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IMPACTS OF CLIMATE CHANGE AND SEA LEVEL RISE ON SALINITY INTRUSION IN THE LOWER DONG NAI RIVER SYSTEM

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ABSTRACT

Ho Chi Minh City (HCMC) is ranked among the top 10 cities in the world most likely to be severely affected by climate change and sea level rise (SLR). This study was to assess the impacts of change of upstream flow and sea level rise due to climate change on salinity intrusion in HCMC. The MIKE 11 model with modules hydrodynamic (HD) and advection-dispersion (AD) was applied to this problem by setting up the whole lower Dong Nai river system. Based upon the observed water level and salinity concentration data in 2009, the calibration and validation results indicated that the MIKE11 model was able to simulate the streamflow and salinity concentration with NSE values exceeding 0.6 for both calibration and validation periods. As a result, the differences in salinity concentration under climate change and SLR scenarios were analyzed. The simulated results illustrate that the saltwater will move inland in the future, especially in the dry season.

Keywords: climate change, MIKE 11, Dong Nai river system, sea level rise, salinity intrusion.

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 [1]. HCMC is the biggest city in Vietnam which is a transport hub of the southern region and largest port system in this country [2]. The city center is about 50 km from the East Sea; therefore, it has been severely impacted by climate change and SLR. One of identified major impacts of climate change and SLR in HCMC is salinity intrusion in the dry season. Thus, understanding the changes in salinity intrusion under these impacts will be useful for HCMC in managing water resources. The objective of this study was evaluating the impacts on saltwater intrusion under changes of streamflow from the upstream and SLR in the whole lower Dong Nai river system. The study results are expected to provide more insight into the changes of salinity intrusion in the future and to provide local managers useful information in managing water resources and planning agriculture.

2. MATERIALS AND METHODS

2.1. Study area

Located in the South of Vietnam, HCMC is the biggest city in Vietnam. HCMC is situated on the downstream of the Dong Nai River Basin and has an area of about 2095 km^2 with population of nearly 8 million inhabitants in 2014. HCMC consists of total 24 districts, 19 urban and 5 suburban. The suburban districts are accounted for 79 % of the total area of the city and 16 % of the total urban population. This area is located in tropical area and has two distinct seasons: the rainy season and the dry season. The average annual rainfall is relatively high, about 1800 mm. The rainy season lasts from May to October and account for 80 – 85 % of the total annual precipitation. Furthermore, HCMC is vulnerable to flooding due to land subsidence, urbanization, heavy rainfall, flow from the upstream, and sea level rise [2].

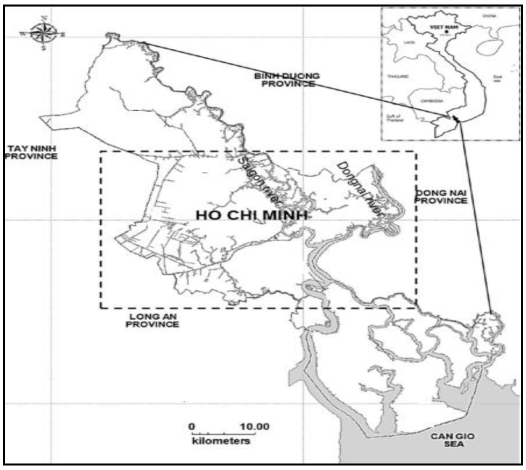

Figure 1. Location of the study area [3].

2.2. MIKE 11 model

MIKE 11 model is a dynamic, one-dimensional modeling tool for simulating flow, water quality, and sediment transport in river and channel network [4]. The governing equations used in MIKE 11 in solving hydraulic problems in rivers and channels are known as Saint-Venant equations. These are written as follows:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\alpha \frac{Q^2}{A} \right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0 \tag{2}$$

where Q (m^3/s) is flow discharge, h (m) is flow depth, A (m^2) is the cross-sectional area, q (m^2/s) is lateral inflow, C ($m^{1/2}/s$) is Chezy resistance coefficient, R (m) is hydraulic radius, α is momentum distribution coefficient, x (m) is the space coordinate, and t (s) is the time. The solution of these equations is based on an implicit finite difference scheme.

