Research on the Middle and Lower Reaches of the Yangtze River and Lake's Hydrological Alterations Based on RVA

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Abstract. On the basis of river-lake relationship analysis, this paper chose the middle and lower reaches of Yangtze River where the Poyang Lake locates as the study area. The storage variable of Three Gorges Project was deduced to hydrological stations at the lower reaches. The natural runoff processes of hydrological stations were restored. Then RVA method was applied to analyze the hydrologic alterations of river channels at the hydrological stations before and after reservoir operation. The analysis result indicated that Hankou hydrological station and Datong hydrological station at the lower reaches had medium changes after operation of the Three Gorges Project. The hydrological regimes of Hankou hydrological station, Hukou hydrological station and Datong hydrological station in different periods before and after operation of Three Gorges Project were analyzed, the water exchange between Poyang Lake and the middle and lower reaches of Yangtze River was investigated, and the relevant results indicated that the inflow of lower reaches river channel decreased during impoundment of Three Gorges Project, the water level of river channel dropped, and the outflow from the lake increased, which was the major reason behind water deficiency of Poyang Lake area. The recommendation is to optimize the Three Gorges Project's water storage scheme, so as to improve the river-lake relationship at the middle and lower reaches of Yangtze River.

1 Introduction

There are many lakes along the middle and lower reaches of Yangtze River, among them Dongting Lake and Poyang Lake are two biggest freshwater lakes connected with Yangtze River. The river-lake relationship at the middle and lower reaches of Yangtze River influences the water resources exploitation and distribution as well as the water system protection at the middle and lower reaches of Yangtze River. In recent years, after the completion of Three Gorges Project and other big hydro projects at the upper reaches, the river-lake relationship at the middle and lower reaches of Yangtze River has witnessed new changes. The researches on the impact of Three Gorges Project and other big hydro projects' operation on the river-lake relationship at the middle and lower reaches of Yangtze River have great significance on the healthy and sustainable development of river-lake relationship.

To explore their comprehensive benefits, water impoundment shall be performed after the flood season, which has caused irreversible impacts on the Poyang Lake area. With more control reservoirs built at upper reaches of Yangtze River, Poyang Lake will witness bigger water level drop during water impoundment of the reservoirs, the dry season will become longer, the low water level will become a normal state, and the challenge on water resources exploitation and water environment protection will become tougher to cope with.

According to the range of variability approach (RVA) (Richter, Baumgartner et al. 1996, Richter, Poff, Allan et al. 1997, Baumgartner et al. 1998), the maintenance of river hydrological regime is vital for integrity of the hydrobiology functions of the river system. This approach is compatible with the theory of Natural Flow Regime. Many researchers have made many researches on the river-lake relationship between Poyang Lake and the middle and lower reaches of Yangtze River before and after operation of the Three Gorges Project and other big hydro projects at the upper reaches. Guo Hua (Guo, Hu et al. 2012) made analyses on the periods of similar climate conditions before and after operation of Three Gorges Project, and found that in July~September the outflow of more than 3,000 m^3/s from Poyang Lake increased by 74%. Jiang Liuzhi (Jiang, Ban et al. 2014) chose the daily flow, water level and sediment amount of Yichang, Jianli, Chenglingji, Luoshan, Hankou, Hukou and Datong hydrological stations at the middle and lower reaches of Yangtze River in 1980~2012 for analysis, divided the study period into two parts namely before (1980~2002) and after (2003~2012) water impoundment of Three Gorges Project, applied range of variability approach (RVA) to quantitatively analyze the alterations of 32 IHAs of the seven hydrological stations before and after water impoundment, and found that Chenglingji, Luoshan and Hankou hydrological stations had low alterations, while the other hydrological stationshad medium alterations. Gao Bing (Gao, Yang et al. 2013) used daily flow to analyze the runoff process at the middle and lower reaches of Yangtze River, concluded that the operation of Three Gorges Project had extended the dry season runoff process at the middle and lower reaches of Yangtze River, and suggested more researches on the river-lake relationship, so as to better protect the hydrobiology system of Poyang Lake. Lai Xijun (Lai, Liang et al. 2014) set up hydrological model, simulated the water exchange between the middle and lower reaches of Yangtze River, Dongting Lake and Poyang Lake, and thought that the operation of Three Gorges Project increased the outflow from the lake and reduced the inflow into the lake. They also recommended the optimization of Three Gorges Reservoir water regulation, so as to improve the river-lake relationship at the middle and lower reaches of Yangtze River.

