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AN ANALYSIS OF WATER RESOURCE CHARACTERISTICS OF THE RIVERS IN THE NORTHERN SLOPE OF THE KUNLUN MOUNTAINS

Xu Youpeng (许有鹏)　　Gao Yunjue (高蕴珏)
(*Department of Geography, Nanjing University, Nanjing* 210008, *PRC*)

ABSTRACT: There are 43 rivers of varying sizes in the northern slope of the Kunlun Mountains, all of which originate from the Kunlun Mountains. Supplied by precipitation and melting water of glacier, the total runoff amounts to $87 \times 10^8 m^3$. The analysis shows that water quantity distribution of the rivers in the area is more in the west, and less in the east. While in the west, the water quantity of the Hotan River amounts to more than half of the total, in th eeast, most rivers are seasonal rivers except the Keriya River and the Qarqan River, which have relatively large amount of waters. From the analysis of inner structures of the runoff series of the major rivers, we can see that the annual runoff series of all rivers are mainly stable independent random series. Such characteristics of the time series are determined by the supply characteristics of the rivers. Some measures of rationally using water resources are proposed finally.
KEY WORDS: river hydrology, water resources, rivers in mountain area, the Kunlun Mountains area

I. INTRODUCTION

Blocked by the high mountains around, the northern slope of the Kunlun Mountains is in the hinterland of Eurasia, where ocean vapour can hardly reach. Thus its precipitation is little. Annual precipitation is between 100 mm and 200 mm in the mountain area, below 50 mm in the plains in front of the mountains. In some years, there is almost no rain. Taklimakan Desert, the most arid area in our country, lies to the north of the area. Most rivers in the northern slope of the Kunlun Mountains belong to small river systems. Their water quantity mainly comes from precipitation in the mountain area, and melting water of the glacier. In administrative term, the area belongs to Hotan Prefecture in Xinjiang region, Qiemo County and Ruoqiang County in Mongolian Autonomous Prefecture of Bayingolin. The total land area is $5.86 \times 10^5 km^2$, the oasis area $1.72 \times 10^4 km^2$, and the cultivated area $17.27 \times 10^4 ha$. And its population is about 1,400,000. Sufficient illumination, strong effective radiation and abundant quantity of heat are all favourable for agricultural production. But due to insufficient water resources economic development in this area has been restricted for quite a long time. After 1949, many water conservancy facilities have been built, greatly promoting economic development, also causing a series of environment problems, such as the reduction of water supply for ecological use in the lower reaches, the retrogression of vegetation, and the quickening of desert invasion. In order to exploit water resources reasonably, develop economy in a better way and protect the natural balance of ecology, it is necessary to analyse the characteristics of water resources and its variation laws in this area. It will provide a decision-making basis for optimization exploitation and utilization of water resources.

II. THE CHARACTERISTICS OF WATER RESOURCES

There are 43 rivers of varying sizes in the northern slope of the Kunlun Mountains, all of which originate from the Kunlun Mountains. Supplied by precipitation and melting water of glacier, the total runoff amounts to $87 \times 10^8 m^3$. Among these rivers, there are only two tributaries of the Hotan River, the Yurungkax River and the Karakax River whose annual runoff is more than $10 \times 10^8 m^3$. The rivers whose annual runoff is more than $5.0 \times 10^8 m^3$ are the Keriya River and the Qarqan River. Those more than $1.0 \times 10^8 m^3$ are altogether ten rivers: the Qira River, the Niya River and the milan River, etc. All the above-mentioned rivers are small independent water systems, flowing into the Taklimakan Desert from south to north and then disapearing, except the Hotan River, which flows across the desert and into the Tarim River. Correspondingly, scattering oases in the alluvial and diluvial plains at foot of the northern slope of the Kunlun Mountains and their seperate irrigation systems have been brought into being. Up to now, 29 rivers in the northern slope with total runoff of $82 \times 10^8 m^3$ are used for irrigation. However, there is no runoff regulation and storage project in the mountain mouthes of all rivers, so it still remains natural. Therefore in summer large amounts of runoff can not be stored and has to flow into the desert. Near these rivers, there scatter more than 60 spring spill points whose total runoff quantity comes to $12 \times 10^8 m^3$. The spring water quantity changes in proportation to the water quantity of the river nearby, while the changing is even slower. In terms of seasonal distribution, four to six months later than the river water, the spring water quantity is the most in winter and the least in summer. In this area, exploitable shallow-layered groundwater amounts to $24\times10^8m^3$. Like spring water, groundwater also comes from rivers, channal leakage and irrigation infiltration water. Thus the distribution of groundwater also corresponds with the river water quantity. Since the Hotan River, the Keriya River and the Qarqan River have most of the water quantity, their hydrologic characteristics can generally represent the hydrologic characteristics of the rivers in the northern slope of the Kunlun Mountains.