The advection-dispersion equation in MIKE 11 model is based on the mass conservation equation. This is written as follows:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} + \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) = -AKC + C_2 q \qquad (3)$$

where C is the concentration, D is the dispersion coefficient, K is the linear decay coefficient, and C_2 is the source/sink concentration. Further details can be found in the MIKE 11 Reference Manual [4].

2.3. MIKE 11 model set-up

Two modules of the MIKE 11 model were hydrodynamic (HD) for flow simulation and an advection-dispersion (AD) for simulation of salinity intrusion. It was applied for the lower Dong Nai river system. HD module has three discharge boundaries and five water-level boundaries. These boundary conditions were given based on the observed data in 2009 at stream gauges, collected by Hydro-Meteorological Data Center (HMDC). The topography of the rivers was collected by Southern Institute of Water Resources Research (SIWRR). In the AD module, 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 by HMDC. The HD and AD modules were calibrated with the observed data from 06/03/2009 to 16/03/2009 and the validated data from 17/03/2009 to 31/03/2009. The location of observed stations was shown in Figure 2.

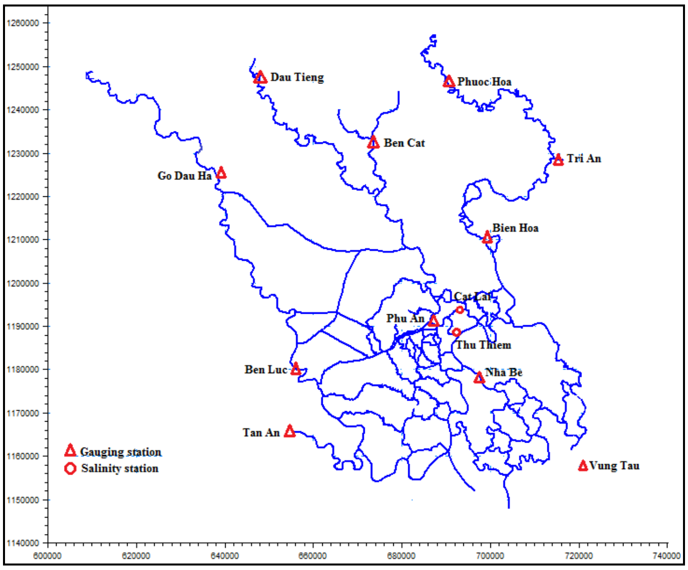

Figure 2. Schematization of River network in MIKE 11 with observed stations.

The model performance was evaluated by using Nash-Sutcliffe efficiency (NSE). According to Moriasi et al. (2007) [5], model simulation can be considered as satisfactory when NSE is above 0.5.

2.4. Climate change and sea level rise scenarios

In this study, scenarios of sea level rise and changes of streamflow from upstream due to climate change for the lower Dong Nai river system was given based on the studies that were conducted by Katzfey et al. (2014) [6] and Khoi et al. (2015) [7]. The RCP 4.5 scenario (average emission) was considered in this study. Table 1 summarizes the changes in sea level and the changes in streamflow from upstream for the 2020s (2015-2040), 2050s (2045-2070), and 2080s (2075-2100) in the dry season under the RCP 4.5 scenario.

Table 1. Scenarios for SLR and change in streamflow from upstream in the study area.

Period	SLR	Change in streamflow from the upstream
2020s	0.03 m	-14 %
2050s	0.17 m	-15 %
2080s	0.35 m	-26 %

3. RESULTS AND DISCUSSION

3.1. Calibration and validation of MIKE 11

Figure 3 compares the simulated and observed hourly water level for calibration and validation periods at the Phu An station. Good agreement can be seen between the simulated and observed water level during these periods. The NSE values for hourly calibration and validation at all stations are listed in Table 2. For both calibration and validation periods, NSE values exceed 0.70. These values indicated good MIKE 11 performance in simulation of streamflow according to the performance criteria of Moriasi et al. (2007) [5]. This is important for simulation of salinity intrusion.