In most researches, the runoff processes before and after operation of Three Gorges Project were used to analyze the hydrologic alterations at the middle and lower reaches of Yangtze River. The runoff data of hydrological stations after operation of Three Gorges Project were not restored, so there was inconsistency in time process, and the hydrologic alterations at the middle and lower reaches after completion of hydro projects could not be fully reflected. In this paper, the observed runoff data of the hydrological stations after operation of Three Gorges Project were restored and combined with the natural runoff processes before the operation of Three Gorges Project, so as to analyze the hydrologic alterations at the middle and lower reaches of Yangtze River before and after operation of Three Gorges Project. By analyzing the runoff processes of control stations including Hankou hydrological station, Hukou hydrological station and Datong hydrological station at the middle and lower reaches of Yangtze River, the hydrologic alterations and river-lake relationship of Poyang Lake and the middle and lower reaches of Yangtze River were investigated.

2 Study Area

Yangtze River Basin runs through three economic zones namely the east, central and west of China, 19 provinces. It's the third longest river in the world. Total area of the basin is 1.8 million km^2 and the total length is 6,397 km. From Yichang upward is the upper reach of the basin with a length of 4,504 km. The section from Yichang to Hukou is the middle reach with a length of 955 km. From Hukou downward is the lower reach with a length of 938 km. Poyang Lake water system is located at south bank of the middle and lower reaches of Yangtze River. The geographical location is between E113°35′~118°29′and N24°29′~30°05′. The Poyang Lake water system is the collective term for the five rivers of Ganjiang, Fuhe, Xinjiang, Raohe and Xiushui. Most of them are in Jiangxi Province. The catchment area is 0.16 million km^2, accounting for 9% of the total area of Yangtze River Basin.

The inflow at the inlet of Poyang Lake is mainly influenced by the operation of Three Gorges Reservoir. The dam site of Three Gorges Hydro Complex is located at Sandouping of Yichang City on the main stream of Yangtze River. The catchment area under its control is 1 million km^2. Three Gorges

Hydropower Station is the largest one in the world. The station and Gezhouba Hydropower Station at the lower reach constitute cascade power stations. At the lower reaches of Three Gorges and Gezhouba cascade reservoir, there are Yichang, Hankou, Jiujiang, Datong and other hydrological stations and two lakes namely Dongting Lake and Poyang Lake. The outflow control station of Poyang Lake is Hukou hydrological station. Because Jiujiang Station is under the influence of outflow from Poyang Lake, this station is not included in the analyses (Lai, Liang et al. 2014). According to statistics, the annual runoff of Hukou hydrological station, Hankou hydrological station and Datong hydrological station was 148 billion m^3, 706.5 billion m^3 and 891.6 billion m^3 respectively in 1950 ~ 2002 and the runoff of Poyang Lake and Hankou hydrological station upward accounted for 16.60% and 79.24% of runoff at Datong hydrological station upward respectively in 1950 ~ 2002, and accounted for 16.52% and 79.90% respectively in 2003 ~ 2012. The difference is not big, indicating that the inflow of Datong hydrological station before and after operation of Three Gorges Project hadn't big change, the outflow from Hankou hydrological station and Hukou hydrological station was the major inflow for Datong hydrological station, and the ratio of inter-section inflow was low. Therefore, Hankou hydrological station was used as upper reach control station for analysis of river-lake relationship at the middle and lower reaches of Yangtze River, and Datong hydrological station was used as lower reach control station. The section from Three Gorges Dam to Datong hydrological station at the middle and lower reaches of Yangtze River was used as the study area of this paper. Details of the analysis range and main hydrological stations are as shown in Fig.1 below.

