FLOODING IMPACTS ON RICE CULTIVATING AREA UNDER CLIMATE CHANGE IN TRA VINH PROVINCE

Mai Van Khiem[1], Tran Tuan Hoang[1], Phan Thi Diem Quy[1]
Huynh Thi My Linh[1], Ho Cong Toan [1], Pham Thanh Long[1], Nguyen Thi Thu Hang[2]
[1]*Viet Nam Institute of Meteorology, Hydrology and Climate Change*
[2]*Sai Gon University*

Received: 7 January 2019; Accepted: 11 February 2019

Abstract: *Climate change (CC) and sea level rise (SLR) are a challenge for many ecosystems, biodiversity and environmental resources, greatly influencing human social life. In this paper, we assess the impact of flooding in the rice cultivating area under climate change and sea level rise by 2100 in Tra Vinh province, through gathering and inheriting database methods, model (MIKE FLOOD) and geographic information system. The results indicated that Cau Ke and Chau Thanh districts have flooded areas on rice growing land larger than other districts. The results obtained in this study can be used to provide options for crop improvement, food security in the region and contributing to the local sustainable development.*

Keywords: *Climate change, sea level rise, rice cultivation area, Tra Vinh, MIKE FLOOD*

1. Introduction

Rice cultivation in Viet Nam was closely associated with the rural population and traditional farmers. Long-term flooding greatly affects cultivated land, rice production, affecting the food security of the province in particular and the Mekong Delta region in general. Under the scenario of climate change and sea level rise for Vietnam to be built and announced in 2016, about 38.9% of the Mekong Delta area will be at risk of flooding if sea level rises by 100cm. Tra Vinh province alone will have a risk of flooding of 21.3% compared to the natural area of the province [1].

Tra Vinh is adjacent to Ben Tre, Vinh Long and Soc Trang provinces; located between Tien River and Hau River (Figure 1). Tra Vinh provincial centre is 130km from Ho Chi Minh City and 100 km from Can Tho city. Tra Vinh province has 1 city, 1 town and 07 districts. Natural land area of Tra Vinh is 235,826ha [2]. Every year, the rice cultivation area of Tra Vinh is quite large. According to Tra Vinh Statistical Office, the total area of 2016 rice cultivation is 234,247ha [6].

Corresponding author: Pham Thanh Long
E-mail: longpham.sihymete@gmail.com

The advantage of the province is wet rice agriculture, the annual area of rice cultivation in Tra Vinh province faces many problems of natural disasters such as drought, saline intrusion, especially inundation. Flooding causes much damage to rice as well as damaging crops, reducing rice productivity. In addition, flooding also causes epidemics to reduce both yield and quality of rice.

In the context of climate change that is increasingly harsh and unpredictable, studies of sea level rise causing flooding on rice are essential.

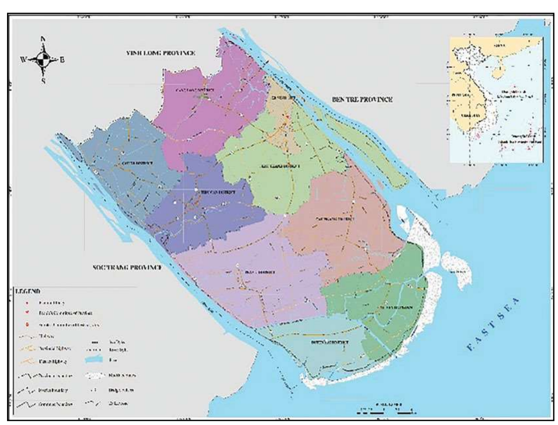


Figure 1. Administrative map of Tra Vinh province

2. Methodology

(1). Methods of gathering and inheriting databases

This method is implemented on the basis of inheriting, analysing, and synthesizing relevant sources of documents, materials, and data in a selective way. After that, assessed according to the requirements and purpose of the study. In this study, the gathered and inherited sources of documents and data include: flow and water level data provided by the Southern Regional Hydrometeorological Center; Hydraulic diagram and river section are measured and collected from research projects and projects directly implemented by the Sub-Institute of Hydro Meteorology and Climate Change.

(2). Model method

The modelling method is widely used in flood simulation and mapping. In particular, the one-way hydraulic model combines GIS such as MIKE 11, ISIS, VRSAP, HydroGIS, integrated 1-way and 2-way or 2-way (full 2D) models such as MIKE FLOOD (MIKE 21 and MIKE 11 integration), MIKE 21, SOLBECK, TELEMAC [3]. In this article, MIKE FLOOD model was used in linking MIKE 11 HD and MIKE 21 FM modules.

