ANALYSIS OF RAINFALL VARIATION UNDER CLIMATE CHANGE IN MIYUN RESERVOIR

by

Xiao-Juan CHEN [a], ***Xiao-Hua YANG**** [a], ***Jun HE*** [a], ***Xing-Hui XIA*** [a], **and *Never MUJERE*** [b]

[a] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing, China
[b] University of Zimbabwe, Department of Geography and Environmental Science, Mount Pleasant, Harare, Zimbabwe

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Miyun reservoir is a surface water source of the city of Beijing. This paper explores the relationship between reservoir basin runoff and climate change. Statistical analyses are employed to analyze the variations in rainfall, air temperature, and runoff in the reservoir basin. Results show uneven inter-annual variability in rainfall data series. Air temperature show a rising trend with 1993 and 1994 being the two significant mutation years. Runoff has been decreasing over the years. Based one inter-annual analysis, July and August had the largest runoff. Elastic analysis shows no significant relationship between rainfall and runoff.

Key words: *runoff, climate change, elasticity analysis, Mann-Kendall test*

Introduction

Miyun reservoir is a large water conservancy that controls flood, supplies water for industrial and agricultural activities in region, which is a major source of urban water supply of Beijing. It has a total capacity of 4.375 billion m^3 and controls 15788 km^2 of river basin area. Miyun River has two main streams, which are Chaohe and Baihe Rivers. The basin receives an average annual rainfall of 480 mm and annual runoff of 948 million m^3, and precipitation mainly concentrated from June to September [1, 2]. The inter-annual variability of precipitation is large, and the maximum annual rainfall of 655 mm was recorded in 1973, while the minimum amount of 295 mm was recorded in 2002.

Given the importance of Miyun reservoir in supplying water for Beijing, it is vital to analyze the meteorological and hydrological conditions. The Mann-Kendall (MK) test and elastic analysis are used to explore the variations of rainfall, temperature and runoff [3]. By analyzing the relationship between meteorological and hydrological variables and explore the main driving factors, these findings can provide reference for basin management in the region.

Methods

Mann-Kendall test method

The MK test is non-parametric test that has been widely used in the analysis of trends in data sequences such as rainfall and runoff. It has been applied in the Yangtze River basin, Guizhou, the Tibetan plateau and other regions to analyze rainfall and temperature

* Corresponding author; e-mail: xiaohuayang@bnu.edu.cn

trends. The method has been shown to identify trends better than other methods like the moving average or linear regression [4].

Elastic analysis method

Climate change refers to long-term changes in rainfall and temperature. For quantitative analysis of the relationship between runoff and climate change, two parametric elastic indices were used to determine the elastic coefficients [5]. The sensitivity of runoff to climate parameters (rainfall, temperature) is defined as:

$$E_{p,\Delta T} = \frac{\mathrm{d}Q/Q}{\mathrm{d}X/X} = \frac{\mathrm{d}Q}{\mathrm{d}X}\frac{X}{Q} \tag{1}$$

where E is the elastic coefficient, Q – the runoff, X – the climate factor value (rainfall, temperature). To calculate the elastic formula, a non-parametric method was used and its formula is:

$$E_{p,\Delta T} = \mathrm{median}\left(\frac{Q_i - \bar{Q}}{X_i - \bar{X}}\frac{\bar{X}}{\bar{Q}}\right) \tag{2}$$

where X_i is the climate (yearly, monthly) value, Q_i – the runoff parameter, $\bar{X}$ and $\bar{Q}$ are the average values of the climate parameter and runoff, respectively.

Results

Rainfall characteristics analysis

Inter-annual variation

Figure 1(a) shows that the inter-annual variability is uneven. Wet years, 1964 and 1991 having a total annual rainfall of more than 600 mm. Extremely dry years are 1999 and 2000 with a total annual rainfall of less than 400 mm. The period 1960-1998 has a large change in annual rainfall with ups and downs, while 1999-2011 has a small change in annual rainfall.

