Research on Drought Retrieve in Baiyangdian Basin, China

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Abstract. Driven by global warming and human activities, the frequency, intensity and duration of drought have all showed an increasing trend. Most of the research on drought are only based on observed records, which cannot represent the natural evolution law of drought. Drought retrieve is of great importance to rational allocation of water resources in both social-economic system and natural ecological environment. This paper established the general framework of drought retrieve and did case study in Baiyangdian Basin, China. The Baiyangdian Basin of China has been suffering from severe drought in the recent years. Under the same precipitation and surface water resources condition, retrieved water flowing into the Baiyangdian wetland is much larger than the actual amount of inflow.

1. Introduction

This paper established the general framework of drought retrieve and did case study in Baiyangdian Basin, China. During 1961-1980, the actual water flowing into the Baiyangdian wetland was 2.996×10⁸m³, which is 68.0% less than the retrieved water under the same precipitation condition and is 50.5% less than that under the same surface water resources condition. During 1981-2011, there are 12 years when the actual water flowing into Baiyangdian wetland was less than 1×10⁸m³. There was only one year (1999) when retrieved water under the same surface water resources flowing into the Baiyangdian wetland was less than 1×10⁸m³ and the retrieved water under the same precipitation condition was all more than 1×10⁸m³.

Historical records and climate models all show increased global warming and aridity since 1950 over many places in the world [1][2]. Compared to 1850-1900, the average temperature in 2003-2012 increased by 0.78°C compared with that during 1850-1900 [15] and the temperature in China also has shown a similar increasing trend [3]. Driven by global warming and human activities, the frequency, intensity and duration of drought have all increased a lot [4]. China has suffered a lot from extreme climate events such as drought [5]. Losses caused by drought is about 55% of that caused by natural disasters on a global scale and that ratio has reached 60% in China. In the recent 20 years, losses caused by drought account for more than 90% of total losses caused by natural disasters in Haihe
River Basin. Coping with drought is one of the core content of coping with climate change, in which identifying its evolution law is the key.

Scholars have done many researches on drought in different countries, such as America, Hungary, Korea, India, Australian and China [6-9]. The results showed that observed drought events are caused by both climate change and human activities. Evolution law of drought events has no longer been the natural state. Using only observed drought events can not represent the natural evolution law of drought [10-14].

With the development of social-economy, water use competition within basins are becoming stronger, especially in drought scenario: social-economic system is less effected by drought compared with that in natural scenario, while natural ecological system is more effected by drought compared with that in the natural scenario. Therefore, research on drought retrieve is needed to be done. Based on drought evolution law in the natural state, targeted drought coping strategy can be got.

This paper follows the guidance of dualistic hydrological cycle, and has established the theory and technological framework of drought retrieve with precipitation-runoff relationship as the core. A case study was also done in Baiyangdian Basin, located in the North of China, so as to develop the theory and method for coping drought.

2. Theory and technological framework of drought retrieve
In drought scenario, social-ecological water demand increases sharply, intensifying water resources competition within a certain region or basin. In order to relieve the stress of water shortage during drought in social-economic system, the amount of water abstraction, water use and water consumption will increase significantly during drought, thus putting ecological environment in greater danger.

Fig. 1 Social-economic system and natural ecological system forced by drought

Drought retrieve aims at characterizing evolution law of drought objectively, with dualistic hydrological cycle as the theoretical basis and precipitation-runoff relationship in the drought scenario as the core. For a certain basin, precipitation-runoff and surface water resource-runoff relationship can be established based on precipitation-runoff relation in drought scenario. We assume the baseline is the initial year of the period in which intense human activities occurred. Natural runoff before the baseline and actual runoff after the baseline can be calculated under the same precipitation condition. Difference between the natural runoff and actual runoff is the reduction of runoff caused by human activities under the same precipitation condition. Similarly, reduction of runoff caused by human activities under the same surface water resources condition can be calculated.
3. Study area

Baiyangdian Basin is located in the middle of Haihe River Basin and the middle of Hebei province, north of China. As the biggest fresh water wetland in the North of China, Baiyangdian wetland is honored as the “Pearl of North China”. Because of its importance in regulating climate, supplying groundwater of North China and maintaining ecological environment of Beijing and Tianjin, Baiyangdian wetland is also called the “kidney of North China”. In the recent years, Baiyangdian Basin is facing severe water shortage and drought threat. Baiyangdian wetland had been dried up for five continuous years in the 1980s and has the biggest contradiction between water supply and water demand [16].

