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Research article

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The trend of salinity changes at coastal stations in The Mekong Delta during the period 1996-2018

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ABSTRACT

The Mekong Delta (MKD) is increasingly suffering from the adverse effects of saline intrusion, primarily due to climate change-sea level rise (SLR), upstream hydropower development, and mangrove forest degradation. This study focuses on using statistical methods to assess salinity changes, by determining the frequency of salinity through ANOVA variance analysis and frequency analysis based on data series from 1996 to 2018 at monitoring stations. The results show that the increasing trend of salinity (at Binh Dai, Ben Trai, Loc Thuan, Huong My, Son Doc, An Thuan, Hung My, Tra Vinh, Cau Quan, Long Phu, Dai Ngai, Phuoc Long, Ganh Hao, CaMau) accounts for 70%, while the decreasing trend of salinity (at Hoa Binh, Vam Kenh, Tra Kha, Tran De, Soc Trang, Song Doc) accounts for 30%. Regarding to frequency analysis, at a frequency of 90%, the stations (Phuoc Long, Ganh Hao, Ca Mau, Song Doc) exceed 33‰, and at a frequency of 95%, the stations (Tran De, Phuoc Long, Ganh Hao, Ca Mau, Song Doc) exceed 33‰. The study's results, which determine the trend of salinity changes, provide a database for further in-depth research as well as support for disaster management efforts concerning local saline intrusion.

Key words: Saline intrusion, statistical methods, ANOVA, salinity frequency, Mekong Delta

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INTRODUCTION

Saltwater intrusion (SI) in MKD has become a serious issue, with salinity levels in the water exceeding permissible limits, negatively impacting the lives and production activities of the local population[1,2]. SI is a consequence of climate change, rising sea levels, and the construction of numerous upstream dams on the Mekong River, these factors lead to a shortage of water flowing into the Mekong River, especially at the end of the dry season[3,4]. Climate change has increased the frequency and intensity of extreme weather events such as El Niño, prolonging dry periods and reducing rainfall, thereby exacerbating the extent of saltwater intrusion. The reduced upstream flow from the dams on the Mekong River also decreases the amount of fresh water flowing into the MKD region, making it easier for seawater to penetrate deep inland[1]. Additionally, flow control structures like dams and canals have altered the natural structure of the river, affecting the region's resilience to saltwater intrusion. SI significantly impacts economic activities and production, particularly agriculture and aquaculture, which are the main economic sectors of the MKD[2]. Saltwater damages land, reduces crop yields, and kills fish and shrimp. This directly affects the livelihoods of the people, creating many difficulties and challenges in efforts to manage and respond to saltwater intrusion[3–5].

Vietnam is significantly affected by climate change, especially the low-lying provinces of the MKD. Climate change and saltwater intrusion (SI) have had major impacts on the environment and production activities in the MKD[3]. Due to the complexity of this phenomenon, SI has garnered the attention of researchers and policymakers aiming to address this issue. Numerous studies have employed various models and methods to assess and forecast the extent of SI in the MKD. For instance, some studies have used the Gamma model to calculate the impact of SI on river systems and hydraulic structures[3–5]. In Bac Lieu, the Gamma model has been applied to simulate the distribution of salinity in water, helping to identify affected areas and propose appropriate management measures. The Mike 11 and Mike 21 models have also been widely used in studies to calculate SI, providing crucial information for managers in making decisions regarding the prevention and mitigation of SI impacts[6–14]. Remote sensing and Geographic Information Systems (GIS) techniques have also been utilized in studies to monitor SI[14–24]. Remote sensing enables the monitoring of SI over a wide range and in real-time, offering continuous and accurate data on salinity changes in the water. Analysis results show that remote sensing is suitable for monitoring SI but is limited by satellite orbital cycles and weather conditions, particularly in tropical countries[20].

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Although studies have achieved significant results, many challenges remain to be addressed. Research often faces difficulties in collecting reliable and long-term input data, the effectiveness of models is highly dependent on the quality and accuracy of this data [21]. While remote sensing techniques offer extensive spatial coverage, they are limited in temporal resolution due to satellite orbital cycles and weather conditions, which reduces the precision and reliability of SI forecasts and simulations. To address these issues, this study aims to enhance input data for SI research through regression methods and frequency analysis. Additionally, it focuses on assessing salinity changes at monitoring stations using trend determination and ANOVA testing methods, employing the p-value coefficient to determine confidence levels. The goal is to provide a dependable database to support advanced research, thereby improving the accuracy and reliability of future SI forecasts and simulations. The study will involve collecting and analyzing data from various sources, including on-site observations, remote sensing data, and relevant statistical information. Regression methods and frequency analysis will be used to process and analyze this data, identifying trends and relationships between factors influencing SI. This research will not only supply reliable input data for SI forecasting models but also contribute to the development of effective management and response strategies for SI in the MKD. By identifying trends in salinity changes, the study aims to create a database for further in-depth research. The study's findings will assist managers and stakeholders in making timely and effective decisions to mitigate the impacts of SI on livelihoods and production, while also protecting and sustainably developing the region's socio-economic environment.

STUDY AREA AND METHODOLOGY

Study area

The study was conducted in six provinces: Tien Giang, Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau and Kien Giang, covering the areas of 10 rivers: Cua Tieu, Co Chien, Hau, K Nhu Gia, K Maspero, Cua Cung Hau, Ham Luong, Phung Hiep, Ganh Hao, and Song Doc. The research was carried out from 1996 to 2018, and the sampling points of this study are depicted in Figure 1.

Data

The salinity measurement data from 20 stations located at river mouths and along rivers were provided by the Southern Region Hydro-Meteorological Centre. These stations have provided the highest salinity data over the years from 1996 to 2018, as presented in Table 1.

Methodology

This study was conducted following the research framework outlined below Figure 2:

The method of trend determination and ANOVA testing

To analyze the trend of salinity variation, the study utilizes the method of linear regression, where the regression equation takes the form: x(t) = at + b (*), with a and b being the regression coefficients. The trend of the series is demonstrated through the analysis of the slope coefficient a, where the sign of coefficient a determines the increasing trend (if a > 0) or decreasing trend (if a < 0), while the absolute value of a represents the degree of variation of the series.

The coefficients a and b in the trend equation are combined with ANOVA testing to determine the confidence level of the trend line. ANOVA testing with a significance level of Alpha = 0.05, meaning the probability of committing a Type 1 error is no more than 5%, indicates that when Alpha is less than 5%, the trend equation ensures confidence. If Alpha > 0.05, the equation does not ensure statistical confidence. These steps are performed using the Regression Statistics tool in Excel software.

Pearson Type III Distribution

This study applies the Pearson Type III cumulative frequency curve (PIII) to analyze the salinity frequency at various stations.

The Pearson III cumulative frequency curve has the following characteristics:

$$\frac{K_p - 1}{C_v} = f\left(C_s, P\right) = \phi \quad (1)$$

In which: Φ is the vertical displacement depending on Cs and P; when Cs and P remain constant, Φ also remains constant and does not depend on Cv.

