

Characteristics of Variation in Runoff across the Nyangqu River Basin in the Qinghai-Tibet Plateau

YANG Dingding^{1,2,3}, ZHOU Caiping^{1*} OUYANG Hua¹ and CHEN Chuanyou¹

1 Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China

2 Graduate University of Chinese Academy of Sciences, Beijing 100049, China

3 Transport Planning and Research Institute, Beijing 100028, China

Abstract: Using annual nature runoff data from 1961–2000 for the Qinghai–Tibet plateau Nyangqu River, the Mann–Kendall method and wavelet transform were adopted to analyse runoff variation characteristics for the Nyangqu River. The results show that the annual change in runoff is relatively stable and that the intra–annual distribution of the runoff is extremely uneven. The disparity in runoff between wet seasons was significant. The runoff for June–September accounted for 65% of the whole year and the highest monthly runoff accounted for 24.56%. From 1961–2000, runoff showed a significant increasing trend with an abrupt increase in 1985. The 5–8 years oscillation period of the runoff was most notable and the 10–15 years period was relatively notable. The principal periods of annual runoff for Shigatse station and Gyantse station were 5a and 7a. The second were 13a and 12 years. Increasing glacial melt water caused by rising temperatures may be the main reason for increased runoff in the Nyangqu River.

Key words: Nyangqu River; Mann–Kendall test; natural runoff; wavelet analysis

Global climate change is one of the important current environmental issues. An increasing number of scientists and managers are researching the impacts of climate change on regional hydrology and water resources with great concern (Ding, 2008; Ren *et al.* 2008). The Qinghai-Tibet Plateau is an area sensitive to climate change. Climate change will inevitably cause changes to the hydrological cycle, change the spatial and temporal distribution of water resources and volume of the water resources, affecting the ecological environment and socio-economic situation. Studies have shown that climate change, particularly the increase in temperature in the Qinghai-Tibet Plateau in recent decades, has had a great impact on many aspects such as runoff and lake water in the cryosphere and the other regions (Lai 1996; Su *et al.* 1999; Wang *et al.* 2008). The Qinghai-Tibet Plateau is a headstream of major Asian rivers and rich in water resources. The hydrological cycle and local water resources are important for the surrounding area (Liu *et al.* 2007; Guan *et al.* 1984).

The Nyangqu River basin is located in the south of the Tibetan Plateau, meanwhile the midstream Brahmaputra River. The basin is a relatively densely populated area and is an important grain production base for the Tibet Autonomous Region. Execution of the "one river-two streams" comprehensive development project in the 1990s promoted regional water conservancy construction and agricultural production. Nyangqu River is the important guarantee for development of the region (Wang *et al.* 2002). Therefore, to study variation in hydrology and water resources in Nyangqu River basin under climate change is of great practical significance. A hydrological time series study of Nyangqu River has important direct significance to regional water resources allocation and scheduling, flood control, drought resistance and agricultural production. Liu jian's study into runoff variations of the Brahmaputra

River mainstream showed that climate change, especially temperature, had a great influence on runoff. However, there has been little research into runoff variation for the

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*Corresponding author: ZHOU Caiping. Email: zhoucp@igsnr.ac.cn.

