Alterational correlation analysis between the water level and the influencing factors of Hukou Station at Poyang Lake

B Xu¹, J J Xu¹,², L Q Yao¹, Z Yuan¹, Y R Lin¹ and L Song¹
¹Changjiang River Scientific Research Institute, 430010, Wuhan, China

E-mail: xujj07@163.com

Abstract. Poyang Lake plays a restricts and interacts role with Yangtze River, the key node of water resources connection between them is Hukou Station. The water level of Hukou Station reflects the inflow, precipitation, evaporation of Poyang Lake Basin and the backflow of the main stream of Yangtze River. Influenced by the climate change and human activities, the water level of Hukou Station appears of the inconsistency characteritics obviously, which induced abnormally low water level, ecological degradation of beach wetlands, and dramatic reduction of water storage capacity in Poyang Lake. In order to analyze the alterational correlation between the water level and the influencing factors of hukou station, and finding out the highest correlation factor, the Hydrological Alteration Diagnosis System was used to diagnose the alteration of water level of Hukou Station and the influencing factors. The results show that, the water level of Hukou station experienced a moderate alteration in a leap-down manner in 2003, and the mean value of the water level decreased 0.8m after the hydrological alteration; the influencing factors experienced different hydrological alteration with different form, the main alteration form is jump alteration, and there is no trend alteration happened in all the series; the alterational correlation between the water level of Hukou Station and Jiujiang Station is the highest, which means the mainstream flow of Yangtze River plays the most important role at the hydrological alteration of the water level of Hukou Station. The alterational correlation has a certain indicative role in analyzing the inconsistency evolution characteristics of Poyang Lake.

1. Introduction
Poyang Lake located in the mid-downstream of Yangtze River, which still remains its natural connection with it. Poyang Lake plays a interacts and restricts role with Yangtze River [1], and the water resources relationship between them has an impact on many aspects of drought risk management, flood disaster prevention, water ecological environment protection and water resources utilization, etc [2]. As the key node of water resources connection between Poyang Lake and Yangtze River, the water level of Hukou station is influenced by the hydrological factors such as runoff and evaporation in the Basin of Poyang Lake and the backflow of the main stream of Yangtze River. The change of water level at Hukou station reflects the evolution characteristics of water resources and the relationship between the lake and the river. In recent years, due to the impact of climate change and human activities, the spatial and temporal distribution regulations of water resources in Poyang Lake has changed, that induced a series of hydrological alteration problems such as abnormally low water level, ecological degradation of beach wetlands, dramatic reduction of water storage capacity in Poyang Lake, the occurrence of the dry season forward significantly, the duration of dry season significantly increased, etc [3]. Affected by the change above, the water level of Hukou station appears
of the inconsistency characteristics obviously. Finding out the influencing factors with the highest degree of correlation with the alteration of water level at the Hukou station, has a certain indicative role in analyzing the inconsistency evolution characteristics of Poyang Lake.

About the inconsistency characteristics of Poyang Lake, the study mainly focused on the influence of the change in the hydrological regime at the main stream of the Yangtze River to the hydrological regime of Poyang Lake. Based on the data analysis from 2004 to 2008, Guo Hua et al [4] concluded that the large amount of water storage in the Three Gorges Reservoir in October, resulting in the decrease of the discharge of the Yangtze River, which significantly weakens the influence of the Yangtze River on the water level of Poyang Lake. The coupled hydrodynamic model of rivers and lakes in the middle steam of the Yangtze River was used by Wang Yingchun et al [5], and the results shown that the water level of Duchang Station in Poyang Lake will be reduced by 0.09-1.11 m due to the impoundment of the Three Gorges Reservoir. Fang Chunming et al [6] predicted that the dry season of Poyang Lake would be advanced by about one month under the combined action of impoundment and river erosion with the operation of the Three Gorges Reservoir. The study of sediment deposition changes with the influence of the operation of the Three Gorges Project in Poyang Lake and main stream of the Yangtze River was carried out by Hu [7] and Zhu [8], the results shown that the operation of the Three Gorges Project reduced the speed and quantity of sediment deposition in Poyang Lake, and caused the intensification of river erosion. Xu [9] considered that the water level of the Three Gorges Reservoir at the end of flood season (October-November) would decrease by 0.4-1.6 m, resulting in a corresponding decrease of 0.3-1.2 m in the water level of Poyang area.

