinh Ba, Long Tau, Thi Vai) which is correlated from the water level data at Vam Kenh and Vung Tau stations (Figure 2).

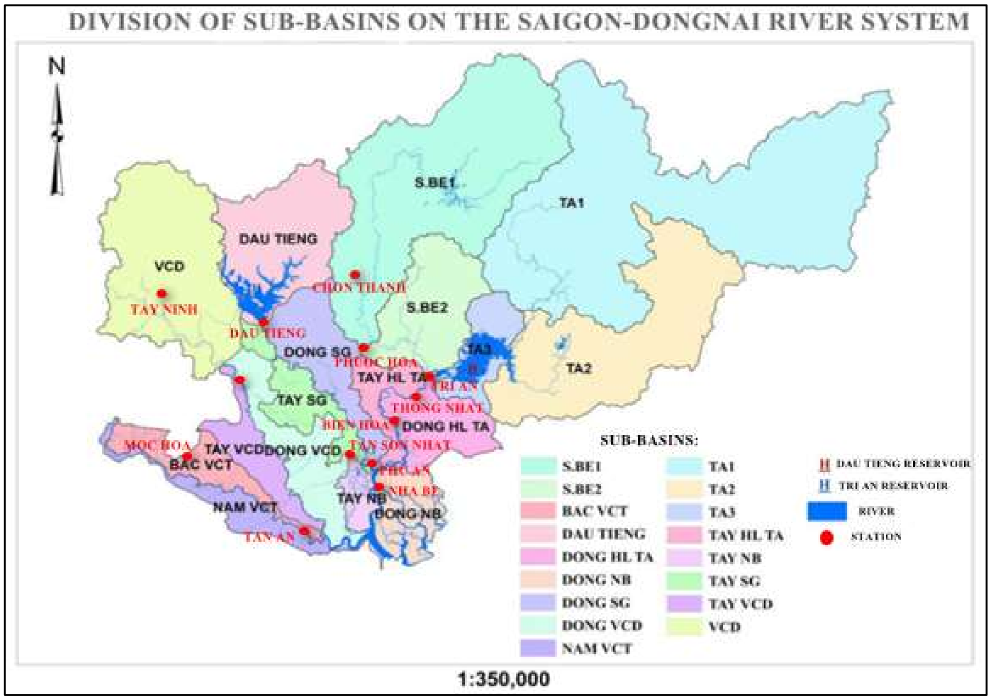


Figure 1. Division of sub–basins on the Saigon–Dong Nai River system.

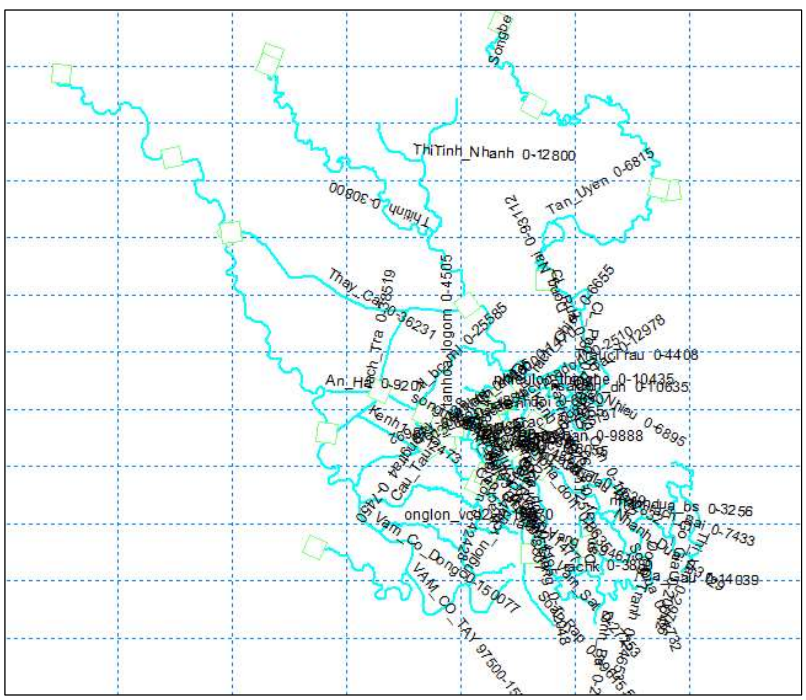


Figure 2. Hydraulic diagram of Saigon–Dong Nai river basin.

