Geomorphic effect of landslide dam on the Jinsha River

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Abstract. As an extreme surface process, landslide dam affects the long-term change of river landform, especially the change of channel and hillslope. The Jinsha River is located on the eastern edge of the Qinghai-Tibet Plateau, the structural geology is active, developed more landslide geological disaster. Based on the 30 m SRTM DEM, we automatically extracted the river longitudinal profile, steepness index, river knickpoint and excess topography using TopoToolbox. Through interpretation of remote sensing imagery and field work, we identified 660 landslide dams, more than 90% are located in the excess topography with a threshold hillslope of 30°. Our analysis reveals that there are 481 river knickpoints were extracted with heights above 30 m, Among them, 70 river knickpoints have good spatial correlation with the landslide dam, landslide dam has an impact can form knickpoints of up to 478m. In the densely distributed river channel of the landslide dam, the steepness index with the relatively high values. Therefore, landslide dams may have a significant inf1uence on the channel and hillslope, we should pay attention to the role of landslide dam in the evolution of river landscape.

Keywords: Landslide dam, excess topography, knickpoint, steepness index, Jinsha river

1. Introduction

River is an intermediate link connecting the process of tectonic uplift and surface erosion in the orogenic zone, and it is an important geomorphic unit to record the information of external driving forces such as tectonic activities and climate change [1-4]. In recent years, many tectonic geomorphology scholars have devoted themselves to extracting past structural information at different time scales from the longitudinal profiles of river channels in orogenic belts [5-7]. However, in the alpine canyon area, landslides dominate the erosion process of the hillslope, and large landslides often fill the valley, forming a barrier dam, causing channel siltation upstream, thus changing the shape of the river longitudinal profile [8]. Landslide dam affects the landscape process of mountainous areas by affecting the river longitudinal profile. Most of the existing river barrier related studies focus on the high mountains and valleys around the Qinghai-Tibet Plateau, for example, analyze its persistent effects on river sedimentation and erosion in southeast Tibet, Karakoram mountains and other areas [9-11], and the stability of the landslide dam and its geomorphic environmental effects [12]. Previous studies have discussed the effects of multiple dams on the comprehensive effect of the longitudinal profile of trunk rivers from the perspective of large watershed scale, such as the eastern and western margin [13], and there is no systematic research on the response of medium scale watershed to damming events.

The topographic rapid change belt on the eastern edge of the Qinghai-Tibet Plateau has the landscape, structure and climatic conditions of the landslide barrier lake, and is also a potential area for frequent high-energy outburst floods [14]. The Jinsha River pass through the Hengduan mountain area with high valley depth, the geological structure is active, and the river drop is large, leading to the frequent dammingings events, which has a huge effect and influence on the evolution of the valley landscape, and makes the study of the landscape evolution of the Jinsha River more complicated. Many scholars, through field trips and indoor analysis, to identify the residual dam and the scale of dam, the identification of dammed lake sediment, sediment dating and other indicators [15-17], Combined with the regional tectonic activities to reconstruct the river damming event in the geological period, explore its effect and influence on the landscape evolution of Jinsha River Valley [18-19].

This paper mainly obtains the spatial distribution of the landslide dam, using the TopoToolbox to extract the river knickpoint, steepness index and excess topography, systematically analyzes the effect of landslide on channel and hillslope, and provides new ideas for the study of landscape evolution in this region.

2. Study Area

The Jinsha River is located on the eastern edge of the Qinghai-Tibet Plateau, which is belong high elevation, low-relief landscape [20]. The Jinsha River is 3481 km long from the source of Yushu, Qinghai province to Yibing, Sichuan province, covering a basin area of 502000 km^2, It is located in the upstream of the Yangtze River. The Jinsha River has an elevation difference of 3300 m and have a rich water resource, accounting for more than 40% of the water resources in the Yangtze River. The Jinsha river flows through the high mountain and deeply valley, and it is within the range of the secondary fault, three river parallel fault and Jinsha River fault in the northern region of Gutetes, such as active fault block extrusion, differential lifting and fracture sliding activities lead to frequent river damming events.