MIKE 11 model is a one-way hydraulic model, in which the hydrodynamic module is a central part, simulating the dynamic process along the unstable flow length with the combination of equation continuous and momentum equations (Saint-Venant equations):

The continuity equation [4]:

$$B\frac{\partial h}{\partial t}+\frac{\partial Q}{\partial x}=q$$

The momentum equation [5]:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\alpha\frac{Q^2}{A}\right)+gA\frac{\partial h}{\partial x}+g\frac{Q|Q|}{AC^2R}=0$$

MIKE 21 FM model includes:

The continuity equation [5]:

$$\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=hS$$

The shallow water equation [6]:

$$\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\overline{uv}}{\partial y}=f\bar{v}h-gh\frac{\partial\eta}{\partial x}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{gh^2}{2\rho_0}\frac{\partial\rho}{\partial x}+$$

$$\frac{\tau_{sx}}{\rho_0}-\frac{\tau_{bx}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial S_{xx}}{\partial x}+\frac{\partial S_{xy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial y}\left(hT_{xy}\right)+hu_sS$$

$$\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\overline{uv}}{\partial x}+\frac{\partial h\overline{v^2}}{\partial y}=-f\bar{u}h-gh\frac{\partial\eta}{\partial y}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial y}-\frac{gh^2}{2\rho_0}\frac{\partial\rho}{\partial y}+$$

$$\frac{\tau_{sy}}{\rho_0}-\frac{\tau_{by}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial S_{yx}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)+hv_sS$$

(3) GIS method

Map tools such as Mapinfo and ArcGIS are used to extract the results of the model, serve the management and exploitation of information and overlap to build flood risk maps.

3. Input data for models

Based on data from the river network throughout the lower Mekong Delta River (see Figure 2) in the project "Update climate change scenarios in Tra Vinh province under the 2016 scenario according to the Ministry of Natural Resources and Environment" , we used to calibrate and validate hydraulic models for Tra Vinh province. After achieving the good results, we extracted separate river, cross-sections and boundary data for Tra Vinh province (see Figure 3).

Model input data for river network in Mekong Delta River, include:

- Documents on the design of irrigation works, irrigation systems in the lower Mekong area of the Southern Institute of Water Resources Research from 2002 to the present and have been provided by Departments of Tra Vinh province.

- Boundary conditions: water level and discharge in 2016 were collected from Southern Regional HydroMeteorology Center

- Climate change and sea level rise scenarios have been used in this study was the set of "Climate change and sea level rise scenarios for Vietnam" newest update of 2016 of Ministry of Natural Resources and Environment.

- Hydraulic diagram of river network in Mekong Delta River including: main rivers and canals such as Tien river, Hau river, Vam Nao river, Co Chien river and other small river branches have been set up based on satellite maps and hydrological maps of the Mekong Delta River region with 1,116 branches. The number of points calculated in the model were about 13,000 points. River sections: about more than 5,000 sections across the Mekong Delta river system.