In summary, many researchers take the operation of the Three Gorges Reservoir as the key factor of the inconsistent change of the hydrological elements of Poyang Lake, but there is few analysis of other hydrological elements that influencing the water level of Poyang Lake; at the same time, there is few analysis of alterational correlation among the influencing factors. In view of the problems above, the Poyang Lake’s water level was taken as the research object, the Hydrological Alteration Diagnosis System was used to detect the hydrological alteration of the inflow runoff, precipitation, evaporation and the main stream runoff of the Yangtze River, and then based on the key factor analysis of alteration in the hydrological series to analyze the alterational correlation with the influencing factors and water level of Hukou station at Poyang Lake.

2. Study area and methodology

2.1. Study area
Poyang Lake is the largest surface water lake in China, which is located at the middle stream of the Yangtze River and the north of Jiangxi Province, the basin area is 162,200 km². It adopts the incoming water major from five rivers: Raohe, Xiushui, Ganjiang, Fuhe, Xi’anjian and other small tributaries, such as Zhangtian and Boyang rivers. The water from Poyang Lake flow into the Yangtze River at Hukou Station, as figure 1 shows below.
2.2. Database

The precipitation data comes from China Meteorological Data Network, which includes 14 stations of Ganzhou, Suichuan, Jinggangshan, Guangchang, J’ian, Nanchang and Yichun, etc. The monthly and annual surface precipitation in the Poyang Lake Basin are counted by Tyson polygon method.

Using daily temperature, wind speed, sunshine and relative humidity, combined with the Penman-Monteith method recommended by FAO, potential evapotranspiration data of 14 stations were calculated. Monthly and annual potential evaporation of Poyang Lake Basin were counted by Tyson polygon method. The time duration of Ganzhou and other 14 stations is shown in table 1.

| NO. | Station       | Time duration | NO. | Station     | Time duration |
|-----|---------------|---------------|-----|-------------|---------------|
| 1   | Ganzhou       | 1951-2013     | 8   | Zhangshu    | 1957-2013     |
| 2   | Suichuan      | 1951-2013     | 9   | Guixi       | 1953-2013     |
| 3   | Jinggangshan  | 1959-2013     | 10  | Nanchang    | 1951-2013     |
| 4   | Guangchang    | 1954-2013     | 11  | Yushan      | 1951-2013     |
| 5   | J’ian          | 1952-2013     | 12  | Boyang      | 1955-2013     |
| 6   | Nancheng      | 1953-2013     | 13  | Xiushui     | 1953-2013     |
| 7   | Yichun        | 1953-2013     | 14  | Jingdezhen  | 1953-2013     |

Based on daily runoff data, the monthly and annual runoff of Waizhou, Meigang, Lijiadu, Hushan, Shizhen Street, Dufeng Keng, Wanjiabu and Qiujin in the Basin of Poyang Lake were compiled as the
inflow sequence of Poyang Lake.

Considering the flow from the upper stream of Yangtze River will affect the outflow of Poyang Lake, Jiujiang Station, which is nearest to Hukou, is used as the representative station of the Yangtze River mainstream. The monthly and annual average flow data of Jiujiang Station are obtained by compiling daily flow data. The time duration of Poyang Lake and Jiujiang Station of Yangtze River is shown in Table 2.