Baiyangdian Basin is the catchment of Zhulonghe River, Xiaoyihe River, Tanghe River, Caohе River and Puhe River of the south rivers of Daqinghe River, and Yishui River and Jumahe River of the north rivers of Daqinghe River, whose total area is 34449.58km². The location of Baiyangdian Basin is 113°40′-116°50′E and 38°10′-40°05′N. The study area is affected by monsoon climate of medium latitudes. Annual mean precipitation is about 520mm but with an uneven intra-annual distribution: 70-80% of the precipitation concentrates within summer. Annual mean temperature is 12.1°C [17].

4. Data and method

4.1 Data

Daily observational precipitation data of 83 meteorological stations comes from the Reference Room.
of National Meteorological Information Center, China Meteorological Administration (Fig. 4). Years that include missing data for a particular meteorological station are deleted prior to analysis. If the missing data reaches up to 80% of the total record for a certain meteorological station, data from this meteorological station is excluded from the analysis. Daily precipitation data in each meteorological station was reorganized into monthly precipitation and temperature. Based on these, monthly precipitation data was converted into grid maps via Co-Kriging method (COK) with the help of digital elevation model (DEM) [18].

The observed runoff data comes from 16 typical hydrological stations: Dongcicun, Luobaotan, Zijinguan, Angezhuang, Longmen, Xingaifang, Daoamaguan, Fuping, Wangkui, Zhongtangmei, Xidayang, Hengshanling, Xinle, Beiguocun, Beixindian and Zaolinzhuan, 1961-2011.

Surface water resources data from 1961-2000 was selected from China Water Resources Comprehensive Plan, and that from 2001-2011 was selected from Haihe River Basin Water Resources Bulletin and China Water Resources Bulletin.

Fig. 4 Distribution of meteorological station and hydrological station of Baiyangdian Basin

4.2 Method

4.2.1 Analysis of break point

Method of moving t-test identifies break point by comparing if the difference between two groups of samples are significant. This paper used moving t-test to identify the break point of runoff coefficient.

\[
\begin{align*}
    t &= \frac{\bar{x}_1 - \bar{x}_2}{s} \cdot \sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \\
    s &= \sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 - n_2 - 2}}
\end{align*}
\]

where, \(n\) is the number of samples, \(x\) is the time series, \(x_1\) and \(x_2\) are the two sub-series cut off from an artificial setting time, the number of samples for the two sub-series are \(n_1\) and \(n_2\) respectively which is \(n_1=n_2=10\) in this paper, mean value of these two series are \(\bar{x}_1\) and \(\bar{x}_2\) respectively, variance of these two series are \(s_1^2\) and \(s_2^2\) [19].

4.2.2 Method of drought retrieve

The breakpoint of inflow was identified; the period before the breakpoint is assumed to be the natural scenario and the period after the breakpoint is assumed to be the artificial period when intense human activities occurred. Simulation models between precipitation/surface water resources and water flowing into the study area before the breakpoint were established, i.e., \(Q_b\) in Fig. 5; simulation models between precipitation/surface water resources and water flowing into the study area after the
breakpoint were established, i.e., $Q_a$ in Fig. 5. Under the same precipitation/surface water resources condition, the difference ($\Delta Q$) between $Q_b$ and $Q_a$ can be calculated, and this is the decreased amount of inflow caused by human activities.

Fig. 5 Method of drought retrieve

According to the analysis of breakpoint, it is assumed that the period before 1980 is natural scenario and that after 1980 is artificial scenario in which intense human activities occurred. Four models can be established as follows:

Unary linear regression model between precipitation and water flowing into Baiyangdian wetland before 1980 was: $Q_b = 5 \times 10^{-7} P_b^{2.6826}$.

Unary linear regression model between surface water resources and water flowing into Baiyangdian wetland before 1980 was: $Q_b = 0.0045 W_b^{2.146}$.

Unary linear regression model between precipitation and water flowing into Baiyangdian wetland after 1980 was: $Q_a = 1 \times 10^{-7} P_a^{2.4869}$.