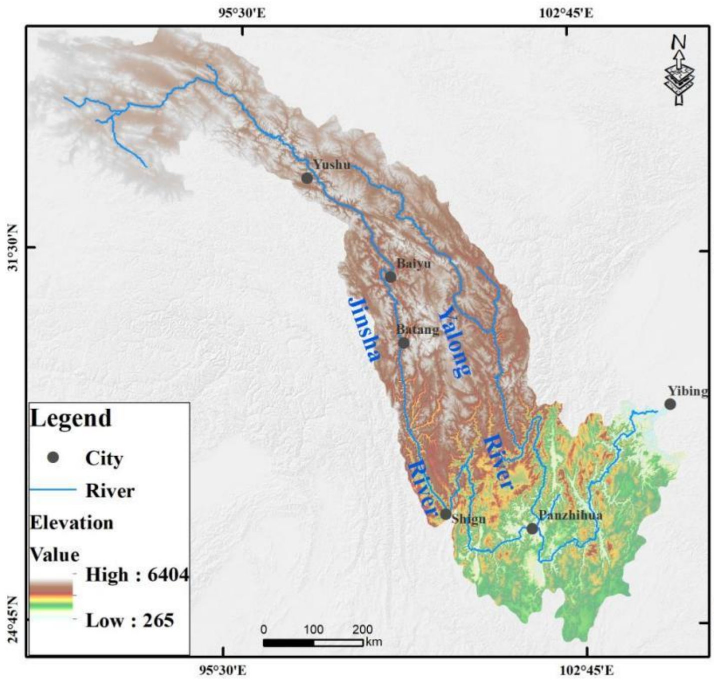

Figure 1. Overview of the study area in the Jinsha River

3. Methods

3.1. Remote Sensing Interpretation of landslide dams

Landslide is generally interpreted by three more recognizable elements: landslide accumulation, landslide back wall and landslide boundary. The visual interpretation of landslide is mainly performed by identifying the shape, size, color, shadow, texture and other characteristics of the remote sensing images of landslide [21]. The remote sensing images show the color and vegetation development different from the surrounding environment. There are obvious landslide remains in the river, and the river width will narrow due to the barrier event; there will be closed depressions between the landslide and the rear wall, and the above are interpretation marks of landslide interpretation. Second, we verified and modified the partially translated landslides through field investigation (Figure 2). In addition, this paper also draws the general boundary of the landslide, estimates the area of the landslide, and then using volume-area scaling relationship to estimate landslide volume [22],

$$V = \alpha A^{\gamma} \tag{1}$$

Where V represents the landslide volume (m^3), A represents the landslide area(m^2), and α and γ are power-law scaling parameters, in this study , we use the α=0.23 and γ=1.41 to calculate landslide volume[18].

