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Research Article

Increase in Suspended Sediment Contents by a Storm Surge in Southern Bohai Sea, China

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Most of the existing results were related to the impact of land storms on sediment, and few explained the impact of storms on sediment movement and its formation law from the mechanism. At present, the research on the impact of storm on sediment suspension on the North Bank of Longkou City in the south of Bohai Sea was not clear. Therefore, this study aimed to explore the formation and mechanism of storm on suspended sediment from the perspective of hydrodynamic characteristics and sediment distribution by monitoring the impact of storm on sediment suspension in the south of Bohai Sea. A storm with wind speeds of 4.5–13.5 m/s occurred in the coastal area of the north side of Longkou City located in Southern Bohai Sea in April, 2015. Suspended sediment samples were obtained using automatic samplers, and the results showed that the suspended sediment content was 7.8 mg/L under normal weather conditions, which reached 121.2 mg/L at the highest during the storm event. Waves and tides were synchronously observed by acoustic Doppler current meter. Wave height was more closely correlated with wind speed when the wind veered to north, and the maximum wave height was 243 cm. The reciprocating motion of the current at the sampling site was strong, with the maximum current speed of 43.8 cm/s and a water depth of 10 m. The results of laser analysis showed that the bottom sediments were composed of 92% sand and 8% silt, with a medium diameter of 0.102 mm. From the experimental observation and result analysis, it was known that the strong dynamic process during storm surge led to the movement of sediment surface and the resuspension of sediment.

1. Introduction

For a long time, the plateau sediment around the Yellow River Basin has been flowing into the Bohai Sea, and the Yellow River Delta of more than 5000 square kilometers has been formed. The long-term interaction between marine geological and biological resources is the main channel for the formation of different geological and chemical deltas. As the intersection area of logistics and energy flow, the delta is affected by different spheres of the Earth, which makes the land and ocean interact with each other, resulting in a certain impact on the ecology and environment. The delta region is greatly affected by human life and climate change.

Storms have a large effect on sediment movement [1]. Strong cyclonic wind stress accelerates sediment resuspension, and the concentration of suspended particles in the seawater column might be increased by dozens of times during and after storms [2, 3]. Under wind speeds of 5–15 m/s and wave heights of 50–150 cm, the suspended content in the Yellow River Delta reached 5.7–49.6 kg/m^3, which is 10–100 times higher than that under normal weather conditions [2]. Sediment resuspension may cause various problems to ocean engineering. For example, scour around piles and pipelines and deposition in harbors and channels occurred in the Yellow River Delta during storms. In October 2006, 1.2 m of sediment was deposited in a test channel with a depth of 2.5 m in only 10 days during a storm after it had been dredged for 1 month [4].

The Bohai Sea belongs to a semiclosed inland sea zone, which has been affected by gale climate for a long time. Storms in the Bohai Sea generally occur in winter every year and last about half a year. On average, there are about 6 storms above grade 8 every year [5]. The waves generated by storms in the Bohai Sea can reach about 7 m. The research shows that the marine dynamic seasonality is obvious. The average water depth in the Bohai Sea area is about 18 m. The sediments are more vulnerable to the impact of waves than other sea areas. The sediment suspension is the result of the impact of storms on the sediments, which leads to certain changes in the structure of sediments in the Yellow River Delta and Bohai Sea. Storm surges in the southwest Bohai Sea are larger than those in the north [6]. Longkou Port, sea embankments, and the intake of Longkou Power Plant were all located in coastal area of the north side of Longkou City, Southern Bohai Sea, China. Erosion and collapse of embankments, siltation of navigable waterways, and abrasion of the inner wall of the circulating water pipeline may be caused by sediment resuspension. According to the statistical data of Longkou Ocean Station, the annual average of wind speed in this area is 6.4 m/s, and the maximum wind speed is 28 m/s. The occurrence frequency of strong wind of force six or above (the speed is more than 10.8 m/s) is 8.44%, and the occurrence frequency of gale-force wind (the speed is more than 13.9 m/s) is 4.54%. Thus, sediment movement during storms is the key question in marine science research in this area. However, to date, it is still unclear how much sediment can be suspended into water column of the north side of Longkou City, and how the suspended sediments are distributed temporally and spatially during storms in this area. Therefore, the research on the diffusion of suspended sediment and its effect on the formation of surrounding landform has important theoretical significance and application value.

At present, there are few studies on the impact of storms on sediments in the Delta and Bohai Sea and the law of sediment suspension movement. In this study, the effects of storm on sediment suspension in coastal area of the north side of Longkou City located in Southern Bohai Sea and the possible mechanisms were researched. First, the suspended sediment contents during and after a storm event in April 2015 were detected and compared with that during normal weather conditions. Then, winds, waves, and tides were synchronously observed and correlation analyses between those indexes were carried out, to explore the possible mechanisms of sediment resuspension from the perspectives of hydrodynamic characteristics. Last, source, composition, and particle size of sediment were discussed, to further explore the possible mechanisms of sediment resuspension from the perspectives of sediment characteristics.