The case where $\boldsymbol{C_v=1}$:

Foster and Rypkin relied on certain characteristics of the P_{III} curve, conducted integrations to find the corresponding F values for different frequencies and C_s>0, and compiled a lookup table (see the appendix).

The case where $\boldsymbol{C_v \neq 1}$:

In practice, when $\mathbf{C}_v \neq \mathbf{1}$, based on the formula above, we deduce:

$$K_p = \phi C_v + 1 \quad (2)$$

The case where $\boldsymbol{C_s<0}$:

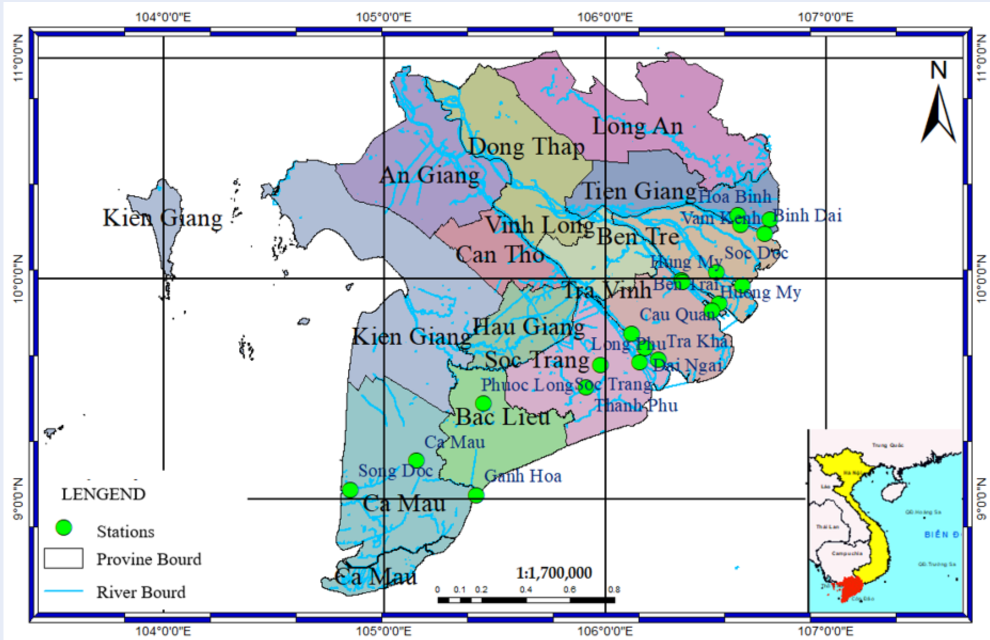

Figure 1: Samling points in the Mekong Delta

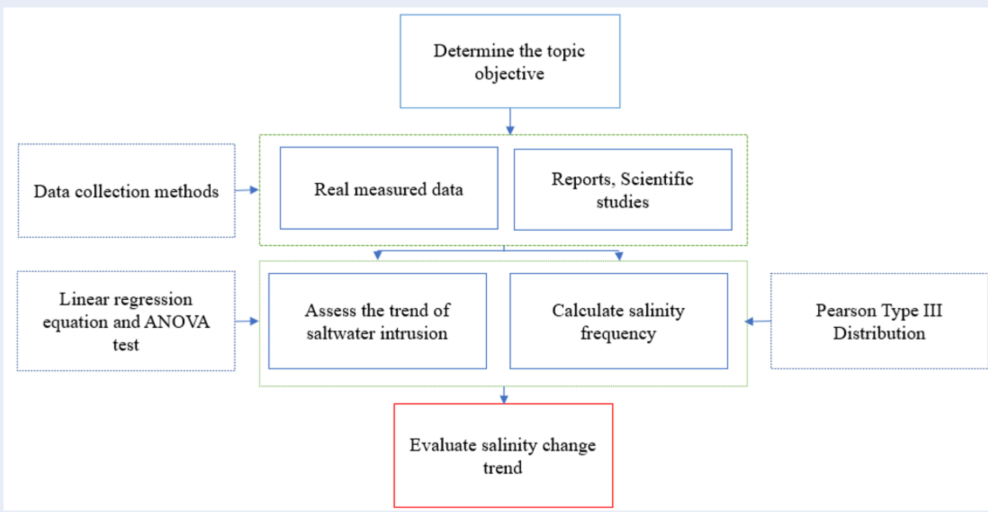

Figure 2: Research orientation framework.

We can still use the Foster-Rypkin lookup table, but we need to transform it accordingly.

$$\phi_{p(C_s<0)} = -\phi_{100-p(|Cs|)} \quad (3)$$

With $F_{100-p\ (|Cs|)}$, we look up the table corresponding to ôCsô and the frequency value equal to (100-p). Thus, from the given dataset, after calculating the values of $\bar{X}$, C_v, C_s; we consult the table to find ϕp (corresponding to P and C_v = 1) and calculate Kp (corresponding to P and C_v of the calculated sequence); then, we obtain $x_p = K_p\bar{X}$ corresponding to each given value of P [13].

RESULTS AND DISCUSSION

The salinity trends at the stations from 1996 to 2018

Figure 3 shows the characteristic variation of salinity at two monitoring stations: Vam Kenh and Hoa Binh.

Table 1: Geographic Locations of Observation Stations

Other	Province/ City	Fax/ Code	Stations name	Longitude	Latitude	Rivers name
1	Tien Giang	552	Hoa Binh	106 ^{o} 35 ’	10 ^{o} 17 ’	Cua Tieu
2		553	Vam Kenh	106 ^{o} 44 ’	10 o 16 ’	Cua Tieu
3	Tra Vinh	602	Tra Vinh	106 ^{o} 20 ’	9 ^{o} 58 ’	Co Chie
4		614	Hung My	106 ^{o} 26 ’	9 ^{o} 52 ’	Co Chie
5		615	Tra Kha	106 ^{o} 15 ’	9 ^{o} 38 ’	Hau
6		616	Cau Quan	106 ^{o} 7 ’	9 ^{o} 45 ’	Hau
	Soc Trang	650	Tran Đe	105 ^{o} 54 ’	9 ^{o} 30 ’	K.Nhu Gia
8		652	Đai Ngai	106 ^{o} 0 ’	9 ^{o} 47 ’	Hau
9		657	Soc Trang	105 ^{o} 58 ’	9 ^{o} 36 ’	K.Maspero
10		672	Long Phu	106 ^{o} 8 ’	9 o 36 ’	Hau
11		802	inh Đai	106 o 42 ’	10 o 10 ’	Cua Đai
12		803	en Trai	106 ^{o} 31 ’	9 ^{o} 53 ’	Co Chie
13	Ben Tre	805	An Thua	106 ^{o} 36 ’	9 ^{o} 58 ’	Ham Luong
14		809	Huong My	106 ^{o} 23 ’	9 ^{o} 59 ’	Cua Cung Hau
15		817	Son Đoc	106 ^{o} 30 ’	10 ^{o} 02 ’	Ham Luong
16		818	Loc Thua	106 ^{o} 36 ’	10 ^{o} 12’	Cua Đai
17	Bac Lieu	902	Phuoc Long	105 ^{o} 27 ’	9 ^{o} 26 ’	K.Phung Hie
18		903	Ganh Hao	105 ^{o} 25 ’	9 ^{o} 00 ’	Ganh Hao
19	Ca Mau	904	Ca Mau	105 ^{o} 8 ’	9 ^{o} 10 ’	Ganh Hao
20		916	Song Đoc	104 ^{o} 50 ’	9 ^{o} 03 ’	ong Đoc

The results indicate that the highest salinity (maximum salinity) recorded at Vam Kenh is 30.9‰, while the lowest salinity (minimum salinity) at Hoa Binh is 7.8‰. This reflects a distinct difference in salinity levels between the two areas.

