

Exploring the Relationship between Climate Parameters and Water Salinity Fluctuations: A Case Study in Binh Chanh District, Ho Chi Minh City

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ABSTRACT

Climate change is expected to worsen drought conditions, which may elevate the risk of salinity intrusion in many regions of Vietnam. Therefore, this research analyzed the annual variations in water salinity in Binh Chanh District by employing the Modified Innovative Trend Analysis method, which interprets not only specific trends but also avoids distributional assumptions found in classical approaches, including normality, independence, and pre-whitening. Additionally, the study proposed a Sobol Index to investigate the relationship between salinity levels and weather variables from 2007 to 2024. The findings indicated a notable increase in annual salinity, reaching up to 8.12% at the Ong Thin station. In contrast, a significant decrease of less than 2% was noted, primarily at the Cong Kenh C station. While An Ha recorded a significant sensitivity value for mean temperature at 56.5%, salinity levels at the Cong Kenh C and Ong Thin stations were highly responsive to precipitation, accounting for over 77.2% and 69.6% of sensitivity, respectively. These findings enhance the understanding of salinity trends and provide a robust scientific basis for informing policy interventions related to land and water resource management, agricultural planning, and estuarine environmental governance in Binh Chanh District under accelerating climate change.

HIGHLIGHTS

- Positive salinity trends appeared at almost all stations in Binh Chanh District.
- The impact of precipitation on salinity was shown to be the most significant.
- Sobol sensitivity analysis was useful in assessing climate change's effect on water salinity.

1. INTRODUCTION

Vietnam is one of five nations most severely impacted by climate change, with Ho Chi Minh City (HCMC) serving as a focal point of the country's economy. Further, due to its social, economic, and environmental characteristics, the World Bank identifies HCMC as one of the cities most vulnerable to climate change (World Bank Group and Asian Development Bank, 2021). Binh Chanh District, a suburban area of HCMC, boasts a strategic river network that supports both agricultural growth and waterway transportation. Nonetheless, being a low-lying area near large rivers has led Binh Chanh to be among the districts most susceptible to climate

change. Low-income households are particularly affected, as they have limited resources to cope with and adapt to climate-related challenges (Martin and Thanh, 2003). In recent years, natural disasters and rising sea levels have had a significant impact on the Binh Chanh District. Heavy rainfall has become more frequent and concentrated during the rainy season, reducing arable land and increasing the risk of flooding (Truong et al., 2022). The infrastructure system of the region's industrial zones-including factories, internal traffic, drainage systems, and production equipment-has been severely inundated, which in turn has had a great impact on business productivity. Rising sea levels also cause aquaculture

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ponds and rice-growing regions to become increasingly saline, which leads to further significant negative economic effects.

Salinization is one of the most serious environmental risks in Vietnam and Southeast Asia, and one of the primary causes of desertification and soil degradation worldwide. Numerous scholars have examined long-term salinity changes using a variety of approaches. For example, several pertinent researchers have used both parametric and non-parametric statistical tests to track and determine salinity changes. For example, to understand seasonal changes in the most heavily saline-intruded areas during the wet-monsoon seasons, the nonparametric Mann-Kendall and Sen's slope tests were applied to detect historical trends in surface water salinity (Shammi et al., 2017), as well as seasonal characteristics of groundwater salinity in the coastal zone of Bangladesh (Meem et al., 2025). Also, the degree and temporal tendencies of salinization in inland rivers in China have been found to be severely aggravated (Meng et al., 2024). Thematic maps and GIS mapping were used to determine the regional variability and trends of groundwater salinity on Munda-Kachchh coastal aquifers over ten years (Shah et al., 2022). By using ANOVA variance analysis and frequency analysis based on data sets from 1996 to 2018 at monitoring stations, Thanh et al. (2023) employed statistical techniques to evaluate salinity variations in the Mekong Delta. The findings indicate that salinity is on the rise (Thanh et al., 2023). Though research has produced significant findings, there are still many issues that need to be resolved. Reliable and long-term input data collection is a challenge in research, and the precision and quality of this data are critical to models' efficacy. For instance, whereas remote sensing methods provide a wide range of spatial coverage, their temporal resolution is constrained by weather and satellite orbital cycles, which lowers the accuracy and dependability of salinity intrusion simulations (Taghadosi and Hasanlou, 2017). Furthermore, parametric approaches have application-related restrictions, such as the need for residuals in normal distributions (Kocsis et al., 2017).

