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Runoff Characteristics of the Nen River Basin and its Cause

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Abstract: Based on annual runoff data collected from several hydrological stations in the Nen River Basin from 1956 to 2004, the cumulative filter method, Mann-Kendall method and Morlet wavelet analysis were used to analyze variations in the characteristics and factors influencing runoff. Specifically, the general characteristics list as: The distribution of runoff was found to be uneven within a year, and the annual variation showed an overall decreasing trend. The abrupt change points of runoff were found to be in the early 1960s, middle 1980s and late 1990s. Multiple time scales analysis revealed three time-scale cycles, a long-term cycle of about 20-35 years with a scale center of 25 years, another cycle of about 8-15 years with a scale center of 11 years and a short-term cycle of about 5 years. Based on the Morlet wavelet transform coefficients figure of the 25-year time scale, it is preliminarily estimated that the Nen River Basin will enter a high flow period in 2013. The results obtained using various methods were consistent with each other. The physical causes of the results were also analyzed to confirm their accuracy.

Keywords: Nen River Basin; Runoff changes; Morlet wavelet analysis; Mann-Kendall test

Introduction

Watershed runoff is the result of climate factors, underlying surface factors and human activities over time (Zhu et al. 2011). Stream runoff processes have changed profoundly in recent years owing to the impact of climate warming and human activities, so that flood and drought disasters occur more frequently. With societal, economic and the environmental changes, service functions of aquatic ecosystems have degenerated and have affected the development and rational distribution of water resources. These changes can cause large financial losses and even lead to life-threatening situations. Investigations of trends in runoff variation and the effects of climate change and human activities on water resources have received increasing attention. Many studies in China (Shi et al. 2007; Wang et al. 2010; Wu et al. 2006; Liu et al. 2007) have used the Mann-Kendall test, R/S analytical method and wavelet analysis. The coupling of climate and hydrological models is an important research strategy to assess variations in water resources under future climate scenarios and new methods are required to solve the problems of scale matching and portability. Zhang and Xu (Zhang et al. 2008; Xu et al. 2008, 2009) showed that runoff in the Nen River Basin, Heilongjiang Province, China, decreased in 1963, increased in the 1980s, and decreased again in the late 1990s, and they also showed that the inter-decadal cycles were 8 years, 20 years and more than 40 years, respectively.

Studies to date have analyzed only the mathematical characteristics of these runoff series but most studies are hampered by a lack of physical explanation of their results. We have analyzed results obtained at stations from the upper reaches to the lower reaches of the Nen River basin and used them to determine the overall hydrological characteristics as well as the runoff characteristics

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of each hydrological station and their relationships. We also assessed the transformation of rainfall, surface and subsurface runoff, and their relationship to recharge runoff discharge, allowing us to elucidate the response of runoff to rainfall and climate change in different river reaches. The annual runoff was analyzed based on the hydrological year instead of the calendar year to include all stages of the water regimen in a year.

