Title of dissertation			
Study on Assessment and Adaptation to saltwater intrusion under the impacts of Tide, Sea Level rise, Flow and Morphological changes in the Vietnamese Mekong Delta			
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Abtract of dissertation

The Vietnamese Mekong Delta (VMD) has to face drought and prolonged saltwater intrusion in the dry season every year. Saltwater significantly affects agriculture, people's daily lives, and the environment. In 2015-2016, the most severe drought in the past 90 years was accompanied by severe saltwater intrusion in the VMD. Salinity threshold of 4 psu has intruded 60-73 km into the VMD, which is 20-30 km further than mean annual years. Over 2,297 thousand hectares of the VMD have been affected by saltwater and approximately 976,000 people lack fresh water for daily consumption. Four years later, an extreme drought year again occurred in 2019-2020. The maximum salinity was 0.6 psu to 0.8 psu higher than that in 2016, and intrusion length is deeper from 3 km to 5 km. However, the most important thing is that the salinity appeared 1 - 1.5 months earlier and reached a peak value of 1.5 - 2.0 months sooner than the average of many years.

Salinity intrusion is a typical phenomenon of river mouths where two distinct water masses, riverine and marine, interact. Tides and sea level have significantly influenced salinity concentration and intrusion length, so upstream currents are needed to push the salinity to the sea. However, over 100 large, medium, and small reservoirs were constructed along the Mekong River causing upstream flow and sediment changes in the VMD. As a result, there was a lack of fresh water in the dry season and severe riverbed incision developed in VMD. Combined with the high sea level which also occurs in January and February, the trend of salinity in VMD became more and more serious.

Therefore, this study assesses the situation of salinity intrusion in VMD under the effect of upstream dam's development, tides, sea-level rise, upstream flow, and morphology changes. So, a long-term series of water level, discharge and sediment data at Chiang Saen, Kratie, TanChau, and ChauDoc stations were used to analyze the altered flow and sediment in the VMD. In addition, data analysis (estuary water levels, tides, and salinity time series) and

numerical simulation model were also used to assess the impact of the four factors mentioned above on the saltwater intrusion mechanism in VMD through six scenarios. Then, seven solutions are proposed to mitigate and adapt to saltwater intrusion.

The upstream dams development changes the upstream flow by transferring water from the wet season to the dry season, so the total wet flow is reduced in the whole basin with a smaller flood peak, and the peak flood occurs a month later than that in the past. The total dry flow increased by 20.96% at Chaing Saen and 34.83% (10.5 km^2) at Kratie; however, the total monthly flow only increases from March to May while the dry season starts from December. So that is the main cause of salinity that started in December and reached its peak value in February. One simulated reservoir scenario released water one month earlier than the baseline scenario in 2016. Salinity concentrations in the VMD were gradually reduced by 11.6% to 15.9% because the discharge increases by 5.1% and 6.9% at DaiNgai and Tra Vinh stations, respectively. The intrusion length would also decrease by about 4 to 7 km on all tributaries.

When the reservoirs are in operation, they store water and trap the sediment flow; the average amount of sediment load in the VMD decreased from 166.4 Mt before the 1993 period to 42.3 Mt since 2012. That is the main reason leading to this problem. The river bed is lowered with an average drop of the main tributary of 0.22 mm/yr and 0.34 mm/yr on the Hau and Tien rivers. Based on simulated scenarios, the impact of river incision on salinity intrusion shows that salinity concentration would be increased by 0.8-0.9 psu, and salinity profile would move 1.8 km and 4.5km further upstream if 1.76m and 2.76 riverbed incisions were in the Hau and Tien rivers.

Global climate change increases sea level by about 5.25 mm/yr at VungTau station. The highest sea level is from October to February. This is one of the main drivers of n salinity intrusion, followed by river flow. For example, the salinity profile would move 4 to 7 km further upstream, and salinity would increase by 1.4 to 1.9 psu if the sea level rises by 47.25 mm in the next five years (2025).

