Proposed Adaptation Measures for Saltwater Intrusion in the Vietnamese Mekong Delta

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PROPOSED ADAPTATION MEASURES FOR SALTWATER INTRUSION IN THE VIETNAMESE MEKONG DELTA

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Abstract. The Vietnamese Mekong Delta (VMD) plays an extremely important and central role in the country's food security. The influences of the upstream dam's development, sea level rise and complicated tidal regime in the dry season have caused barriers and constraints for local agricultural activities in VMD. Once these causes combined climate change, the salinity intensity is more severe and intrusion length is likely further in seven Mekong estuaries. This paper aims to propose mitigation and adaptation measures for saltwater intrusion (SI) for sustainable agricultural development in the Mekong estuary areas. The relationship between Q ~ S and Q ~ L have been built to predict the S and L along five of seven branches. Also, the boundary between freshwater - brackish - saltwater zone also was proposed for planning the land use and water use. Moreover, the location of salinity monitoring stations, as well as the kinds of saltwater control works, are also discussed to serve the operation of saline control works based on analysis of field measurement data. The study will be very meaningful for local farmers to develop agriculture sustainably, especially, since the farmers can select crops that are suitable for the salt concentrations or change land use and cultivation models for higher yields.

Keywords: Saltwater intrusion, Upstream dams, Sea level rise, tidal regime, Vietnamese Mekong Delta.

1 Introduction

The Mekong river flows through 6 countries with total length of about 4,800km from Tibetan Plateau China to Vietnam and total basin area of 795,000km^2. The Vietnamese Mekong Delta (VMD) is located at the lowermost of MR with total area of 39,000 km^2 from Vietnam-Cambodia border to the East Sea. The MR is divided into two branches flowing into Tien River and HauRiver in Vietnamese territory. Firstly, Tien River carries of the majority of the flow (85%) and later convert to Hau River through VamNao linking channel. After MyThuan and CanTho, TienRiver and HauRiver flow into the East Sea of Vietnam through eight estuaries such as Tieu, Dai, HamLuong, CoChien, CungHau, DinhAn and TranDe (Fig.1)

VMD have been facing with so many critical problems such as flooding, river and coastal erosion, subsidence, drought, and salinity intrusion. Specially, salinity intrusion in 2016 and 2020 was a most severe over 90 years in the delta. Fig. 1 show the trend of salinity concentration more complicated and serious with maximum concentration increasing for 30 years. The intrusion length of 4 psu in 2020 is 78km, 68km, and 65km on HamLuong, CoChien, and Hau Rivers, 5km, 3km and 5km deeper than 2016 and 35km, 24km and 24km deeper than the average 26 years, also on all three estuaries of HamLuong, CoChien and Hau rivers. That affected on 52.7% areas of the VMD with a total economic loss approximate US$360 million because the salinity impacted on over 405,139 ha of rice field, 28,457 ha of fruit free areas, 194,163 ha of aquaculture area and over 389,831 household have been faced water shortage [1]. So, understanding the causes and the mechanism of salinity intrusion was very necessary to propose the solutions, the mitigation and adaption measures.

Saltwater intrusion (SI) is a natural phenomenon occurring in the estuary and coastal areas where tidal influence is observed. Previous studies have shown factors affecting saline intrusion, including river flow, topography, morphology, river bed slope, water use, precipitation, sea level, tidal regime, wind direction, wind speed, and human activities.

