The Influence of Knickpoints on the Erosion in Songlin River Basin

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Abstract: Based on fieldwork and the longitudinal section obtained by ArcGIS, seven major knickpoints in Songlin River Basin are located. It is found that the regions with a great average elevation difference between ridge and valley suffer more from disasters such as collapse, landslides, and debris flows. Dimensionless number Vindex is used to quantitatively describe the cross-section of the Songlin River Valley. The Vindex coefficient is below 0 outside the upstream influence of knickpoint and in downstream of knickpoint and it is over 0 in the upstream of knickpoint and at the knickpoint. The overall change trend is “super V shape-U shape-super V shape”. The formation and development of knickpoints strongly influence the geomorphological characteristics of the Songlin River Basin. Due to the rising erosion base level of the upstream of knickpoint, sediment is deposited and the incision rate of riverbed decreases or it even stops down cutting. In this way, the average elevation difference between ridge and valley is tend to reduce, which lowers the energy that causes geological hazards and improves the stability of the upstream. The gradient of both riverbanks decreases, forming a flat and wide U-shaped river valley. Although the elevation difference between the river and the downstream watershed of the knickpoint remains constant, the current energy increases and the erosion is still severe, keeping the valley in a V shape.

1. Introduction
Under a balanced condition, the gradient of the river gradually decreases with the increase of the basin area of the downstream, and the longitudinal section of the river appears as a relatively smooth concave. Once this balanced condition is broken, the river system will be in a transient imbalance [1]. The development of knickpoints is one of the most typical characteristics of the transient imbalanced geomorphologic system [2]. Its causes mainly include: different tectonic activities [3], changes in lithology of riverbed [2], river blocking [4], sea-level changes, and the dropping erosion base level caused by river capture [5-7]. As the longitudinal section of the river under a transient imbalance state will continuously adjust itself to a balanced state, the knickpoint can control the erosion process of the entire valley (including the slope and the channel itself) [1].

The knickpoint can significantly change the distribution characteristics of water energy in the river and make the flow energy significantly different upstream and downstream. It can also adjust the erosion capacity of the river, and change the stability of the riverbed and even the entire river basin. Crosby’s [5] research on the Waipoua River Basin in New Zealand suggests that the knickpoint is the boundary between the remnant topography and the adjusted topography in the basin, and the erosion effects in the upstream and downstream areas of knickpoint are different. Zhang Kang [8] et al. propose that large knickpoints can change riverbed evolution and river geomorphology. Guo Chenwen
[9] et al. apply the HI value to the study on knickpoint and stability of the bank slope. They confirm the rationality of judging the stability of bank slope based on the HI value, and find that different causes of knickpoints have different effects on the evolution of the river basin. Yu Guoan[10] et al.’s analysis on the geomorphological environmental effects of the collapsed Yansai Dam shows that the long-term existence of the dam generates knickpoints on the riverbed surface. They raise the base level of erosion of the upstream riverbed, increase the flow resistance of the river, control riverbed’s undercutting, and stabilizes the bank slope.

The formation and development of knickpoints are closely related to basin erosion. The Songlin River Basin is rich in water energy resources, but frequently suffers from geological disasters. This paper studies the Songlin River Basin and explores the relationship between knickpoints and basin erosion with quantitative indicators.

2. Introduction to the Songlin River

The Songlin River, formed by the Wanba River (mainstream) and the Hongba River branch, is a first tributary on the right bank of the middle reaches of the Dadu River. The Songlin River basin covers an area of 1445 km², and the Hongba River basin is 640 km². The lowest point of the basin is Songlin River Estuary with an elevation of 882m and the highest point is the top of the watershed of the Songlin River Basin and the Tianwan River Basin, with an altitude of 5946m. The elevation difference of the basin is 5064m. The basin is located in the mountainous area on the western edge of the Sichuan Basin, at the intersection of the north-westward Xianshui River fault zone and the NS-trending Anning River fault zone. The western region belongs to the western Sichuan trough, and the rest belong to the eastern Sichuan platform area. The basin is located between the platform and the trough, where the crustal movement is frequent [11]. The mountain shows a north-south trend, with a terrain of triangular shape. The topography of the mountain is high in the west and low in the east, and there are numerous rigid magmas and metamorphic rocks [12]. The main source of surface runoff is atmospheric precipitation, followed by snow meltwater and glacial meltwater. Changes in flooding and drying flow are large, and the maximum flow is 39 times the minimum flow [11]. The climate in the region is mild. The temperature difference in the four seasons is small, and the dry and wet seasons are clear [12-13].