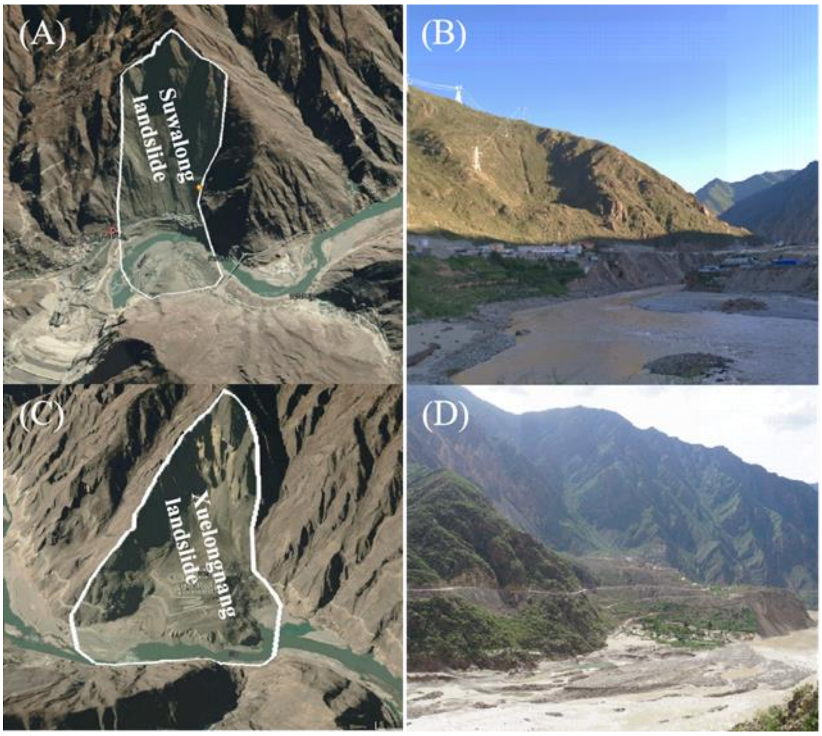

Figure 2. Remote sensing interpretation of landslide dams

3.2. Digital Terrain Analysis

The SRTM DEM data at the 30m spatial resolution used in this paper are all obtained from the US Geological Survey United States Geological Survey (USGS) data sharing platform (https://earthexplorer.usgs.gov/). In this paper, the TopoToolbox was used to extract the river geomorphic parameters [23-24], and the TopoToolbox to extract the DEM containing projection information as the input data (https:// topotoolbox.wordpress.com/). Considering the geographical location of the transection area, the projection coordinate system used in this study is WGS_1984_UTM_zone_47 N.

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3.2.1. Excess Topography Extraction. Excess topography refers to a potentially unstable hillslope with a slope greater than the threshold hillslope. Assuming that the threshold hillslope always exists, the excess topography can be used to represent all the large bedrock landslides within the region. The site-specific threshold hillslope surface extraction excess topography process is performed as follows [25],

$$\dot{z}(x,y) = \min_{(s,t)\in(-\infty,\infty)} \left\{ z(x+s, y+t) + s_t\sqrt{s^2+t^2} \right\} \tag{2}$$

where z represents the real elevation of the topography, x, y represents coordinates, and s, t represents the filter coefficient, which refers to the distance from the center of the filter to the point (x, y).

The elevation of excess topography z_E can be extracted by subtracting the elevation of the threshold hillslope surface from the real surface elevation as follows:

$$z_E(x,y) = z(x,y) - \dot{z}(x,y) \tag{3}$$

3.2.2. Steepness Index Extraction. To obtain the effect of the landslide dam on the river longitudinal profile in the Jinsha River, we used the Stream-Power River Incision Model, it can be quantified by relationship between upstream catchment area and channel gradient [3]:

$$\mathrm{S} = \mathrm{k_s A^{-\theta}} \tag{4}$$

where S is channel slope, °; k_s is the steepness index, $m^{0.9}$; A is the upstream catchment area, m^2; in This study we fixed concavity index of θ = 0.45 to extract the normalized steepness index (k_{sn}) to facilitate the comparison of the differences between of more reaches[26].

3.2.3. River Knickpoint Extraction. The river knickpoint refers to the position where the channel gradient changes significantly and the river longitudinal profile appears obviously convex [27]. In this study, the improved longitudinal profile elevation steep descent method was used to extract river knickpoint. Then we used the knickpoint finder function in TopoToolbox to automatically extract the smooth river longitudinal profile from the 30m STRM DEM to reduce the artificial subjective error [23]. Knickpoint Finder adjusts the strictly concave upward profile to the actual profile until offsets fall below a specified tolerance value (Figure 3) [24]. In this paper, the tolerance value was set to 30m to extract the knickpoint in the Jinsha River, and knickpoint height was used to directly quantify of knickpoint magnitude.