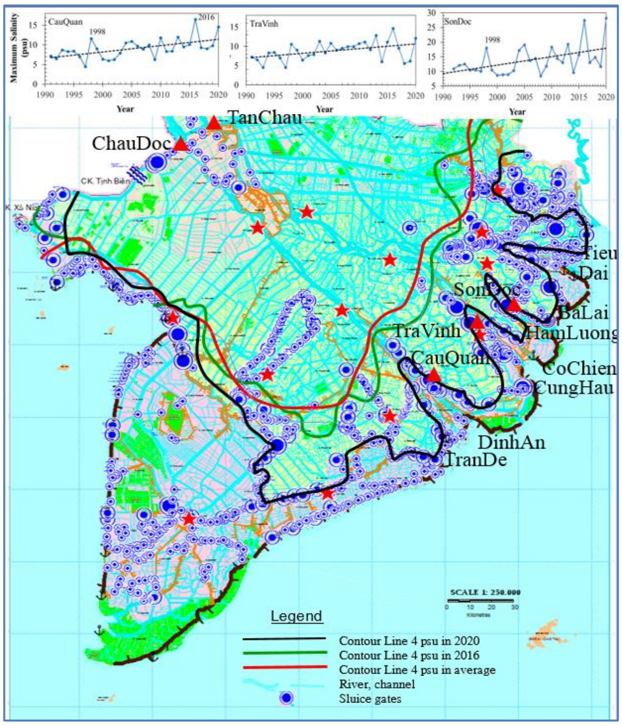

Fig.1 Map of study area and salinity intrusion contour in mean average years, 2016 and 2020

Several recent studies have concluded that sea level rise and upstream flow changes have significantly impact on salinity concentration (S) and intrusion length (L). For example, the results show that the S increases 2.5 psu and L increases from 10 to 20km in the main river and 20 to 35km in the paddy field under 20 to 45cm of sea level rise [2]. One of the main causes, up to 2016, over 56 upstream dams were completed, so the total dry flow has an increasing trend by 5,1% due to shifting water from the wet season to the dry season, the S will be reduced by 11.6% at 28km from the river mouth [1]. But the total dry flow was unevenly flowing distribution during 6 months of the dry season. The flow has increased from March to May while it has decreased from November to February. Hence, the S raised from November and maintained a high concentration from December to February and reached the peak value in February [1]. That was causes of maximum S occurred earlier and more severely in recent years.

Besides, the upstream dams do not only store water but also trap the sediment inside the reservoir, causing the flood peak, the frequency of floods, and the amount of sediment to be significantly reduced downstream, especially in the VMD area. Such as since 1993, when large upstream dams were built and over 56 hydropower dams have been completed in 2016, the Mekong dams have caused large-scale morphology changes in VMD. In the building dam period of 1993-2011, the annual sediment load decreased by 64.1% (59.7 Mt) and by more than 74.6% (42.3 Mt) in the completed dam period 2012-2016 [1]. This is the main cause of erosion or incision of the bottom topography of the Hau and Tien rivers in VMD. A comparison of the riverbed elevation data between 2009 and 2017 shows that the mean incision rate from ChauDoc to CanTho (0.22 m/yr) is more than 3 times that of CanTho to the DinhAn estuary (0.07 m/yr). Also, the maximum incision rate in the lower part is 0.22 m/yr so 0.22 m/yr of riverbed incision is used for the whole Hau River for simulation, while the mean incision rate in the upper and lower part of Tien (CoChien branch) is 0.34 m/yr and 0.19 m/yr respectively [1].

The reduction of upstream flow and sediment may cause many related environmental issues, such as riverbank erosion and the lowering of riverbed elevation, a reduction in nutrient-rich sediment transference into floodplains, and increased saltwater intrusion. In addition to human-induced factors, sea-level rise and tides are also threats to the VMD.
As a result, these issues have changed farming practices by intensifying the use of agrochemicals and affecting the livelihoods of people in the VMD. These issues may lead to serious challenges for the Vietnamese government in terms of food security and environmental sustainability. Therefore, setting up operation rules for the upstream reservoir and proposing suitable water resources management solutions to ensure sustainable socio-economic development downstream are needed.

2 The mitigation and adaptation measurement on SI

2.1 Mitigation measures for Mekong River Basin (MRB)

Based on analyzing the changes of upstream flow regime into the downstream region, especially in the VMD and its related environmental issues, this study proposed some measures to enhance sustainable socio-economic development in the downstream, especially in the VMD by reducing adverse impacts of upstream dam development. Therefore, it is needed to maintain environmental flow, sediment flow and to ensure a water demand in the downstream region which could support people's livelihoods, farming practices, and ecosystem services.

