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Research On The Hydrodynamics Of Seagoing Rivers Affected By Marine Monsoon: A Case Study In Duliujian River

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ABSTRACT
In this study, the surface water flow velocities were seasonally measured in the Duliujian River and the hydrodynamical characteristics of seagoing river affected by marine monsoon were also analyzed from the perspective of flow velocity distribution. The results showed that the distribution of the surface water flow velocity in the Duliujian River was significantly affected by the wind. The flow velocity distribution was found relatively irregular in winter and the maximum value was larger to near twice of that of the other three seasons. For the other three seasons, the large flow velocity regions were moved downstream season by season while the maximum flow velocities were very close. The results of this study may provide some inspiration to the comprehensive understandings on the wind driven surface water flow in rivers.
Keywords – Hydrodynamics, Flow velocity distribution, Duliujian River, Seagoing rivers, Marine monsoon

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I. INTRODUCTION

As an important link in water resources recycling, natural rivers play important roles in water supply, power generation, shipping, aquaculture, tourism, as well as aquatic ecology [1]. River-to-sea material is the basis of the coastal geology, geomorphology and biogeochemical processes, and its transmission is an important way of geochemical cycle of the earth [2-6]. As such, the water quality and pollutant transport flux of seagoing rivers have attracted increasing attention as an important issue of land-to-sea impacts [7].

The hydrodynamics of seagoing rivers are complex due to the complex interactions among the upstream water flow, tides, oceanic monsoon, etc. [8]. Particularly, the seasonal hydrodynamics of such seagoing rivers must significantly affect their biogeochemical processes and the other functions, especially for these rivers affected by the marine monsoon [9]. In order to reduce the effects of seawater intrusion on farmland, sluice gates were built at most of the estuaries of seagoing rivers in China [10]. Therefore, such seagoing rivers mostly presented as long and narrow lakes for most of the year, and the main driving force for the hydrodynamics of the surface flow were wind-driven flow caused by the marine monsoon [11-12].

In previous studies on wind-driven flow, more attention has been focused on surface water flow in shallow-lakes. The effects of wind-driven flow on pollutant diffusion was investigated by Wang et al.

with 3D numerical simulation method [13]. The results showed that the water quality model with wind-driven flow was more accurate in determining the environmental objective whether it was affected by the marine sewage or not [13]. In North Coast of Rio Grande do Sul, Brazil, Cardoso and Marques studied the rate of change of the phytoplankton community in Itapeva Lake where the hydrodynamic regime was driven by wind on daily and seasonal scales [14]. It was demonstrated that more abrupt rises in the rates of plankton succession occurred in a shallow lake driven by wind (where the wind velocities and directions fluctuated constantly) such as Itapeva Lake rather than in the Lake Batata where the environment was ruled by the changes of water level [14]. In Anderson and Schwab's research, the mixing and the relationship between hydraulic and wind-induced currents in a shallow lake system within a river delta utilizing a 3D hydrodynamic forecasting model of the Great Lakes Huron-Erie Corridor [15]. Based on the research results, the dependence of the hydraulic flow with the lake-river delta system on the wind field was emphasized, the variation of the dominated force of the surface water flow in the lake was also demonstrated [15]. Although research on the wind-driven flow in shallow lake can be found commonly in literature, such research on the wind-driven flow in seagoing rivers was relatively rare.

In this research the seasonal hydrodynamics of seagoing river affected by marine monsoon were studied based on seasonal measurements of hydraulic parameters in Duliujian River which is located in the southern area of Tianjin, China. The results of this study may promote the comprehensive understandings and provide some inspirations on the wind-driven hydrodynamical characteristics of seagoing rivers.

II. STUDY AREA AND METHOD

2.1 Study area

Duliujian River, which is an important artificial flood channel and an important flood control line for the Tianjin City, China, is located in the southern region of the city (see Fig. 1). Since that the Duliujian River is located near the Bohai Bay, the area of the Duliujian River is within the temperate semi humid continental monsoon climate zone [16]. It can be known from literature that the daily average temperature is 12.8℃ in this zone, the average daily water vapor pressure is 1180Pa, amd the daily average rainfall is 1.4mm, and daily average wind speed is 4.1m/s [17]. At the watershed scale, the Duliujian River belongs to the southern Haihe River Basin system. In addition, most of the rivers in the basin are connected with the Duliujian River and lead the flood into the Bohai Bay. It is therefore also the main seagoing channel of downstream Daqing River, Ziya River, etc. As can be seen in Fig. 1, beginning with Jinghai County, the river runs through three districts and counties, namely Jinghai, Xiqing and Dagang, and then reaches the estuary flood gate which is named Gongnongbing Gate. In total, the Duliujian River is 67km in length and runs through the northern boundary of these counties from west to east. Generally speaking, the river channel of the Duliujian River is broad and straight. In addition, the Duliujian River is also the main recharge water source of Beidagang wetland, an important station for migratory birds in eastern Asia.