2. Materials and Methods

2.1. Sampling Time and Sampling Site. In order to explore the influence of storm, wave, and other factors on the change of suspended sediment content, the experiment is mainly carried out under the adverse weather conditions in the coastal area north of Longkou City in the south of Bohai Sea, and different stations are selected to observe the relevant indicators in this area. According to the hydrological and meteorological forecast, the coastal area of the north side of Longkou City, Southern Bohai Seat, was expected to experience strong winds on April 11–14, 2015. Therefore, the wind, wave, tide, and suspended sediment were observed from 20 : 00 on April 11, 2015 to 02 : 00 on April 14, 2015. During the test, the observation indexes mainly include suspended sediment, wind speed and direction. Among them, the samples for sediment sampling are mainly suspended sediment, and the sampling point is the same as that of wave and tide observation station (station 1), while the wind speed and direction data are from Longkou hydrometeorological station (station 2), which is located about 8 km west of station 1. To study the suspended sediment characteristics under normal weather conditions and make comparisons to those during storms, suspended sediment sampling was carried out at 09 : 00 on April 10 (before the storm) and 9 : 00 on April 15 (after the storm), and suspended sediment data were also collected and analyzed from four nearby stations (station 3–6) set up by our team during good weather conditions in June 2004. Bottom sediment was sampled from seven stations (No. 7–13) along a cross section of the suspended sediment sampling station (station 1) during normal weather conditions in April 2015 for analysis of sediment composition and particle size. As shown in Figure 1, this is the basic distribution of the sampling station map. Table 1 shows the basic geographic information of the sampling station.

Figure 2 shows the process diagram of water exchange in the Bohai Sea and other sea areas.

The experiment is mainly completed by outdoor sampling and indoor analysis. Outdoor sampling mainly measures the flow velocity and direction of water meter, water and underwater at each station. The direct reading current meter is used to observe the flow velocity and direction. The measurement range of flow velocity is 0.05–3.5 m/s, the accuracy is +2.5%, the measurement range of flow direction is 0–360°, and the accuracy is +5°. At the same time, water samples are collected at different water levels for indoor measurement of suspended sediment content and salinity. Among them, the salinity is measured by a salinometer with a measurement range of 2.5–45.5 psu and a measurement accuracy of 0.01 psu. The suspended sediment content is treated by suction filtration, drying, and weighing. The diameter of the filter membrane is 45 mm and the pore diameter is 0.55 μm fiber double filter membrane, the lower filter membrane is used for correction, and the weighing is carried out on the balance. The water depth is measured by single frequency sounder. Suspended sediment samples were obtained using an improved MULTI-LIMNOS automatic sampler (Hydro-bios, German). The samples were filtered

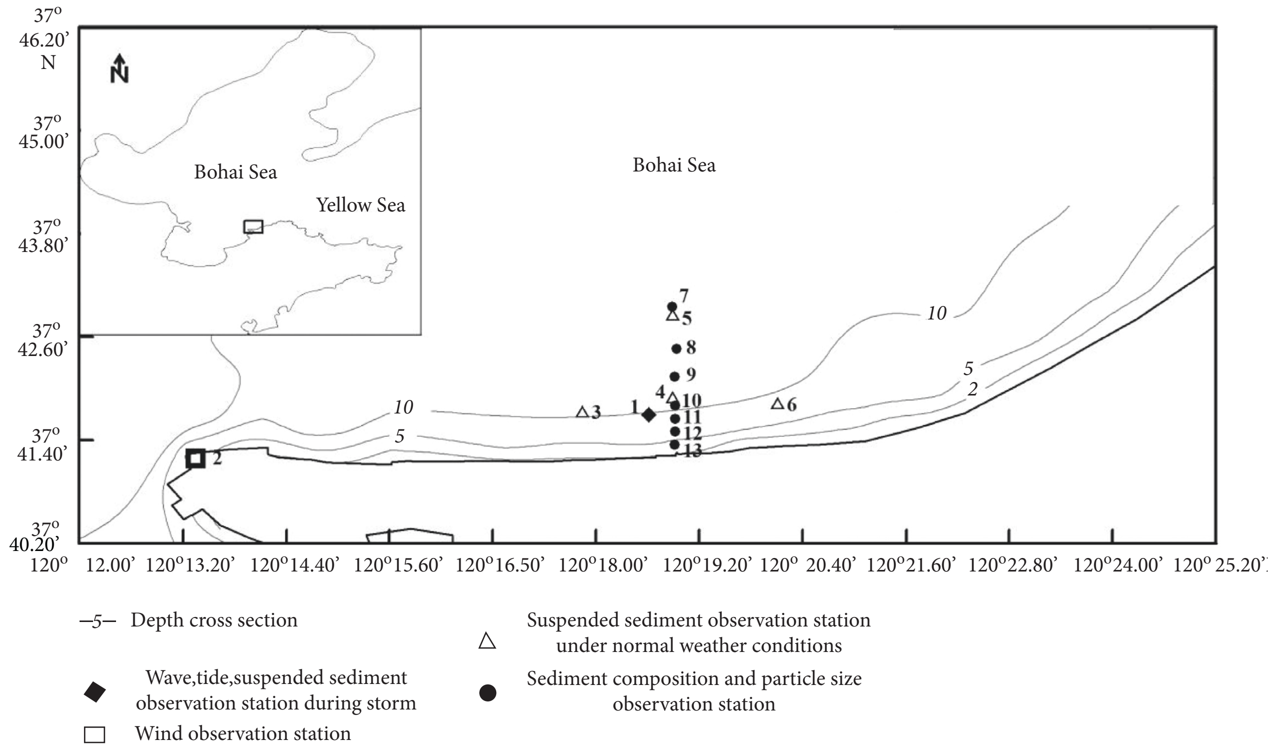

Figure 1: Map of sampling stations.

