VIETNAM JOURNAL OF HYDROMETEOROLOGY

Check for updates

Research Article

Trend and forecast the saline intrusion at estuaries in the coastal Mekong delta: A case study of the coastal sub–region between the Tien and Hau rivers

Nguyen Van Hong[1*], Nguyen Thao Hien[1], Nguyen Thi Diem[2], Le Duc Thuong[2]

[1] Sub–Institute of Hydrology Meteorology and Climate Change; nguyenvanhong79@gmail.com; nthien2710@gmail.com

[2] Mien Trung University of Civil Engineering, Phu Yen, Viet Nam; nguyenthidiem@muce.edu.vn, leducthuong1980@gmail.com

*Corresponding author: nguyenvanhong79@gmail.com; Tel.: +84−913613206

Received: 15 December 2022; Accepted: 16 February 2023; Published: 25 March 2023

Abstract: Saline intrusion is a big challenge for the Mekong Delta region, a negative factor that greatly affects water and food security. In particular, the most severely affected areas are the coastal sub–regions between the Tien and Hau rivers in the lower Mekong basin, which are directly influenced by the tidal regime. In the dry season, the salinity changes complicatedly from year to year. It is necessary to analyze and assess the trend and forecast of saltwater intrusion in 2 main tributaries. In this paper, the study are used Mann–Kendall non–parametric testing method, Sen's slope estimator test, and the MIKE 11 model (HD+AD). The results are evaluated based on statistical analysis at the significance level $\alpha < 0.1$ (probability of making type I error is 10%), ensuring the exclusion of extremely unstable values to the trend, the selecting the station that is qualified to calculate the Sen's slope tr Sen's slope trend will represent a typical regional saline intrusion regime feature. At the same time, the article also gives the results of forecasting the level of saline intrusion at a few main stations on the two tributaries of the Tien and Hau rivers in 2022.

Keywords: Saline intrusion; Tien river; Hau river; Mann–Kendall; Sen's slope; Forecast.

1. Introduction

The Tien and Hau river systems are two important international waterways from Phnom Penh (Cambodia) flowing through the center of the Mekong Delta in the East Sea, facilitating the development of regional economic trade with ASEAN countries and the world. Currently, most of the socio–economic centers of the Mekong delta are formed and developed along these two tributaries.

However, the Mekong delta is a young delta, which has been expected to be increasingly affected by climate change, especially saline intrusion, which is a negative factor that greatly affects resource security. water and food security. The problem of sea level rise, high tide, lack of upstream flow, hot weather, high and water demand, caused the Mekong delta to experience dry years, causing heavy damage to the economy, society, and the environment. In 1998, 2005, and 2010, especially in recent years, there were two historic salinity intrusions with the earlier occurrence and deeper penetration in the river and canal system [1]. Comparison of saline intrusion in 2016 and 2020 in the Mekong delta: Tien river system (Cua Dai, Cua Tieu, Ham Luong), saline intrusion from 65 to 95 km in 2020; On the Hau river tributary, in 2016 the intrusion into the field is about 55–60 km, in 2020 there is little change, from 60–65 km [2]. According to the RCP4.5 scenario by the middle of the 21st century, the sea level will rise by 23 cm (13÷31 cm); By the end of the 21st century, the sea level will rise by 53 cm (32÷77 cm). According to the RCP8.5 scenario, by the middle of the 21st century, sea level could rise by 28 cm (19÷37 cm), and by the end of the 21st century, by 73 cm (48÷105 cm) [3]. Rising sea levels will push salinity further inland along major tributaries such as the Tien and Hau rivers, especially in the dry season when the Mekong river flows are lowest, contaminating large farming areas [4–15].