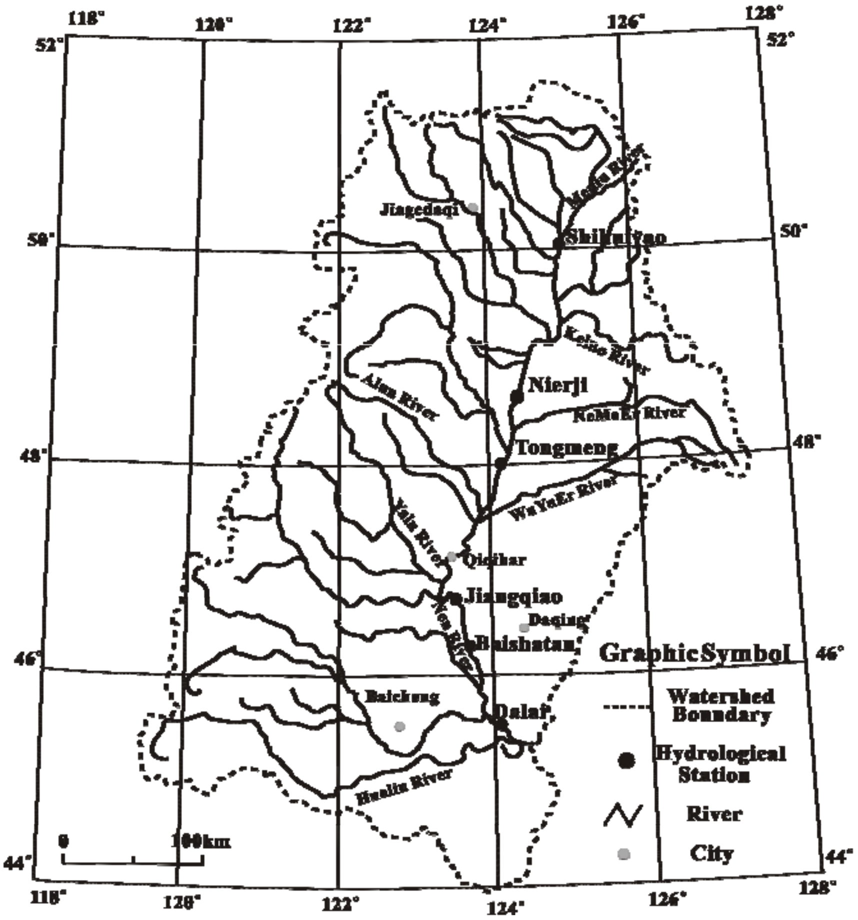

Figure 1 Water system of Nen River Basin.

1 Materials and Methods

1.1 Study area

The Nen River lies in the Midwest of Heilongjiang Province, China, and originates in the Yilehuli Mountain of Great Khingan. The Nen River is the northern source of the Song Hua (Sun and Bai 2005). The length of the river is 1,370 km with a catchment area of 283,000 km^2, accounting for 51.8% of the total River Basin (total area is 546,000 km^2). The Nen River Basin (Figure 1) lies on the north margin of the East Asian monsoon region and has a cold and semi-humid continental monsoon climate with long, cold winters and short, rainy summers. However, its unique geographical position, shape and terrain features, result in great climate variation throughout the basin, which results in spatial and temporal differences in rainfall and temperature. The average annual temperature ranges from -4°C to 6°C. Rivers are frozen from late October to early November, and melt in early April.

1.2 Methodology

1.2.1 Methods for runoff regime analysis

We investigated the general characteristics of runoff variation within a year.

Analyses and predictions of extreme hydrological events, such as floods and droughts, throughout any one year are essential although most floods occur during flood season. The nonuniformity coefficient , defined in Equation (1) can be used to show the changes in runoff during a year.

$$C_u = \sigma / \overline{R} , \sigma = \frac{1}{12}\sqrt{\sum_{i=1}^{12}(R_i - \overline{R})^2} , \overline{R} = \frac{1}{12}\sum_{i=1}^{12} R(i) \quad (1)$$

where C_u is the nonuniformity coefficient, R_i is monthly runoff, and $\overline{R}$ is mean annual runoff.

The variation coefficient (Equation 2) is an indicator that can reflect the general characteristics of yearly variation.

$$Cv = \frac{\sigma}{\overline{x}} \quad (2)$$

where $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$; $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2}$; x_i is the value of the year i ; $\overline{x}$ is the mean value of the series; and σ is the standard deviation.

1.2.2 Methods for evaluation of variations in runoff trends

The cumulative filter method and Mann-Kendall test were used to analyze variations in runoff trends. The first method is qualitative analysis, and the second is quantitative analysis.

(1) The cumulative filter method (Equation 3) can qualitatively reflect variations in time series (Chen et al. 2002).

$$S_i = \frac{\sum_i^n R_i / n}{\overline{R}} \quad (n = 1, 2, ..., N) \tag{3}$$

where S_i is the accumulated average value; R_i is the runoff series; $\overline{R}$ is mean value of runoff; N is the length of data series.