As the influence of small knickpoints on the geomorphology of the basin is limited, this paper studies the major knickpoints of higher research value. According to the river longitudinal section and field investigation, seven major knickpoints in the Songlin River are identified. The seven knickpoints divide the basin into nine regions, which are named 1-9 (Fig. 1).

Fig 1. River system and major knickpoints in the Songlin River Basin
3. Research Methods
With ArcGIS, DEM (http://www.gscloud.cn/) with a resolution of 30m was used to extract the longitudinal section of the river. Based on field investigations, the authors identified the knickpoints and used ArcGIS to obtain the river valley cross-section of the upstream and downstream of knickpoint. Then, they calculate the average elevation difference $\bar{H}$ and Vindex coefficients of knickpoints regions, and explore the relationship between the knickpoints and basin erosion.

4. $\bar{H}$ of Knickpoints Regions

The main river of the Songlin River flows from south to northeast, with a length of 73.2km, a drop height of 2834m, and the average river gradient of 38.7 ‰. Four major cracks were found along the way. The longitudinal section of the main river is as follows (Fig. 2):

The Hongba River is the left tributary of the Songlin River and it flows from southwest to northeast. The Hongba River Basin’s area accounts for 44% of the entire Songlin Basin. Therefore, it is studied together with the main river. The Hongba River has a natural drop of 3473m, a length of 49.7km, and the average river gradient of 69.9 ‰. Three main rifts were found along the mainstream. The longitudinal section of the Hongba River is as follows (Fig. 3):

![Fig 2. Longitudinal section of the main river and the corresponding watershed and major knickpoints along the way (①-④)](image)

![Fig 3. Longitudinal section of the Hongba River and the corresponding watershed and major knickpoints along the way (⑤-⑦)](image)
The basic characteristics of the seven knickpoints are shown in Table 1.

| River     | the main river | Hongba Rive |
|-----------|----------------|-------------|
| knickpoint| 1  2  3  4     | 5  6  7     |
| Distance from river source (km) | 19 35 41 60 | 19 24 37 |
| Elevation (m) | 2460 2040 1880 1210 | 2945 2440 1970 |
| Upstream specific gradient (‰) | 25.8 41.9 16.9 18.2 | 36.6 22.7 37.0 |
| Downstream specific gradient (‰) | 82.1 | 147.8 93.6 87.2 | 188.8 96.4 102.8 |

From Table 1, 6 of the 7 major knickpoints in the basin are above the altitude of 1500m, indicating that there are mainly high-altitude knickpoints in the basin. The difference of gradient between upstream and downstream of the knickpoints is large, and the gradient of downstream is mostly more than three times that of upstream.

Figures 2 and 3 are about the main river, the Hongba River and their corresponding watershed. The steps for drawing the figures are: make a series of parallel lines at equal intervals (approximately 1km in this paper) and perpendicular to the river from the river source and along the way; then take the elevation of the intersection of each parallel line and the corresponding watershed of the entire river basin as the ordinate. According to the 9 regions, the area enclosed by the longitudinal section and the watershed in each region is divided by the horizontal distance between the knickpoints and the river source or between the knickpoints and the knickpoints to obtain the average elevation difference $\bar{H}$ of each region.

It can be seen from Fig. 4 that the $\bar{H}$ of the main river and the Hongba River along the river from the top to the bottom increase at first and then decrease, while the left and right banks have the same change trend and the $H$ of left watershed is greater than that of the right. In the main river basin, the region of maximum elevation difference is region 4, with $\bar{H}$ of 3078m, and the region of minimum elevation difference is region 5, with $H$ of 946m. In the Hongba River Basin, the region of maximum elevation difference is region 7, with $H$ of 2926m, and the region of minimum elevation difference is region 6, with $\bar{H}$ of 867m.

