Theme 1: Changes in the Landscape and Water Dynamics

Monitoring land use change in response to temporal salinity in the Mekong Delta

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Introduction

As the third-largest delta globally, the Mekong Delta (MD) is acknowledged for its role as an agricultural production region and biodiversity hotspot (Xiao *et al.*, 2021) . Over the past few years, substantial changes in land use and land cover (LULC) in the MD have occurred, primarily due to the increasing impact of salinity intrusion and anthropogenic activities (Park *et al.*, 2022). Salinity intrusion in the MD significantly obstructs agricultural practices by increasing soil salinity levels and changing the quality of irrigation water. This phenomenon poses a major challenge to crop cultivation, particularly rice, impacting yields and overall productivity (Le *et al.*, 2018) and potentially requiring alternative crops for future cultivation (Kaveney *et al.*, 2023). In parallel to the changing salinity regime has been substantial changes in spatial patterns of farming and water regime (Vu *et al.*, 2022). Understanding the relationship between temporal salinity over time and spatial distribution of land use changes is crucial for effective land management. By monitoring salinity variations over time and how land use has changed with it, we can inform strategic decision-making for sustainable adaptation in vulnerable regions like the MD. This knowledge contributes to more resilient and adaptive land use planning in response to changing environmental conditions. There are some studies that encompassed all types of land use to explore the LULC and its driving forces in the Mekong Delta from a holistic perspective (Liu *et al.*, 2020; Ngo, Lechner and Vu, 2020). However, the lack of comprehensive knowledge about the interconnection between salinity intrusion and land use changes in the MD hinders the formulation of effective strategies for sustainable development. This information gap limits the implementation of targeted mitigation measures, impeding the region's ability to adapt to evolving environmental conditions and protect agricultural productivity. This study aims to address the relationship between temporal salinity and land use changes in the MD, offering insights for sustainable development strategies.

Methodology

Soil samples were collected and analysed on a monthly basis in Soc Trang province, selected as a case study region, with the measured soil salinity (EC1:5) converted to electrical conductivity of the saturation extract (ECe). The classification of salinity levels followed the criteria outlined by Slavich and Petterson (1993), which categorizes the results into six distinct classes. Hexagonal binning was employed as a spatial aggregation method to transform point data into a continuous representation of soil salinity distribution. This technique offers advantages over traditional interpolation methods by reducing bias and providing a more accurate representation of spatial patterns (Weckmüller and Dunkel, 2023). The hexagonal bins served as spatial units with a size of 10 square kilometres, and salinity values from the surveyed samples within each bin were aggregated to create a continuous salinity map using ArcGIS. This spatial representation allows for a comprehensive depiction of temporal changes in soil salinity, enabling a nuanced understanding of its variations across the study area.

To develop the LULC map, this study applied the Random Forest (Breiman, 2001) classifier to map land cover in the MD using Sentinel-1 and Sentinel-2 data. The process involved enhancing data quality through pre-processing and partitioning the ground truthed data into training and validation sets. Utilizing ground-truth data for training, the Random Forest algorithm has been shown to have good accuracy in classifying different land cover types, especially in capturing complicated landscape variations (Binh *et al.*, 2021), however, we are still collecting additional data to conduct our own accuracy assessment for the MD. This approach can effectively handle multi-spectral or hyperspectral data, making them valuable for tasks such as land cover classification, vegetation mapping, and change detection, contributing to the generation of accurate land cover maps essential for sustainable regional management. Change detection of LULC was performed through the overlay and post-classification comparison of the LULC maps across the different time periods. Change maps are being developed with cross-tabulated matrices to show change pathways. To enhance the clarity of our results, the change dynamics are visually presented in maps.

Results

The spatial representation revealed distinct patterns in salinity levels, with varying degrees observed across the surveyed points Figure 1. Hotspots of elevated salinity were identified, suggesting localized areas of concern, with clear seasonal patterns showing elevated salinity across many farms in 2020. This seasonal pattern highlights the dynamic changes in salinity in space and time emphasizing the need for ongoing monitoring and adaptive management strategies to address the evolving environmental conditions.

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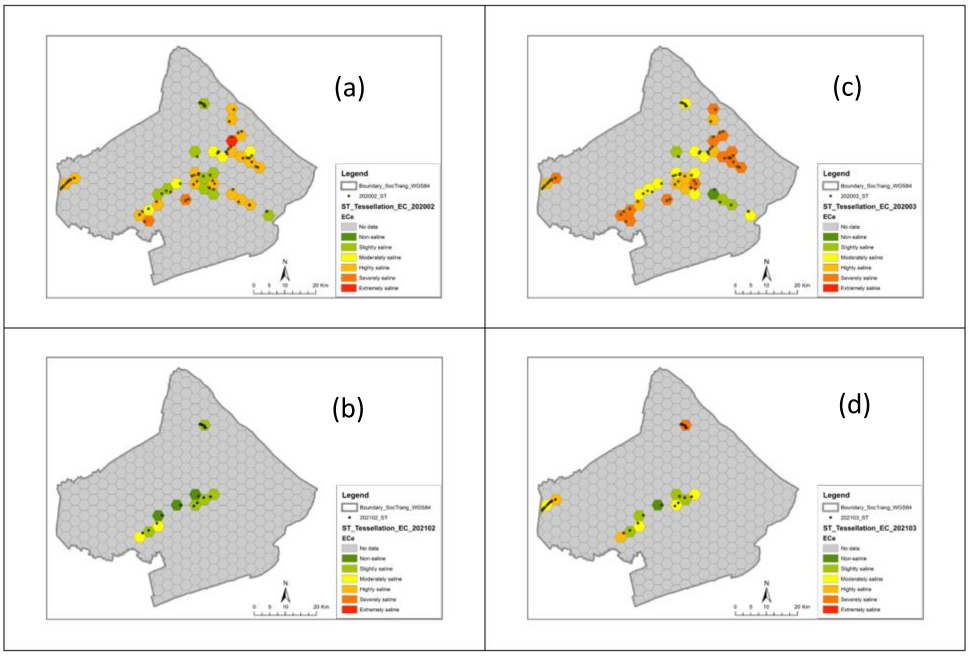