| NO. | River/lake | Station | Time duration   |
|-----|------------|---------|-----------------|
| 1   | Ganjiang  | Waizhou | 1955-2013       |
| 2   | Xinjiang  | Meigang | 1953-2013       |
| 3   | Raohe     | Hushan  | 1953-2013       |
|     | Shizhenjie|         | 1957-1998       |
| 4   | Fuhe      | Lijiadu | 1955-2013       |
| 5   | Xiushui   | Wanjiabu| 1955-2013       |
| 6   | Poyang Lake|        | Hukou 1950-2013 |
| 7   | Yangtze River | Dufengkeng | 1988-2013 |

2.3. Hydrological alteration diagnose system

The hydrological series mainly contains stochastic and definite composition, and the definite composition contains jump, tendency and circle elements. If the physical causes have not change with time, the definite composition will have no influence to the hydrological series, and in the time scale, the hydrological series is consistent and the hydrological data fluctuates in random around the mean value, which means no alteration happened in statistical regulations. Otherwise, the statistical regulations of hydrological series are inconsistent, which means the physical causes and parameters of hydrological series changed in time scale. So the hydrological alteration means the distribution style and parameters of hydrological series are changed obviously in the statistical scale [10].

The methods, such as Sliding T Test, Sequential Cluster etc. used to detect the jump alteration, the methods of Kendall Rank Correlation Test, Spearman Rank Correlation Test etc. used to detect the trend alteration. Based on the utilization of methods above, XIE [11] put forward the Hydrological Alteration Diagnosis System (HADS) at 2010. In this system, the trend and jump alteration could be diagnosed comprehensively. The HADS contains 3 sections, Preliminary Diagnose (PD), Detailed Diagnose (DD) and Comprehensive Diagnose (CD).

In the section of PD, HADS uses the Hurst Coefficient Analysis, Sliding Average Analysis and Hydrograph Analysis to detect the hydrological alteration exist or not, and considering the correlation within Hurst coefficient and Fractional Brownian Motion parameter to decide the degree of hydrological alteration.

In the section of DD, the Spearman Rank Correlation, Linear Correlation Coefficient methods etc. are used to diagnose the trend alteration, the Rank Sum Test, Brown-Forsythe methods etc. are used to diagnose the jump alteration. If the jump alteration or trend alteration was diagnosed in the hydrological series, the section of CD will be activated.

In the section of CD, comprehensive jump and trend diagnose would be achieved. Based on coefficient of efficiency, the fitting degree of trend or jump proportion in the hydrological series will be estimated, and the better coefficient of efficiency will be taken as the hydrological alteration result. By actual conditions analysis and investigation, the hydrological alteration style conclusion could be confirmed at last.

3. Alteration diagnose of time series

3.1. Hukou station

With the first confidence degree α=0.05 and the second confidence degree β=0.01, the hydrological alteration diagnosis results by HADS were shown in Table 3.

The result shows that, there is a moderate decrease jump alteration happened in the water level
The series of Hukou station, and the jump alteration point is the year of 2003.

### Table 3. Series of Annual average water level alteration diagnose results of Hukou station.

| Hydrological elements | water level of Hukou |
|-----------------------|----------------------|
| PD Hurst coefficient  | 0.753                |
| Total alteration degree | middle            |
| Bayesian analysis     | 2003(+)             |
| R/S analysis          | 1987(0)             |
| Sequential Cluster    | 2003(0)             |
| Brown-Forsythe        | 2003(-)             |
| Sliding F Test        | 1958(-)             |
| Sliding Run Test      | 1958(-)             |
| Sliding Rank-Sum Test | 2003(+)             |
| Sliding T Test        | 2003(+)             |
| Optimal information two segmentation | 1999(0) |
| Lee-Heghinan          | 2005(0)             |
| Mann-kendall          | 1967(+)             |
| Tendency diagnose     | -                   |
| Kendall               | -                   |
| Spearman              | -                   |
| Relevant coefficient method | -       |
| Tendency alteration degree | -            |
| CD Jump               | 2003(+)             |
| Jump point            |                    |
| Comprehensive weight  | 0.61                |
| Comprehensive significant | 2(+)           |
| Tendency Compare      | 3(-)                |
| Efficiency coefficient |                    |
| Jump                  | 10.87               |
| (%)                   |                     |
| Tendency              | 0.02                |
| FINAL result          | 2003(+)             |

Notes: the “+”, “-”, “0”, “↑”, “↓” means significant, not significant, could not be tested, decrease and increase. Same below.