ANOVA testing with an alpha level of 0.026 < 0.05 at the Vam Kenh station shows a confidence level of 95%. Similarly, at the Hoa Binh station, an alpha level of 0.001 < 0.005 also indicates high reliability, ensuring statistical significance for both stations in the study area.

Analysis of the trend from Figure 3 shows a decreasing salinity trend at Vam Kenh with a rate of 0.1459‰/yr, while at Hoa Binh, the rate of decrease is faster, reaching 0.6506‰/yr. This indicates that Hoa Binh is experiencing a significantly faster reduction in salinity compared to Vam Kenh. The cause of this trend may be related to the northeast monsoon (northeast winds and easterly winds throughout the dry season) blowing directly into the Mekong River delta region, especially the coastal area from Can Gio to Ben Tre and Tra Vinh. This wind may push seawater further into the river, increasing the salinity of the water.

In summary, both Vam Kenh and Hoa Binh show a trend of decreasing salinity over time, with the rate of decrease at Hoa Binh being significantly faster. This highlights the importance of studying and managing water resources to mitigate the impact of saltwater intrusion on the environment and socioeconomic conditions.

The calculations in Figure 4 show the characteristics and trend of salinity at 6 stations (Binh Dai, Ben Trai, Loc Thuan, An Thuan, Huong My, Son Doc) in Ben Tre Province. The highest salinity is recorded at the An Thuận station with 31.5‰, while the lowest salinity is 2.3‰ at the Huong My station. At the Binh Dai station, the salinity trend shows a slight decrease over the years with a reduction coefficient of approximately 0.1484‰/yr, indicating stability in salinity in this area. The Ben Trai station has a very slight increasing trend in salinity, only 0.033‰/yr, reflecting

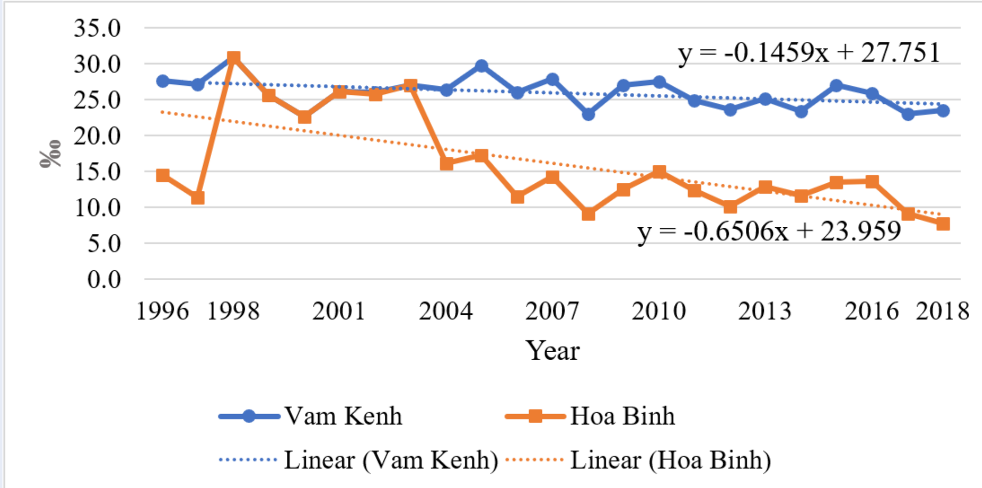

Figure 3: Salinity variation chart at stations in Tien Giang province.

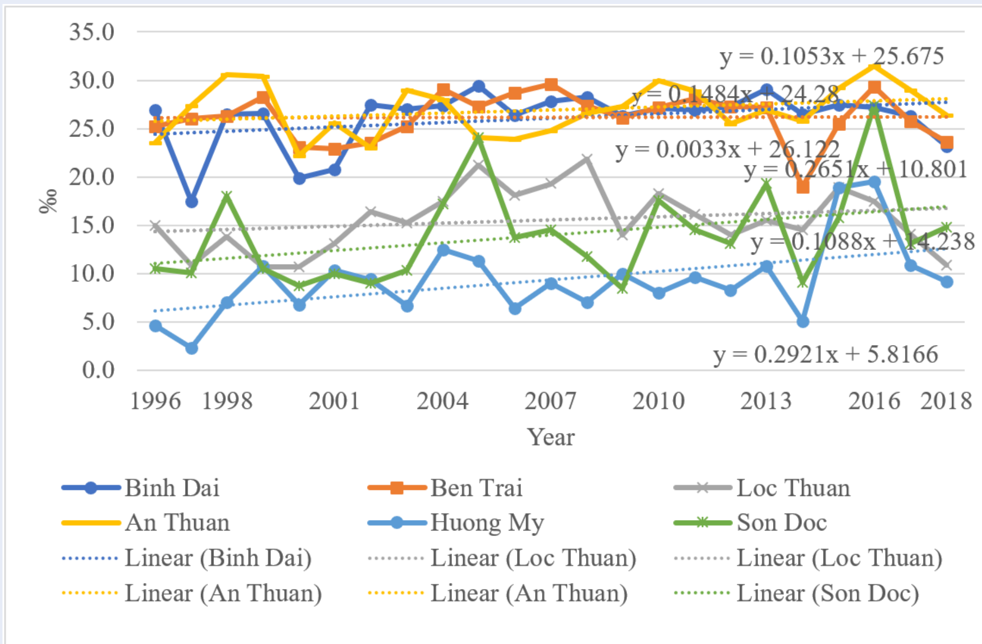

Figure 4: Salinty variation chart at stations in Ben Tre province.

negligible fluctuations and maintaining stability over time.

The An Thuan station shows a slight increasing trend in salinity over the years, with a linear trend indicating an increase of 0.1053‰/yr. Although there is an increase, it is not significant. The Huong My station exhibits a slight increasing trend with a rate of 0.291‰/yr, indicating a faster increase compared to other stations in the area due to its location at the large Co Chien River branch and its proximity to the sea, only about 20 km away, subject to various factors such as water shortage from upstream, flow, waves, and tides.

At the Loc Thuan station, salinity shows an increasing trend with a rate of 0.1087‰/yr. The fluctuations in salinity levels in this area are not very pronounced, indicating that salinity remains relatively stable. Meanwhile, the Song Doc station has a trend of increasing salinity over the years, with a rate of 0.265‰/yr. This trend reflects a relatively stable salinity level at Song Doc.