(2) Mann-Kendall test (M-K test)

The M-K trend test is :

$$M = \tau / \sigma_\tau \ , \tau = \frac{4S}{N(N-1)} - 1 , \quad \sigma_\tau^2 = \frac{2(2N+5)}{9N(N-1)} \tag{4}$$

where M is the rank correlation coefficient; S is the number of times when $x_i < x_j$ occurs in all dual observed values ($x_i, x_j, i < j$); N is the length of the series.

If the rank correlation coefficient is $|M| \le M_{(1-\alpha/2)}$, it indicates no significant variation tendency in this series; otherwise, it indicates that there is a significant variation tendency in the series. ($M < -M_{(1-\alpha/2)}$: significant descending trend; $M > M_{(1-\alpha/2)}$: significant ascending trend). α is the level of significance, $M_{(1-\alpha/2)} = 1.96$ when $\alpha = 0.05$.

1.2.3 Methods for abrupt change analysis

The M-K test can be used in time-series trends analysis, as well as for abrupt change point testing. The M-K test method is widely employed for abrupt change point testing of hydrologic climatic time series because it is widely applicable, reflects less human impact, and is highly quantifiable (Wei 2007).

We assume that the time series under study is $x_{i-1}, x_{i-2}, \ldots, x_2, x_1$, n is the length of the data set, and p_i denotes the accumulative total samples for which $x_i > x_j$ ($1 \le j \le i$). The definition of the statistic parameter of d_k is as follows:

$$d_k = \sum_{i=1}^{k} p_i (K = 2, 3, \ldots, n) \tag{5}$$

With the assumption that the time series being investigated is independent and random and that there are free from correlations between items, the definition of the statistic index of UF_k is given by the following equation:

$$UF_k = \frac{[d_k - E(d_k)]}{\sqrt{Var(d_k)}} (k = 1, 2, 3, \ldots, \ n) \tag{6}$$

where $UF_1 = 0$, $Var(d_k)$ and $E(d_k)$ refer to the variance and mean of d_k . Additionally, $Var(d_k)$ and $E(d_k)$ are defined as follows:

$$E(d_k) = \frac{n(n-1)}{4} \tag{7}$$

$$Var(d_k) = \frac{n(n-1)(2n+5)}{72} \tag{8}$$

Given the significance of α, when $|UF_k| > U_\alpha$, (U_α is the value determined by the significance level of α), the time series are considered to have obvious trends of changes.

Computation of UB_k was conducted again based on the adverse sequence mentioned above (e.g., $x_n, x_{n-1}, \ldots, x_1$). If the intersection of these two curves lies within the two-side 95% confidence limit, then this intersection point is viewed as an abrupt change point.

This method is a simple calculation that can be used to test the abrupt change point and assess the significance of trends of the time series before and after the abrupt change point. For the reasons mentioned above, the M-K test method is widely used in testing.

The calculation process is:

(1) Calculate d_k of the time series in a positive sequence, and then calculate UF_k according to Equation (6);

(2) Calculate d_k of the time series in negative sequence, and then calculate UB_k according to Equation (6);

(3) Use a significance level of α =0.05, so the critical value $U_{0.05} = \pm 1.96$.

1.2.4 Methods for periodic characteristics

Wavelet analysis is a time-scale analysis method that has multi-resolution. The period of a signal at different time scales can be identified based on the localization characteristics of time-frequency from the wavelet transform, so the wavelet analysis method can provide a basis for the trend analysis and predictions of the high and low flow changes in the basin's runoff.

Hydrological time series are composed of a series of observed samples with diverse and complex changes. With the multi-resolution function, wavelet analysis is quite suitable for hydrological time series analysis (Wang et al. 2005).

