World Journal of Engineering and Technology, 2024, 12, 1083-1089
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Recent Variations of Water and Sediment Transport in the Adjacent Area between Two Large Estuaries

Dongfeng Xie[1,2], Shenyang Zhang[1,2*]

[1]Zhejiang Institute of Hydraulics and Estuary, Hangzhou, China
[2]Zhejiang Key Laboratory of Estuary and Coast, Hangzhou, China
Email: *399971530@qq.com

How to cite this paper: Xie, D.F. and Zhang, S.Y. (2024) Recent Variations of Water and Sediment Transport in the Adjacent Area between Two Large Estuaries. *World Journal of Engineering and Technology*, **12**, 1083-1089.
https://doi.org/10.4236/wjet.2024.124068

Received: August 30, 2024
Accepted: November 24, 2024
Published: November 27, 2024

Abstract

The Changjiang Estuary and Hangzhou Bay are adjacent large estuaries. They have close water and sediment exchanges. Over the past decades, the Changjiang Estuary and Hangzhou Bay region have been affected by human activities such as dam construction and land reclamation. Based on hydrological data at the adjacent area of the two estuaries in 2014 and 2023, this study analyzed the recent variations of water and sediment transport between the two estuaries. The results show that the flow velocities, SSC and unit width sediment transport varied with the tides, decreasing from spring tides to neap tides. In recent years, the flow velocity and SSC decreased to a certain extent. Accordingly, the unit width sediment transport also decreased, with the magnitude of change being about one-third. These observed variations may have a profound influence on the estuarine ecological systems.

Keywords

Changjiang Estuary, Hangzhou Bay, Hydrodynamics, Sediment Transport, Estuarine Engineering

1. Introduction

Estuaries are located at the interface between land and ocean. They are generally densely populated, and various social-economic activities, such as tidal flat reclamation, harbor and navigational channel construction, damming, etc., often have important impacts on the estuarine environment and ecology. Water and sediment movement is of major significance for physical and chemical processes in estuaries. They are closely related to seabed erosion and sedimentation, water intakes, and designs of infrastructures. In addition, sediments in suspension and floored on the seabed are also carriers for nutrients and organic matter and hence important for marine primary productivity, and other ecological aspects.

The Changjiang Estuary and Hangzhou Bay are two adjacent large estuarine systems (**Figure 1**). The Changjiang River discharges a huge amount of sediments into the East China Sea, about half of which spreads southward into Hangzhou Bay under the role of tidal currents and waves [1]. Particularly, there are direct water and sediment exchanges between the two estuaries in front of Nanhui tidal flat. In the past decades, especially since the operation of the Three Gorges Dam in 2003, the sediment load from the Changjiang River has reduced by more than over 70% [2]. Many scholars investigated the long-term variations of suspended sediment concentration (SSC) in the Changjiang Estuary and adjacent waters and found SSC showed a decreasing trend [3]-[5]. Moreover, it has been observed that bed erosion in the subaqueous delta of the Changjiang Estuary has occurred in recent years whereas it was under a state of accumulation before the construction and operation of TGD [6]-[8]. Meanwhile, a number of estuarine engineering have been conducted in the Changjiang Estuary and Hangzhou Bay, including channel dredging, land reclamation and bridge constructions [9]. However, there is still limited research on the response of water and sediment changes at the adjacent area of the two estuaries to these human activities.