Fig. 1 The geographical location of the Duliujian River

The Duliujian River is a typical wide and shallow river with a maximum width of about 1km in the upper and middle reaches. The river channel of Beidagang section downstream from Wanjia Wharf with a length about 18.7km has an extremely great width up to 5km. In this section, a unique river channel wetland was formed since the decrease of the upstream water flow discharge. Since that the Duliujian River connects two coastal wetland ecological environment protection zones including Beidagang Wetland Nature Reserve and Tuanbo Bird Nature Reserve, the mainstream of the Duliujian River was also assigned into the area of these nature reserves. As such, apart from the functions of flood control and irrigation, the Duliujian River also has extremely special and important ecological significance. According to the “Tianjin Space Development Strategic Plan” formulated in 2016, the Beidagang Reservoir - Duliujian River - Tuanbowa Reservoir constitutes the ecological corridor running through the east and west in the southern part of Tianjin. This area is therefore the core area of the ecological construction in southern area of the city.

Overall, as a seagoing river affected by marine monsoon, the Duliujian River is an artificial river excavated in the coastal area of the lower reaches of Haihe River Basin and has its own unique characteristics. It was therefore selected as the research object in this study.

2.2 Experimental method

In order to investigate the hydrodynamical characteristics of seagoing river affected by marine monsoon, the hydraulic parameters including surface flow velocity and the flow depth were measured at set measuring points with field experiments in Dec. 2016, May, Jul. and Sept. 2017. Before the field experiments were conducted, the Gongnongbing Gate at the estuary was confirmed to be closed to avoid the effects of tides.

For the filed experiments, 15 measuring transverse cross-sections were set along the whole Duliujian River with a near uniform interval of 5km. In addition, 3 measuring points were uniformly distributed on each transverse cross-section since that the width of the Duliujian River is relatively high. Therefore, there were 45 measuring points all over the river.

At each measuring points, the surface water flow velocity was measured with the Micro ADV (SonTek 3D 16-MHz Micro Acoustic Doppler Velocimeter) at 0.5m below the water surface, while the flow depth was determined by a measuring tape with a heavy hammer hung. For the flow velocity measuring, the sampling time at each measuring point was set to 60s since that the measured mean flow velocity would be stable when the sampling time is larger than 45s [18, 19]. Then, the time-averaged flow velocity (V) could be calculated with 3000 instantaneous samples at each measuring point as the frequency of the ADV was set as 50Hz. Besides, the signal-to-noise ration of these velocity measurements were maintained above 15 to ensure the quality of the data [20]. For the flow depth measuring, 3 times were measured at each measure point and the average value was adopted as the final measured flow depth (h).

III. RESULTS AND DISCUSSION

After the field experiments, the data of the surface water flow velocity and flow depth measured in the Duliujian River were statistically analyzed. And the time-averaged value of the surface water flow velocity (V) and the final measured flow depth (h) were obtained for each measuring point in the river. Then, these results were potted in the figures in order to further analyze the hydrodynamical characteristics of seagoing river affected by marine monsoon.

As can be seen in Fig. 2, the maximum value of the surface water flow velocity in Dec. 2016 was up to 63.8cm/s which is the largest in four different seasons. However, the overall variation and distribution of the flow velocity in Duliujian River was obviously very irregular. There were several regions where the flow velocities were locally much higher than the other areas, and such large flow velocity regions were distributed in all the upper, middle and lower reaches in the river. The difference was that the area of the region with larger flow velocity was larger in the upper reach than the other two regions. Besides, all these large flow velocity regions were near the edge of the river. This may be due to that the wind was distributed unevenly in space, and there was locally strong wind of short period in winter.