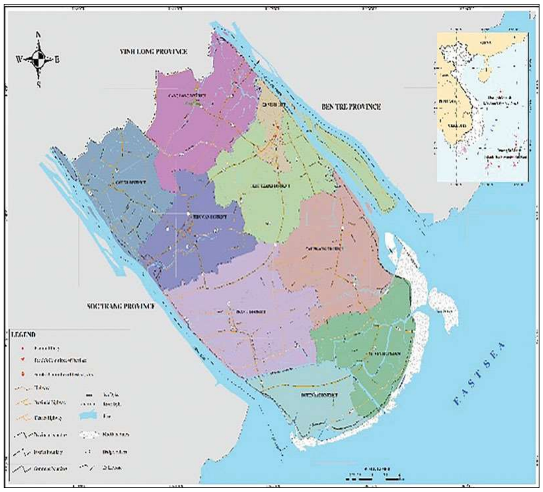


Figure 2. Hydrodynamic diagram of river network in Mekong Delta River

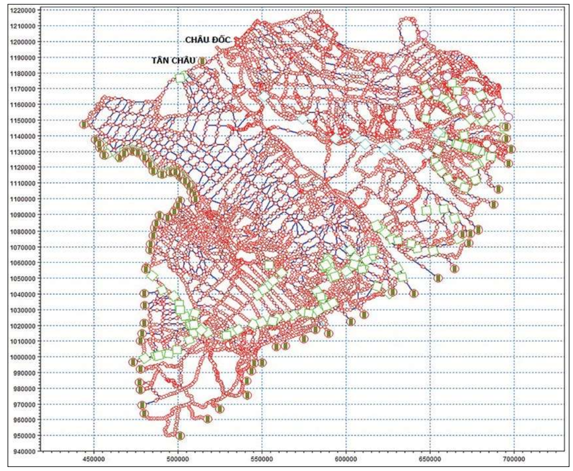


Figure 3. The river network uses flood calculation for Tra Vinh province

- Hydraulic modules are built based on 2 main flow profiles in Tan Chau and Chau Doc in 2016. Other discharge margins without other rivers or small canals starting in the field are priced value of 0 m3/s. There for, hydraulic diagram including real measured datas in Tan Chau and Chau Doc Stations in 2016.

- Data of water level in coastal estuaries is taken as downstream boundary used in the model is the actual data measured in 2016 at coastal stations such as Vam Kenh station (Tieu gate), Binh Dai station (Dai gate), An Thuan (Ham Luong gate), Ben Trai (Co Chien gate), and My Thanh station (My Thanh, Dinh An gates) and Tran De station (Tran De gate).

- The system of checking water level data includes data at hydrological stations such as Vam Nao, My Thuan, My Tho (Tien river), Can Tho, Dai Ngai, Tran De (Hau river) or Cho Lach station, Tra Vinh (Co Chien river) and My Hoa (Ham Luong river) are collected at the Hydrological Meteorological Station in the Southern region in 2016, serving for model calibration and validation. This set of data ensures reliability and accuracy for model calculation and correction.

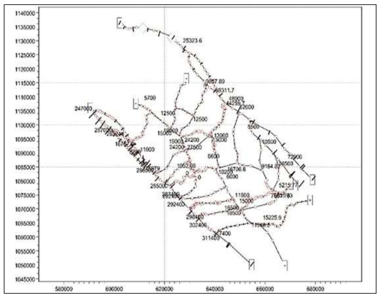
Input data for river network is calculated for Tra Vinh province:

- The boundaries have been used in the river network of Tra Vinh province include the upper boundary which is the data of water level and flow extracted from the Mekong Delta River network (downscaling), including the boundary of Can Tho, My Thuan (water level data and flow data). Downstream boundaries were downstream water level in 2016 at hydrological stations such as Ben Trai station and Tran De station. Figure 3 shows the river network of Tra Vinh province extracted from river network of Mekong Delta River region.

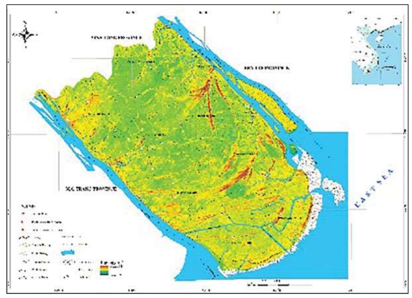
- Topography has been used in flood calculation for Tra Vinh province was Digital Elevation Models (DEM) topography data of Viet Nam Ministry of Natural Resources and Environment (MONRE), with dimensions of 10x10 meter (see Figure 4).

- Topographic data have been used to construct the topography and calculate for the MIKE FLOOD model and the MIKE 21FM model, as follows: topographic data has been extracted from 1: 200,000 map of the Vietnamese People's Navy, published in 2009; in addition, the study area topography has been also measured during the 2016 survey in the project "Climate Change Adaptation in the Mekong Delta in Tra Vinh Province (Tra Vinh AMD Project)". It included 78,489 elements and 39,678 nodes (see Figure 5)

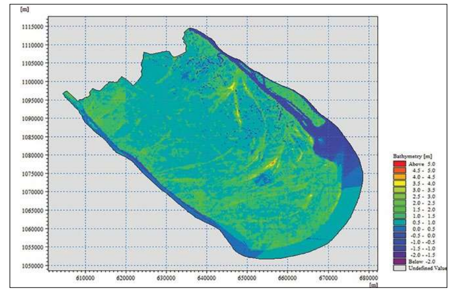
- River network in MIKE 11HD model was linked to topography of MIKE 21FM in MIKE FLOOD model by lateral link (see Figure 6).



Figue 4. DEM topography data for Tra Vinh province



Figue 5. Topography data in MIKE 21FM model



Figue 6. Lateral link between MIKE 11HD model and MIKE 21FM model

4. Results

4.1. Calibration and validation of models

The hydraulic model of saline intrusion calculation has been calibrated, validated based on the actual measured data at Tra Vinh station in 2016 and 2010. Data were collected from Southern Regional HydroMeteorology Center. Stations location is shown in the Figure 7.

