Development of Tianwan river system and characteristics of river geomorphology

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Abstract. The uplift of Gongga Mountain has greatly affected the development of water system and topography of Tianwan River Basin. In this paper, ArcGIS software is used to extract the water system and main channel profile of Tianwan River Basin, and Horton theory is used to analyze the water system development and river network characteristics of Tianwan River Basin. The results show that the water system development of Tianwan River Basin basically conforms to Horton’s law, but the Horton ratio is larger at some levels, and the Horton ratio of the right bank is larger than that on the left bank. There are many river fissures in the basin, the largest of which are the Bawanghai Sea, which raises the river erosion benchmark and effectively suppresses the upstream disasters.

1. Introduction

Gongga Mountain is a kind of geomorphic and geological landscape formed under the influence of the geotectonic structure. Because of the squeeze between the Qinghai-Tibet Plate and the Yangzi Plate and the distinct difference in the uplifting due to neotectonic movement, the inner mountain rivers lie toward each other, running from north to south[1]. The Tianwan River Basin originates from the western slope of Gongga Mountain, with the left bank developing around the Mountain, which gives it the unique geological and geomorphological features and river network characteristics. The geomorphological characteristics of the basin influence the structure of the river system. At the same time, geological structures and the natural environment also have an impact on the patterns of river network. The features of the geomorphology and water system structure determines the water ecology and water environment[2]. In recent years, as the DEM data becomes more accurate, many scholars have studied the effects of the river network morphology and geomorphology on river systems using Horton’s law. For example, Liu Le et al. [3] compared Qinghai-Tibet Plateau river network with the general river networks described by Horton’s law so as to analyze its development law and the influence of plateau uplift on river network and topography. Lei Xue et al. [4] based on the digital terrain analysis method, compared the differences in the morphology of the small-and medium-sized mountain river networks in the hilly, plateau and plain, respectively. Yu Guoan et al. [5] analyzed the morphology of Yajiang River network and the characteristics of its geomorphology through field investigation, using SRTM and Google Earth. There are also scholars who have studied the relationship between the characteristics of the water system and that of the geological and geomorphological development by calculating the fractal dimension of basin systems[6-9]. This paper analyzes the characteristics of the water system and geomorphological development of the Tianwan River Basin based on the Horton’s law.
2. Overview of the study area
Tianwan River originates from the west slope of Gongga Mountain. It is located at 101°41′~102°11′ east longitude and 29°12′~29°47′ north latitude. As the first-level tributary of the right bank of the middle reaches of Dadu River, it flows through Kangding County of Ganzi Prefecture and Shimian County of Ya’an City. The basin is located in the transition zone from the Sichuan Basin to the Qinghai-Tibet Plateau, with the subtropical monsoon climate. The vertical and horizontal gullies in the basin are mostly in the formation and development stages of geomorphological development, with a large bed ratio, strong lateral erosion and traceability erosion, and a complex geological structure. The north-south Caoke fault and Moxi fault run cross this area, which are mainly composed of P2 marble, metamorphic rocks and D2 slate. The drainage area totals 1441km², with the total length of the main stream of 89km. The average annual flow of the estuary is 42.3m³/s, the elevation ranges from 1015m to 7375m, and the average river channel gradient is 44.2‰.

3. Research method
This paper extracts the map of water system and the main channel longitudinal section of the Tianwan River Basin based on the GDEMDEM-30 resolution digital elevation data (2009) using ArcGIS software, and obtains the number, average length, and average area of the channels. Then, obtain the Horton ratio between the water systems at different levels using Horton topology theory. For the convenience of the study, the threshold of river length is taken as 0.5km and the water system level is determined according to the Horton-Strahler system[10-11] (Level 1 is the lowest; two Level 1 rivers merge into a Level 2 river; two Level 2 rivers merge into a Level 3 river, and so on). The Level 6 river is the main stream of the Tianwan River, based on which the water system development and river network characteristics of the Tianwan River Basin is analyzed. At the same time, combined with field investigation and measurement of the Tianwan River Basin, this paper obtains the features of the topographical geology in the basin and the characteristics of the main fracture points.