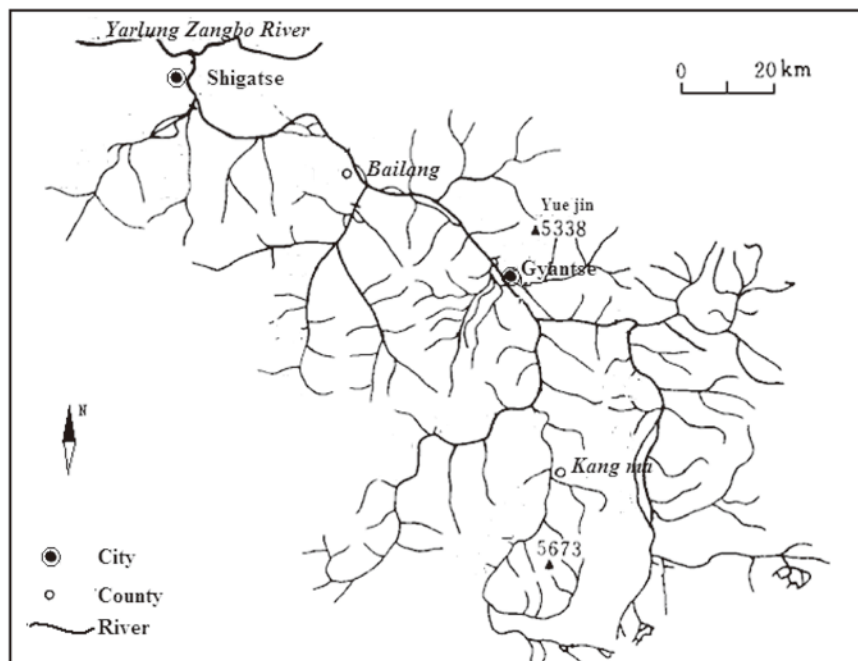


Fig. 1 Sketch map of the Nyangqu River.

Nyangqu River.

1 Overview of the study area

The Nyangqu River is a first order tributary of the Brahmaputra River and originates from the northern foot of the middle Himalayas. The basin is located at $28^{\circ}10' N$ – $29^{\circ}20' N$ and $88^{\circ}35' E$ – $90^{\circ}15' E$ and covers $11,130 \text{ km}^2$. Karela Snow Mountain and Yamzhog-Poumeayumco basin lie to the east of this river; Bhutan and Mountain Himalayas is to the south. The Xiabuqu River basin is to the west and the Brahmaputra River valley lies to the north (Xia *et al.* 2001). Nyangqu River basin is in the temperate semi-arid highland climate zone, characterized by a distinct dry and wet season plateau continental climate. As the Himalayas are to the south, a rain shadow zone is formed by the northern slope, resulting in lower precipitation. Average annual rainfall at Shigatse is only 430 mm, and 288 mm at Gyantse. Kangma and Nirvana are areas affected intensely by the rain shadow zone, with less annual precipitation (Liu 1995). The Nyangqu River basin's topography is undulate. The basin slopes from southeast to northwest and the flow direction of Nyangqu River is also generally from northwest to southeast. The region to the northwest of Gyantse is a mountain canyon with narrow valleys, high mountains and steep slopes. Compared to this, the southeast is low mountains and hilly Loess landforms with open valley and moderate undulate mountains. Vegetation and soil show a distinct vertical distribution across the plateau. The soil is cold desert soil at an altitude of 5200 m above sea level, the alpine meadow soil and sub-alpine grassland soil are at 4200–5200 m, and mountain shrub and grassland soils at 4200 m. Sophora (*Sophora moorcroftiana*) and kobresia (*Kobresia*) are mainly distributed in the basin with low coverage. For the developed inner fracture, broken

mountains and sparse vegetation, soil erosion is serious. The river source area has many glaciers and glacial lakes such as the Chumbyumco, White Lake and Sang Mong Lake. Glacier melt water is an important supply source for the Nyangqu River.

2 Data and methodology

The hydrological data used in this article is natural runoff data from Nyangqu River Shigatse Hydrological Station (Shigatse station) and Gyantse Hydrological Station (Gyantse station) from 1961 to 2000 (Bureau of Hydrology and Water Resources, Tibet Autonomous Region). Natural runoff was chosen because of the water conservancy project water facilities. Then the effect of human activities including water conservancy construction and agricultural irrigation can be removed. The effect of natural factors including temperature, precipitation and Earth surface conditions in the basin on runoff emerged. The Mann-Kendall test was used to analyze runoff trends and characteristics of mutations. Wavelet analysis was used to find the periodic of runoff.