Table 2. The performance of MIKE 11 for the simulation of water level.

Station	Calibration (06/03 – 16/03/2009)	Validation (16/03 – 17/03/2009)
	NSE	NSE
Thu Dau Mot	0.93	0.92
Bien Hoa	0.94	0.95
Nha Be	0.9	0.91
Phu An	0.96	0.96
Ben Luc	0.8	0.78

Because of a lack of salinity data, the salinity calibration was performed for few days (08/03 – 16/03/2009). The comparison plot of simulated and observed salinity concentration for the calibration and validation periods at the Cat Lai and Thu Thiem station was presented in Figure 4. The results of statistical evaluations at all stations (Table 3) suggest a fit between measured and simulated salinity concentration. This is confirmed by the NSE values above 0.68.

Considering the goodness-of-fit statistics and the statistical evaluations discussed above, it is generally concluded that the MIKE 11 model can simulate the streamflow and salinity concentration with satisfactory results for the lower Dong Nai river system. And, the well-calibrated model was used to investigate the salinity intrusion under the scenarios of SLR and streamflow from upstream.

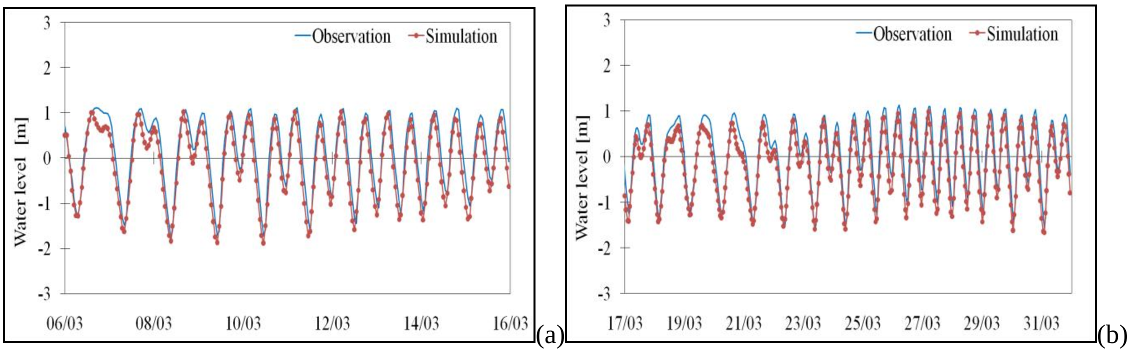

Figure 3. The comparison plot of observed and simulated water level at the Phu An station, (a) calibration (06/03 – 16/03/2009) and (b) validation (17/03 – 31/03/2009).

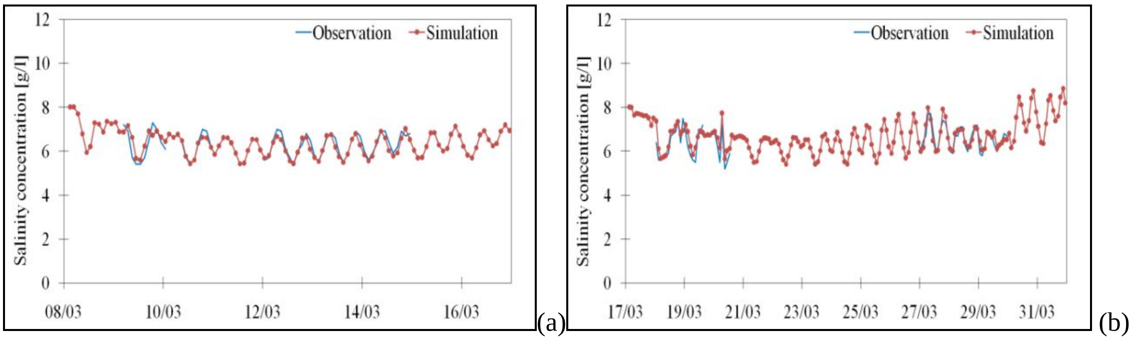

*Figure 4.*The comparison plot of observed and simulated salinity concentration at the Thu Thiem station, (a) calibration (08/03 – 16/03/2009) and (b) validation (17/03 – 31/03/2009).