Tides strongly influenced the river's spatial and temporal salinity distribution in the daily, monthly, and seasonal cycles. In the daily tidal cycle, maximum salinity (S_{max}) occurs at the bottom and lags one to three hours after maximum water level. In the spring–neap tidal cycle, S_{max} at the bottom occurs at the transition period from neap to spring tides (3-7 days before spring tide), while S_{min} appears in the transition period from spring to neap tides. Also, in the springtide, the intrusion length of 0.4 psu threshold at the flood tide is longer than 14.3km, 15km, 16.5km than at the ebb tide in TranDe, DinhAn, and CoChien branches, respectively combined with partial mixing and moderate stratification prevails over the 50 km TranDe and DinhAn branches. At the same time, weak mixing and strong stratification appeared during the Neap tide of the Hau and Co Chien Rivers.

The results of my research are an essential reference for the dividing ecological zone (Freshwater–Brackish water–Saltwater) along the main river and the land. Furthermore, seven mitigation measurements including four non-structural solutions (early warning, long-term adaptation plans, long term water use plan, saving water use) and three structural solutions (improving infrastructure, household water storage, and keeping flood inundation areas) as mentioned earlier. If most of the above-mentioned solutions are applied simultaneously and

continuously; the results will be very effective. Particularly for the solution number five (improving infrastructure), it is necessary to have a plan, a roadmap for implementation, funding sources, an assessment of the level of impact on the environment and how to effectively and long-term manage and operate the project.

List of Publications

2.1 Journal papers:

Mai, N.T.P,, Trung, L.V. (2017). The impact of Upstream Dams on the mechanism of salinity intrusion of estuaries of Mekong River, *Journal of Water Resources and Environment*, No. 58, pp. 157-163.

Mai, N.P., Kantoush, S., Sumi, T., Thang, T.D., Trung, L.V., and Binh, D.V. (2018). Assessing and adapting the impacts of dams operation and sea level rising on saltwater intrusion into the Vietnamese Mekong Delta. *Journal of Japan Society of Civil Engineering, Ser. B1 (Hydraulic Engineering)*, Vol. 74, No. 5, pp. I_373-I_378.

Binh, D.V., Kantoush, S., Sumi, T., and Mai, N.P. (2018). Impact of Lancang cascade dams on flow regimes of Vietnamese Mekong Delta. *Journal of Japan Society of Civil Engineering, Ser. B1 (Hydraulic Engineering)*, Vol. 74, No. 4, pp. I_487-I_492.

Binh, D.V., Kantoush, S., Mai, N.P., and Sumi, T. (2018). Water level changes under increased regulated flows and degraded river in Vietnamese Mekong Delta. *Journal of Japan Society of Civil Engineering, Ser. B1 (Hydraulic Engineering)*, Vol. 74, No. 5, pp. I_871-I_876.

Mai, N.P., Kantoush, S., Sumi, T., Thang, T.D., Trung, L.V., and Binh, D.V. (2019). Study on salinity intrusion processes into Hau river of Vietnamese Mekong Delta. *Journal of Japan Society of Civil Engineering, Ser. B1 (Hydraulic Engineering)*, Vol. 75, No. 5, pp. I_751-I_756.

Binh, D.V., Kantoush, S., Saber, M., Mai, N.P., Maskey, S., Phong, D.T., Sumi, T. (2020) "*Long-term alterations of flow regimes of the Mekong River and adaptation strategies for the Vietnamese Mekong Delta*. Journal of Hydrology, Regional Studies. 32, 100742. https://doi.org/10.1016/j.ejrh.2020.100742.

Loc, H.H., Binh, D.V., Park, E., Shrestha, S., Dung, T.D., Son, V.H., Truc, N.H.T., Mai, N.P., Seijger, C. (2021). *Intensifying saline water intrusion and drought in the Mekong Delta: from physical evidence to policy outlooks*. Science of the Total Environment, 757, 143919. DOI: 10.1016/j.scitotenv.2020.143919.