4. Water system development and river network morphology
The channels in the upper reaches of the Tianwan River Basin (above Bawanghai) is mainly in the shape of a Chinese character called “‖”, and the middle and lower ones are mostly in the shape of branches (Fig. 1). The left and right banks of the basin are quite different: the area of the left bank is 499.2km², while that of the right bank area of 941.8km² (the ratio of the left bank area to that of right bank is 0.53); the total length of the left bank is 420.6km, and that of the right bank is 805.3km (the ratio of total length of left bank to that of the right bank is 0.52).

Figure 1 Water System of Tianwan River Basin
Based on Horton-Strahler classification, the following ratios are calculated using $N_ω$, the number of rivers of level $ω$, $L_ω$, the average length, and $A_ω$, the average basin area. Then, the topological properties of the river network mechanism can be analyzed macroscopically.

$$\frac{N_{ω}}{N_{ω+1}} = R_{Bω}; \ \frac{L_{ω}}{L_{ω-1}} = R_{Lω}; \ \frac{A_{ω}}{A_{ω-1}} = R_{Aω} \quad (1)$$

$R_{Bω}$, $R_{Lω}$, and $R_{Aω}$ represent the branch ratio, length ratio and area ratio, respectively, which are collectively referred to as the Horton ratios.

It is suggested that most natural river networks are in line with the Horton’s law, with the ratio varying within a small range (the river network branch ratio ranges between 3 and 5; the river network length ratio: 1.5 and 3; area ratio: 3 and 6[11]. With the increase of river level, the branch ratio, length ratio, and area ratio tend to reach 4, 2, 4[12]. However, when the rivers are influenced by geological structures, the development of river networks tends to deviate. According to Table 1, there are 835 Level 1 rivers, 183 Level 2 rivers, 37 Level 3 rivers, 7 Level 4 rivers, 2 Level 5 rivers, and 1 Level 6 river. The overall branch ratio, length ratio and area ratio of the basin are calculated to be 4.56, 2.36, and 5.18, respectively, indicating that the water system development in the Tianwan River Basin is generally consistent with Horton’s law.

| River level | Number of rivers / strips | Average length /km | Average watershed area/km² |
|-------------|---------------------------|--------------------|---------------------------|
| 1           | 835                       | 0.80               | 0.99                      |
| 2           | 183                       | 1.57               | 6.30                      |
| 3           | 37                        | 4.05               | 39.96                     |
| 4           | 7                         | 9.91               | 186.67                    |
| 5           | 2                         | 24.49              | 679.56                    |
| 6           | 1                         | /                  | /                         |

Figure 2 shows the change of Horton ratios of rivers of different levels in the entire basin and on the left and right banks. Affected by geology, the Horton ratios of the left and right banks are significantly different. The branch ratio of the entire basin is between 3.50 and 5.29, that of the left bank is between 2 and 4.56, and that of the right banks is between 2 and 5.50. Although the ratio of the maximum and minimum level of the left and right banks are different to a small extent, that of the right bank of the other levels are significantly larger than that of the left bank (Fig. 2(a)). The length ratio of each level of the whole basin is between 1.96 and 2.56, that of the left bank is between 1.65 and 2.19, and that of the right bank is between 1.31 and 3.35. The length ratio of the right bank of Level 2 and Level 3 is 2.01 times that of the left bank, while there is little difference between that of the other levels (Figure 2(b)). The area ratio of the whole basin is between 3.64 and 6.37, that of the left bank is between 3.67 and 6.38, and that of the right bank is between 3.62 and 6.47. The area ratio of the entire basin is not much different from that of two sides, but that of the right bank is slightly larger than that of the left bank (Fig. 2(c)).

Figure 2 Horton ratios of different water systems
There also exist some situations where the Horton ratio of the Tianwan River Basin is not within the scope of Horton’s law. For example, the branch ratio between Level 4 to Level 5 rivers is 5.29, and that between Level 3 and Level 4 of the right bank is 5.45. The length ratio between Level 3 and Level 4 is 3.35. However, the area ratio between the entire basin and the left and right banks of Level 1 and Level 2, Level 2 and Level 3 exceeds the range of Horton’s law. Due to the strong uplift of the Gongga Mountain crust, the characteristics of the river network deviate from the general law. Since the geological uplifting effect on the right bank is smaller than that of the left bank, the Horton ratio of the right bank is generally larger than that of the left bank.