Table 1: Geographical information of sampling stations.

Station	East longitude	North latitude
1*	120°18.645′	37°41.696′
2#	120°13.300′	37°41.200′
3&	120°17.862′	37°41.719′
4&	120°18.934′	37°41.866′
5&	120°18.909′	37°42.859′
6&	120°20.127′	37°41.824′
7¤	120°18.924′	37°42.947′
8¤	120°18.957′	37°42.466′
9¤	120°18.945′	37°42.142′
10¤	120°18.947′	37°41.834′
11¤	120°18.938′	37°41.648′
12¤	120°18.939′	37°41.500′
13¤	120°18.933′	37°41.345′

*Collected data: wave, tide, and suspended sediment during storm. #Collected data: wind. &Collected data: suspended sediment under normal weather conditions. ¤Collected data: average sediment concentration, sediment composition, and particle size.

with the filter membrane of 0.45 μm pore size and dried in the laboratory to calculate the suspended content. The automatic water samplers are easy to be damaged under bad weather conditions. Especially, the sample bottles may fall off from the sampler due to the strong current. Thus, the automatic sampler was reinforced with antiwave grid structure (patent of China: 201320886378.7) and set up using an anchor system at approximately 1.5 m above the seabed to ensure the collection of suspended samples during storms.

The automatic water sampler was equipped with ten sampler bottoms, each with a volume of 1 L. Two rubber tubes were installed in the mouth of the sampler bottom, one of which was water inlet and the other was exhaust tube. Before the water sample was collected, the two tubes both were bent and fixed in bow-shaped knot to ensure that the sampler bottom was closed. When the predetermined time was coming, the tubes opened to collect water sample and exhaust the air. The process for each bottle to obtain enough water sample was about 10 minutes, and the ball valve floated to block the inlet when the bottle was full-filled. The sampling interval during the storm event was 6 hours. The sampling of the suspended sediment in normal weather conditions in a spring tide lasted for 25 hours with a sampling interval of 1 hour, and the average suspended sediment content was calculated to represent the baseline under normal weather conditions.

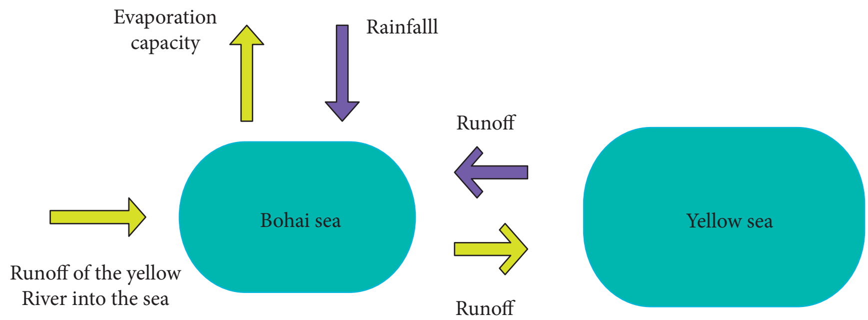

Figure 2: The observed wind direction and speed during the observation under the storm.

2.2. Collection and Observation of Wind and Hydrodynamics Data. In addition, wind speed, wind direction, and other important indicators affecting suspended sediment content were observed during the experiment. Wave direction, wave height (H1/10), current velocity, and current direction were obtained by a WHS600-1-UG57 acoustic Doppler current profiler (ADCP, RDI, USA) placed at the bottom of the seabed, with the sampling frequency of 2 Hz and the observing frequency of 1 h. Water level was observed by a TGR-2050 self-capacitance tide gauge (RBR, Canada) placed at the bottom of the seabed, with the observing frequency of 10 min.

2.3. Analysis of Bottom Sediment Composition and Particle Size. A total of seven bottom sediment samples were obtained with a grab sampler along the cross section. The sediment composition and particle size was analyzed in the laboratory by a laser analyzer (GSL–101Bi).

3. Results and Discussion

In order to facilitate analysis and comparison, the observation data of some stations with the same location of continuous stations during sampling in summer 2010 and winter 2015 are selected for comparison, and the average sediment concentration and its changes of these stations are selected for comparative study. The comparison results are shown in Table 2.

According to the observation and statistics results in Table 2, the concentration of suspended sediment in Bohai Sea area in winter is significantly higher than that in summer. The results of sampling data from different observation stations show that the average sediment concentration in winter in the inlet area is about 25 times higher than that in summer, while that in other observation stations is about 15 times higher than that in summer.

During the period of water and sediment regulation in the surrounding waters of the Bohai Sea in summer, the diffusion range of sediment into the sea is small. In the sediment content of the surface and middle water body of the sea, except that the sediment content near the coast is greater than 15 mg/L, the sediment content in most other areas is less than 3 mg/L. Although the bottom sediment concentration of the seabed is mostly greater than 3 mg/L, the range of water areas with sediment concentration greater than 15 mg/L is basically the same as that of the surface and middle layers. However, in winter, the sediment concentration of the experimental observation station is greater than 15 mg/L in all layers of the water body, and the water area with sediment concentration greater than 80 mg/L near the coast is significantly greater than the water area with sediment concentration of 15 mg/L in summer.

