Assessment of Salinization in the Main River Systems of Long An Province, Vietnam

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Abstract: Three provinces including Long An, Tien Giang and Dong Thap, located at Dong Thap Muoi area in the Mekong Delta, belong to the southern key economic region of Vietnam. These provinces run from west to east with a vast network of rivers. Among them, VCD (Vam Co Dong), VCT (Vam Co Tay) and Soai Rap rivers are the three biggest rivers crossing the province. In recent years, the flows of rivers have changed a lot and saline intrusion has been very complicated. Salt water has intruded deeply into the field. In the 2000s, salt water only reached Tuyen Nhon (Thanh Hoa district), but now it has reached Vinh Hung district, about 50 km far from Tuyen Nhon. In 2016, the maximum of salinity in Xuan Khanh (Duc Hoa district) in VCD river was 6.8‰ and Tuyen Nhon (Thanh Hoa district) in VCT river was 5.2‰. In the coming years, the situation of salt intrusion is going to happen more unpredictable under effects of global climate change and sea level rise.

Key words: Salinization, Vam Co river system, LA (Long An) province.

1. Introduction

1.1 Natural Condition in LA (Long An) Province

LA is a province in the southern region of Vietnam, 50 km far from the center of Ho Chi Minh city, bordered by Svay Rieng province (Cambodia) in the north, Tien Giang province in the south and Tay Ninh province and Ho Chi Minh city in the east (Fig. 1). The province runs mostly from west to east with a vast network of rivers. Among them, VCD (Vam Co Dong), VCT (Vam Co Tay) and Soai Rap rivers are the three biggest rivers crossing the province for waterway transport and agriculture [1, 2].

1.1.1 Geographic Location

LA province with area of 449,194.49 ha and population of 1,542,606 has a rather special geographic location in the Mekong Delta, belonging to the southern key economic development zone. It is defined as a dynamic economic region that plays an important role in the economic development strategy of Vietnam [1, 2].

1.1.2 Topography

The topography of LA province is relatively flat with elevation ranging from 0.5 m to 1.0 m, except for 2.0 m and 3.0 m in the border area between Vietnam and Cambodia and up to 4 m in some areas of Duc Hoa. In general, the terrain of LA province slopes from northwest to southeast [1, 3].

1.1.3 Climate

LA has high, quite stable temperature and humidity throughout the year. The proportion of annual evaporation is quite high and distinct seasonal variation. There are two types of monsoons prevalent in the year: the northeast monsoon from November to April and the southwest monsoon from May to October. LA is one of the provinces in the Mekong Delta with low annual rainfall varying from 1,600 to 1,740 mm/year [4, 5].
1.1.4 The River System (Fig. 2)

VCT river with 235 km length originates from Svayri (Cambodia), flows through Binh Tu, Binh Chau to VCT river and joins with Vam Co river, and pours into the East Sea at Soai Rap.

VCD river with 278 km length originates from Cambodia, flows through Xa Mat to Go Dau (Tay Ninh province) and enters Vam Co river and flows into the East Sea.

Cai Cai is a natural canal, connecting with the Trabek (Cambodia) river to the center of Dong Thap Muoi region. This canal with about 100 m width and 8-10 m depth is also a boundary between Dong Thap and LA province. In the flood season, a large amount of water from Cambodia comes to LA through this canal.

Internal canal system includes the canals connect with two rivers VCT and VCD with 70 km length. The canals connecting the Tien river to VCT river are the main sources supplying freshwater in the flood and dry season from the Tien river to the Dong Thap Muoi region through the VCT river. The other canals connecting the Mekong river to the Saigon river are quite shallow and the water level is completely fluctuated by tide.

1.2 The Flows and Tidal Water Level in LA Province

1.2.1 The Flow

The flood season in LA is from August to December (5 months) in the west-northwest. In the south-southeast, floods usually appear later with lower water level.
Every year, the flood in the Mekong river overflows the Dong Thap Muoi region and VCT river. This leads to water level of VCT river always higher than that of VCD river. Therefore, the flood flows from VCT river to VCD river and from VCD river flows to the southwest area of Ho Chi Minh city.

At present, the system of embankments and dikes in this area has been developed and controlled the flood flow very well. Thus, the flows with low water level will go from VCT river to the VCD river through the canals. On the other hand, the flows with high water level will overflow the dike system to the VCD river [6].

1.2.2 The Tide

The rivers and canals in LA province were affected by the irregular semi-diurnal tidal regime of the East Sea with high tidal range (about 300 ± 350 cm). Foot tidal water level is about 160 ± 300 cm and peak tidal water level is approximately 80 ± 100 cm. As a result, the maintaining duration of high water level is longer than that of low water level and the daily mean water level is as high as the tide peak [2].

