APPLICATION OF NON-PARAMETRIC STATISTICAL METHODS FOR ANALYZING SEA SURFACE TEMPERATURE AND SALINITY TRENDS IN THE SOUTHERN COAST OF VIET NAM

Tran Thi My Hong[1], Le Duc Quyen[2]

[1]Ho Chi Minh City University of Technology, Viet Nam National University Ho Chi Minh City

[2]The Viet Nam Institute of Meteorology, Hydrology and Climate Change

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Abstract: *This study analyzes the long-term and seasonal trends of sea surface temperature and salinity from 2003 to 2023 at six monitoring stations located along the coast and on islands in Southern Viet Nam using non-parametric statistical methods, including the Mann-Kendall trend test and Sen's slope estimator. These methods are well-suited for non-normally distributed and highly variable time series data. The results show a general warming trend in sea surface temperature, more pronounced during the rainy season, with statistically significant increases observed at Phu Quoc and Tho Chu, indicating regional ocean warming in the Southwestern coast, while Vung Tau exhibits a slight cooling trend. Sea surface salinity trends are more spatially heterogeneous, with Truong Sa being the only station showing a consistent and statistically significant decline in salinity across both seasons, whereas other stations display weak or statistically insignificant variations. These findings reflect differences in oceanographic dynamics, including the effects of rainfall, evaporation, ocean currents, and regional climate variability across the Southern coastal region and the East Sea. The study provides a valuable scientific basis for environmental monitoring, marine spatial planning, sustainable fisheries development, and climate change adaptation, and recommends enhancing data coverage through expanded observations, remote sensing integration, and regional ocean climate modeling to improve future trend assessments.*

Keywords: *Sea surface temperature, sea surface salinity, non-parametric methods, climate change.*

1. Introduction

In recent years, global climate change has caused significant alterations in various marine environmental factors, among which sea surface temperature (SST) and sea surface salinity (SSS) are two fundamental physical parameters. These variables play a foundational role, exerting widespread influence on marine ecological structure, oceanic circulation partterns, and coastal livehood activities [1]. The rise in global average temperature has led to ocean warming and changes in current regimes, directly affecting marine environmental conditions.

In Viet Nam, the coastal region of the Southern provinces, stretching from Lam Dong to An Giang, is one of the country's key marine zones, supporting numerous socio-economic activities such as aquaculture, offshore fisheries, maritime trade, and marine tourism development.

This coastal area lies in the Southwestern part of the South China Sea and is strongly influenced by large-scale climatic phenomena such as the El Niño-Southern Oscillation and the Indian Ocean Dipole (IOD), which markedly impact seasonal oceanographic characteristics such as temperature and salinity [2-5].

However, studies evaluating the long-term trends of SST and SSS in the Southern coastal region remain fragmented. Most focus on analyzing individual variables or rely on traditional linear statistical methods, which

Corresponding author: Tran Thi My Hong
E-mail: tranthimyhong@hcmut.edu.vn

impose strict assumptions regarding data normality, homoscedasticity, and linearity [6-7]. Meanwhile, marine environmental data series often exhibit nonlinearity, high noise, and are affected by extreme weather events, making traditional approaches prone to bias in trend assessments.

As a result, in recent years, many researchers have shifted toward non-parametric statistical methods, such as the Mann-Kendall test and Sen's slope estimator [8-11]. These methods allow for more objective and robust detection of increasing or decreasing trends, particularly under conditions of long-term, non-normally distributed, and seasonally fluctuating data series. They have been successfully applied in hydro-meteorological and oceanographic trend studies across various global regions, including the Indian coastline [12-13], the Bay of Bengal [14], and the East China Sea [15-16]. In Viet Nam, a number of recent studies have adopted this approach, such as meteorological trends in Quang Nam-Da Nang [17], salinity intrusion variability in the Mekong Delta [18], and rainfall and temperature trends in Kien Giang province [19]. Nonetheless, the application of non-parametric statistical methods in oceanographic data analysis remains limited. Given this context, this study aims to analyze the trends of SST and SSS in the Southern coastal region of Viet Nam over the 2013-2023 period using non-parametric statistical methods, specifically the Mann-Kendall test and Sen's slope estimation. The analysis is based on in-situ observational data from oceanographic monitoring stations. The results not only clarify recent decadal changes in the marine environment of Southern Viet Nam but also provide valuable scientific insights to support local marine resource management, marine spatial planning, and climate change adaptation efforts.

2. Data and Methods

2.1. Study Data

This study focuses on analyzing the trends in sea surface temperature (SST) and sea surface salinity (SSS) in the coastal region of Southern Viet Nam, extending from Lam Dong to An Giang (Figure 1a). The analysis is based on data collected from oceanographic monitoring network in Viet Nam, which consists of 17 fixed sea level observation stations distributed along the coast of the South China Sea, from the Northern to the Southern sectors. At these stations, SST and SSS are measured four times per day using electronic thermometers and conductivity-based salinometers. For this study, key stations including Vung Tau, Con Dao, Phu Quy, Truong Sa, Phu Quoc, and Tho Chu were selected to ensure representative coverage of both the Southeastern coastal zone and the offshore archipelagos, which are areas of critical ecological and economic importance to Southern Viet Nam. The dataset spans a 20-year period, from January 1, 2003, to December 31, 2023, providing sufficient temporal depth to examine long-term variability and capture major climate phenomena such as the 2015-2016 El Niño and the prolonged La Niña events of 2007-2008 and 2010-2011.

The geographical coordinates of the six study sites are shown in Figure 1b, spatially distributed from the Southeastern coastal region (Vung Tau, Phu Quy), through the central archipelagic zone of the South China Sea (Con Dao, Truong Sa), to the Southwestern maritime zone (Phu Quoc, Tho Chu). This spatial layout allows for a comprehensive reflection of the region's oceanographic diversity and serves as a foundation for comparing trends across areas with differing geographic and climatic characteristics.