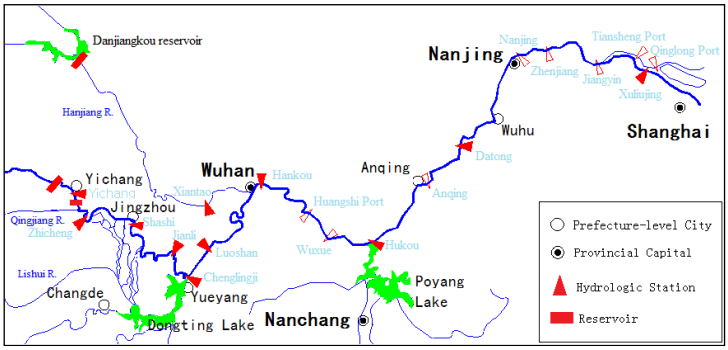

Figure 1 Study area and hydrological stations

3 Methodology

The RVA method can determine key hydrological indicators by analyzing the hydrological regime of rivers, and indirectly reveal the impact on the hydrological system of river by analyzing hydrologic alterations in different periods. In RVA method (Richter, Baumgartner et al. 1996, Richter, Baumgartner et al. 1998), 32 hydrological characteristics values in five aspects namely river flow, occurrence time, frequency, duration and change rate were used to assess the hydrologic alterations of river. The hydrological characteristic values are often calculated by indicators of hydrologic alteration (IHA). Indicator 23 is also called "base flow"; indicators 30 and 31 mean the flow average reduction rate and average increase rate between two consecutive days; and indicator 32 means the number of reversion from runoff increase to decrease or from decrease to increase in each year.

By analyzing the alterations of IHAs of control stations before and after operation of hydro projects, the impacts on the river channels at the cross-section can be revealed. In calculation, the impact periods were divided, the IHAs before completion of hydro project were calculated, the change range of each indicator was set, then the indicator values at 25% and 75% occurrence probabilities were chosen as upper and lower boundaries of range (Richter, Baumgartner et al. 1996, Richter, Baumgartner et al. 1998).

4 Results and discussion

Three Gorges Reservoir began water impoundment in June 2003. To analyze the impact of Three

Gorges Reservoir on the hydrological regime of rivers and lakes at the middle and lower reaches of Yangtze River, the runoff processes affected by impoundment of Three Gorges Reservoir after 2003 were restored. RVA method was applied to analyze hydrologic alteration of natural runoff processes at Hankou, Datong and Hukou hydrological stations before and after operation of Three Gorges Project, so as to reveal the river-lake relationship at the middle and lower reaches of Yangtze River.

(1) Analysis of hydrologic alteration of Hankou hydrological station before and after operation of Three Gorges Project

We first deduced the capacity of Three Gorges Project to Hankou hydrological station, restored the natural runoff process of Hankou hydrological station, and then compared the runoff processes of Hankou hydrological station at different periods, as shown in Fig.2.

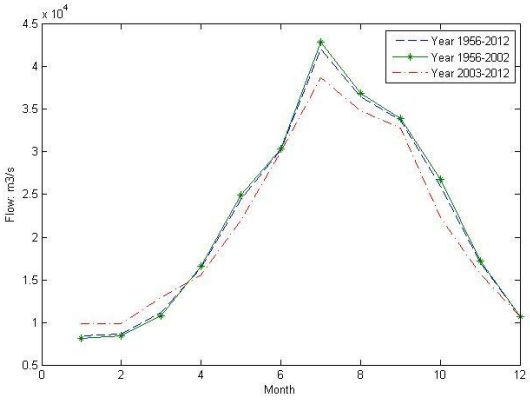

Fig.2 Runoff characteristic values of Hankou hydrological station after runoff restoratio

The Fig.2 above indicates that: the annual average flow of Hankou hydrological station in 1956 ~ 2012 was 22,200 m³/s, and the relevant runoff was 700 billion m³; in the dry season of 2003~2012, the annual average runoff decreased by 4.1%. This indicates that the hydrological regime analysis on the basis of time periods before and after operation of Three Gorges Project in 2003 was not objective enough, because the relatively dry period of 2003~2012 was not taken into consideration, and the impacts of Three Gorges Project operation on the hydrological regime at the middle and lower reaches of Yangtze River can't be fully reflected.

