Sediment Transport and Diffusion in the Yellow River Estuary in 2018 Based on Numerical Analysis

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Abstract. As the river with the highest sediment concentration in the world, the Yellow River carries a huge amount of sediment in the Yellow River estuary every year. The Yellow River estuary extends and forms a forward extension zone of land-sea interaction. It is of great significance to fully understand the movement and diffusion law of the sediment from the Yellow River to the sea and keep the balance of scouring and silting. A two-dimensional mathematical model from Luokou to the Yellow River estuary and Bohai Bay was established, and the diffusion law of sediment movement in the Yellow River flood and dry season was obtained by simulation calculation. The influencing factors of sediment movement and diffusion mainly include flood magnitude, sea level tide fluctuation and tidal current direction. The analysis of the movement range and diffusion rate of sediment under different conditions provides a reference basis for the control of the sand bar in the Yellow River estuary and the balance of scouring and silting in the lower reaches of the Yellow River.

1. Introduction

In the spirit of the sixth meeting of the Central Finance and Economic Commission, chaired by General Secretary Xi Jinping on 3 January 2020, the meeting emphasized 'the implementation of major projects such as wetland ecosystem restoration in the Yellow River Delta', 'giving full play to the leading role of urban agglomerations in Shandong Peninsula and promoting the high-quality development of central cities and urban agglomerations along the Yellow River', and further explained the basic role of estuary governance in the Yellow River Delta and Yellow River governance in Shandong Province and the efficient use of water resources in promoting ecological protection and high-quality development in Implementation Plan of Ecological Protection and High Quality Development in the Yellow River Basin of Shandong Province and even the whole Yellow River Basin [1].

The treatment of the Yellow River estuary is closely related to the treatment of the lower reaches of the Yellow River. Sediment deposition and diffusion are affected by sea level fluctuation and tidal current reciprocating motion. For the study of the Yellow River water and sediment into the sea, Shi Changxing calculated the deposition and erosion of the delta plain and front in the Qingshuigou and Diaokou river bank sections by using the underwater topographic survey data of the Yellow River Delta.
from 1976 to 2015[2]. It is found that with the decrease of the erosion rate of the abandoned river port slope, the sediment diffusion rate from the estuary and the delta bank slope to the far sea will tend to decrease. Zhai Qiumin uses the method of multi-year mean to analyze the changes of sediment in the Yellow River from 1957 to 2017[3]. It is found that due to the limitation of incoming water and sediment in the middle reaches of the Yellow River, the propulsion rate of the Yellow River Delta to the Bohai Sea will slow to a certain extent. Wang Kuifeng used the three-dimensional HEM-3D numerical model to simulate and analyze the flow field change[4], salinity, suspended sediment concentration and coastal erosion and deposition distribution in the Yellow River Delta in the tidal cycle[4]. The results show that in the current estuary area, deposition is the main factor. Under the control of plume flow diffusion, the sediment transports southward after entering the sea, and gradually weakens in the Laizhou Bay area.

Studying the diffusion law of sediment movement into the Yellow River estuary is conducive to the prediction of the future evolution of the Yellow River Delta and the formulation of reasonable watershed management planning. In this paper, a two-dimensional mathematical model from Luokou to the Yellow River estuary and Bohai Bay is established to calculate and analyze the movement form and diffusion law of sediment into the sea.

2. Fundamental theory[5]-[8]

2.1. Fundamental equation
The basic equations used in model calculations can be found in literature[5]-[8]

2.2. Boundary conditions
Import boundary conditions. In the import boundary conditions, the flow and sediment concentration of Luokou Hydrological Station in 2018 are used.

Boundary conditions of outlet flow. The water boundary connecting the calculation area and the sea area is controlled by the changing tidal level.

Closed border. On the closed boundary, it is considered that the normal velocity of the closed boundary is 0, but the velocity along the tangent direction is not 0, that is, $V_n \big|_\Gamma = 0$, $V_t \big|_\Gamma \neq 0$.

Sediment movement boundary conditions. The boundary condition of suspended sediment movement should satisfy the normal sediment flux of 0 in the closed boundary besides the sediment content of each node at the entrance and exit section.

2.3. Model validation
The boundary conditions and validation of the model are presented in the literature[5]-[8].

3. Model Calculation and Result Analysis
Based on the post-flood section data of the Yellow River in 2018 and the topographic map of the Bohai Bay, a two-dimensional numerical model from Luokou to the estuary of the Yellow River and the Bohai Bay is established. Select 500m$^3$/s, 10kg/m$^3$ typical flow sediment concentration simulation, simulation time is one year. The model range is shown in Fig. 1.
The main research area of this paper is at the estuary of the Yellow River, and the range and terrain of this area are shown in Fig. 2.

