Postprint: Study on Sediment Distribution Patterns and Water-Sediment Relationships in the Shule River Basin

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Abstract

Sediment is one of the important factors affecting river health and water environment. Under the influences of climate change and human activities, hydrological elements and underlying surface conditions in watersheds have undergone significant changes. Particularly after implementing large-scale soil and water conservation measures, sediment content in some rivers has decreased substantially. However, in the Shule River basin, which originates from the western Qilian Mountains within the Hexi inland river basin region, sediment loads exhibit an increasing trend due to precipitation conditions and human activities. This paper applies measured long-term hydrological data from the Shule River basin and employs methods including hydrological statistical method, cumulative deviation curve method, trend test method, abrupt change test method, and nonlinear multiple correlation model method to analyze the spatiotemporal distribution patterns of sediment and water-sediment relationships in the basin. The results indicate that the annual sediment load at Changmabao Station on the Shule River main stream is 333.5×10 t, decreasing to 223.5×10 t at Panjiazhuang Station downstream; the annual sediment load at Dangchengwan Station on the Dang River is 76.56×10 t, increasing to 121.3×10 t at Shazaoyuan Station downstream; sediment transport in the Shule River main stream is primarily concentrated in the flood season of July–August, accounting for 81.9%–84.0% of the annual total, while sediment load in the Dang River basin is mainly concentrated from April to August, accounting for 92.3% of the annual total; overall sediment change in the basin shows an increasing trend, and after the abrupt change point in 1998, annual sediment load increased by 86.3%–148.2%. Models for precipitation–sediment, runoff–sediment, and annual sediment load–annual runoff–annual maximum flood peak discharge relationships were established for Panjiazhuang Station, with good correlations and correlation coefficients reaching 0.717–0.858. The main factor influencing sediment above the mountain pass in the basin is precipitation, while below the mountain pass it is

primarily human activities such as reservoir construction, hydropower stations, water diversion projects, and river sand mining. With increasing national attention to the Qilian Mountains and Hexi Corridor in inland river basins, and the implementation of the national River Chief System, river ecological health has become a priority. Research on sediment distribution patterns and water-sediment relationships in the Shule River basin is of great significance for the implementation of the national western ecological security strategy, regional ecological environment restoration and management, and sustainable utilization of water resources.

Full Text

Sediment Distribution and Runoff-Sediment Relationship in the Shule River Basin

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Abstract: River basin hydrological factors and underlying surface conditions have been profoundly altered by climate change and human activities. While sediment concentrations have decreased significantly in some rivers following large-scale soil and water conservation measures, the Shule River basin—originating in the western Qilian Mountains within the Hexi Inland River Basin of Gansu Province, China—has exhibited an increasing sediment trend driven by precipitation patterns and anthropogenic activities. This study systematically analyzed the spatiotemporal distribution patterns of sediment and the relationships between sediment, water, and sediment transport using data from four hydrological stations (Changmabu, Panjiazhuang, Dangchengwan, and Shazaoyuan) spanning from their establishment through 2012.

The annual sediment discharge of the Shule River mainstream is 333.5×10 t · a ^{1} at Changmabu station, decreasing to 223.5×10 t · a ^{1} at downstream Panjiazhuang station. The Danghe River' s annual sediment discharge is 76.56×10 t · a ^{1} at Dangchengwan station, increasing to 121.3×10 t · a ^{1} at downstream Shazaoyuan station. Sediment transport in the Shule River mainstream is concentrated during the flood season from July to August, accounting for 81.9%-84.0% of the annual total, while the Danghe River basin shows sediment discharge from April to August, representing 92.3% of its annual total.

Trend analysis employing Kendall rank correlation, Berman rank correlation, and linear trend correlation, combined with mutation detection using the Man-Kendall method, order clustering method, and Lee-Hegnan method, reveals that basin sediment exhibited a significant increasing trend. Annual sediment discharge increased by 86.3%-148.2% following the identified mutation point in 1998. At Panjiazhuang station, correlation models between precipitation and sediment, runoff and sediment, and among annual sediment discharge, annual runoff, and annual maximum peak flow were established using linear and nonlinear complex correlation methods, yielding high correlation coefficients ranging from 0.717 to 0.858.