As the only big river in the northern slope, the Hotan River has two tributaries in its upper reaches, the Yurungkax River and the Karakax River. The catchment area of the former is $1.45\times10^4m^2$, and the latter $2.0\times10^4km^2$. These two tributaries are mainly supplied by the melting water of glacier. From their runoff process analyses, we can see that the annual changes and seasonal changes of the two rivers are almost the same, that is to say, the two tributaries have almost the same hydrologic variation law. After the two tributaries joining near Kuoshilashi, the Hotan River continue its way north, flowing through the Taklimakan Desert, and in the end joining the Tarim River in the northern desert. The average annual runoff of the Hotan River is $46.38\times10^8m^3$. Its variation coefficient (C_V) is 0.20. In the rainy year, the annual runoff is $69.08\times10^8m^3$. In the lowest water year, it is $24.38\times10^8m^3$. The proportion is 2.8:1, which is similar to the annual change of the rivers in the humid area in eastern China. While in respect of runoff distribution within a year, there are great seasonal changes (Table 1). Water quantity is mainly in summer, making up 77 percent of the total amount, which results in fierce flood havocs. While water quantity in spring and winter only amounts to 4 percent and 7 percent of the total, which results in water shortage in agricultural irrigation and fierce drought in spring. At present, the oases and irrigation diversion mainly centralize in the alluvial and diluvial plain of the two tributaries of the Hotan River. In the oases, diverting the river is the main means to supply water for people's daily use and agricultural production. Average annual water quantity from the Hotan River to the Tarim River is $11.2\times10^8m^3$, which plays an important role in preserving the natural vegetation along each side of the river in the desert, preventing encroachments of wind-drift sand, and keeping the balance of ecology in the Tarim River and the whole Tarim Basin.

Originating from the middle part of the Kunlun Mountains, the Keriya River has many tributaries in its upper reaches. After going through the mountain mouth, the river goes across the alluvial and diluvial plain 4.5km by 20—30km (the oasis of Yutian County). In the end, it dissapears in the big desert. The catchment area is 7,358 km^2. The average annual runoff is $7.07 \times 10^8 m^3$. The river is supplied both by precipitation and the melting water of glacier. Water supplied by the melting water makes up 47 percent. The annual runoff variation coefficient is 0.17. Its annual change is small, and the proportion of the annual runoff in the high water year to that of the low water year is 2.1:1. The water quantity is more stable than that of the Hotan River. Though the variation process is milder than that of the Hotan River, the runoff distribution within a year is also uneven. In summer, water quantity is of the largest amount, while in spring and winter, water quantity is low, which results in lacking irrigation water and fierce drought in spring. At present, in Yutian County which is in the east of the area, agricultural irrigation and people's daily life mainly depend on the Keriya River.

Table 1 Seasonal distribution character of rivers in the north slop of Kunlun Mountains

River	Frequency of typical year	Year	Discharge (m^3/s)	Seasonal distribution (%)			
				Winter (Dec. — Feb.)	Spring (Mar. — May)	Summer (Jun. — Aug.)	Autumn (Sept. — Nov.)
Hotan	Rainy (25%)	1967	156	2.6	10.7	76.5	9.2
	Median (50%)	1985	138	4.2	7.4	76.5	11.9
	Low water (75%)	1975	117.1	3.6	9.1	74.3	14.0
Keriya	Rainy (25%)	1957	23.7	7.3	11.2	67.6	13.9
	Median (50%)	1962	22.0	6.9	10.6	70.1	12.4
	Low water (75%)	1959	20.2	7.4	11.0	66.6	15.0
Qarqan	Rainy (25%)	1974	18.5	5.9	32.9	40.2	21.0
	Median (50%)	1966	15.5	9.2	20.3	47.2	23.3
	Low water (75%)	1962	13.6	4.7	23.0	59.1	13.2

The Qarqan River starts from the peak Muzitage of the Kunlun Mountains and flows into Tatema Lake in Ruoqiang County. The length of the river is 774km. The catchment area above Qiemo station is $2.7 \times 10^4 m^2$. The average annual runoff is $5.09 \times 10^8 m^3$. The variation coefficient is 0.22. The proportion of the annual runoff in the high water year to that of the low water year is

2. 7:1, which is similar to the annual runoff variation of the Hotan River. The seasonal distribution is also uneven: abundant in summer, a little in winter and lacking in spring. But its variation range is much smaller than the above—mentioned two rivers. In summer water quantity makes up 47. 3 percent of the total amount, in winter water quantity, 9. 2 percent, in spring and autumn, the water quantity occupies 20. 3% and 23. 3%. therefore, there is less danger of floods in this area. The water quantity distribution is also favourable to the agricultural irrigation. This season distribution feature results from the geological structures in the upper reaches as well as the supply characteristics of the river, which is supplied not only by precipitation and the melting water of glacier, but also by crevice water from bedrocks. The river is the main irrigation water source in Qiemo County.