The nonparametric Mann-Kendall test is appropriate for analyzing hydro-meteorological data and other non-normal distributions, has been recommended by the World Meteorological Organization and is widely used. Time series trends can be determined by calculating the statistical test value "Z" of the Mann-Kendall test and mutability can be determined by drawing an order out curve of the time series (Wei 1999). In the time series x are the sequential data values, n is the data set record length, and the Mann-Kendall test statistic S is given by the formula:

$$S_k = \sum_{i=1}^k r_i \quad (k=2,3,\dots,n) \quad (1)$$

$$r_i = \begin{cases} +1 & \text{if } x_i > x_j \quad (j=1,2,\dots,i) \\ 0 & \text{else} \end{cases} \quad (2)$$

The test statistic Z is computed as follows:

$$Z = \begin{cases} \frac{S_k + 1}{\sqrt{Var(S_k)}} & \dots S > 0 \\ 0 & \dots S = 0 \\ \frac{S_k - 1}{\sqrt{Var(S_k)}} & \dots S < 0 \end{cases} \quad (3)$$

In formula (3), the statistic Z is accorded with a normal distribution. The positive value of Z indicates an increasing trend and negative value indicates a decreasing trend. The statistic sequence UF is computed as follows:

$$UF_k = \frac{[S_k - E(S_k)]}{\sqrt{Var(S_k)}} \quad (k=1, 2, \dots, n) \quad (4)$$

The inversion sequence UB is computed with the inversion data series of x by such same formula. The diagram is drawn the sequences of UF and UB . If the cross of curves is between lines of U_α based on the level of significance α , the time of the cross point indicates the beginning of the abrupt change.

Wavelet analysis was introduced to hydrological research by Kumar and Foufoular Gegious. It has been developed into a multi-time scale analysis, characteristic analysis, and hydrologic forecasting and simulation (David L 2008; Koscielny BE *et al.* 2006). The wavelet method has applications in China and abroad (Xue *et al.* 2002; Wang *et al.* 2002; Torrence *et al.* 1998). Much research indicates that the regular patterns of hydrologic systems differ across different spatial and temporal scales. Prevailing hydrological time series analysis methods include moving average, filter, and Fourier transform. These are all base on a single time scale and can not objectively reflect the multi-scale structure of space-time without characteristics such as localization, multi-level and multi-resolution. Wavelet analysis can more accurately determine the specific period of the time scale of hydrological time series (period) (Liang *et al.* 2007; Liu *et al.* 2005) due to the inclusions of time-frequency, localization and multi-resolution.

3 Results and Analysis

3.1 Essential Analysis Nyangqu River runoff

The Nyangqu River basin is a typical plateau watershed,

with glacier melt water, groundwater and precipitation as sources. Gyantse station is located near the midstream and Shigatse station is near to downstream. Data from these two stations runoff are representative of the hydrological situation across the whole watershed.

As seen from Table 1, coefficients of variation Cv of Nyangqu Shigatse station and Gyantse station were 0.2758 and 0.1981, respectively. These values are lower than most rivers as well as the annual extremes at each station of 3.1569 (Shigatse) and 2.0235 (Gyantse). The conclusion is that annual variation in Nyang River annual flow is relatively stable. This is related to the slight variation of coefficient of variation of precipitation and inter-annual values. Meanwhile, historical data showed that the groundwater recharge to Nyangqu River accounts for about 50% of total runoff, which explains the small coefficient of variation in Nyangqu River runoff (Guan *et al.* 1984).

To a large extent, seasonal change influences runoff recharge of the Nyangqu River. The annual runoff distribution is extremely uneven. Figure 2 shows the monthly runoff distribution of Shigatse station and Gyantse station. The monthly mean temperature and precipitation in the basin are shown in Figure 3. Nyangqu River basin is with the same quarter of rain and heat, where moisture mainly from the Bay of Bengal warm airflow with significantly different between summer and winter (Yin *et al.* 1997). Precipitation from June to September accounts for more than 90% of annual precipitation. The higher temperatures cause more melting of glaciers and flooding. From November to March precipitation is close to zero. The low temperature reduces glacial melting and as a result runoff depends mainly on groundwater recharge and river flow is relatively stable. We found obvious differences in runoff in the Nyangqu River between the wet season and dry season (Fig. 1). The runoff at Shigatse station and Gyantse station in the wet season accounted for a large proportion of the whole year. Among them, runoff from June to September in the two stations accounted for about 65.52% and 64.89% of the whole year, respectively. Runoff of the maximum month (August) accounted for 24.56% and 21.52% of runoff in whole year, respectively.