In LA province, changes in extreme weather make the characteristics of the flow unpredictable (Fig. 3).

In Moc Hoa district (northwest area), the annual rainfall decreases, especially in the dry season. This causes drought, water shortage and salt intrusion more strictly.

The data measured in LA coastal station show that high tide combined with big waves has caused landslides and salt intrusion into the field in recent years. This affects on socio-economic development. The data from 1984 to 2014 indicate that high tide levels are from September to December each year and the tidal range varies from 0.70 m to 1.00 m. The lowest water level is from March to August every year and the tidal range varies from 2.45 m to 2.50 m. The tidal range in the dry season is greater than that of the flood season.

From 2010 to 2014, the tide water level changed complicatedly. In the dry season (February-April), the increased water level at tidal peak and tidal foot, more and more intense wind, strong sun, as well as high temperature cause serious salt intrusion into the field.

At the Soai Rap estuary, the irregular semi-diurnal tidal regime of the East Sea, the tide time per day is 24 hours 50 minutes and a tide period is 13-14 days. The peak tidal range reaches 235 cm at Tan An and 85 cm at Moc Hoa. The southern districts are affected the most by the salt intrusion, about 4 to 6 months each year [6].

2. Material and Methods

The research methods used in this study include: collecting, analyzing documents from existing sources, surveying field, sampling and analyzing samples at river monitoring stations to assess salt intrusion. Then, it is necessary to apply the mathematical modeling method to simulate hydraulic, hydrological regime and water quality in the main river system in LA province [7, 8].

Hydraulic module is developed from the one dimensional Saint Venant equation for unstable flows, expressed by Eqs. (1) and (2) [8, 9]:

Continuity equation:

$$\frac{\partial q}{\partial x} + \frac{\partial A}{\partial t} = q$$  \hspace{1cm} (1)

Momentum equation:

$$\frac{\partial q}{\partial t} + \frac{\partial (qa)}{\partial x} + g.A \frac{\partial h}{\partial x} + \frac{gq|q|}{c^2 A R} = 0$$  \hspace{1cm} (2)

Advection-Dispersion module is used to simulate the one dimensional transport of suspended solids or dissolved compound in open channel, based on the
equation for cumulative storage assuming that these substances are dissolved and mixed. This process is represented by Eq. (3) [8, 9]:

\[
\frac{\partial AC}{\partial t} + \frac{\partial AC}{\partial x} - \frac{\partial}{\partial x} \left( A. D. \frac{\partial C}{\partial x} \right) = -A. K. C + C_2 Q \tag{3}
\]

Ecological module is included with the advection-dispersion module. This means that the ecological module calculates the bioremediation processes of the compounds in the river while the advection-dispersion module is used to simulate the transport and diffusion of the compounds [8, 9].

In which \( Q \): flow rate (m\(^2\)/s); \( A \): cross section area (m\(^2\)); \( x \): length (m); \( t \): time (s); \( R \): hydraulic radius (m); \( h \): water depth (m); \( g \): gravity acceleration (m\(^2\)/s); \( C \): concentration of dissolved compound (g/L); \( K \): linear decay coefficient; \( \alpha \): dynamical correction coefficient; \( D \): diffusion coefficient (m\(^2\)/s); and \( C_2 \): concentration of input streams [8, 9].

3. Results and Discussion

The process of establishing, calibrating and verifying the model and hydrodynamic simulation results is presented by Can, T. V. and Nguyen, T. S. [8].

Results of analysis, calculation and simulation of salinity were determined at Tan An, Ben Luc, Cau Noi, Xuan Khanh and Tuyen Nhon stations, which is shown in Fig. 4, in the dry season from February to July (the lowest period) from 2005 to 2016 as Figs. 5-9.

The basic data of actual measurements and simulations of salinity in the dry season several years showed that the highest salinity was reached in March, April and May. That is because the water volume from the Mekong river upstream flow through Tan Chau (Tien river) to the VCT in the dry season was a very small amount. Moreover, precipitation amount is not available or very little at that time, and the water volume in rivers’ downstream was being reduced, leading to that result that the East Sea tide has been more and more intruded into the delta.

3.1 At Cau Noi Station (Called My Loi Bridge) (Fig. 5)

This location is about 30 km far from the Soai Rap river estuary of Vam Co river in LA province, therefore this area has been impacted by the East Sea tide and the salinity is the highest in the simulated
locations. This located at nearby the river estuary, so this has been only lightly impacted by Mekong upstream, thus the salinity at Cau Noi was not hardly affected by the amount of water volume in the dry season flows to Tan Chau. The highest salinity in the Cau Noi was $33.1\%\circ$ in July 2009 and other months in dry season in 2009 showed the salinity also was more higher than $10\%\circ$. At here, in 2005, 2010 and 2016, the highest salinity was over $20\%\circ$ and lowest salinity was $14\%\circ$, especially in 2016 the salinity of the dry season was over $17.5\%\circ$.