This paper analyzed the hydrological regime of Hankou hydrological station in two periods before and after operation of Three Gorges Project: first the daily runoff process of Hankou hydrological station in 1956 ~ 2002 and the observed daily runoff process in 2003 ~ 2012 before the operation of Three Gorges Project was compared; then the daily runoff process of Hankou hydrological station in 1956 ~ 2002 and the observed daily runoff process in 2003 ~ 2012 after runoff restoration was compared, and finally RVA method was used to calculate the alterations of IHAs, as shown in Fig.3.

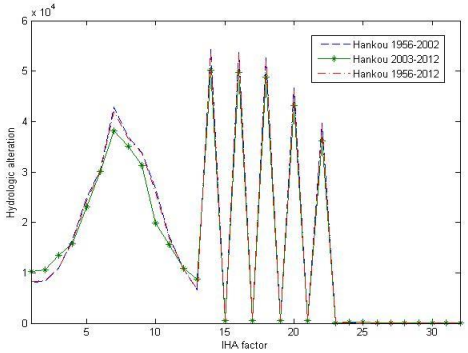

Fig.3 Analysis of IHAs alteration at Hankou hydrological station in different periods

Fig.3 indicates that: before and after restoring the runoff of Hankou hydrological station, except monthly average runoff, the IHAs of Hankou hydrological station were roughly the same. Calculation result indicated that Hankou hydrological station had medium alterations in both conditions. The comprehensive alteration value was 0.54 (without restoration of runoff) and 0.51 (with restoration of runoff), indicating that it is reasonable to choose the period 1956 ~ 2002 for natural hydrological regime analysis of river channel before operation of Three Gorges Project. Compared with the runoff process of 1956 ~ 2002, the monthly average runoff of Hankou hydrological station from December to March increased because of the operation of Three Gorges Project. The annual extreme runoff process, high/low runoff frequency and change rate had big changes, indicating that the operation of Three Gorges Project had changed the natural inflow of rivers and the hydrological regime at the lower reach.

The runoff change of Hankou hydrological station after 2003 had direct correlation with the operation of Three Gorges Project. The runoff process of Hankou hydrological station at the lower reach during impoundment of Three Gorges Reservoir was slightly lower than that of in natural status. During letdown period, the water replenishment of Hankou hydrological station during dry season increased (Lai, Liang et al. 2014).

(2) Analysis of hydrologic alteration of Datong hydrological station before and after operation of Three Gorges Project

The runoff data of Datong hydrological station in 1956 ~ 2002 indicated that the inflow from Hankou hydrological station and upward accounted for 79.24% of all runoff volume. By analyzing the hydrological regime of Hankou hydrological station, the runoff of 1956 ~ 2002 before operation of Three Gorges Project can be obtained and used as reference basis. The inflow process of Datong hydrological station was influenced by the inflow process of Hankou hydrological station and Hukou hydrological station, the condition was complicated, so the analysis of Datong hydrological station was based on the runoff processes before and after completion of Three Gorges Project, and the restoration of Datong hydrological station's runoff process will not be considered. The runoff processes of Datong hydrological station in 1956 ~ 2002 and 2003 ~ 2012 were used to analyze the hydrologic alteration of Datong hydrological station after completion of Three Gorges Project. The alterations of 32 IHAs are as shown in Fig.4.

