

## **Variability in stream sediment transport in Liaoning Province and its relation to environmental change**

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**Abstract** Soil erosion and its related sediment transport are major issues of central importance in considerations of environmental change. Using long-term records on precipitation and sediment transport, the characteristics and variability of sediment yields of streams in east and west parts of Liaoning Province are set forth in this paper. The influence of temporal and spatial scales on variability of sediment transport is analyzed. After analyzing the main factors of influence, the relation between variability in fluvial sediment yield and environmental change, including that caused by human activity, is presented. The future development of fluvial sediment transport for the next decade is predicted.

### **INTRODUCTION**

Erosion caused by water is the most important factor in changing an ecological environment. Liaoning Province, one of the economically developing provinces in China, is in the southern part of northeast China (Fig. 1) where water and soil conservation are problems concerning social and economic development. Because the province has different regions, the eastern part being humid hills and mountains and the western part being semiarid hills and lower mountains, there are different characteristics and variability of sediment transport in the different parts of the province.

Analysis of the relation between variability of fluvial sediment transport and physical environment, which is conditioned by geography and human activity, makes it possible to assess the efficiency of basin management and estimate fluvial sediment yield on the basis of environment. It is believed that the analysis of variability in fluvial sediment transport in the province may be of substantial significance for the effective and reasonable development of the water resources and of the economy.

### **BACKGROUND**

The south of Liaoning Province faces two seas – the Bohai Sea and the Yellow Sea. There are many large rivers within the province, such as the River Liao and its tributary the River Qing, the River Hun, the River Taizi and the River Daling, all of which flow into the Bohai Sea. The River Yaiu and its tributary, the River Ai, flow into the Yellow Sea. There are also many medium and small rivers that flow directly into sea, such as the Rivers Xiaoling and Liugu which flow into the Bohai Sea, and the Rivers Biliu and

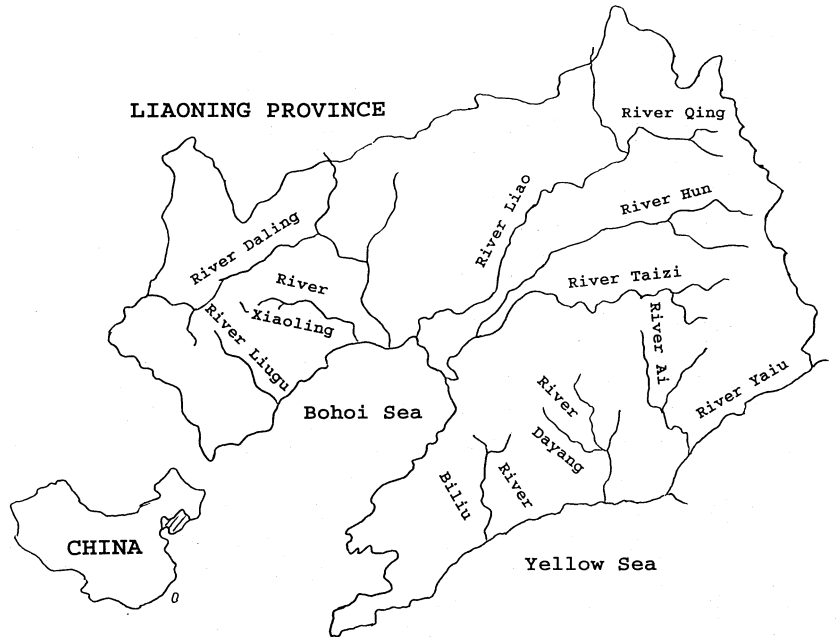


Fig. 1 Map showing location of study area.

