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Quantifying the Impact of Sluice Gate Operation on Spatiotemporal Variability of Salinity Intrusion in the Vietnamese Mekong Delta

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1. Introduction

The Vietnamese Mekong Delta (VMD) is increasingly exposed to severe salinity intrusion due to the combined impacts of climate change and upstream human interventions. During the dry season, reduced river discharge, intensified tidal forcing, and sea-level rise allow saline water to penetrate far inland, causing serious damage to agricultural production and freshwater supply for local communities. Extreme salinity intrusion events in 2016, 2020, and 2024 resulted in the loss of large areas of rice fields and fruit crops, underscoring the growing vulnerability of the delta.

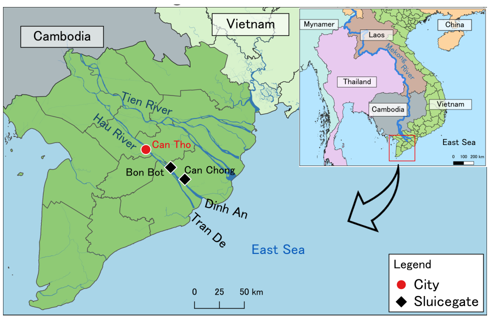

Fig. 1 Location of the study area in the Vietnamese Mekong Delta

To mitigate these impacts, local authorities have progressively planned and constructed sluice gates to control saline intrusion and secure freshwater with salinity levels below 1 g/L, a critical threshold for many crops. However, despite extensive implementation, few studies have systematically evaluated the effectiveness of sluice gate operation, including their spatial arrangement, timing, duration, and long-term performance, particularly during the dry season.

This study aims to quantify the historical impact of sluice gate operation on the spatiotemporal variability of salinity intrusion in the Vietnamese Mekong Delta using long-term, high-resolution salinity observations from an IoT-based monitoring network. In addition, to support the optimization of planned sluice gate construction and operation, a numerical modeling framework was developed to simulate salinity dynamics under different sluice gate locations, operational strategies, arrangements, and timing scenarios. The analysis focuses on secondary channel networks that are critical for irrigation and domestic water use but are often overlooked in regional-scale assessments. By combining observed data analysis with numerical simulations, this study provides robust scientific evidence to evaluate existing infrastructure and to support adaptive and effective water resource management under increasing climatic and anthropogenic pressures.

2. Methodology

The salinity data utilized in this study were retrieved from the Rynan Mekong platform, an integrated environmental monitoring system developed by Rynan Technologies. This system utilizes a network of IoT-based smart monitoring stations and buoys strategically positioned across the main river branches and secondary channel in the Mekong Delta. These stations are equipped with high-precision sensors that provide real-time, continuous measurements of water quality parameters, including salinity and water levels.

For the spatiotemporal assessment, the daily maximum salinity concentration was selected as the primary metric. The monitoring period for the selected stations varies according to their respective installation dates, ranging from 2018 to 2021, with all data consistently collected up to November 2025. The non-uniform start dates across the stations were addressed by focusing on the overlapping periods for spatial comparison while maintaining the full longitudinal record for individual site analysis.

3. Spatiotemporal Characteristics of Salinity Intrusion and Agricultural Impact

The spatial distribution of salinity in the study area was characterized through a contour map of the annual maximum salinity recorded in 2024. The analysis revealed that in subchannels without operational sluice gates, salinity concentrations remained relatively high and constant throughout the channel network. In contrast, the presence of infrastructure such as the Can Chong Sluice Gate created a distinct salinity gradient, significantly reducing concentrations between the river-facing (front) and protected (back) sections as shown in Fig. 2.

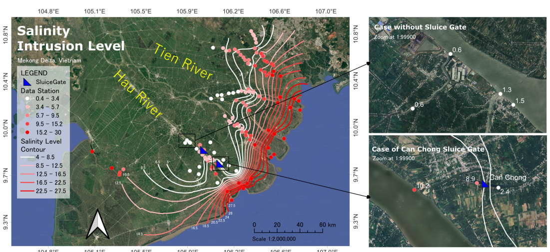

Fig. 2 Spatial distribution of annual maximum salinity in 2020

4. Assessment of Sluice Gate Effect

The effectiveness of the Can Chong Sluice Gate in mitigating salinity intrusion was quantitatively assessed using the Percentage Change (PC) in maximum salinity concentration (Table 2). Long-term observation data from 2019 to 2025 demonstrated that the gate maintained a high reduction efficiency, with an average PC of 77%. The highest reduction efficiency was recorded in 2022 and 2023, reaching 85%.

Year	Front(g/L)	Back(g/L)	PC(%)
2019	11.68	2.85	75
2020	13.51	2.47	81
2021	7.59	2.89	61
2022	11.8	1.71	85
2023	11.9	1.71	85
2024	8.92	2.35	73
2025	10.45	1.84	82

Year	Threshold(g/L)	Front	Back	PC(%)
2020	1	309	99	67
	2	192	14	92
	3	145	0	100
	4	93	0	100

Table 1, 2 (1) annual maximum salinity reduction and Percentage Change (PC) from 2019 to 2025 and (2) reduction in the duration of salinity exposure exceeding critical thresholds (1–4 g/L) (JICA, 2013; Ayers & Wescot, 1989) during the 2020 dry season.

Beyond reducing peak concentrations, the sluice gate proved highly effective in limiting the duration of exposure to saline water. As shown in Table 2, in 2020, the gate reduced the number of consecutive days exceeding the 1 g/L and 2 g/L thresholds by 67% and 92%, respectively. Most notably, for higher thresholds critical to freshwater exploitation (3–4 g/L), the gate achieved a 100% reduction in consecutive days, effectively preventing high-salinity water from persisting in the protected secondary channels.

5. Conclusion

This study confirms that while salinity intrusion poses a staggering threat to the Vietnamese Mekong Delta, existing infrastructure provides a critical shield for the region's agricultural heartland. The spatiotemporal analysis of the Hau River basin revealed a stark contrast: in secondary channels without protection, saline water infiltrates deep into the network, whereas the presence of the Can Chong Sluice Gate creates a vital freshwater sanctuary. By achieving an average 77% reduction in peak salinity, these structures do more than just manage hydraulic levels; they directly prevent the devastating crop losses quantified by the correlation between salinity and paddy yield.