The significance of these trends indicates changes in natural environmental conditions, the impact of climate change, and the geographical location of the stations. Ben Tre Province has 4 river branches flowing into the sea through 4 main river mouths: Dai River Mouth, Ba Lai River Mouth, Ham Luong River Mouth, and Co Chien River Mouth. Notably, Ben Tre Province has a coastline directly exposed to the monsoon winds (northeast monsoon and easterly winds), leading to severe coastal erosion and more intense saltwater intrusion during the dry season.

From the above analysis results, although an increasing trend in salinity is observed at the stations, the Song Doc station has the highest amplitude of variation in the province. The Song Doc station is located on the Hau River branch, about 20 km from the sea, with relatively high and complex salinity levels, specifically showing the most significant salinity peaks in the years 1999 (18‰) and 2016 (27.4‰). At the Huong My station, at the Cung Hau mouth, salinity varied significantly during the period 2014-2016, from 5.2‰ to 19.5‰. Overall, the analysis of linear trends shows a clear increasing trend in salinity at the stations, with varying levels of increase.

The calculations in Figure 5 show the spatial characteristics of salinity levels at 4 stations (Huong My, Tra Vinh, Tra Kha, Cau Quan) in Tra Vinh Province. The highest salinity recorded was at the Tra Kha station with 22.8‰ in 2005, while the lowest salinity was 6.0‰ at the Tra Vinh station in 2014. In terms of trends, the Huong My station shows a slight increase over the years, with a rate of 0.08‰/yr. The linear trend at this station indicates an increase in salinity but with significant fluctuations during the period 1996-2005. At the Tra Vinh station, a slight increase over the years is observed, with a rate of 0.0259‰/yr. The linear trend at the Tra Vinh station shows an increase in salinity, but the changes are not very pronounced, ensuring spatial stability.

At the Tra Kha station, there is a slight decreasing trend in salinity, with a rate of only 0.008‰/yr, indicating a negligible reduction compared to other stations in the area. Meanwhile, at the Cau Quan station, a slight increasing trend is observed with a rate of 0.0542‰/yr. The fluctuations in salinity at this station are not very pronounced, especially during the period 2004-2009.

The significance of these trends indicates that three stations (Huong My, Tra Vinh, Cau Quan) show an increasing trend, while the Tra Kha station shows a decreasing trend. The cause of these changes may be related to the El Niño phenomenon during the 2015-2016 period, which resulted in very low rainfall combined with the impact of upstream dams, leading to severe drought in the Mekong Delta region.

Figure 6 shows the trend in salinity at monitoring stations in Soc Trang Province, where the highest salinity (maximum salinity) is greater than 33‰ at the Tran De station and the lowest salinity (minimum salinity) is only 1.5‰ at the Soc Trang station. Salinity at the Tran De station shows the most significant decrease over the years. The linear trend indicates a reduction rate of -0.4511‰/yr, reflecting a considerable decrease in salinity in this area, which may be due to the station's location in a small canal, with the area and riverbed topography having a gentle slope.

At the Dai Ngai station, the salinity trend shows a slight increase over the years, with an increase of only 0.01‰/yr. The linear trend indicates relative stability but still shows a slight upward trend. Meanwhile, at the Long Phu station, a significant increasing trend is observed, with the linear trend showing an increase of 0.0503‰/yr, reflecting a high level of stability in salinity. At the Soc Trang station, there is a slight decreasing trend over the years with a rate of -0.0071‰/yr, indicating that the changes in salinity levels over the years are not significant compared to other stations in this area.

Based on the calculated salinity trends of the 4 stations, 2 stations show an increasing trend (Long Phu 0.0503‰/yr, Dai Ngai 0.0099‰/yr), while the other 2 stations show a decreasing trend (Tran De -0.4511‰/yr, Soc Trang -0.0071‰/yr). Overall, the significance of these trends indicates a reduction in salinity at the stations. However, salinity intrusion indices in Soc Trang still show an increasing trend, particularly in the area along the Co Chien River. Soc Trang Province is one of the regions at high risk due to climate change, with erratic weather changes and a shortage of main upstream flow being the two main factors directly affecting changes in salinity over time and across different spatial areas.

Figure 7 shows that the highest salinity (maximum salinity) exceeded 33‰ at the Ganh Hao station in 2015, while the lowest salinity (minimum salinity) was 3.7‰ at the Phuoc Long station in 1999, located in Bac Lieu Province. Analysis of the trend from this figure indicates that the trend rate at both stations is increasing, with the most significant increase at the Phuoc Long station, which has a rate of 0.4482‰/yr. The linear trend for Phuoc Long shows that SI fluctuates slightly over the years, indicating stability in

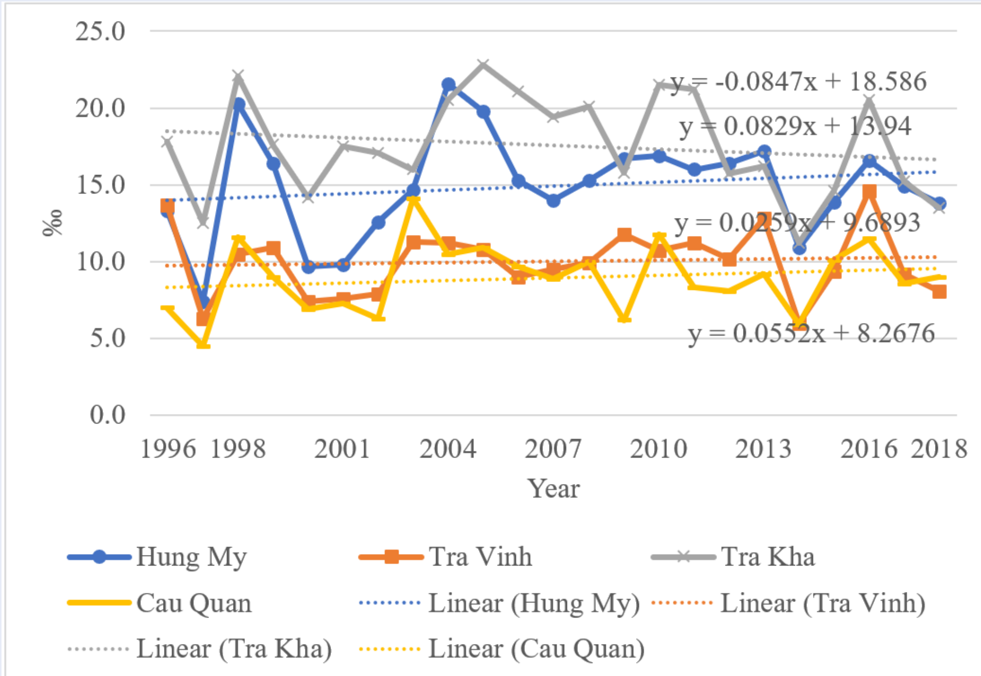

Figure 5: Salinity variation chart at stations in Tra Vinh province.