3.2 Abruptness and trend detection of runoff variation for the Nyangqu River

The formula for the Mann-Kendall test is presented in detail in other papers (e.g. Lin *et al.* 2008). The statistic value Z of annual runoff, annual temperature and annual precipitation in Shigatse station and Gyantse station and the trend statistic value of Mann-Kendall were calculated (Table 2).

Table 1 Eigenvalues of the hydrological stations, annual runoff in Nyangqu river basin.

Hydrological station	Annual average runoff volume	Cv	Cs	Extreme ratio	Data length year
Shigatse	50.9020 m ³ s ⁻¹	0.2758	1.0638	3.1569	40
Gyantse	33.3825 m ³ s ⁻¹	-10.1981	1.0327	2.0235	40

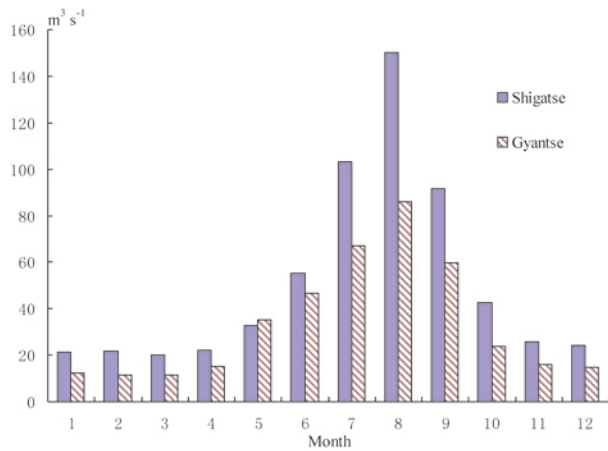


Fig. 2 Annual distribution of runoff in Nyangqu River basin.

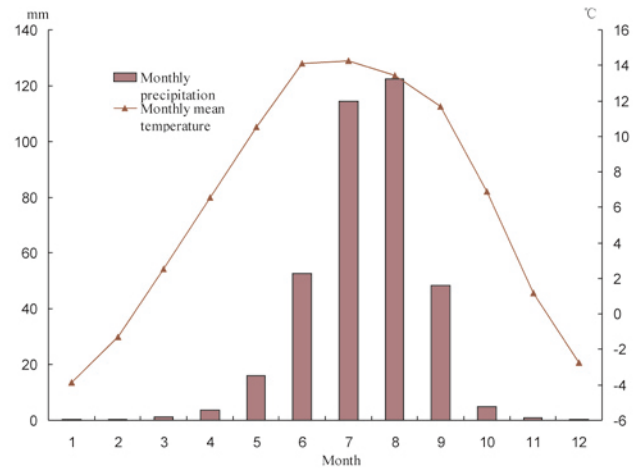


Fig. 3 Monthly mean temperature and precipitation in Nyangqu River basin.

As seen from Table 2, the statistical tests values Z on time series of annual runoff in Shigatse station and Gyantse station were greater than 0. This result indicates that runoff of the two stations trends increased from 1961 to 2000; the trend of Shigatse station is extremely pronounced. Precipitation and temperature are the two most direct factors affecting runoff, so we completed a trend analysis for these variables. Results showed that annual temperature in the two stations from 1961–2000 followed a significant increasing trend, and that annual precipitation had no significant trend. The main reason for increased runoff in the Nyangqu River is probably the increase in melt water caused by increases in temperature. Shigatse runoff increases more than that at Gyantse and we propose two reasons to explain this pattern. First, in this basin runoff is supplied by ice-snow melt water and groundwater. Nyangqu river basin has special hydro-geological character with loose soil, incompact rock and underground stratum cracks. Part of the ice-snow melt water flows into the river directly and the other part supplies ground water, replenishing the lower reaches. Second, there are several branches below the Shigatse station. The ice-snow melt water from these branches is concentrated in the main stream and this contribute to the greater increase in runoff observed at Shigatse.