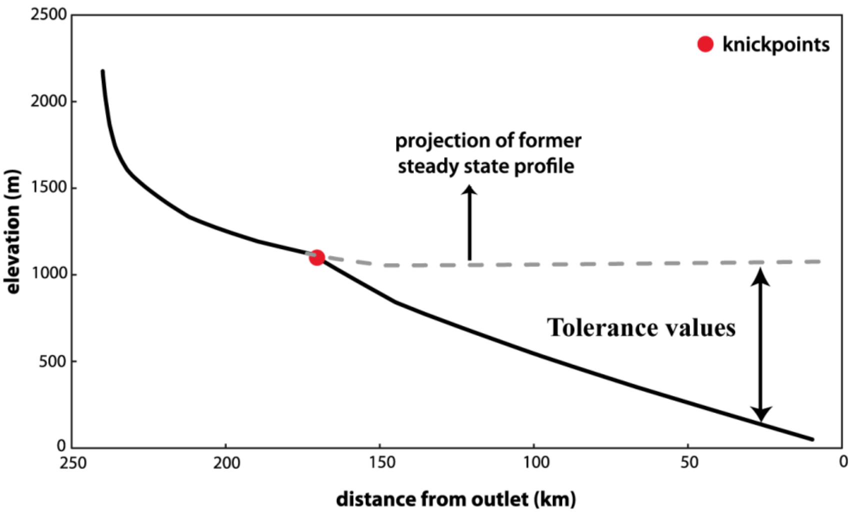

Figure 3. Schematic diagram of the knickpoint tolerance values

4. Result

4.1. Relationship between landslide dam and excess topography

Through remote sensing interpretation and field investigation, we found a total of 660 landslide dams in the Jinsha River (Figure 4), and we obtained the landslide volume by using empirical formulas. We divided the landslide into four types according to the volume of the landslide (Table 1), respectively small, medium, large, giant. 12 small landslides, mainly distributed in the upper reaches of the plateau surface of the Jinsha River. 37 medium landslides, mainly distributed in the small tributaries of the Jinsha River.111 large landslides, mainly distributed in big tributaries of the Jinsha River, and 500 giant landslide, mainly in the upper and middle reaches of the Jinsha River, it indicates that blocking river are require large or giant volume landslide. Among the 660 landslides, 626 landslides are located in the excess topography with a threshold hillslope of 30°, more than 90%, indicating that landslide is one of the important manifestations of hillslope erosion, and also one of the most common and efficient hillslope erosion events.

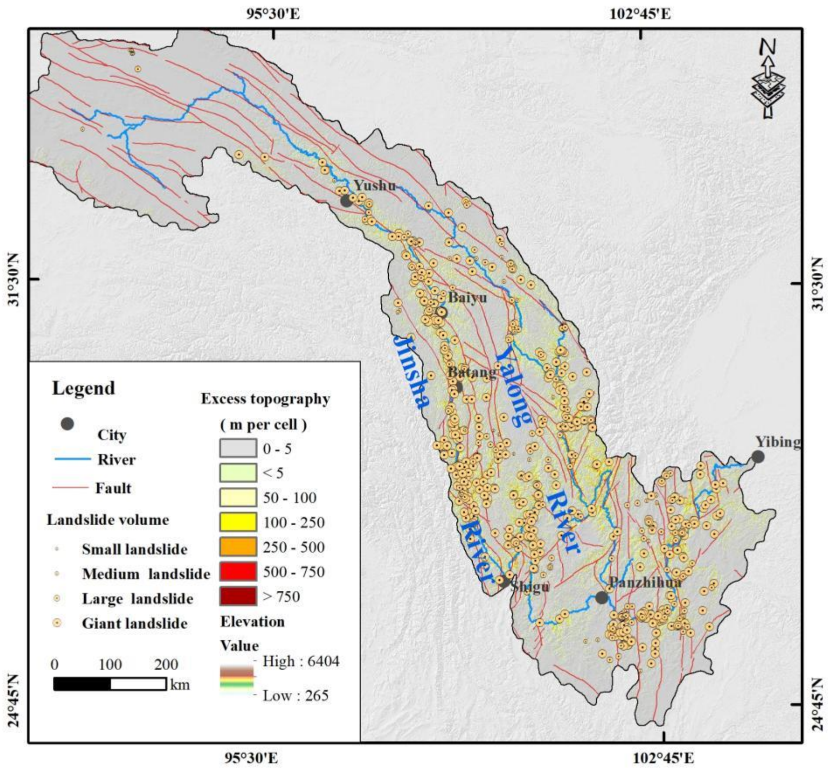

Figure 4. Distribution map of landslide and excess topography

Table 1. Classification of landslide types

Landslide type	Landslide volume(m^3)	Number	Percent
Small landslide	< 10×104	12	2%
Medium landslide	10×104 - 100×104	37	5%
Large landslide	100×104 - 1000×105	111	17%
Giant landslide	> 1000×104	500	76%

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4.2. Distribution of river knickpoint and $k_{s\,n}$

We extracted a total of 418 river knickpoint in the Jinsha River, It is mainly concentrated in the tributaries of the and middle and downstream reaches (Figure5). We made preliminary statistics of the height and elevation distribution of the knickpoints (Table 2). Among the 418 knickpoint, 271 knickpoints between the 30 m to 50 m in height difference distributed in the middle reach of the Jinsha river. 141 knickpoints between the 50 m to 100 m in height difference distributed in the small tributaries. 31 knickpoints between the 100 m to 150 m in height difference distributed near the big tributaries. 22 knickpoints between the 150 m to 250 m in height difference distributed near the upstream of tributary valley. 16 knickpoints are above 250 m in height difference distributed near the fault line. Through the comparison of spatial relations, it is found that in these 481 river knickpoints, there are 70 knickpoints overlapping with the landslide dam space, among which the maximum knickpoint height can reach 478m(Figure 6).