3. Results and Discussion

3.1. Results of calibration and validation of NAM model for rainfall–runoff

The calibration and verification are based on the flows to the Tri An Reservoir, the Dau Tieng Reservoir, and Be River "The Q data about the lake was collected at the hydro-meteorological station of Nam Bo province. On the Be river, Q data is taken from Phuoc

Long hydrological station to correct upstream. And Q returned to Phuoc Hoa lake to test the downstream side of the river", with the error between the calculated and measured values being evaluated by the coefficient of determination R^2 and NSE. The results of model calibration and verification are presented in detail in Table 1. In addition, the basin of the Dau Tieng Reservoir is also calibrated and tested further for three more stages with the parameters of the model taken in the year of further calibration in 2016.

The results of the correlation analysis between the measured and calculated flows are pretty good for the basins of Dau Tieng and Be rivers (NSE and R^2 are greater than 0.65) and good for the Tri An Reservoir ($R^2 > 0.8$). This result shows that the discharge process curve calculated from rain by NAM model is quite consistent with the measured flow process curve. The results of calibration and verification are presented representatively at the Tri An Reservoir as in Figure 3.

In general, the above results are consistent with the hydrological conditions of the study area. The set of parameters achieves high reliability, which is qualified to simulate the flow from rainfall, corresponding climate change scenarios. The runoff generated from the rain and the discharge of wastewater generated from economic activities is used as the inflow of rivers.

Table 1. Results of calibration and verification of NAM model.

Basin	**Coefficient**	**Calibration**		**Validation**				
		2016	**2017**	**2011–2015**	**2007–2010**	**2000**	**2010**	**2018**
The The Dau Tieng Reservoir	NSE	0.752		0.657	0.7	0.669		
	R^2		0.65					
Be River	NSE	0.867					0.717	
Tri An Reservoir	R^2	0.82						0.80