In extreme cases, reservoir operation rules should be appropriately adjusted to mitigate extreme drought events in the downstream regions, which may minimize transboundary impacts. For example, if the upstream reservoirs have suitable operation rules (such as releasing water one or two months earlier than usual) during extreme drought events in dry seasons of 2016 and 2020, the VMD would have avoided severe socio-economic losses. So, it is very necessary to set up and improve the monitoring system and sharing hydrology data and operation rules among countries for proactive preparedness to face extreme events and make a future plan. Moreover, strategic collaboration among riparian countries and different geographical regions is crucial to share the benefits from the Mekong River.

2.2 Mitigation and adaptation measures for Vietnam Mekong Delta (VMD)

It was noted that saltwater intrusion processes (SI) in the VMD in recent years have been very complicated, especially in 2016 and 2020. SI has caused 389.831 households to lack fresh water and over 405.139 hectares of rice crops were affected so short-term and long-term solutions need to be considered. Therefore, both structural and non-structural measures are needed for mitigating the risks of saltwater intrusion.

The comprehensive solutions were proposed in Fig. 2 to prevent and mitigate the impact of drought and salinity intrusion in short (such as days, weeks, months, seasons, or years) and long-time frames (many years). This diagram includes seven solutions, including four non-structural solutions and three structural solutions.

2.2.1 Early warning

Until 2020, there have been about 81 salinity monitoring stations located along 13 main tributaries of the VMD. Thirty-nine monitoring stations of them in the seven estuaries of the Mekong River have been installed to service the operation of over 130 sluice gates located along seven MR estuaries and 122 salinity control sluices in the delta. Most of the manual stations only monitor from January to May with an interval time of 2 hours so the results were less correct. So, it is necessary to set up automated monitoring stations and share salinity data to be more proactive with the intake of fresh water and prevent seawater intrusion to reduce the damage of the latter.

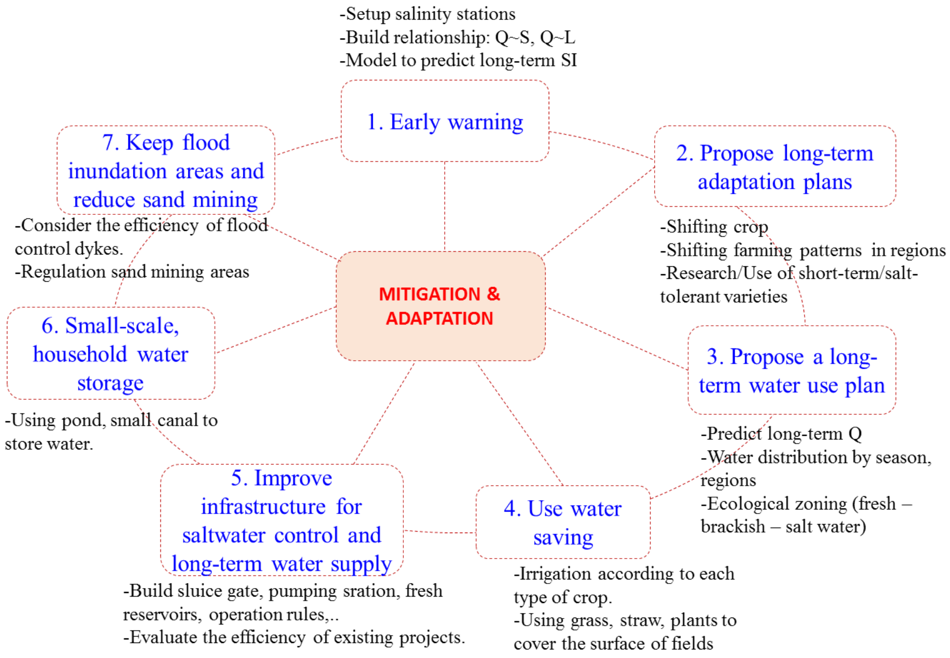

Fig. 2 Long and short-term measures for mitigation and adaptation with SI in VMD

The location of salinity monitoring station has been suggested that at the intersection of the river and the canal, it is advisable to incorporate monitoring stations on the main river upstream of these tributaries which have saltwater control sluices and a single station in front of the sluice gates if those sluices are located far from the main river.