The above analysis shows that water quantity distribution of the rivers in this area is more in the west, and less in the east. While in the west, the water quantity of the Hotan River amounts to more than half of the total in the northern slope; in the east, most rivers are seasonal river except the Keriya River and the Qarqan River, which have relatively larger amount of water. In the annual runoff variations, the variation coefficient ranges from 0. 1 to 0. 23. The water quantity is stable, which is determined by the supply characteristics of the rivers. The melting water of glacier is mainly affected by temperature. In a rainy year when temperature is low, the melting water is less; in a hot and dry year with little rainfall, the melting water is more so that its supply amount is large. The intercompensation of the two kinds of supply sources, precipitation and the melting water of glacier, mitigates the runoff variation situation. In the seasonal distribution of runoff of the rivers, the water quantity changes with temperature. In summer , the water quantity of the Hotan River in the west changes drastically, however, in the east, the change of Qarqan River is comparatively slower. The small rivers whose water quantity is below $1.0 \times 10^8 m^3$ are mainly floods in summer and they have hardly any water in winter.

III. TIME SERIES ANALYSIS OF THE RIVERS

With actual runoff data, we have analyzed the hydrologic characteristics and water resource condition of the rivers in respects of climatic factor, geographic factor of the basin and supply source. In the following section, we will further analyze the inner structures and variation laws of the runoff series in time domain and frequency domain. Owing to complex factors influencing the runoff formation, which include random components as well as definite components, the annual runoff series is a random series composed of various components, bound or sudden change components and periodic components, etc., it might be composed of interdependent components and pure random components as well. Time series analysis is to infer the characteristics of various components in the annual ruuoff series, extract the definite components and deal with the random components.

All the rivers in the northern slope rise in the Kunlun Mountains. Few people populating the river basin above the measuring station, so human activities have little influence on the runoff. No great changes of the climatic factors and natural geographical factors of basin are even taken place. Moreover, there is no obvious bounds and sudden changes in the course of actural annual runoff. Therefore, we can draw a conclusion that there is no sudden change components in the annual runoff series of the rivers. The 3-year and 5-year average sliding curves of the three rivers in the area indicate that there is neither upward tendency, downward tendency nor fluctuation tendency in every curve for a long time and runoff process generally flickers at random near the average value[2,3]. With the average sliding method, we can filter the high frequency fluctuation, which makes the series tendency more apparent. Therefore there is no tendency components in annual runoff series of the rivers.

The self-correlation is a statistical technique for studying linear interdependent characteristics of hydrologic series in given interval. The self-correlation coefficient is a time function. There is a formula for calculating the self-correlation coefficient of actural series:

$$r_k = \hat{C}_k / (\hat{\sigma}_t \times \hat{\sigma}_{t+k})$$

where $\hat{C}_k$ is the covariance of the sample; $\hat{\sigma}_t$, $\hat{\sigma}_{t+k}$ is the variance of the sample and K is time lag. With actual measuring runoff series of each river in 31 years, from 1957 to 1987, and $K=1,2,\cdots 12$, we obtain respective self-correlation coefficients in given intervals of annual runoff series of each river. A self-correlation coefficients diagram of annual runoff series of major rivers can be drawed (Fig. 1). From the diagram, we can see that the self-correlation coefficient of annual runoff series decreases rapidly with the increase of K. Except few coefficients, the correlation coefficients are relatively small, which are all below 0.4. None of them surpasses the allowance of random independent series with the confidence level of 95%. Therefore we can deduce that the annual runoff series of each river is independent random series. We can also regard the annual runoff series of the Keriya River as a weak second order self-correlation series.

The self-correlation coefficient method analyses the inner structures of annual runoff series in the time domain, however, spectral analysis method

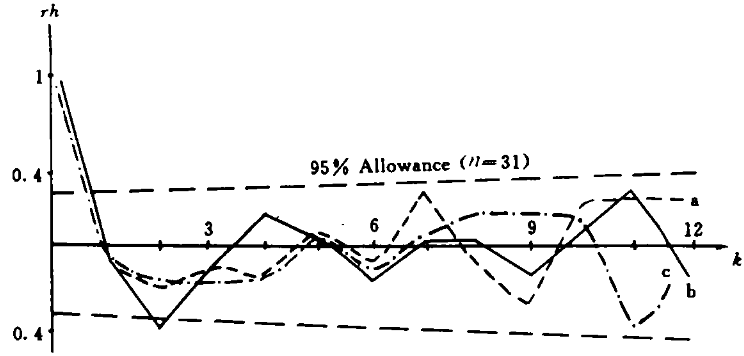

Fig. 1 Self-correlation diagram of annual runoff
a—Hotan River b—Keriya River c—Qarqan River