In order to observe the movement law of suspended sediment in different seasons, the changes of sediment flux at different stations in summer and winter are compared in the experiment, as shown in Table 3.

According to the observation results of sediment flux changes at different stations, during the water and sediment regulation in summer, except that the sediment flux at the observation station near the sea inlet is less than that in summer, the sediment flux at other stations in winter is 3–120 times that in summer, as shown in Table 3. The observation results show that the suspended sediment flux increases significantly at stations with shallow water depth, which is more than 8 times that in summer and up to 120 times. Meanwhile, during the period of water and sediment regulation, the suspended sediment flux is affected by the flow velocity and direction, and the suspended sediment mainly moves from nearshore to offshore.

3.1. Wind. Based on the data from Longkou hydrometeorology station, there were 3 stages of storms during the observation period, as shown in Figure 3. During stage 1 (from 20 : 00 on April 11 to 08 : 00 on April 12), the wind speed was increased abruptly with a maximum value of 13.5 m/s at the end. A steering effect was observed as the wind changed from partial southern direction at stage 1 to partial northern direction at stage 2 (from 08 : 00 on April 12 to 02 : 00 on April 13) and stage 3 (from 02 : 00 on April 13 to 02 : 00 on April 14). The velocity was kept on a high plane ranging from 11.0 m/s to 13.5 m/s at stage 2, and then the wind speed was decreased gradually to 4.5 m/s at stage 3.

3.2. Suspended Sediment Content. In order to explore the suspended sediment content and its variation law, the suspended sediment concentration at different observation stations was tested. According to the experimental sampling results, the low concentration suspended sediment waters on the surface of the station occupy most of the Bohai Sea area,

Table 2: Comparison of sediment concentration between summer 2010 and winter 2015.

Station	Average sediment concentration in summer of 2010 (mg/L)	Average sediment concentration in winter of 2015 (mg/L)
7	16.1	342.6
8	13.5	241.8
9	23.7	586.4
10	9.3	143.7
11	8.5	119.4
12	16.3	303.6
13	12.8	218.5

Table 3: Comparison of sediment flux between summer 2010 and winter 2015.

Station	Sediment flux in summer 2010 (mg/L)		Sediment flux in summer 2015 (mg/L)	
	Size (kg/m/s)	Direction (°)	Size (kg/m/s)	Direction (°)
7	0.18	158.4	5.64	167.2
8	0.43	238.7	8.39	135.6
9	0.27	196.5	5.17	179.5
10	0.14	214.3	6.28	95.3
11	0.06	318.6	5.14	126.5
12	0.07	194.5	6.46	135.9
13	0.06	316.7	5.27	103.6

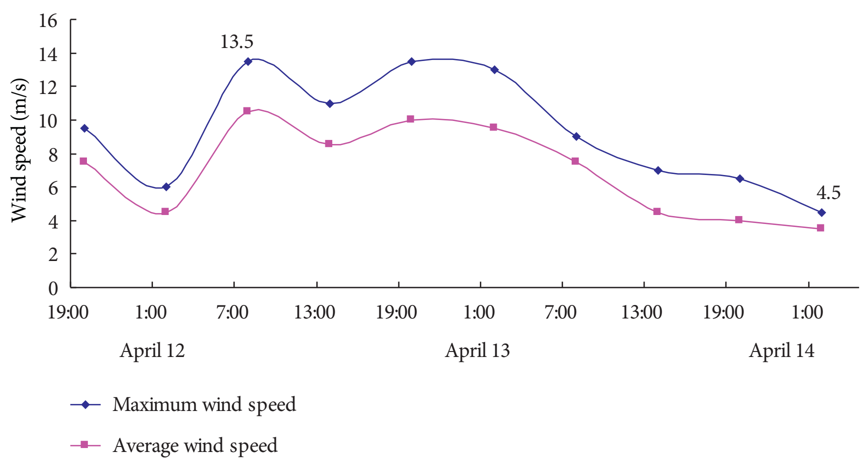

Figure 3: The observed wind direction and speed during the observation under the storm.

and the areas with high sediment concentration are mainly concentrated near the coast and the estuary. The high concentration sediment at the sea inlet is mainly distributed in the sea and its north and south sides. The sediment concentration near the sea inlet is the highest, but the distribution is limited. Medium concentration sediment is mainly distributed within 10–20 km from the shore, and the sea area with sediment concentration less than 5 mg/L is generally beyond 20 km, especially in the area of washed fresh water, with relatively low sediment content. The experimental results show that the distribution characteristics of sediment concentration in the middle water area are basically consistent with that in the surface. The sediment concentration in the bottom water area is significantly higher than that in the surface and middle water areas. The sediment concentration in some areas of the estuary can reach 6500 mg/L, while the water area with sediment concentration >5 mg/L has a large distribution range.