#### 3.2. Influence factors time series

Under the same degree of confidence, the yearly series from January to December and Annual average series of water level of Hukou Station, precipitation, evaporation and inflow of Poyang Lake Basin, flow of Jiujiang Station were diagnosed by HADS. The concise alteration diagnose results were shown in table 4.

### Table 4. Concise alteration diagnose results of influence factors.

| Yearly series | Water level of Hukou | Basin precipitation alteration & results | Basin evaporation alteration & results | Basin inflow alteration & results | Jiujiang Station alteration & results |
|---------------|----------------------|-----------------------------------------|---------------------------------------|-------------------------------|--------------------------------------|
| Jan.          | 1982(+)?             | 1988(+)?                                | 1968(+)?                              | 1988(+)?                       | 1982(+)?                            |
| Feb.          | 1988(+)?             | none alteration                         | 1963(+)?                              | none alteration                | 1980(+)?                            |
| Mar.          | 1979(+)?             | none alteration                         | 2000(+)?                              | 1979(+)?                       | 1979(+)?                            |
| Apr.          | 1998(+)?             | none alteration                         | 2001(+)?                              | none alteration                | 1998(+)?                            |
| May           | 1977(+)?             | none alteration                         | none alteration                       | 1958(+)?                       | 2003(+)?                            |
| June          | none alteration      | 1991(+)?                                | none alteration                       | none alteration                |                                     |
| July          | 2003(+)?             | none alteration                         | 1965(+)?                              | 1965(+)?                       | 2003(+)?                            |
| Aug.          | none alteration      | 1993(+)?                                | 1979(+)?                              | 1992(+)?                       |                                     |
| Sept.         | none alteration      | 1961(+)?                                | 1969(+)?                              | 1978(+)?                       |                                     |
The result above shows the monthly and annual water level of Hukou station and the influencing factors experienced different alteration with different form, the main alteration form is jump alteration, and there is no trend alteration happened in all the series.

4. Alterational correlation analysis
Based on the hydrological alteration diagnose results of water level of Hukou Station, the alterational correlation with precipitation, evaporation and inflow of Poyang Lake Basin, flow of Jiujiang Station could be calculated as follows:

Step 1: Alteration form correlation. As the alteration form could be divided into none alteration, jump alteration and trend alteration, the alteration form correlation could be defined as the alteration with the same form. For the alteration form of jump, it contains two elements, the alteration year and the alteration tendency.

Step 2: Weight of alteration correlation. If the different time series have the same alteration form, the assignment of alteration correlation weight is 1.0. If the alteration form is jump alteration, but only the alteration year or the alteration tendency has the same alteration form, the assignment of alteration correlation weight is 0.5.

As the steps above, the alterational correlation between the water level of Hukou Station and its influencing factors were calculated, the results were shown in table 5.

### Table 5. Alterational correlation between the water level of Hukou Station and its influencing factors.

| Items       | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual | sum |
|-------------|------|------|------|------|-----|------|------|------|-------|------|------|------|--------|-----|
| Precipitation | 0.5  | 0.0  | 0.0  | 0.0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.5   | 0.0  | 0.0  | 0.0  | 0.5    | 0.0  | 1.5   |
| Evaporation  | 0.0  | 0.0  | 0.5  | 0.0  | 0.0 | 1.0  | 0.5  | 0.0  | 0.0   | 0.0  | 0.0  | 0.0  | 0.5    | 0.0  | 2.5   |
| Inflow       | 0.5  | 0.0  | 1.0  | 0.0  | 0.5 | 1.0  | 0.0  | 0.0  | 0.5   | 0.0  | 0.0  | 0.5  | 0.0    | 0.0  | 4.0   |
| Jiujiang     | 1.0  | 0.5  | 1.0  | 1.0  | 0.5 | 1.0  | 1.0  | 1.0  | 1.0   | 1.0  | 1.0  | 1.0  | 1.0    | 1.0  | 11.0  |

From the results in table 5, the alterational correlation between the water level of Hukou Station and Jiujiang Station is the highest, which means the mainstream flow of Yangtze River plays the most important role at the hydrological alteration of the water level of Hukou Station.