Several studies and assessments on the fields of meteorology, hydrology, and climate change relating to using the Mann–Kendall non–parametric test method and Sen's slope estimator test in Vietnam were studied in Vietnam. Such as analysis and calculation of salinity evolution: [16–19] using integrated SWAT and HEC–RAS models to simulate and analyze the trend of flooding and saline intrusion for Ho Chi Minh City according to the baseline and scenario scenarios. RCP4.5 (2016–2035) follows the Mann–Kendall method, combines the Theil–sen slope, and creates a dynamic partition map. On the field hydrology–groundwater hydraulics: [20] assesses the level of underground water level decline in Holocene and Pleistocene aquifers in the upper MD, using Mann–Kendall and Sen's slope estimator test methods in the calculation. Rainfall distribution, additional rainfall in two periods of the rainy season and dry season, period 1995–2015. For analysis and assessment of climate change: [16] calculates the trend of changes in rainfall during the period: 15', 30', 45', 60', 90', 120', and 180' at Tan Son Hoa station in the period 1971–2016 using Mann–Kendall non–parametric testing method and Sen's slope estimator test. [17] Assess the climate change trend of Binh Phuoc province in the period 1981–2018 on the factors of average temperature, and annual rainfall, combined with the assessment according to the scenarios RCP4.5 and RCP8.5 for different periods: 2025, 2030, 2050 and 2100.

The results obtained from the above studies, prove that the Mann–Kendall non–parametric test method and Sen's slope estimator test method are effective and have high reliability [16–19]. To have a basis for developing prevention and mitigation measures, strategic measures to cope with drought and salinity in the Mekong delta, and appropriate economic transformation policies for aquaculture, fishing, or energy development clean quality but still ensure and maintain a high–quality agricultural economy, it is necessary to study, analyze and evaluate the trend of saline intrusion changes from the past to the current status. From there, it is possible to make predictions about the level of development in the future. Therefore, this paper presents a study to assess the trend of saline intrusion change in the 5 coastal sub–regions between the Tien and Hau rivers in the period 1997 to 2022. To have a better overview of the fluctuations of saline intrusion the paper used the 26 years data series of the maximum salinity value from the years 1997 to the present time in 2022 in 5 coastal provinces: Tien Giang, Ben Tre, Tra Vinh, Vinh Long, Soc Trang.

2. Materials and Methods

2.1. Study area and data collection

The Mekong Delta is divided into 4 sub–regions: the East Coast, the Dong Thap Muoi, the Ban Dao Ca Mau, and the Tu Giac Long Xuyen. the East Coast includes 4 provinces: Tien Giang (the part along the Tien River accounts for 53% of the province's area, with a length of 115 km within the province), Ben Tre (including Tien river: 83 km, Ba Lai river 59 km, Ham Luong: 71 km, Co Chien: 82 km), Vinh Long (with Co Chien river being a branch of the Tien River, with a length of 90km, Hau river flowing through has a length of about 75 km), Tra Vinh (covered by Tien, Hau River with 02 gates Cung Hau and Dinh An, total length 578 km). Although Soc Trang province belongs to the Ban Dao Ca Mau, it is a coastal province located at the lower end of the Hau River, with an inadequate river system with large and small islets, more than 50 km along the Hau river and 2 large estuaries are Dinh An, Tran De empties into East Sea [21–23].

The series of data used is the maximum salinity value in the dry season (S_{max}) in 26 years from 1997 to 2022 at some stations on the main tributaries (Figure 1 and Table 1).

Figure 1. Study area and stations used to assess the trend of salt intrusion in the coastal sub–region between the Tien and Hau rivers.

Table 1. List of stations to assess the trend of salt line intrusion change in the Tien and Hau rivers.

Number	Salinity Monitoring Station	Sites
1	Vam Kenh	Cua Tieu, Tan Thanh, Go Cong Dong–Tien Giang
2	Ben Trai	Co Chien, An Thuan, Thanh Phu–Ben Tre
3	Binh Dai	Cua Dai, Binh Thang, Binh Dai–Ben Tre
4	Tra Vinh	Brand of Cung Hau, Co Chien river, Tra Vinh
5	Tra Kha	Cua Dinh An, Tra Cu–Tra Vinh
6	An Thuan	Ham Luong, An Thuy, Ba Tri–Ben Tre
7	Cau Quan	Brand of Đinh An, Hau river, Tieu Can–Tra Vinh
8	Đai Ngai	Hau, Đai Ngai, Long Phu–Soc Trang
9	Hoa Binh	Cua Tieu, Vinh Huu, Go Cong Tay–Tien Giang
10	Hung My	Co Chien, Hung My, Chau Thanh–Tra Vinh
11	Huong My	Brand of Co Chien, Huong My, Mo Cay Nam–Ben Tre
12	My Thanh	Cua Tran De, Vinh Hai, Vinh Chau–Soc Trăng

