VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

www.arpnjournals.com

PADDY SOIL SALINIZATION PROCESS IN TIEN HAI DISTRICT, THAI BINH PROVINCE UNDER SEA LEVEL RISE IMPACTS

Tran Ngoc Trang, Nguyen Hoang Long and Nguyen Xuan Hai
VNU University of Sciences, Nguyen Trai, Hanoi, Vietnam
E-Mail: nguyenxuanhai@hus.edu.vn

ABSTRACT

Through different pathways, sea level rise will cause certain impacts on paddy soil salinization process in Tien Hai district, Thai Binh province. In which, irrigation water pathway is found to be a major factor increasing the salinization process there. Mike 11 is applied to predict the irrigation water salinity of Tien Hai district due to seawater intrusion in Red river under sea level rise impacts. From 2060, the irrigation water salinity will exceed 0.75ppt - the safety level for soil salinization risk. Proceeding with the salinity, it is the application of Saltmod for the paddy soil salinity trend prediction under sea level rise impacts through the irrigation pathway. The general salinity trend is predicted to increase from 2007 to 2100. In particular, the salinity of root zone and transition zone increases from 0.33% (2007) to 0.56% (2100) and from 0.36% (2007) to 0.84% (2100), respectively, while the aquifer salinity is nearly stable at 0.35%. Finally, the research shows that it is possible to apply Mike and Saltmod for the prediction of the soil salinization process of agricultural land in estuary areas under the sea level rise impacts of climate change in Vietnam.

Keywords: paddy soil, salinization process, sea level rise, Tien Hai district, Thai Binh province, Mike 11, Saltmod, irrigation water, salinity trend, climate change.

INTRODUCTION

In climate change context, sea level rise impacts on soil salinization process have become increasingly stronger, especially in coastal areas. Tien Hai is a coastal district of Thai Binh province, Vietnam. As the agricultural land accounts for about 86.09% of the total district area in which 71.88% is served to rice cultivation [1], paddy soil salinization process under sea level rise impacts also becomes an urgent issue there. However, there have been no official researches proposing sea level impact assessment on the soil salinization process in Tien Hai district, Thai Binh province. Hence, we conducted a research with two objectives. Firstly, the impact level of sea level rise on paddy soil salinization process is assessed through different pathways so that a major pathway can be found. Secondly, it is the prediction of paddy soil salinity trend up to 2100 under sea level impacts through the major pathway.

We found that irrigation water pathway was a decisive factor increasing the salinization process in Tien Hai district. Although Red river water is a main water supply source for Tien Hai district, due to sea level rise impacts, a saline intrusion is deeper in the riverbed especially in dry seasons. Thus, Mike 11 model is applied and shows that from 2060 the irrigation water salinity in dry seasons is predicted to be higher than 0.75ppt - the safe level for proposing soil salinization risk [2]. Then, with the application of Saltmod model in case of the continuity of the irrigation water use, the paddy soil salinity trend is predicted to increase significantly by 2100. In particularly, the salinity of root zone and transition zone in dry seasons increases from 0.33% (2007) to 0.91% (2100) and from 0.36% (2007) to 0.84% (2100), respectively, while the aquifer salinity is nearly stable at 0.35%.

The research can be considered as one scientific basis contributing the determination of salinization process at Tien Hai district under the context of climate change and sea level rise impacts. From that, measures to mitigate and minimize sea level impacts on salinization process can be proposed timely.

MATERIAL AND METHODS

a) Field survey

To determine possible pathways through which sea level rise possibly causes impacts on paddy soil salinization process, we conducted a survey at Tien Hai via observation channel and information collection channel from residents as well as the local government about:

- River systems; dyke systems and irrigation system of Tien Hai district
- Economic and social activities of Tien Hai district
- Agronomic questions: crops, irrigation way …

b) Data collection

After the field survey, we conducted the material collection and analysis. The list of necessary materials and sources is presented in Figure-1:

