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# Adaptation to Saline Intrusion in the Coastal Area of Vĩnh Châu, the Vietnamese Mekong Delta

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**Abstract**: The extraction of groundwater has increased rapidly over the past decades and forms one of the main causes of saline water intrusion into the coastal aquifers. Such the intrusion has been accelerated by the on-going rise of the sea level. Saline intrusion in groundwater in the Vietnamese Mekong Delta is highly complex as it depends heavily on different factors, including changes in water supplies (e.g. the magnitude of the annual upstream hydrograph during both the flood and dry seasons and timing distribution of the annual rainy season) and rising water demands (e.g. the amount of fresh groundwater extracted for different purposes like domestic, agriculture and aquaculture use). This article is to provide an insight into current adaptations to increasing salinity concentration in the groundwater resource in Vĩnh Châu - a coastal district of the Sóc Trăng province, the Vietnamese Mekong Delta. The existing adaptations to maintain the current livelihood of local residents were investigated and possible adaptations to sustain such the valuable fresh groundwater resources were proposed. In fact, adaptations have already taken place by switching from paddy rice to marine aquaculture over the last decades; however, it is not widely applicable due to high inputs and great economic risks. No problems were found in the current situation with farmers who grew upland crops on high sand ridges due to low salinity levels of the deep groundwater. However, decreases of yield in saline-sensitive agriculture irrigated by groundwater were experienced in the study area.

*Keywords:* Saline intrusion, groundwater, climate change, adaptation, coastal area, and Vietnamese Mekong Delta.

The Vietnamese Mekong Delta (VMD) covers about 39,000 km$^2$ of fertile alluvial plain and is home to over 18 million people. Groundwater is amongst the important sources of drinking water for millions, especially those who live in the coastal areas [1]. The extraction of deep groundwater has increased rapidly over the past decades and forms one of the main causes of saline water intrusion into coastal aquifers [2]. In fact, the land use change, one of the main driving factors leading to groundwater extraction at different extents over time in the coastal areas of the VMD, happened over the past 20 years (from paddy rice cultivation to shrimp farming on the low lying areas). The changes (initiated by local farmers) protested

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against the protection of the salinity-controlled area and the local government allowed diversification of land use from the year 2000 onwards. The shift from fresh to brackish water has had great impacts on the ecology and society in coastal areas [3]. Local farmers who went for rice farming systems got problems with the new diversification policy as the fresh surface-water resources was not sufficent for single (crop) season. Even thought saline / brackish aquaculture earned benefits from changes of water resources, local aquaculture was not developed effectively as it required high (financial and technological) input and has relatively high economical risks. In addition, incomes of local farmers who went for shrimps were not secure given constraints of poor quality of post larval, on-farm technologies and poor quality of the irrigation network [3].

Saline intrusion into deep groundwater resources in the VMD is a highly complex natural process as it depends heavily on different factors including changes of water supplies (e.g. the magnitude of the annual upstream hydrograph during both the flood and dry seasons and timing distribution of the annual rainy season) and rising demands (e.g. the amount of fresh groundwater extracted for different purposes like domestic, agriculture and aquaculture use) [4]. Such trend of saline intrusion into the coastal aquifers becomes even more serious due to lack of fresh surface-water resources as a consequence of increasing demands (especially for agriculture) in the upstream section of the Mekong River [5].

Scenarios of climate change in the VMD showed that the annual dry and wet seasons will become even drier and wetter respectively in the future [6] (Figure 1). Together with a sea level rise (up to 30 and 75 cm in 2050 and 2100 according to the B2 scenario; [6], the decrease of rainfall might lead to a significant increase of saline intrusion in surface-water and groundwater during the dry season [7].