Because salt concentration in the main rivers and canals is quite different due to the riverbed elevation of the tributary and the main canal. This is due to the retention of saltwater along the river bottom.

Fig. 3 show that S_{max} in the mainstream is 4psu while S_{max} in the front of the sluice gate is 6psu in the flood tide. In the ebb tide the S_{max} in the mainstream is less than 1 psu but the gate still close because the S_{max} in the canal still high about 3-4psu. So, the gate could not intake fresh water from the mainstream.

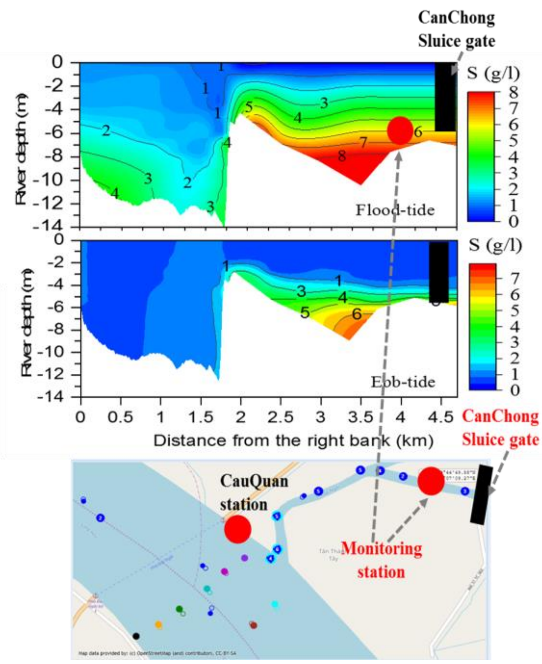

Fig.3 The vertical distribution of salinity at one cross-section of the Hau River and 2.5 km long of CauQuan river in front of the CanChong sluice gate

In addition to automatic salinity monitoring, it is easy to estimate salinity concentration in the VMD by using the relationship curve between Q_{TC+CD} ~ Salinity by historical data (Fig.4a) and Q ~ L intrusion length in the main estuaries (Fig. 4b) by numerical model.

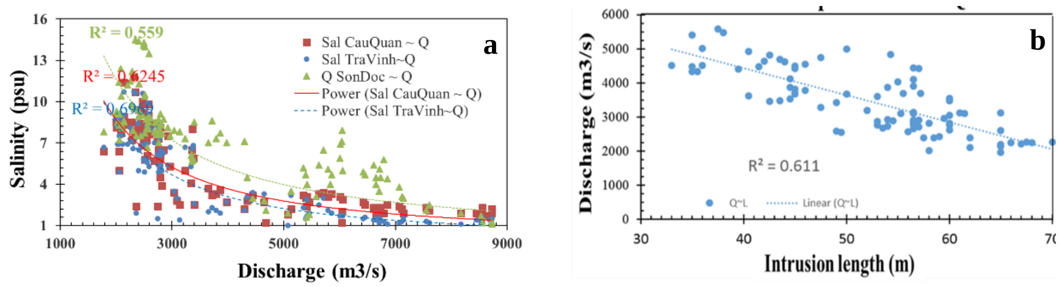

Fig 4a, b The relationship between discharge at TanChau+ChauDoc and Salinity concentration at three stations and intrusion length.

2.2.2 Proposed long-term adaptation plans and water use plans

To prevent serious impacts of salinity drought in the VMD, it is very important to develop an adaptation plan which considers the changes of water sources from upstream regions. Then make the production calendar according to the river flow such as shifting the rice crops or shifting the farming patterns in some regions according to the salt-tolerant crops. For example, in coastal areas where the salinity concentration is frequently higher than 6 psu during the six-month of dry season, the most reasonable solution is to change the land use purpose. Converting from land for rice cultivation, green flowers for aquaculture or a combination of shrimp-rice rotation model. In the rainy season, it is possible to combine rice cultivation with freshwater fish, while in the dry season with high salinity value, shrimp and crab can be cultured.

Fig.5 divide the ecological zoning according to the saltwater value, such as freshwater (< 1 psu: saltwater tolerance of plants), brackish (1-16 psu), and saltwater (>16 psu: saltwater threshold which is suitable shrimp farming). To have a basis for dividing water use and corresponding production zoning, the author uses the numerical model results for the Baseline scale to partition the VMD into 3 parts according to the above saline boundary [1].