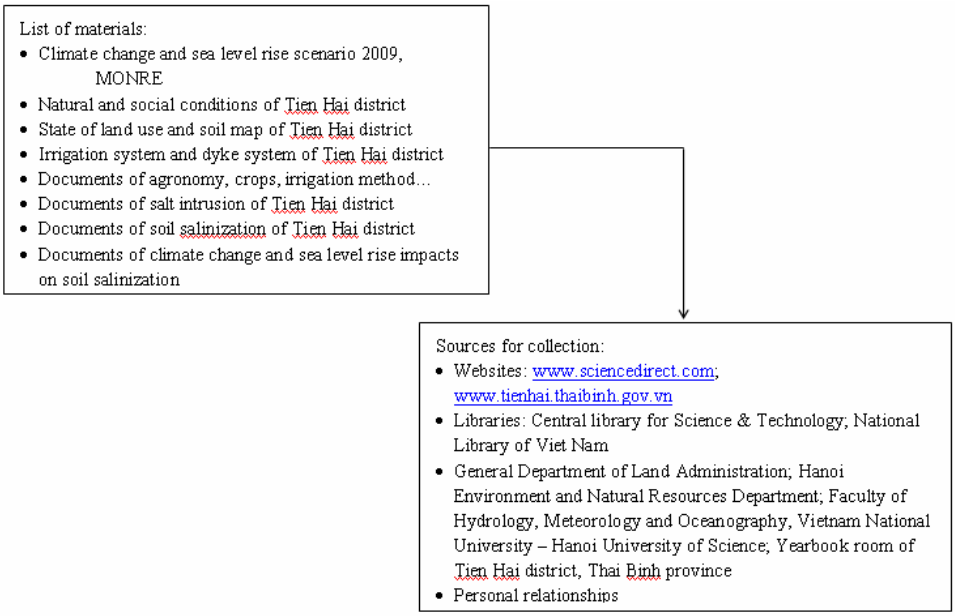

Figure-1. List of materials and sources.

Based on Climate change and Sea level rise impacts Scenario 2009 of Vietnam Ministry of Natural Resources and Environment (MONRE), we conducted sea level rise impact assessment on paddy soil salinization process through different pathways in Tien Hai district.

Climate change and sea level rise impacts scenario 2009 of Vietnam MONRE includes 3 scenario types: B1 - low emission; B2 - medium emission and A2 - high emission. Nevertheless, according to MONRE's recommendation that is "with the existence of uncertainties, both scenarios of climate change and sea level rise impacts corresponding to upper bound and lower bound is less reliable than the medium scenario [3]", B2 - medium emission scenario is selected as the scientific basis for our research.

Table-1. Sea level rise (cm) in comparison with the period of 1980 - 1999, B2 scenario 2009.

Scenario	Time scale of 21st century		
	2050	2080	2100
B2	30	54	75

Besides that, data input of the 2 models used in our research was also collected from the above sources, including:

- Soil characteristics indices (salinity, thickness, porosity, water storage efficiency, salt leaching efficiency of each zone: root zone, transition zone and aquifer)
- Agronomic data (rice cultivated land area, seasonal irrigation water, evapotranspiration)
- Hydrological data (cross - sections of Red river, water flows of Red river in 2006 and 2007, water river salinity 2006 and 2007 at Ba Lat and Duong Lieu hydrological stations, rainfall in the 1980 - 1999 period, groundwater flow of the upper Holocen aquifer through Tien Hai region).

c) Model application

- **MIKE 11**

Because Kem sewer in Red river is responsible for the major irrigation water supply in Tien Hai, the salinity of Red river at Kem's location can be considered similar to the irrigation water salinity of the district. Thus, the prediction problem of the irrigation water salinity will be turned into the prediction problem of the saline intrusion in Red river up to 2100.

To solve that problem, we applied Mike 11 Model of Denmark Danish Hydraulic Institute with the hydrodynamic module (HD) and the material transmission model (AD). Mike 11 is currently one of the most advanced one-dimensional models in the world. It is widely applied in almost universities, institutes and consultation units. Besides common advantages of this model such as: stable mathematical base, fast computation and easy use, the key preeminence of Mike 11 in comparison with other similar models like HEC-RAS (US) is the more suitability for estuary regions and low steep terrains in our specific condition research.