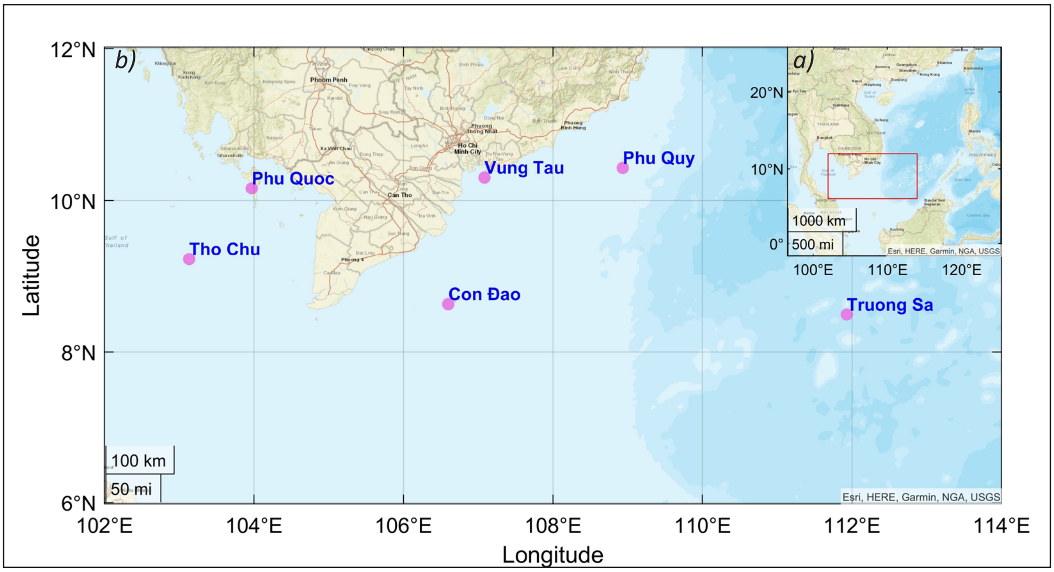

Figure 1. (a) The red rectangle indicates the location of the study area. (b) Geographic locations of oceanographic monitoring stations in the Southern Coastal Region of Viet Nam

2.2. Non-parametric methods

2.2.1. Man-Kendall trend test method

In climate, hydrological, and oceanographic studies, numerous statistical methods have been developed to analyze temporal trends in data series [20-22]. One such method-the Mann-Kendall trend test-compares the relative magnitudes of data rather than their actual values. This helps avoid spurious trends caused by a few local extreme values, which may otherwise distort trend estimation using conventional linear methods such as least squares regression based on the slope of a fitted line.

Furthermore, the Mann-Kendall method does not require the data to follow any specific probability distribution, making it especially useful for environmental time series that often exhibit non-normality, seasonality, and outliers.

The Mann-Kendall statistic (S) is computed by comparing all possible pairs of values in the time series, where n is the total number of observations, and x_i and x_j are data values at time i and j, respectively. The test statistic S is calculated as:

$$s = \sum_{i}^{n} \sum_{j=i+1}^{n} sign(x_i - x_j) \quad (1)$$

Where the *sign* function is defined as:

$$sign(x_i - x_j) = \begin{cases} +1\ khi\ (x_i - x_j) > 0 \\ 0\ khi\ (x_i - x_j) = 0 \\ -1\ khi\ (x_i - x_j) < 0 \end{cases} \quad (2)$$

The variance of *S* is given by:

$$VAR(S) = \frac{s(n-1)(2n+5) - \sum_{k-1}^{q} m_k(m_k - 1)(2m_k + 5)}{18} \quad (3)$$

Where m_k is the number of tied ranks in group k, and q is the number of such tied groups.

The standardized Mann-Kendall statistic *Z* is computed as follows:

$$Z = \begin{cases} \dfrac{S-1}{(VAR(S))^{0.5}}, S > 0 \\ 0, \quad S = 0 \\ \dfrac{S-1}{(VAR(S))^{0.5}}, S < 0 \end{cases} \quad (4)$$

The sign of Z indicates the direction of the trend: Positive for upward, negative for downward. This test was applied to monthly, annual, and seasonal oceanographic data series to assess statistically significant trends. At the

5% significance level, the null hypothesis (H_0: no trend) is rejected if the absolute value of Z exceeds 1.64.

After calculating the standardized test statistic Z, the p-value-representing the probability that the observed trend is due to chance-can be determined by:

$$p = 2 \times (1 - \phi(|Z|)) \quad (5)$$

Where $\phi(Z)$ is the cumulative distribution function of the standard normal distribution. If $p \leq 0.05$ (corresponding to a 5% significance level), the observed trend is considered statistically significant and unlikely to be the result of random variation [23].

2.2.2. Sen's slope estimation method

The Sen's Slope method is used to estimate the rate of annual and seasonal changes in oceanographic variables by calculating the slope between all possible pairs of data points in the time series, then taking the median of these slopes:

$$\beta = median\left(\frac{x_j - x_i}{j-i}\right), \text{ with } j>I \quad (6)$$

Where x_j,x_i are the values of the oceanographic variables at time points *j* and *i*, respectively, *j-i* is the time interval between the two data points and β is the Sen's slope, representing the average trend of change over time [24].

3. Results and Discussions

3.1. Trend of long-term SST Changes

3.1.1. Average Annual SST

The trends in annual average sea surface temperature (T_{avg}), maximum temperature (T_{max}), and minimum temperature (T_{min}) during the period 2003-2023 are illustrated in Figure 2 and analyzed in detail in Table 1. The non-parametric statistical methods Mann-Kendall and Sen's Slope were applied to assess the trends and rates of temperature change at six oceanographic stations located along the coastal and island regions of Southern Viet Nam. The Z-statistic is used to test the statistical significance of the trends, while the Sen's Slope coefficient represents the rate of temperature change per year.

The results reveal considerable differences in the T_{avg} trends across the stations. Most stations exhibit a slight upward trend in T_{avg}. However, only Phu Quoc shows a statistically significant increasing trend at the 95% confidence level, with Z = 2.721, p = 0.0065 < 0.05, and a Sen's slope of 0.0265°C/year, indicating a clear and stable warming pattern over time. This suggests that Phu Quoc is particularly affected by climate change. Conversely, Vung Tau shows a noticeable decreasing trend in average temperature, with Z = -1.904 and Sen's slope = -0.0608°C/year, statistically significant at the 90% confidence level (p = 0.0569 < 0.1). Other stations such as Tho Chu, Con Dao, and Phu Quy also show warming trends (Z > 0), but these are not statistically significant (p > 0.05). Nevertheless, their average increase of about 0.01°C/year contributes to the general warming trend across the region. Notably, Truong Sa is the only station showing a slight cooling trend in T_{avg}, with Z = -0.785 and Sen's slope of approximately -0.0107°C/year.

Regarding T_{max}, most stations show an increasing trend, especially at Tho Chu (0.02°C/year) and Phu Quy (0.025°C/year). Although these trends are not statistically significant, they still suggest a slight increase in temperature extremes at offshore islands. In contrast, Vung Tau and Phu Quoc show decreasing T_{max} trends, with Vung Tau showing the most notable decline (-0.0387°C/year).