Dayang which flow into the Yellow Sea. The province is in the humid, temperate zone and has a continental, monsoonal climate. Mean annual temperature decreases gradually from south to north and varies between 4.6 and 10.2°C. Average annual precipitation in the province varies from 400 mm in the northwest to 1200 mm in the southeast. In the eastern part of the province the elevation gradually decreases from east to west; in the western part, elevation gradually decreases from west to east. Mountains in the eastern part of the province consist mainly of two mountain chains, the Changbai and Qianshan, that constitute the watershed divide between Rivers Liao, Hun, Taizi, Yaiu, Dayang, Biliu and others. In the western province, the Nuluerhu, Songlin and Daqing Mountains form watershed divides separating the basins of the Rivers Daling, Xiaoling, Liugu and others. The geology of the east region of Liaoning Province is dominated by old metamorphic rocks and granites. There are carbonatite and fragmentary rocks of marine deposits of the Palaeozoic Era distributed in most parts of the region (Yin, 1993). The geology of the west region is mainly sandstone and conglomerates of Cretaceous age overlain by deposits of Mesozoic age. The valleys contain a wash layer and diluvial deposits of the fourth system of Neozoic age (Gu *et al.*, 1989). The dominant soil of the east region is a brown forest soil, whereas the major soils of the west region are yellow with a sub-sand in the hilly areas and are derived from sandy shales of Mesozoic age in the mountainous areas. Natural vegetation in the northeast of the east region is a mix of coniferous and broad leaf forest; throughout the remainder of the region the forest is of warm temperate-zone broad leaf species. The average forest cover in the mountainous area of the east Liaoning region is slightly over 45%. The average forest cover in the east coast peninsula is about 28%. Most of the vegetation in the west region is bushes, some with shrubs; vegetative cover in the 1950s, during the early stage of basin

management, was about 5%, but had increased to about 20% in the late 1980s.

There are 10 large reservoirs and many small impoundments that were constructed in the province since new China was founded. The large reservoirs provide water for irrigation and industrial use, the smaller reservoirs provide water for irrigation only. Considerable work, such as planting trees and grass, building terraces, and closing forests, has been accomplished to help conserve soil and water. Although results have been generally positive, some areas of the province still suffer soil and water losses.

## **CHARACTERISTICS OF STREAM SEDIMENT IN THE PROVINCE**

Erosion in the province is mainly caused by rain water, especially by storms that occur usually in the summer. Analysis of hydrologic elements over the past three decades shows that characteristics of fluvial sediment yield in the province can be summarized by two sets of generalizations.

A first conclusion is that a large amount of sediment is discharged during a few large storms with high rainfall intensity, but the average annual sediment yield includes discharges caused by many moderate-sized storms (Wischmeier & Smith, 1978). The former is illustrated by observation of large sediment discharges in either the east or west parts of the province. In River Liugu in the west part of the province, for instance, 188.1 mm of rain fell over the basin during 24-26 July 1962, accounting for 28.3% of the 1962 precipitation, but sediment discharge during the storm was 1.86 million tonnes, about 48.9% of the total for the year. In July 1963, 307.2 mm rainfall in 3 days, or 42.3% of the annual total, resulted in 4.85 million tonnes of sediment discharge, 82.7% of the total for the year. In Haicheng basin in the eastern part of the province, areal rainfall of 202.1 mm during 19-21 July 1985, accounting for 20.0% of the annual precipitation, caused 0.94 million tonnes of sediment discharge, 65.4% of the total for the year.

The latter generalization is indicated by several decades of measurements. In the eastern part of the province, for example, there are 27 years of sediment measurements in Lazigou basin of the tributary Pushi River of the Yaiu River. In that basin most sediment discharge occurred from moderate-sized storms except during the years 1964, 1979 and 1985. In the Habaqi basin of the River Daling in the western part of the province, about 30 years of sediment measurements show that most sediment discharge occurred from moderate-sized storms in all years except 1962. The analysis summarized above shows that calculations for average sediment yield should include the cumulative effects of the many moderate-sized storms as well as the effects of occasional severe storms.

A second conclusion is that the distribution of sediment discharge within a year is extremely uneven, far more so than is that of precipitation. In the eastern part of the province, most precipitation occurs in the flood season of June through September, accounting for 65-88% of the precipitation for the year. Maximum precipitation in the months of July and August normally accounts for 45-70% of the yearly total, and the maximum for one month, normally in August, accounts for 35-55% of the annual total. Almost all the sediment discharge occurs in flood season, accounting for 98.7-100% of the total. During the two months of maximum streamflow, 80-99.6% of the total sediment discharge occurs, whereas 70-93% of the annual total occurs in one month.

In the western part of the province, most precipitation occurs during the flood season of June through September. Precipitation during that period accounts for 74-88% of the annual total; maximum precipitation in the two peak months of July and August amounts to 50-78% of the annual total, and maximum precipitation for one month, normally in August, is 25-65% of the total. Regarding fluvial sediment discharge, nearly 100% of the sediment moves in the flood season. During the peak 2-month period, 80-99% of the sediment discharge occurs, and 80-98% of the total occurs during one month.