An appropriate wavelet function is the basis of wavelet analysis, and the Morlet wavelet is commonly used in the hydrological multi-time scale analysis. Morlet wavelet transformation is complex and can be expressed as:

$$\varphi(t) = e^{i\omega_0 t} e^{-t^2/2} \quad (9)$$

Its Fourier transform is:

$$\hat{\varphi}(\omega) = \sqrt{2\pi} e^{-\frac{(\omega-\omega_0)^2}{2}} \quad (10)$$

where ω is the frequency, ω_0 is the wavelet central frequency, and i is an imaginary. If $\omega_0 \geq 5$, the admissible condition is satisfied approximately. The time scale a and the period T are related as follows:

$$T = \frac{4\pi a}{w_0 + \sqrt{2 + w_0^2}} \quad (11)$$

When w_0 =6.2, then $T \approx a$. Therefore, the Morlet wavelet can be used in periodic analysis (Li et al. 2011).

For the given hydrological time series $f(t)$, its continuous wavelet transform (CWT) is defined as:

$$w_f(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t)\hat{\varphi}(\frac{t-b}{a})dt \quad (12)$$

where $w_f(a,b)$ indicates the coefficients of the wavelet transform, $\hat{\varphi}$ is the conjugate function of φ , a is the scale parameter, and b is the time parameter. CWT can produce numerous wavelet coefficients, which indicates the approximation degree of the signal with the wavelet.

Wavelet coefficients will change with scale parameter and time parameter. The variation of $w_f(a,b)$ is depicted by two-dimensional isograms, in which a is denoted by the y-coordinate and b is represented by the x-coordinate. The modular of wavelet coefficients indicates the signal intensity, and its real parts reflect the intensity and phase of different time scale signals at different times.

At the same time scale, the changes in wavelet coefficients over time reflect the variance features of runoff on this time scale. A positive wavelet coefficient indicates high runoff during this period, while a negative wavelet coefficient indicates runoff below normal during this period and a wavelet coefficient of zero indicates that the runoff has an abrupt change. A larger absolute value of wavelet coefficients indicates a more significant time scale. The closed center of the contour line stands for the abundance or owe of runoff, and the value of the center can reflect fluctuations in intensity of the signal.

To further analyze the change characters pertaining to an actual part of the wavelet coefficients of annual runoff processes in a time scale, wavelet coefficients change diagrams of annual runoff in 25a and 11a time scales are drawn.

2 Results and Analysis

2.1 Runoff variation

2.1.1 Monthly runoff distribution

Figure 2 shows the monthly distribution of average runoff at Shihuiyao, Nierji, Tongmeng, Jiangqiao, Baishatan and Dalai Stations in the main stream of the Nen River from 1956 to 2000. The monthly distribution of runoff was not even throughout the Nen River Basin. Specifically, the runoff in August was greatest, accounting for 24.79% of the total runoff, while that in January, February and March accounted for only a small portion, and runoff during flood season (June to September) accounts for 60% or more of the total runoff.

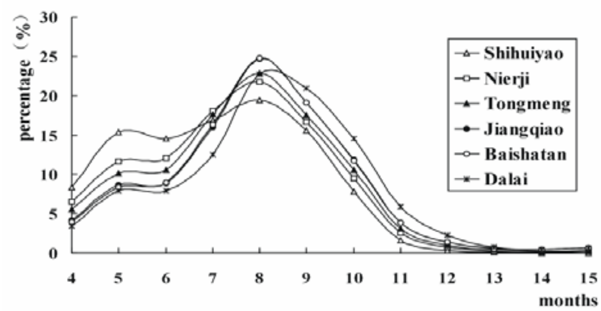

Figure 2 Annual runoff distribution curve at the stations of the Nen River Basin.

Additionally, the proportion of the total monthly runoff from each station during August to December and January to March of the following year from the upper to the lower reaches showed a growing trend. Conversely, there was a decreasing trend from April to July. The monthly distribution curves for the stations in the Nen River Basin were drawn to reflect these variations. It should be noted that if several unexpected situations are neglected the entire hydrological year can be divided into two parts, August to March of the next year and April to July.