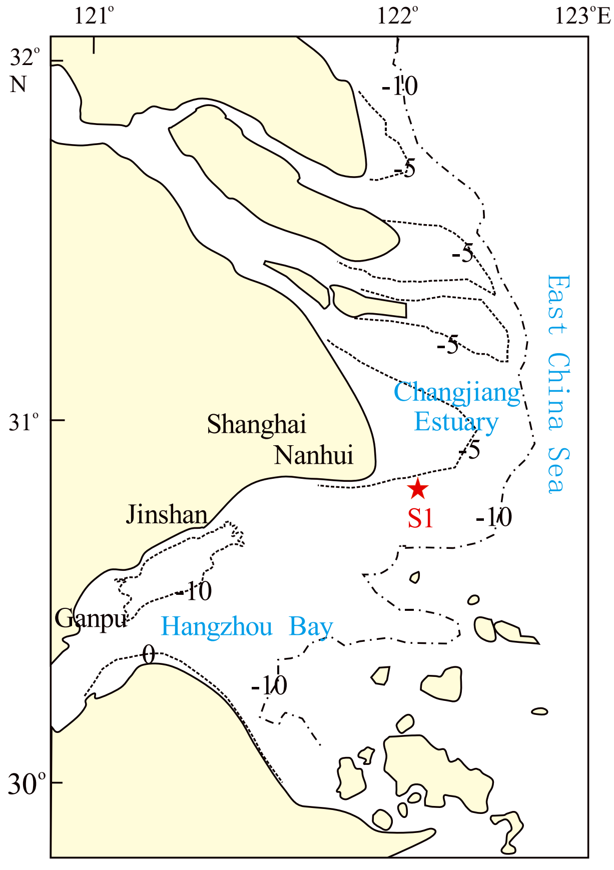

Figure 1. Study area and location of the hydrographic station.

2. Methods

2.1. Observations

A hydrological measurement was carried out at station S1, which was located at immediately south of Nanhui flat in 2023, in order to observe hydrological characteristics such as depth, flow velocity and SSC (**Figure 1**). The data at the same location was also collected for comparison. ADCP was used to observe the velocity and depth. OBS was used to observe SSC. Both cruises of observations covered a spring-neap tidal cycle.

2.2. Analysis

The methods for the data analysis in this study follow references [4] [8]. Firstly, after the field works, the average values over each flood and ebb tides of flow velocity, SSC, unit width sediment transport were calculated. Then, quantitative relationships between these hydrodynamic and sediment parameters and the local tidal range were built up so that the observation data of various periods can be unified to the same tidal conditions for comparative analysis.

3. Results and Discussion

3.1. Variations in Water and Sediment Transport

Figure 2 shows the correlation between the average bottom flow velocities over flood or ebb tides at S1 station and the local tidal range. As shown in the figure, the local tidal range in 2023 was between 2.91 m and 4.48 m. The average flow velocity at S1 station ranged from 0.5 m/s to 0.9 m/s. There is a significant positive correlation between flow velocity and tidal range. That is, the larger the tidal range, the greater the flow velocity, with a correlation coefficient of 0.95. The local tidal range in 2014 is between 2.0 m and 5.1 m, a little larger than that in 2023. The average flow velocity at S1 station in 2014 ranged from 0.5 m/s to 1.2 m/s. The correlation between flow velocity and tidal range was similar to that in 2014, with correlation coefficients of 0.96 for both stations. The flow velocity tidal range relationship between the two measurements changed to some extent during the period of 2014-2023. Taking the local average tidal range as an example, the flow velocity at LCG station decreased from 0.9 m/s to 0.7 m/s under this tidal range. This means that flow velocity in this region has decreased by about 20% in the recent ten years.

Consistent with the variations of flow velocity, the sediment concentration also showed periodic variations between spring and neap tides, with the maximum suspended sediment concentration during spring tides, followed by middle tides, and the minimum during neap tides. The relationships between the average sediment concentration over flood or ebb tides at S1 station and the local tidal range were good during the 2023 and 2014 measurements, respectively. Under the mean local tidal range conditions, the sediment concentration at S1 station decreased from 1.1 kg/m^3 to 0.6 kg/m^3, indicating a decrease of 45%.

The unit width sediment transport at S1 station ranged from 1.9 kg/m/s to 13.4 kg/m/s in 2023 (**Figure 3**), with an average of 6.3 kg/m/s over the spring-neap tidal cycle. In 2014, the unit width sediment transport varied between 1.7 kg/m/s and 23.1 kg/m/s, with the average over the spring-neap tidal cycle being 11.0 kg/m/s. The unit width sediment transports during both years were correlated well with the local tidal range, with the correlation coefficient being 0.94 and 0.97, respectively. Compared with that in 2014, the unit width sediment transport at S1 station has decreased by 43% in the recent ten years.

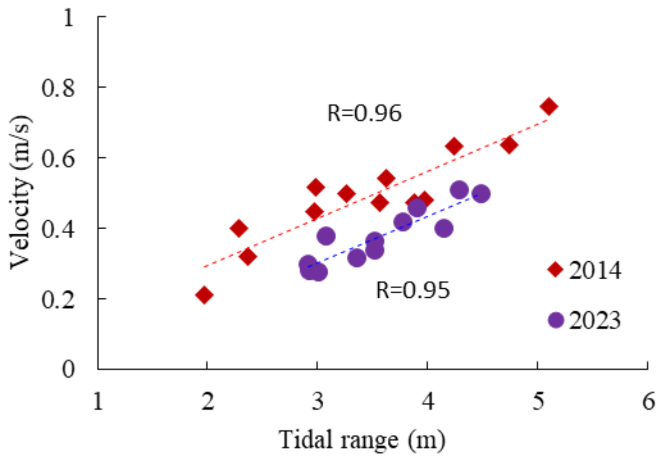

Figure 2. Relationship between the bottom flow velocity and tidal range.