## VARIABILITY OF STREAM SEDIMENT

### Temporal scales

Precipitation changes as climate changes and stream sediment is entrained by rainwater. Variability of stream sediment results from the changes in rainfall and its intensity; soil erosion varies directly as intensity of rainfall. For sediment discharge of a storm in the same basin, the same amount of rainfall can create different sediment discharge because of different rainfall intensity. The same amount of rainfall and the same rainfall intensity can also create different sediment discharge due to storms occurring in different growth seasons of the forest, the canopy of which can reduce more erosion in the late part of the season than in the early part. Variability of stream sediment in different months is obvious and sediment yield changes with yearly precipitation. The coefficient of variation of annual precipitation is 0.15-0.25 in the eastern part of the province and 0.25-0.35 in the western part, whereas the coefficient of variation for annual sediment discharge is mostly 0.75-1.2 in the eastern part and 0.9-1.4 in the western part of the province. In the Gengwangzhuang basin of the eastern part of the province, for example, there are about 25 years of sediment observations and corresponding precipitation data; it can be seen that a large amount of sediment transport occurred in the same year as did a large amount of precipitation, and that years of small amounts of precipitation resulted in small amounts of sediment discharge. Five-year moving-mean values of both precipitation and sediment discharge have two peak values and one value of low precipitation and sediment discharge during this period.

### Areal scales

As noted above, erosion and sediment discharge are caused by heavy rainfall. Typically the intensity of storms decreases in the fall season and the duration and areal extent of each storm increase. In addition, as drainage basin area increases, soil erosion per unit area, thus sediment yield, decreases. There are also differing characteristics of heavy rainfall between the east and west parts of the province. In the eastern part, the frequency of storm occurrence is greater than in the western part, and the areas receiving rainfall from a storm tend to be larger, the rainfall durations longer, and the intensities lower. In the western part, the frequency of storms is lower, the durations are short, the areal extents are small, and the intensities are high. These differences result in variability of sediment discharge between the two parts of the province. In addition, sediment yield is affected by the environment of the underlying surface including topography,

soil, and forest cover. Though there are differences between the two parts of the province in topography and soils – mountainous areas of forest and brown soil in the eastern part and lower mountains and hills of yellow sandy soils in the western part – the greatest difference between the two parts is in forest cover. During the last three decades the amount of forest cover in the eastern part of the province has been about 45% and the forest cover in the peninsula has been 28%. Owing to environment, the strong forest cover in the east part of the province has been resistant to soil erosion and sediment yields have been relatively low, 100-200 t km<sup>-2</sup> year<sup>-1</sup> in general and 200-500 t km<sup>-2</sup> year<sup>-1</sup> in the east Liaoning peninsula. In the western part of the province, forest cover averages 5-20%, which, combined with the easily eroded sandy soils, results in sediment yields generally in the range of 1000-5000 t km<sup>-2</sup> year<sup>-1</sup>.

### Influence of scale on sediment yield

Sediment yield is different from soil erosion. Erosion, which mainly includes sheet and rill erosion, is caused by rain splash detachment of soil particles. Eroded soil particles often move only a short distance before a decrease in runoff velocity causes deposition. Soil particles may remain near the sites where they were detached or they may be deposited on gentler slopes that are still remote from a stream channel system (US Department of Agriculture, 1971). Sediment discharge at a given location of the stream channel is all of the eroded soil material from the basin above that location delivered by runoff to that location. Sediment yield is only a part of gross erosion due to sedimentation of silt along the basin area and in the river bed. The relation between sediment yield and gross erosion is:

$$S = E(DR) \quad (1)$$

and

$$M = E(DR)/A \quad (2)$$

where  $S$  is sediment discharge,  $E$  is gross erosion,  $DR$  is sediment delivery ratio,  $M$  is modulus of sediment yield, and  $A$  is basin area above the point of sediment yield computation. The ratio of sediment delivered at a site in the stream system to the gross erosion from the drainage area above that site is the sediment delivery ratio for that drainage area.

Due to several reasons, average intensity of storm rainfall decreases as rainfall area increases, and sediment delivery ratio usually decreases as basin area increases. Thus, sediment discharge at a stream site may not be directly and linearly proportional to the area of the basin above that site. The modulus of sediment yield decreases as the area of the basin increases. Under the same conditions of rainfall and surface characteristics, the larger the area of the basin, the smaller is the modulus of sediment yield. In upstream basins of River Hun in the eastern part of the province, for example, where basin area is 500 km<sup>2</sup>, the modulus of sediment yield is about 160 t km<sup>-2</sup> year<sup>-1</sup>; where the area is 1000 km<sup>2</sup>, the modulus of sediment is about 130 t km<sup>-2</sup> year<sup>-1</sup>. In upstream basins of River Daling in the western part, where the basin area is about 500 km<sup>2</sup>, the modulus of sediment yield is about 1800 t km<sup>-2</sup> year<sup>-1</sup>; where the basin area is 1000 km<sup>2</sup>, the modulus of sediment yield is about 1500 t km<sup>-2</sup> year<sup>-1</sup>.

