気候変動による海面上昇がベトナム・メコンデルタにおける塩水遡上へ及ぼす影響に関する研究

A Research on effects on sea level rise due to climate change on seawater intrusion in Mekong River Delta, Vietnam

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Key Words : *hydrodynamic model, advection-dispersion model, statistic downscaling, seawater intrusion map*

1. Background

Viet Nam has a rice-based agricultural economy. Rice planting plays significant role in agricultural activities. Meanwhile, the main source of water supply comes from the river. Any changes in climate or sea level rise will cause the serious effect on this water source, especially in the dry season when the discharge in the river will be decreased, create a favorable condition for seawater intrusion into the river. In the context of climate change in the future, this problem will become more and more serious. If sea level increases 1m, more than 5% of total land area, 7% of agriculture area, and 28% of 2 wetland in Vietnam will disappear (Dasgupta et al., 2009).

Until present many researchers have focused all their interests on this issue. However, all of the studies on Mekong River Delta used the same climate change - sea level rise scenarios from IPCC (Intergovernmental Panel on Climate Change) for Vietnam to assess the effect of sea level rise on seawater intrusion; or they only evaluate the salinity problem at the current situation. Using the sea level rise scenarios for Vietnam to apply for Mekong River Delta will not be able to assess the true nature of seawater intrusion problem in Mekong River Delta because each river has own characteristics of meteorology, cross- section, and structure of estuaries.

2. Objective

Due to the limitations in the previous studies, the main objective of my research is to evaluate the effect of seawater intrusion in Mekong River Delta, Vietnam in the context of climate change with my own sea level rise scenario for Mekong River Delta.

3. Research flow chart

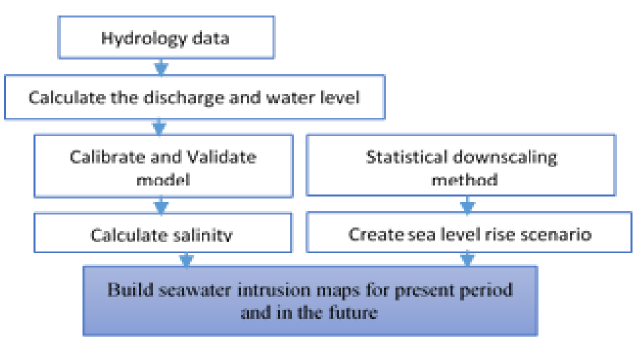

Fig. 1 Research flow chart

4. Method and model description

(1) Method

The research is conducted in the Mekong Delta in Vietnam. Due to the characteristics of Mekong River in Vietnam such as: the bed slope is small; the flow changes gradually in space and time; the estuaries are partially-mixed estuaries and change to well-mixed estuaries when entering the river deeper which the distribution of seawater intrusion in the river is longitudinal axis, the change of salinity in depth and horizontal can negligible, so the use of 1D Saint-Venant seems to be better than using 2D or 3D model. Furthermore, selecting whether to use a 1D, 2D, or 3D model depends on the water body, available field data and the answer desired, so with the condition of Mekong River data and the objective of the research, 1D Saint-Venant equation will be used to calculate in this research.

(2) Model description

Hydrodynamic model uses the two following basic equations including the equation of continuity and equation of momentum to calculate the discharge and water level:

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

$$\frac{\partial\left(\alpha \dfrac{Q^2}{A}\right)}{\partial x} + \frac{\partial Q}{\partial t} + gA\frac{\partial h}{\partial x} + \frac{g|Q|Q}{C^2 AR} = 0 \tag{1b}$$

Whereas salinity will be calculated by depend on Advection – dispersion transport equation:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) = -AKC + C_2 q \tag{1c}$$

K: linear decay coefficient, D: Dispersion coefficient, C: Concentration, C_2: Source/sink concentration, Q: Discharge-[m^3/s], A: Cross-section area-[m^2], x: Space independent variable-[m], t: Time independent variable-[s], g: Acceleration gravity-[m/s^2],h: Water level-[m], q: Lateral flow per unit length-[m^2/s], R: Hydraulic radius-[m], C: Chezy coefficient, α: Kinematic energy correction factor.