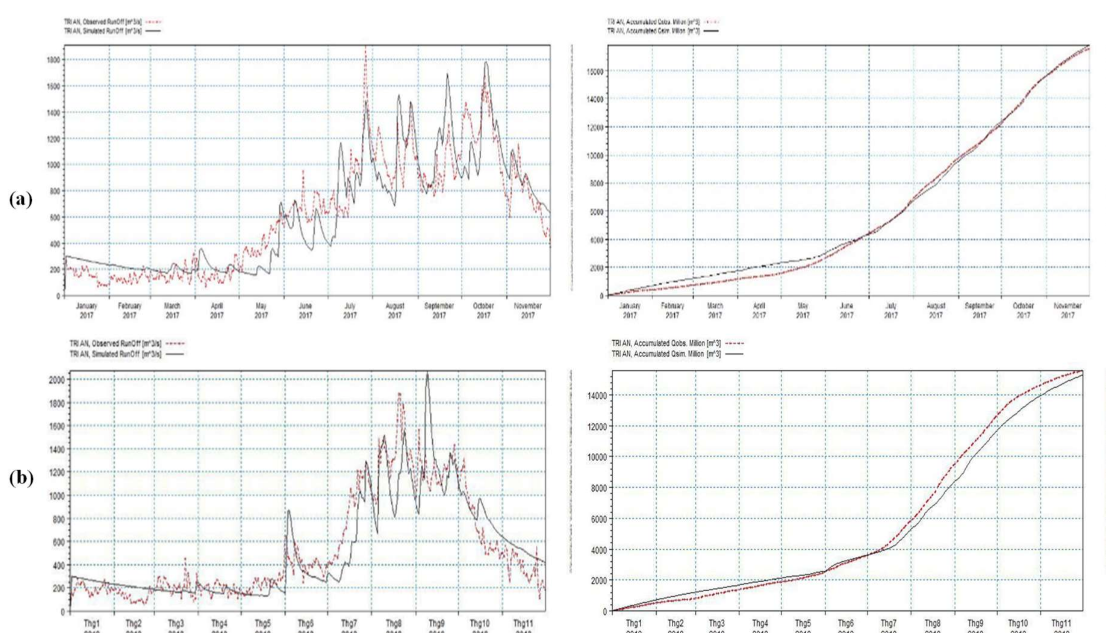


Figure 3. Results of calibration (a) and verification (b) of MIKE NAM model at Tri An reservoir.

Because the article inherits the results from the climate assessment project of HCMC. Therefore, data collection is quite difficult, the authors can only test the dry and rainy seasons in 1 year.

3.2. Calibration and validation results of the MIKE 11 model

+ Time to calibrate the model is taken from 0:00 on April 1, 2017 to 23:00 on April 30, 2017; then data for three days from 9:00 on April 26, 2017 to 8:00 p.m. on April 28, 2017, was extracted for hydraulic testing for the study area; time step $\Delta t = 1$ minute.

+ Initial conditions: At the initial time of taking the static water level, the flow Q = 0 m^3/s.

+ Stations for saline calibration and verification: Cat Lai, Nha Be, Phu An, Phu Cuong, Vam Sat, Vam Co, Hoa An, Binh Phuoc, from 9:00 April 26, 2017, to 20:00 April 28, 2017.

+ The time to calibrate the hydraulic model is from April 1-25, 2017. The time to test the hydraulic model is from April 26-28, 2017.

+ The time to test the salinity model is from 9:00 on April 26, 2017 to 20:00 on April 28, 2017.

3.3. Simulation results of saline intrusion according to the scenarios

3.3.1. Saline intrusion in Ho Chi Minh City in the current period

The saline intrusion has been defined by the boundaries of the salinity thresholds (SB) corresponding to the selection criteria for the salinity limit based on the influence on the demand for surface water of water treatment plants in the Saigon–Dong Nai basin, as presented explicitly in Table 2. To analyze the spread of salinity in the river, the displacement of the saline boundary over each period will be considered and evaluated based on the inherited mapping (Figure 5).

Table 2. The boundaries of the salinity thresholds affect the demand for surface water.

No.	Limits of saline zones correspond to salinity thresholds	Criteria for selecting the salinity limit based on the influence on the demand for surface water usage
1	< 0.25‰ SB1 (0.25‰)	Qualified for domestic water supply (after normal treatment)
2	0.25–0.5‰ SB2 (0.5‰)	Qualified for domestic water supply (after normal treatment), conservation of aquatic plants, and other purposes
3	0.5–1‰ SB3 (1‰)	Qualified for irrigation purposes or other uses with equivalent water quality requirements
4	1–2‰ SB4 (2‰)	- Good for brackish water aquaculture - Yield reduction of salt–sensitive crops
5	2–4‰ SB5 (4‰)	- Good for brackish water aquaculture - Yield reduction of different crops
6	4–8‰ SB6 (8‰)	- Cultivating some types of brackish–water aquatic products - Yield reduction of salt–sensitive crops
7	8–18‰ SB7 (18‰)	- Cultivating some types of brackish water aquatic products - Impossible for irrigation.
8	> 18‰	Saline intrusion, unusable.