As the vadose zone water drains to the river channel as groundwater flow in dry seasons (January, February, March, October, November, December), the water-storing capacity of the lower reaches becomes higher than that of upper reaches, and the proportion of monthly runoff at hydrological stations in the upper reaches becomes smaller than that in the lower reaches. Snowmelt is the main source of runoff in April, May and June, and it simultaneously recharges the unsaturated zone; therefore, the proportion of monthly runoff at hydrological stations in the upper reaches is larger than that in the lower reaches. During flood season (July, August, September), the main source of runoff is rainfall, while groundwater flow accounts for a small part of runoff due to the small catchment, and there is a large gradient in the riverway and little infiltration of rainfall in the upper reaches of the Nen River Basin. However, for the lower reaches, runoff is composed of both surface runoff and subsurface runoff because there are abundant suspended solids in the water. Thus, forms of monthly distribution vary because the runoff composition is different in various sections of the main stream. In general, surface runoff is the main portion of runoff in the upstream section, and downstream runoff is composed of both subsurface and surface runoff. The runoff in the upper reaches shows a direct response to water source (rainfall and snowmelt). Therefore, if we investigate the influence of climate change on runoff, it is better to use data from stations in the upper reaches. The transformation of surface runoff and subsurface runoff is complicated in the lower reaches, and the human activity makes it more complicated.

Calculation of the nonuniformity coefficient of monthly distribution C_u at typical stations in the Nen River Basin is conducted according to Equation (1), and the results are shown in Table 1.

It can be seen from the mean values of the nonuniformity coefficient that monthly variation in the upper stream is relatively larger than that downstream, and the monthly distribution of downstream runoff is becoming stable and uniform.

Table 1 Statistical characteristic of nonuniformity coefficients (Coef.) at the hydrological stations in Nen River Basin

Coef.	Hydrological stations			
	Shihuiyao	Nierji	Tongmeng	Jiangqiao
Max.	0.48	0.46	0.46	0.52
Min.	0.26	0.23	0.23	0.22
Mean	0.34	0.32	0.31	0.31

This is mainly because river water is supplied by groundwater in the downstream reaches during the dry season, and by river water in the wet season. These findings agree with the conclusions presented in Figure 2.

The Nen River Basin is surrounded by mountains on three sides, and the basin's morphology slopes from northwest to southeast, forming a south-facing opening pocket. The north border of this basin is Yilehuli Mountain of the Great Khingan Ridge, the west border is the east slope of the Great Khingan Ridge, the east border is the west slope of the Less Khingan Ridge, and the southeast border is the Songnen Plain. Nen River flows from north to south without any large bends. The upper reaches of the Nen River Basin are mainly mountain areas that are not heavily impacted by humans. Flowing out of Ayanqian, the Nen River enters into the Nen Plain, which is China's major grain cultivating area. This region has been heavily influenced by anthropogenic activities, especially since the 1980s (Li et al. 2012; Xu et al. 2009) investigated the influence of changes in vegetation cover on hydrological characteristics and showed that rainfall was inconsistent with runoff which was heavily influenced by external factors. However, the runoff data in our study were based on the average of the stations of Tongmeng, Jiangqiao and Dalai. The relationship between runoff and rainfall is complicated and nonlinear; thus, it is not reasonable to replace the actual runoff data with average data for typical stations in the mainstream of this basin. We studied the development of runoff of each station so as to reveal the response of runoff.

2.1.2 Yearly runoff variation

As shown in Figure 3, yearly variation at Shihuiyao Station in the upstream portion of the

Table 2 Variation coefficient (CV) and ratio for extreme values (Ratio) of annual runoff in Nen River Basin.