The solution of the equations (1) and (2) is based on an implicit finite difference scheme developed by (Abbott and Ionescu 1967), allows Courant numbers up to 10-20 if the flow is clearly sub-critical (Froude number less than 1). The simulation period is from 1 January 2001 to 30 June 2001 with the time step Δt= 30 minutes for hydrodynamic model and Δt= 20 seconds for advection-dispersion model. The minimum spacing dx equals 1000 m and maximum spacing dx equals to 10000 m. The Manning coefficient n was assigned to all river branches with the value of 0.018 to 0.04 in hydrodynamic model, and the initial condition is set up in 0.5m of water level in all the rivers. For the advection-dispersion model, dispersion coefficient D was assigned to the value of 50- 700 m^2/s.

5. Results

The hydrodynamic model and advection-dispersion model module was calibrated and validated with observed data from some stations in 2001 and 2000, respectively. The calibrated parameter is Manning's roughness (n) of all rivers in hydrodynamic model; and dispersion coefficient (D) is the calibration parameter in the advection-dispersion model. To assess the model performance, we need to use some model performance indexes such as: Nash-Sutcliffe efficiency (NASH), and coefficient of determination R2.

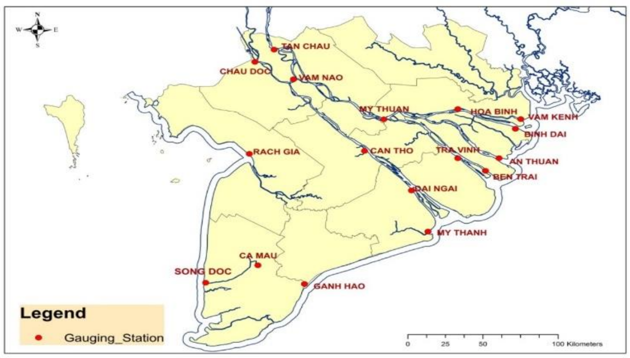

Fig. 2 Location of gauging stations in Mekong River Delta

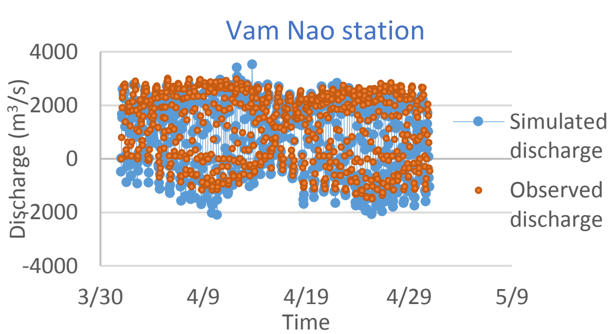

Fig. 3 Calibration of calculated and measured discharge at Vam Nao station with NASH =0.87, R^2=0.96 in April, 2001.

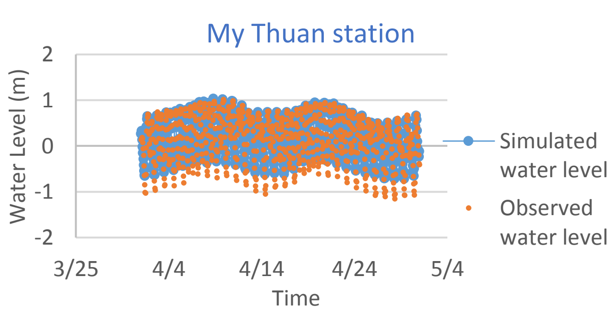

Fig. 4 Calibration of calculated and measured water level at My Thuan station with NASH =0.79, R^2=0.77 in April, 2000.

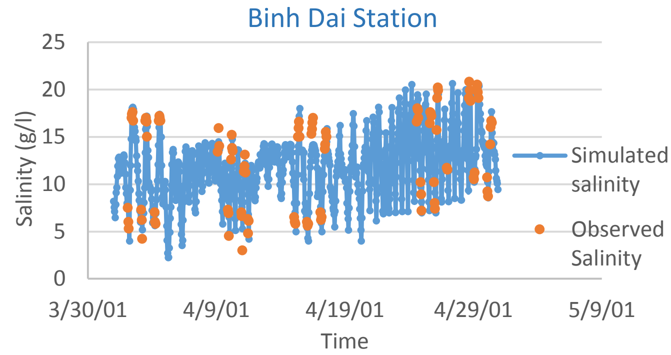

Fig. 5 Calibration of calculated and measured salinity at Binh Dai station with NASH =0.8, R^2=0.82 in April, 2001.