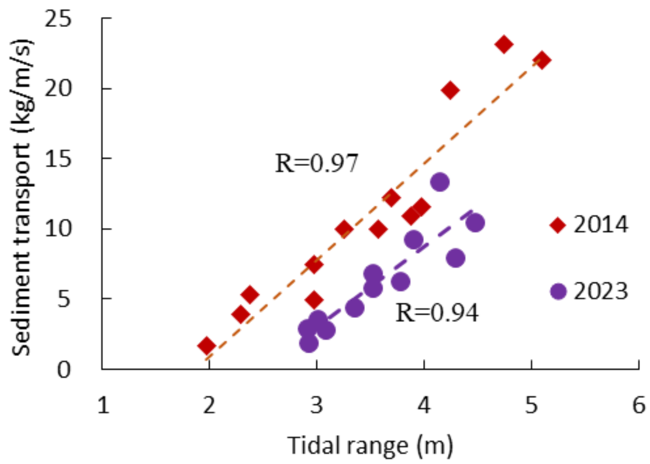

Figure 3. Relationship between unit width sediment transport and tidal range.

3.2. Forces for Recent Variations

Due to reasons such as dam construction and soil and water conservation in the Changjiang River catchment, the amount of sediment load entering the sea from the Changjiang River has sharply decreased in recent years. Correspondingly, the sedimentation rate of the tidal flats at the mouth of the Changjiang River has slowed down or even turned into erosion, and the subaqueous delta has turned from sedimentation to erosion [2] [6]-[8]. However, the observed decrease in sediment concentration and the unit width sediment transport at the adjacent area of the Changjiang Estuary and Hangzhou Bay turned out to be less than the decrease in sediment load. This is mainly due to the fact that local sediment resuspension in the Changjiang Estuary and subaqueous delta can, to a certain extent, compensate the direct influence of the decrease in sediment load. Meanwhile, there is a certain lag effect in the response of sediment concentration and sediment transport in the middle and lower reaches of the Changjiang Estuary to the sediment load decrease, with a lag period of about 5 - 10 years compared to the upper reaches of the Changjiang Estuary [5].

On the other hand, the Changjiang estuary has developed extensive tidal flats, and the fine sediments on these tidal flats can be easily resuspended by tidal currents and waves, which has a significant impact on the sediment concentration in the adjacent waters. Especially in winter, the wind waves are relatively strong, and the sediment resuspension by wind waves causes the sediment concentration in the adjacent areas to be significantly higher than those in summer [4]. Due to the sediment load decrease of the Changjiang River, the area of tidal flats at the mouth of the Changjiang River has significantly decreased. Meanwhile, a large amount of tidal flats in the estuary have been reclaimed for the aims of land requirements and economic development. It has been reported the total area of the tidal flats in the Changjiang Estuary has decreased from 4231 km^2 in 1990 to 2236 km^2 in 2020 [9], indicating that the area of the tidal flats has decreased by about 50%. Correspondingly, the amount of sediments that can be resuspended by wind waves in winter decreases, resulting in a decrease in suspended sediment concentration in the water column of the adjacent area between the two estuaries.

Based on empirical mode decomposition and wavelet neural network methods, Dou *et al*. (2020) predicted that the sediment load from the Changjiang River into the East China Sea will be 122 - 218 million tons per year in the next 10 - 50 years [10], which is comparable with the sediment load in recent years. Namely, although there is still a certain decreasing trend in sediment load under the present basin and climate conditions, the magnitude of the decrease is much smaller than that from 2003-2023. Therefore, the direct impact of the decrease in sediment load on the adjacent area between the Changjiang Estuary and Hangzhou Bay would be very limited in the future. However, the response of seabed evolution to the decrease in sediment load is relatively slow, and seabed evolution may have an impact on the water and sediment transport in the adjacent waters. Therefore, it is still necessary to strengthen tracking and observation.