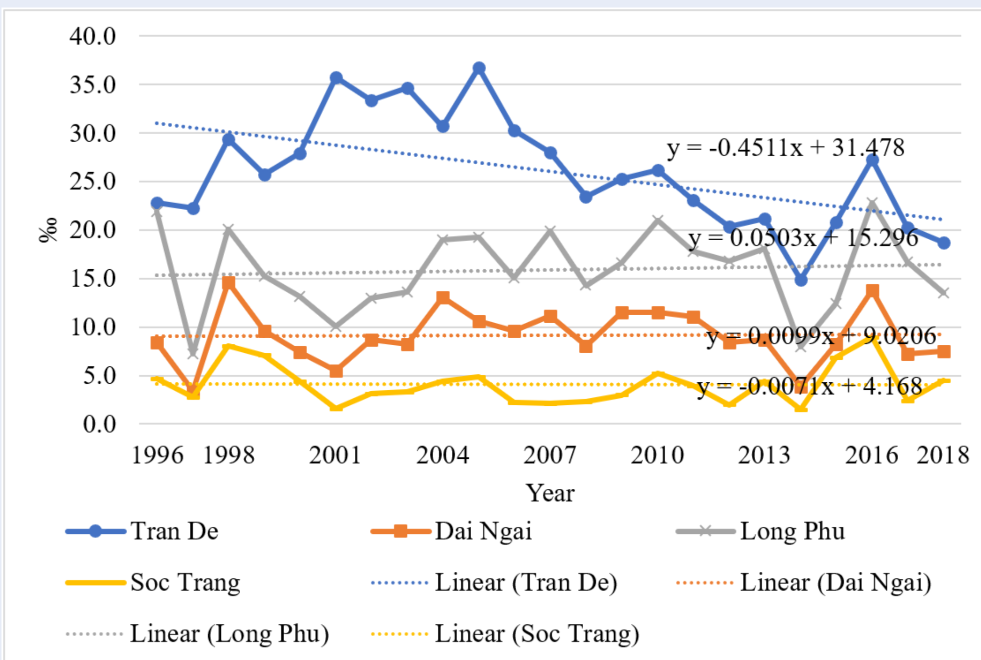

Figure 6: Salinity variation chart at stations in Soc Trang province.

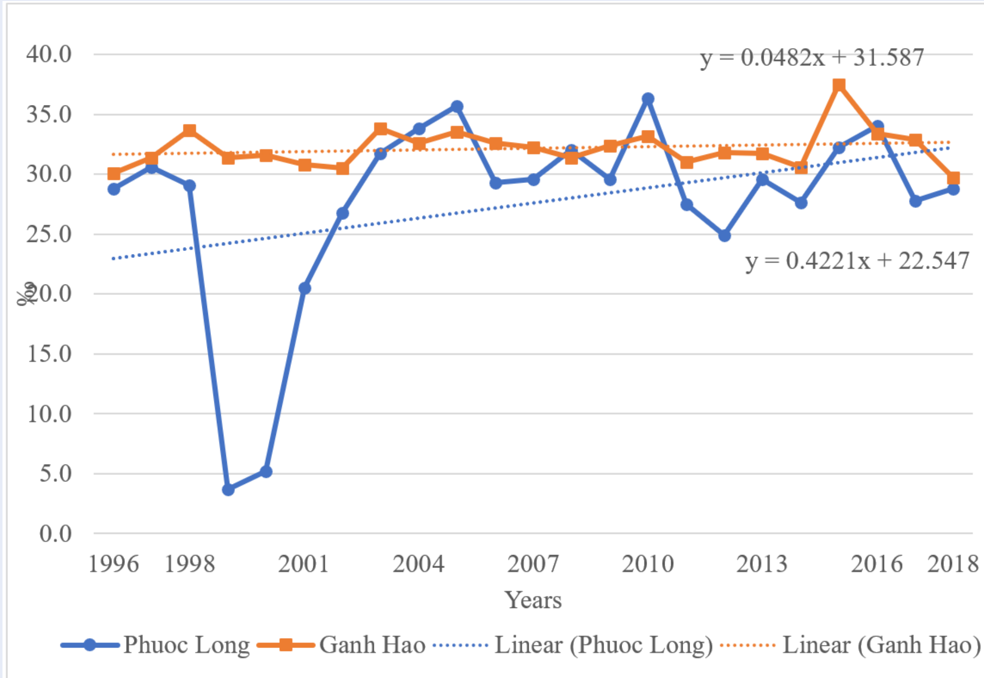

Figure 7: Salinity variation chart at stations in Bac Lieu province.

the Phuoc Long area, due to the station's location in a small, deep inland river branch.

At the Ganh Hao station on the Phung Hiep River, the salinity trend shows a slight increase over the years, with an increase rate of 0.0221‰/yr. Salinity levels fluctuate continuously over the years; although there are variations, these changes are not significant. However, salinity fluctuated significantly during the 1999-2000 period due to the complex structural changes in the province's production, with a simultaneous shift in economic development to a higher structural scale. As a result, the coastal water area also changed due to the resonant nature of the complex riverbed topography, leading to widespread salinity intrusion along the river throughout the province.

The analysis results show that the salinity trend at the Phuoc Long station fluctuates slightly, indicating stability in this area. Meanwhile, at the Ganh Hao station, although there is a slight increasing trend, the salinity levels vary insignificantly over the years, reflecting a relatively stable salinity level in this area. Climate change and changes in production structure have significantly affected the level of salinity intrusion in the region.

Figure 8 presents the results of the study and analysis of the salinity time series data from 1996 to 2018 for the two stations Ca Mau and Song Doc in Ca Mau Province, combined with ANOVA testing to assess SI in the province. The highest salinity (maximum salinity) exceeded 33‰, and the lowest salinity (minimum salinity) was 27.3‰.

At both Ca Mau and Song Doc stations, the trend in salinity changes over the years shows a slight increase, with rates of 0.0476‰/yr at Ca Mau and 0.0108‰/yr at Song Doc. This trend indicates that the variation in salinity is not very pronounced, suggesting that salinity at these two stations remains relatively stable.

The research results show that the salinity trends at both stations are similar, particularly during the dry season of 2016 when the El Niño phenomenon caused severe drought in the MKD, the Central Highlands, and South Central Coast. At that time, the Mekong Delta faced historic salinity intrusion, with salinity in the river recorded at 4‰ and intruding up to about 50km. In the study area, salinity intrusion exceeding 33‰ was most distinctly observed at the Cà Mau and Song Doc stations.

With the aforementioned complex characteristics, the impact of salinity intrusion has spread across all coastal provinces in the MKD, including Ca Mau Province. This is clearly demonstrated by the data and salinity trends analyzed at the monitoring stations in the study.

The calculation results for the method and the R^2 are presented in Table 2.