	Shihuiyao	Nierji	Tongmeng	Jiangqiao
CV	0.38	0.37	0.43	0.46
Ratio	5.09	6.39	7.84	9.71

basin was smallest, while the greatest variation was observed at Jiangqiao Station, which is located in the downstream reaches. The variation coefficients for the Shihuiyao, Nierji, Tongmeng and Jiangqiao stations (Table 2) were and were associated with more volatile yearly variation. As shown in Table 2, the yearly variation in the Nen River Basin is relatively large, with the smallest value appearing in Nierji (0.37) and the largest in Jiangqiao (0.46). Obviously, the variation coefficient increases from upstream to downstream. This is likely because (a) runoff upstream is supplied by both rainfall and snowmelt, which directly reflect variations in climate factors that are relatively stable when compared with human activity, such as rainfall and air temperature. (b) Because some rivers that have great variation in runoff amounts, such as the Chuoer and Taoer rivers, flow into the Nen River, intermediate inflow is complicated. Moreover, both the relationship of mutual supplies, between surface water and ground water and the channel capacity, influence annual variation. (c) Agriculture and urban life are greater in the lower reaches of Nen River Basin; therefore, human activity is a more important influential factor in this region.

The largest ratio of the maximum to minimum annual runoff in the main stream of the Nen River was 9.7 at Jiangqiao Station (max.: $61.99\times10^8m^3$, 1998a; min.: $57.86\times10^8m^3$, 1979a).

If the average runoff amount is considered a critical value to divide high flow years and low flow years from 1956 to 2004, there will be 23 high flow years and 26 low flow years. The number of each type of year is almost the same, and high flow years and low flow years appear in turn in the way of year group.

The basic reason for the yearly variation in runoff proposed by Li et al. (2011) is cyclical changes in solar activity. Atmospheric circulation, which is the immediate cause of runoff variation, is affected by solar activity. Thus, the periodicity of solar activity will inevitably affect yearly variation of runoff. For example, Wang and Peng found that runoff variation in the Yellow River Basin was closely related to solar activity (Wang and Peng 1993). Disasters such as floods and droughts occur approximately every 22 years in the Yellow River Basin and the Yangtze River Basin, which is two times as long as the 11-year period(Li et al. 2011). Taken together, these findings demonstrate that runoff variations are directly related to solar activity.

The yearly variation law runoff of each section in the mainstream of Nen River indicates that the climate factor (rainfall) is relatively stable, but human activity is more stochastic and unsteady.

2.2 Variation tendency

We applied the linear trend method to ascertain the variation tendency of runoff. The linear trend slopes at four stations in the mainstream of the Nen River were -0.13 (Shihuiyao), -0.02 (Nierji), -0.30 (Tongmeng) and -0.95 (Jiangqiao). It is clear that the runoff at the 4 stations tended to decrease, but to different degrees.

Figure 4 shows the cumulative filter curves of four stations from which we can deduce the overall runoff amount. The data indicated that from 1956 to 1980 runoff decreased, after which it increased

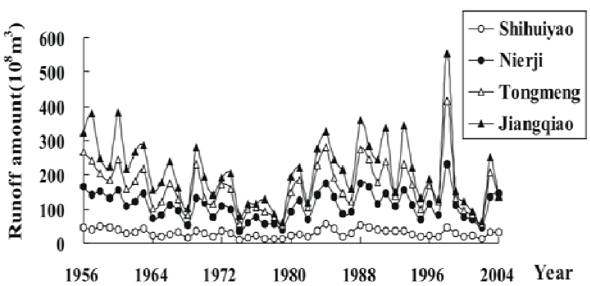

Figure 3 Graph of annual runoff (1956-2004).

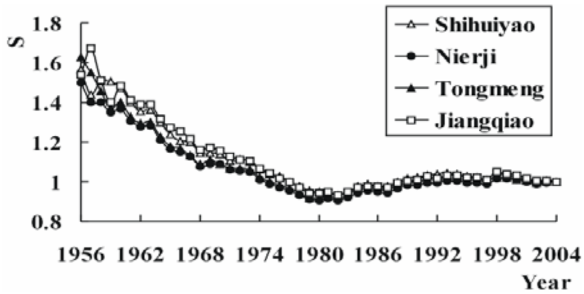

Figure 4 Cumulative filter curves of stations Shihuiyao, Nierji, Tongmeng and Jiangqiao.

from 1980 to 1998, and was then reduced again after 1998, but this trend was not significant.