## RELATION OF VARIABILITY OF SEDIMENT YIELD TO ENVIRONMENTAL CHANGE

As noted above, sediment yield is affected by the environmental characteristics of the underlying surface, including topography, soil and forest cover, and rainfall and its intensity. For a given basin, some conditions are relatively stable, such as topography, geology and soils of the basin. Although the environment of the forest cover varies as land use changes, forest cover can reflect accurately the overall condition of the vegetative cover, and its influence on sediment yield includes the effective rainfall energy by intercepting rainfall and changing the fall of raindrops. Raindrops falling from the canopy may regain appreciable velocity, but usually less than the terminal velocity of free-falling raindrops. Mulch cover may prevent soil particle detachment by rain splash and erosion by runoff. Sediment yield, therefore, changes with environment, mainly forest cover, and changes and decreases as the rate of forest cover increases. There are some sediment measurements, for example, from four small catchments with areas of 0.15-0.61 km<sup>2</sup> that are near each other in Ye baishou experimental basin in the western part of the province. The results of observations of sediment yield at these small catchments are shown in Fig. 2, which suggests that under conditions of nearly the same rainfall during flood season, sediment yield of the period decreases as the ratio of forest-cover area to catchment area increases.

Owing to human activities during different decades, such as water and soil conservation, forest cover and sediment yield have been changing. Sediment yield in most basins is decreasing. An example is Jinzhou basin of the River Xinoling in the western part of the province where 5-year moving averages of precipitation in the mid-1960s and mid-1980s are nearly equal. The five-year moving mean average of sediment yield in the 1980s, however, is 78% less than that in the 1960s (Table 1). This change is mainly the result of a forest cover increase in the basin from about 5% in the 1960s to 17% in the 1980s.

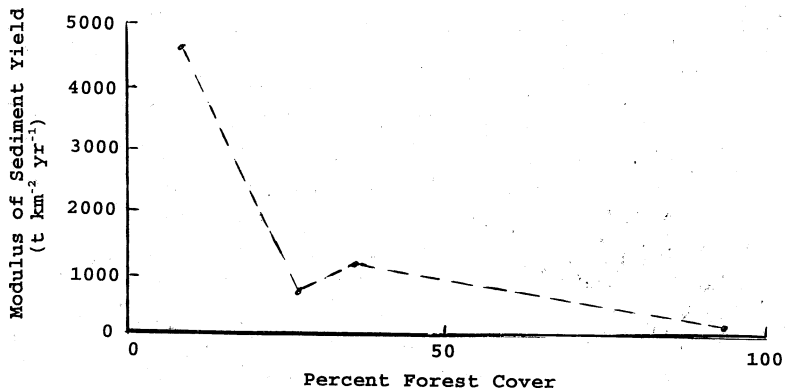


Fig. 2 Average relations between modulus of sediment yield and rate of forest cover, 1989 through 1991.

**Table 1** Comparison of five-year average areal precipitation and sediment yield in Jinzhou basin.

Period	Average annual precipitation (mm)	Sediment yield (tonnes x 10 <sup>4</sup> )
1963-1967	439	588
1983-1987	444	132

## CONCLUSION

Sediment is the complex result of climate, topography and underlying environmental conditions of soil and forest cover. Owing to different conditions of climate, soil texture, and forest cover, sediment yields of 100-500 t km<sup>-2</sup> year<sup>-1</sup> in the eastern part of the province differ markedly from those of 1000-5000 t km<sup>-2</sup> year<sup>-1</sup> in the western part of the province. The sediment yield at a site in a basin reflects the environmental conditions of the region, a high sediment yield indicating that environmental conditions in the basin are poor. Low sediment yield, similarly, suggests that environmental conditions are good. Programmes of water and soil conservation, especially tree planting, have played an important role in the province to improve environmental conditions. Fluvial sediment discharge changes mainly as forest cover changes, and the modulus of sediment yield decreases as the rate of forest cover increases. Based on trends of forest cover change, sediment yields in most parts of western Liaoning in the 1990s will be about 90% less than those of the 1960s, and in eastern Liaoning, where forest cover has been good, sediment yields in the 1990s will be 40-70% less than those of the 1960s. Environmental conditions in the province continue to improve owing to conservation efforts by humans.

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