Unary linear regression model between surface water resources and water flowing into Baiyangdian wetland after 1980 was: $Q_a = 3 \times 10^{-6} W_a^{3.8882}$.

Where, $Q_b$ is the water flowing into Baiyangdian wetland before 1980, $10^8 \text{m}^3$; $Q_a$ is the water flowing into Baiyangdian wetland after 1980, $10^8 \text{m}^3$; $P_b$ is the precipitation before 1980, mm; $P_a$ is the precipitation after 1980, mm; $W_b$ is the surface water resources before 1980, $10^8 \text{m}^3$; $W_a$ is the surface water resources after 1980, $10^8 \text{m}^3$.

Under the same precipitation condition $P^*$, water flowing into the study area before 1980 can be calculated: $Q^*_{b} = 5 \times 10^{-7} P^*_b^{2.6826}$; water flowing into the study area after 1980 can be calculated: $Q^*_{a} = 1 \times 10^{-7} P^*_a^{2.4869}$; changes of water flowing into the study area due to human activities can be calculated: $\Delta Q^* = Q^*_{b} - Q^*_{a}$.

Under the same surface water resources condition $W^*$, water flowing into the study area before 1980 can be calculated: $Q^*_b = 0.0045 W^*_b^{2.146}$; water flowing into the study area after 1980 can be calculated: $Q^*_a = 3 \times 10^{-6} W^*_a^{3.8882}$; changes of water flowing into the study area due to human activities can be calculated: $\Delta Q^* = Q^*_b - Q^*_a$.

5. Results and Discussion

Fig. 6 Change of water that flows into and out of Baiyangdian Basin
Change of water flowing into and out of Baiyangdian Basin during 1961-1980 is shown in Fig. 6. Annual mean water flowing into Baiyangdian Basin was $16.37 \times 10^8$ m$^3$ during 1961-1980, in which the amount reached $71.65 \times 10^8$ m$^3$ and $56.37 \times 10^8$ m$^3$ in 1963 and 1964 respectively. Annual mean water flowing out of Baiyangdian Basin was $12.44 \times 10^8$ m$^3$.

Annual mean water flowing into Baiyangdian Basin was $2.996 \times 10^8$ m$^3$ during 1981-2011, in which the annual mean water flowing into Baiyangdian Basin was no more than $1.5 \times 10^7$ m$^3$ during 1983-1987. Besides, the amount was less than $1.0 \times 10^8$ m$^3$ in 2013. During 1981-2011, only $1.85 \times 10^8$ m$^3$ water flowed out of Baiyangdian Basin annually. What’s more, there has been no water coming out of the study area since 2006.

Runoff coefficient is the ratio between runoff and precipitation within a certain same period in a certain area, which can comprehensively reflect the impacts of naturally geography on runoff. Yearly runoff coefficient of the study area changed abruptly in about 1980. It is probably because Hengshanling Reservoir, Wangkuai Reservoir, Xidayang Reservoir, Longmen Reservoir and Angezhuang Reservoir was being built since the 1950s and the 1960s on Zhulonghe River, Tanghe River, Caohai River, Puhe River and Jumahe River. Besides, precipitation decreased since the 1980s. Baiyangdian Basin has been dried up for 5 years during 1983-1988. The runoff coefficient after 1980 was less than that before 1980, and the interannual variation was also much bigger. Since the 1990s, Baiyangdian Basin has been in the danger of drying up for several times. Ministry of Water Resources of China and the government of Hebei province had to transfer $9 \times 10^8$ m$^3$ water into the study area for 11 times to solve the crisis [19].
Fig. 9 Relationship between precipitation and runoff depth of mountain area in Baiyangdian Basin

![Graph showing relationship between precipitation and runoff depth](image1)

Fig. 10 relationship between precipitation and water flowing into Baiyangdian Basin

![Graph showing relationship between precipitation and water flowing](image2)

Fig. 11 Relationship between surface water resources and water flowing into Baiyangdian Basin

![Graph showing relationship between surface water resources and water flowing](image3)