As shown in Table 3, Spearman's coefficients of correlation for the four stations were all negative, which shows that there is a downward tendency of runoff. However, the absolute value of M is less than 1.96 (the critical value under 0.05 significance level); therefore, the downward tendency is not significant.

The runoff of each hydrological station in the Nen River Basin decreased overall based on the results of the cumulative filter method and M-K test, but their degrees differed from each other.

2.3 Abrupt change

Figure 5 shows the abrupt change points of annual runoff series for Jiangqiao Station. The results indicated that the amount of runoff decreased from 1960 to 1985, at which point it showed an increasing trend. In 1995 there was a decreasing trend, but the occurred year is different among the stations (Shihuiyao 1993a; Nierji and Tongmeng 1995a; Jiangqiao 1997a).

2.4 Period change

Figure 6 shows the time-frequency structure figure of the real part of the modulus determined by the complex Morlet wavelet transform at Jiangqiao Station of the Nen River Basin. The anomaly of annual runoff was used as the runoff data.

The contours shown in Figure 6 are alternate with positive and negative signs. Specifically, the 20-35 year cycle of runoff, which had a scale center of about 25 years is outstanding. Its periodic variation is steady, coherent and universal throughout the entire studied period. For this time scale, the amount of runoff was above normal before 1969, less than normal from 1969 to 1983, above normal during 1983 to 1998, then less than normal after 1998. Moreover, the 8-15 years period, which also has a scale center of about 11 years, was significant before the 1990s. For this time scale, the runoff amount showed three periods when the amount of runoff was above normal and two periods when the amount of runoff was less than normal. Specifically, runoff was above normal from 1956 to 1962, less than normal from 1962 to 1968, above normal from 1968 to 1975, less than normal from 1975 to 1983 and above normal from 1983 to 1989. Another cycle of runoff of about five years in which there was severe runoff variation was observed; however, there were large discrepancies in this cycle and the periodicity was relatively weak.

Figure 7 shows the wavelet coefficients change

Table 3 Spearman's coefficient of correlation (M) in Nen River Basin

Stations	Shihuiyao	Nierji	Tongmeng	Jiangqiao
M	-1.41	-0.5	-1.14	-1.52

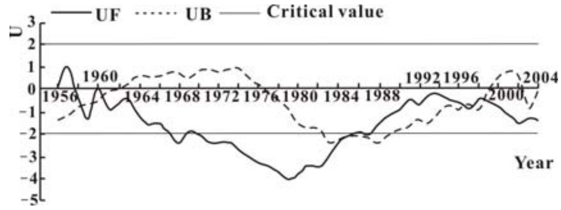

Figure 5 Mutational points of annual runoff series of Jiangqiao Station based on M-K test Explain lines.

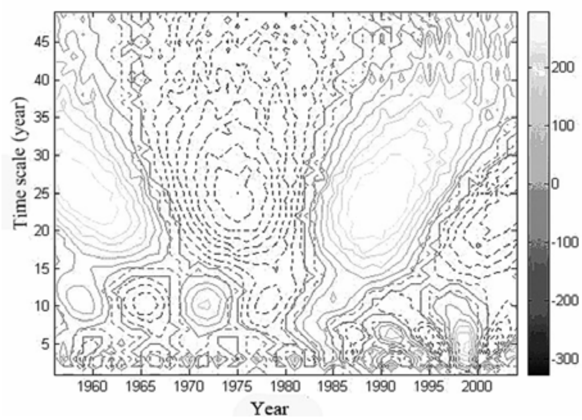

Figure 6 Time-frequency structure figure of the real part of modulus by complex morlet wavelet transform at Jiangqiao Station.