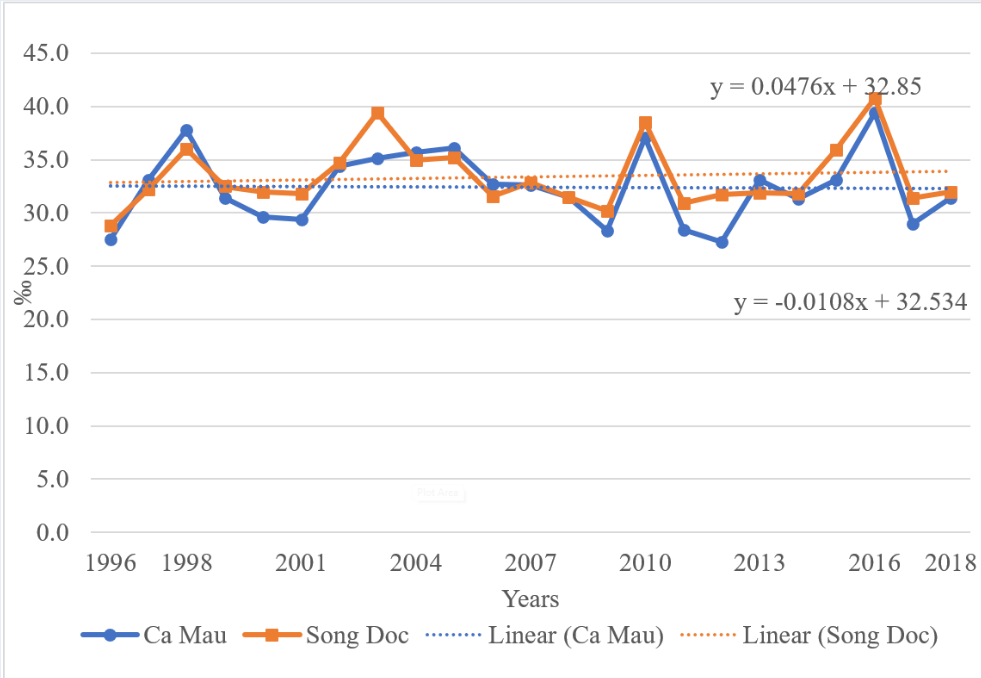

Figure 8: Salinity variation chart at stations in Ca Mau province.

Salinity Characteristics by Frequency

The study has constructed a salinity frequency equation as shown in Table 3, indicating that after calculating the frequencies, the highest salinity of greater than 33‰ with a frequency of 95% occurred at the Phuoc Long station on the Hau River in Bac Lieu province. The lowest salinity of 0.78‰ with a frequency of 5% was observed at the Soc Trang station in Soc Trang province.

The authors used the PIII to conduct a comprehensive assessment of salinity intrusion for 20 stations in the study area. The results, based on two evaluation criteria, are shown in Figure 9, which illustrates the frequency of salinity exceeding 33‰ at the Hoa Binh, Tran De, An Thuan, Phuoc Long, Ca Mau, and Song Doc stations. This chart shows the relationship between the frequency of salinity occurrences and the salinity values at these stations.

The chart in Figure 9 illustrates the cumulative salinity frequency at the Hoa Binh, Tran De, An Thuan, Phuoc Long, Ca Mau, and Song Doc stations. From the chart, we observe that the Hoa Binh station has the highest and most variable salinity among the stations, especially at lower frequencies, indicating a high level of salinity intrusion and significant variation at this station. The Tran De and An Thuan stations have relatively high salinity but show a decreasing trend as frequency increases, although the variability is not as large as at Hoa Binh. Meanwhile, the Phuoc Long and Ca Mau stations have relatively stable and lower salinity compared to Hoa Binh, Tran De, and An Thuan, with slight fluctuations and maintaining stability as frequency increases. The Song Doc station has quite high salinity but is more stable compared to Hoa Binh, Tran De, and An Thuan, with less variation and remaining at a relatively high level as frequency increases. Overall, all stations show a trend of decreasing salinity with increasing frequency, indicating a relative stability of salinity values as salinity intrusion conditions occur more frequently. This chart clarifies the differences in the levels and variability of salinity intrusion among the stations in the study area, highlighting the importance of managing and monitoring salinity intrusion to protect water resources and ecosystems in these areas.

The chart in Figure 10 illustrates the cumulative frequency of salinity at the Vam Kenh, Long Phu, Son Doc, Binh Dai, Ben Trai, and Ganh Hao stations. Salinity at the Vam Kenh and Ganh Hao stations remains at the highest levels compared to the other stations and shows a slight decreasing trend as frequency increases but still remains high. The Long Phu and Son Doc stations have salinity ranging from average to high, with the frequency curve indicating a grad-

Table 2: Table showing the equations and the correlation coefficient R^2

Station	Equation	R^2
Vam Kenh	y=-0.1459x+318.93	0.2136
Hoa Binh	y = -0.6506x + 1321.9	0.4312
Hung My	y = 0.0829x - 151.46	0.0272
Tra Vinh	y = 0.0259x - 41.96	0.0064
Tra Kha	y = -0.0847x + 187.53	0.0308
Cau Quan	y = 0.0552x - 101.93	0.0273
Tran Đe	y = -0.4511x + 931.4	0.2805
Đai Ngai	y = 0.0099x - 10.693	0.0006
Long Phú	y = 0.0503x - 85.045	0.0066
Soc Trang	y = -0.0071x + 18.362	0.0005
Binh Dai	y = 0.1484x - 271.82	0.1182
Ben Trai	y = 0.0033x + 19.616	8E-05
Loc Thuan	y = 0.1088x - 202.81	0.0528
An Thuan	y = 0.1053x - 184.47	0.074
Huong My	y = 0.0829x - 151.46	0.0272
Song Đoc	y = 0.0476x - 62.169	0.0113
Phuoc Long	y = 0.4221x - 819.61	0.1254
Ganh Hao	y = 0.0482x - 64.615	0.0392
Ca Mau	y = -0.0108x + 54.021	0.0005