According to the data sampled from different stations, the suspended sediment content during the storm is significantly higher than that under normal weather conditions, as shown in Table 4. The suspended sediment content before the storm (April 10) was determined to be 7.8 mg/L, which was consistent with the results from the four nearby stations during good weather conditions in June 2004 (7.3 mg/L–27.6 mg/L), as shown in Table 5. During the storm event, the suspended sediment content varied from 17.6 mg/L to 121.2 mg/L, as shown in Table 4. To be specific, on the first two days of the storm occurrence (April 11 and 12), the suspended sediment content was around 20 mg/L, slightly increased compared with that before the storm, but it was still in the range of suspended sediment content during good weather conditions according to the observation of June 2004. Conversely, on the last two days of the storm occurrence (April 13 and 14), the suspended sediment content was increased markedly to at least 54.4 mg/L,

TABLE 4: Suspended sediment content before, during, and after the storm surge in April, 2015.

Period	Sampling time Day	Sampling time Hour	Sampling water depth (m)	Suspended sediment content (mg/L)
Before the storm	April 10, 2015	09:00	9.1	7.8
During the storm	April 11, 2015	20:00	8.8	26.8
	April 12, 2015	02:00	9.4	20.0
		08:00	9.1	17.6
		14:00	9.2	21.2
		20:00	9.1	20.8
	April 13, 2015	02:00	9.7	98.8
		08:00	*	
		14:00	9.5	60.0
		20:00	9.2	121.2
	April 14, 2015	02:00	9.4	54.4
After the storm	April 15, 2015	09:00	9.3	28.0

*Data at 08:00 in April 13, 2015, were not used in the analysis because the bottle did not open during the observation period.

TABLE 5: Suspended sediment content in normal weather conditions in June 2004.

Station	Average suspended sediment content (mg/L) Spring tide	Neap tide
3	14.1	7.3
4	15.1	11.7
5	15.6	14.0
6	21.4	27.6

and the maximum value of 121.2 mg/L appeared at 20:00 on April 13.

Combined with the influence of storm factors and seasons on the variation of suspended sediment content, the results show that the sediment content in winter is significantly higher than that in summer. Among them, the suspended sediment at the entrance observation station in winter is 15 times higher than that in summer. The sediment in winter is greatly affected by the change of wind direction and wind force, while the sediment in summer is also affected by wind direction and wind force, but it is smaller than that in winter. Therefore, winter is the main season for sediment transport in the Bohai Sea area, and the transport of suspended sediment to the southern sea area mainly occurs in winter, which is basically consistent with the variation law of sediment in the east coast of China.

3.3. Wave, Current, and Water Level. According to the sediment concentration in the corresponding layer of each observation station and the influence of sediment content on water body density [7–9], the water body density of the observation station can be calculated, and the calculation formula is as follows:

$$\rho_w = \rho_z + s_c\left(1 - \frac{\rho_z}{\rho_0}\right), \quad (1)$$

where ρ_w denotes the density of water body and ρ_z is the seawater density calculated according to the parameters such as temperature, salinity, and pressure, using the international seawater equation of state. s_c is the sediment content and ρ_0 is the sediment density constant.

Consistent with the wind, there were 3 stages of wave process during the observation period, as shown in Figure 4. During stage 1 (from 20:00 on April 11 to 02:00 on April 13), the wave height was increased significantly with a maximum value of 1.82 m at the end. The wave height was kept on a high plane ranging from 1.68 m to 2.43 m at stage 2 (from 02:00 on April 13 to 14:00 on April 13), with the maximum appearing when the wave direction was north-north-east, and then it was decreased gradually at stage 3. Statistics showed that the wave lasted for approximately 21 hours with a significant wave height of more than 100 cm.

The reciprocating motion of the current at the sampling site was strong. Normally, the direction of flood current was north-west and the direction of ebb current was north-east. The effects of storm on flow direction and velocity was significant on the last two days of the storm occurrence (April 13 and 14). Specifically, under the influence of partially north wind, the flow direction in April 13 is eastern-biased, and the current speed was accelerated, with the maximum current speed of approximately 43.8 cm/s appearing at 17:00 on April 13.

Under normal weather conditions, depth of water changed between 9.3 m and 10.0 m. During the storm, there was a clear additional water level increase apart from the tidal level change. For example, the storm caused the low tide level at 20:00 on April 12 to be increased by approximately 30 cm, and the subsequent high tide level in the small hours of April 13 also rose by approximately 40 cm. As shown in Figure 5, the observed current direction, current speed, and water level during the observation under the storm are described.

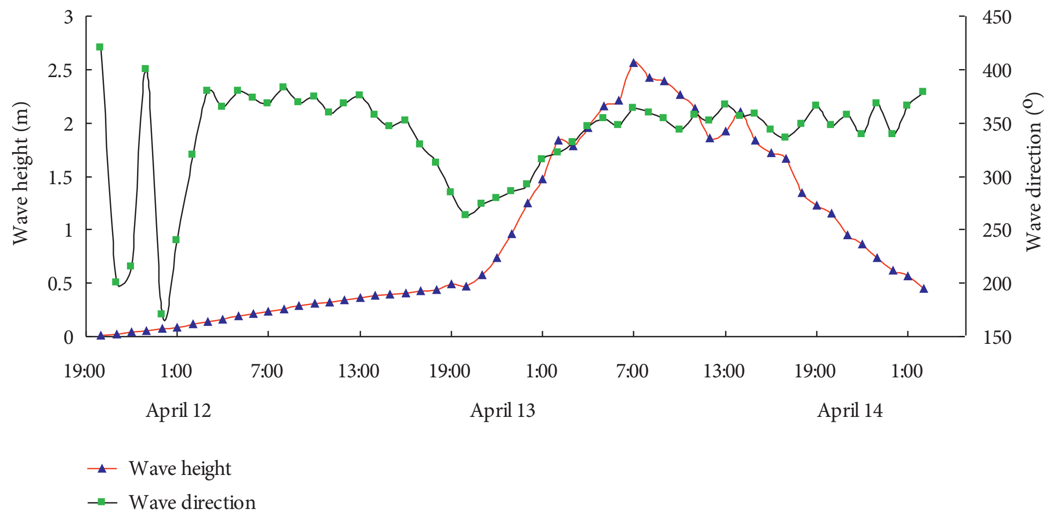

Figure 4: The observed wave direction and height during the observation under the storm.