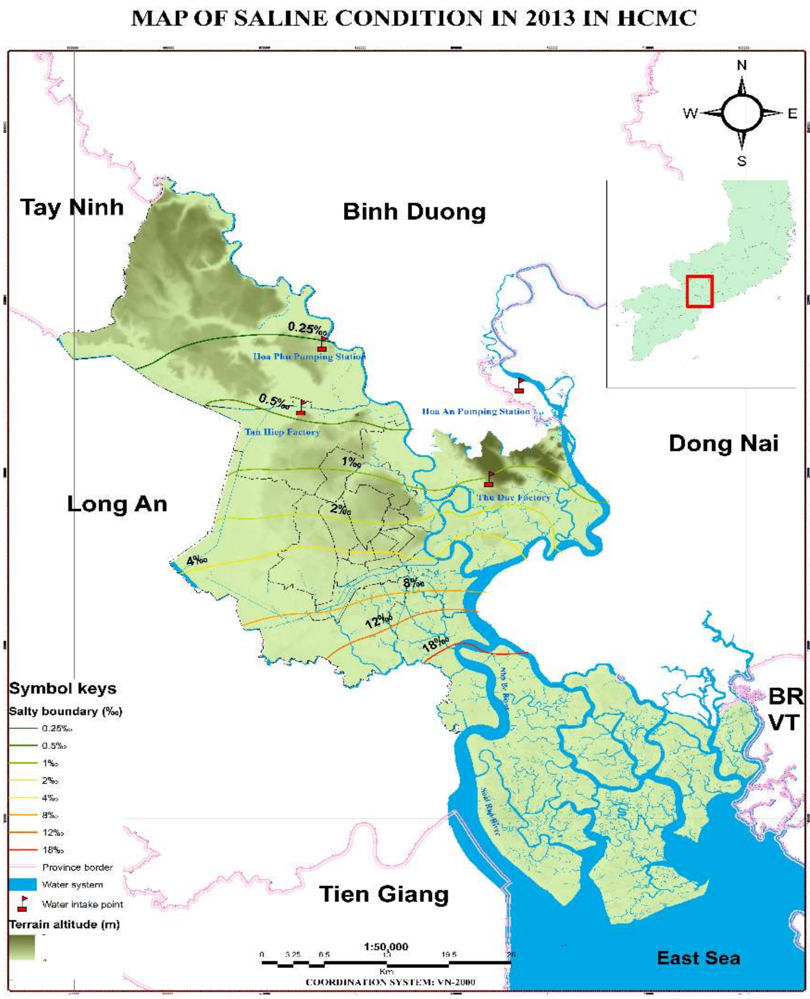


Figure 4. Map of saline condition in 2013 in HCMC.

Using 2013 as the current condition is because the article inherits some results from the project to update the action plan for Ho Chi Minh City in 2020.

a) Analysis of saline boundary on the Saigon River in the current condition

- SB1 < 0.25‰: farthest to the upstream of the Dau Tieng Reservoir, passing Hoa Phu pumping station, but the distance between this SB and the pumping station is negligible from 0.5–1 km.

- SB2 0.25–0.5‰: available at Tan Hiep water plant, from SB2 position, about 10 km from Hoa Phu pumping station to the downstream of the Saigon River.

- SB3 0.5–1‰: about 18 km from Hoa Phu pumping station and Binh Phuoc hydrological station, 5 km toward the downstream of the Dau Tieng Reservoir.

- SB4 1–2‰: SB4 is 5 km from SB5 along the length of the Saigon River from upstream to downstream.

- SB5 2–4‰: SB5 is 5 km from SB4 along the length of the Saigon River from upstream to downstream and 28 km from Hoa Phu pumping station and Tan Hiep water plant, and 18 km toward the upstream of the reservoir; This SB is located near Phu An hydrological station and about 1km from Thu Thiem salinity measurement station toward the upstream of the Dau Tieng Reservoir.

- SB6 4–8‰: SB6 is about 1 km from Cat Lai salinity measurement station toward the upstream.