Above the valley outlet, precipitation represents the primary factor controlling water and sediment generation. To mitigate soil erosion, authorities should implement comprehensive soil and water conservation measures in upstream areas, including prohibiting reclamation, mining, and grazing activities while preventing over-exploitation. Below the valley outlet, water-sediment dynamics are predominantly influenced by human activities such as reservoir construction, hydropower development, water diversion projects, and river channel excavation. Water quantity in downstream reaches has been sharply reduced or depleted, exacerbating Gobi Desert desertification and ecological deterioration. Appropriate ecological water allocations should be increased in middle and lower reaches to improve environmental conditions. With growing attention to the Qilian Mountains and Hexi Corridor in inland river basins, including the establishment of the Qilian Mountains National Park System pilot and implementation of the national river chief system, river ecosystem health has become a priority. Investigating watershed sediment distribution laws and water-sediment relationships is crucial for implementing western ecological security strategies, restoring regional ecological environments, and promoting sustainable water resource utilization.

Keywords: sediment; distribution law; trend variation; runoff-sediment relationship; Shule River

3.3 Temporal Distribution Characteristics

The temporal distribution characteristics of precipitation, runoff, and sediment were analyzed using multi-year average monthly data from representative stations. The analysis reveals that precipitation is concentrated from April to September, with July and August accounting for 76.5% of the annual total. Runoff distribution follows a similar pattern, with the main flood season occurring from May to September, representing 75.3% of annual runoff at Changmabu station, 71.8% at Panjiazhuang station, and 78.8% at Dangchengwan station. Sediment discharge is even more concentrated, with July and August comprising 81.9% and 84.0% of the annual total at Changmabu and Panjiazhuang stations respectively. At Dangchengwan station, sediment transport occurs from April to August, accounting for 92.3% of the annual sediment discharge.

4. Analysis

4.1 Correlation Analysis Correlation analysis was conducted using linear and nonlinear complex correlation methods to establish relationships between precipitation and sediment, runoff and sediment, and among annual sediment discharge, annual runoff, and annual maximum peak flow. The results demonstrate high correlation coefficients ranging from 0.717 to 0.858, indicating strong relationships between these hydrological variables. The precipitation-sediment and runoff-sediment relationships show that above the valley outlet, precipitation is the dominant factor influencing water and sediment generation, while human activities become increasingly important downstream.

4.2 Trend Analysis The Man-Kendall statistical test was applied to detect trends in annual sediment discharge at all stations. The M-K statistical curves indicate significant increasing trends in sediment discharge across the basin. Following the identified mutation point in 1998, annual sediment discharge increased by 11.9%-37.7% at Changmabu station, 6.5%-52.9% at Panjiazhuang station, and 86.3%-148.2% at Dangchengwan station. The trend analysis confirms that sediment loads have been rising substantially, particularly in the Danghe River sub-basin.

4.3 Mutation Analysis Mutation analysis was performed using the Man-Kendall method, order clustering method, and Lee-Hegnan method to identify significant change points in the sediment time series. The year 1998 was identified as a primary mutation point, after which sediment discharge increased dramatically by 39.8% at Changmabu station and 39.2% at Panjiazhuang station. This mutation corresponds to intensified human activities including reservoir construction, water diversion projects, and agricultural development in the basin. The analysis reveals that human interventions have fundamentally altered the natural sediment regime, with anthropogenic impacts becoming the dominant driver of sediment changes downstream of the valley outlet.

References

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Figure and Table Captions

[Figure 1: see original paper] River system of the Shule River basin

Hydrological eigenvalues of representative stations in the Shule River basin

[Figure 2: see original paper] Multi-year hydrological diagram of representative stations in the Shule River basin

[Figure 3: see original paper] Residual mass curve of multi-year sediment discharge and average sediment concentration of representative stations in the Shule River basin

[Figure 4: see original paper] Average monthly precipitation, runoff and sediment discharge allocation process diagram of representative stations in the Shule River basin

[Figure 5: see original paper] M-K statistical curve of annual sediment discharge of representative stations in the Shule River basin

Note: Figure translations are in progress. See original paper for figures.