2.2. Theoretical basis of Mann–Kendall (MK–test) non–parametric testing method

The Mann–Kendall test [18] compares the relative sizes of elements in the data series, which can avoid local maxima or minima of the value series. If it is hypothesized that there is a time series data ($x_1, x_2, \ldots, x_n$) with x_i representing the data at the time i, then each data value at each time point is compared with the values. across the time series. The initial values of the Mann–Kendall statistic, S are 0 (that is, there is no trend). Then the Mann–Kendall (S) statistic is calculated by:

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

where

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

Value S > 0 indicates an uptrend, and S < 0 indicates a downtrend. However, it is necessary to calculate the probabilities associated with S and n to determine the significance level of the trend. The variance of S is calculated according to the formula:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5)\right] \quad (2)$$

where g is the number of groups with the same value, t_p is the number of elements in the path group.

The normal value Z of S follows the law of the normal distribution:

$$Z = \frac{S-1}{[VAR(S)]^{1/2}}, S > 0 \quad (3)$$

where Z = 0, S = 0

$$Z = \frac{S+1}{[VAR(S)]^{1/2}}, S < 0 \quad (4)$$

2.3. Sen's slope

To determine the magnitude of the trend of the Q series (trend line slope) we use Sen's slope estimator test method [19]. Q is the median of the series n(n–1)/2 elements.

$$Q = median\left\{\frac{x_j - x_i}{j-i}\right\} \text{ with } i = 1,2,.., n-1; j>i \quad (5)$$

Q > 0: chain tends to increase and vice versa

2.3. Establishing a model for predicting salinity in 2 tributaries of the Tien and Hau rivers

Regarding the water environment, to predict the impact of saline intrusion on the water resources of the Mekong River, it is appropriate to choose MIKE 11 as the key model. MIKE 11 (HD+AD): 1–D model for river and canal system, using input data series from MIKE NAM to simulate flow in a river basin. Combined with the AD module (1D–dimensional diffusion) to simulate the propagation of salinity on the river system.

Two important upstream factors that dominate the water resources in the Mekong Delta are the amount of water stored in Tonle Sap (TonleSap), which helps to regulate and limit the flood flow in the Mekong Delta during the flood season and increase the source of fresh water during the flood season. dry season. And the flow to Kratie station (the beginning of the Mekong Delta) is located about 300 km upstream from the Vietnam–Cambodia border, representing the starting point of the lower Mekong. The downstream point is 8 estuaries: (1) Vam Kenh, (2) Binh Dai, (3) An Thuan, (4) Ben Trai, (5) My Thanh, (6) Ganh Hao, (7) Song Doc and (8) Rach Gia (Figure 2).

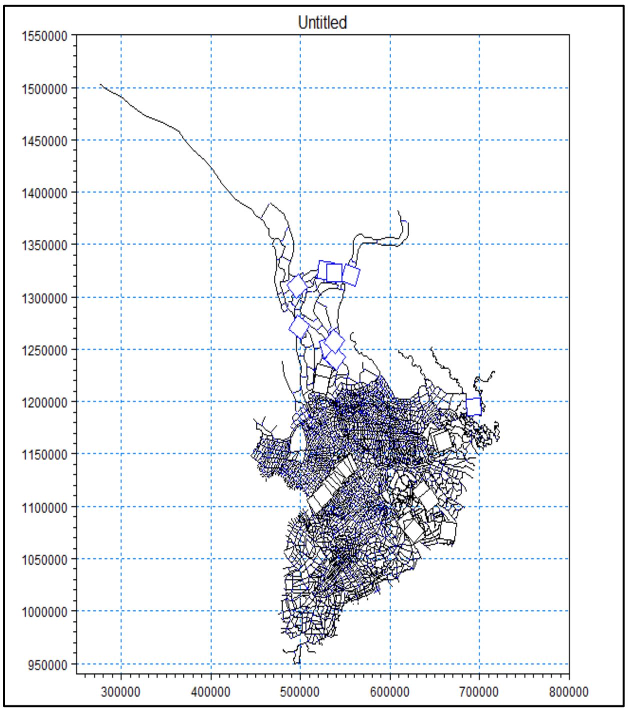


Figure 2. Network of Mekong River Delta.