The Vĩnh Châu district is located in the coastal zone of the Sóc Trăng province with the mean land surface elevation of about 1.0 m above mean sea level (Figure 2). This is a former salinity-controlled area where rice farming systems were dominated (Figure 3). From the year 2000 onwards, farmers protested against the protection of the salinity-controlled measures leading to a diversification of local land use [3]. The new diversification allowed re-entries of saline water, resulting in a shift from fresh to brackish surface-water resources. In fact, over the last 20 years, many areas of Vĩnh Châu was converted from paddy rice to marine aquaculture (Figure 3), leading to saline intrusion in the surface and groundwater resources [8].

Even though different studies were done to provide an insight into the groundwater resources in the VMD (e.g. [7]; Figure 4) and saline intrusion in groundwater has been considered seriously over the last decade, little amount of research was done to quantify the actual changes of the groundwater quality. To realize possible adaptations to slow down the processes and to figure out possible changes in terms of agriculture and aquaculture to sustain both the livelihood of local residents and the ground water resources are actual needs for further study. This article is to investigate on the current adaptations to increasing salinity concentration in the groundwater resource in Vĩnh Châu and to propose possible adaptations to sustain such the valuable fresh groundwater resources.

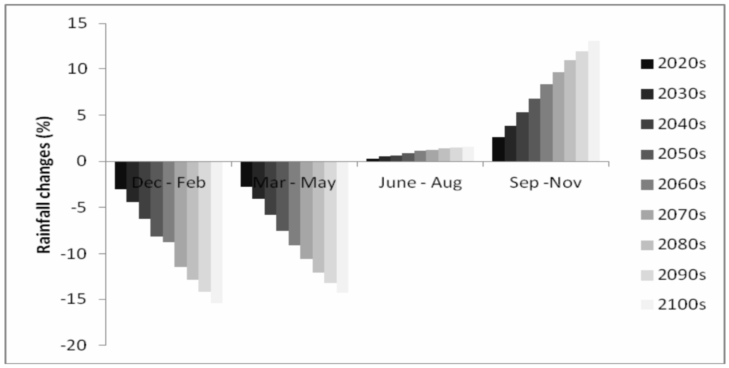


Figure 1: Projected rainfall during a year in the future in the VMD according to the B2 scenario (i.e. increased concerns for environmental and social sustainability).

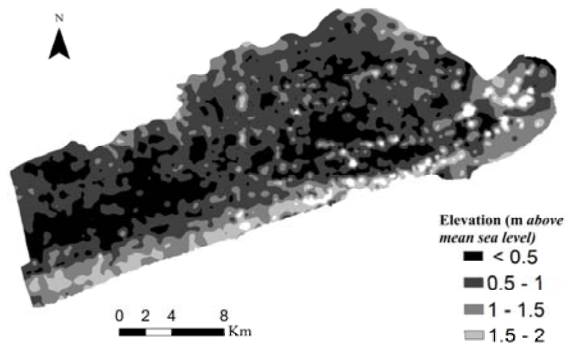


Figure 2: Digital Elevation Model of the Vĩnh Châu district.