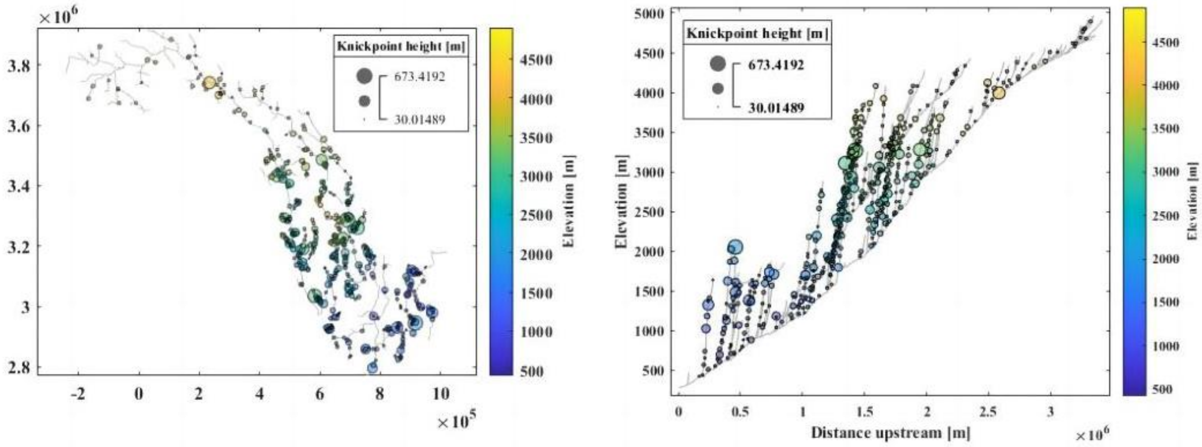

Figure 5. Distribution of river knickpoints in the Jinsha River.

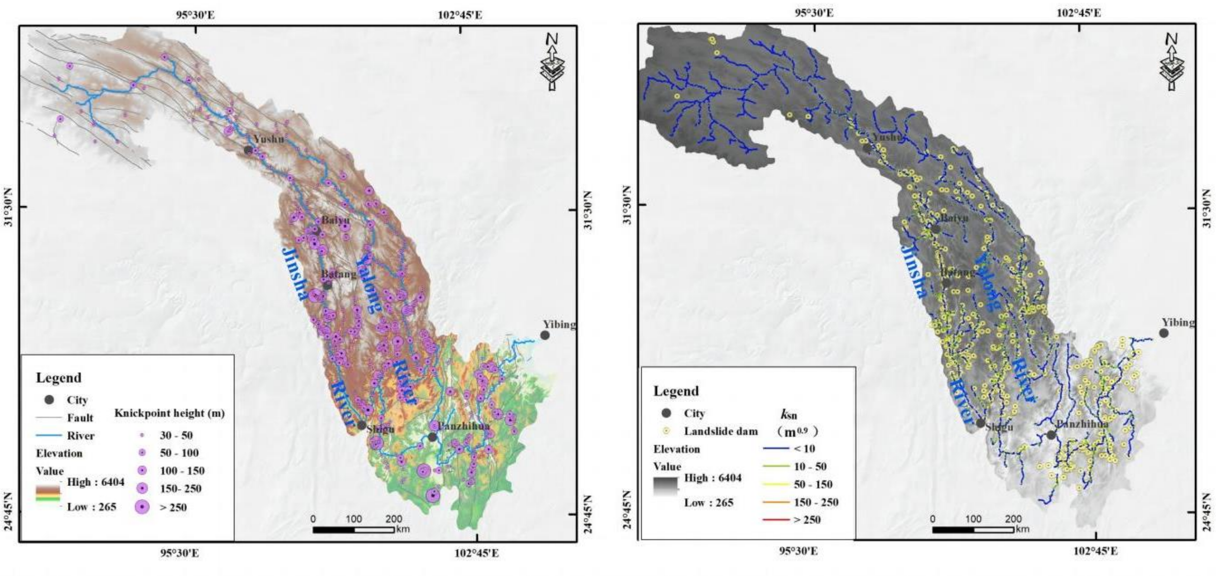

Figure 6. Relationship between landslide dam, faults, k_{sn} in the Jinsha River.