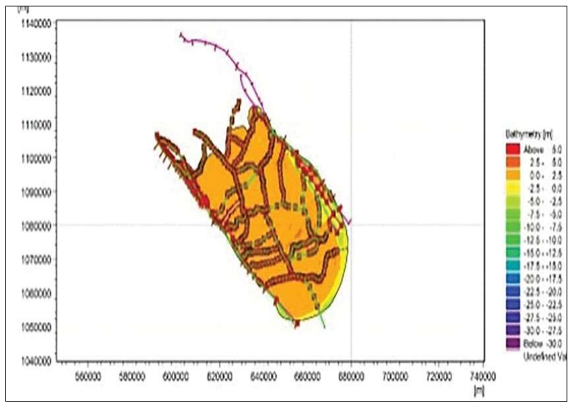


Figure 7. Location map of hydrological stations in Southern of Viet Nam

- Manning roughness coefficient has been adjusted from 30 to 65 depending on the river section;

- Initial conditions: The water level was 0.5m and the flow was equal to 5m^3/s for the entire river system;

- Time step for hydraulic calculation (HD) Δt = 5 minutes.

- Time to calibrate model parameters from July 1, 2016 to July 31, 2016 and validate in the period of July 1, 2010 to July 31, 2010. The results of the water level calculation in the above time were compared with the actual measured data based on the correlation coefficient and the NASH suitability index and the hydraulic model calibration results are shown below.

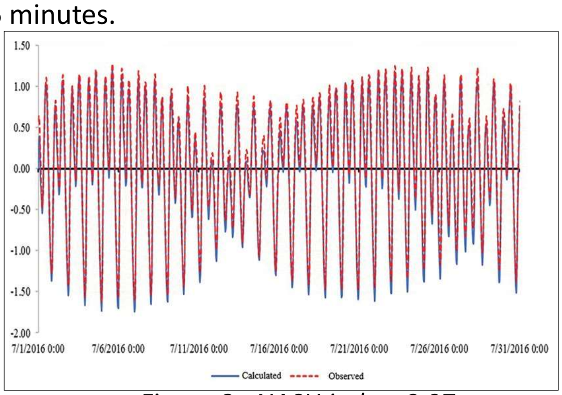


Figure 8a NASH index: 0.97

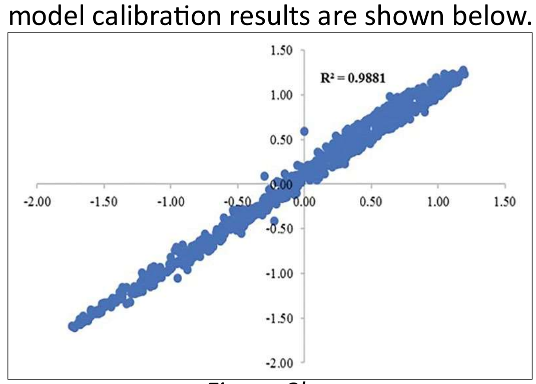
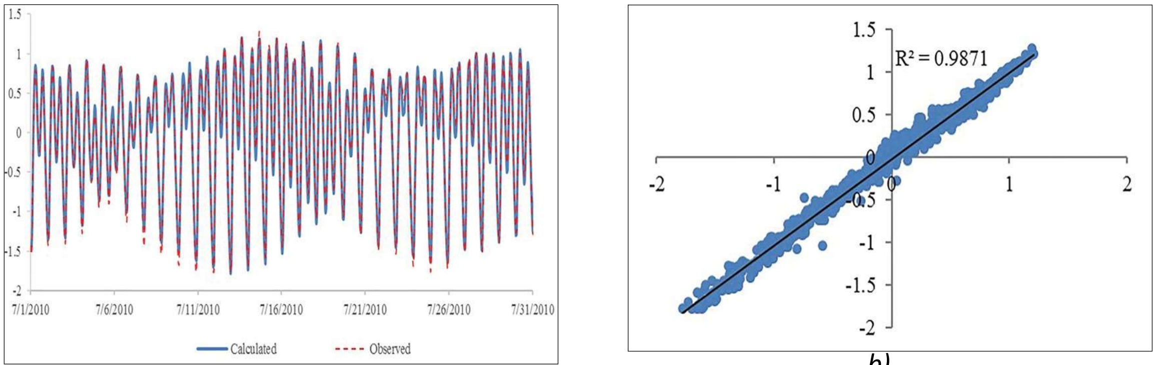


Figure 8b

Figure 8 (a-b): Calibration water level at Tra Vinh Station in July 2016



a) NASH index: 0.92 *b)*

Figure 9 (a-b). Validation water level at Tra Vinh Station in July 2010

Calculation results and actual measured data of water level satisfying the permissible error limit of value and tidal phase for the NASH coefficient in the range of 0.92-0.97. Thus, the data set used to build the model and the model correction parameter set were reliable.