T_{min} trends are more distinctly varied across stations. Phu Quoc again stands out with the strongest increasing T_{min} trend, having the highest Sen's slope of 0.0833°C/year and Z = 1.422. This is a clear indication of nighttime warming, a common feature in climate change scenarios.

Additionally, Con Dao shows a slight increase in T_{min} at 0.0226°C/year. In contrast, Vung Tau and Truong Sa exhibit decreasing T_{min} trends, at -0.07°C/year and -0.0111°C/year, respectively. T_{min} remains relatively stable at Phu Quy and Tho

Chu, with very low rates of change, reflecting negligible variation in minimum temperatures in these locations throughout the study period.

Annual-scale SST variability across the region appears to be strongly influenced by ENSO events. During El Niño years, particularly 2009-2010 and 2015-2016, most stations recorded temporary increases in T_{min}, reflecting intensified surface warming. In contrast, La Niña episodes in 2007-2008 and 2010-2011 were associated with cooler anomalies at most stations, especially at Vung Tau and Truong Sa, where noticeable decreases in T_{max}, T_{min}, and Tavg were observed. These patterns underscore the role of ENSO in driving short-term fluctuations that are superimposed on the longer-term warming or cooling tendencies across Southern coastal and island regions.

Table 1. Trend analysis of annual average, maximum, and minimum SST using non-parametric methods. Bold black and blue text indicate statistical significance at the 95% and 90% levels, respectively

Stations	**Temperature (°C)**	**Z index**	**p index**	**β (°C/year)**	**Trend equations** y = ax ± b
Phu Quy	T_{avg}	+ 0.725	0.468	+ 0.006	y = + 0.006x + 14.89
	T_{max}	+ 1.153	0.248	+ 0.025	y = + 0.025x - 20.97
	T_{min}	- 0.122	0.903	+ 0.000	y = + 0.000x + 24.90
Vung Tau	T_{avg}	**- 1.904**	**0.056**	**- 0.060**	y = - 0.060x + 150.39
	T_{max}	- 1.486	0.137	- 0.038	y = - 0.038x + 107.41
	T_{min}	- 1.574	0.115	- 0.070	y = - 0.070x + 167.01
Tho Chu	T_{avg}	+ 1.179	0.238	+ 0.012	y = + 0.012x + 4.01
	T_{max}	+ 1.557	0.119	+ 0.020	y = + 0.020x - 9.36
	T_{min}	- 0.610	0.542	- 0.007	y = - 0.007x + 42.55
Truong Sa	T_{avg}	- 0.785	0.432	- 0.010	Y = - 0.010x + 50.64
	T_{max}	+ 0.455	0.648	+ 0.009	y = + 0.009x + 11.69
	T_{min}	- 0.363	0.716	- 0.011	y = - 0.011x + 50.65
Con Dao	T_{avg}	+ 0.755	0.450	+ 0.010	y = + 0.010x + 8.22
	T_{max}	+ 0.456	0.648	+ 0.006	y = + 0.006x + 17.85
	T_{min}	+ 1.033	0.301	+ 0.022	y = + 0.022x - 19.26
Phu Quoc	T_{avg}	**+ 2.721**	**0.006**	**+ 0.026**	y = + 0.026x - 23.76
	T_{max}	- 0.575	0.565	- 0.018	y = - 0.018x + 67.31
	T_{min}	+ 1.422	0.155	+ 0.083	y = + 0.083x - 141.81

3.1.2. Seasonal Average SST

The seasonal variations of average temperature (T_{avg}), maximum temperature (T_{max}), and minimum temperature (T_{min}) at six coastal and island oceanographic stations in Southern Viet Nam from 2003 to 2023 are shown in Figure 3 and detailed in Table 2.

a. Rainy Season

During the rainy season (May to November), a warming trend in seasonal average temperature (T_{avg}) is observed at most stations. Notably, Tho Chu station exhibits a significant upward trend with Z = 2.188, p (= 0.0287) < 0.05 and a warming rate of 0.0333°C/year. In addition to T_{avg}, both T_{max} and T_{min} at Tho Chu also show statistically significant increases at the 95% confidence level, with rates of 0.0389°C/year and 0.0333°C/year, respectively, indicating comprehensive warming at this location during the rainy season. Other stations such as Phu Quy, Con Dao, and Phu Quoc also display increasing T_{avg} trends, with Sen's slope values ranging from 0.0129 to 0.0613°C/year. Although these trends are not statistically significant ($p > 0.05$), they still indicate a potential warming signal during the rainy season. Particularly, Phu Quoc shows a sharp increase in T_{min} (0.08°C/year) a characteristic sign of nighttime warming associated with global climate change.

Conversely, Vung Tau station shows a clear decreasing trend in T_{avg} during the rainy season, with $Z = -1.975$ ($p = 0.0482$) and a cooling rate of -0.0667°C/year. Notably, T_{min} at this station has the strongest decreasing trend among all stations, at -0.1°C/year ($Z = -2.675$, $p = 0.0075$), indicating localized nighttime cooling along the Southeast coast. Meanwhile, no significant trends are detected at Truong Sa during the rainy season, with near-zero Sen's slope values and no statistical significance.

b. Dry Season

In contrast to the rainy season, temperature trends during the dry season (December to April) generally show a cooling tendency. Several stations including Phu Quy, Vung Tau, Tho Chu, and Truong Sa exhibit slight decreasing trends in T_{avg}, though none are statistically significant ($p > 0.1$), with Sen's slope values ranging from -0.0057 to -0.0667°C/year. Con Dao shows no clear trend ($Z = 0.031$, slope = 0), and Phu Quoc has a negligible decreasing trend (-0.0056°C/year).