The seawater intrusion in Red river is solved through 3 steps:

- **Step-1:** The hydraulic network is built from input data (topographical data and hydrological data: water level, flow, salinity)
- **Step-2:** Model modification and verification is to find approximate parameters for AD and HD

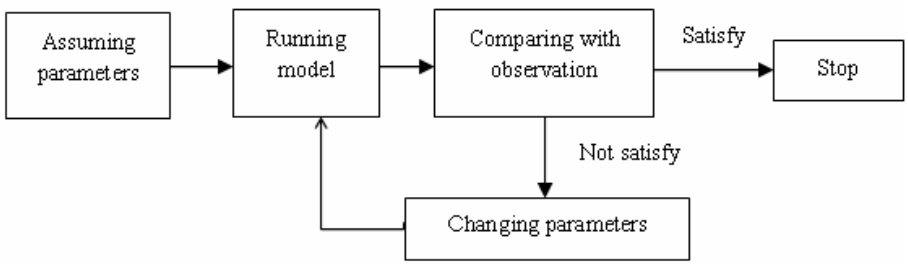

Figure-2. Method to modify and verify AD and HD modules.

- **Step-3:** The hydraulic network (step 1), the parameters of AD and HD (step 2) and climate change boundaries (sea level, the flow of the Red River) which had been collected is used to run the model for the saline intrusion prediction in February, Mar, April in 2050, 2060, 2070, 2080, 2090, 2100.

However, it is noticed that Mike 11 is only applied to predict seawater intrusion in dry seasons. About rainy seasons, due to large rainfall amounts from Red river upstream, seawater is pushed back away from the riverbed. Thus, Red river water at Kem sewer is considered without seawater intrusion impacts. Total soluble salt (TSS) of the irrigation water in rainy seasons is inputted with the current value.

- **SALTMOD**

Saltmod is a computer program aiming at predicting the long term soil salinity in terms of general trend. Its set-up is based on 3 main factors, namely: water balance, salt balance and seasonally agronomic features. The program is designed to obtain a relative simplicity of operation for users. Its input data is generally available or can be estimated with reasonable accuracy.

Realizing the appropriateness of the above features to our research objective, we decided to apply Saltmod in the research. Because light and medium salic fluvisols accounts for the most rice cultivate land area in Tien Hai (roughly 90%), we treated this type as a research target in Saltmod with 2 rice crops per year (from February to May and from July to October) to predict the paddy soil salinity trend up to 2100 under sea level rise impacts through irrigation pathway in Tien Hai district.
Besides the input data collected during the data collection method, there were coefficients affected by climate change and sea level rise impacts. They were estimated as followings:

- **Precipitation:** its measurement is based on B2 scenario - Climate change and sea level rise impacts Scenario 2009, Vietnam MONRE.
- **Evapotranspiration (ET):** because this coefficient depends on different factors (plants, temperature…) we based on Blanney - Cridle method to estimate [4]. This method is recommended by FAO in case of cannot obtaining the real value of the coefficient [5].

$$ET_c = K_c \times ET_o \text{ (mm/ day)}$$

K_c = plant coefficient
ET_o = reference evapotranspiration (mm/day)

$$ET_o = p(0.48T + 8) \text{ (mm/ day)}$$

(Blanney - Cridle)

T = average daily temperature (^{0}C)
p = percentage of average yearly sunshine hours comparing to days of months in a watering cycle.

However, the evapotranspiration is inputted as seasonal data while the above formations are in unit of mm/day. Because Climate change and Sea level rise impacts scenario had just proposed the temperature change of months, it would be hard to calculate future evapotranspiration. Moreover, our objective is to predict the soil salinity trend under sea level rise impacts. Therefore, we accepted the evapotranspiration estimation by the following conversion

T = average monthly temperature (^{0}C)
ET = ET_c × (number of days in one month) (mm/month)

Groundwater flow: this coefficient is affected by precipitation. Nonetheless, the problem of groundwater flow under climate change and sea level rise impacts was hard and had been unsolved in Vietnam. Thus, we have no basic to suppose a measurement for it. Therefore, we would fix this coefficient during the whole running time of Saltmod. Instead, the drainage water amount would be changed so as to maintaining the initial water Table (0.35m). The solution for the drainage water had been considered as one separated problem of Saltmod to be solved [6].