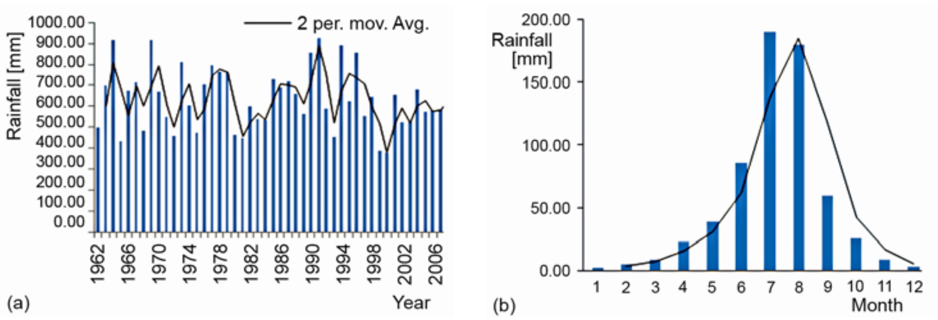

Figure 1. Rainfall variation trends in Miyun reservoir; (a) inter-annual variation, (b) intra-annual variation

Intra-annual variation

Figure 1(b) shows that the monthly average rainfall in Miyun reservoir basin from 1962 to 2011 is normally distributed. The rainfall reached a maximum of 190.33 mm in July and minimum of 2.56 mm in January. The flood season spans from June to September and it accounts for more than 70% of annual rainfall. Flood season rainfall is mostly in the form of heavy rain or thunderstorms.

Trends of air temperature

Annual variance

Using statistical analysis, the inter-annual variability of temperature is uneven, fig. 2(a).

From fig. 2(b) we can see the temperature presents a regularity from January to December. The maximum month temperature is 26 ºC which occurs in July and the minimum temperature is –5.41 ºC which occurs in January [6, 7].

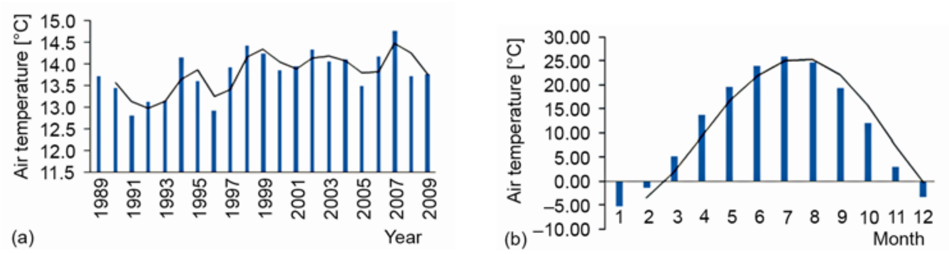

Figure 2. Air temperature variation trends in Miyun reservoir; (a) inter-annual variation, (b) intra-annual variation

MK test method

The yearly temperature data sequence is analyzed by Mann-Kendall (MK) test. Figure 3 shows that there is only one intersection point (1993-1994) between lines *UF* and *UB*. The point lies within the 95% confidence limits and the statistic value is almost zero. Therefore the intersection is the climatic jump point.

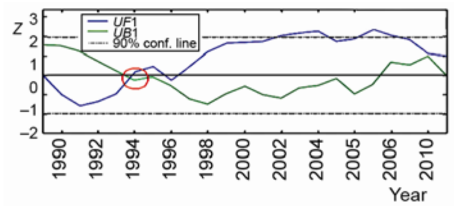

Figure 3. Climatic jump of the annual average temperature in Miyun reservoir

In the MK method, the null hypothesis H_0 is a time series (x_1, x_2, …, x_n), the sample includes the independent and random variables with the same distribution. m_i represents the accumulation number of the *i*-th sample that $x_i > x_j$ $(1 \le j \le i)$, here we define statistic S_k:

$$S_k = \sum_{i=1}^{k} m_i \quad (2 \le k \le n) \tag{1}$$

UF_k is defined by the formula:

$$UF_k = \frac{|S_k - E(S_k)|}{\sqrt{Var(S_k)}} \quad (k = 1, 2, ..., n) \tag{2}$$

where $E(S_k) = k(k+1)/4$; $Var(S_k) = k(k-1)(2k+5)/72$.

UF_k composed of a *UF* curve can be drawn through the reliability test whether there is a significant change in trend.

Reverse the time series order to attain a new time series and again to calculate the statistic variable UB_k based on eq. 2. At the same time:

$$\begin{cases} UB_k = -UF_k & x_i > x_j \\ k = n+1-k & \end{cases} \quad (k = 1, 2, ..., n) \tag{3}$$

If there are intersections of UF_k and UB_K, and the intersections are between the critical lines, they are the mutational points.