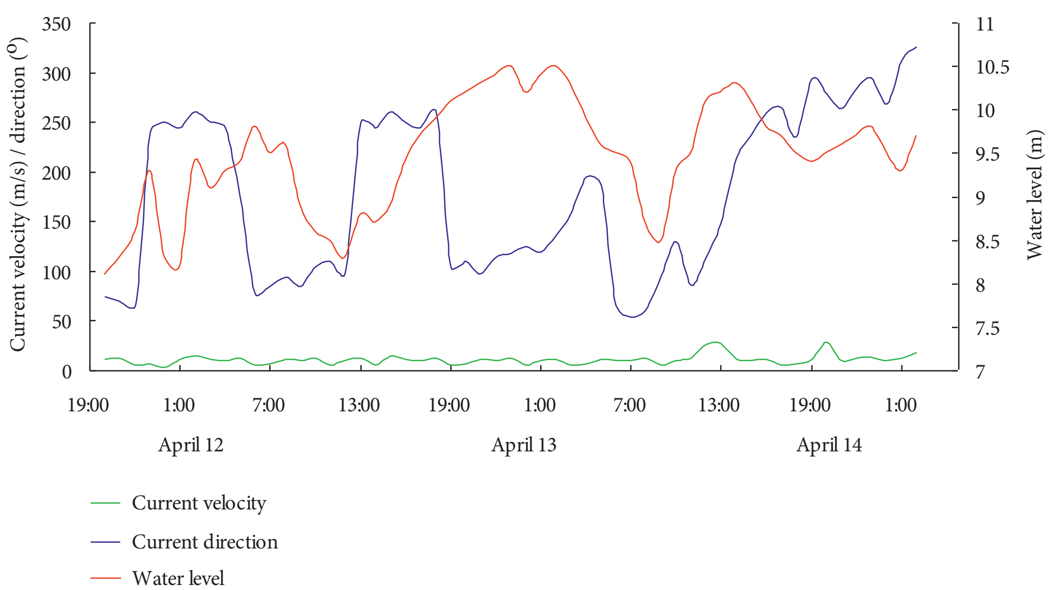

Figure 5: The observed current direction, current speed, and water level during the observation under the storm.

According to the experimental results and existing studies, there is a positive correlation between the force causing sediment movement and wave height. In other words, the higher the waves, the greater the sediment incipient motion and the higher the suspended sediment content [10]. It can be seen that hydrodynamics was closely correlated with wind especially when the wind veered to north, with lag phases of about 6 h for wave and 12 h for current. Then, the seafloor particles were carried by storm-driven wave and current and resuspended in the seawater, resulting in an order-of-magnitude increase in suspended sediment content [11, 12].

It is known from the existing research that during the period of water and sediment regulation, the runoff in the Bohai Sea is large. In the process of ebb tide, the runoff into the sea enters the relevant observation stations due to factors such as high temperature, low salt, and high sediment concentration. As the runoff from the Bohai Sea mainly diffuses on the surface of the water body, there is an obvious density difference between the low-density water body with high temperature and low salt on the surface of the observation station and the high-density seawater with high salt and low temperature on the lower layer, and a density thermocline is formed in a certain water depth [13]. The sediment entering the sea is gradually deposited during diffusion. When the sediment settles to the pycnocline, due to the difference of water density, the suspended sediment cannot continue to settle due to the reverse action of the pycnocline and then form a suspended state near the pycnocline. The research shows that the shear front usually causes a large amount of sedimentation of suspended sediment in the water body, which leads to the rapid sedimentation of surface sediment, the destruction of layered structure, the continuous downward diffusion of upper water body, the continuous increase of temperature and sediment content of lower water body, and the gradual decrease of salinity [14]. It can be seen that the sediment content of the water body after being affected by the shear front shows a downward trend. In the process of diffusion to the sea, due to the capture effect of the circulation, most of the sediment entering the sea is deposited in the area about 15 km away from the estuary. At the same time, because the high concentration of suspended sediment generally cannot reach the surface of the water body, these sediments are mainly distributed in the water area below the thermocline [15, 16].

From the density distribution of water body and the vertical distribution law of velocity, in order to reflect the vertical structure difference of water body, the vertical coefficient of water body V_w can be calculated according to the following formula:

$$V_w = -\frac{(g/\rho_w)(d\rho_w/du)}{(dy/du)^2}, \tag{2}$$

where ρ_w indicates the density of water body, y is the horizontal velocity of water body, and u is positive upward. The denominator reflects the sediment flow caused by the flow velocity of the water body, and the numerator reflects the stratification structure strength caused by the change of water density. When $V_w > 0.3$, it means that the intensity of water body stratification structure is greater than the sediment flow caused by the action of water velocity; at this time, it is mainly stratified structure. While $V_w \leq 0.3$ means that the water body is mainly sediment flow.