RESULTS AND DISCUSSIONS

1. Sea-level rise impacts on the primary salinization process of paddy soil in Tien Hai

a) Direct pathway of seawater

Direct pathway of seawater is mentioned here as seawater overflowing, seawater transmission and seawater percolation. Because the research target is located in Tien Hai's interior field, the target – paddy soil is covered by river dyke systems and sea dyke systems with an average height of 2-3 m. Moreover, according to Climate change and Sea-level rise scenario 2009 of Vietnam MONRE, the

sea-level rises 0.75 m by 2100 which is lower than the average height of Tien Hai's dyke systems. Hence, the sea level rise will cause no seawater overflow for the paddy soil there. On the other hand, the dyke systems in Tien Hai district are built in brick and concrete, so saltwater percolation and transmission from the area outside the dyke systems into the interior field are hardly reached.

In brief, due to the dyke systems' cover, the sea-level rise has no impacts on the primary salinization process of paddy soil in Tien Hai district via seawater overflow and seawater percolation and transmission.

b. Groundwater pathway

The origin of salic fluvisols in Tien Hai is alluvial soil formed by the deposition of the Red River and Tra Ly River system [7]. Soil salinization process was initially caused by the seawater overflow and salty groundwater. However, salic fluvisols used for the rice cultivation is now located in the interior field, so the soil is no more affected by the seawater overflow while salty groundwater impacts on the soil salinization has been still existing [8]. Upper Holocen aquifer (qh_2) is an unconfined aquifer overlaying the entire surface of Tien Hai district. The total mineral content of this aquifer is ranged from 0.3 g/L to 18.3 g/L [9]. The paddy soil salinization process in Tien Hai district has been increased due to the capillary action of groundwater with high salinity in the unconfined aquifer.

In addition, because this aquifer is most exposed on the surface with its static water level near the ground, it should be directly influenced by the meteorological and hydrological factors. Moreover, in coastal regions, the aquifer is also significantly affected by the oceanographic factors about water level, temperature and groundwater components. Therefore, the sea level rise may cause impacts on the aquifer water quality, in particular of TSS. Or whether this aquifer in coastal regions may be intruded by saltwater because of the sea level rise? It is necessary to conduct specialized researches before making assertions of that point.

2. Sea-level rise impacts on the secondary salinization process of paddy soil in Tien Hai

a) Aquaculture pathway

Under climate change and sea level rise impacts, the rice cultivation in Tien Hai is becoming harder. Firstly, there is a reduction in the local rainfall. Secondly, the seawater intrusion is deeper in Red riverbed [9]. Thirdly, the surface water supplying for Tien Hai district varies annually [8]. Thus, with the negative impacts, the fresh water for the agricultural cultivation in the district is no more plentiful. Even there have had years which the irrigation water was insufficient for the rice cultivation in Tien Hai. On the other hand, because the most common soil for rice cultivation there is salic fluvisols, the annually total rice productivity in Tien Hai is often lowest in the entire province - Thai Binh [7]. Therefore, in combination with the climate change and sea level rise impacts, the rice yield of the district will be supposed to decrease in the aquaculture exchange in Tien Hai.

With the exchange, the scale of the aquaculture is expanded deeper into Tien Hai interior field so that there is an improvement on the salinization process development of paddy soil there. Firstly, it is easier for the seawater intrusion into the interior water source which can cause high salinity for the irrigation water of rice fields. As a result, when this irrigation water is applied, soluble salts in the water will be gradually stored in soil leading to an increase in the secondary salinization process. For example, because there have been no specific development manners for the aquaculture in Tien Hai district, sewer doors with the purpose of the seawater intrusion prevention are sometimes served water to the aquaculture. From that, the salty water can intrude in irrigation canals, especially in dry seasons when there is a lack of the supply surface water for Thai Binh to push back the seawater intrusion. Secondly, the salty water in the aquaculture areas can be percolated and transmitted in soils so that causing salinization to the surrounding areas (radius < 500m) [8].