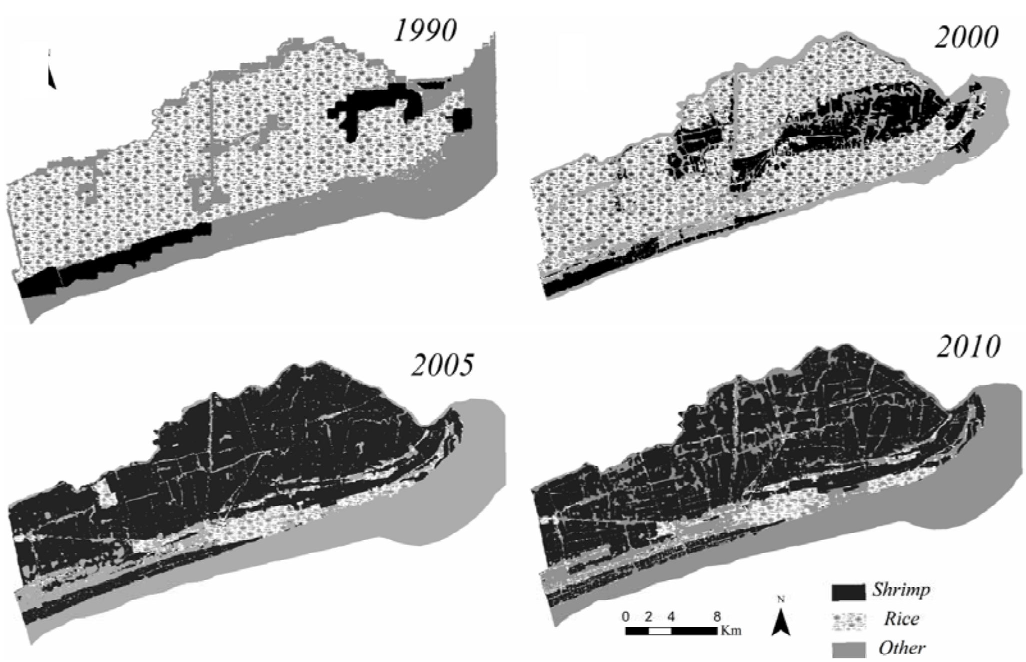


Figure 3: Land use change Vĩnh Châu district from 1990 to 2010.

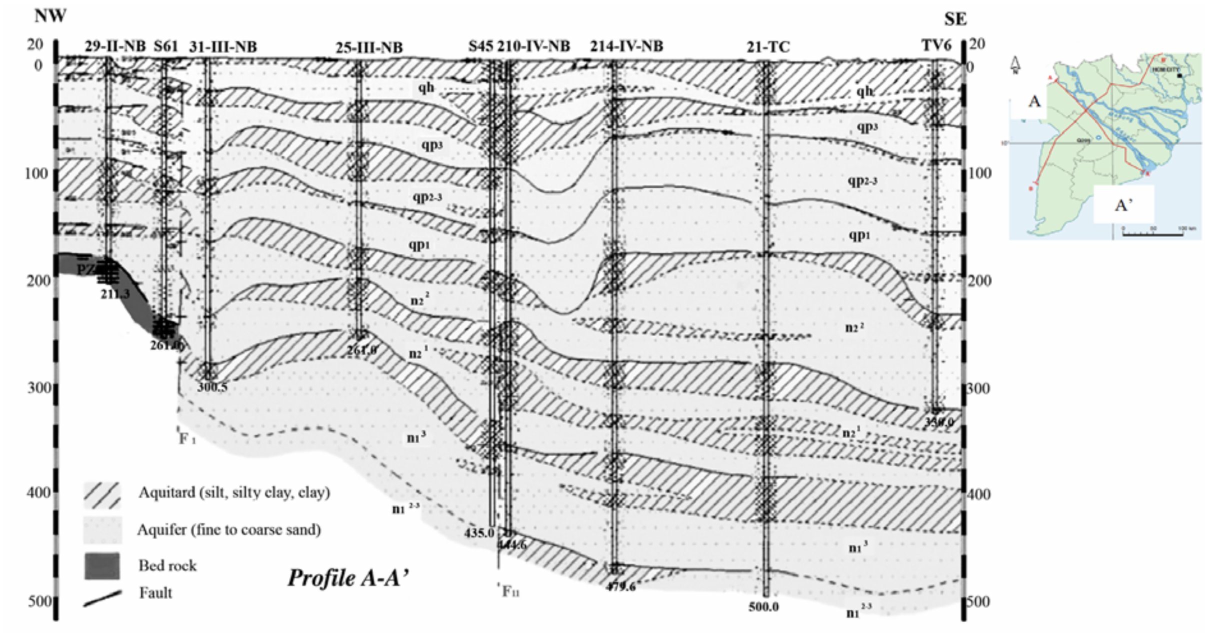


Figure 4: North West - South East directed hydro-geological profile of the VMD **[7]**.

## 2. Methodology

The literature study provides an insight into: (i) main causes of saline intrusion into both surface and groundwater; and, (ii) existing adaptations to adapt to saline intrusion of the groundwater in the coastal areas of the VMD over the past 50 years. Information on historical agricultural land use changes in the study area was collected to provide insights into saline intrusion dynamics of the groundwater. In addition, climate change scenarios were also studied to project changes of saline intrusion of groundwater in the future.