4.2. Simulation results and updated maps flooded on rice cultivation land for Tra Vinh province

We carried out the calculation and comparison of flooding levels on rice cultivation land in 2016 in the current situation (in 2016) and climate change scenarios (2025, 2050, 2070, 2100). According to the land use planning map, the area of land for rice cultivation in Tra Vinh in 2016 was about 99,822.47 hectares.

(1). Current status of flooding in 2016

The flooded map of Tra Vinh province according to the current status 2016 is presented in Figure 10.

The total flooded area was 23,497.68 ha, accounting for nearly 10% of the province's natural land area. The total area of flooded rice paddy land was 4,211.11 hectares, accounting for about 4.2% of the province's paddy land.

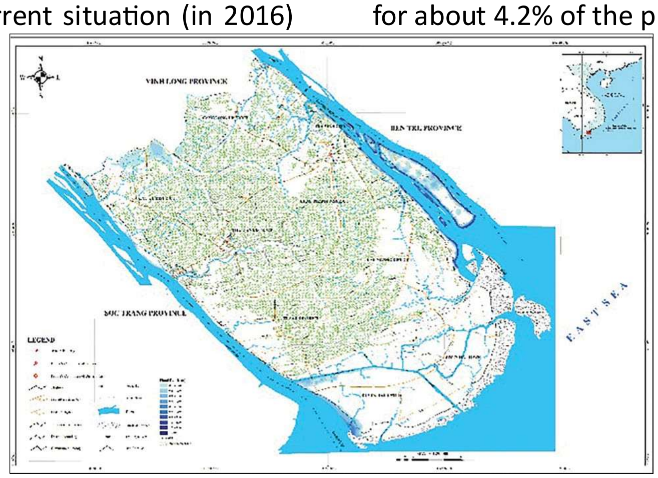


Figure 10. Map flooded in Tra Vinh province in 2016

(2). Forecasting the risk of flooding on rice cultivation land until 2025

To simulated and updated the flood risk map on rice cultivation land in Tra Vinh province until 2025, the study used Sea level rise for Vietnam was published by the Ministry of Natural Resources and Environment in 2016. Accordingly, in 2025, sea level rise will be 0.12m for RCP4.5 [1]. Flood hazard map of Tra Vinh rice land in 2025 is shown in Figure 11.

The total flooded area will be 26,491 hectares, accounting for about 11.2% of the province's natural land area.

The total area of flooded rice paddy land will be 5,531.7 hectares, accounting for about 5.5% of the province's rice cultivation land.

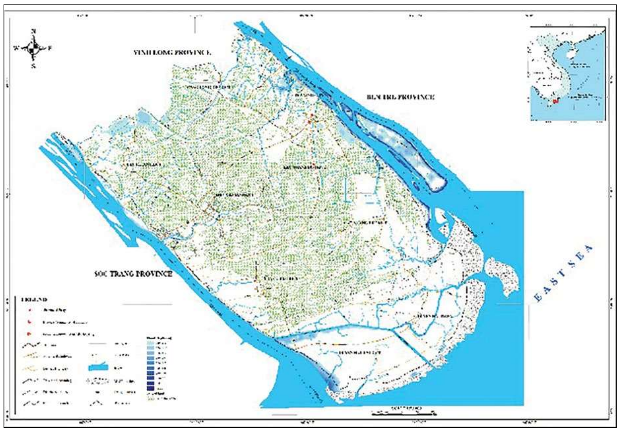


Figure 11. Flood risk map according to scenario RCP4.5_2025 and current status of wet rice cultivation in Tra Vinh province