- SB7 8–18‰: available at the intersection between Saigon River and Dong Nai River.

b) Analysis of saline boundary on the Dong Nai River in the current condition

- SB1 < 0.25‰: toward the upstream of Tri An Reservoir, SB1 goes further about 3 km from Hoa An pumping station.
- SB2 0.25–0.5‰: SB2 is located between Hoa An pumping station and Thu Duc water plant.
- SB3 0.5–1‰: available at the water source area of Thu Duc plant, about 10 km from Hoa An pumping station and about 0.5 km from Long Dai salinity measurement station toward the upstream of Tri An reservoir.
- SB4 1–2‰: SB4 is available at the location of the Cat Lai hydrological station.
- SB5 2–4‰: about 1–1.5 km from SB4.
- SB6, SB7 are evenly distributed along the river.

In general, from the distribution map of SB on the Saigon–Dong Nai river system in the HCMC area: SB1 and SB2 are evaluated to determine the area serving the domestic water supply after only the normal treatment process, conservation of aquatic plants, and activities for other purposes with similar water quality factors with salinity > 0.5‰. SB3 is assessed to determine the area for water use for irrigation or other purposes consistent with the salinity of this saline boundary. Similarly, SB4 and SB5 are suitable in conditions that can be treated by conventional systems and satisfied for most of the water demand for residential areas from SB to the upstream of the reservoir. Particularly for SB6, SB7 with high salinity < 18‰, it is impossible for water supply purposes or crops due to yield reduction, including salt–tolerant crops, but they can mainly be used for some good salt–tolerant aquatic species.

3.3.2. Impact of saline intrusion on water resources in the context of climate change in Ho Chi Minh City in case of no salinity prevention works

Under the impacts of climate change factors such as temperature, heat, rainfall, and sea–level rise, the hydraulic regime in the river is changed, and the saline intrusion is deeper toward the inner field, causing changes compared to the current status. The salinity change and salinity spreading tend to increase gradually in the future, toward the upstream of the Dau Tieng Reservoir in Saigon River and the Tri An Reservoir in Dong Nai River. For each RCP scenario, the movement of saline boundaries in each period (year) is different, corresponding to sea–level rise.

According to the sea level rise RCP4.5 and RCP8.5 with salinity risk atlas, it is shown that there are no significant differences between 2025 and 2030; it seems that salinity is not much intruded into the upstream. Particularly for the RCP scenario for the year 2050, the data about the sea level rise increases significantly, resulting in apparent changes in the risks of saline intrusion and salinity as well as the negative impacts on the domestic water supply of water treatment plants and regulating irrigation of canals and channels in the city. As a result, the study will analyze and assess the salinity changes in 2025 and 2030 in general and analyze separately and, more specifically, the salinity changes in 2050. The evaluation of the process of saline intrusion is based on the current situation and (in the context of) climate change in the Saigon and Dong Nai rivers from Table 3 to Table 6.

Table 3. Risk assessment of the saline intrusion according to the RCP4.5 scenario compared with the current situation in the absence of structures on the Saigon River.

Saline boundary	2025	2030	2050
Saline boundary 0.25‰ (SB1)	SB1 moves further about 0.25 km from Hoa Phu pumping station toward upstream of the		SB1 moves further the Hoa Phu pumping station about 3.5 km compared to the 2025 and 2030 scenarios.

Saline boundary	2025 2030	2050
	Dau Tieng Reservoir compared to the current situation.	
Saline boundary 0,5‰ (SB2)	SB1 moves further into the field, about 3–5 km from Hoa Phu pumping station toward upstream of the Dau Tieng Reservoir compared to the current situation.	From the position from Hoa Phu pumping station to the upstream of Dau Tieng lake, it was moving about 1.5 km compared to the current situation and 5 km compared to the period of 2025–2030.
Saline boundary 1‰ (SB3)	SB3 is about 24–25 km from Hoa Phu pumping station toward downstream.	Compared to 2013, SB3 continues to move upstream, about 20 km from Hoa Phu pumping station toward downstream.
Saline boundary 2‰ (SB4)	It is 35 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	Compared to 2013, it is 30km from Hoa Phu pumping station, moving about 5km more.
Saline boundary 4‰ (SB5)	It is 46 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	It is 45 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.
Saline boundary 8‰ (SB6)	It is 60 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	It is 56 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.
Saline boundary 18‰ (SB7)	It is 70 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	It is 67 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.

