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Analysis on the Water Exchange between the Main Stream of the Yangtze River and the Poyang Lake

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Abstract

Analysis on the hydrologic characteristics of the main stream of the Yangtze River and Poyang Lake were studied to discuss the water exchange between the main stream of the Yangtze River and Poyang Lake before and after the operation of Three Gorges Reservoir, as well as in the typical dry year of 2006. The annual runoff distribution for dry season of Hukou station, located at the outlet of Poyang in 2000s has increased, compared to previous years. And the percentage of runoff in September and October has also increased, compared to 1990s in last century. The water exchange coefficient was 0.51 in the year 2006, which means nearly stable effect between the Yangtze River and the Poyang Lake. Meanwhile, the Poyang Lake provide water supply up to $1564\times10^8 m^3$, accounts for about 23% of the Datong runoff in the same period, and 5% more than the normal year. This is the main reason that the discharge maintained more than $10000 m^3/s$ at Datong all over the year 2006, reaching a positive phenomenon of 'no drought in dry season'

Keywords: water exchange, runoff regulation, the Three Gorges Reservoir, the Poyang Lake, The Yangtze Rive.

1. Introduction

The context of global climate change in lake water balance, changes in deposition and erosion and flood regulation and storage and other issues is an important aspect of relationship between rivers and lakes [1-7]. The Three Gorges Dam reflects the strong transformation of human activities on natural environment [8-9], which regulates the construction of the upper reaches of Yangtze River in temporal and spatial changes between rivers and lakes in Yangtze River and affect the exchange process [8-14]. Moreover, the lake is an important water source of the Yangtze River. The changes in volume and water and sediment after building a database on the interaction between rivers and lakes has been discussed by many researchers, such as Huang Qun, Ma Yuanxu, Guo Peng, Wang, Luo Xiaoping, Zheng Lin[15-21].

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However, the exchange of water between rivers and lakes downstream has changed a lot after the operation of the Three Gorges Dam, which has effected the environment, water use and socio-economy in the lakes and delta.

2. Study area and data

2.1. Study area

The Yangtze River is the longest river in China, and the third one in world. The total water resources reach to about $9613\times10^8 m^3$, accounting for 34.2% of the national sum. As for Spatial distribution, the water flow rate per square kilometer ranges from $85.3\times10^4 m^3$ to $32.6\times10^4 m^3$, a difference of more than 2.5 times. As for time allocation, there is an obvious difference of flood and dry season. The runoff concentrates in the flood season from May to October, accounting for 70-75% of water throughout the year. The difference in the monthly average discharge of maximum and minimum accounts for 12-20 times. And the difference in the annual average discharge of maximum and minimum accounts for 1.2-2.2 times. [22-24].

Poyang Lake, located at the junction of the south bank of Yangtze River, is the mouth of the Yangtze River through the largest single river lakes, and the largest freshwater lake (Fig.1) in China. It has an area of about $4000km^2$, volume of about $300\times10^8 m^3$. Poyang Lake is a lake had water throughput model [25], it is absorbs the runoff from Gan River, Fu River, Xin River, Rao River and Xiu River (hereinafter referred to as the 'Five Rivers'), and flow into the Yangtze River at Hukou after regulation. The Basin area is $16.2\times10^4 km^2$, accounting for 9% of the Yangtze River drainage area. The water from five river water accounts for about 90%, and the rest 10% is local Poyang Lake water. The average runoff of five years is $1268\times10^8 m^3$ of which the largest 47% coming from Gan River. The annual average runoff at Hukou is $1436\times10^8 m^3$. The regulation effect of Lake water on the River can not be ignored.

2.2. Data

The hydrological data is collected by the Ministry of Water Resources [22-24]. The monthly discharge at Hankou is collected from 1950 to 2009. Hukou is from 1950 to 2009, and the Five Rivers are from 1953 to 2009.