Mann-Kendall test analysis results on abrupt change in runoff at Shigatse station and Gyantse station are shown in Fig. 4 and Fig. 5.

As can be seen from Figure 5, the value of the UF curve is less than 0 at Gyantse station before the 1980s, meaning that runoff decreased slightly but with fluctuations. Then the value of UF curve changed from negative to positive and gradually increased after the 1980s; the value is greater than 0, which means runoff increased continually. With the critical line in between ± 1.96 , the UF curve crosses the UB curve at 1985. The conclusion can be drawn that around 1985 the runoff began to mutate. At the $\alpha = 0.05$ level of significance, the value of UF was larger than the $+1.96$ reliability line in 1987, indicating that the runoff continued to increase. As can be seen from Figure 5, the value of the UF curve in Gyantse station located in the upstream are smaller than 0, meaning that runoff did not show an increasing trend the same as in Shigatse station located downstream All UF values are within the ± 1.96 critical line and shows no obvious trend for Gyantse station. With the critical line in between ± 1.96 , the UF curve crosses the UB curve at the year 1963 (Fig. 4). This finding indicted that the short-term mutation whereby runoff reduced around 1963 at Gyantse station and that later there is no significant runoff mutation.

3.3 Periodic analysis of runoff changes for the Nyangqu River

Morlet wavelet was chosen to analyze runoff for the Nyangqu River at Shigatse station and Gyantse station.

Table 2 Results of trend analysis by Mann-Kendall test of annual runoff, temperature and precipitation in the Nyangqu River basin.

Series	Runoff 1961–2000		Annual mean temperature 1961–2000		Annual precipitation 1961–2000	
	Z	α	Z	α	Z	α
Shigatse	3.87	***	4.28	***	-0.10	
Gyantse	0.20		2.48	*	-0.08	

Tested significance levels α : + is 0.1; *is 0.05; *** is 0.001; blank is >0.1

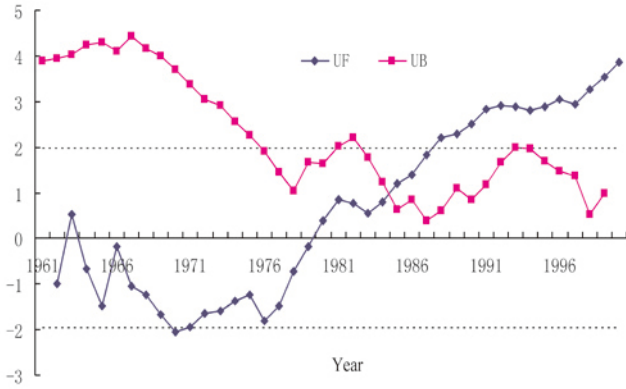


Fig. 4 Results of abruptness by Mann-Kendall test of runoff at Shigatse station 1961–2000.

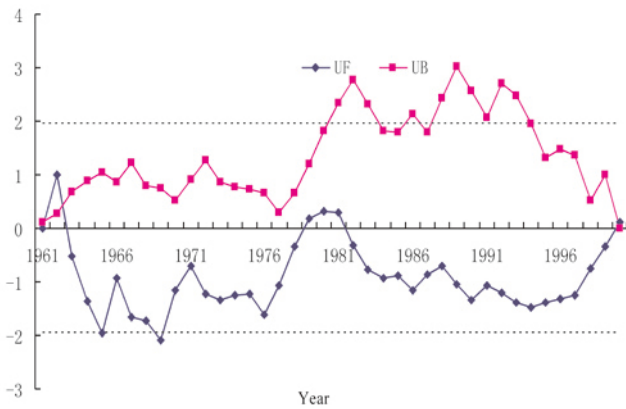


Fig. 5 Results of abruptness by Mann-Kendall test of runoff at Gyangze station 1961–2000.