Table 4. Risk assessment of the saline intrusion according to the RCP8.5 scenario compared with the current situation in the absence of structures on the Saigon River.

Saline boundary	2025 2030	2050
Saline boundary 0,25‰ (SB1)	SB1 moves further about 0.25 km from Hoa Phu pumping station toward upstream of the Dau Tieng Reservoir compared to the current situation.	It is 5 km from Hoa Phu pumping station upstream to Dau Tieng lake, increasing 4 km more than in 2013.
Saline boundary 0,5‰ (SB2)	SB1 moves further into the field, about 3–5 km from Hoa Phu pumping station toward upstream of the Dau Tieng Reservoir compared to the current situation.	It is 9.1 km from Hoa Phu pumping station toward Dau Tieng lake downstream, increasing 7 km more than in 2013.
Saline boundary 1‰ (SB3)	SB3 is about 24–25 km from Hoa Phu pumping station toward downstream	It is 19.7 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.
Saline boundary 2‰ (SB4)	It is 35 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	It is 30 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.
Saline boundary 4‰ (SB5)	It is 46 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	It is 45 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.
Saline boundary 8‰ (SB6)	It is 60 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	It is 56 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.
Saline boundary 18‰ (SB7)	It is 70 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.	It is 66 km from Hoa Phu pumping station toward downstream to Dau Tieng lake.

Table 5. Risk assessment of the saline intrusion according to the RCP4.5 scenario compared with the current situation in the absence of structures on the Dong Nai River.

Saline boundary	2025	2030	2050
Saline boundary 0,25‰ (SB1)	SB1 moves further about 3–5 km from Hoa Phu pumping station toward upstream of the Tri An Reservoir compared to the current situation.		Moving further upstream from Hoa An Pumping Station, about 8 km toward upstream, compared to 2013.
Saline boundary 0,5‰ (SB2)	SB1 moves further into the field, about 6–7 km from Hoa An pumping station toward upstream of the Tri An Reservoir compared to the current situation, increasing about 2–3 km.		It is 4 km from Hoa An pumping station toward downstream to Tri An lake, increasing about 5 km.
Saline boundary 1‰ (SB3)	It is 17.5 km from Hoa An pumping station toward downstream to Tri An lake, increasing about 1.5 km.		It is 14.5 km from Hoa An pumping station toward downstream to Tri An lake, increasing about 5 km.
Saline boundary 2‰ (SB4)	It is 30 km from Hoa An pumping station toward downstream to Tri An lake.		It is 27 km from Hoa An pumping station downstream to Tri An lake.
Saline boundary 4‰ (SB5)	It is 34 km from Hoa An pumping station toward the downstream to Tri An lake.		It is 32 km from Hoa An pumping station toward downstream to Tri An lake.
Saline boundary 8‰ (SB6)	It is 40 km from Hoa An pumping station toward downstream to Tri An lake.		It is 37 km from Hoa An pumping station toward the downstream to Tri An lake.
Saline boundary 18‰ (SB7)	It is 52 km from Hoa An pumping station toward the downstream to Tri An lake.		It is 49 km from Hoa An pumping station toward downstream to Tri An lake.

Table 6. Risk assessment of the saline intrusion according to the RCP8.5 scenario compared with the current situation in the absence of structures on the Dong Nai River.