3.4. Bottom Sediment Composition and Particle Size. According to Shepard's ternary diagrams, S (sand), TS (silty sand), and ST (sandy silt) were successively distributed along the measured section [17]. The sand content decreased, while the silt, which can be suspended, increased with the offshore distance and the water depth along the section. Station 9, the nearest bottom sediment sampling site to the suspended sediment sampling site (station 1), was located in shallow sea area around the 10 m depth contour, where the bottom sediments were composed of a large amount of sand (92%) and a small amount of silt (8%).

The particle size of the bottom sediments in the study area became finer from the coast to the sea. Station 9, the nearest bottom sediment sampling site to the suspended sediment sampling site (station 1), was located in shallow sea area around the 10 m depth contour, where the medium diameter (Md) was about 3.3 φ (0.102 mm). As shown in Figure 6, the composition and medium diameter of the bottom sediment along the cross-section are described.

According to the Misaki Sato's empirical formula [18, 19], 2.0 m-high wave can cause sediment surface movement with a particle size of 0.1 mm under a water depth of 10 m, and intense movement of sediment with a particle size of 0.1 mm under a water depth of 10 m will be induced by wave with a height of 2.8 m, as shown in Table 6.

The water depth of sediment surface movement is calculated as

$$\frac{H_0}{L_0} = 1.35\left(\frac{d_m}{L_0}\right)^{1/3} \sinh\left(\frac{2\pi D_C}{L}\right) \cdot \frac{H_0}{H}. \tag{3}$$

The water depth of sediment intense movement is calculated as

$$\frac{H_0}{L_0} = 2.40\left(\frac{d_m}{L_0}\right)^{1/3} \sinh\left(\frac{2\pi D_C}{L}\right) \cdot \frac{H_0}{H}, \tag{4}$$

where H_0 denotes the deep-water wave height, L_0 is the deep-water wave length, H represents the wave height at the calculation point, L shows water depth at the calculation point, D_C indicates the water depth of sediment movement, and d_m expresses the medium diameter of bottom sediment.

During the observation period in this study, the maximum wind speed was 13.5 m/s, and the maximum wave height was 2.43 m, leading to the sediment surface movement of station 1. This is just a representative of wind and wave with moderate intensity in coastal area of the north side of Longkou City. According to the statistical data of Longkou Ocean Station, the occurrence frequency of wind with the speed of more than 10.8 m/s is 8.44%, the occurrence frequency of wave with the height of more than 2 m is 8.7%, and the maximum wave height is 7.2 m, as shown in Table 7. Thus, it is reasonable to suspect that the suspended sediment content measured in April 2015 is far from the maximum for the study area, and more seabed sediments will be suspended under stronger storm events, especially when sediment intense movement is caused by wave ranging from 2.8 m to 7.2 m.

According to the sediment content measured by some scholars in summer and the estimated water outflow from the Bohai Sea, the sediment flux from the Bohai Sea to the Yellow Sea can be calculated, which is basically consistent with the observation results in this paper. This shows that although the observation stations selected in this experiment are different from previous studies, the observation results are basically consistent.

Although the amount of sediment entering the sea of the Yellow River is decreasing, its impact on the sediment content in the Bohai Sea is not significant [20, 21]. The predecessors did not consider the seasonal variation of suspended sediment content and flow in the study area, which makes the calculation of sediment content inaccurate. In addition, the material transported from the Bohai Sea to the Yellow Sea is mainly the suspended sediment from the Yellow River into the sea caused by storms in winter [22]. In addition to the newly deposited sediment, it also includes the sediment from the Yellow River Delta into the sea. Compared with the previous research results, this paper considers the seasonal variation, but the experiment is mainly based on the measured data in winter, and the continuous observation stations selected are limited. Therefore, the calculation of suspended sediment content and its variation affected by storms in the Bohai Sea is also rough [23]. If we want to obtain more accurate results, we need to observe at multiple continuous stations in different seasons over a long period of time in the future. Nevertheless, the observation results