Hence, under climate change and sea level rise impacts, the aquaculture activities are able to encourage the secondary salinization process development of paddy soil in Tien Hai district, Thai Binh.

b) Irrigation water pathway

The supply water source for Tien Hai district includes both the local rainfall and upstream water of Red river which is primarily transported into the interior field through Kem sewer (Nguyet Lam hamlet, Vu Binh commune, Kien Xuong district, Thai Binh province) by artificial canals. The position of this sewer is 21km apart from Ba Lat estuary. However, because of buffer surface factors, the interior water TSS is not completely similar to the supply water. The current TSS of the interior water is in a range of 165 - 500 mg/L while the TSS of the local rainfall and the Red river upstream water is lower than 50 mg/L and 200 mg/L, respectively [8].

Nonetheless, the quality of the irrigation water in Tien Hai will be affected because of sea level rise impacts. Due to the 12km length (measured from Ba Lat estuary) of the seawater intrusion boundary with the 1ppt salinity in Red river in dry season in 2007 [9], this limit in 2100 under the sea level rise of 0.75m will be closer to Kem sewer leading to an increase of the river water salinity at that position. We applied Mike 11 to predict the irrigation water salinity in dry seasons and got the result as followings (Table-2).

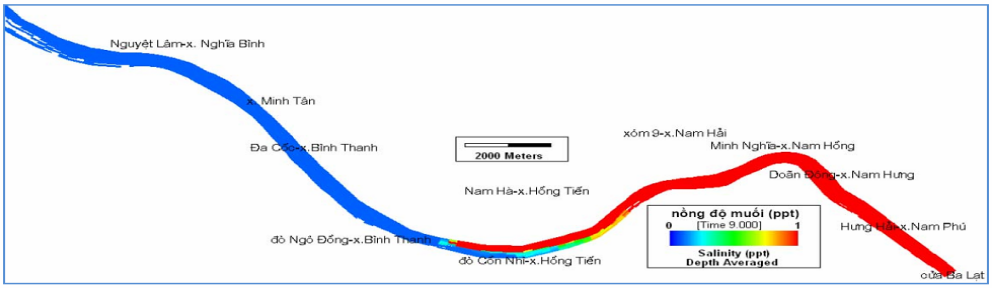

Figure-3. Seawater intrusion in the ecological flow condition and current seawater level, 2007.

Table-2. Irrigation water salinity from 2007 to 2100 in dry seasons under sea level rise impacts

Year	2007	2050	2060	2070	2080	2090	2100
Irrigation water salinity	0.051%	0.074%	0.075%	0.077%	0.079%	0.081%	0.083%

Under sea level rise impacts, the irrigation water salinity will be higher than 0.075% in the next 100 years. Besides that, irrigation water with high salinity (> 0.075%) enables to propose soil salinization risks [2]. Hence, if this irrigation water is still applied for rice cultivation in Tien Hai district, soluble salts in the water will be gradually accumulated in soil leading to a stronger salinization process.

In summary, after assessing the impact levels of sea level rise on the salinization process of paddy soil in Tien Hai district through different pathways, we can see that the irrigation water pathway is a major factor increasing the paddy soil salinization process there. Thus, the increasing trend of the paddy soil salinity through this pathway will be predicted in the next part.

3. Salinity trend of paddy soil up to 2100 under sea-level rise impacts through the irrigation water pathway in Tien Hai

To predict the salinity trend of paddy soil under sea level rise impacts though the irrigation water pathway, we applied Saltmod model based on B2 scenario - Climate change and sea level rise impact scenario 2009, Vietnam MONRE. The result is as followings:

In general, due to sea level rise impacts, the paddy soil salinity trend will increases from 2050 to 2100 (Figure-4).