3.1. Effect of sea-level tidal fluctuation on suspended sediment concentration

The Yellow River estuary is an irregular semi-diurnal tide with a tidal range of 1.3–1.5m. The rising tide velocity is 1.6-2.4m/s and the retreating tide velocity is 1.5-2.2m/s. The flood and ebb tide durations are different. The flood tide duration is smaller than the ebb tide duration, and the flood tide velocity is slightly larger than the ebb tide velocity [9]. When the tide rises, the flow entering the Yellow River estuary is under the action of tidal current, and the flow velocity decreases. The minimum flow velocity appears at the highest tide level, so the sediment content decreases during the tide rise. The maximum velocity appears when the tide falls to the lowest tide level, so the sediment concentration increases when the tide falls. As shown in Fig. 3.
A point is selected on the -6m isobath of the Yellow River estuary, and the point is located on the river extension line. The tidal level and sediment concentration data of the point in 2 days are plotted. As shown in Fig. 4, the tidal level shows obvious irregular semi-diurnal tidal variation. The maximum tidal range is 1.2m, and the concentration of seawater sediment is floating in the range of 3.25-7.70 kg/m³, and the maximum value appears at the lowest moment of tidal level, and the minimum value appears at the highest moment of tidal level.

3.2. Influence of tidal current movement on the direction of sediment movement

The flow characteristics in the estuary area of the Yellow River are reciprocating flow. The direction of the fluctuation trend is roughly the opposite. The fluctuation trend is eastward to the south and westward to the north, and is roughly parallel to the coastline, which is conducive to the movement of sediment.
along the coastline. As shown in Fig. 5, the sediment moves southward during the flood tide and northward during the ebb tide.

![Figure 5. Distribution of sediment concentration into the sea](image)

The same point on-6m isobath was selected to analyze the relationship between tidal current direction and sediment concentration. As shown in Figure 6, the sediment concentration varies obviously with the tidal current direction, with a difference of about 160°. The maximum sediment concentration appears at the moment when the tidal current direction is 280°, and the minimum sediment concentration appears at the moment when the tidal current direction is 120°.

![Figure 6. Relationship between tidal current direction and sediment concentration](image)

4. Conclusion
When the tide rises, the water surface gradient decreases, the flow decreases, and the sediment deposits, and the sediment content decreases. When the water surface gradient increases and the flow velocity increases, the sediment concentration increases when scouring occurs. However, it is difficult to take away all the sediment deposited during the flood tide when the sediment deposition is restored to the
same velocity condition. Therefore, the rise and fall of sea level tide has an important influence on the 
diffusion of sediment movement into the sea, which is characterized by small sediment content at the 
rising tide and large sediment content at the ebb tide.

In the estuary of the Yellow River, tidal current is the main hydrodynamic force in this area, which 
plays an important role in the initiation and transportation of sediment along the Yellow River Delta. 
Under the influence of tidal current movement, the diffusion range of sediment to both sides of the 
estuary is larger than the longitudinal range of river entering the sea.

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Laboratory for Technology in Rural Water Management of Zhejiang Province.

References
[1] Zhang Hongwu, Zhang Luohao, Jingwa, Cai Rongrong, Miao Runze. Shandong plays an 
irreplaceable role in ecological protection and high-quality development of the Yellow River 
Basin [J]. Water conservancy and hydropower technology (English and Chinese), 2021,52 
(01): 1-21.
[2] Shi Changxing. Sediment deposition and diffusion analysis of the Yellow River Estuary since 1976 
[J]. People 's Yellow River, 2020,42 (09): 41-45 + 111.
[3] Zhai Qiumin, Ning Yuxin, Liu Shuai. Sediment changes in the middle and lower reaches of the 
Yellow River and their impact analysis [J]. Henan Science and Technology, 2020 (16): 78-80.
[4] Wang Kuifeng, Zhang Taiping, Song Xinqiang, Xu Guohui, Shang Guiyong, Zheng Jianguo. 
Numerical simulation analysis of coastal erosion and sediment transport model in the Yellow 
River Delta [J]. Land and resources of Shandong, 2018, 34 (11): 22 – 31.
[5] Li Dongfeng, Li Zegang, Zhang Qingyu 1998 Numerical analysis of effect of sediment from 
Northward Route of Qingshuigou on Dongying Port Journal of Oceanography of Huanghai 
&Bohai Seas 01(1998)2-7.
[6] Li Dongfeng, Li Zegang 1998 Computational study on the influence of sediment discharge into the 
sea on Dongying Port Yellow River 03(1998)8-9.
[7] Li Dongfeng, Cheng Yiji, Zou Bing, Zhang Hongwu, Han Qiaolan 2004 Two-dimensional finite 
element mathematical model of the Yellow River estuarine sediment and its application(I) - 
- model and verification Advances in Marine Science 01(2004)21-28.
[8] Li Dongfeng, Zhang Xiuzhong, Han Qiaolan, Cheng Yiji, Chen Mei 2004 2-D mathematic model 
of the Yellow River estuarine tidal wave and sediment and its application- - water and sediment 
movement process simulation Advances in Marine Science 03(2004)284-291.
[9] Li Zegang. Basic characteristics of hydrological elements in the sea area near the Yellow River 
Estuary [J]. Yellow Sea, Bohai Sea, 2000 (03): 20-28.