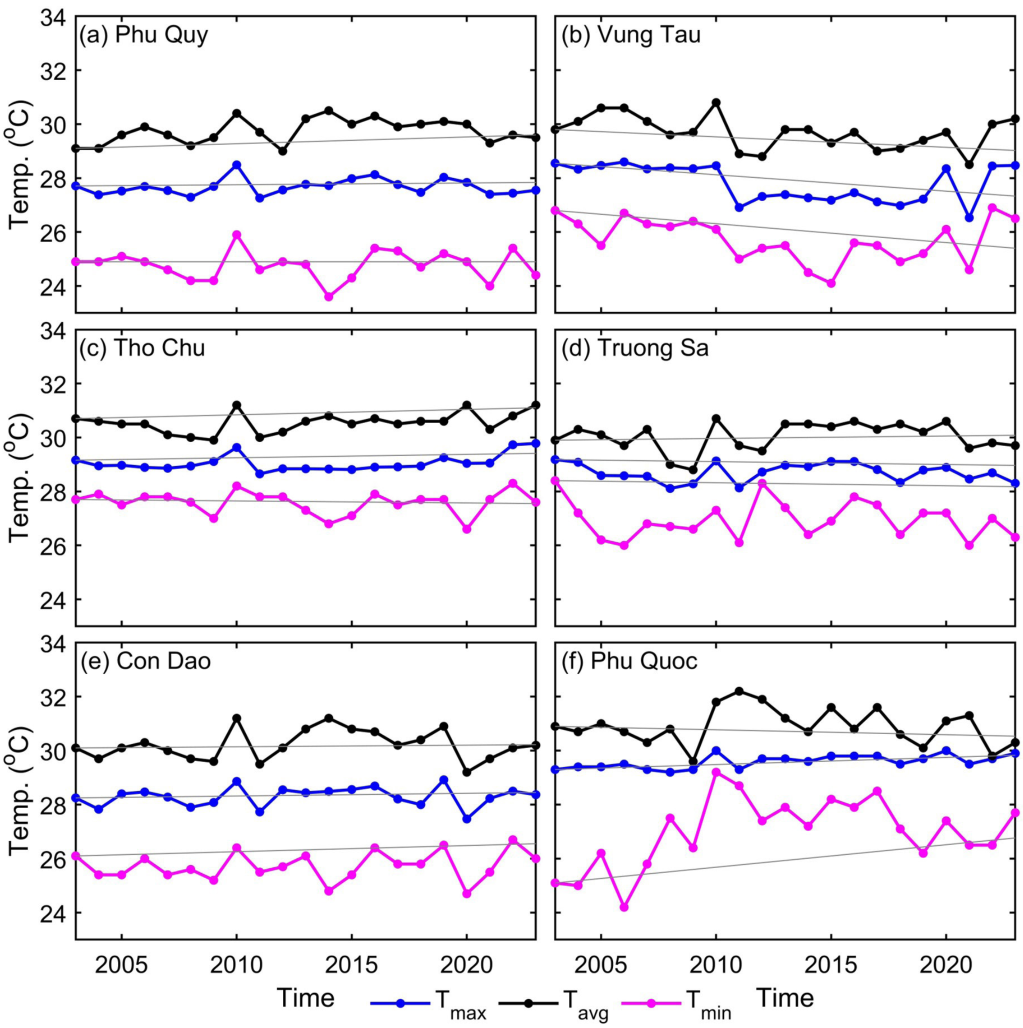

Figure 2. Annual average SST trends from 2003 to 2023 at six oceanographic stations based on the Sen's slope method

Table 2. Seasonal Temperature Trend Analysis Using Mann-Kendall and Sen's Slope Methods. Bold black and blue text indicate statistical significance at the 95% and 90% levels, respectively

Stations	**Seasons**	**Temperature (°C)**	**Z index**	**p index**	**β (°C/year)**	**Trend equations** y = ax ± b
Phu Quy	Rainy season	T_{avg}	+ 1.316	0.188	+ 0.013	y = + 0.013x + 1.77
		T_{max}	+ 1.214	0.224	+ 0.025	y = + 0.025x - 21.07
		T_{min}	- 0.122	0.903	+ 0.000	y = + 0.000x + 27.70
	Dry season	T_{avg}	- 0.456	0.648	- 0.005	y = - 0.005x + 37.85
		T_{max}	- 0.395	0.693	- 0.008	y = - 0.008x + 45.14
		T_{min}	- 0.122	0.903	+ 0.000	y = + 0.000x + 24.90
Vung Tau	Rainy season	T_{avg}	- 1.975	0.048	- 0.066	y = - 0.066x + 162.73
		T_{max}	- 1.486	0.137	- 0.038	y = - 0.038x + 107.41
		T_{min}	- 2.675	0.007	- 0.100	y = - 0.100x + 228.80
	Dry season	T_{avg}	- 1.456	0.145	- 0.066	y = - 0.066x + 161.23
		T_{max}	- 2.208	0.027	- 0.078	y = - 0.078x + 187.81
		T_{min}	- 1.574	0.115	- 0.070	y = - 0.070x + 167.01
Tho Chu	Rainy season	T_{avg}	+ 2.188	0.028	+ 0.033	y = + 0.033x - 37.46
		T_{max}	+ 2.340	0.019	+ 0.038	y = + 0.038x - 47.59
		T_{min}	+ 1.950	0.051	+ 0.033	y = + 0.033x - 38.16
	Dry season	T_{avg}	- 0.517	0.604	- 0.006	y = - 0.006x + 42.41
		T_{max}	- 0.730	0.465	- 0.010	y = - 0.010x + 50.73
		T_{min}	- 0.610	0.542	- 0.007	y = - 0.007x + 42.55
Truong Sa	Rainy season	T_{avg}	+ 0.000	1.000	+ 0.000	y = + 0.000x + 29.40
		T_{max}	+ 0.455	0.648	+ 0.009	y = + 0.009x + 11.69
		T_{min}	+ 0.183	0.854	+ 0.000	y = + 0.000x + 29.00
	Dry season	T_{avg}	- 0.999	0.317	- 0.023	y = - 0.023x + 75.12
		T_{max}	- 0.458	0.647	- 0.002	y = - 0.002x + 35.59
		T_{min}	- 0.363	0.716	- 0.011	y = - 0.011x + 50.65
Con Dao	Rainy season	T_{avg}	+ 0.887	0.375	+ 0.012	y = + 0.012x + 2.92
		T_{max}	+ 0.728	0.466	+ 0.011	y = + 0.011x + 5.85
		T_{min}	+ 1.469	0.142	+ 0.018	y = + 0.018x - 8.61
	Dry season	T_{avg}	+ 0.031	0.975	+ 0.000	y = + 0.000x + 27.50
		T_{max}	+ 0.000	1.000	+ 0.000	y = + 0.000x + 30.10
		T_{min}	+ 1.033	0.301	+ 0.022	y = + 0.022x - 19.26
Phu Quoc	Rainy season	T_{avg}	+ 1.211	0.226	+ 0.061	y = + 0.061x - 95.48
		T_{max}	+ 0.213	0.831	+ 0.000	y = + 0.000x + 29.50
		T_{min}	+ 1.455	0.145	+ 0.080	y = + 0.080x - 135.14
	Dry season	T_{avg}	- 0.427	0.669	- 0.005	y = - 0.005x + 41.02
		T_{max}	- 0.729	0.466	- 0.018	y = - 0.018x + 67.31
		T_{min}	- 1.330	0.182	- 0.064	y = - 0.064x + 158.06

A notable observation in the dry season is the significant decrease in T_{max} at Vung Tau, with a rate of -0.0789°C/year (Z = -2.208, p = 0.0272), indicating daytime cooling. Other stations like Phu Quy and Tho Chu also show decreasing T_{max} trends, although not statistically significant.

