Research Paper

ASSESSING THE IMPACTS OF THE CHANGES IN THE UPSTREAM FLOW AND SEA LEVEL RISE DUE TO CLIMATE CHANGE ON SEAWATER INTRUSION IN HO CHI MINH CITY USING THE HEC - RAS 1D MODEL

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ARTICLE HISTORY

Received: April 12, 2018; Accepted: May 08, 2018
Publish on: December 25, 2018

ABSTRACT

The aim of this study was to assess the impacts of the changes in upstream flow and sea level rise due to climate change on seawater intrusion in the Sai Gon and Dong Nai Rivers in Ho Chi Minh City. The HEC-RAS model was used for simulating the salinity intrusion. The results of model calibration and validation indicated that the HEC-RAS model could simulate reasonably the streamflow and salinity concentration with NSE values exceeding 0.5 for both calibration and validation periods. Based on the results in the calibration in the HEC-RAS model, differences in salinity concentration under the separate and combined impacts of the changes in the upstream flow and sea level rise were analyzed. The results indicated that the salinity intrusion is likely to increase by 0.9 to 13% under the impact of sea level rise, by 1.6 to 4.3% under the impact of the changes in the upstream flow, and by 2.6 to 16.9% under the combined impacts of changes in the upstream flow and sea level rise. The research obtained in this study could be useful for local authorities in proposing solutions to reduce the impacts of seawater intrusion in Ho Chi Minh City.

Keywords*: HEC-RAS, Ho Chi Minh City, sea level rise, seawater intrusion, changes of river flow in the upstream.*

1. Introduction

Climate change is one of the biggest challenges to humanity in the 21st century. The Intergovernmental Panel on Climate Change - Fifth Assessment Report (IPCC-AR5) indicated that the coastal countries in Southeast Asia, including Vietnam, are highly vulnerable to climate change and sea level rise (SLR) (IPCC, 2013). One of identified major impacts of climate change and SLR in Viet Nam is salinity intrusion in the dry season. Thus, understanding the changes in salinity intrusion under these impacts will be useful for water resource management and agricultural development.

In recent years, many researcher have investigated the impact of climate change and SLR on salinity intrusion. For example, Ha et al. (2016) used the one-dimensional hydraulic model to simulate the salinity intrusion under the impact of SLR in the Mekong Delta and they showed that the salinity concentration increases by 1.2 to 10% in the future. Tri and Tuyet (2016) investigated the effect of climate change on the seawater intrusion in the Ca River Basin and they indicated that the impacts of salinity intrusion to the inland will increase in the future. However, there are very few studies on evaluating the separate and combined impacts of climate change and SLR on salinity intrusion. The objective of

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this study was assessing the separate and combined impacts on saltwater intrusion under changes in the upstream flow and SLR due to climate change in the Sai Gon and Dong Nai Rivers in Ho Chi Minh City (HCMC). The model used in this study was the HEC-RAS 1D model. This model was selected because of its availability and user-friendliness in handling input data and output results. Besides that, the HEC-RAS model has been used as a powerful tool for modeling the streamflow and water quality in the rivers.

2. Study area

HCMC is one of the largest cities in Vietnam, which has the fastest economic growth in the country. HCMC is situated on the downstream of the Dong Nai River Basin. The distance of the city center to the East Sea is about 50 km (Van Leeuwen et al., 2016) (Figure 1).

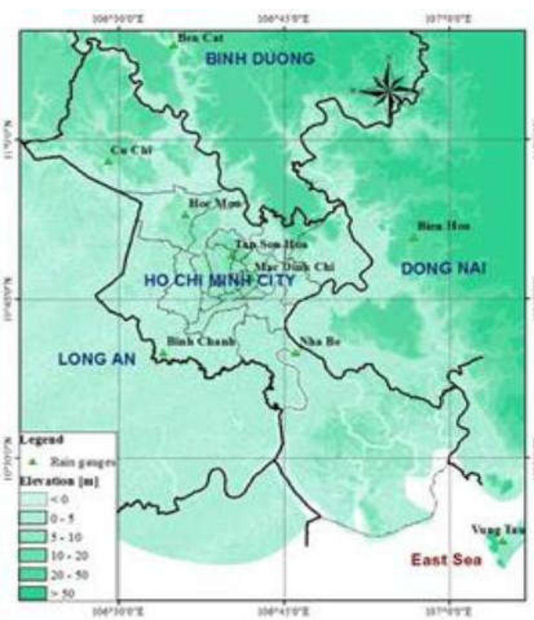


Fig. 1. Location of the study area

The city has an area of about 2061 km^2 and a population of nearly 8.45 million in 2017 (GSO, 2018). HCMC consists of 24 districts, including 19 urban districts and 5 suburban districts. These suburban districts are accounting for 79% of the total area of the city and 16% of the total urban population. HCMC is the biggest economic center in Vietnam and a transport hub of the southern region. This area is located in tropical area and has two distinct seasons: the rainy season and the dry season. The average annual rainfall is quite high, about 1800mm. The rainy season lasts from May to October and accounts for 80-85% of the total annual precipitation. In addition, HCMC is vulnerable to flooding due to land subsidence, urbanization, heavy rainfall, flow changes from the upstream, and SLR (Van Leeuwen et al., 2016).