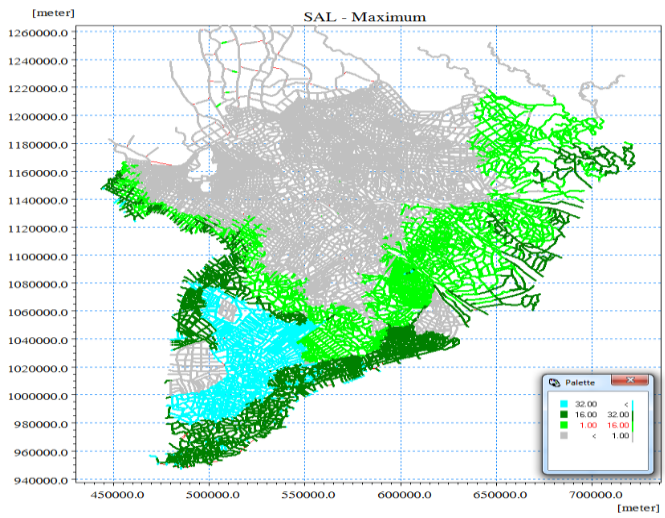

Fig.5 Saltwater results by three partitions as above (freshwater < 1psu, brackish water: 1-16 psu)

2.2.3 Saving water use

Alternating Wetting Drying (AWD) method was recommend to apply for saving water for irrigation. This method is very developed and widely used in Asia because it can save 30% of water use depending on the type of soil so the local farmers can apply to reduce their irrigation water consumption in rice fields without decreasing its yield.

2.2.4 Improve infrastructure systems for saltwater control and long-term water supply

The hydraulic work systems of over 880 small-large sized sluices, 450km sea-dike, 1290 km of river dikes, and 7000 km ring dikes in high salinity areas have received investment but have not yet been completed (closed), so there is still pollution of water sources [1]. Also, the environment and construction work efficiency are not high. The sea dike, river dike, and sluices at TranDe, DinhAn, and Cung Hau estuaries have been closed, but the height of the dikes is still low and needs to be upgraded. Along the left bank of the CoChien and HamLuong rivers, the dikes system has been completed, but the sluice system has not been closed, so the whole province of BenTre is affected by the 4 psu salinity line.

So, it is necessary to create a new land use plan in coastal areas, scheduled seasonally to develop effective operating procedures for sluices and pumping stations. The land use should be shifting from agriculture to aquaculture in areas always faced with high salinity concentration to increase income and adapt with the changing of flow regime conditions. However, aquaculture farming practices must be friendly to the environment and systems. When the estuary is aquatic, the sluices located along 15 to 20 km from the estuary should not closed in the dry season, so saltwater will not intrude deeper upstream. However, it is necessary to build small sluice systems at the boundary of aquaculture and rice cultivation so that salt water does not penetrate deep upstream of the tributary canal. If the L increases in the mainstream when all the sluices are closed, we should propose constructing new sluice gates along the main rivers toward upstream. Furthermore, re-evaluation of existing structures is needed to assess the location and operation routines and propose suitable new operations.

Furthermore, needs to propagate to raise people's awareness for saving water use, strengthen measures to store fresh water in each household, comply with land use plans for each area and support local people from finance to technology during the process of livelihood transformation.

3 Conclusion

Salinity trends are increasingly complex and adversely affect agriculture, fisheries, and livelihoods. So, salinity adaptation measures are necessary. Mitigation measures from MRB are collaborative and call for action. So, to minimize the effect of salinity intrusion in VMD, the seven mitigation measures mentioned above need to conduct simultaneously and immediately. The results show the relationship between Q ~ S and Q ~ L for short salinity prediction and propose the location of salinity monitoring for sluice gates operations and location of new sluices along the boundary of rice field and aquatic field. The results also propose three ecological zones according to the saltwater value from 1 to 16 psu and suggest raising people's awareness for saving water use, strengthen measures to store fresh water in each household.

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