T_{min} trends during the dry season vary considerably across stations. Con Dao shows a slight increase (0.0226°C/year, Z = 1.033), while most other stations either show no significant trend or a decreasing trend. Phu Quoc, in particular, records a notable decrease in T_{min} (-0.0646°C/year), reflecting a drop in nighttime temperatures during the dry season - opposite to the strong T_{min} increase observed during the rainy season at the same station.

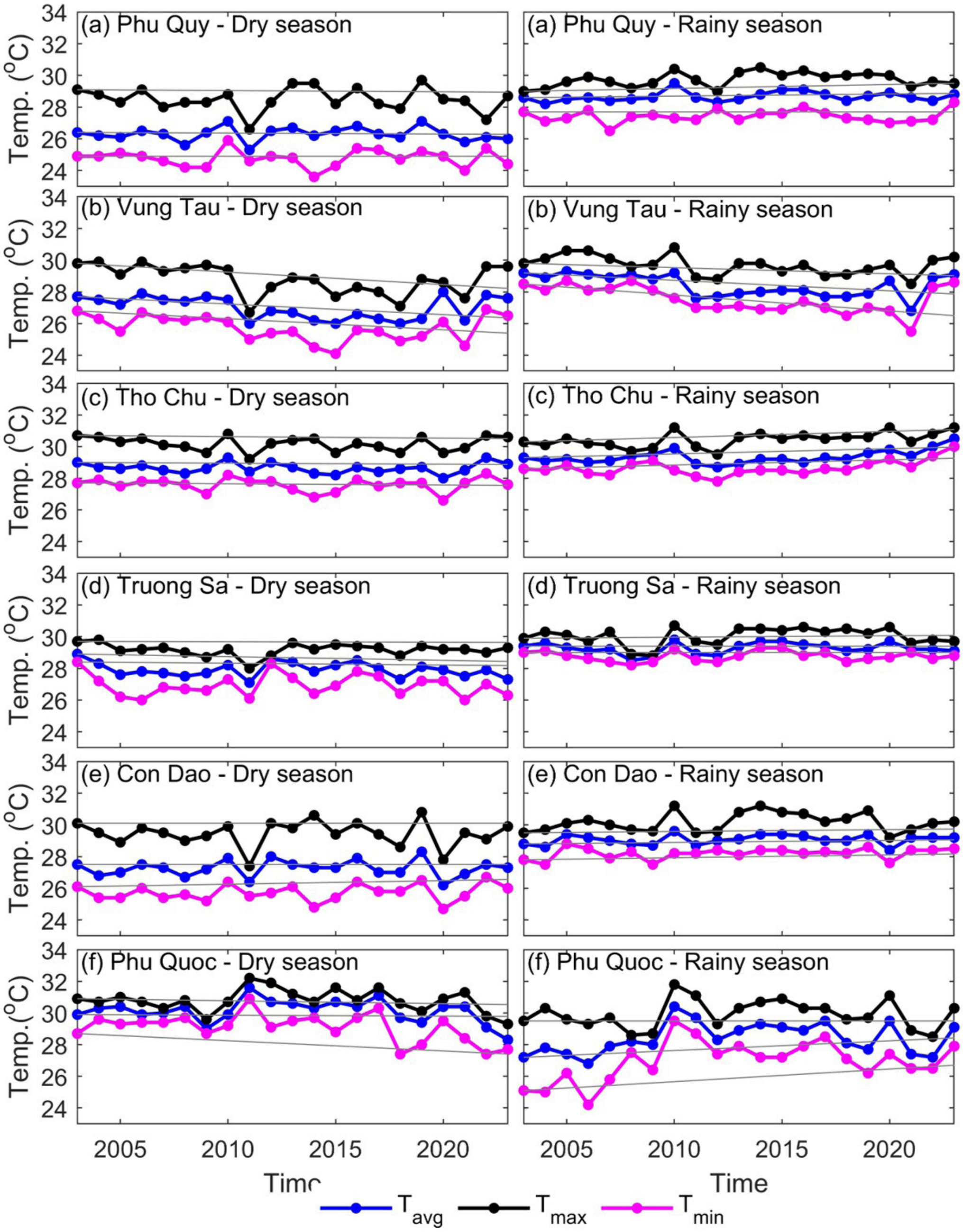

Figure 3. Seasonal trends of average SST from 2003 to 2023 at six oceanographic stations

3.2. Trend of long-term SSS Changes

3.2.1. Average Annual SSS

The annual variation in average salinity (S_{avg}), maximum salinity (S_{max}), and minimum salinity (S_{min}) at six coastal and island stations in Southern Viet Nam - namely Phu Quy, Vung Tau, Tho Chu, Truong Sa, Con Dao, and Phu Quoc-reveals notable differences in fluctuation levels and salinity trends across regions during the period 2003 - 2023. Trend analysis was conducted using the Mann-Kendall test to assess statistical significance, along with Sen's slope estimator to determine the annual rate of salinity change. Results are summarized in Table 3 and visually illustrated in Figure 4.

Overall, most stations showed no significant salinity trend, with Z-values ranging within ±1 and p-values greater than 0.1, indicating relatively stable average salinity across most areas over the past two decades. However, Truong Sa stood out as the only station with a statistically significant decreasing trend, showing Z = -3.827 (p = 0.0001) and Sen's slope of -0.2296 ‰/year. All three indicators - Savg, Smax, and Smin - at this station exhibited a sharp decline, particularly Smin, which decreased at a rate of -0.1477 ‰/year (Z = -3.447; p = 0.0006). This reflects a pronounced freshening trend in the central South China Sea, potentially linked to changes in ocean current patterns, increased rainfall, or large-scale climate variability.

At the individual station level, both Phu Quy and Vung Tau showed slight decreasing trends in salinity, with Phu Quy's Savg decreasing at -0.1 ‰/year (Z = -1.150; p = 0.2501), and Vung Tau's trend being negligible at -0.0146 ‰/year. Although these trends are not statistically significant (p > 0.1), they suggest a gradual decline within natural fluctuation bounds.