The following table presents factors affecting saline intrusion in the Mekong Delta:

Table 1. Factors affecting the flow–saltwater intrusion in the Mekong Delta.

Impact factors	Featured	Methods forecast forecasts
Upstream flow to the Mekong Delta	- The development of hydropower in the upstream area; - Water regulation in upstream reservoirs; - Demand for upstream water.	- Monitor rainfall at the end of the flood season and capture information on water reserves at the beginning of the dry season in upstream reservoirs.
Water level	- There is an increasing trend over time; - Bringing salinity deep into the field.	- Tidal forecast results.
Rainfall	- dry season: low; - difficult to forecast seasonal purchases.	- Follow the current data.
Construction of sluice to prevent saltwater	- to build in coastal areas and small tributaries.	- Present.

Main river network system of the Mekong River Basin and data of irrigation works (salinity sluices):

Table 3. Construction of sluice to prevent saltwater.

Construction of sluice to prevent saltwater	Area serviced (hectare)	Featured
North Ben Tre	54,000	- Salt control; - Freshwater resources in coastal areas are still very difficult.
South Ben Tre	80,000	- Salt control; - Freshwater resources in coastal areas are still very difficult.
South Mang Thit	25,682	- Salt control; The last part of the system is worth switching to a salty–brackish ecology (shrimp farming);
Long Phu–Tiep Nhat	53,910	- Salt control; The last part of the system is worth switching to a salty–brackish ecology (shrimp farming); - Lack of fresh water in coastal areas.

3. Results and discussions

3.1. MK–test result

The results of Mann–Kendall testing at salinity measurement stations along Tien and Hau rivers in 5 provinces: Tien Giang, Ben Tre, Tra Vinh, Vinh Long, and Soc Trang are presented in Table 2.

Table 4. Mann–Kendall test results for salinity trends in the Mekong Delta.

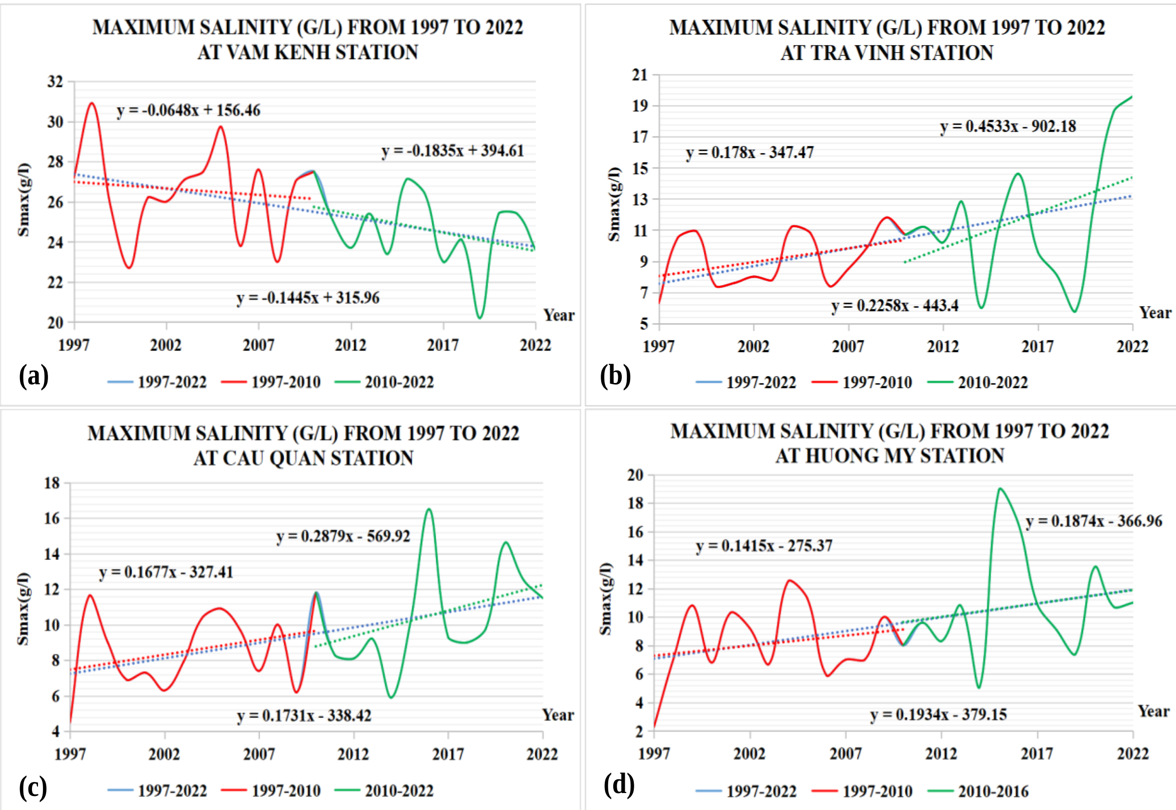
Station	M	Min	Max	Mean	Std. deviation	MK–test (S)	Var(S)	P–value
Vam Kenh	26	20.2	30.9	25.6	2.3	–99	2051.7	0.030
Ben Trai	26	17.8	29.3	25.6	2.8	–21	2053.7	0.659
Binh Dai	26	17.5	29.4	25.8	2.8	57	2053.7	0.217
Tra Vinh	26	5.8	19.6	10.4	3.4	111	2056.3	0.015
Tra Kha	26	11.1	25.9	17.9	3.5	–16	2057.3	0.741
An Thuan	26	23.0	31.5	27.5	2.3	65	2054.3	0.158
Cau Quan	26	4.5	16.5	9.4	2.7	104	2057.3	0.023
Đai Ngai	26	3.4	14.6	9.2	2.9	2	2055.3	0.982
Hoa Binh	26	8.5	24.1	13.6	3.6	19	2053.7	0.691
Hung My	26	7.4	22.6	15.3	3.7	21	2056.3	0.659
Huong My	26	2.3	18.9	9.5	3.5	93	2053.7	0.042
My Thanh	26	18.3	35.8	24.9	4.7	–153	2058.3	0.001