3. Methodology

3.1 HEC-RAS model

HEC-RAS 1D model is developed by the Hydrologic Engineering Center, a division of the Institute for Water Resources, U.S Army Corps of Engineers. It is used to simulate one-dimensional unsteady flow and water quality in the rivers. In the HEC-RAS model, two modules, including hydrodynamic module and advection-dispersion module, were used for the present study.

In the hydrodynamic module, HEC-RAS solves the following 1-D equations of continuity and momentum known as the Saint-Venant equations (Brunner, 2010). These equations are written as follows:

$$\frac{\partial A}{\partial t} + \frac{\partial S}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0 \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (VQ)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \quad (2)$$

Where: Q: flow discharge (m^{3}s^{-1})

A: the cross-sectional area (m^2)

X: distance along the channel (m)

S: storage from non-conveying portions of cross section (m^2)

q_l: lateral inflow per unit length (m^{2}s^{-1})

V: velocity (ms^{-1})

G: acceleration of gravity (ms^{-2})

S_f: friction slope for the entire cross section

T: the time (s).

The solution of these equations is based on an implicit finite difference scheme.

In the advection-dispersion module, the basic equation is the mass balance equation of a conservative constituent (Brunner, 2010). This is written as follows:

$$\frac{\partial AC}{\partial t} = \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) - \frac{\partial QC}{\partial x} \quad (3)$$

Where: C: the salinity concentration (gL^{-1})

A: the cross-sectional area (m^2)

Q: the freshwater discharge (m^3s^{-1})

D: the longitudinal dispersion coefficient ($m^2 s^{-1}$).

3.2 HEC-RAS model set up

The HEC-RAS 1D model was applied to simulate flow and salinity intrusion in Sai Gon and Dong Nai Rivers. In the hydrodynamic module, the discharge at three upstream stations and water level at six downstream stations water-level boundaries were assigned as boundary conditions. These boundary conditions were given based on the observed data in 2009 at stream gauges, collected from Hydro-Meteorological Data Center (HMDC). The cross section of the rivers was collected from Southern Institute of Water Resources Research (SIWRR). For simulation of salinity intrusion, the salinity concentration of the upstream boundaries was zero and the salinity concentration of the downstream boundaries was given by measured data. The salinity data in 2009 also were collected from HMDC. Calibration was performed from 06/03/2009 to 15/03/2009 and the observed data from 16/03/2009 to 31/03/2009 was used for validating. The location of observed stations was shown in Figure 2.

The model performance was evaluated by using three statistical indices, including coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), and ratio of the root mean square error to the standard deviation of measured data (RSR). According to Moriasi et al. (2007), the model simulation can be considered as satisfactory when NSE and R^2 are above 0.5 and RSR is less than 0.7.

3.3 Scenarios of the upstream flow change and sea level rise

In this study, scenarios of SLR and changes in upstream flow due to climate change in Sai Gon – Dong Nai Rivers were given based on the previous studies conducted by Katzfey et al. (2014) and Khoi et al. (2015). The RCP 8.5 scenario (high emission) was considered in this study. The RCP 8.5 scenario was selected for this study because it emphasizes the largest impacts of climate change due to the assumption of this greenhouse gas emission scenario, which is suitable to the studies on salinity intrusion. Table 1 summarizes the changes in sea level and upstream flow for the 2020s (2015-2040), 2050s (2045-2070), and 2080s (2075-2100) in the dry season under the RCP 8.5 scenario.