4. Conclusions

Based on two hydrological survey data in 2014 and 2023, this paper analyzed the recent variations in water and sediment transport in the adjacent area of the Changjiang Estuary and Hangzhou Bay. It has been found that there are good positive relationships between the average flow velocity, sediment concentration, and unit width sediment flux over flood or ebb tides and the local tidal range. In recent years, the flow velocity at the Nanhui front has decreased by about 20%, and the sediment concentration and sediment transport rate have decreased by about 40%. This is mainly related to the indirect effect of the decrease in sediment load from the Changjiang River and the engineering of promoting siltation and reclamation in the estuary. The direct water and sediment exchanges between the Changjiang Estuary and Hangzhou Bay have been weakened. The results of this study can also provide a reference for other similar large-scale estuarine and coastal systems. Particularly, the variations in sediment concentration and sediment transport have major implications for ecological evaluation and policy.

Acknowledgements

This research was financed by the key project of Zhejiang Provincial Natural Science Foundation (No. LZJWZ23E090003), the Zhejiang Provincial Hydraulic Science and Technology Plan (No. RC2432), the National Natural Science Foundation of China (No. 42176170), Special Project of Zhejiang Provincial Research Institutes (No. ZIHEYS23002). Anonymous reviewers are sincerely thanked for valuable comments in improving this work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Chen, J., Liu, C., Zhang, C. and Walker, H.J. (1990) Geomorphological Development and Sedimentation in Qiantang Estuary and Hangzhou Bay. *Journal of Coastal Research*, **6**, 559-572.

[2] Yang, S.L., Milliman, J.D., Li, P. and Xu, K. (2011) 50,000 Dams Later: Erosion of the Yangtze River and Its Delta. *Global and Planetary Change*, **75**, 14-20. https://doi.org/10.1016/j.gloplacha.2010.09.006

[3] Dai, Z., Chu, A., Li, W., Li, J. and Wu, H. (2013) Has Suspended Sediment Concentration near the Mouth Bar of the Yangtze (Changjiang) Estuary Been Declining in Recent Years? *Journal of Coastal Research*, **289**, 809-818. https://doi.org/10.2112/jcoastres-d-11-00200.1

[4] Xie, D., Pan, C., Wu, X., Gao, S. and Wang, Z. (2017) The Variations of Sediment Transport Patterns in the Outer Changjiang Estuary and Hangzhou Bay over the Last 30 Years. *Journal of Geophysical Research*: *Oceans*, **122**, 2999-3020. https://doi.org/10.1002/2016jc012264

[5] Luo, W., Shen, F., He, Q., Cao, F., Zhao, H. and Li, M. (2022) Changes in Suspended Sediments in the Yangtze River Estuary from 1984 to 2020: Responses to Basin and Estuarine Engineering Constructions. *Science of the Total Environment*, **805**, Article ID: 150381. https://doi.org/10.1016/j.scitotenv.2021.150381

[6] Cheng, S., Zeng, X., Wang, Z., Zeng, C. and Cao, L. (2023) Spatiotemporal Variations of Tidal Flat Landscape Patterns and Driving Forces in the Yangtze River Delta, China. *Frontiers in Marine Science*, **9**, Article ID: 1086775. https://doi.org/10.3389/fmars.2022.1086775

[7] Wu, X., Yue, Y., Borthwick, A.G.L., Slater, L.J., Syvitski, J., Bi, N., *et al.* (2023) Mega-reservoir Regulation: A Comparative Study on Downstream Responses of the

Yangtze and Yellow Rivers. *Earth-Science Reviews*, **245**, Article ID: 104567. https://doi.org/10.1016/j.earscirev.2023.104567

[8] Zhang, D., Xie, W., Shen, J., Guo, L., Chen, Y. and He, Q. (2022) Sediment Dynamics in the Mudbank of the Yangtze River Estuary under Regime Shift of Source and Sink. *International Journal of Sediment Research*, **37**, 97-109. https://doi.org/10.1016/j.ijsrc.2021.07.005

[9] Guo, L., Zhu, C., Xie, W., Xu, F., Wu, H., Wan, Y., *et al*. (2021) Changjiang Delta in the Anthropocene: Multi-Scale Hydro-Morphodynamics and Management Challenges. *Earth-Science Reviews*, **223**, Article ID: 103850. https://doi.org/10.1016/j.earscirev.2021.103850

[10] Dou, X., Jiao, J., Chu, A. and Tong, C. (2020) Review of Hydro-Sediment Change and Tendency in Yangtze Estuary. *The Ocean Engineering*, **38**, 2-10. https://doi.org/10.16483/j.issn.1005-9865.2020.04.001