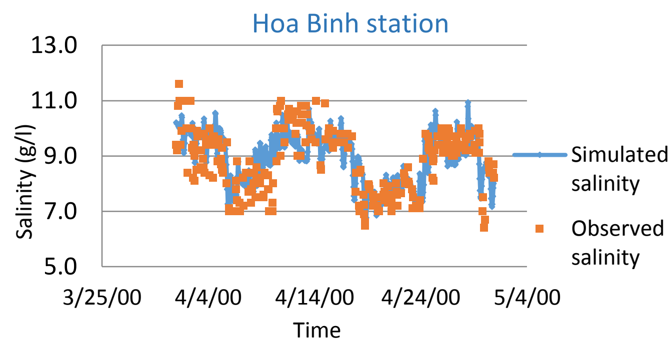

Fig. 6 Calibration of calculated and measured water level at Binh Dai station with NASH =0.84, R^2=0.85 in April, 2000.

Based on the performance of the advection-dispersion model in **Fig. 5** and **Fig. 6** that was checked with comparison of observed and simulated salinity at some stations. The coefficient demonstrated that the model results are acceptable, and the simulated salinity follows the similar trend to the observe salinity. Therefore, the model can be used to predict salinity in the rivers in both of baseline period and in the future. After the salinity results from model have been calibrated and validated, they will be used to simulate the salinity distribution in Mekong River Delta at the baseline period. In this case, we need to set up an assumption that only the water in the river will be used to irrigate.

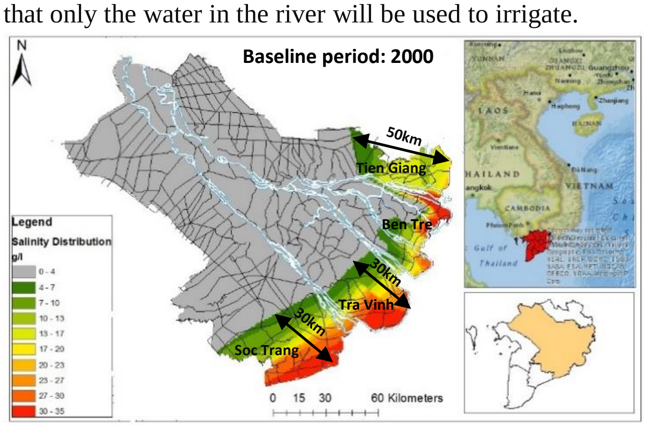

Fig. 7 The spatial temporary intrusion map of baseline period

In the map, we will focus on the salinity (>*4 g/l*) because growth of rice will be affected with salinity *4 g/l-7 g/l* and the rice will be died if salinity is greater than 7*g/l*.

Depend on the **Fig. 7**, we can understand the salinity distribution in the river at the baseline period. In general, the salt concentration that larger than 4 *g/l* has been intruded up to 30 – 40 *km* into the river, especially the provinces that very near the sea such as: Soc Trang, Tra Vinh, Ben Tre. Meanwhile, Tien Giang province recorded the maximum length of salinity intrusion up to 50 *km*, but the maximum salinity is only 20 *g/l*. The reason is that in Tien Giang province, the magnitude of the tide is smaller than other provinces.

6. Climate change, sea level rise scenario

Climate change is one of the most significant challenges facing human beings in the 21st century. In the next 20 years, Vietnam will be one of the most severely impacted by Climate Change. In Vietnam, all of studies still use the climate change-sea level rise scenarios that were developed by IPCC for Vietnam. Applying the same scenario for all of study areas will express some limitations. In order to have climate change – sea level rise scenarios that are suitable for personal research purposes, the sea level rise scenario will be built in this research. I will use the statistic downscaling method to create my own sea level rise scenario for Mekong River Delta depend on the result of sea level rise scenario for Vietnam that have been published.

(1) The necessity of downscaling method

With a coastline of more than 3100*km* long, the detailed sea level rise scenario for Vietnam coastal areas is essential, because this will more accurately reflect the degree of change in sea level in the small scale area. Furthermore, using the same scenario for all of coastal area will decrease the degree of accuracy because each of coastal area will have own characteristics of the tide. The downscaling scale is 50*km**25*km*.

(2) Statistical downscaling method

According to **Fig. 8** there are three data sets will be used, include: observed sea level data, satellite sea level data and simulated global sea level data. The next step is that we will evaluate the correlation relationship between observed sea level data and simulated global sea level data, and between satellite sea level data and simulated global sea level data by two test methods: F-test and t-test. After evaluating the correlation relationship, the transfer function will be determined depending on the best relationship between two upper groups of data.