Table 2. Distribution characteristics of knickpoints in the Jinsha River.

Knickpoint height (m)	Number	Knickpoint elevation (m)	Number
30-50	271	<1000	81
50-100	141	1000-2000	132
100-150	31	2000-3000	152
150-250	22	3000-4000	130
>250	16	>4000	40

5. Discussion

From the perspective of the long-term evolution process of landscape, river erosion and hillslope erosion are coupled in the development process of river evolution. The river continues to erode the hillslope, leading to the steeper foot. When the slope reaches a certain steep degree, the slope becomes unstable, and the earthquake and heavy rainfall events will quickly adjust to the original balance in the form of landslide [25]. The occurrence of landslide is the instantaneous response of the slope process to the erosion of rivers. The rapidly moving landslide can accumulate in the narrow channels within minutes or even seconds to form a barrier dam . Through DEM, we extracted the river longitudinal profile and k_{sn}, and superimposed the landslide dam with the them (Figure 7). We found that the landslide dam has can effect river landscape elevation. In the densely distributed river channel of the landslide dam, the k_{sn} with the relatively high values, and the corresponding river longitudinal profile is steeper in the Jinsha River. Fan et al. (2020) [28] extracted 666 knickpoint in the Min River basin, and found that most of the knickpoint were related to the debris or landslides.

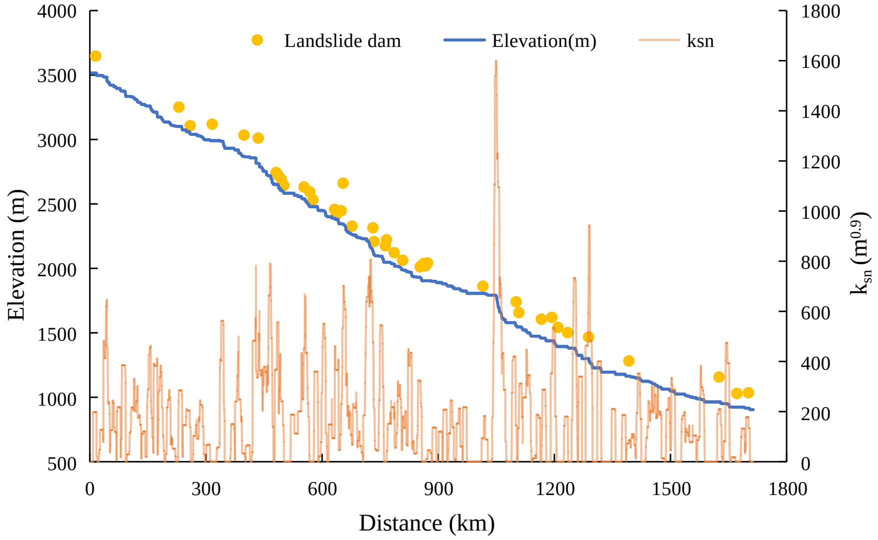

Figure 7. The spatial relationship between the landslide dam and k_{sn} in the Jinsha River

6. Conclusion

By using TopoToolbox, we extracted the longitudinal profile, knickpoints and k_{sn} values of the Jinsha River basin, and compared them with the field survey and remote sensing interpretation. There are 481 knickpoints and 660 landslide dams were identified, more than 90% landslides dams are located in the excess topography with a threshold hillslope of 30°. Our analysis reveals that the locations of 70 landslide dams and river knickpoints with heights above 30 m are spatially consistent. Among these landslide dams, the influence of 6 landslide dams on the channel can reach more than 100m, they can have knickpoint maximum height of over 478 m. Overall, By comparing the relationship between the landslide dam, k_{sn}, excess topography and knickpoint, They were found to have a good spatial correlation in the Jinsha River, it can indicate landslide dams play an important role in the landscape evolution with hillslope and channel.

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