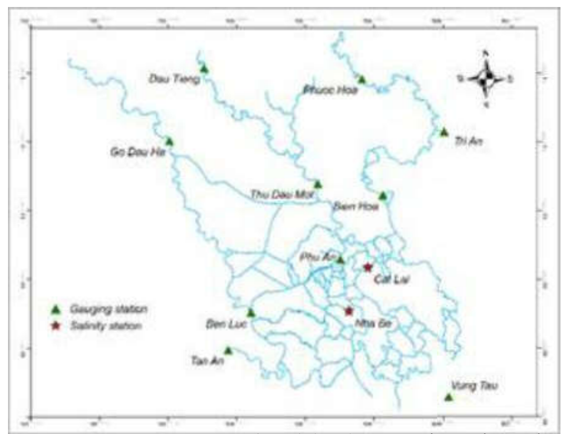


Fig. 2. River network with observed stations in study area

Table 1. Scenarios for SLR and changes of upstream flow in the dry season in the study area

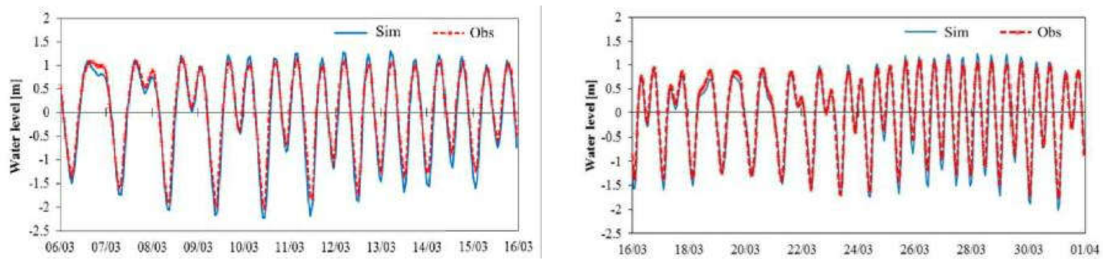
Period	Sea level rise	Upstream flow change
2020s	0.04m	-30%
2050s	0.21m	-29%
2080s	0.47m	-47%

4. Results and discussion

4.1 Calibration and validation of HEC-RAS for simulating the streamflow and salt concentration

Calibration and validation were performed to improve model performance at the main gauging stations. Water level calibration was conducted first, followed by salinity calibration.

Figure 3 compares simulated and observed hourly water level for calibration and validation periods at Nha Be station. Good agreement can be seen between the simulated and observed water level during these periods. The values of NSE, R^2, and RSR for hourly calibration and validation at all stations are listed in Table 2. For both calibration and validation periods.



(a) Calibration period (06/03 - 15/03/2009) *(b) Validation period (16/03 - 31/03/2009)*

Fig. 3. The calibration and validation results of water level at the Nha Be station

Table 2. The performance of HEC-RAS for the flow simulation

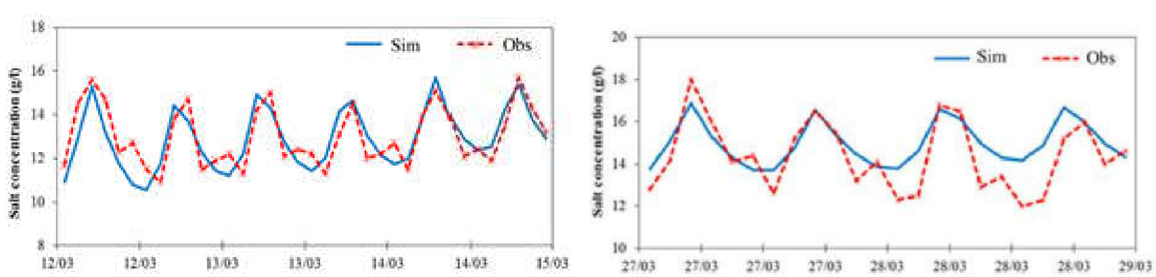
Station	Calibration (06 - 15/03/2009)			Validation (16 - 31/03/2009)		
	NSE	R^2	*RSR*	*NSE*	R^2	*RSR*
Thu Dau Mot	0.87	0.95	0.36	0.87	0.94	0.38
Bien Hoa	0.94	0.96	0.25	0.91	0.96	0.30
Nha Be	0.92	0.96	0.29	0.92	0.96	0.28
Phu An	0.92	0.96	0.29	0.95	0.97	0.21
Ben Luc	0.90	0.94	0.32	0.85	0.94	0.39

Because of a lack of salinity data, the salinity calibration was performed for three days. The calibration and validation results of salinity concentration for at the Nha Be station was presented in Figure 4. The results of statistical evaluations at all stations (Table 3) suggest an agreement between measured and simulated salinity concentration. This is confirmed by the NSE and R^2 values above 0.52, and the RSR values below 0.6.

Considering the goodness-of-fit statistics and calibration and validation results discussed above, it is generally concluded that the HEC-RAS model can simulate satisfactorily the streamflow and salinity concentration for the Sai Gon and Dong Nai Rivers. And, the well-calibrated model was used to investigate the salinity intrusion under the separate and combined impacts of the upstream flow change and SLR.