Geological disasters are actually short-distance movements of solid detrital material. The energy to transport detrital material is the potential energy of the elevation difference along the river valley or of hillside [14]. The $H$ of the river and the left watershed is greater than that of the right watershed, indicating that at the same time external conditions, the left watershed are easier to cause disasters. In regions with large $H$, there are many disasters such as collapse, landslides, and debris flows. According to field investigations, the seven major knickpoints in Songlin River Basin were formed because a large number of rocks and sediment generated by disasters like debris flows in the channel went into the river and they were deposited and blocked the river inflow operation. Five of knickpoints were formed under the influence of disaster in the left branch gully (Fig. 5-6). Only 3 small landslides
were observed along with the upstream of the first knickpoint 5 of Hongba River, and more than 30 landslides were observed along the downstream. This is the impact of knickpoints on basin erosion.

The formation and development of knickpoints raise the upstream erosion base level. So, the flow velocity decreases, the sediment is deposited, and the riverbed undercut is controlled, which reduces the average elevation difference of the region. The bank slope tends to be stable. In addition, the erosion in upstream is weakened [10], but the erosion in the downstream is still severe.

The formation of knickpoint 5 decreases the incision rate of upstream, reduces the potential energy provided for the occurrence of geological disasters, and improves the stability of upstream more than downstream. If this knickpoint is destroyed, the incision rate of upstream will increase rapidly, and the average elevation difference of the region will increase. Then the materials on both banks of the slope will have enough potential energy, which will increasingly cause disasters like collapses and landslides.

5. Vindex Coefficient of River Valley cross-section in Knickpoint Area

The characteristics of the cross-section of the river valley can reflect the erosion of the basin. The evolution of eroded landforms of the incised river in mountainous can be divided into 4 stages [14], and different stages will present different cross-section features. When there is rapid river incision, the valley will form a narrow “V” shape or super “V” shape. When the river incision reaches a certain level, slope instability will cause disasters such as collapse, landslides, and debris flows to widen the valley. Then, it will become a wide “V” shape. When the incision rate slows down and aggradation occurs, the valley develops into a "U" shape. When the supply rate and transport rate of sediment finally match, the flow energy is consumed, the incision stops, and the riverbed becomes stable, forming the valley a wide "U" shape. The slope stability of the U-shaped valley is greater than that of the V-shaped valley. The slope stability of a U-shaped valley is better than that of a V-shaped valley.

In order to quantitatively describe the cross-section shape of the valley in the knickpoint region, this paper uses the Vindex coefficient [15] to describe the deviation of the actual valley cross-section area $A_x$ from the ideal V-shaped valley cross-section area $A_v$, and it can also describe irregular valley cross-section, the expression is:

$$V_{index} = \frac{A_x}{A_v} - 1$$

For the ideal V-shaped valley, Vindex is equal to 0; for the super V-shaped valley, Vindex is less than 0; for U-shaped valley, Vindex is more than 0. (Fig. 7)

The extraction of valley cross-section must meet three conditions [15-16]: (1) the cross-section is basically perpendicular to the river; (2) the cross-section avoids crossing the branch gully; (3) with the river as the base point, the distance extracted from both banks should be approximately the same and longer than the distance set in the study (1.5km in this paper) so as to ensure that the Vindex coefficient of cross-section is a description of the entire valley, not a local one. To calculate the ideal
cross-section area $A_v$ of the river valley, the calculation boundary of the cross-section of the ideal V-shaped valley should be determined, the standard is [15-16]: (1) find the first inflection point of the cross-section curve from the river to the banks; if the elevation difference from this inflection point to the next inflection point is more than the set threshold (10m in this paper), take this inflection point as the peak elevation of the bank slope; (2) if no inflection point meets the requirements, then take the elevation of the end position of the cross-section curve as the peak elevation of the bank slope; (3) take the smaller peak of the elevation of the left and right banks as the maximum elevation of the ideal section.