Figure 1. Spatial variation of soil salinity in Soc Trang province (a) February 2020, (b) February 2021, (c) March 2020 and (d) March 2021. The coastal zone of Soc Trang is the south eastern edge of the province and the river channel flows along the north eastern edge of the province.

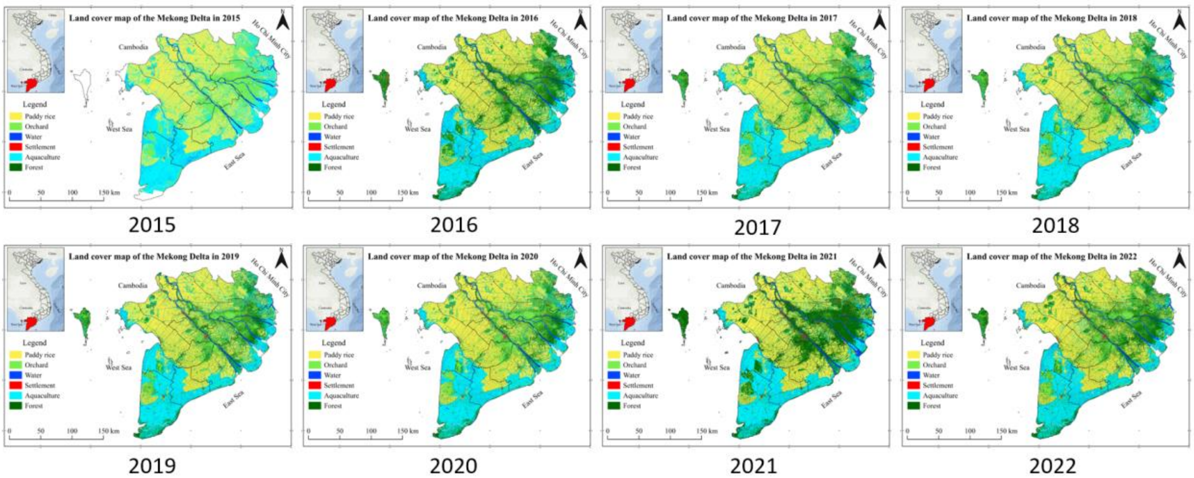

Figure 2. LULC classification maps of the MD in the year 2015-2022 based on Sentinel images.

The LULC maps for the years 2015 through 2022, generated from Sentinel satellite imagery, are depicted in Figure 2. The classification result represents six primary categories of land use: (1) Paddy rice, (2) Orchard, (3) Water, (4) Settlement (or urban area), (5) Aquaculture, and (6) Forest. These categories serve as key indicators in the systematic analysis of land utilization patterns over the specified timeframe. It can be observed that LULC has changed spatially with particular changes evident in the decline in paddy rice areas, largely converted to aquaculture and orchard. While these patterns are generally consistent with other recent remote sensing research (Vu *et al.*, 2022), we are still developing the classification algorithm to address uncertainty in such a complex aquatic landscape as the Mekong Delta.

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Discussion

The observed spatial variations in soil salinity over time with an evident increase compared to previous years, highlights the dynamic nature of environmental factors influencing the study area. The elevation in salinity levels can be attributed to a variety of factors, encompassing changes in climate patterns, changes in land use practices, and the impact of natural processes in the MD (Kaveney *et al.*, 2023; Ha *et al.*, 2024).

The LULC maps indicate a comprehensive of land cover across a seven-year span, from 2015 to 2022, with six different classes. Notably, spatial analysis reveals dynamic changes in land cover, with coastal regions experiencing particularly pronounced changes with aquaculture conversion. These changes underscore the evolving nature of the landscape, influenced by various factors over time. The map serves as a valuable tool for understanding the spatial distribution of land cover classes and highlights the significance of coastal areas as dynamic zones where environmental factors, including potential salinity impacts, significantly contribute to the changes of land cover patterns.

Conclusion

In conclusion, the analysis of land use and land cover changes, particularly in the context of salinity intrusion, reveals a complex interplay between environmental factors and human activities. The observed alterations in land cover and land use patterns underscore the impact of salinity intrusion on the MD's landscape over the examined period. The results of this preliminary analysis show how there has been substantial change in land use across the delta. This is consistent with other studies analysing this phenomenon (e.g. Vu *et al.*, 2022). The project efforts to train farmers in collecting soil salinity has been valuable for their monitoring and highlighting salinity hotspots in Soc Trang Province. The next stage of this work will examine remotely sensed soil salinity data as a potential driver of the observed land use change (e.g. Nguyen *et al.*, 2020). Such soil salinity data comes with its own limitations, however, a large scale spatial statistical study offers an avenue to understand the overlap between increasing salinity and land use change. The temporal evolution of soil salinity patterns, identified hotspots, and accuracy assessments of the remote sensing work provide valuable insights for sustainable land management and precision agriculture practices in regions affected by soil salinity.

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