Relationship between precipitation and water flowing into Baiyangdian Basin and that between surface water resources and water flowing into Baiyangdian Basin were established. It can be seen from Fig. 9 that runoff in the mountain area of Baiyangdian Basin decreased significantly under the same precipitation condition after 1980. For the Baiyangdian wetland within the basin, water flowing into the wetland decreased significantly after 1980 under the same precipitation and surface water...
resources condition, which is shown in Fig. 10 and Fig. 11. More human activities after 1980 is the main reason of the above phenomenon. During 2001-2011, annual mean water use in Shijiazhuang, Baoding, Hengshui, Cangzhou, Zhangjiakou and Langfang (six typical cities of the study area) has reached up to 31.9×10^8 m^3, 32.0×10^8 m^3, 16.1×10^8 m^3, 13.7×10^8 m^3, 10.4×10^8 m^3 and 10.5×10^8 m^3 respectively. Water use for human activities has caused further decrease of water flowing into Baiyangdian wetland.

Fig. 12 Retrieved water amount of Baiyangdian wetland

Based on the relationship between precipitation and water flowing into the wetland and the relationship between surface water resources and water flowing into the wetland, yearly retrieved water flowing into the wetland according to surface water resources and precipitation can be calculated respectively (Fig.12). The amount of retrieved water is obviously more than the actual amount.

The retrieved annual mean water flowing into Baiyangdian wetland according to the same precipitation condition was 9.35×10^8 m^3 and the retrieved annual mean water according to the same surface water resources was 6.05 ×10^8 m^3 during 1961-1980. The actual water flowing into the wetland was only 2.996×10^8 m^3, which was 68.0% less than the retrieved water under the same precipitation condition and was 50.5% less than the retrieved water under the same surface water resources condition.

During 1981-2011, there are 12 years when the actual water flowing into Baiyangdian wetland was less than 1.0×10^8 m^3, which are 1981, 1983-1987, 1992, 1994, 1999-2000, 2006 and 2009. For the retrieved water under the same surface water resources during 1981-2011, only in 1999 would the water flowing into the wetland be less than 1.0×10^8 m^3. Similarly, the retrieved water flowing into Baiyangdian wetland under the same precipitation condition would be more than 1.0×10^8 m^3 during 1981-2011.

6. Conclusions

This paper took Baiyangdian Basin in the North of China and the Baiyangdian wetland within it as the subject and established the basic theoretical framework of drought retrieve. Changes of precipitation and runoff in Baiyangdian Basin during 1961-2011 were analyzed. Temporal changes of runoff coefficient, water flowing into and out of Baiyangdian wetland were also investigated. Retrieved water flowing into Baiyangdian wetland under the same precipitation and surface water resources condition were calculated.

The results show that Baiyangdian Basin of the North of China has been in drought state in the recent 20 years. The annual mean amount of water flowing into and out of Baiyangdian wetland were 16.37×10^8 m^3 and 12.44×10^8 m^3 respectively during 1961-1980. During 1981-2011, the annual mean amount of water flowing into and out of Baiyangdian wetland were 2.996×10^8 m^3 and 1.85×10^8 m^3 respectively. Besides, there has been no water flowing out of Baiyangdian wetland since 2006.
Since 1980, watershed condition and the mechanism of runoff generation and confluence of Baiyangdian Basin have changed a lot due to human activities. Runoff coefficient changed abruptly around 1980. Runoff coefficient after 1980 was less than that before 1980 with big interannual variation.

After 1980, natural ecological water was squeezed by social-economic water, especially during drought. Runoff in the mountain area of Baiyangdian Basin after 1980 decreased significantly compared with that under the same precipitation and surface water resources condition. During 1961-1980, the actual water flowing into the Baiyangdian wetland was $2.996 \times 10^8 \text{m}^3$, which is 68.0% less than the retrieved water under the same precipitation condition and is 50.5% less than that under the same surface water resources condition. During 1981-2011, there are 12 years when the actual water flowing into Baiyangdian wetland was less than $1 \times 10^8 \text{m}^3$. There was only one year (1999) when retrieved water under the same surface water resources flowing into the Baiyangdian wetland was less than $1 \times 10^8 \text{m}^3$ and the retrieved water under the same precipitation condition was all more than $1 \times 10^8 \text{m}^3$. Nowadays, Baiyangdian Basin is in a more dangerous drought crisis than that in the natural state.

This paper has done drought retrieve in a temporal scale of one year and spatial scale of a basin, and we will do further research on typical drought events retrieve in monthly scale so as to identify the mechanism of drought disaster.

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