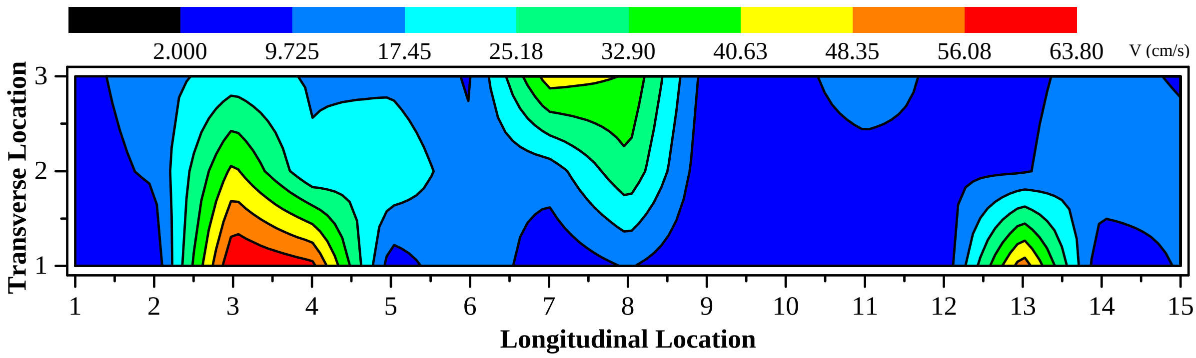

Fig. 2 The 2D plan view of the flow velocity (cm/s) distribution of the Duliujian River in Dec. 2016

The 2D distribution of the flow velocity of the Duliujian River in May 2017 was plotted in Fig. 3. As can be seen in the figure, the variation of flow velocity in the river was obviously the most uniform in comparison with those of the other seasons. The maximum value of flow velocity was about 33.20cm/s which is about half of that in winter (Dec. 2016). However, there were also three regions where the flow velocity was relatively higher than the other region. But these regions were large enough and more regions were distributed in the central area along the river width, and then the distribution of flow velocity seemed more uniform in this season. The relatively more uniform and stable wind in the spring season might be responsible to this phenomenon.

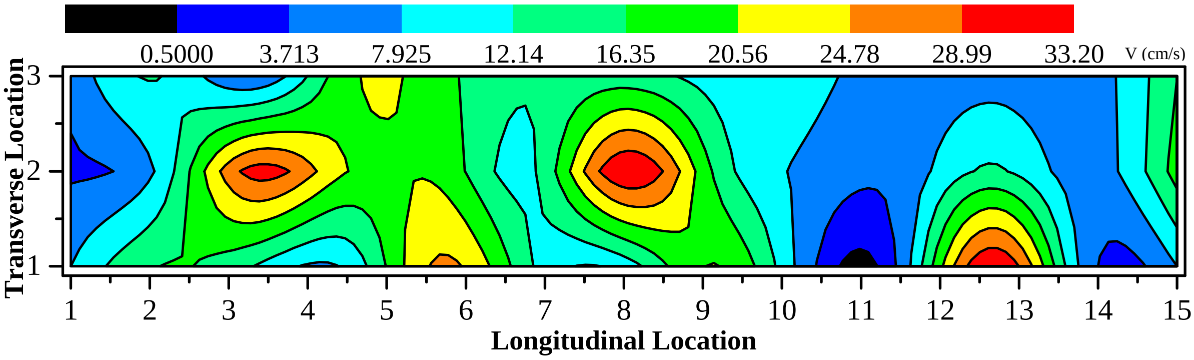

Fig. 3 The 2D plan view of the flow velocity distribution of the Duliujian River in May 2017

For Jul. 2017 which presented summer, both the flow velocity and the large velocity area in the upstream reach were narrowed (see Fig. 4) although the maximum flow velocity in the whole river was 32.50cm/s which was very close to that in spring (May 2017). The region in the middle reach was similar to that in May 2017. In the lower reach, the large flow velocity region was extended. In summary, in comparison to the spring season, the large flow velocity region in summer was reduced in upper reach and expended in the lower reach, while that in the middle reach varied slightly. That means the influences of the wind in summer on the surface water flow velocity in the inland areas was weakened and the impacts on coastal areas was increased.