Table 3. Annual Average Salinity Trend Analysis Using Mann-Kendall and Sen's Slope Methods. Bold black and blue text indicate statistical significance at the 95% and 90% levels, respectively

Stations	**Salinity (°/$_{oo}$)**	**Z index**	**p index**	**β (°/$_{oo}$ /year)**	**Trend equations y = ax ± b**
Phu Quy	S_{avg}	- 1.150	+ 0.250	- 0.100	y = - 0.100x + 232.10
	S_{max}	- 1.879	+ 0.060	- 0.136	y = - 0.100x + 306.30
	S_{min}	- 0.030	+ 0.975	+ 0.000	y = + 0.000x + 30.50
Vung Tau	S_{avg}	- 0.242	+ 0.808	- 0.014	y = - 0.014x + 59.51
	S_{max}	- 0.818	+ 0.413	- 0.017	y = - 0.017x + 68.06
	S_{min}	+ 1.300	+ 0.193	+ 0.054	y = + 0.054x - 79.94
Tho Chu	S_{avg}	+ 1.271	+ 0.203	+ 0.009	y = + 0.009x + 10.83
	S_{max}	+ 1.557	+ 0.119	+ 0.020	y = + 0.020x - 9.36
	S_{min}	- 0.610	+ 0.542	- 0.007	y = - 0.007x + 42.55
Truong Sa	S_{avg}	- 2.753	- 0.229	- 0.128	y = - 0.229x +288.12
	S_{max}	- 1.694	+ 0.090	- 0.100	y = - 0.100x + 230.90
	S_{min}	- 3.447	+ 0.000	- 0.147	y = - 0.147x + 326.19
Con Dao	S_{avg}	+ 1.494	+ 0.135	+ 0.027	y = + 0.027x - 23.82
	S_{max}	+ 0.972	+ 0.331	+ 0.019	y = + 0.019x - 5.30
	S_{min}	+ 1.942	+ 0.052	+ 0.098	y = + 0.098x - 168.66
Phu Quoc	S_{avg}	+ 0.516	+ 0.606	+ 0.020	y = + 0.020x - 13.19
	S_{max}	- 0.575	+ 0.565	- 0.018	y = - 0.018x + 67.31
	S_{min}	+ 1.422	+ 0.155	+ 0.083	y = + 0.083x - 141.81

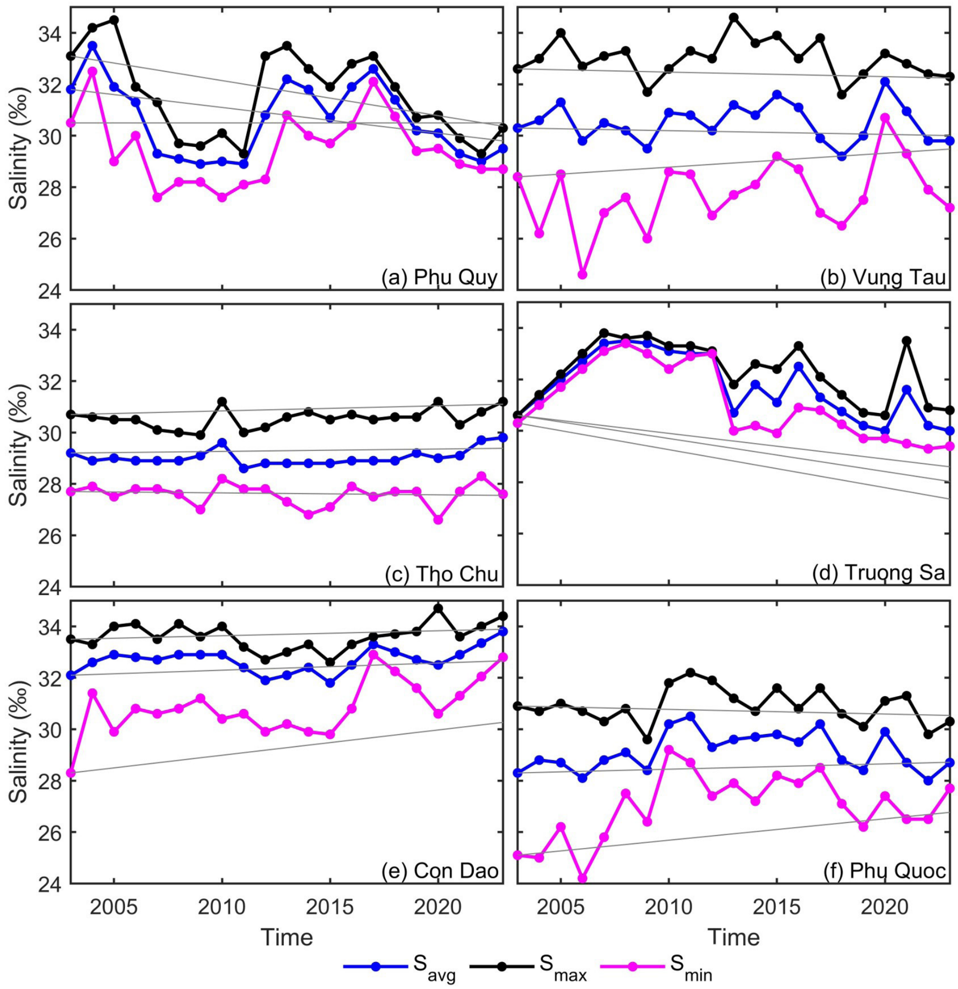

Figure 4. Change of Annual Average SSS Over Time

Conversely, Tho Chu, Con Dao, and Phu Quoc exhibited slight increasing trends. Notably, Con Dao recorded a S_{avg} increase of 0.0279 ‰/year (Z = 1.494), with S_{min} increasing by +0.0983 ‰/year (Z = 1.942; p ≈ 0.05), nearing statistical significance. At Phu Quoc, S_{avg} also showed a slight upward trend (Sen's slope = 0.0207 ‰/year), while S_{min} rose more markedly (Sen's slope = +0.0833 ‰/year), suggesting a potential reduction in freshwater influence and increased saltwater intrusion during certain periods.

Interannual variations in SSS appear to be closely linked to major ENSO events. During strong El Niño years (2009-2010 and 2015-2016), several stations, particularly Phu Quy, Con Dao, and Truong Sa, recorded increases in Smax, likely due to enhanced evaporation driven by surface warming. Conversely, prolonged La Niña episodes (2007-2008 and 2010-2011) were generally associated with decreases in S_{min} at most stations, consistent with stronger freshwater input from intensified rainfall and river discharge. These patterns highlight the significant influence of ENSO in regulating salinity variability across the coastal and island regions of Southern Viet Nam.