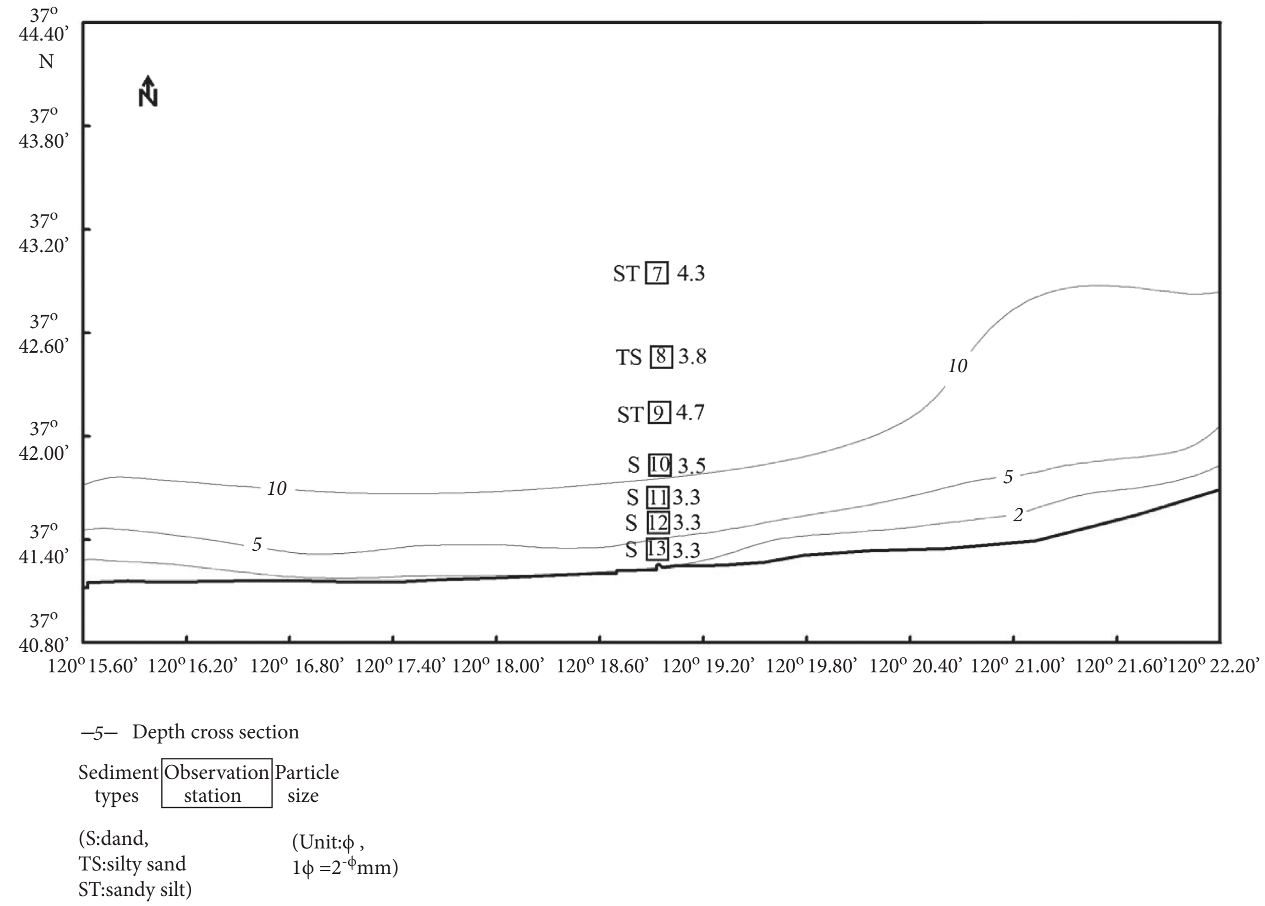

Figure 6: Composition and medium diameter of the bottom sediment along the cross section.

Table 6: Water depth of sediment movement with a particle size of 0.1 mm according to wave with different heights.

$H_{1/10}$ (m)	Water depth of sediment surface movement (m)	Water depth of sediment intense movement (m)
2.0	10.07	6.97
2.8	14.57	10.01

Table 7: Occurrence frequencies of wave with different heights in Longkou ocean station.

Wave height	Occurrence frequency
$H_{1/10} \leq 0.9$ m	71.66
$1.0\,m \leq H_{1/10} < 2.0$ m	19.74
$2.0\,m \leq H_{1/10} < 3.0$ m	5.76
$H_{1/10} \geq 3.0$ m	2.90
Total	100.00

obtained in this experiment have been greatly improved compared with previous studies, and the change of suspended sediment content is obtained under the influence of storms in winter and spring [24]. If the effects of other seasonal storms or geological factors on the suspended sediment content and its changes are considered, the sediment content formed in the Bohai Strait may be doubled higher than the results obtained in this paper, which is also a problem that needs to be verified by experimental observation in the future [25–27].

4. Conclusion

Most of the existing achievements were based on the impact of storms on land sediment, but there was a lack of research on the impact mechanism of storms on suspended sediment. Therefore, this paper took the sediment suspension on the North Bank of Longkou City in the south of Bohai Sea as the research object. By monitoring the impact of storm on sediment suspension in the south of Bohai Sea, this paper explored the formation and action law of storm on suspended sediment from the perspective of hydrodynamic characteristics and sediment distribution. Through the test sampling and analysis of different observation stations, the results showed that under normal weather conditions, the suspended sediment content was 7.8 mg/L, reaching the highest value of 121.2 mg/L during the storm. When a storm surge occurred in the coastal area on the north side of Longkou City in the south of the Bohai Sea, the maximum wind speed was 13.5 m/s and the maximum wave height was 2.43 m. At a water depth of 10 m, the surface movement of seabed sediments was caused, and the content of suspended sediment increased to 121.2 mg/L. The test results showed that the strong dynamic process during storm surge led to the movement of sediment surface and the resuspension of sediment. The research results of the impact of storm on the sediment suspension on the North Bank of Longkou City in the south of Bohai Sea will have certain guiding significance for exploring the diffusion of suspended sediment and its impact on the formation of surrounding landform.

Data Availability

The labeled dataset used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Yongqiang Zhang wrote the manuscript. Yongfu Sun and Yongfu Sun designed the experiment. Wanqing Chi and Shuhua Bian undertook the experimental tasks and data processing work. Jianqiang Liu and Bingzhi Huang prepared the figures. All authors reviewed the manuscript.

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