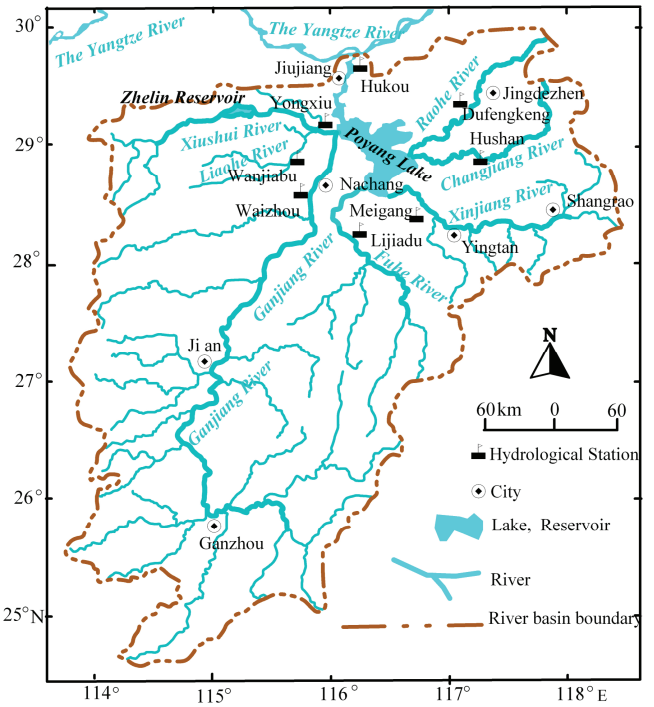

Figure1 Schematic diagram of the location and the watershed of the Poyang Lake water system.

3. The function of diversion water of Poyang Lake

The regulation and storage function of the Poyang Lake on the Yangtze River flood is mainly reflected in two aspects: one is handling the Yangtze River flow backward into the lake by the flood; the other is satisfied by order of five rivers flooding of Poyang Lake water system, a corresponding reduction in the lake into the river Hukou Flow. It can reduce the flood discharge for the Yangtze River, Yangtze River to reduce flood Hukou the following, to play on the Yangtze River flood diversion, detention, consumption peak, peak load shifting role of such regulation and storage.

3.1. Downdraft Yangtze River water in Poyang Lake.

According to statistics, during the year 1950-2010, the phenomenon of water intrusion into the lake happened in 47 years, with a total of 124 times and 720 days. The total amount of water intrusion reached up to $1408.5\times10^8 m^3$, with an average of 15.3 days per year, and amount of $30.0\times10^8 m^3$, 2041 m^3/s per day. And the most downdraft days happen in 1958, with a number of 47days. The biggest water intrusion happened in 1991, with an amount of $113.9\times10^8 m^3$.

The water downdrafts in a certain regularity. River water generally occurs during June to December, mainly in the Yangtze River's main flood season from July to September. There is are decadal fluctuations in the year of water downdraft, total days and total amount of water, presenting a less and a more interval distribution. Compared to 1960s and 1980s, the the total number of days and total amount of water has declined in 2000s.

3.2. The complementary role of the Poyang Lake on the Yangtze River water

The discharge amount coming from Five Rivers directly affects the water supply ability of Poyang Lake into the Yangtze River. After the statistics of runoff during 1950 and 2010, a slight increase in water discharge is found. The annual average runoff is about $1054\times10^8 m^3$, accounting about 15% of the runoff per year at Datong. The maximum annual runoff is $2671\times10^8 m^3$ (in the year of 1998), and the second one is $2630\times10^8 m^3$ (in the year of 1954), and the minimum is $574\times10^8 m^3$ (in the year of 1963). The runoff at Hukou station distributed intervally of high-flow years group and low-flow years group. For example, 1905s was a period with high flow, and 1960s was low flow. And so on and the period of 2000-2009 can be considered as low water