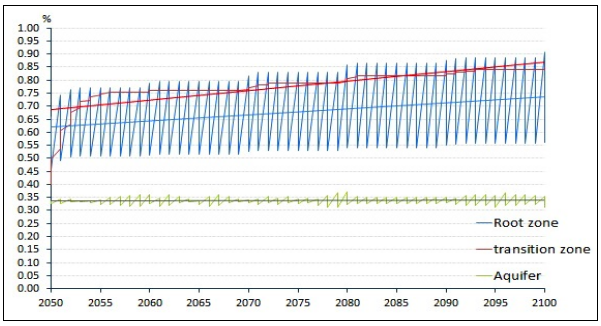

Figure-4. Salinity trend of paddy soil under sea level rise impacts through irrigation pathway in Tien Hai.

The highest increase of the salinity is at transition zone and the next is root zone. About the aquifer, the salinity there mostly remains constants around 0.35%. This can be explained by 2 reasons. Firstly, the aquifer salinity is mainly controlled the groundwater of upper Holocen formation (qh_2). This groundwater salinity is inputted in Saltmod model as 0.35%. Secondly, because the salt leaching efficiencies of the root zone and the transition zone are small (0.12% and 0.1% respectively), soluble salts in the irrigation water will be captured in these above zones leading to non-accumulation of salt in the aquifer.

Besides that, the salinity trend of the root zone progressively changes in the direction of increasing and then decreasing. In summer, because of large rainfall amounts, the water flow from upstream repels seawater away from Red riverbed. Thus, the seawater intrusion in this time is not great as in dry seasons and the irrigation water taken from Kem sewer is not affected by the seawater intrusion. Therefore, we can consider the summer time as the desalinization time for paddy soil in Tien Hai. From that, the root zone salinity trend will be fluctuated as the result. In contrast, the transition zone salinity increases in both rainy seasons and dry seasons. This is due to the small value of the salt leaching efficiency of the transition zone so that the removed salt ions from the root zone will be stored in the next zone - transition zone.

In dry season, due to sea level rise impacts, the root zone salinity increases by 0.58% (from 0.58% in 2007 to 0.91%) and the transition zone salinity increases by 0.48% (from 0.36% in 2007 to 0.84% in 2100) while the salinity of the aquifer is almost stable at 0.35% (Figure-5).

In rainy seasons, the root zone salinity decreases after each season (Figure-6). However, because the salt leaching efficiency of this zone is small, the general trend of the zone salinity is still a slight increase from 0.33% in 2007 to 0.56% in 2100. In contrast, the salinity of the transition zone continuously increases by 0.49% up to 2100. This can be explained by that the removed salt ions from the root zone in rainy seasons are captured in the successive zone owning to the small value of the salt

leaching efficiency of the transition zone. Finally, the salinity negligibly decreases by 0.04% in the aquifer.

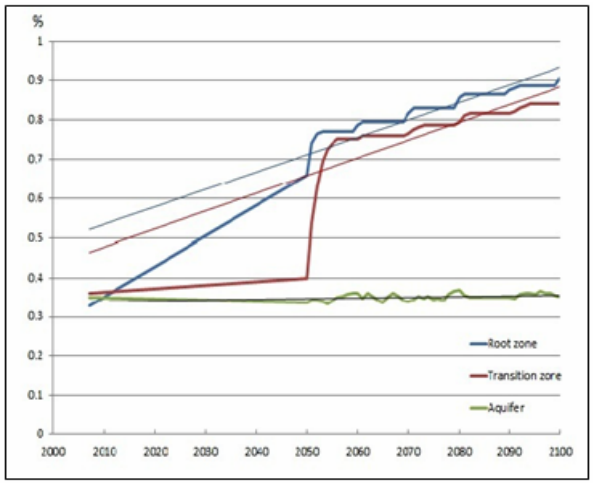

Figure-5. Salinity trend of paddy soil in dry seasons under sea level rise impacts though irrigation water pathway in Tien Hai district.