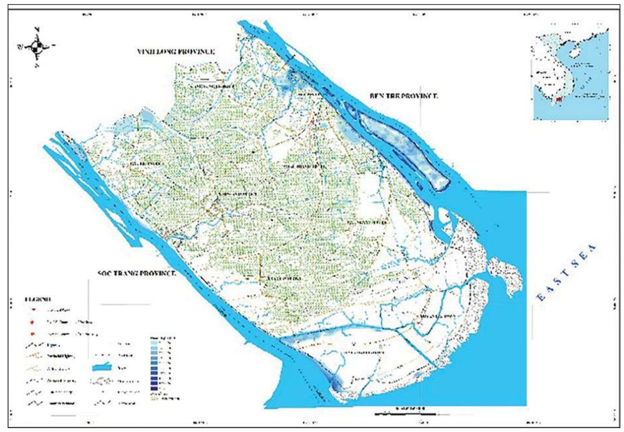


Figure 12. Flood risk map according to scenario RCP4.5_2050 and current status of wet rice cultivation in Tra Vinh province

(3) Forecasting the risk of flooding on rice cultivation land until 2050

To simulated and update the flood hazard map on the rice cultivation land in Tra Vinh province until 2050, the study used Sea level rise for Viet Nam was published by the Ministry of Natural Resources and Environment in 2016. Accordingly, in 2050, sea level rise will be 0.22 m corresponding to RCP4.5 [1]. The risk map of flooding in Tra Vinh rice land in 2050 is shown in Figure 12. The total flooded area will be about 28,762 hectares, accounting for 12.2% of the natural land area. The total area of flooded rice paddy land will be 6,815 hectares, accounting for 6.8% of the province's rice cultivation land area.

(4) Forecasting the risk of flooding on rice cultivation land until 2070

To simulated and updated the flood hazard map on the paddy land in Tra Vinh province until 2070, the study used Sea level rise for Viet Nam was published by the Ministry of Natural Resources and Environment in 2016. Accordingly, in 2025, sea level rise will be 0.33 m for RCP4.5 [1]. Flood hazard map of Tra Vinh paddy land in 2070 is shown in Figure 13.

The total flooded area will be 32,101 hectares, accounting for 13.6% of the natural land area. The total flooded area on paddy land will be 8,231 hectares, accounting for 8.2% of the province's rice land.

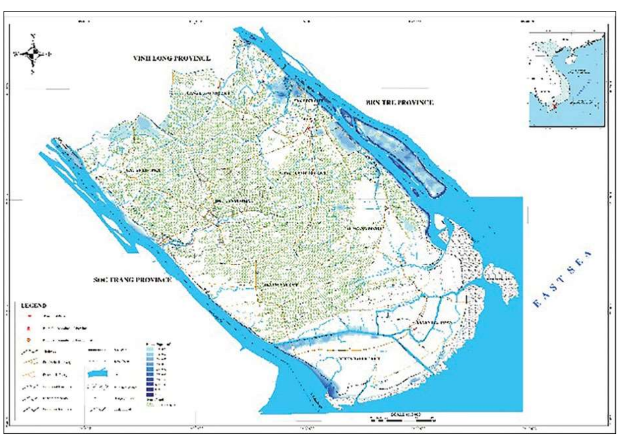


Figure 13. Flood risk map according to RCP4.5_2070 scenario and current status of wet rice cultivation in Tra Vinh province

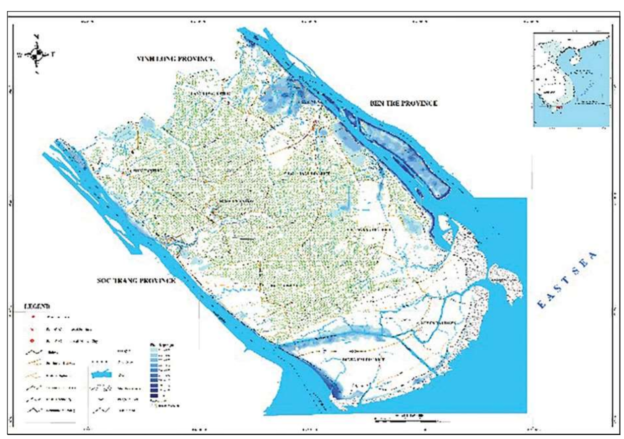


Figure 14. Flood risk map according to RCP4.5_2100 scenario and current status of wet rice cultivation in Tra Vinh province

(5). Forecasting the risk of flooding on rice cultivation land until 2100

To simulated and updated the flood hazard map on the paddy land in Tra Vinh province until 2100, the study used Sea level rise for Viet Nam was published by the Ministry of Natural Resources and Environment in 2016. Accordingly, in 2025, Sea level rise will be 0.53m for RCP4.5 [1]. The flood risk map of Tra Vinh rice land in 2100 is shown in Figure 14.