5. River landscape

The difference of geological structure and lithology of the Tianwan River Basin are mainly reflected in the huge difference of geological development of the left and right banks. The basin originates from the western slope of Gongga Mountain, which is located at the junction of the Qinghai-Tibet Plate and the Yangtze Plate, where the frequent geological tectonic activities result in many folds and faults. New tectonic movement of the Gongga Mountain has been active since the Quaternary Period, leading to strong and differentiated block uplifting[13]. As the landform develops, the neotectonic movement has a greater impact on the marginal zone. Therefore, the rising crust of the Gongga Mountain has a greater impact on the topography of the left bank of Tianwan River, resulting in the huge difference in the distribution and the features of water system in the left and right banks.

Under normal circumstances, the longitudinal section of the river is in the shape of a concave, but that of the main stream of the Tianwan River is in the shape of a convex. There is a relatively obvious change in the slopes of Bawanghai (left branch) and Nichanggou (left branch). The average longitudinal slope above Bawanghai is 35‰, that from Bawanghai to Nichanggou is 50‰, and that below Nichanggou is 37‰. Therefore, the area above Bawanghai is upstream, with a total length of 41km, the area between Bawanghai to Nichanggou is midstream, totaling 33km, and the area below Nichanggou is downstream, totaling 15km (Fig. 3).

![Figure 3](image_url)  
Figure 3 The longitudinal section of the Tianwan River main stream and the watershed of both sides

The transition point on the longitudinal section of the river is called the “river crack” [14]. It can be seen from Fig. 3 that the elevation difference between the left bank watershed and the channel shows basically the same trend in the whole basin. The altitude of the right bank watershed continues to increase, that is, the elevation difference of the middle and lower channel and the left and right banks...
are relatively large. The cracks in the Bawanghai are mainly formed due to the accumulation of solid matter during mudslides. According to the 2015 survey, its formation and influence range is about 12km upstream and about 9km downstream. Based on the trend of the longitudinal profile of the river, the thickness of the crack deposit is about 178m. The upstream channel is relatively wide, with a maximum width of 455m. In addition, there are many turbulences and shoals, and the average slope is 5.2‰. The downstream is narrow, with the average slope decreasing to 39.1‰ (Fig. 4(a)). There are also many cracks in the middle and lower reaches of the Tianwan River. In the middle reach of the Gongjiagou, the average slope of the upper reaches of the crack is 29.7‰; the average slope of the downstream is 77‰ (Fig. 4(b)); at the junction of the middle and lower reaches in the vicinity of Nichanggou, the average slope of the upper reaches of the crack is 54.6‰; the average slope of the downstream reaches is 64.5‰ (Fig. 4(c)). As can be seen from Figure 4, the upper reaches of these cracks are relatively broader and more gentle, while the downstream ones are relatively narrower (Figure 4).

The formation of cracks lifted the erosion datum of the riverbed, which slowed down the erosion rate of the upstream channel, and even prevented undercutting or turned into siltation, thus widened the riverbed. The formation of the Bawanhai barrier has changed the erosion datum point, slowed down the undercutting of the downstream channel, and greatly reduced the occurrence of upstream disasters. Therefore, there has been no mudslide and collapse landslide in the upper reaches of the Bawanhai; Gongjiagou for a long time. In addition, within the influence range of cracks at Gongjiagou and Nichanggou, there is a small number of geological disasters. In the other areas of the middle and lower reaches, the main river and the branch ditch continued to undercut, making the mountain body less stable. In addition, the larger height difference between the two sides also leads to more geological disasters such as collapse, landslide and mudslide every year.

6. Conclusion
The water system of the Tianwan River Basin has the characteristics of a branched river network. The branch ratio, length ratio and area ratio of the river network are basically in accordance with Horton’s law. However, due to the geological tectonic activities of the Gongga Mountain, there are some situations where the ratios are deviated from the Horton’s law. Generally speaking, Horton ratios of the right bank are bigger than those of the left bank. River cracks in the basin slowed down the undercutting in the upper main river and branches, which significantly prevented the occurrence of upstream geological disasters.

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