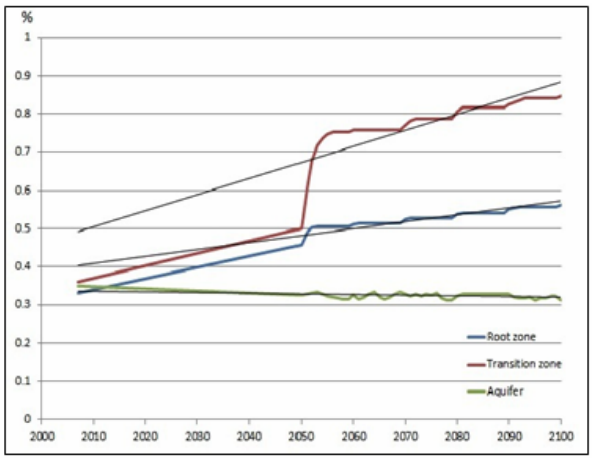

Figure-6. Salinity trend of paddy soil in rainy seasons under sea level rise impacts through irrigation water pathway in Tien Hai district.

CONCLUSIONS

In Vietnam climate change context, sea level rise will have various impact levels on paddy soil salinization process through different pathways in Tien Hai district, Thai Binh province as presented in the following table:

Salinization process	Pathway	Impact level under sea level rise context
Primary	Seawater overflow	No impact
	Percolation/ transmission from the outside of the dyke systems into the interior field	Negligible
	Groundwater	Maybe (small impact)
Secondary	Aquaculture	Initiate the salinization process development
	Irrigation water	Increase the salinization process

We found that the irrigation water pathway was a decisive factor increasing paddy soil salinization process in Tien Hai district under sea level rise impacts. In particular, with the application of Mike 11, from 2050 to 2100, the irrigation water salinity of the district will exceed the safety level (0.75ppt) for soil as well as plant. Hence, if this irrigation water is continued to be used, the soluble salt in the water will be accumulated in soil leading to an increase of salinization process there.

Thus, Saltmod applied with the result from Mike 11 predicts that the paddy soil salinity trend under sea level rise impacts through irrigation water pathway will increase significantly. The highest increase of salinity from 2007 to the end of 2100 is an increase by 0.48% of the transition zone (from 0.36% to 0.84%). Then, the root zone increases by 0.23% from 0.33% in 2007 to 0.56% after the rainy season of 2100. In contrast, the aquifer salinity nearly remains stable at 0.35%.

Finally, the research initially shows that Mike 11 and Saltmod models can be applied to predict the soil salinization of agricultural land in estuary areas under the sea level rise impacts in Vietnam climate change context.

REFERENCES

[1] 2010. Vietnam General Department of Land Administration, Statistical Yearbook.

[2] Nước mặn; Wikipedia. 2014. http://vi.wikipedia.org/wiki/N%C6%B0%E1%BB%9Bc_m%E1%BA%B7n. Last accessed 22nd.

[3] 2009. Vietnam Ministry of natural resources and environment. Kịch bản Biến Đổi Khí Hậu và Nước Biển Dâng cho Việt Nam.

[4] Lê Anh Tuấn, Hệ thống tưới-tiêu, Can Tho University, 2009.

[5] 1998. FAO. Crop evaporation - Guidelines for computing crop water requirement.

[6] 2002. R.J.Oosterbaan. Saltmod - Description of principles, user manual, and examples of application; International Institute for Land Reclamation and Improvement.

[7] Địa lý tự nhiên; Tien Hai district, Thai Binh province Portal; http://tienhai.thaibinh.gov.vn/News/Lists/DKXaHoi/View_Detail.aspx?ItemID=5. Last accessed 22th May 2014.

[8] Phạm Hoàng Hải, Nghiên cứu đánh giá thực trạng xâm nhập mặn vào khu vực nội đồng các huyện ven biển tỉnh Thái Bình, đề xuất các giải pháp và định hướng quy hoạch cây trồng, vật nuôi phù hợp với thay đổi sinh thái, Institute of Geography - Vietnam Academy of science and technology, 2007.

[9] Nguyễn Văn Hoàng, Nghiên cứu, đánh giá tác động của biến đổi khí hậu tới tỉnh Thái Bình, đề xuất các giải pháp thích ứng, giảm thiểu thiệt hại, Institute of Geological Science - Vietnam Academy of science and technology, 2011.