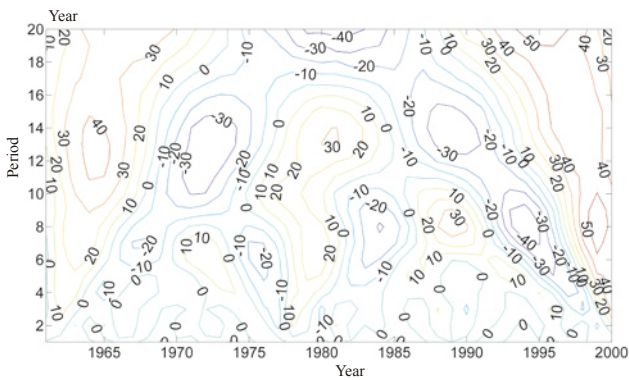


Fig. 6 Morlet wavelet transform of annual runoff of Shigatse station

Contour of wavelet coefficients can reflect the cycle and amplitude of various sizes of runoff and the variation in amplitude of the same cycle with time (Liu *et al.* 2005). Figures 6 and 8 show contour figures of wavelet coefficients of runoff of Shigatse station and Gyantse station during 1961–2000 for the Nyangqu River, in which the strength of the signal is indicated by wavelet coefficients. The deeper color of the contour figures represent positive values,

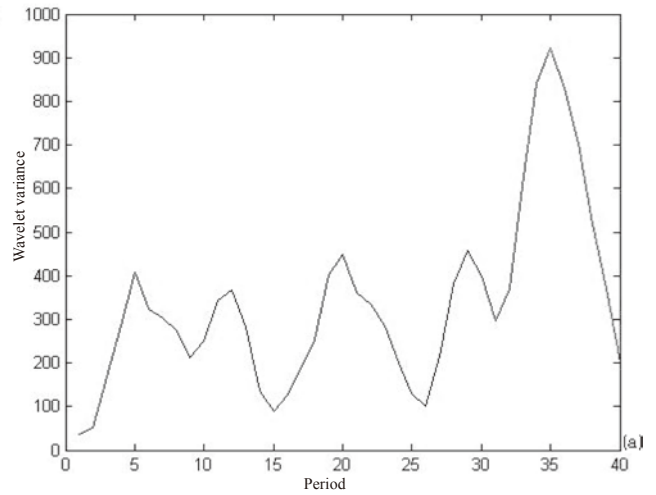


Fig. 7 Wavelet variance of annual runoff at Shigatse station.

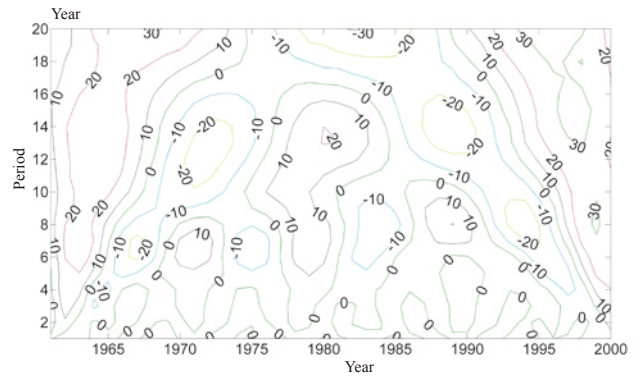


Fig. 8 Morlet wavelet transform of annual runoff of Gyangze station.