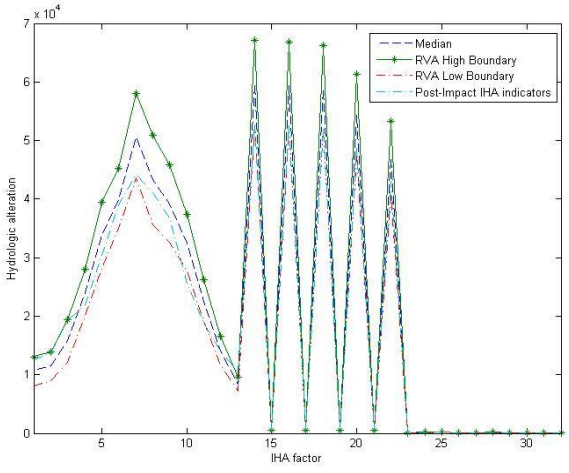

Fig.4 Alterations of IHAs of Datong hydrological station before and after 2003

After the Three Gorges Project was put into operation, the hydrological regime of river channel at Datong hydrological station had medium alteration (comprehensive alteration is 0.58); IHAs had medium or low alterations; the annual average runoff of Datong hydrological station in 1956 ~ 2002 was 891.4 billion m³, and the annual average runoff in 2003 ~ 2012 was 837.2 billion m³; in 2003 ~ 2012, the annual average runoff of Datong hydrological station was 6.1% less than that of 1956 ~ 2002;

in July ~ August, the runoff decreased by 23 billion m³, in September ~ October, the runoff decreased by 24.5 billion m³ (accounting for 13% of runoff in the same period), and the runoff in January ~ March decreased by 19.5 billion m³. The maximum monthly average runoff decreased in all the months; the minimum monthly average runoff increased in all the months except May, September and October.

Comparison of runoff processes of Datong hydrological station before and after 2003 indicates that: after Three Gorges Project was put into operation, the maximum monthly average runoff of Datong hydrological station decreased from January to December; the minimum monthly average runoff increased in all the months except May, September and October, indicating that the coordinated regulation and impoundment of Three Gorges Project and the lakes at the middle reaches of Yangtze River had effect of dry season water replenishment for the river course at the middle and lower reaches; the regulation and impoundment of Poyang Lake could alleviate the impact of Three Gorges Project on the lower reach of Yangtze River.

(3) Analysis of the runoff of Poyang Lake outlet Hukou hydrological station

Poyang Lake was under the influence of rivers at the middle and lower reaches of Yangtze River. Sometime back flowing happened and the runoff of Hukou hydrological station was negative, which made the calculation by RVA method inconvenient. To simplify the analysis, some IHAs were used in the analysis, as shown in Fig.5.

Fig.5 indicates that: the annual average runoff of Hukou hydrological station in 1956 ~ 2002 was 148 billion m³, and the annual average runoff of 2003 ~ 2012 was 138.3 billion m³, decreasing by 6.6% in comparison to the annual average runoff of 1956 ~ 2002. The runoff of July ~ August decreased by 3.43 billion m³, the runoff of September ~ October decreased by 0.88 billion m³ (accounting for 4.4% of the runoff in the same period), and the runoff of January~March increased by 1.35 billion m³. The maximum monthly average runoff decreased in all the months; the minimum monthly average runoff increased in all months except May and June.

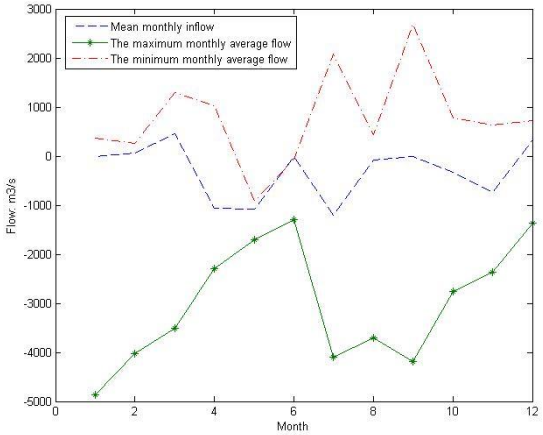

Fig.5 Observed runoff changes of Hukou hydrological station before and after 2003