3.2.2. Seasonal Trends of Average SSS

The seasonal variations of average salinity (S_{avg}), maximum salinity (S_{max}), and minimum salinity (S_{min}) at six coastal and island oceanographic stations in Southern during 2003-2023 are summarized in Table 4 and presented in Figure 5.

a. Rainy Season

Trend analysis of salinity during the rainy season (May to November) at six coastal and island stations from Lam Dong to An Giang reveals notable differences across geographic locations. Among them, Truong Sa is the only station that shows a strong and statistically significant decreasing trend in salinity, with average salinity declining at Z = -3.844 (p = 0.0001) and a Sen's slope of –0.2000‰/year. Both S_{max} and S_{min} at Truong Sa also exhibit clear downward trends, indicating a significant reduction in salinity during the rainy season in the central South China Sea.

In contrast, Tho Chu is the only station displaying a distinct increasing trend in salinity during the rainy season, with Z-values ranging from 2.084 to 2.388 (p between 0.017 and 0.037) and Sen's slopes ranging from 0.0333 to 0.0368‰/year. This suggests a gradual salinization trend at this island during the rainy season.

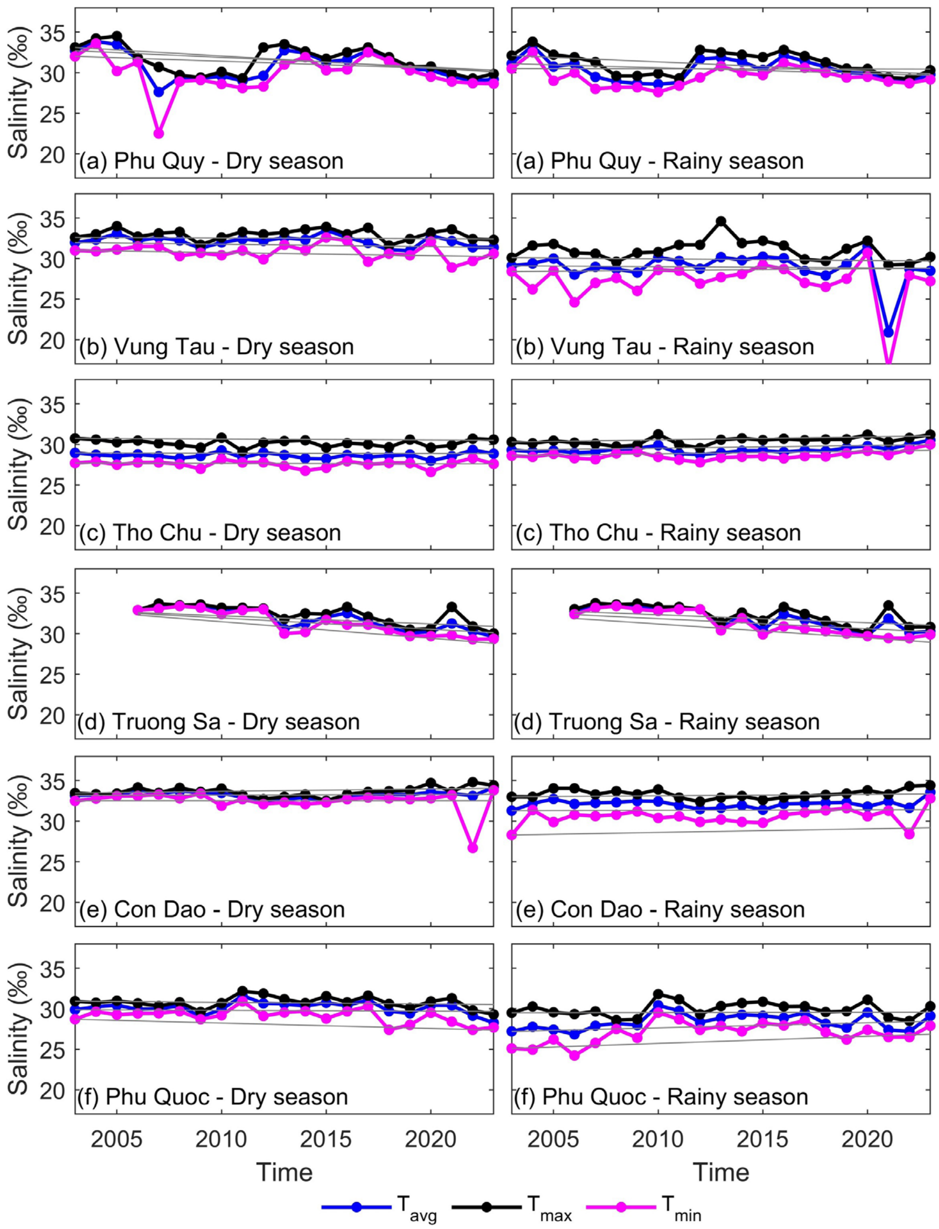

Figure 5. Seasonal SSS change trends at six oceanographic stations based on the Sen's slope method

Table 4. Seasonal Average Salinity Trend Analysis Using the Mann-Kendall Test and Sen's Slope Method. Bold black and blue text indicate statistical significance at the 95% and 90% levels, respectively

