Analysis on Channel Deposition and Erosion in Liaohe River

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Abstract. For study the deposition and erosion of on channel of Liaohe, the annual series of data of hydrological stations is based and supplies sediment budget to study temporal and spatial contribution of sediment; Using statistical methods to study the relationship between sedimentation of the main deposition area and water and sediment from different sediment district. Research have shown that Liujian-fang to Juliu-he is a big deposition district; Changes of sediment area-Liuhe play a main role in controlling changes of sedimentation in channel of Liaohe; For change the question of deposition, the management of soil erosion should be enhanced in Liuhe basin.

1. Introduction

A river basin can be divided into transporting, erosion, and sedimentary zones, with coupling relationships between them [1]. For large watersheds with water-sediment heterogeneity, the sediment effects of different water-sediment sources on the sedimentary processes differ [2]. Based on this understanding, downstream sedimentation can be alleviated by targeting the sediment source area with the greatest impact. Thus, the pressure of sediment deposition on flood control infrastructure can be reduced.

Liao River has the third highest sediment concentration in China, higher than that of the Yellow and Hai rivers, with an average annual sediment load within the lower reaches of $1,187.96 \times 10^4$ t. The current study used a large amount of data to conduct a systematic analysis of sediment deposition characteristics of the middle and lower reaches of the Liao River, which is of theoretical and practical significance.

2. The overview of the study area

Liao River Basin (LRB) is located within the southern part of Northeast China, and is one of China’s seven major rivers. The confluence of its two main tributaries (East and West Liao rivers) is regarded as the main stem, which runs through Fudian, Changtu and Liaoning. The middle and lower reaches run from the Fudedian-Liujianfang estuary within Liaozhong County. The area of the LRB is approximately $4.5 \times 104$ km\textsuperscript{2} with a total length of 512 km. The LRB has a hilly topography from Fudian to Tieling, after which the basin becomes flatter with densely distributed tributaries. The LRB contains 129 tributaries with combined catchment areas of > $100$ km\textsuperscript{2}, with 29 being first class tributaries. The middle reaches of the LRB extend from Fudian to Juliuhe, with the Zhaosutai, Qing, Chai and Pan rivers joining from the east and the Xiushui and Yangximu rivers joining from the west. The lower LRB extends from the lower reach of the Juliuhe River to Liujianfang estuary, into which the Liu River enters from the west.
3. Data sources and the study methods

The sediment budget method was used to estimate sediment deposition for the middle and lower reaches. Fudian station marks the point at which the two main tributaries of the upper reach (East and West Liao rivers) join the main stream. The catchment area of West Liao River accounts for 90% of the total basin area above Fudian and 67% and 92.8% of annual runoff and sediment transport, respectively. However, East Liao River accounts for less water and sediment for which there are less available data; therefore, these data were not included. Thus, Fudian station was regarded as the control station of West Liao River, and cumulative water and sediment from the Sutai, Qing, Chai, Pan, Xiushuir and Xiumu tributary rivers can be calculated from the difference between those measured at the Juliuhe and Fudian stations. Liu River (a downstream tributary) joins Liao River at the Xinmin and Liujianfang stations at the exit of Liao River. The relationship between the sediment input and output for the middle and lower reaches of the Liao River is represented in Fig. 1.

Based on the sediment budget, annual sediment deposition for the middle and lower reaches of the Liao River is:

\[
\text{Sediment load} = \text{input load} - \text{output load}
\]  

(1)

Sediment deposition for the middle and lower reaches of the Liao River was calculated by Eq. 1 to determine the key sedimentary reach, after which a statistical method was used to correlate sediment deposition of the key stream segment with the hydrology and sediment characteristics of the upstream water and sediment source areas. An empirical statistical correlation was established [8] to reveal the relationship between the sediment deposition in the middle and lower reaches of the Liao River and the water and sediments amounts for different upstream water source areas. Thus, the most influential sediment source area for the key sedimentary stream segment was determined.
4. Research results