This study uses the non-parameter approach of Innovative Trend Analysis (ITA) to evaluate salinity variations at monitoring stations in order to overcome these problems. ITA has been used for a wide range of environmental parameters, such as temperature (Esit, 2023), precipitation (Caloiero et al., 2019), and

relative humidity (Esit, 2023), and it has numerous benefits over standard trend assessment methods in managing assumptions. Among the various tests, the Pettitt test is one of the most widely used in hydro-climatological studies to detect abrupt changes at an unknown point in a time series to deal with extremes. For example, Villarini detected temporal trends in flood peaks and abrupt changes in the mean and variance of flood peak distributions by using the Pettitt test (Villarini and Smith, 2010). Another simulation was studied to examine the sensitivity of the Pettitt test when detecting abrupt changes in climate parameters, and it was found that the Pettitt test performed effectively (Mallakpour and Villarini, 2016). Hence, the strength of the ITA and Pettitt tests and their ability to become more effective for trend detection were integrated into what is known as the modified ITA method. These studies have provided convincing evidence of the effectiveness of the ITA method in exploring climate trends. However, most researches have analyzed salinity at regional or river-basin scales, with limited district-scale studies using advanced statistical methods.

Sensitivity analysis is an important part of research on climate assessment, and currently a major interest in hydrometeorology, where it is used to detect correlations between relevant climatic factors (Haj-Amor et al., 2023). A number of scholars have also detected and noted an association between temperature, precipitation, solar radiation, and evapotranspiration (Aizen et al., 2001; Danlu et al., 2017; Gupta et al., 2020; Luo et al., 2023; Tyagi et al., 2019). In sum, the global sensitivity analysis is a powerful tool that provides a complete and consistent sensitivity measure of climate variables, while also assessing a wide range of climate change possibilities for different models with varying data requirements (Wagener and Pianosi, 2019). However, there remains a lack of research concerning the applicability of SA methods for salinity in climate change conditions.

Given the importance of salinity parameter assessment, our study aims to assess the tendencies of salinity and its correlations to temperature and precipitation in Binh Chanh District by applying the Modified Innovative Trend Analysis, and Sobol sensitivity analysis methods, respectively. These results have been anticipated to offer an overall view of salinity across various climatic scenarios, and to aid in water enhancement, management, and salinization prevention at both regional and global levels.

2. METHODOLOGY

2.1 Study area

Binh Chanh is a rural district located in the southwest of HCMC. It covers an area of 253 square kilometers. The Binh Chanh district borders the Binh Tan, Hoc Mon, and Nha Be districts ([Figure 1](#)). The landscape of Binh Chanh is relatively wide and elongated, with a substantial amount still dedicated to agricultural use. Serving as a gateway for trade with the Mekong Delta, a major economic region in the south, Binh Chanh has increasingly become a conduit for economic exchanges between the Mekong Delta and the key zones of the southeastern economic region. Binh Chanh is characterized by extensive

agricultural land, and agricultural production constitutes a notably larger proportion of the economic framework when compared to the inner city districts ([Prime Minister's Office of Vietnam, 2023](#)).

Climate change impacts are another important consideration. Due to its lowland natural features and the terrain being divided by a system of rivers and canals, Binh Chanh district is heavily affected by climate change. Currently, the impact of saltwater intrusion on rivers and canals in Ho Chi Minh City has increased to an alarming level, and Binh Chanh is one of the most seriously affected provinces ([Danh et al., 2024](#)).