Interviews (with local farmers and authorities) are based on a structured standardized interview [9] to understand the actual farming systems and to provide an insight into the current adaptations to different salinity levels in both surface and groundwater resources. In fact, local land use map, Digital Elevation Model (DEM) and agro-ecological map (unpublished works done by the Can Tho University) form a base for selecting farms to survey. The interviews with local farmrs were done ranging from sea to inland to provide a spatial-dependence of the salinity level in the groundwater. The folowing equipment were used for measuring the salinity levels of the groundwater (of 29 pumps) in the field:

- Basic Conductivity Meter, Orion, Model 105 (EC-probe) (calibrated conform the instruction manual [10]);
- Lab glasses;
- Calibration solution; and,
- Check solution.

The salinity levels of the pumped groundwater were directly recorded with an EC-probe (following guidelines for recording from [11]). Classification of the groundwater salinity was done by converting from an EC value (µS/cm) to a chloride concentration (mg/l) ((Equation 1):

*Chloride concentration (mg/l) = 0.31 EC (µS/cm) - 170.03* (Equation 1) [12]

## 3. Results

### *3.1. Current salinity levels of deep groundwater along hydro-geological profiles in Vĩnh Châu*

The salinity measurements only take place for the deep groundwater with an average depth of 110 m. In fact, depths of the groundwater pumps are between 50 - 200 meters, which concerns three different aquifers, including:

- One groundwater pump is located in the Upper Pleistocene aquifer. This aquifer starts at approximately 40 m below the land surface and has a thickness of 20m. The salinity measurement showed an EC value of 2.139 µS/cm (494 Cl-mg/l), the greatest amongst all 29 measurements.

- The Upper-Middle Pleistocene could be found at a depth of approximately 80 m, with a thickness of 55 m and low saline concentration in groundwater [7]. 26 out of 29 measured groundwater pumps are located in this layer. The results of the salinity measurements in this aquifer show a very divers pattern, with EC values between the 1.050 - 1.600 µS/cm.

- The Lower Pleistocene aquifer starts at a depth of 135 meters and ends at approximately 220 meters and is commonly used for exploitation. 2 out of 29 groundwater pumps have a depth that reaches this aquifer.

Figure 5a, b, c and d present the salinity concentration (in the groundwater) changes from coast to inland. Segment lines (including sub-lines) (Figure 6) show an increase of salinity further inland.