4.1. The division of the water-sediment source area
Runoff and sediment transport of the main tributaries of the east and west sides of Liao River were compared based on hydrological data for 1988–2005. The western tributaries contributed considerably less than that of the eastern tributaries, with the eastern tributaries accounting for 57.52% and 11.61% of total runoff and total sediment, respectively, whereas the western tributaries accounted for 42.48% and 88.39%, respectively. In particular, the Xiliao and Liu rivers accounted for 43.78% and 34.11% of total sediment, respectively. The annual sediment yields of the Xiliao and Liu river basins were 53.77 t km\(^{-2}\) and 366.09 t km\(^{-2}\), respectively; therefore, it is evident that water and sediment of the Liao River is derived from different sources, with water from the east and sediment from the west. The tributaries of the Xiliao and Liu rivers are the key sediment producing areas of the Liao River, which can be termed the “sandy area”. The remaining areas, mainly the catchments of the East Liao, Zhaosutai, Qing, Chai and Pan rivers, can be considered as areas contributing little sediment and clear water.

4.2. The temporal and spatial distribution of sediment deposition
Fig. 1 shows that sediment in the Fudian–Tieling stream segment of the Liao River was mainly caused by scouring from 1988 to 2005, whereas that below Tieling mainly resulted from deposition. In addition, few scouring periods were evident with a small scouring amount. Most sediment deposition occurred from Juliu to Liujianfang. As shown in Table 2, Liao River contained large amounts of water and sediment from 1988 to 1999; thus, the stream segments of Liao River undergo both heavy scouring and deposition. In addition, the highest sediment deposition was found for the stream segment from Juliuhe to Liujianfang at 5,630 \times 10^4 t over 12 years, with an average annual deposition 511.82 \times 10^4 t. There was limited flow during 2000–2005 resulting in only light scouring of the stream segments above Tieling. Sediment deposition in the stream segment from Juliuhe to Liujianfang was 308.21 \times 10^4 t at an annual average of 61.64 \times 10^4 t. Sediment deposition in the stream segment from Fudian to Liujianfang for 1988–2005 was 7969.64 \times 10^4 t. Sediment amounts deposited in the stream segments from Juliuhe to Liujianfang and Tieling to Juliuhe were 5,938.21 \times 10^4 t and 2,031.43 \times 10^4 t, 74.51% and 25.49% of the total, respectively. Therefore, the stream segment from Juliuhe to Liujianfang in the middle and lower reaches of the Liao River was identified as a sediment source area.

4.3. The relationship between annual sediment deposition and water-sediment within the Juliuhe–Liujianfang stream segment
Table 3 shows the relationship matrix between annual sediment deposition and water-sediment for the Juliuhe–Liujianfang stream segment in the upper reaches. It is evident that the correlation coefficients between Sdep and J-L and the annual water-sediment transport of the Fudian station are 0.50 and 0.55,
respectively, whereas those for the Xinmin station are 0.74 and 0.86, respectively; significance correlation coefficients for Fudian station were 0.119383 and 0.095041 respectively, whereas those for the Xinmin station were 0.037269 and 0.020192, respectively. It is evident that annual sediment deposition for the Juliuhe–Liujianfang stream segment is significantly correlated with annual water-sediment transport for Xinmin station, but not for Fudian station. The correlation coefficients for the above relationships for the east and west tributaries for Fudian to Juliuhe were low and not significant. Therefore, it can be concluded that annual sediment deposition of the Juliuhe–Liujianfang stream segment is mainly controlled by the sediment flowing from the Liu River sandy area, and is not closely related to the sandy areas of the Xiliao and Qingshui rivers.

Table 1. Correlation coefficient values between sediment deposition in the Juliuhe–Liujianfang stream segment and water-sediment from different source areas (1988–2005)