In dry season, Poyang Lake replenishes the lower reaches of Yangtze River with water. The water level at the lake outlet drops and the outflow from the lake area increases. From February to June in 1956~ 2002, the runoff of Hukou hydrological station accounted for more than 20% of runoff of Datong hydrological station in the same period. Hukou hydrological station was one of the major water sources of Datong hydrological station. In September, the runoff ratio was only 9.74%. From December to January, Yangtze River was in the extreme dry season. Because the water level of Poyang Lake was very low and the lake capacity was small, so water replenishment for the lower reaches was limited. In 2003 after the Three Gorges Project was put into operation, the inflow of Yangtze River decreased and the frequency of back flowing from Yangtze River into Poyang Lake also diminished. In 1956 ~ 2002, the minimum average flow of Hukou hydrological station was -1,350

m^3/s, in 2003 ~ 2012 this value was -710 m^3/s, so the average back flowing flow decreased by 640 m^3/s. This indicates that because of flow reduction at the lower reaches caused by impoundment of Three Gorges Reservoir, the back flowing from Yangtze River into Poyang Lake became less frequent.

After the Three Gorges Project was put into operation in 2003, the impoundment of Three Gorges Reservoir caused runoff decreased at the lower reach, and the replenishment water for Poyang Lake became scarcer. Compared with the annual average flow of 1956 ~ 2002, Hukou hydrological station had roughly same ratio of "annual average runoff" to "the annual average runoff of Datong hydrological station" in 2003 ~ 2012. This indicates that during the impoundment of control reservoir at the upper reach, because the decrease of main stream water level and annual runoff, the outflow of Poyang Lake increased.

5 Conclusion

In this paper, the runoff process of Hankou hydrological station after operation of Three Gorges Reservoir was restored, the natural runoff process of Hankou hydrological station in 1956 ~ 2012 was established, the IHAs alterations of Hankou hydrological station before and after operation of Three Gorges Reservoir were compared, and the medium IHAs alterations of the river section at Hankou hydrological station after operation of Three Gorges Project were identified. The analyses of hydrologic alterations of Hankou hydrological station, Hukou hydrological station and Datong hydrological station indicated that the runoff process of Datong hydrological station had gone through medium alteration. According to the statistics of Datong hydrological station, the annual average runoff of 2003 ~ 2012 was 6.1% less than that of 1956 ~ 2002; the maximum monthly average runoff decreased in all the months; and the minimum monthly average runoff increased in all months except May, September and October. According to the statistics of Hukou hydrological station, the annual average runoff of 2003~2012 was 6.6% less than that of 1956~2002; the maximum monthly average runoff decreased in September and October; and the minimum monthly average runoff increased in September and October. All these facts indicated that the coordinated regulation and impoundment of Three Gorges Project and the lakes at the middle and lower reaches of Yangtze River had effect of dry season water replenishment for the river course at the lower reaches and could alleviate the water deficiency at the middle and lower reaches of Yangtze River.

To explore the comprehensive benefits of control reservoirs at upper reaches of Yangtze River, water impoundment after flood season is inevitable. This will cause the decrease of river channel water level and the increase of outflow from the lake, which is one of the major reasons behind water deficiency of Poyang Lake area. For the concern of economic development and environmental protection of Poyang Lake area, to alleviate the impact of upper-reach hydro project's impact on the lakes of middle and lower reaches, and to realize harmonious co-existence between rivers and lakes, Three Gorges Reservoir and other reservoirs of the upper reaches shall bring forward the schedule of water impoundment, which can reduce letdown process and mitigate the impact of reservoir impoundment on the inflow of Poyang Lake area.

The hydrologic alterations of rivers and lakes at the middle and lower reaches of Yangtze River are influenced not only by regulation and impoundment of hydro projects at the upper reaches, but also by the natural precipitation in the lake area and activities of population in the proximity. This is a multi-factor complicated problem. The analysis of relationship between the middle and lower reaches of Yangtze River and Poyang Lake was based on the hydrologic alterations of the stations at upper and the lower reaches. The climate condition, human activities and other external factors were not taken into consideration, but shall be further studied in the future.

Acknowledgments

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