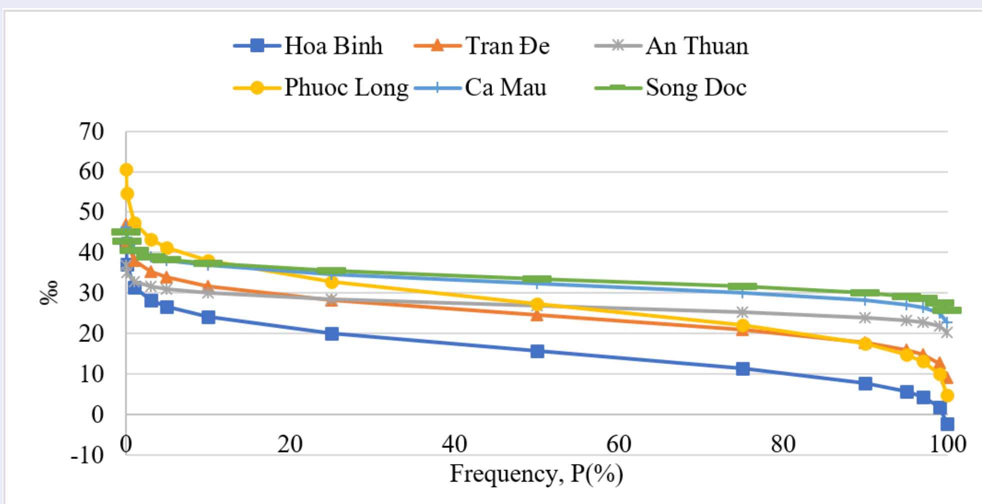

Figure 9: Chart illustrating salinity frequency

Table 3: Table representing salinity frequencies from 95% to 5%

Other	Name station	P = 95%	P = 90%	P = 75%	P = 50%	P = 25%	P = 10%	P = 5%
1	Vam Kenh	29.43	28.64	27.33	25.95	24.61	23.44	22.77
2	Hoa Binh	26.55	24.07	19.97	15.65	11.46	7.81	5.71
3	Hung My	20.67	19.35	17.16	14.85	12.61	10.66	9.54
4	Tra Vinh	18.36	16.80	14.96	13.94	13.41	12.61	11.29
5	Tra Kha	22.59	21.45	19.57	17.60	15.68	14.01	13.04
6	Cau Quan	12.48	11.68	10.35	8.95	7.60	6.41	5.74
7	Tran Đe	33.82	31.69	28.18	24.47	20.87	17.73	15.93
8	Đai Ngai	13.82	12.74	10.95	9.07	7.24	5.65	4.73
9	Long Phú	22.52	21.17	18.95	16.60	14.33	12.34	11.21
10	Soc Trang	7.59	6.78	5.44	4.03	2.66	1.46	0.78
11	Binh Dai	30.97	29.84	27.96	25.99	24.07	22.40	21.44
12	Ben Trii	30.35	29.39	27.79	26.10	24.46	23.03	22.22
13	Loc Thuan	20.52	19.43	17.63	15.72	13.87	12.26	11.34
14	An Thuan	31.02	30.09	28.56	26.94	25.36	23.99	23.21
15	Huong My	15.92	14.39	11.88	9.22	6.65	4.40	3.12
16	Son Đoc	22.23	20.33	17.18	13.86	10.64	7.83	6.22
17	Phuoc Long	41.23	38.09	32.89	27.41	22.09	17.46	14.80
18	Ganh Hao	34.93	34.29	33.24	32.12	31.05	30.11	29.57
19	Ca Mau	38.11	36.80	34.62	32.32	30.09	28.15	27.03
20	Song Đoc	38.31	37.23	35.45	33.57	31.74	30.15	29.24

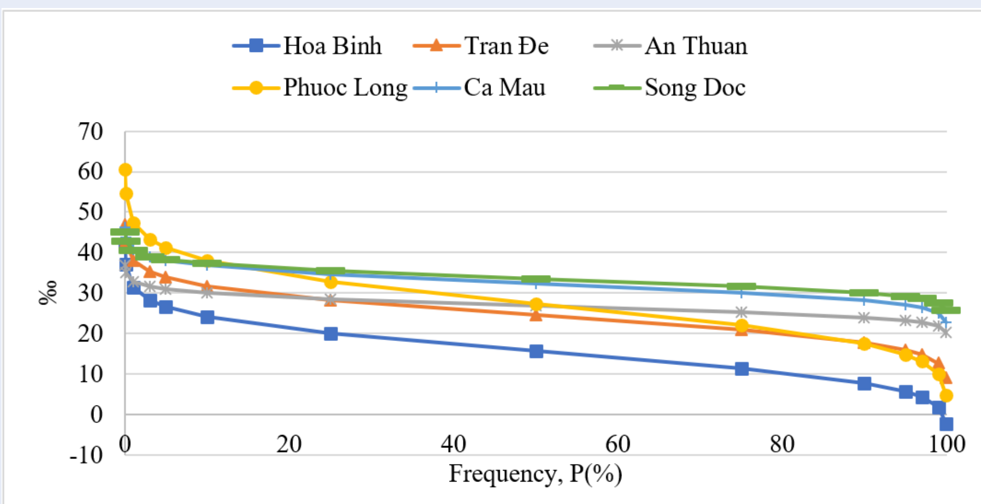

Figure 10: Chart illustrating salinity frequency from 35-40‰

ual decrease in salinity as frequency increases, showing that the level of saline intrusion varies moderately. Salinity at the Binh Dai and Ben Trai stations remains at lower levels compared to the other stations and shows a gradual decrease as frequency increases, indicating stability and less fluctuation.

In particular, the frequency curves at four stations (Vam Kenh, Long Phu, Son Doc, Binh Dai, Ben Trai) show that 90%-95% do not exceed the threshold of 33‰. However, at the Ganh Hao station, the frequency curve shows that 90%-95% of salinity levels have exceeded the 33‰. The general trend at all stations is that salinity decreases as frequency increases, indicating that at higher frequencies, the level of saline intrusion gradually decreases and reflects the relative stability of salinity values when saline intrusion conditions occur more frequently.

From Figure 11, the 90% and 95% frequency curves show that salinity at the Tra Kha, Dai Ngai, Loc Thuan, and Huong My stations does not exceed of 33‰. Overall, at a 95% frequency, salinity at all four of these stations is higher compared to the 90% frequency, indicating the stability and lack of significant fluctuation in salinity at these stations.

The results from Figure 12 show that the salinity frequency curves at the Hung My, Tra Vinh, Cau Quan, and Soc Trang stations are the lowest, below the 20‰, in the dataset of 20 stations. The salinity at these four stations also does not exceed the 30‰ threshold, indicating a stable and low level of saline intrusion at these stations.

The analysis results are consistent with several previous studies in the Mekong Delta region. The study of Nguyen Van Thuong (2015) study shows that the highest salinity at the Vam Kenh station also tends to increase during the period of 1984-2014 (30 years) [25,26]. In Ben Tre province, another study calculated the salinity trends at 6 stations (An Thuan, Ben Tre, Binh Dai, Huong My, Loc Thuan, Song Doc), and the results indicate that salinity at the Loc Thuan station increased, while the other stations decreased in the trend period of 2000-2016 (16 years) [21]. In Tra Vinh province, another study shows that salinity in this province has an increasing trend, especially at the Huong My and Tra Vinh stations [27]. In the provinces of Bac Lieu and Soc Trang, another author calculated that the average annual temperature increased during the period of 1980-2017 (37 years), thus concluding that the level of saline intrusion in this area is increasing [28].

The summary of the research results shows that the trend of salinity changes at the study stations in the Mekong Delta is complex and diverse, reflecting the impact of climate change and local environmental factors.

However, the correlations are based on linear correlation with $R^2 > 0.8$, so there will be errors when forecasting future years; this represents the uncertainty in this study. The more historical values there are, the more reliable the correlation curve and the empirical frequency curve will be [29,30]. This study is based on salinity values from 1996-2018, which is a sufficiently long period to ensure the reliability of the data series.

CONCLUSION

The study has constructed trend equations using the ANOVA statistical method with a significance level of 95%, providing quick computational results on trend variations for 20 stations along the coastal areas of six provinces (Tien Giang, Ben Tre, Tra Vinh, Bac Lieu, Soc Trang, Ca Mau).