Mann–Kendall test results show S>0 values at 8/12 stations, which shows that 2/3 of the stations along 2 tributaries of the Tien and Hau rivers have a trend of increased saline intrusion. The strongest growth was at Tra Vinh and Huong My stations (Co Chien river), and Cau Quan station (Hau river) with S values of 111–93–104, respectively.

However, in terms of statistical significance P–value has $\alpha < 0.1$ (probability of making type I error is 10%), removing extreme values, only 5 stations are Vam Kenh (Tieu gate), Tra Vinh and Huong My (Co Chien river), Cau Quan (Hau river), and My Thanh station (Tran De gate) met the requirements. The remaining stations all tend to increase/decrease clearly but the non–parametric level of the MK–test does not satisfy the significance $\alpha < 0.1$.

3.2. Changing trend of saline intrusion

Figure 3 shows the process of S_{max} change trend at Vam Kenh, Tra Vinh, Huong My, Cau Quan, and My Thanh stations according to the data series from 1997 to 2022. The results of increasing saline intrusion trend at 3 stations with an average speed (S–slope) are Tra Vinh station 0.2258 g/l/year; Cau Quan station 0.1731 g/l/year; Huong My station 0.1934 g/l/year. The remaining two stations, Vam Kenh in the Tien River estuary and My Thanh station at the Tran De estuary in the Hau river, tend to decrease by 0.1445 and 0.3812 g/l/year.



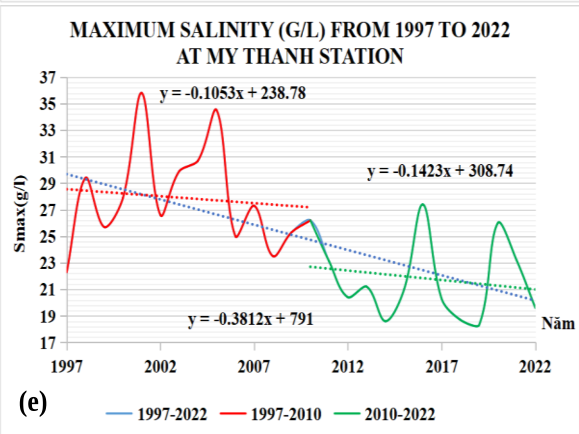


Figure 3. The trend of saline intrusion at some stations in the coastal sub–region between the Tien and Hau rivers in the period 1997–2022: (a) Vam Kenh; (b) Tra Vinh; (c) Cau Quan; (d) Huong My; (e) My Thanh.