3.3. Poyang Lake and Yangtze River water exchange coefficient

If we consider I_p as the water exchange coefficient between Poyang Lake and Yangtze River, R_j the annual runoff coming from Five Rivers into the lake, R_h the annual runoff flowing out of Hukou, T_i the downdraft days of the i year, and t_i the downdraft coefficient into Yangtze River at Hukou, I_{pc} the normalized result of t_i, t_{min} the minimum value of t_i, t_{max} the maximum value of t_i, i = 1,2,3 … n, n is the statistics year, I_{pz} and I_{pc} reveal the exchange effect of river and the lake, aa well as the downdraft effect between the Five Rivers and Hukou station. r_1、r_2 are balance coefficient, and q_p is adjustment factor.

Then, according to the formula of water exchange coefficient between Poyang Lake and Yangtze Rive.

$$I_p = r_1\left(\frac{R_j}{R_h}q_p - 0.5\right) + r_2 I_{pc} \qquad \left(q_p = 1.362\right) \tag{1}$$

$$I_p = r_1 I_{pz} + r_2 I_{pc} \tag{2}$$

$$I_{pz} = \frac{R_j}{R_h}q_p - 0.5 \tag{3}$$

$$I_{pc} = \frac{t_i - t_{\min}}{t_{\max} - t_{\min}} \tag{4}$$

$$t_i = T_i \Big/ \frac{1}{n}\sum_{i=1}^{n} T_i \tag{5}$$

The physical meaning of Eq. 1: when I_p = 0.5, it indicates that the water exchange remains stable; when $I_p < 0.5$, it indicates that the role of Poyang Lake on the Yangtze Rive is less effectible, the lower of I_p the stronger ability of regulation and storage of the Poyang Lake to the Yangtze Rive; when $I_p > 0.5$, it indicates that the role of Poyang Lake on the Yangtze Rive is more effectible, the higher of I_p the stronger ability of water supply of the Poyang Lake back to the Yangtze Rive.

Using Eq. 1-5, the water exchange coefficient of the Poyang Lake and Yangtze River can be calculated. The results found in Poyang Lake and Yangtze River main stream agree with the actual situation of the exchange. The average water exchange is the arena for many years relatively stable state (I_p = 0.50). High-flow year in 1954 and 1998 [26], I_p values were 0.34 and 0.39, indicating that the flood in Poyang Lake on the Yangtze River and storing function strongly. Low-flow year 1978 the river flowed backward for 15 days, I_p = 0.56, showing that the flow of the Yangtze River backwater effect on the Hukou large role in river water is strong. Low-flow year in 2006 (I_p = 0.51), the non-intrusion phenomenon in the river,

the lake on the role of the Yangtze River to supply water close to the average level for many years (Table 1).

Table 1 Statistics of River-Lake water exchange between Poyang Lake and the Yangtze River mainstream in different years

Item Year	Runoff of Huou (10^8m^3)	Runoff of Five River (10^8m^3)	The number of days of the water backward from Yangtze into Poyang Lake（day）	The water exchange coefficient of Yangtze River and Poyang Lake (I_p)
1954	2581	1633	0	0.34
1978	947	726	15	0.56
1998	2650	1713	0	0.39
2006	1564	1206	0	0.51
Annual average	1494	1089	15.3	0.50

4. Changes in water exchange after the Three Gorges Reservoir

According to the monthly distribution of the runoff at Hukou, after the operation of Three Gorges Reservoir in 2000s, compared to the previous years, the proportion of dry season has increased. The runoff in October, when the reservoir keeps water, increases compared to 1990s (Fig. 2). The ratio of the water out of Lake Poyang Lake increased at the same time reservoir store water.

It is a high-flow year in 2010, when the Three Gorges reservoir reached a water level of 175m. During this period, the monthly discharge distribution at Hankou in September and October is 12.2% and 7.7%, respectively. Compared with the average annual, the values reduced of 0.6 and 3.0 percentage points. And compared with the values of 2006-2009, there is an increase of 0.2 and 0.6 percentage points respectively (Fig. 2). During the reservoir storage period, the monthly runoff distribution at Hankou has changed. And the runoff distribution in September and October are also less than the annual mean values.