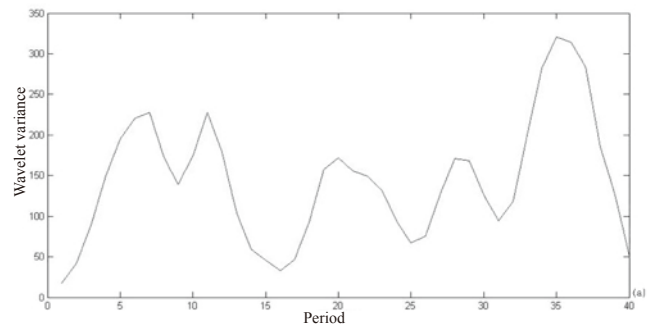


Fig. 9 Wavelet variance of annual runoff of Gyangze station.

the lighter color represent negative values. The wavelet coefficients at different time scales reflect variation of the system in the time scale (period). The greater the absolute value of wavelet coefficients, more prominent the change of the time scale. The feature of the runoff at Shigatse station and Gyantse station is a multiple time scale. The most prominent oscillation time scales of the two stations are about 5–8 years, followed by 10–15 years. The time-

frequency changes in large-scale contains that at a small-scale.

Wavelet variance var (a) can reflect the energy intensity of time series in special periodic fluctuations, and equal to the integral of the square of the wavelet transform coefficients (WT) in time domain. The formula of var (a):

$$Var(a) = \int_{-\infty}^{\infty} |WT_f(a,b)|^2 db$$

Wavelet variances can present the variational characteristics of the energy in different scales and can determine the accurate periods of the time series (Jiang et al. 2008; Liao et al. 2007). Figs. 7 and 9 show wavelet variance curves of runoff at the two stations, and the time scale corresponding to the peaks of the curve is the main period of runoff. Usually, the length of the time series is limited, so the usual time series analysis of the length of cycle characteristics is limited and the general practice is to choose the time scales in the 1/2 length of the time series as the actual period. As can be seen from Figs. 8 and 10, the principal period of the Shigatse station runoff variation is 5 years and the second period is 13 years. The corresponding periods in Gyangze station are 7 years and 12 years. The difference in the periods between the two stations may be caused by the different location of these in the basin and the difference composition of runoff sources.

4. Conclusions

(1) The intra-annual distribution of runoff for the Nyangqu River was extremely uneven. The disparity of runoff between wet seasons was significant. Runoff from June to September accounted for 65% of the whole year and the highest monthly runoff accounted for 24.56% of annual runoff.

(2) Runoff at the two stations Shigatse and Gyantse during 1961–2000 showed an increasing trend. The increasing trend in annual runoff of Shigatse station was significant. The temperatures in the Nyangqu River basin from 1961–2000 showed a significant increasing trend, but no significant change in annual precipitation. Increasing glacial melt water caused by rising temperatures might be the main reason for increased runoff in the Nyangqu River, but this idea requires further research.

(3) Mann-Kendall tests showed that an abrupt change point in Shigatse station runoff occurred in 1985, after which runoff has continued to increase.

(4) The 5–8 years oscillation period of the runoff was most notable and the 10–15 years period was relatively notable. The principal periods of annual runoff of Shigatse station and Gyantse station were 5 years and 7 years. The second were 13 years and 12 years.

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青藏高原年楚河流域径流变化特征分析

杨丁丁^{1,2,3}, 周才平¹, 欧阳华¹, 陈传友¹

1 中国科学院地理科学与资源研究所, 北京 100101;

2 中国科学院研究生院, 北京 100039;

3 交通运输部规划研究院, 北京 100028

摘要: 基于青藏高原河流年楚河1961-2000年天然径流量资料, 选用Mann-Kendal分析方法和小波分析等方法对年楚河径流变化特征进行研究。结果表明: 年楚河流域径流量年际变化相对平稳, 年内分配极不均衡。丰水季节与枯水季节径流量相差悬殊, 6-9月径流量占全年65%, 最大月径流量占全年百分比达24.56%; 在1961-2000年中, 年楚河径流量呈现显著增加趋势, 在1985年左右径流量发生突变性增加; 日喀则和江孜两站5-8年左右时间尺度的周期震荡最显著, 其次10-15年左右时间尺度的周期震荡也较为显著, 两站径流量变化的主周期分别为5年和7年, 次周期分别为13和12年。年楚河流域气温升高引起冰川融水增加可能是年楚河径流量增加的主要原因。

关键词: 年楚河; Mann-Kendall检验; 天然径流量; 小波分析