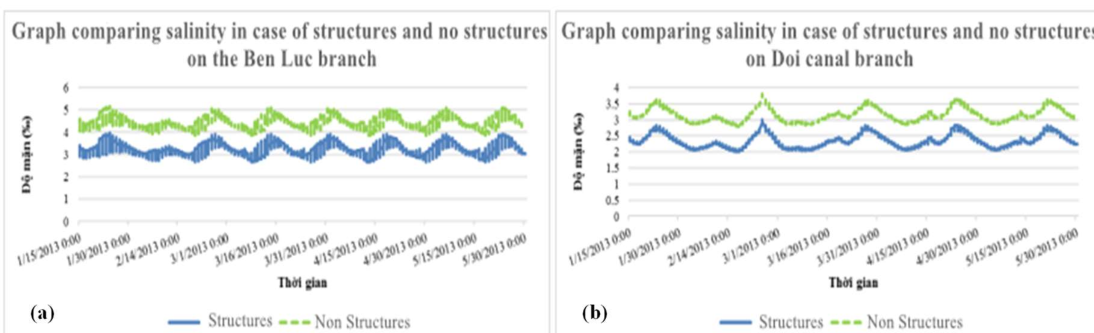
Saline boundary	2025	2030	2050
Saline boundary 0,25‰ (SB1)	SB1 moves further about 3–5 km from Hoa Phu pumping station toward upstream of the Tri An Reservoir compared to the current situation.		SB1 is 8km from the pumping station upstream to Tri An lake.
Saline boundary 0,5‰ (SB2)	SB1 moves further into the field, about 6–7 km from Hoa An pumping station toward upstream of the Tri An Reservoir compared to the current situation, increasing about 2–3 km.		It is 3 km from Hoa An pumping station toward downstream to Tri An lake, increasing about 6 km.
Saline boundary 1‰ (SB3)	It is 17.5 km from Hoa An pumping station toward downstream to Tri An lake, increasing about 1.5 km.		It is 14 km from Hoa An pumping station toward downstream to Tri An lake, increasing about 5 km.
Saline boundary 2‰ (SB4)	It is 30 km from Hoa An pumping station toward downstream to Tri An lake.		It is 27 km from Hoa An pumping station downstream to Tri An lake.
Saline boundary 4‰ (SB5)	It is 34 km from Hoa An pumping station toward downstream to the Tri An Reservoir.		It is 31.5 km from Hoa An pumping station toward downstream to Tri An lake.
Saline boundary 8‰ (SB6)	It is 40 km from Hoa An pumping station toward downstream to Tri An lake.		It is 37 km from Hoa An pumping station toward the downstream to Tri An lake.
Saline boundary 18‰ (SB7)	It is 52 km from Hoa An pumping station toward the downstream to Tri An lake.		It is 48.5 km from Hoa An pumping station toward downstream to Tri An lake.

3.3.3. Impact of saline intrusion on water resources in the context of climate change in Ho Chi Minh City in case of available salinity prevention works

The Saline control gate are mainly located at the intersections of rivers entering the field. If the works are completed and put into operation by 2019, the effectiveness of these gates in salinity prevention is shown in Figures 6a–6b.

When there are no structures to prevent salinity in normal conditions, salinity will increasingly encroach into the upstream area. The saline intrusion will be spread far away in the future, narrowing the safety level of freshwater sources, affecting the daily production and daily life of the local people. Thanks to the operation of 6 Saline control gate in the future, the salinity will be significantly reduced on small river tributaries going deep into the field, such as Ben Luc branch, Doi cannel – Te cannel, Phu Xuan canal (District 7), Cay Kho canal (Nha Be). However, the effectiveness of salinity prevention on the two main rivers (Saigon River and Dong Nai River) is negligible.