Runoff trends

Inter-annual variation

The average runoff of Miyun reservoir during years studied is 1013 million m^3. Figure 4 shows the annual runoff series histogram and 10-year moving average. It can be seen that the annual runoff is gradually decreasing. In the 1980s, there is a decreasing trend and since 1999 runoff has been falling sharply with runoff in 2000 as low as 185 million m^3.

Intra-annual variation

Figure 5 shows that runoff during flood season accounts for 66.5% with runoff in July and August accounting for 50% of yearly runoff. August experiences the highest runoff of 266.2 million m^3 while the minimum runoff of 28.5 million m^3 is experienced in January.

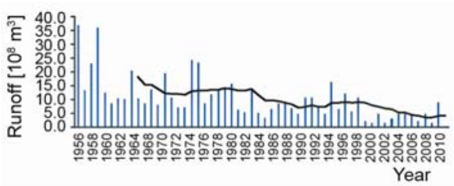

Figure 4. Annual runoff variation in Miyun reservoir from 1956 to 2011

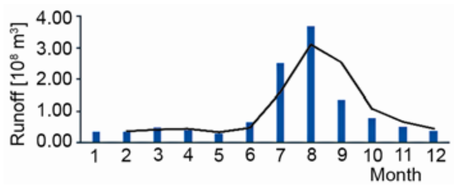

Figure 5. Runoff variation of each month in Miyun reservoir from 1956 to 2011

Result of elastic analysis

The estimation of rainfall-runoff elastic coefficient was based on the monthly data series of Miyun reservoir. It can be seen from fig. 6(a) that the elastic coefficient of rainfall to runoff lacks a trend. This means that the change of rainfall doesn't have great influence on runoff in Miyun reservoir. It implies that runoff may have been affected by other factors such as land use, human activity and so on.

We used the change proportion of monthly runoff and rainfall sequence for linear regression, and taking the slope as the elastic coefficient of runoff to rainfall. Results are shown in fig. 6(b). The average elastic coefficient of runoff to rainfall is about 0.24, which means that 1% change of rainfall will lead to 0.24% change of runoff in Miyun reservoir. The value R^2 is less than 0.5, hence rainfall and runoff do not have a linear relation.

Conclusions

This study analyzed the meteorological and hydrological situation in Miyun reservoir. Through the analyses of data series, we can get the following conclusions.

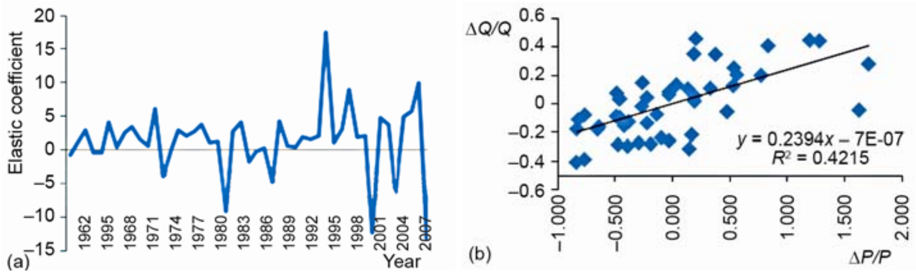

Figure 6. Relationship between runoff and rainfall; (a) elastic coefficient, (b) linear regression

- Rainfall changed significantly. Rainfall in flood season (June to September) is more than four times greater than during the non-flood season (October to May). Rainfall in flood season is characterized by heavy storm or thunderstorms. Light rain is the least frequent, and heavy rain is the largest.
- Although the inter-annual variability of temperature is uneven, temperature data series show upward trends and regularity from January to December. The MK test shows that the climatic jumps occur from 1993 to 1994, but there is no trend in temperature data series.
- Based on the inter-annual analysis, the results show that monthly runoff data series have obvious downward trend. The intra-annual analysis shows that runoff in July and August accounts for about 50% of the total annual runoff.
- The elastic coefficient analysis shows that change of rainfall does not have great influence on runoff. Linear regression between the change proportion of monthly runoff and rainfall sequence shows that every 1% change in rainfall causes a 0.24% change in runoff.

Acknowledgments

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