3.2 At Ben Luc Station (Fig. 6)

Ben Luc is the location in VCD river and is the location where measured the salinity from the East Sea intruding into the VCD river through the Vam Co river and the distance from Ben Luc to the estuary is about 64 km and about 34 km to Cau Noi station. The salinity was highest at $15.4\%\circ$ in May 2005 and in other months from February to June 2005 also reached $8.3\%\circ$ to 14.2\%\circ. The salinity in 2010 was the highest at $13.0\%\circ$ and at $12.9\%\circ$ in 2016. Except for the years 2005, 2010 and 2016 with high salinity, the other years in that time there was a low salinity. From 2006 to 2009, the highest salinity in the months of the year in Ben Luc was continuously decreased and the lowest was $4.2\%\circ$ in 2006 and $5.7\%\circ$ in 2009, especially the lowest salinity in 2009 was only $0.6\%\circ$. From 2011 to 2015, the highest salinity was in the range of $3.5\%\circ$ to $8.2\%\circ$ in 2013, and the lowest salinity of the year was $0.8\%\circ$ in 2012. Especially in 2005, 2010 and 2016, the salinity in Ben Luc was high in 4 months from February to May with salinity over $9\%\circ$. In period 2005-2016, the lowest salinity in Ben Luc was $3.5\%\circ$ in 2012.

3.3 At Tan An Station (Fig. 7)

This site locating at the VCT river, helps to measure the salinity from the sea intruded into the Vam Co river. Tan An is about 77 km from Soai Rap estuary and about 47 km from Cau Noi station. The same as Ben Luc station, Tan An station also recorded in three years 2005, 2010 and 2016 with high salinity. The highest salinity was $15.7\%\circ$ in April and May 2005, was $11.2\%\circ$ in April and May of 2010, and reached $11.7\%\circ$ in 2016, conversely the salinity was lower than $7\%\circ$ in other years. In Tan An, the years of salinity were devided in three groups: (i) over $11\%\circ$ in 2005, 2010 and 2016; (ii) $7-8\%\circ$ in 2007, 2008, 2013 and 2015; (iii) under $3\%\circ$ in 2006, 2009, 2011, 2012 and 2014; even in 2012, the highest salinity was only $0.7\%\circ$ (almost not affected sanility).

3.4 At Xuan Khanh Station (Fig. 8)

This station is about 106 km from Soai Rap estuary and about 41 km from Ben Luc. The salinity was remarkable only in the dry season in the years of 2005,
3.4.5.6.7.8.9.10.11.12.13.14.15.16.17.18.19.20.21.22.23.24.25.26.27.28.29.30.31.32.33.34.35.36.37.38.39.40.41.42.43.44.45.46.47.48.49.50.51.52.53.54.55.56.57.58.59.60.61.62.63.64.65.66.67.68.69.70.71.72.73.74.75.76.77.78.79.80.81.82.83.84.85.86.87.88.89.90.

Fig. 7 The salinity at Tan An station (VCT river).

Fig. 8 The salinity at Xuan Khanh station (VCD river).

2010, 2015 and 2016. Especially in 2005 and 2016, the driest season happened and then there was a serious shortage of water, and the salinity was up to 6.9‰ in 2005 and 6.8‰ in 2016. The salinity was in the range of 3-4.5‰ in the years of 2010 and 2015 but only two months each year.

Fig. 9 The salinity at Tuyen Nhon station (VCT river).

3.5 At Tuyen Nhon Station (Fig. 9)

Tuyen Nhon located in the upstream of VCT and is about 48 km from Tan An in VCT river and 115 km from Soai Rap estuary. As the same Xuan Khanh station, the salinity here was only remarkable in the flood season with low water in the years of 2005, 2010 and 2016. Especially in 2005, the highest salinity was 9.6‰ in April and May, and the salinity was 5.2‰ in 2 months of the year 2016.

4. Conclusions

The collection, calculation and simulation at locations on the main river system in LA such as VCD river, VCT river and Vam Co river showed that salinity was very fluctuated unpredictably. The salinity in the river system in LA was influenced by the upstream flow of the Mekong river and the tidal regime of the East Sea.

Moreover, in the coming years, the situation of salt intrusion is going to happen more unpredictably under effects of global climate change and sea level rise.

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