In 2025, salinity at a point located 1.3 km from Phu An station, nearly 1 km from Ben Nghe sluice, along the Ben Luc branch (in District 1) will decrease by nearly 36% when the works are in operation. Similarly, the salinity concentration at a point on the Doi cannel branch located 1.4 km from Tan Thuan sluice along the Doi cannel branch will decrease by nearly 29%, showing the difference in salinity concentration in the 2 cases. On the Saigon River, the salinity does not change significantly during the salinity observation at any point, about 100 m from Phu Cuong station upstream and 500 m from Hoa Phu water pumping station downstream (Figure 6c). The salinity in the case of available structures increases by 0.002% compared to the case without structures. Therefore, the Saline control gate can only reduce salinity into the field, reduce salinity in water for production and irrigation, but they are not effective for the two main rivers, Saigon River and Dong Nai River. In short, the effect of the works on the deep saline intrusion upstream of the main river can be negligible.



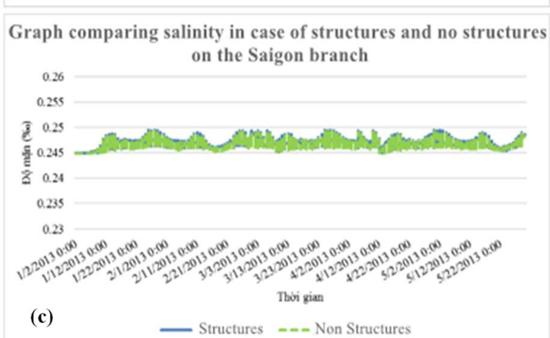


Figure 5. (a) The Effectiveness of saline intrusion prevention of Ben Nghe gate (6.3 km from An Phu Station); (b) The Effectiveness of saline intrusion prevention on Doi channel branch (1.4 km from Doi channel–Sai Gon); (c) The effectiveness of saline intrusion prevention on Sai Gon branch (100 m from Phu Cuong station toward upstream).

The saline intrusion toward inland in the Ho Chi Minh City in the RCP4.5 scenario 2025 in the case of operational Saline control gate is presented in below Figure 7.

Figure 6. Map of saline intrusion in Ho Chi Minh City under the 2025–RCP4.5 scenario.

4. Conclusion

As Saigon River and the Dong Nai River are the two main rivers serving the water supply of the city, the saline boundaries impacting river water quality are analyzed corresponding to the location of the Hoa Phu raw water pumping station (Cu Chi) on the Sai Gon River and Hoa An station (Dong Nai) on the Dong Nai River.

According to the current scenario, SB1 0.25‰ on the Saigon River moves the farthest to the upstream of the Dau Tieng Reservoir, going through Hoa Phu pumping station with a distance of 0.5–1 km. On the Dong Nai River, SB1 moves toward the upstream of the Tri An Reservoir, about 3 km from Hoa An pumping station. The differential in salinity between the two scenarios RCP 4.5 and RCP 8.5 in the absence of salinity compartments, on the Saigon River branch, respectively in 2025–2030 and 2050, according to RCP4.5, the salty border is 0.25 ‰ away Hoa Phu station is 0.25 km in turn; 3.5 km compared to 0.25 km; 3.5 km according to RCP8.5. On Dong Nai river branch, compared with station Hoa An, the corresponding figures are 3–5 km; 8.0 km under RCP4.5 and 3–5 km; 8.0 km according to RCP8.5.

When the Saline control gate are put into operation, the saline intrusion shall decrease significantly on small tributaries such as Ben Luc, Doi channel–Te channel, Phu Xuan canal (District 7), Cay Kho canal (Nha Be) but these gates do not have many effects on the two main rivers, Saigon River and Dong Nai River. However, the salinity of the Saigon River toward upstream will increase by 0.002% compared to the case without the structure.

Therefore, the proper usage of the surface water should be paid attention to distribute the surface water and rain between the two seasons reasonably to serve the daily life, economic activities, and operation of water treatment plants in the future with the impacts of climate change.

However, the study of factors influencing saline intrusion in Ho Chi Minh city remains limited. Especially the regulation of neighboring reservoirs and the Tri An system from the upstream and the limitted of saline monitoring data. This factor necessitates a long-term research complex because of the climate change of the current period and is influenced by reservoir regulation upstream.

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Conflict of interest: The authors declare that there are no conflicts of interest.

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