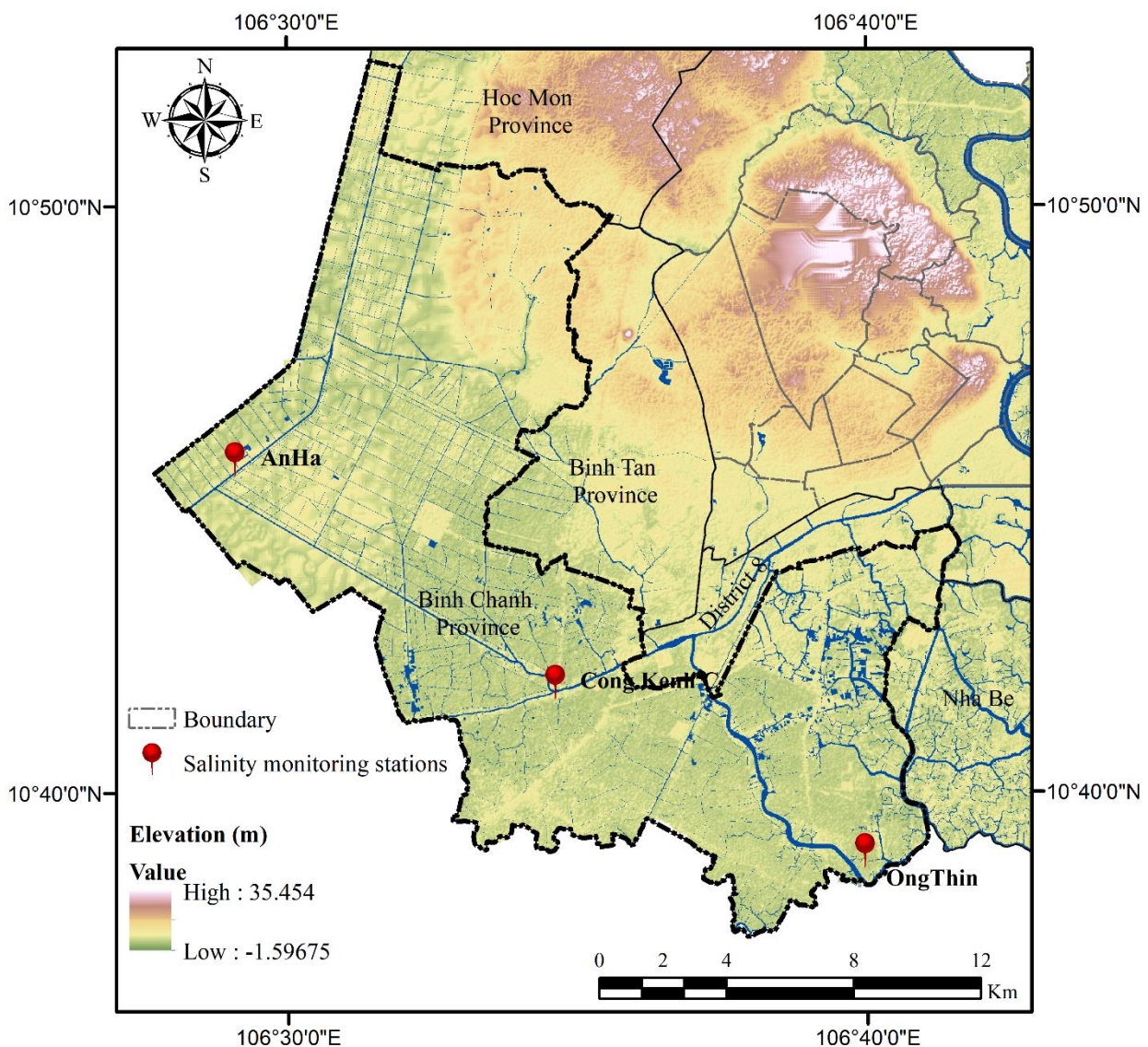


Figure 1. The geography and salinity monitoring stations of Binh Chanh Province in Ho Chi Minh City.

This study used salinity data (g/L) from three monitoring stations, namely An Ha, Cong Kenh, and

Ong Thin ([Figure 1](#)), along with weather variables, including rainfall (mm), average temperature (°C),

maximum temperature (°C), and minimum temperature (°C), obtained from the Tan Son Hoa station of the Meteorological Administration for the period 2007-2024.

2.2 Modification of Sen-ITA method

Trend detection investigations in hydro-meteorological series have increasingly gained attention over the last few decades. The modification of ITA has produced several versions, including one known as the parameter trend test. In the original ITA, a time series was plotted in a two-dimensional Cartesian coordinate system after being split into two equal sub-series. This modification of ITA was defined as a way to demonstrate different types of trends, and depict the dimensions and quantity of time series data by combining with the Pettitt test to identify sudden change points (Mallakpour and Villarini, 2016).