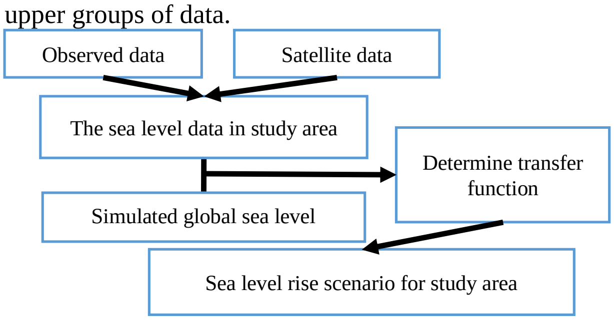

Fig. 8 Statistical downscaling method for sea level rise

(3) F-test, t-test method and results

Before calculating the t-test, F-test I need to set up the hypothesis: there is no relationship between observed sea level data and simulated global sea level data, and between satellite sea level data and simulated global sea level data. I will accept or reject this hypothesis by following steps:

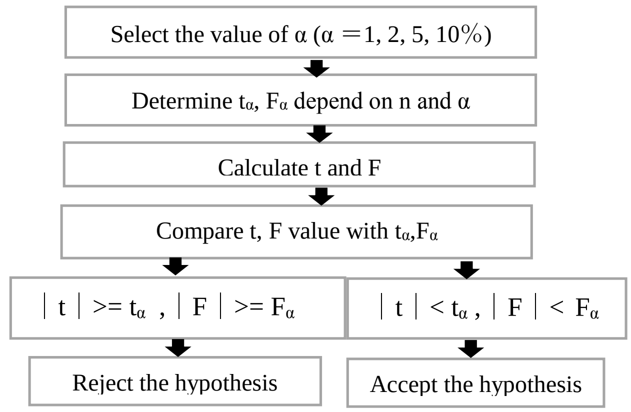

Fig. 9 Evaluate the correlation relationship of data

Where α is the significance level, by definition, α level is the probability of rejecting the hypothesis, and n is the degrees of freedom (with n being the total number of observations). In this case, I choose α is 5%.

Table.1 Checked relationship results between observed sea level data and simulated global sea level data.

R	F	F_α	t	t_α
0.82	39.51	4.38	6.28	2.09

Table.2 Checked relationship results between satellite sea level data and simulated global sea level data.

R	F	F_α	t	t_α
0.49	10.96	4.17	3.31	2.04

Results of **Table.1** and **Table.2** show that $|t| >= t_\alpha$, $|F| >= F_\alpha$, so we will reject the hypothesis and confirm that there is the relationship between observed sea level data and simulated global sea level data, and between satellite sea level data and simulated global sea level data, however the relationship between observed sea level data and simulated global sea level data is much better in case of statistical significant (R=0.82 in Table. 1 >>R=0.49 in Table. 2). Thus I will use the relationship between observed sea level data and simulated global sea level data to determine the sea level rise in the future.

The **Fig. 10** shows the projected sea level in the future including upper bound and lower bound. For example, sea level is projected to rise from 60 *cm* to 78 *cm* in 2100 compared to the baseline period in 2000. However, in my research, I will concentrate on the sea level rise in 2050 in Mekong River Delta because Vietnamese Government has planned for oriented development of Mekong River Delta in Vietnam to 2020 and vision to 2050.

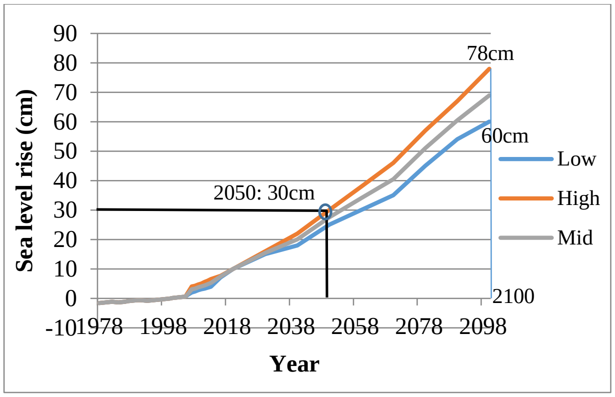

Fig. 10 Projected sea level for the Mekong Delta, Vietnam under RCP 6.0 scenarios for the period 2016-2100

(4) Seawater intrusion in 2050

As in the sea level rise scenario I have built, the sea level is expected to rise in the highest level of 30 *cm* in 2050. The map below will describe the seawater intrusion in Mekong River Delta in 2050