Table 3. The performance of HEC-RAS for the simulation of salt concentration

Station	Calibration (12 - 15/03/2009)			Validation (27 - 29/03/2009)		
	NSE	R^2	*RSR*	*NSE*	R^2	*RSR*
Nha Be	0.63	0.68	0.60	0.52	0.69	0.60
Cat Lai	0.78	0.79	0.47	-	-	-



(a) Calibration period (12/03 - 15/03/2009) *(b) Validation period (27/03 - 29/03/2009)*

Fig. 4. The calibration and validation results of salt concentration at the Nha Be station

4.2 Separate and combined impacts of the changes in upstream flow and SLR on salinity intrusion

Based on the simulation results for the dry season in 2009, the map of salinity intrusion for the study area in the baseline period was established (Figure 5). In general, the salinity with a concentration greater than 4 g/l, which affects the agricultural activities, had intruded up to 68 km into the rivers. The salinity concentration reduced when it goes up to the upstream river. And, the salinity level of 0.25 g/l had intruded up to 93 km from the Soai Rap estuary.

To investigate the separate and combined impacts of climate change and SLR on salinity intrusion, the approach which varies only one factor or variable at a time while keeping others fixed was used. The following three scenarios were investigated, including changes in SLR considered in Scenario 1, changes in the upstream flow considered in Scenario 2, and changes in SLR and upstream flow considered in Scenario 3. Table 4 illustrates the average changes in salinity concentration in the RCP 8.5 scenario under the three scenarios. Under the impact of SLR, the salinity concentration increases by 0.9 to 13%. In addition, the changes in the upstream flow will increase the salinity concentration by 1.6 to 4.3%. In case of combined impact of changes in sea level and upstream flow, the salinity concentration is predicted to increase by 2.6 to 16.9%. In general, the separate and combined impacts of SLR and the upstream flow change will increase salinity intrusion in the Sai Gon and Dong Nai Rivers in the future, and the salinity intrusion have stronger responses to SLR than the upstream flow change. These changes mean that the saltwater will move to inland in the Sai Gon and Dong Nai Rivers in the future and have significant impacts on agricultural activities as well as livelihoods for the HCMC citizens.

Table 4. Percentage changes in salinity concentration under sea level rise scenarios

Period	Nha Be			Cat Lai		
	Sce. 1	Sce. 2	Sce. 3	Sce. 1	Sce. 2	Sce. 3
2020s	0.9%	1.7%	2.6%	1.3%	2.8%	4.1%
2050s	4.6%	1.6%	6.1%	6.7%	2.7%	9.2%
2080s	8.8%	2.6%	11%	13%	4.3%	16.9%

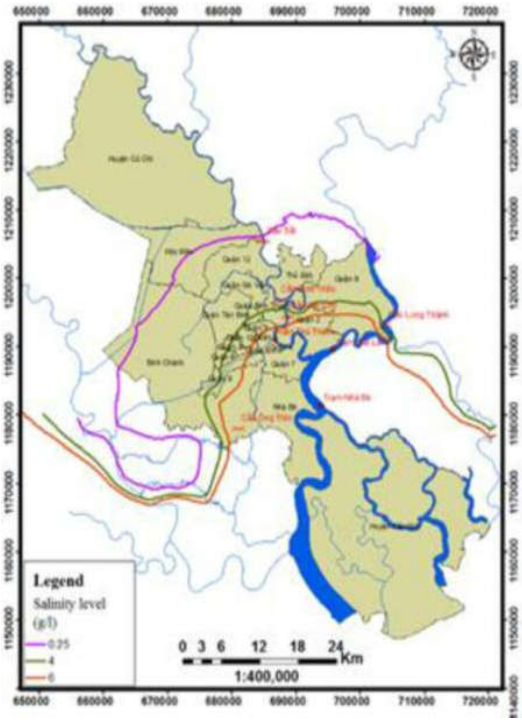


Fig. 5. Map of the salinity intrusion in the baseline period

5. Conclusion

This study investigated the separate and combined effects of SLR and the changes in the upstream flow c due to climate change on salinity intrusion in HCMC by using the HEC-RAS model. The calibration and validation results were carried out to evaluate model performance in simulation of streamflow and salinity concentration. The results indicated that the HEC-RAS is a useful tool for assessing impacts of SLR and changes in the upstream flow in HCMC. Under the separate and combined impacts of changes in sea level and upstream flow, the saltwater will move deeply into inland in the dry season. And, the SLR influences salinity intrusion in the study area more strongly than due to the changes in the upstream flow. The results obtained in this study could be useful for managing water resources in this region through enhancing the understanding of the impacts of climate change and SLR on salinity intrusion.

Acknowledgements

The study was supported by Science and Technology Incubator Youth Program, managed by Center for Science and Technology Development, Ho Chi Minh Communist Youth Union, the contract number is "20/2018/HĐ-KHCN-VƯ".

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