In the calculated data series with a length of 26 years, it can be divided into two periods 1997–2010 (97–10) and 2010–2022 (10–22) to further consider the changes in salinity in the first 13 years and 12 years after. In most of the 5 calculation stations, Vam Kenh, Cau Quan, and Huong My stations, the up/down trend of each period compared to the average of many years does not change too much. The remaining two stations have trend slopes markedly different from the multi–year average value chain. At Tra Vinh station in the period 10–22, the growth trend is strong compared to the period 97–10. In contrast, the curve showing the fluctuation of salinity intrusion at My Thanh station has the S'slope period 97–10 and 10–22 decreasing relatively slightly compared to the multi–year average.

It was found that in the estuary area, salinity tends to decrease markedly, and in the inland area, on the contrary, the salinity increases rapidly, the salinity peak in recent years is much higher than in the previous period. According to the 26–year statistical data series, the highest salinity occurs in 1998, 2005, 2010, 2016, and 2020. Thus, the average salinity peak occurs once every 4–5 years.

However, the spread of salinity into the interior of the field clearly depends on the amount of water from upstream to the delta, especially the two main receiving sources at Tan Chau station (Tien river) and Chau Doc station (Hau river). The value of salinity concentration in the coastal area and tributaries here depends entirely on the tidal regime of the East and West seas, and to comprehensively assess the process of salinity fluctuations, many factors such as upstream currents must be considered. source, sea level rise, storm surge, climate change, demand for water in daily life, production, the operation process of a sluice gate to prevent saline intrusion, etc.

3.3. Forecast results of salinity intrusion in 2 tributaries of Tien and Hau rivers

The forecasts below are the highest salinity (S_x) from January to June 2022 with a forecast period of 1 time/month. At the same time, this forecast result is compared with data collected from the Southern Regional Hydrometeorological Station. From there, it is possible to accurately assess the predicted level of saline intrusion using the MIKE 11 model (HD+AD). The table below presents the evaluation results (Figure 4 and Table 5).

Table 5. The compares the forecast results with the reality.

	Station	River	Area	18–27/03/2022	
				Forecast results (S_{max})	**Monitoring data**
1	Vam Kenh	Cua Tieu	Tien Giang	22	21.8
2	Ben Trai	Co Chien	Ben Tre	22	19
3	Binh Đai	Cua Đai	Ben Tre	25	21
4	An Thuan	Ham Luong	Ben Tre	27	22.2
5	Tra Kha	Hau	Tra Vinh	13	14.2
6	Huong My	Co Chien	Tra Vinh	15	10.2
7	Hung My	Co Chien	Tra Vinh	20	12
8	Đai Ngai	Hau	Soc Trang	13	6

The time to choose the assessment is in the middle of the dry season (March) in 2022. Because currently, salinity usually reaches the maximum value. According to the forecast from the saline intrusion calculation model. In the Mekong Delta, salinity intrusion is greatest from March to early April and gradually decreases from mid–April onwards. From the end of May to November, the salinity intrusion in the South gradually weakens, with low intensity because this period coincides with the rainy season in the South and the water upstream of the Mekong River replenishes the Mekong Delta, so the salinity is washed away. salinity is reduced (especially in the coastal areas) and the saline boundary is restricted from entering the field.