The total flooded area will be 41,159 hectares, accounting for 17.5% of the natural land area. The total area of flooded rice paddy land will be 12,214 hectares, accounting for 12.2% of the province's rice growing area.

Statistics of the current flooded area in 2016 and the RCP4.5 scenarios in 2025, 2030, 2050, 2100 on the area of rice cultivation and the increase/decrease compared to 2016 is presented in tables 1, 2 , 3, 4 below.

Table 1. Statistics of flooded areas in Tra Vinh province over the years

Number	Flooding level (m)	Flooded area (hectares)				
		2016	**45_2025**	**45_2050**	**45_2070**	**45_2100**
1	0.1-0.2	5,830.61	6,729.02	6,803.48	7,259.09	9,015.82
2	0.2-0.3	2,803.63	3,773.24	4,681.73	4,975.96	6,137.65
3	0.3-0.5	3,026.27	3,482.81	4,127.96	5,482.37	9,070.76
4	0.5-0.6	1301.59	1,301.92	1,254.12	1,367.75	2,132.33
5	0.6-0.7	1,117.84	1,226.62	1,296.25	1,211.78	1,505.16
6	0.7-0.8	1,021.75	1,056.04	1,139.55	1,264.21	1,225.00
7	0.8-1.0	1,390.22	1,632.85	1,822.34	2,048.54	2,331.98
8	1.0-1.2	1,074.83	1,143.94	1,213.14	1,377.83	1,766.99
9	1.2-1.5	1,232.46	1,267.89	1,311.44	1,427.26	1,699.25
10	>1.5	4,698.48	4,876.45	5,112.14	5,686.92	6,274.26
	Total	**23,497.68**	**26,490.77**	**28,762.16**	**32,101.71**	**41,159.21**

Table 2. Statistics difference in flooded area according to the schedule compared to the area flooded in Tra Vinh province in 2016

Number	Flooding level (m)	Flooded area compared to 2016 (hectares)			
		45_2025	**45_2050**	**45_2070**	**45_2100**
1	0.1-0.2	+898.40	+972.87	+1,428.48	+3,185.21
2	0.2-0.3	+969.60	+1,878.09	+2,172.33	+3,334.02
3	0.3-0.5	+456.54	+1,101.69	+2,456.10	+6,044.49
4	0.5-0.6	+0.33	-47.47	+66.15	+830.73
5	0.6-0.7	+108.78	+178.41	+93.94	+387.33
6	0.7-0.8	+34.29	+117.80	+242.46	+203.25
7	0.8-1.0	+242.63	+432.13	+658.32	+941.76
8	1.0-1.2	+69.11	+138.31	+303	+692.16
9	1.2-1.5	+35.43	+78.98	+194.80	+466.79
10	>1.5	+177.97	+413.66	+988.44	+1,575.78
	Total	**+2,993.09**	**+5,264.47**	**+8,604.03**	**+17,661.53**

(+: increase: -: decrease)

Table 3. Statistics of flooded areas on rice cultivation land in Tra Vinh province over the years

Number	Flooding level (m)	The area is flooded on the current land for rice cultivation (hectares)				
		2016	**45_2025**	**45_2050**	**45_2070**	**45_2100**
1	0.1-0.2	2,040.85	2,806.62	2,944.22	3,011.01	4,241.34
2	0.2-0.3	702.57	1,000.42	1,655.20	2,072.49	2,388.25
3	0.3-0.5	371.57	549.81	843.70	1,482.12	3,231.44
4	0.5-0.6	85.29	119.63	184.53	283.93	557.52
5	0.6-0.7	71.95	73.48	103.20	157.96	342.48
6	0.7-0.8	81.14	68.67	69.03	92.51	192.40
7	0.8-1.0	193.55	172.77	164.71	155.99	197.81
8	1.0-1.2	145.87	174.30	198.20	205.19	161.89
9	1.2-1.5	159.21	165.34	183.50	227.34	280.48
10	>1.5	359.10	400.66	468.84	542.76	620.50
	Total	**4,211.11**	**5,531.70**	**6,815.11**	**8,231.28**	**12,214.12**

Table 4. Statistics of the difference of flooded area on rice cultivation land according to the schedule compared to the area flooded in Tra Vinh province in 2016