analyses the inner structures in the frequency domain. A hydrologic series is a kind of regular viberation phenomenon, that is, it is a group of resonant waves composed of sine waves and cosine waves with various frequencies. It can be expressed by the Fourier series:

$$X_t = \mu_t + \sum_{j=1}^{l} (a_j \cos\omega_j t + b_j \sin\omega_j t)$$

where X_t is the hydrologic series, μ_t the average value of series, l the number of resonat waves, and ω_j the angular frequency. Moreover, we examine what freqencies of resonant wave component are included in hydrologic series, and their respective proportions, so as to determine the period components of the series. When we decompose the hydrologic series, as usual, we only chooes several resonant waves with obvious frequencies. The formula for calculating variance density is:

$$S_{f_j} = 2[1 + 2\sum_{k=1}^{m} D_k r_k \cos 2\pi f_j k];$$

$$D_k = 0.50 + 0.50\cos(\pi k/m)$$

where r_k is the self-correlation coefficient in K time lags, f_j the common frequency and m the biggest time lags. With this formula, we can calculate variance densities of different frequencies of the annual runoff series of the studied rivers and then draw a diagram showing their relation (Fig. 2)

The diagram indicates that the variance density curves of the rivers are all stable with neither high nor abrupt peak value frequencies. It also indicates that variance density value of every river fluctuates up and down along the horizontal axis whoes numerical value is 2. Moreover, it shows that no variance densities surpasses the stable independent randoms series' allowance value, of which the confidence level is 95%. Therefore without any obvious period components, the annual runoff series of the studied rivers can be believed to be a

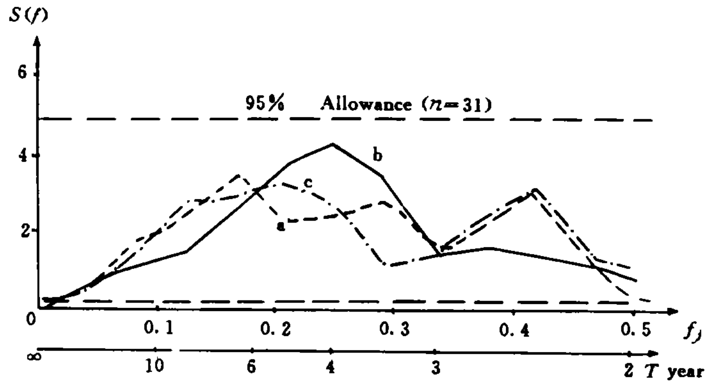

Fig. 2 Variance density diagram of annual runoff
a—Hotan River b—Keriya River c—Qarqan River

pure random series. The accumulated anomaly curves of the annual runoff series of the studied rivers also shows that no river is continuously rainy or of continuous low water in years, that is to say, the change from rainy year to low water year is frequent, which again proves the above conclusion we have drawn[2,3].

From the analysis of inner structures of the runoff series of the major rivers, we can see that the annual runoff series of all the rivers are mainly stable independent random series. Such characteristics of the time series are determined by the supply characteristics of the rivers in the arid area. More than half of water resource of the studied riverd are supplied by the melting water of glacier. In addition, the upper reaches of the rivers lie in the high and cold miuntain area, where is a world of ice and snow. Vegetation is spares and little precipitation and melting water can be infiltrated, so a large groundwater aquifer is unlikely to form, which results in the low runoff year-to—-year regulating storage ability.

IV. POSTSCRIPT

From the analysis of the characteristics of surface water resources of the rivers in the northern slope of the Kunlun Mountains, we can see that in recent decades the annual runoff change is relatively stable and no tendencies shows that natural runoff of the major rivers is reducing. Climatic analysis in recent centuries can testify it in another way[1]. The reduction in the river water quantity in this area is caused by over diversion for irrigation use in the oases and human activities. In order to protect the ecological environment and prevent the spread of the desert, it is important to utilize the surface water resource scientifically and reasonably. In respect of agricultural water use, we should make effort to improve both the ability of preventing leakage and the effective coefficients of the chanal system, so as to save water. Meanwhile, we should try to tap new water resources and make a conjoint use of surface water, springs and guoundwater in the shallow layer. Moreover, we should change planting structures to alleviate water use contradiction. If possible, we can build some large storage projects in the mountain area and increase the utilization ratio of water resource. Because the area is in the edge of the desert, there are serious damage from wind-drift sand. Therefore, it is necessary to guarantee the water for shelter-belt use in both old and new oases. In this way, we will be able to protect the ceological environment.

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