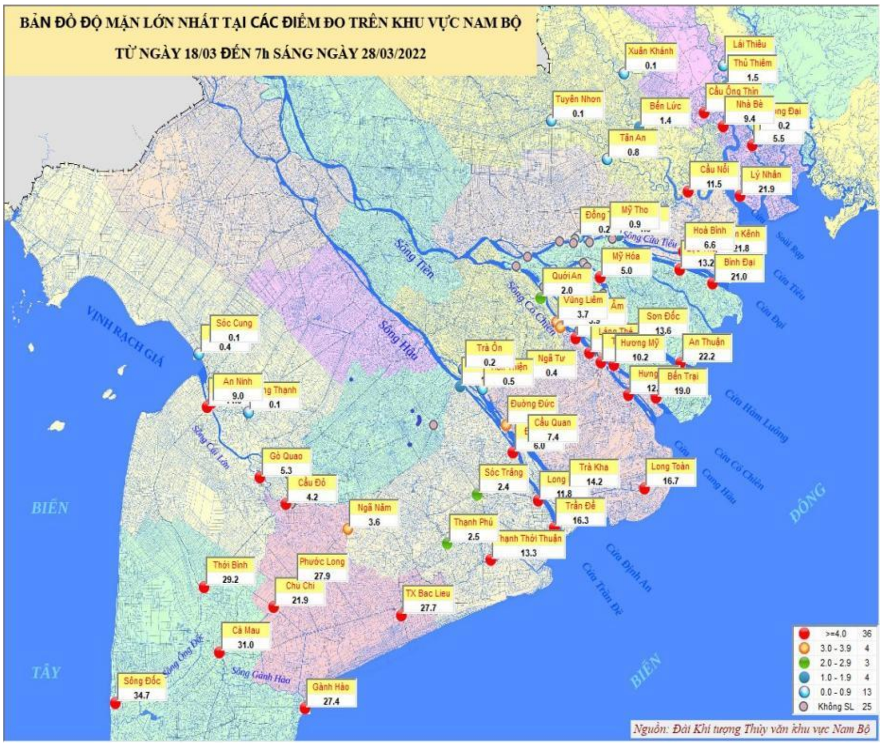


Figure 4. The map of the distribution of salinity at stations in the Southern region on March 18–27, 2022 (Resource: Southern regional hydrometeorological center).

4. Conclusion

The article has evaluated the trend of salinity change with a reliable and long enough data series of 26 years, from 1997 to the present time 2022 by the Mann–Kendall method and estimated Sen trend. It is found that, with the MK–test, there are many extreme values (local max, min) that appear to affect the general trend chain at the Mekong Delta salinity measurement stations. Out of 12 stations used for calculation, only 5 stations met the standard to estimate the Sen trend. However, in general, the trend of increasing salinity occurred in 8/12 stations and 4 stations tended to decrease according to calculated data.

The fluctuation of saltwater intrusion mainly depends on two main factors: the upstream flow of the Mekong Delta and the tidal regime in the East Sea. Part of the factor affecting the upstream flow is the amount of water at the end of the flood season. Kratie station and Kompng Luong station (Bien Ho) are considered as two points upstream of the Mekong River before pouring into the Red River Delta, which are decisive factors for the regulation of water to the Mekong Delta in the dry season. Therefore, to predict changes in saltwater intrusion in the future, it is necessary to study and evaluate the overall factors affecting the saltwater intrusion process.

Author contribution statement: Conceptualization and methodology: H.V.N., H.T.N.; validation, formal analysis: D.N.T.; investigation and project administration: H.T.N.; resources, data curation, software, draft: H.V.N., H.T.N., T.D.L; preparation and writing–original: H.V.N., H.T.N., D.N.T.; writing–review, and editing, visualization: H.V.N., H.T.N. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: This research is completed in the program of regular assignment by the functions Decision No. 2339/QĐ–TNMT date 13th, Sept 2022 of MONRE of the Sub–Institute of Hydrometeorology and Climate Change in 2023, specifically Task 9: “Forecasting tides and saline intrusion in the main rivers of the Southern region”.

Competing interest statement: The authors declare no conflict of interest.