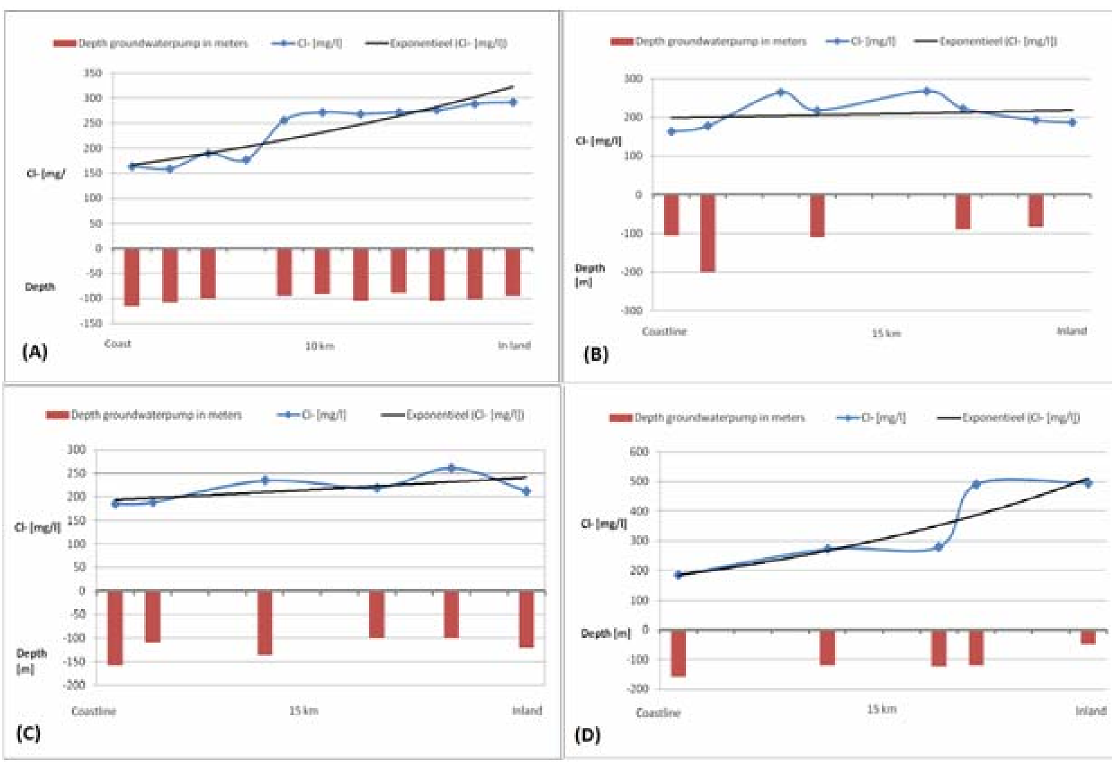


Figure 5: Salinity changes groundwater in the coastal zone - Segment line 1 (A), Segment line 2, subline 1 (B), Segment line 2, subline 2 (C) and Segment line 2, subline 3 (D).

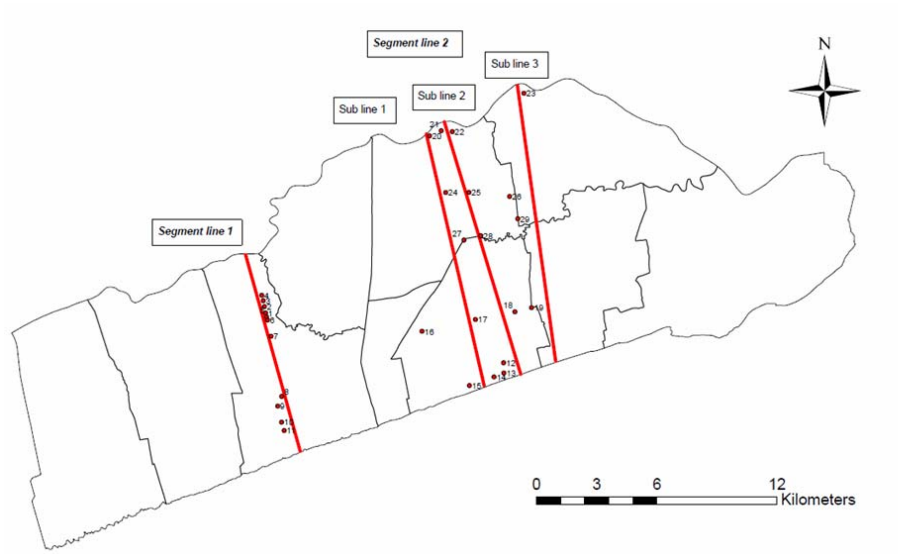


Figure 6: Locations salinity level measurements with different segment lines.

Figure 7 presents the current salinity levels (EC values) of the groundwater with reference to the pump depths. The average chloride concentration was about the 246 mg Cl-/l, with a maximum of 495 mg Cl-/l (brackish) and minimum of 159 mg Cl-/l (mild brackish). The deep groundwater was classified as light brackish to brackish. The EC values of the pumps located near the coast of Vĩnh Châu were lower than the values further inland.