The results show that due to the influence of various factors, the salinity trend at the stations differs. The salinity trend is increasing at 15 stations (Binh Dai, Ben Trai, Loc Thuan, Huong My, Son Doc, An Thuan, Huong My, Tra Vinh, Cau Quan, Long Phu, Dai Ngai, Phuoc Long, Ganh Hao, Ca Mau, Song Doc), accounting for 75%. These stations are affected by factors such as direct onshore winds, long coastlines, the effects of El Nino events, and upstream water reservoirs.

Meanwhile, decreasing trends are observed at 5 stations (Hoa Binh, Vam Kenh, Tra Kha, Tran De, Soc Trang), accounting for 25%, due to these stations being located deeper inland with smaller river areas, experiencing less impact from tidal surges and having flat bottom topography

Regarding frequency analysis, at the 90% frequency, the stations (Phuoc Long, Ganh Hao, Ca Mau, Song Doc) exceed 33‰, and at the 95% frequency, the stations (Tran De, Phuoc Long, Ganh Hao, Ca Mau, Song Doc) exceed 33‰. However, due to the comprehensive coverage of the research data, the highest salinity data at the stations are still limited.

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CONFLICT OF INTEREST

The authors collectively affirm that this article is the result of their research, not published elsewhere, not copied from previous studies, and there is no conflict of interest among the author group.

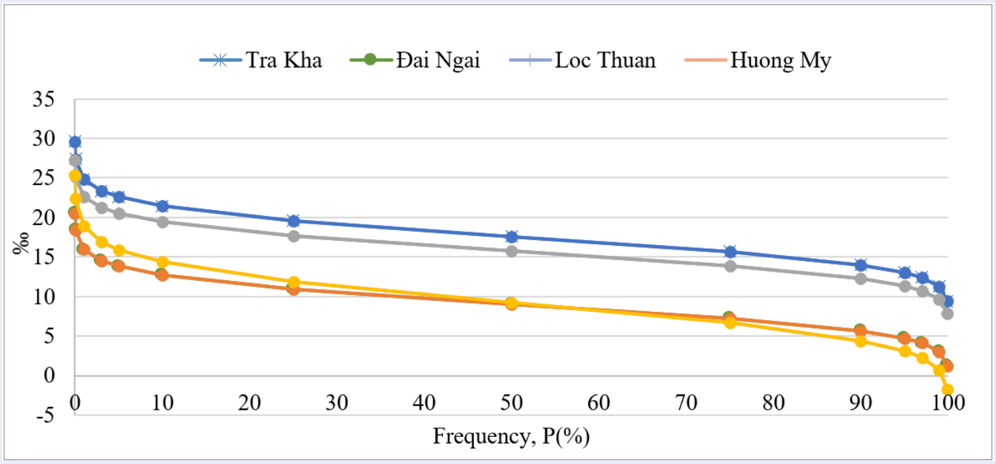

Figure 11: Chart illustrating salinity frequency from 20-30‰

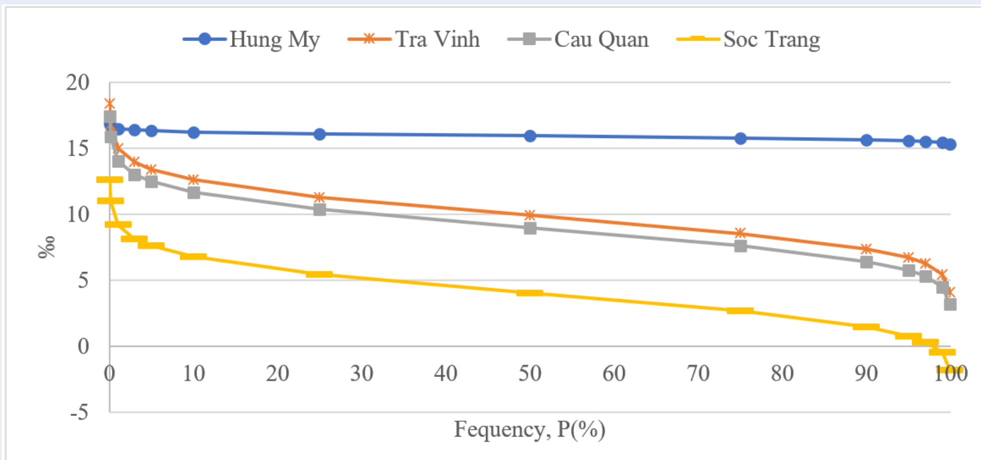

Figure 12: Chart illustrating salinity frequency from 20-10‰

AUTHORS' CONTRIBUTION

Research idea development: N.V.T., T.T.K., P.T.M.D. Research method selection: N.V.T., P.T.M.D. Data processing: N.T.H.T. Result analysis: N.T.H.T. Manuscript editing: T.T.K., P.T.M.D., N.T.H.T.

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Bài nghiên cứu

Xu hướng biến đổi độ mặn tại các trạm ven biển Đồng bằng sông Cửu Long giai đoạn 1996-2018

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TÓM TẮT

Đồng bằng sông Cửu Long ngày càng chịu tác động nặng nề từ tình trạng xâm nhập mặn, đặc biệt trong bối cảnh biến đổi khí hậu, nước biển dâng, phát triển thủy điện thượng nguồn và suy thoái rừng ngập mặn.. Nghiên cứu này tập trung sử dụng các phương pháp thống kê để đánh giá sự thay đổi độ mặn, bằng cách xác định tần suất độ mặn thông qua phân tích phương sai ANOVA và phân tích tần suất dựa trên chuỗi số liệu từ năm 1996 đến 2018 tại các trạm quan trắc. Kết quả cho thấy xu hướng gia tăng độ mặn (tại các trạm Bình Đại, Bến Trại, Lộc Thuận, Hương Mỹ, Sơn Đốc, An Thuận, Hưng Mỹ, Trà Vinh, Cầu Quan, Long Phú, Đại Ngãi, Phước Long, Gành Hào, Cà Mau) chiếm 70%, trong khi xu hướng giảm độ mặn (tại các trạm Hòa Bình, Vàm Kênh, Trà Khá, Trần Đề, Sóc Trăng, Sông Đốc) chiếm 30%. Về phân tích tần suất, tại tần suất 90%, các trạm (Phước Long, Gành Hào, Cà Mau, Sông Đốc) vượt ngưỡng 33‰, và tại tần suất 95%, các trạm (Trần Đề, Phước Long, Gành Hào, Cà Mau, Sông Đốc) cũng vượt ngưỡng 33‰. Kết quả nghiên cứu, xác định xu hướng thay đổi độ mặn, cung cấp cơ sở dữ liệu cho các nghiên cứu chuyên sâu hơn cũng như hỗ trợ công tác quản lý thiên tai liên quan đến xâm nhập mặn tại địa phương.

Từ khoá: Xâm nhập mặn, phương pháp thống kê, ANOVA, tần suất độ mặn, Đồng bằng sông Cửu Long

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