In this study, the annual salinity dataset in Binh Chanh Province was divided into two halves in the coordinate system, with the horizontal axis representing the number of years of collection data (from 2007 to 2024) and the vertical axis representing the values of salinity (g/L) in Binh Chanh District. Values falling above or below the horizontal line ($y=0$) show an increasing or decreasing tendency. Furthermore, by combining the Pettitt tests, the quantitative salinity trends for low and high-value categories were computed, including the change magnitude, change point, and percentage of growing and declining trends.

The Pettitt test is a non-parametric method derived from the Mann-Whitney two-sample test, and designed to identify a single change occurring at an unspecified point in time t (Anthony, 1979). The non-change appears in the distribution of a sequence of random variables; the change point exists when the distribution function $F_1(X)$ of the random variables from X_1 to X_t is different from the distribution function $F_2(X)$ of the random variables from X_{t+1} to X_T (Equation 1).

$$D_{ij} = \text{sgn}(X_i - X_j) = \begin{cases} -1 & (X_i - X_j) < 0 \\ 0 & (X_i - X_j) = 0 \\ 1 & (X_i - X_j) > 0 \end{cases} \quad (1)$$

The next step involves computation of test statistic U_k by using the following (Equation 2)

$$U_{t,T} = \sum_{i=1}^t \sum_{j=t+1}^T D_{ij} \quad (2)$$

Finally, the significant change point (K_T) is selected (Equation 3) where the value of $|U_{t,T}|$ and each is the largest:

$$K_T = \max |U_{t,T}| \quad (3)$$

2.3 Sobol sensitivity analysis method

For hydro-meteorological models, accurately estimating weather parameters can be challenging, especially when numerous parameters lack a distinct effect on the output variables-or when many parameters exhibit similar impacts on the output variables (Song et al., 2015). In such situations, the Sobol method is effective for identifying critical parameters. Specifically, this method analyzes the interactions of climatic factors (rainfall (R), maximum temperature (Tmax), minimum temperature (Tmin) and mean temperature (Tmean)) with average salinity. The results from Sobol's analysis provide the first-order (S_i) and total sensitivity indices (S_{Ti}), expressed in the respective equations (4) and (5) (Sobol, 1990). The first-order indices measure the direct individual influence of each temperature or precipitation parameter on salinity, while the total indices consider variance contributions from each input variable, including their interactions with other variables, concerning the overall variance of the salinity model.

$$S_i = \frac{V_{X_i}(E_{X_{\sim i}}(Y|X_i))}{V(Y)} \quad (4)$$

$$S_{Ti} = \frac{E_{X_{\sim i}}(V_{X_i}(Y|X_{\sim i}))}{V(Y)} = 1 - \frac{V_{X_i}(E_{X_{\sim i}}(Y|X_i))}{V(Y)} \quad (5)$$

3. RESULTS AND DISCUSSION

3.1 Salinity trend analysis results

One of our aims was identifying potential trends in salinity values recorded over 18 years at various stations in Binh Chanh Province. With this end in mind, a modified version of the ITA method was applied to the annual data for this parameter. The results, displayed in Figure 2, illustrated the findings from three stations: An Ha, Cong Kanh C, and Ong Thin. Most data from the selected stations exhibited positive trends, with variations extending up to 2.5 g/L per year. Notably, the An Ha station showed two distinct trends, according to the Pettitt test on the difference series; the modified ITA indicated a growth trend of 1.81% for the Low Values category, while the High Values category

demonstrated a 0.98% growth trend. Although all trend tests yielded the same conclusion for Ong Thin, the modified ITA indicated an increasing trend of 3.19% for Low Values and 8.12% for High Values (Figure 2(c)). At the Cong Kenh C station, the High Salinity values exhibited a notable decreasing trend of -1.6%, whereas the trend for Low values showed a slight and

insignificant increase of 0.79% (Figure 2(b)). Additionally, the change points identified by the Pettitt test in the alternative version of ITA revealed differing numbers for Low and High values. Figure 2 further illustrates the quantity and range of salinity data, reflecting variations in different salinity stations within a single scale.