Table 3. The performance of MIKE 11 for the simulation of salinity intrusion.

Station	Calibration (08/03 – 16/03/2009)	Validation (17/03 – 31/03/2009)
	NSE	NSE
Cat Lai	0.68	0.81
Thu Thiem	0.88	0.78

3.2. Impact of climate change and SLR on salinity intrusion

In this study, the impacts of climate change and SLR on salinity intrusion was separated and combined. One factor is approached while the others kept constant. The following three scenarios were investigated, including changes in SLR considered in Scenario 1, changes in streamflow from upstream considered in Scenario 2, and changes in SLR and streamflow from upstream considered in Scenario 3. Table 4 illustrates the average changes in salinity concentration in the RCP4.5 scenario with the three scenarios. In general, the salinity intrusion will increase dramatically under the impacts of climate change and SLR in the future. The study results present that the salinity intrusion has stronger response to SLR compared with changes in streamflow from upstream. These changes indicate that the saltwater will move to inland in the lower Dong Nai river system in the future and have significant impacts on agricultural activities as well as livelihoods of the citizens in HCMC.

*Table 4.*P ercentage changes in salinity concentration under sea level rise scenarios.

Period	Cat Lai			Thu Thiem		
	Sce.1	Sce.2	Sce.3	Sce.1	Sce.2	Sce.3
2020s	1.01 %	0.46 %	1.44 %	0.73 %	0.40 %	0.76 %
2050s	4.72 %	0.49 %	5.18 %	2.04 %	0.41 %	2.07 %
2080s	9.41 %	0.81 %	10.21 %	3.66 %	0.43 %	3.73 %

4. CONCLUSION

This study investigated the effects of climate change (changes in streamflow from upstream) and SLR on salinity intrusion in the lower Dong Nai river system by using the MIKE 11 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 MIKE 11 is a useful tool for assessing impacts of climate change and sea level rise in the lower Dong Nai river system. Under the possible separated and combined impacts of changes in sea level and streamflow from upstream, the saltwater will move deeply into inland, especially in the dry season. Also, salinity intrusion under SLR influences is stronger than the changes in streamflow from the upstream. 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.

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REFERENCES

1. IPCC - The Physical Science Basis: Contributing of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 2013.
2. Van Leeuwen C. J., Dan N. P., and Dieperink C. - The Challenges of Water Governance in Ho Chi Minh City, Integrated Environmental Assessment and Management, **12** (2) (2016) 345-352.

3. Ngo M. T., Lee J. M., Lee H. A., Woo N. C. - The sustainability risk of Ho Chi Minh city, Vietnam, due to saltwater intrusion, Geosciences Journal **19** (3) (2015) 547-560.
4. DHI - MIKE 11:A modeling system for rivers and channels,Reference manual, 2007.
5. Moriasi D. N., Arnold J. G., Van Liew M. W., Bingner R. L., Harmel R. D., Veith T. L. - Model evaluation guidelines for systematic quantification of accuracy in watershed simulations,Transaction of ASABE **50** (2007) 885-900.
6. Katzfey J., McGregor J., Ramasamy S. - High-resolution climate projections for Vietnam, Technical Report, 2014.
7. Khoi D. N., Thom V. T., Linh D. Q., Quang C. N. X., Phi H. L. - Impact of climate change on water quality in the Upper Dong Nai River Basin, Vietnam. 36th IAHR World Congress, Netherland, 28 Jun – 3 Jul, 2015.