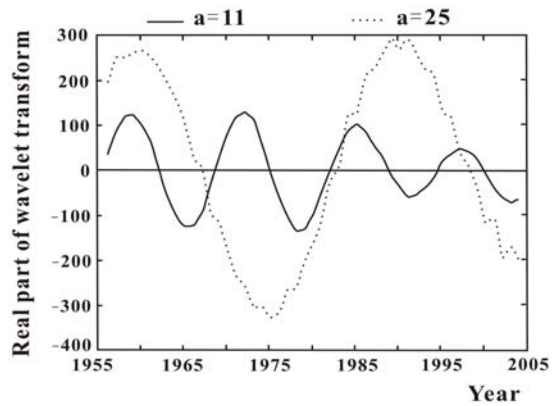

Figure 7 Wavelet coefficients change of annual runoff at Jiangqiao Station in 25a and 11a time scales.

Table 4 Methods and results of runoff variation law analysis

Content	Trend analysis	Mutation test	Multi-time scale analysis	
Methods	Cumulative filter method	M-K test	Time-frequency structure of the real part of modulus	Mutation points with 25-year period
Results	1956-1980:decrease 1980-1998: increase After 1998: decrease	Early 1960s About 1984 Late 1990s	Before 1969: above normal; 1969-1983: less than normal; 1983-1998: above normal; After 1998: less than normal	1967 (wet-dry) 1983 (dry-wet) 1998 (wet-dry)

of annual runoff with a 25-year period and 11-year period. From the 25-year period, the abrupt change points were 1967 (wet to dry), 1983 (dry to wet), 1998 (wet to dry), which is consistent with the results shown in Figure 6. Additionally, these data indicate that the river basin has just entered a drought period, and will enter a high flow period in 2013 (1998+15).

From the 11-year period, the abrupt change points lie in 1962 (wet-dry), 1968 (dry-wet), 1975 (wet-dry), 1982 (dry-wet), 1989 (wet-dry), 1995 (dry-wet) and 2001 (wet-dry), which is also consistent with the results shown in Figure 6. As wet and dry years alternate frequently with an 11-year period and are limited by data length, the future wet-dry years cannot be forecast based on this period.

3 Conclusions

The effects of climate warming and human activity in recent years have led to dramatic changes in the temporal and spatial distribution of runoff. In this study, a variety of statistical methods and wavelet analysis were employed to analyze the variation law of runoff for a hydrological year in the Nen River Basin qualitatively and quantitatively. The results of each method are compared in Table 4.

Overall, the following conclusions can be drawn based on the data provided in this table:

(1) M-K testing and 25-year time-scale analysis identified two abrupt change points close to each other, at about 1983 and 1998. The other abrupt change points have several years excursion. Analyzing its causes, as 25 years is the main period of runoff time-series at Jiangqiao Station, the abrupt change point calculated with the main period should be close to the results of statistical test for runoff time-series. However, their theories are not the same; their results may vary from each other.

(2) The time-frequency structure of the real part of the modulus determined by wavelet transform and 25-year time-scale analysis indicates that changes in the high and low water are in substantial agreement. The runoff amount is above normal before 1967 (or 1969), less than normal from 1969 to 1983, above normal from 1983 to 1998, and less than normal after 1998.

In sum, this paper draws the following conclusions:

1) Runoff in the upstream section is dominated by surface runoff that originates from rainfall, while downstream it is composed of both surface runoff and subsurface runoff. Comparison of the hydraulic characteristics of surface water with those of subsurface water indicates that subsurface runoff should be steadier than surface runoff with a smaller variation coefficient. However, the actual conditions are contrary to this. These findings show that runoff in the upstream section directly reflects the annual and yearly variation of climate (rainfall), which is relatively stable, while runoff in the downstream section is more heavily influenced by human activities and therefore more random and variable. Thus, we should use upstream sections as the object of study for investigations of runoff variation based on climate change.

2) Runoff is not distributed evenly, and is instead concentrated in the flood season. Yearly variations in runoff tend to decrease overall. In this study, three abrupt change points were found, one in the early 1960s, one at about 1984 and one in the late 1990s. Multiple-time scales analysis shows that there are three time-scale periods, a 20-35 year period with a scale center of about 25 years, an 8-10 year period with a scale center of about 11 years, and a 5 year period. The Nen River Basin will enter a high flow period in 2013 according to wavelet transformation with the main period.

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