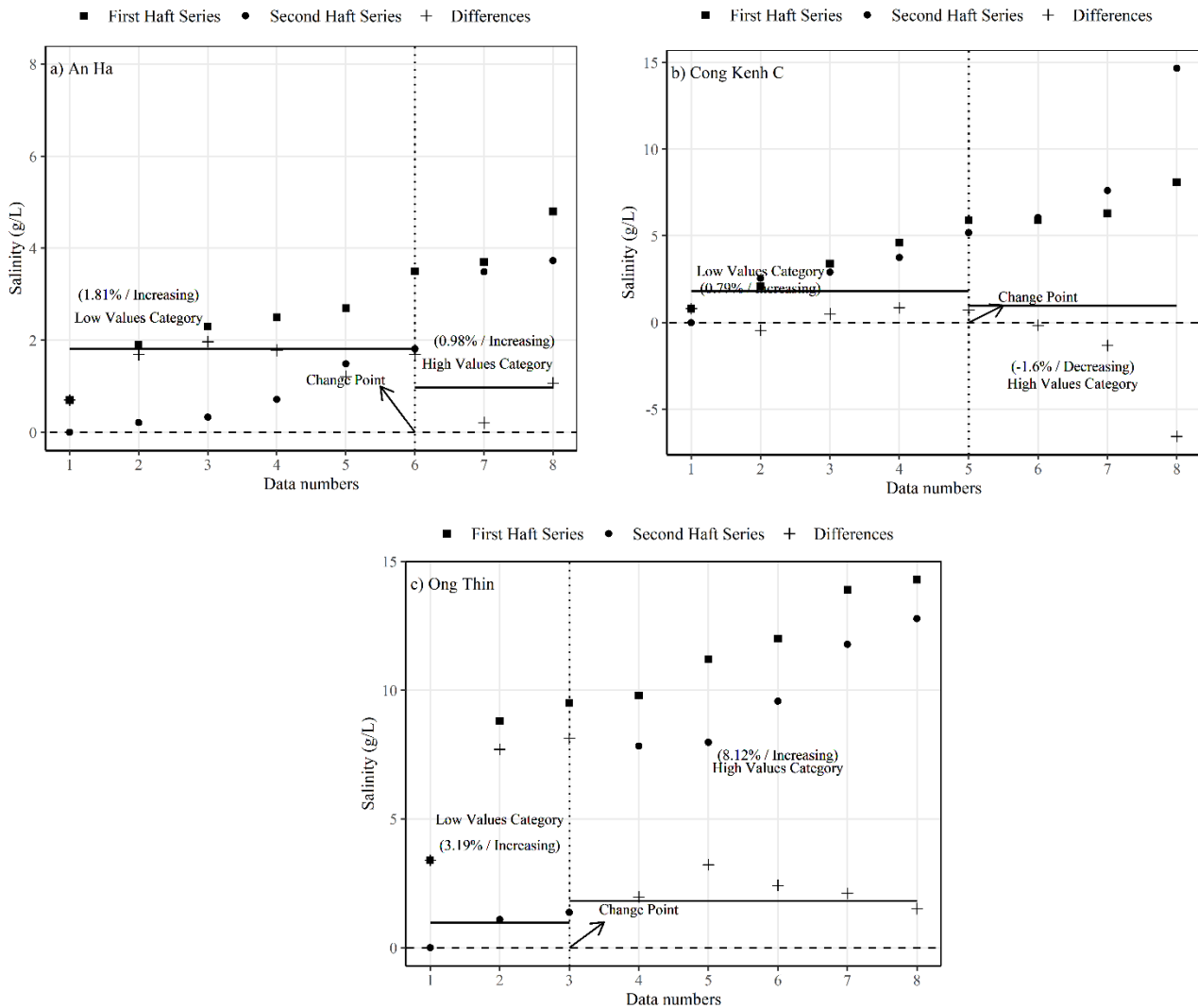


Figure 2. The results of salinity trend analysis in Binh Chanh province from 2007 to 2024.