Stations	Seasons	Salinity (°/oo)	Z index	p index	β (°/oo / year)	Trend equations y = ax ± b
Phu Quy	Rainy season	S_{avg}	- 0.996	0.319	- 0.070	y = - 0.070x + 172.48
		S_{max}	- 2.027	0.042	- 0.111	y = - 0.111x + 256.12
		S_{min}	- 0.121	0.903	- 0.003	y = - 0.003x + 36.75
	Dry season	S_{avg}	- 1.419	0.155	- 0.118	y = - 0.118x + 270.83
		S_{max}	- 1.967	0.049	- 0.150	y = - 0.150x + 333.55
		S_{min}	- 0.877	0.380	- 0.085	y = - 0.085x + 202.98
Vung Tau	Rainy season	S_{avg}	- 0.242	0.809	- 0.015	y = - 0.015x + 59.81
		S_{max}	- 0.393	0.694	- 0.020	y = - 0.020x + 71.59
		S_{min}	+ 0.393	0.694	+ 0.020	y = + 0.020x - 11.66
	Dry season	S_{avg}	- 1.180	0.238	- 0.030	y = - 0.030x + 93.09
		S_{max}	- 0.273	0.785	- 0.009	y = - 0.009x + 50.96
		S_{min}	- 1.060	0.289	- 0.038	y = - 0.038x + 107.07
Tho Chu	Rainy season	S_{avg}	+ 2.084	0.037	+ 0.033	y = + 0.033x - 37.46
		S_{max}	+ 2.388	0.017	+ 0.036	y = + 0.036x - 43.35
		S_{min}	+ 2.115	0.034	+ 0.033	y = + 0.033x - 38.36
	Dry season	S_{avg}	- 0.393	0.694	- 0.004	y = - 0.004x + 37.59
		S_{max}	- 0.695	0.487	- 0.011	y = - 0.011x + 53.33
		S_{min}	- 0.393	0.694	- 0.004	y = - 0.004x + 37.32
Truong Sa	Rainy season	S_{avg}	- 2.659	0.007	- 0.124	y = - 0.124x + 282.42
		S_{max}	- 1.694	0.090	- 0.098	y = - 0.098x + 230.81
		S_{min}	- 3.146	0.001	- 0.172	y = - 0.172x + 377.07
	Dry season	S_{avg}	- 2.929	0.003	- 0.139	y = - 0.139x + 311.44
		S_{max}	- 1.602	0.109	- 0.100	y = - 0.100x + 233.19
		S_{min}	- 3.689	0.000	- 0.204	y = - 0.204x + 442.84
Con Dao	Rainy season	S_{avg}	+ 0.393	0.694	+ 0.005	y = - 0.005x + 19.98
		S_{max}	+ 0.908	0.363	+ 0.017	y = - 0.017x - 1.09
		S_{min}	+ 1.090	0.275	+ 0.044	y = - 0.044x - 60.94
	Dry season	S_{avg}	+ 0.272	0.785	+ 0.006	y = - 0.006x + 20.60
		S_{max}	+ 1.422	0.154	+ 0.029	y = - 0.029x - 26.18
		S_{min}	+ 0.152	0.879	+ 0.000	y = - 0.000x + 32.50
Phu Quoc	Rainy season	S_{avg}	+ 1.239	0.215	+ 0.062	y = - 0.062x - 98.73
		S_{max}	+ 0.272	0.785	+ 0.003	y = - 0.003x + 22.12
		S_{min}	+ 1.481	0.138	+ 0.088	y = - 0.088x - 151.30
	Dry season	S_{avg}	- 0.272	0.785	- 0.011	y = - 0.011x + 51.82
		S_{max}	- 0.755	0.450	- 0.020	y = - 0.020x + 72.15
		S_{min}	- 1.391	0.164	- 0.066	y = - 0.066x + 162.23

Other stations, including Phu Quy, Vung Tau, Con Dao, and Phu Quoc, show slight or unclear variations. Although Phu Quoc and Con Dao have positive Sen's slope, their p-values exceed 0.13, lacking statistical significance. Vung Tau shows a slight decrease in S_{avg} and S_{max}, but an increase in S_{min}, suggesting a narrowing salinity range. However, these changes are negligible (Z between ±0.4, p > 0.6).

b. Dry Season

During the dry season (December to April), salinity variations are generally weaker than in the rainy season, with Truong Sa being the only station showing a significant change. Here, average salinity decreased with Z = -3.560, p = 0.0004, and a Sen's slope of -0.1391 ‰/year. The reduction is even more pronounced for S_{min} with Z = -3.689 and a Sen's slope of -0.2047‰/year. These results indicate a consistent salinity decline trend at Trường Sa across both seasons.

At Phu Quy, Vung Tau, Tho Chu, and Phu Quoc, negative Z-values were observed, indicating a slight downward trend in salinity. However, high p-values (from 0.13 to 0.69) reflect statistically insignificant trends. Notably, Phu Quoc shows relatively larger declines in S_{min} (-0.0667 ‰/year) and S_{avg} (-0.0110 ‰/year), suggesting a slight decreasing salinity trend in the dry season, though not statistically significant.

Interestingly, Con Dao exhibits virtually no change, with Z ≈ 0 (Z = +0.098), indicating stable salinity during the dry season at this location. Furthermore, Tho Chu - where salinity increased during the rainy season -shows no significant change in the dry season, highlighting a clear seasonal contrast at the same site.

4. Conclusions

This study evaluated the long-term and seasonal variation trends of two key oceanographic parameters - sea surface temperature and salinity - during the period 2003 - 2023 at six representative stations across the coastal and island regions of Southern Viet Nam. These stations include Phu Quy, Vung Tau, Tho Chu, Truong Sa, Con Dao, and Phu Quoc. The non-parametric Mann - Kendall statistical test combined with the Sen's slope estimator was employed to detect and quantify trends, as well as to assess the statistical significance of these changes. Regarding temperature, the results reveal a prevailing warming trend at most stations, particularly during the rainy season. Phu Quoc stands out with a pronounced increase in minimum temperature (Sen's slope = +0.0833°C/year), indicating signs of nighttime warming - a characteristic feature of global climate change. Other stations such as Tho Chu and Con Dao also recorded slight increases in mean or minimum temperatures, although not all trends reached strong statistical significance. In contrast, Vung Tau and Truong Sa showed decreasing trends in minimum temperature, highlighting clear spatial heterogeneity in thermal changes.

As for salinity, the trends exhibit high spatial and temporal variability. Truong Sa is the only station that showed a significant and consistent decrease in salinity across both seasons, with a Sen's slope of -0.2296 ‰/year and high statistical significance (Z = -3.827; p = 0.0001). Conversely, Tho Chu displayed a statistically significant increasing trend in salinity during the rainy season (Z > 2.0, p < 0.05), suggesting that this island is strongly influenced by seasonal climate variability. Other stations such as Phu Quy, Vung Tau, Con Dao, and Phu Quoc exhibited only minor fluctuations in salinity, with most trends not reaching statistical significance (p > 0.1), reflecting relative stability in salinity over the past 20 years.

These findings can play an important role in climate change monitoring for Southern Viet Nam's coastal regions and serve as a valuable data source for oceanographic forecasting models and applications in environmental management, aquaculture, and marine conservation.

However, the study also acknowledges certain limitations in the current dataset, particularly in terms of time series length and sampling frequency. Future research should expand the spatial coverage, integrate automated monitoring stations, remote sensing data, and regional climate-ocean models to better clarify the underlying drivers and physical mechanisms behind the identified trends.

The analysis further shows that interannual variability in both SST and SSS is influenced by ENSO events. El Niño phases (e.g., 2009-2010, 2015-2016) were associated with temporary increases in SST and localized rises in SSS, whereas La Niña periods (2007-2008, 2010-2011) coincided with cooler SST anomalies. This suggests that ENSO not only drives short-term fluctuations but may also interact with long-term climate change signals in Southern coastal and island regions.

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