### *3.2. Analysis of salt tolerance for upland crop and aquaculture*

Deep groundwater was used for irrigating upland crops during the dry seasons. While there was no significant yield reduction in the current situation for cabbage, chilli and sweet corn, onions were under threats of the salinity of groundwater. In fact, according to FAO (1999) the threshold EC of onion occurs at 1.200 µS/cm with a slope of 16% per dS/m while the irrigation water used for onions has a range of 1.200 –1.500 µS/cm. In addition, thresholds of EC for chilly, corn and cabbage are 1.500 µS/cm, 1.700 µS/cm and 1.800 µS/cm, respectively [14].

Shrimp farming increased over the past 20 years (Figure 3). The Black Tiger shrimp (Penaeus monodon) and Artemia Franciscana were cultivated in Vĩnh Châu with the combination use of fresh groundwater and sea/river water. The ideal salinity range of Black Tiger shrimps ranges between the 10.000 - 30.000 mg/l [15]. When the salinity becomes too high the shrimps grow slowly but are still healthy and resistant to diseases. If the level of salinity becomes too low, the shrimp shell becomes weak and prone to diseases [15]. Problems with salinity levels could occur when sea/river water was mixed with groundwater without a proper application of technology and knowledge of shrimp farmers in Vĩnh Châu. Artemia forms a ideal adaptation measure due to high salinity tolerances [16].

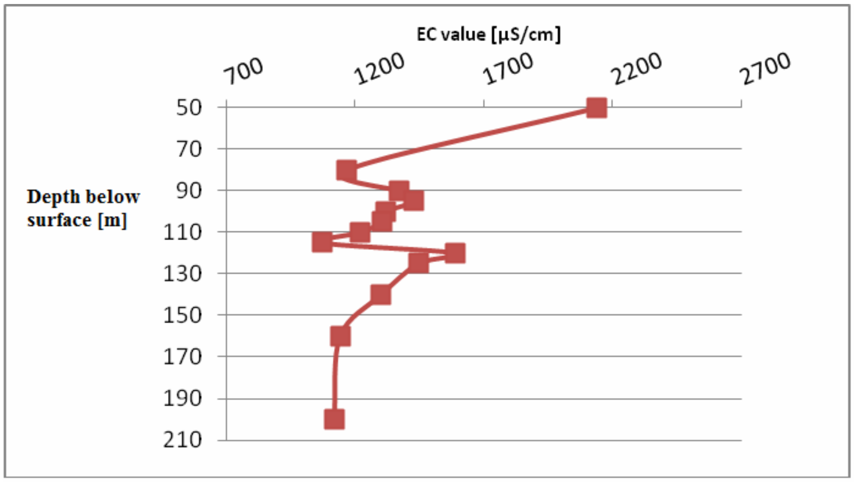


Figure 7: EC values based on different depths Vĩnh Châu district.

## 4. Discussions and conclusions

The obtained results of the salinity measurements of the deep groundwater showed that salinity concentration increases from the coast to inland. Analyses of the hydrogeology showed that each aquifer has different qualities depending on the depth and rather un-predictable; further studies are needed to get an overview on groundwater quality distribution in the VMD.

Acceptable ranges of salinity of groundwater depend strongly on the crop choice of local farmers. Groundwater for agriculture use is classified as fresh until 150 mg Cl-/l [17]. Further research is needed to understand the complex processes of saline intrusion into deep groundwater.

Farmers with land on high sand ridges often practiced upland crops systems (Figure 2). Deep groundwater is used for irrigation of the upland crops. In the current situation yield reduction takes place for the cultivation of onions (with the range between 0-5%). If the salinization of the groundwater increases in the future due to climate change predictions, local farmers with upland crops might face problems of yield reduction [18].