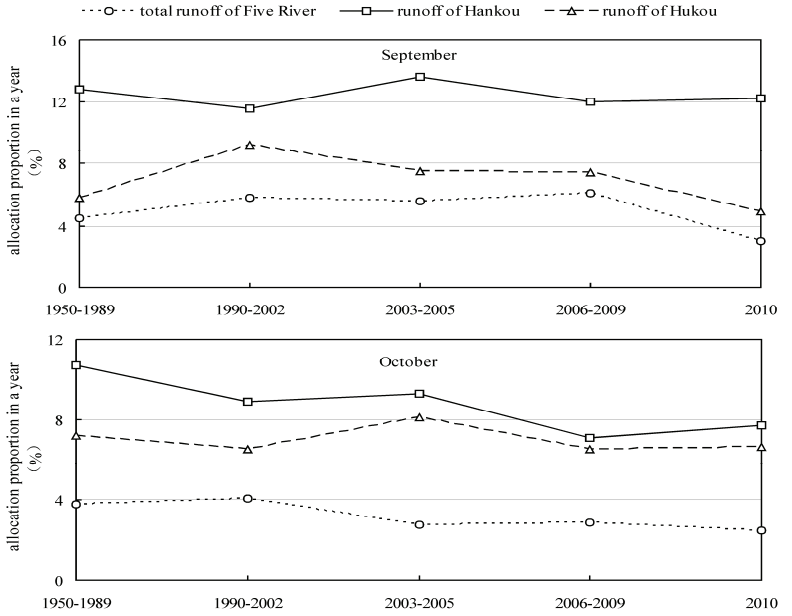

Figure. 2 The water discharge at Hukou, Hankou and the Five Rivers in September and October

From Fig. 2 we can see that the runoff distribution in September and October at Hukou are 4.9% and 6.6%, decreased by 0.9 and 0.6 percentage points compared with the annual average; and decreased by 2.5 percentage points compared with 2006-2009; and increase by 0.1 percentage points in October. At the same time in 2010, the runoff distribution of the total runoff of the Five Rivers in September and October are 3.0% and 2.5%, decreased by 1.5 and 1.3 percentage points compared with the annual average; and decreased by 0.5 and 0.4 percentage points compared with 2006-2009. It can be seen that the runoff distribution of the total runoff of Hukou the in September and October are not at the same phase with that of Five Rivers. Its amplitude is much smaller than that of Five Rivers, and even become increased. As a result, the discharge at Hukou increased during these 2 months, mainly because it is affected together by the discharge in the lake itself and the water level of the main stream of Yangtze River. The river supply of the Three Gorges Dam decreased in September and October 2010, resulting in a decreased water level in the main stream, and a bigger distance in and out of the lake, and a *Constrained Action* appeared. This caused strengthen outlet discharge and higher flow velocity, and finally resulting in higher discharge distribution in September and October.

5. Water exchange processes between river and lake during dry year

The year 1978 and 2006 are extremely dry years [27, 28], the middle and lower reaches of the Yangtze River have been drought, and the lakes on the river played a very positive role in water regulation.

5.1. Analysis on the average monthly discharge of the driest month

When entering the dry season when the Yangtze River, Yichang station and a rapid reduction of flow at Datong Station (Fig. 3). The flood season does not end on 10 monthly flow as a reference value, Yichang station for many years in October average flow 19315m^3 / s, while the February average flow of only 3950 m^3 / s. February and October flow, a decrease of value of 80%. Similarly, Chase has a similar change in outbound traffic. However, control over the same period of Poyang Lake's Hukou station reduction in the flow rate is relatively small (Fig. 3), the minimum average flow of the month in December, compared with October to reduce the value of 58%