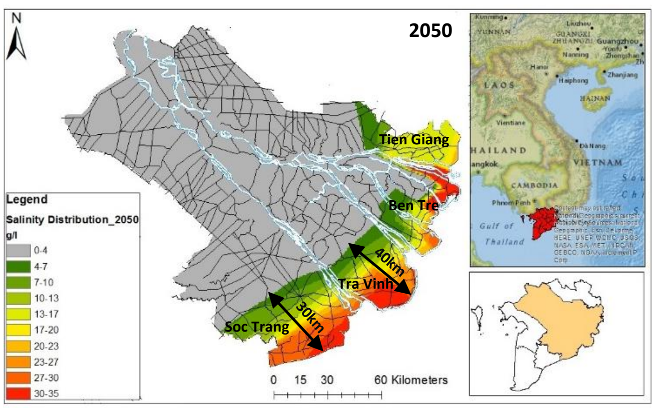

Fig. 11 The spatial temporary intrusion map in 2050

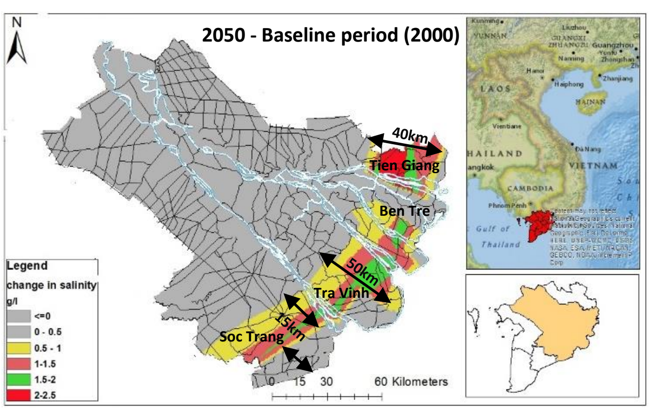

Fig. 12 The change of seawater intrusion in Mekong Delta, Vietnam between 2050 and base line period

It is quite difficult to see the change of salinity in 2050 compared to baseline if seeing in **Fig. 11**. So the **Fig. 12** will describe more detail about this change. In basically, there is no change in salinity concentration in the estuaries and in the upstream of the Mekong River Delta because these estuaries in baseline period has reached the maximum of salinity. In Soc Trang, Tra Vinh, Ben Tre province, the salinity concentration is expected to increase by 0.5 – 2.5 *g/L* in the place that`s far from the sea about 15*km*. In Tien Giang province, the seawater tends to intrude deeper into the river and effect to the river basin. The salinity concentration that increase by 1-1.5 *g/l* will intrude up to 30 *km*.

7. Conclusions

(1) The research has developed a set of parameters including roughness coefficient *n* and dispersion coefficient *D* in the main rivers in Mekong River system with high reliability. So they can be applied for future study relating to calculate salinity in Mekong River system.

(2) My research also created an own sea level rise scenario for Mekong River Delta. In general, the sea level will continue increasing with higher speed in the future under the effects of climate change. However, this scenario was created by applying one method, so in the future, if it can be compared with other methods, the result will more accuracy.

(3) Though the seawater intrusion map in the context of climate change, we can understand that the effect of salinity on the Mekong Delta will be significant in the future. Salinity will intrude up to river deeper with higher concentration. With the sea level rise more 30 *cm* in 2050, there is an increase of 30,000 *ha* of agricultural area affected by salinity that >4*g/l*. It means that about 138,000 *ton* of rice product will be lost. It is necessary to have some mitigation methods for restriction seawater intrusion.

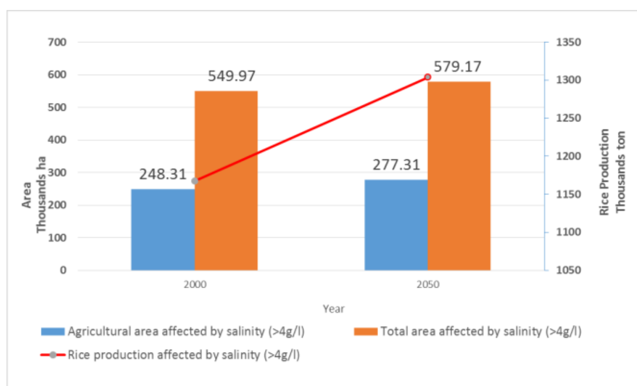

Fig. 13 Area affected by salinity of irrigation water in 2000 and 2050

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2) Sam, L. (2006). Salinity intrusion in the Mekong delta. Agric. Pub. House, Ho Chi Minh City: 123-135.