References

1. Dat, T.Q.; Likitdecharote, K.; Srisatit, T; Trung, N.H. Modeling The Influence of River Discharge and Sea Level Rise on Salinity Intrusion in Mekong Delta. In First Environment Asia International Conference on "Environmental Supporting in Food and Energy Security: Crisis and Opportunity, 2011, 685–701.
2. National Centre for Hydro–Meteorological Forecasting, 2/3/2020.
3. Ministry of Natural Resources and Environment, Climate Change Scenario. 2020.
4. Linh, V.T.; Liem, N.D.; Dung, H.M.; Loi, N.K. Research on the application of models for trending evaluation of flood and salinization in the climate change context: Pilot research in Ho Chi Minh city. *J. Hydrometeorol*. **2019**, EME2, 98–110.
5. Institute of Meteorology, Hydrology and Climate Change. The Impacts of Climate Change on Water Resources and the Mekong Delta Adaptation Measures. 2010.
6. Hong, N.V.; Dong, N.P. Simulation of saline intrusion in main rivers of Ba Ria – Vung Tau province under the context of climate change. *VN J. Hydrometeorol*. **2021**, *728*, 67–79.
7. Hong, N.V.; Dong, N.P. Studying building the flood scenarios in ho chi minh city by the impacts of climate change. *VN J. Hydrometeorol*. **2021**, *729*, 1–13.
8. Hong, N.V.; Hien, N.T.; Minh, N.T.T.; Toan, H.C. Forecasting saline intrusion under the influence of the northeast monsoon in the Mekong Delta. *VN J. Hydrometeorol.* **2021**, *9*, 23–36.
9. Hong, N.V.; Dong, N.P. Research on assessing the impact of saline intrusion on the water resources in Ho Chi Minh City in the context of climate change. *VN J. Hydrometeorol*. **2021**, *10*, 11–23.
10. Tri, D.Q. Application MIKE 11 model on simulation and calculation for saltwater intrusion in the Southern region. *VN J. Hydrometeorol*. **2016**, *671*, 39–46.
11. Nicholls, R.J.; Lowe J.A. Climate Stabilization and Impacts of Sea–Level Rise. Avoiding Dangerous Climate Change. Cambridge University Press, ISBN: 13 978-0-521-86471-8, 2006.
12. Hanh, P.T.T.; Furukawa, M. Impact of sea level rise on the coastal zone of Viet Nam. Bulletin of the College of Science, University of the Ryukyus, ISSN: 0286-9640. 2007.
13. Apel, H.; Khiem, M.; Quan, N.H.; Toan, T.Q. Brief Communication: Seasonal Prediction of Salinity Intrusion in The Mekong Delta. *Nat. Hazards Earth Syst. Sci.* **2020**, *20(6)*, 1609–1616.
14. Tien, K.D.; Adam, L.; Micheal, D.Y. Perceptions and responses to rising salinity intrusion in the Mekong River Delta: What drives a long–term community–based strategy. *Sci. Total Environ*. **2020**, *711*, 134759.
15. Khang, D.K.; Kotera, A.; Sakamoto, T.; Yokozawa, M. Sensitivity of Salinity Intrusion to Sea Level Rise and River Flow Change in Vietnamese Mekong Delta–Impacts on Availability of Irrigation Water for Rice Cropping. *J. Agric. Meteorol.* **2008**, *64*, 167–176.
16. Tin, N.V. Non–Parametric Mann–Kendall test for trend detection of the maximum of short–term rainfall in Ho Chi Minh City from 1971–2016. *J. Hydrometeorol*. **2017**, *11*, 52–55.
17. Nam, L.H. Constructing climate change scenarios for Binh Phuoc province. *J. Hydrometeorol*. **2020**, *717*, 32–43.
18. Kendall, M.G. Rank Correlation Methods. Charles Griffin, London, **1975**, pp. 272.
19. Sen, P.K. Estimates of the Regression Coefficient Based on Kendall's Tau. *J. Am. Stat. Assoc.* **1968**, 1379–1389.
20. Van, P.T.C. Assessment of groundwater level decline and the potential for

replenishment of the Holocene (qh): case studies in the upper Mekong Delta. *Vietnam J. Agric. Sci*. **2022**, *2*, 135–143.
21. World Bank. The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. World Bank Policy Research Working Paper 4136. 2007. Online available: http://go.worldbank.org/775APZH5K0 (accessed on 15 March 2017).
22. MONRE (Ministry of Natural Resources and Environment of Vietnam). Vietnam's special report on managing the risks of extreme events and disasters to advance climate change adaptation. Vietnam publishing house of Natural Resources, Environment and cartography, 2015.
23. Thuc, T.; Huong, T.T.T.; Thang, N.V.; Nhuan, M.T.; Tri, L.Q.; Thanh, L.D.; Huong, H.T.L.; Son, V.T.; Thuan, N.T.H.; Tuong, L.N. Special Report of Vietnam on Managing the Risks of Natural Disaster and Extreme Phenomena to Promote Climate Change Adaptation. Vietnam. Vietnam Publishing House of Natural Resources, Environment and Cartography. Hanoi, Vietnam, 2015.