Based on this study, a number of key lessons can be identified for the further considerations:

- The salinity level of the deep groundwater that is used for irrigating agriculture (especially upland crops) and mixing with sea water for aquaculture does not cause yield reduction in the current situation. In the future, with possible impacts of climate change and sea level rise, rising salinity level of the deep groundwater may introduce great threats to agriculture;

- As Vĩnh Châu faces directly the East Sea and marine aquaculture is one of the main sources of income, saline intrusion of the groundwater is not a major problem constraining livelihood of local residents. However, areas further inland with less favorite for saline environment, saline intrusion in the surface-water resources may lead to more constraints for agriculture, resulting in groundwater extraction at greater extents;

- According to staffs of Department of Environment and Natural Resources in Vĩnh Châu (*personal communication*, 2013) apart from deep groundwater and fresh surface-water resources, collecting shallow groundwater and rainfall might help sustain livelihood of local residens living in the coastal areas of the VMD (like Vĩnh Châu). Even though local farmers rely on the deep groundwater, other water sources like shallow groundwater and rainwater could ease the constraints and make farming systems more sustainable;

- The mixed shrimp-mangrove systems could form a suitable adaptation strategy due to the advantages of integrating ecology and agriculture [19]. Such system is reachable to small-scale and family-based operations. Further research on how farmers implement this system is an actual need.

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# Thích ứng với xâm nhập mặn ở vùng ven biển Vĩnh Châu, Đồng bằng Sông Cửu Long


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**Tóm tắt**: Việc khai thác nước dưới đất để phục vụ cho các hoạt động sinh hoạt hằng ngày cũng như các hoạt động sản xuất nông nghiệp và thủy sản của người dân vùng ven biển đã gia tăng đáng kể trong những năm gần đây; đây là một trong những nguyên nhân dẫn đến sự xâm nhập mặn ở các tầng nước dưới đất ở vùng ven biển. Ngoài ra, tình trạng nhiễm mặn cũng được dự báo là sẽ tăng lên đặc biệt là trong điều kiện mực nước biển dâng trong tương lai. Tình trạng xâm nhập mặn vào các tầng nước dưới đất ở Đồng Bằng Sông Cửu Long (ĐBSCL) diễn ra khá phức tạp và phụ thuộc vào nhiều yếu tố khác nhau như, suy giảm nguồn nước cấp (suy giảm nguồn nước ở thượng nguồn sông Mekong) và tăng nhu cầu sử dụng nước (nước sinh hoạt hằng ngày trong gia đình cũng như nhu cầu nước cho các hoạt động nông nghiệp và thủy sản). Bài báo này tập trung tìm hiểu những giải pháp thích ứng hiện có ở vùng ven biển Vĩnh Châu, tỉnh Sóc Trăng, ĐBSCL trong điều kiện xâm nhập mặn nguồn tài nguyên nước dưới đất đang diễn ra ngày càng phức tạp. Những giải pháp thích ứng hiện có được khảo sát nhằm đánh giá nhằm tính ổn định trong sinh kế của cộng đồng dân cư địa phương (liên quan đến hoạt động khai thác nước dưới đất); bên cạnh đó, một số giải pháp thích ứng cũng được đề xuất nhằm hỗ trợ sự phát triển bền vững của vùng. Theo kết quả khảo sát, một số chiến lược thích ứng đã được áp dụng ở địa phương trong những năm qua (ví dụ: chuyển từ các hoạt động nông nghiệp sang nuôi trồng thủy sản); tuy nhiên, việc chuyển đổi cơ cấu canh tác (từ nông nghiệp sang thủy sản) cũng đã gặp một số khó khăn do nhu cầu đầu tư cũng như rủi ro (về lợi nhuận) từ các hoạt động nuôi trồng thủy sản là khá cao. Ngoài ra, theo kết quả khảo sát, hiện tại người dân trồng màu trên các *giồng cát* trong vùng nghiên cứu không gặp phải những khó khăn đáng kể (về nguồn tài nguyên nước) do nồng độ muối trong nước dưới đất không cao. Tuy nhiên, nhìn chung, các hoạt động canh tác nông nghiệp đã có xu hướng bị ảnh hưởng tiêu cực do tình trạng nguồn nước dưới đất trong vùng nghiên cứu bị nhiễm mặn.

*Từ khóa:* Xâm nhập mặn, nước dưới đất, biến đổi khí hậu, thích ứng, vùng ven biển, và Đồng Bằng Sông Cửu Long.