3.2 The association between climate variables and salinity changes

One of the study's key objectives was evaluating how climate variables affect salinity variations. In this regard, sensitivity analysis results for An Ha, Cong Kenh C, and Ong Thin were performed and designed to be analyzed separately. Figure 3 illustrates that both precipitation and average temperature positively impacted maximum salinity. The horizontal, blue, and red dash lines represent the upper boundaries of the S_{Ti} and S_i indices for the

parameters. This study indicated which parameters influence the model output; when the S_i and S_{Ti} of parameters exceed the horizontal lines, they can be considered significant. The findings accurately identified the sensitivity parameters affecting salinity as R for both Ong Thin and Cong Kenh, with precipitation emerging as the most impactful (at 69.6% and 77.2%, respectively), followed by mean and minimum temperatures (at about 20%). Conversely, maximum temperature had only a minor effect, remaining below the red and blue boundary

lines. At the An Ha station, however, among the climate variables, mean temperature was the most

influential factor, accounting for 56.5% of the impact on salinity.

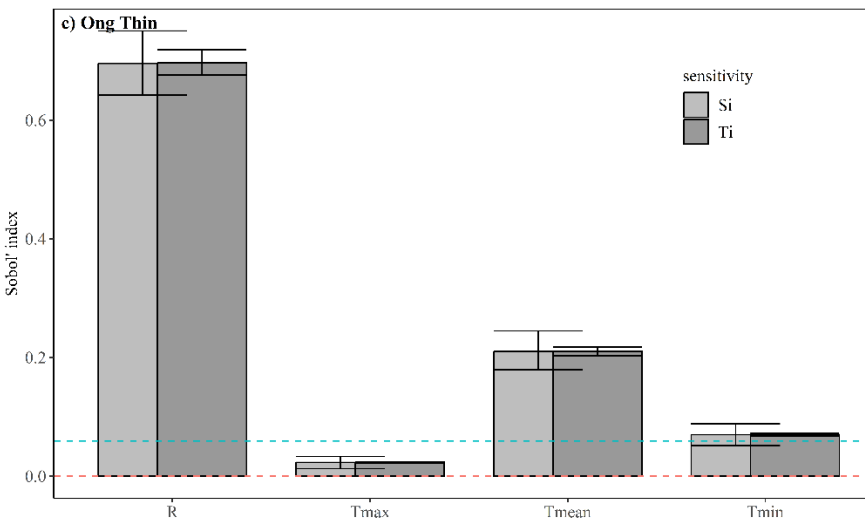
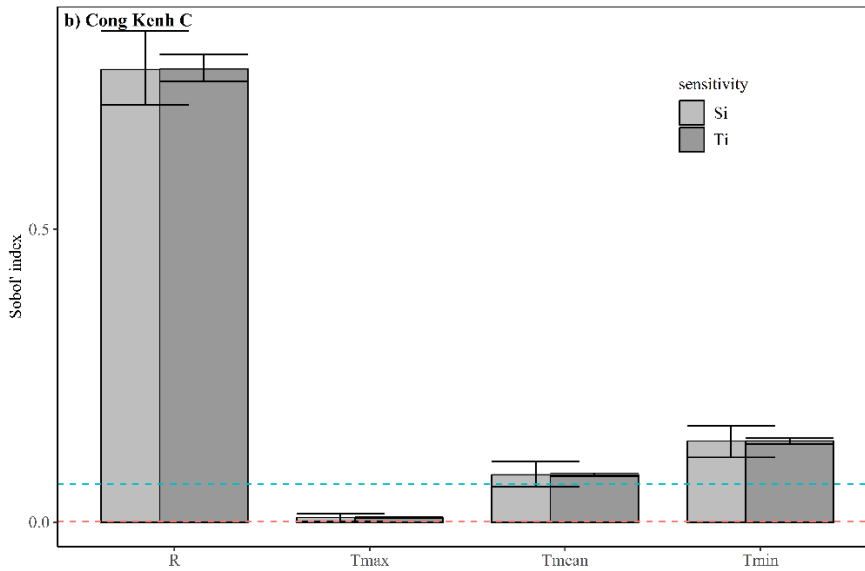
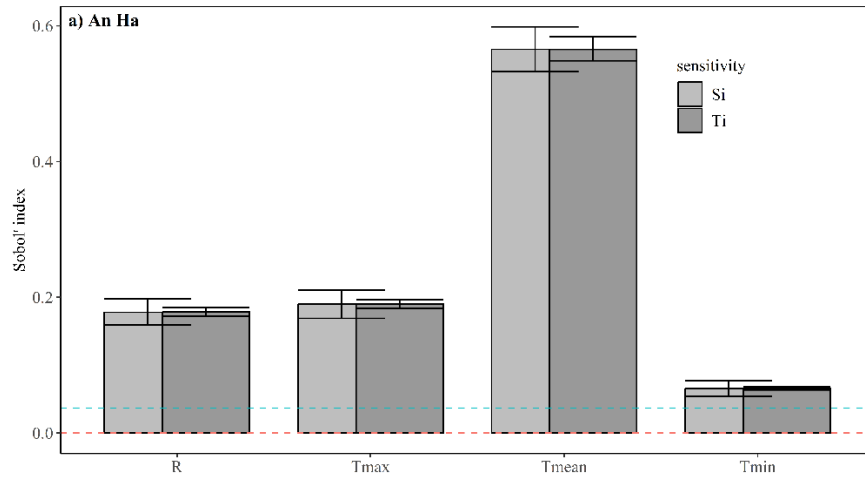