\[
\text{(a) } V_{\text{index}} = 0 \quad \text{(b) } V_{\text{index}} < 0 \quad \text{(c) } V_{\text{index}} = 0
\]

Fig 7. Schematic diagram of $V_{\text{index}}$ calculation [16]

According to the above standards, this paper extracts the typical cross-sections of the river valleys in the seven major knickpoints in the Songlin River Basin. The schematic diagram of the typical knickpoints is as follows (Fig. 8):

From Fig. 8 we can see that the bank slope of the river valley cross-section outside the upstream influence of the knickpoint is steeper than that in upstream of the knickpoint and the river valley is narrower. The cross-section at the knickpoint appears to be much wider, and the cross-section of the downstream valley appears to be steep and narrow. The Vindex coefficient of typical river valley cross-section in the Songlin River knickpoint region is calculated in Table 2.
Table 2. $V_{\text{index}}$ coefficient of river valley cross section in Songlin River knickpoint region

| knickpoints | Outside the upstream influence of knickpoint | Upstream of knickpoint | Knickpoint | Downstream of knickpoint | Outside the downstream influence of knickpoint |
|-------------|---------------------------------------------|------------------------|------------|--------------------------|----------------------------------------------|
| 1           | -0.05                                       | 0.13                   | 0.10       | -0.06                    | -0.08                                        |
| 2           | -0.05                                       | 0.09                   | 0.05       | -0.01                    | -0.02                                        |
| 3           | -0.02                                       | 0.02                   | 0.03       | -0.03                    | -0.10                                        |
| 4           | -0.05                                       | 0.08                   | 0.29       | -0.05                    | -0.06                                        |
| 5           | -0.01                                       | 0.02                   | 0.29       | -0.02                    | -0.14                                        |
| 6           | -0.10                                       | 0.04                   | 0.07       | -0.11                    | -0.18                                        |
| 7           | -0.06                                       | 0.05                   | 0.07       | -0.07                    | -0.19                                        |

It is known from Table 2 that the $V_{\text{index}}$ coefficients of the region outside the upstream influence of the knickpoint and that of downstream are less than 0, and the $V_{\text{index}}$ coefficients of the typical cross-section of upstream of the knickpoint and at the knickpoint are more than 0. It indicates that the valleys outside the upstream influence of the knickpoint and downstream are super V-shape, while the cross-section of the valley at the rift and its upstream influence area is U-shape. The change trend of the whole river valley cross-section is "super V-U-super V". And the $V_{\text{index}}$ coefficient of the typical cross-section outside the downstream influence of knickpoint is less than that within the influence.

The formation and development of knickpoints have a strong influence on the geomorphological characteristics of the Songlin River Basin. The $V_{\text{index}}$ coefficient of the cross-section of the river valley gradually increases from the position outside the upstream influence of the knickpoint to the position at the knickpoint. The river valley showed a change from a super V shape to a U shape. It shows that the formation and development of the knickpoints can decrease the incision rate of upstream or even stops the incision and turns it into aggradation. It controls the longitudinal section adjustment of the channel, turns it from longitudinal evolution to transverse evolution. In this way, the gradient of the banks becomes small, and a U-shaped river valley is formed [8], enhancing the overall stability. Although the elevation difference between the channel and the downstream watershed of knickpoint remains the same, the flow energy increases, leading to severe erosion, and forming the V-shaped valley. The $V_{\text{index}}$ coefficient of this section is less than 0, and the stability is poor. The cross-section $V_{\text{index}}$ coefficient of typical river valley outside the downstream influence of knickpoint is less than that within the influence, which reflects that the formation and development of knickpoint can make the downstream valley narrow and deep.

6. Conclusion
The formation and development of knickpoint significantly influence the geomorphological characteristics of the Songlin River Basin. Its formation causes erosion base level of upstream to rise and reduces the average elevation difference between ridge and valley. Then, the water flow velocity decreases, sediment is deposited, which control river incision, and stabilize the bank slope, forming a "U" river valley, and weakening the erosion of river basins. When the elevation difference between the downstream watershed and the river remains the same, but the flow energy increases to keep severe erosion, a super V-shaped valley with poor slope stability is formed.

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