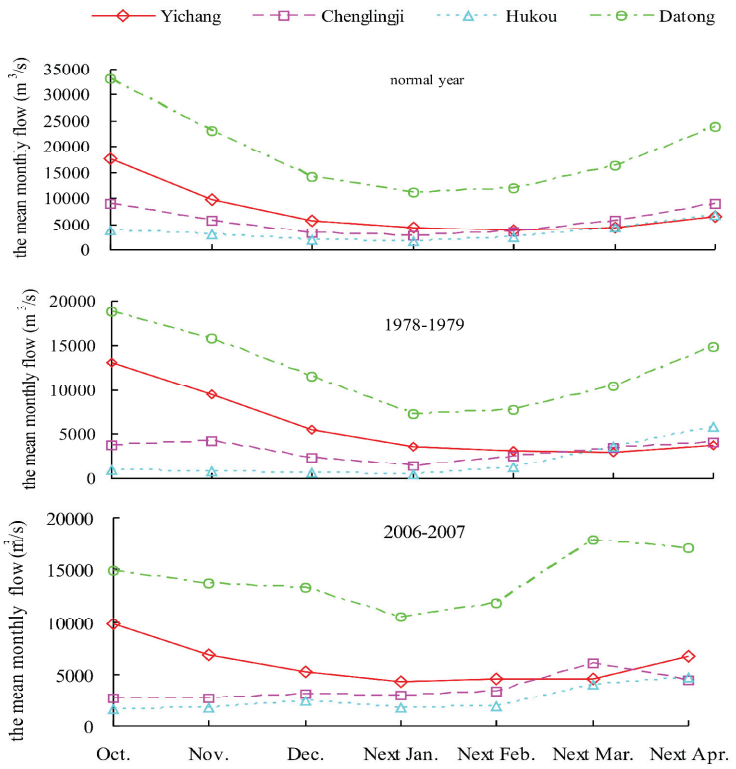

Figure 3 Variations in the mean monthly flow in dry season in different years at Yichagn, Chenglingji, Hukou, Datong hydrological stations

5.2. Changes in average flow rate of dry season

To many years of dry season (November to next April) 6-month average flow and flood season has not ended March 10 compared to the average monthly flow (Fig. 3), can show the lake dry season water added to the contribution of the main stream. Yichang station for many years in October average flow of 19 315 m^3/s, for many years an average of 6 months dry season flow of 6 132 m^3/s, flow impairment to 69%. The average flow Datong station years in October 32 799 m^3/s, for many years an average of 6 months dry season flow of 16 509 m^3/s, flow impairment to 50%. Hukou station for many years in October while the average flow of 3 844 m^3/s, for many years 6 months, the average dry season flow of 3 723 m^3/s, flow impairment only 3%, especially after January the following year with the upstream To continue to reduce the amount of water, declining water level of Yangtze River case, the addition of lake water continued to leak River, the River flows increase. Thus, the water supplement of Poyang Lake on the Yangtze River mainstream is obviously during a typical dry year.

6. Conclusions

There was a slight increase in runoff trends at Hukou station in 1950-2010; annual change in how water and a small group of white water in the distribution of group characteristics.

Poyang Lake, Yangtze River water intrusion Hukou phenomenon, not a pattern of variation; However, decadal changes between the intrusion, 2000s and 1980s the same group of dry years and the 1960s compared to number of years of river water, the total number of days and total water are On the decline.

Hukou station runoff distribution in the 2000s during the previous decade compared with the percentage increase in dry season, the Three Gorges Reservoir 9 and October runoff distribution ratio than an increase in 1990s. In September 2010 and October for the 175m stage of reservoir water level, discharge for reduction, the main stream flow of small water level is low, the Poyang Lake River runoff to increase supply.

The water exchange coefficient is 0.51 during extreme dry year in 2006, indicating that dry years the complement of the Poyang Lake on the Yangtze River water to the average amount of years that the Yangtze River is not dead in the dry season appears good

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