Figure 3. Sensitivity of climate parameters on salinity in Binh Chanh Province (Si: grey color; STi: dark-grey color)

4. CONCLUSION

This research investigated the changes in salinity from 2007 to 2024 and responsiveness to climate factors in Binh Chanh Province. The findings indicated an increase in annual salinity at almost all monitoring locations, with the most significant upward trend observed at Ong Thin station, which showed approximately 8.12% growth. In contrast, Cong Kenh C, situated in the center of Binh Chanh district, was an exception and exhibited declining salinity within the higher value group, decreasing by about 16%. The outcome aligned closely with earlier research in Ho Chi Minh City (Danh et al., 2024; Hong and Dong, 2022), which showed that trends in salinity and their association with impacted areas differ, depending on both the geographical location and size of specific sluices, as well as the width of rivers where salinity exists upstream and is increasing by 0.002% (Hong and Dong, 2022). The salinity levels in stations were also influenced by flows coming from upstream. When the upstream flow decreases, it often results in a greater intrusion of saltwater into inland regions. Conversely, an increase in discharge helps mitigate this saltwater intrusion.

Sensitivity analysis also showed that salinity was more heavily affected by precipitation and mean temperature. The flow and amount of fresh water from rainfall both increase upstream, and both are decisive factors in reducing salinity. This finding supports the broader argument that when freshwater flows are reduced, whether due to less rain or water exploitation, this in turn enables salinity to penetrate further inland.

An increase in sensitivity can elevate crop water demands, exacerbate water loss (due to salinization in surface reservoirs), reduce agriculture productivity, and intensify competition among different water-use sectors (Leeuwen et al., 2016; Thien et al., 2015). Consequently, we recommend that the district explore strategies to minimize consumption where feasible, and optimize the distribution of available resources wherever possible. At the same time, it is essential to prioritize freshwater storage during the rainy season. These reserves serve many purposes, including for use during periods of salinity intrusion, as reservoirs, in underground tanks, and for water storage lakes.

One final note, this study relied on an 18-year historical dataset, and the limited duration of climate data utilized may lead to drawbacks. Therefore, it is vital to extend the time series when future data becomes accessible. Additionally, further research

could focus on assessing the influence of topography, land use dynamics, hydraulic infrastructure, and climate change on the salinity trends in Binh Chanh Province.

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AUTHOR CONTRIBUTIONS

Conceptualization: Ha PT, Khanh PQ, Ngan TTK, Hai LT, Loi NK; Methodology: Ha PT, Khanh PQ, Loi NK; Formal analysis and investigation: Ha PT, Khanh PQ, Ngan TTK, Hai LT, Loi NK; Writing-original draft preparation: Ha PT, Khanh PQ, Loi NK; Writing-review and editing: Ha PT, Khanh PQ, Ngan TTK, Hai LT, Loi NK; Supervision: Hai LT, Loi NK.

DECLARATION OF CONFLICT OF INTEREST

There are no conflicts of interest to declare in this manuscript.

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