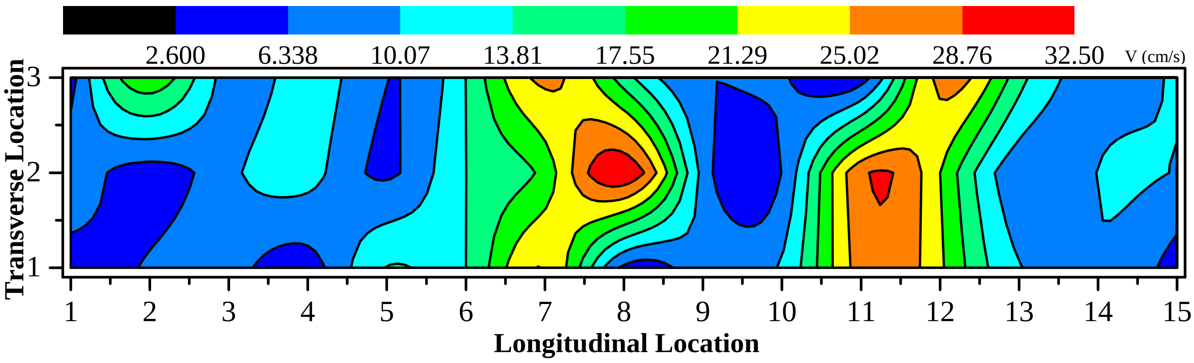

Fig. 4 The 2D plan view of the flow velocity distribution of the Duliujian River in Jul. 2017

In Sept. 2017, similar to the variation tendency concluded from the comparison between the results of spring (May 2017) and summer (Jul. 2017) seasons, the large flow velocity area in the continued to moved downstream. As can be seen in the Figure 5, in Sept. 2017 (autumn), the region with large flow velocity in the middle reach was moved downstream from the area between the transverse cross-sections 6 and 9 to the area between the transverse-sections 6 and10 in comparison with that in summer (Jul. 2017), and the flow velocities within the region were also greatly reduced. The large flow velocity area in the lower reach was also moved downstream from the area between the transverse cross-sections 10 and 13 to 13 and 15. Besides, the maximum value of flow velocity in this season was 33.70cm/s which is also very close to that in spring (May 2017) and summer (July 2017) seasons.

In summary to these four seasons, except that the distribution of surface water flow velocity was relatively irregular, the large flow velocity region moved downstream from the spring, summer to autumn season while the maximum flow velocities were very close in different seasons.

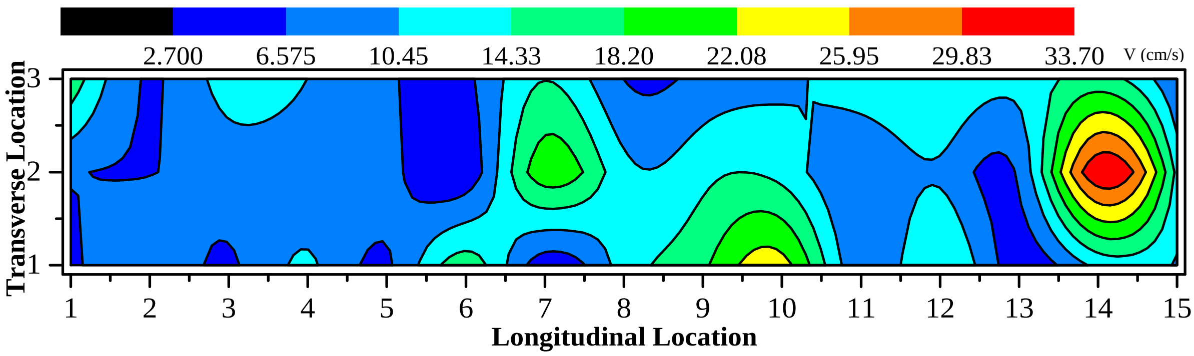

Fig. 5 The 2D plan view of the flow velocity distribution of the Duliujian River in Sept. 2017

IV. CONCLUSION

Based on the filed measurements of surface water flow velocity in Duliujian River. The seasonal hydrodynamics of seagoing rivers affected by marine monsoon was investigated from the perspective of the variation of flow velocity distribution. Based on the results, the following conclusions could be drawn. The surface water flow velocity in the Duliujian River was significantly affected by the seasonal variation of wind. In winter, the distribution of flow velocity was relatively irregular with the highest value about twice of the other seasons. In the other 3 seasons, although the maximum flow velocities in the river were very close, the large flow velocity regions were moved downstream season by season. The results of this study may promote the comprehensive understandings on the wind driven surface water flow. However, further research based on the data of real-time online monitoring are needed to analyze the detailed effects of wind on the hydrodynamical characteristics of surface water flow in rivers.

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