| Qw, Fudedian | Qw, Liujianfang | Qw, Xinmin | QS, Fudedian | QS, Liujianfang | QS, Xinmin | Sep, J-L |
|--------------|----------------|-----------|-------------|----------------|-----------|---------|
| Qw, Fudedian | 1.00 | 0.69 | 0.13 | 0.97 | 0.73 | 0.21 | 0.50 |
| Qw, Liujianfang | 0.69 | 1.00 | 0.22 | 0.60 | 0.78 | 0.17 | 0.42 |
| Qw, Xinmin | 0.13 | 0.22 | 1.00 | 0.11 | 0.19 | 0.83 | 0.74 |
| QS, Fudedian | 0.97 | 0.60 | 0.11 | 1.00 | 0.64 | 0.23 | 0.55 |
| QS, Liujianfang | 0.73 | 0.78 | 0.19 | 0.64 | 1.00 | 0.28 | 0.33 |
| QS, Xinmin | 0.21 | 0.17 | 0.83 | 0.23 | 0.28 | 1.00 | 0.86 |
| Sep, J-L | 0.50 | 0.42 | 0.74 | 0.55 | 0.33 | 0.86 | 1.00 |

4.4. Analysis of the relationship between annual sediment deposition of the Juliuhe–Liujianfang stream segment and water-sediment of the Liu River for the entire year and flood season.

Fig. 2 shows the relationship between water-sediment for the Xinmin station on the Liu River and sediment deposition for the Juliuhe–Liujianfang stream segment for the entire year and flood season. A power function was fitted to the regression relationship and significance of the correlation coefficient was tested. The results showed a significant correlation coefficient at P = 0.05.

It is evident that sediment deposition for the Juliuhe–Liujianfang stream for the entire year and flood season shows a good correlation with that for the Xinmin station. However, the calculated coefficients show that the relationship is stronger in the flood season than that for the entire year, indicating that the sediment contribution of the Liu River to sediment deposition in the Juliuhe–Liujianfang stream segment is slightly larger in the flood season. The relationship between sediment deposition of Juliuhe–Liujianfang stream segment for the entire year as well as for the flood season and sediment at the Xinmin station shows that sediment deposition is proportional to inflow, with the trend evident during the flood season being larger than that for the whole year. Thus, the contribution of inflow volume from the Liu River to sediment deposition within the Juliu–Liujianfang stream segment during the flood season is larger. The sediment yield of the Juliuhe–Liujianfang stream segment was proportional to inflow for the Liu River, since sediment yield increases with inflow in the Liu River. Since the Naodehai reservoir situated in the upper reaches of the Liuh River has adopted an operation mode focused on storing and clearing of turbid water, increasing sediment will be transported downstream during the flood season under the same flow rate, which results in increasing of sediment deposition with erosion in the lower reaches during the flood season. Stronger runoff may result in this relationship becoming more complex.

The above analyses shows that sediment deposition for the lower reaches of the Liao River is mainly controlled by the water and sediment originating from the Liu River sandy area. Moreover, more water and sediment is transported by the Liu River during the flood season compared to that for the entire year. Liu River is well known in China to carry a high sediment load since the basin contains many barren mountains, which results in serious soil erosion. A large amount of sediment is transported to the Liao River after Naodehai reservoir. Since floods in the Liu River are isolated from those of the Liao River, most sediment is deposited at the mouth of the Liu River and the lower
reaches of the Liao River. Therefore, the river bed is continuously raised and the flood discharge capacity of the river is reduced, which seriously affects industrial and agricultural production as well as river traffic safety in the lower reaches of the Liao River. Appropriate management of the Liu River is important for increasing profits, removing pest species and reducing sediment.

**Fig. 3** The relation between the coming water and sediment df xinmin and the deposition of the lower reaches df liaohe

5. Conclusion

Sediment found in the lower reaches of the Liao River is mainly due to long-term deposition and minor erosion. The Juliuhe–Liujianfang segment is therefore a strong sediment deposition area. Sediment deposition in the Juliu–Liujianfang stream segment is mainly controlled by water and sediment originating from the Liu River sandy area, which is not closely related to water and sediment from the less sandy catchments of the Xiliao and Qingshui rivers. Sediment deposition of the Juliu–Liujianfang stream segment shows a good correlation with water and sediment at the Xinmin station on the Liu River for the entire year and flood season. In addition, the flood season contribution to sediment deposition for the Juliuhe–Liujianfang segment is larger than that for the entire year. Urgent soil management in the Liu River catchment is required to reduce the problem of sediment deposition in the lower reach of the Liao River.

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