Number	Flooding level (m)	Difference in area flooded on rice cultivation land compared to 2016 (hectares)			
		45_2025	**45_2050**	**45_2070**	**45_2100**
1	0.1-0.2	+765.77	+903.37	+970.16	+2,200.49
2	0.2-0.3	+297.85	+952.63	+1,369.91	+1,685.67
3	0.3-0.5	+178.24	+472.13	+1,110.55	+2,859.87
4	0.5-0.6	+34.34	+99.23	+198.63	+472.23
5	0.6-0.7	+1.53	+31.25	+86.00	+270.53
6	0.7-0.8	-12.47	-12.11	+11.37	+111.26
7	0.8-1.0	-20.78	-28.84	-37.56	+4.26
8	1.0-1.2	+28.43	+52.32	+59.32	+16.02
9	1.2-1.5	+6.12	+24.29	+68.12	+121.27
10	>1.5	41.55	+109.73	+183.65	+261.40
	Total	**+1,320.59**	**+2,604.00**	**+4,020.17**	**+8,003.00**

(+: increase: -: decrease)

According to the flooded statistics on the natural land of Tra Vinh province, the current situation and climate change scenarios, the total flooded area on natural land gradually increases over the years. In which the total flooded area of the scenario RCP45_2100 is the largest of 41,159.21 hectares, an increase of 17,661.53 hectares compared to the current situation in 2016. The common flood level is from 0.1-0.2 m for the current situation in 2016, the scenarios RCP45_2025, RCP45_2050, RCP45_2070. For RCP45_2100 scenario, the common flood level is from 0.3 to 0.5 m.

The total flooded area on rice cultivation land also tends to increase, the total flooded area on the rice paddy scenario RCP45_2100 is the largest of 12,214.12 hectares, an increase of 8.003 hectares compared to the current situation in 2016. In particular, the common flood level on the paddy land from 0.1-0.2m for all years.

5. Concluding

This study has applied the model MIKE FLOOD to simulate the risk of flooding on rice cultivation land in Tra Vinh province according to the 2016 status and the average emission scenarios (RCP4.5) in 2025, 2050, 2070, 2100. From the calculation results, the study has constructed flooded maps on rice cultivation land for Tra Vinh province.

The simulation results, overlapping map and calculating the risk of flooding on rice cultivation land for Tra Vinh province shows: The risk of flooding in 2025 will be about 5,531.7 hectares, accounting for 5.5% of the province's rice cultivation land area; For 2050 will be about 6,815 ha, accounting for 6.8% of the province's rice cultivation land area; For 2070, about 8,231 ha, accounting for 8.2% of the province's rice cultivation land area and in 2100, the risk of flooding will be about 12,214 hectares, accounting for 12.2% of the province's rice cultivation land area. The universal flood level is from 0.1-0.2m, the flood level greater than 1.5m accounts for mainly in the alluvial and canal alluvial areas. According to flooding map then Chau Thanh and Cau Ke districts are the two areas with flooded largest area on rice cultivation land in Tra Vinh province.

Flooding levels in rice and inundation rates are not high, but they also have a certain effect on the yield and quality of local rice. Flooding can cause root rot, reducing yield. Flooding also causes disease to lower the quality of rice. In addition, flooding due to sea level rise also leads to saline intrusion, narrowing the area of land where rice can be cultivated, greatly affecting production and improving fields due to salinity.

At the same time, Tra Vinh province has the sixth rice output in Mekong Delta River region, contributing to ensuring food security in region. Fluctuations in the and yield and quality of rice in the province will significantly affect the region in particular and Viet Nam country in general.

The updated results of the study are the basis for the agencies and agencies in the province to consider and update flood risks due to climate change, sea level rise ink affecting rice land. Since then they have adjusted, integrated climate change issues, sea level rise to future development programs and plans for the province's wet rice, as well as coordinated with neighbouring provinces in the Mekong Delta River region.

The paper only calculated the impact of flooding in the rice growing area, not yet assessed the effect of each flood level, the time to maintain flooding of rice.

References

1. Ministry of Natural Resources and Environment (2016), *Climate Change and Sea level rise scenarios for Viet Nam*, Ha Noi.
2. Tra Vinh Statistical Office (2017), *2016 Statistical Yearbook*, Tra Vinh.
3. Nguyen Hong Quan (2013), "Some methods to build flooded maps of Long An province in conditions of climate change and sea level rise, *Journal of Science and Technology Development,* Vol 16, No. M1-2013, page 32-39.
4. DHI Water & Environment (2017), *MIKE 11 - A Modelling system for Rivers and Channels Reference Manual.*
5. DHI Water & Environment (2017), *MIKE 21 - Flow model FM*.
6. Department of Agriculture and Rural Development in Tra Vinh province, *2016 summarized report and tasks of 2017 plan of Tra Vinh province.*