Binh, D.V., Kantoush, S.A., Sumi, T., Mai, N.P., Ngoc, T.A., Trung, L.V., An, T.D (2021). *Effects of riverbed incision on the hydrology of the Vietnamese Mekong Delta*. Hydrological Processes, 35, e14030, 2021 https://doi.org/10.1002/hyp.14030.

Mai, N.P., Kantoush, S.A., Sumi, T., Thang, T.D., (2021). *Influence of river discharge and morphology on saltwater intrusion into the Vietnamese Mekong Delta*, Journal of Water Resources and Environment, Journal of Water Resources and Environment, No. 77, pp. 10-18.

2.2 Conference papers

Binh, D.V., Kantoush, S., Sumi, T., Mai, N.T.P., Ata, R., Kadi Abderrezzak, K.El., and Trung, L.V. (2017). Flow regime changes in Vietnamese Mekong Delta due to river-damming. In *Proceeding of 10th Symposium on River, Coastal and Estuarine Morphodynamics*, Padova, Italia, pp. 25.

La, T., Nguyen, M., Kantoush, S., Sumi, T., and Doan, B. (2017). Evaluation on the impacts of hydropower development on salinity intrusion into Vietnamese Mekong Delta. *The 3rd Symposium on JASTIP Disaster Prevention International Cooperation Research (JASTIP-WP4 Symposium)*.

Nguyen, T.P.M., La, V.T., Doan,V.B., Do, T.M.L. (2018). The evolution of salinity intrusion at Mekong River mouths under the impacts of dams upstream", *International Symposium on Lowland Technology (ISLT 2018).* Hanoi, Vietnam.

Mai, N.P., Kantoush, S., Sumi, T., Thang, T.D., Trung, L.V., and Binh, D.V. (2018). Impacts of cascade hydropower development on salinity intrusion into Vietnamese Mekong Delta. In *Proceeding of the 21st IAHR-APD Congress,* Yogyakarta, Indonesia, pp. 503-511.

Binh, D.V., Kantoush, S., Sumi, T., Mai, N.P., and Trung, L.V. (2018). Changes in the sediment budget and morphodynamics of Vietnamese Mekong Delta. In *E-Proceedings of the 12th ISE 2018*, Tokyo, Japan.

Binh, D.V., Sumi, T., Kantoush, S., Mai, N.P., and Trung, L.V. (2018). Historical changes of flow and sediment budget in Vietnamese Mekong Delta due to upstream dam development. In *Proceeding of the 21st IAHR-APD Congress 2018*, Yogyakarta, Indonesia, pp. 123-131.

Mai, N.P., Thang, T.D., Kantoush, S., Sumi, T., Trung, L.V., Binh, D.V. (2019). The processes of saltwater intrusion into Hau River. *Proceeding of the 10th International Conference on Asian and Pacific Coasts (APAC),* HaNoi, VietNam, pp.1477-1483.

Mai, N.P., Kantoush, S., Sumi, Thang, T.D., T., Binh, D.V., Trung, L.V. (2019). The influences of tidal regime and morphology change on salinity intrusion in Hau River. E-*Proceedings of the 38th IAHR World Congress,* Panama City. Doi:10.3850/38WC092019-1351, pp.2413-2420.

Binh, D.V., Kantoush, S., Sumi, T., Mai, N.P., and Trung, L.V. (2020). Dam-induced riverbed incision and saltwater intrusion in the Mekong Delta", *Proceedings of River Flow.* Taylor and Francis group, London, ISBN 978-0-367-62773-7.

Binh, D.V., Kantoush, S., Sumi, T., Mai, N.P., and Trung, L.V. (2020). Riverbed incision in the Vietnamese Mekong Delta due to altered flow regime and sediment load. In *Proceeding of the 22st IAHR-APD Congress 2020*, Sapporo, Japan, pp. 123-131.

Photos

Picture 1: Take picture with Sumi Sensei at Sumi's office.

Picture 2: the certificate ceremony