5. Conclusions and discussion

5.1. Conclusions
In this paper, the water level series in Hukou Station and its influencing factors, including precipitation, evaporation, inflow of Poyang Lake Basin, and the mainstream flow of Yangtze River were diagnosed by the HADS. Based on the alteration forms, the alterational correlation between water level of Hukou Station and its influencing factors was calculated. By the study results above, the following conclusions are drawn:

- There is a moderate decrease jump alteration happened in the water level series of Hukou station, and the jump alteration point is the year of 2003.
- The monthly and annual water level of Hukou station and the influencing factors experienced different alteration with different form, the main alteration form is jump alteration, and there is no trend alteration happened in all the series.
- The alterational correlation between the water level of Hukou Station and Jiujiang Station is
the highest, which means the mainstream flow of Yangtze River plays the most important role at the hydrological alteration of the water level of Hukou Station.

5.2. Discussion
There are still existing some problems need to be studied in the next step.
- The alterational correlation between the water level of Hukou Station and its influencing factors only show the qualitative relationship, but the quantitative relationship should be studied next step.
- The weight of alteration correlation should be reflected with the characteristics of different alteration form, and the value of weight should be studied further more.

Acknowledgments
This work is funded by the National Key Research and Development Program of China (2017YFC0405300, 2017YFC0405304); the National Natural Science Foundation of China (No. 41890822; 51801043); National Public Research Institutes for Basic R & D Operating Expenses Special Project (CKSF2017061; CKSF2017057; CKSF2016023/SZ). Special thanks are given to the anonymous reviewers and editors for their constructive comments.

References
[1] Wan R R, Yang G S, Wang X L et al 2014 Progress of research on the relationship between the Yangtze River and its connected lakes in the middle reaches J. Lake Sci. 26 1-8
[2] Yang G S 2012 Water issues in the yangtze river and its formation causes and controlling strategies Resources Environ. Yangtze Basin 21 821-30
[3] Xu B and Chen G C 2018. Inner-annual allocation evolution research on flow backward of Poyang Lake in the changing environment J. Yangtze River Sci. Res. Inst. 35 30-5
[4] Guo H, Hu Q and Zhang Q 2011 Changes in hydrological interactions of the Yangtze River and the Poyang Lake in China during 1957-2008 Acta Geog. Sinica 66 609-18
[5] Wang Y C, Lai X J, Jiang J H et al 2011 Effect of the three gorges reservoir on the water regime of the lake Poyang wetlands during typical water regulation period J. Lake Sci. 23 191-5
[6] Fang C M, Cao W H, Mao J X et al 2012 Relationship between Poyang Lake and Yangtze River and influence of three georges reservoir J. Hydr. Eng. 43 175-81
[7] Hu C H and Wang Y G 2014 Sediment problems and relationship between river and lakes since the operation of three gorges project J. Yangtze River Sci. Res. Inst. 31 107-16
[8] Zhu L L, Chen J C, Yuan J et al 2014 Sediment erosion and deposition in two lakes connected with the middle Yangtze River and the impact of three gorges reservoir Adv. Water Sci. 25 348-57
[9] Xu J J and Chen J 2013 Study on the impact of three gorges reservoir on Poyang Lake and some proposals J. Hydr. Eng. 44 757-63
[10] Xie P, Xu B, Liu Y and Liu J J 2013 Key factor analysis of alteration in the hydrological series on time scale J. Hydr. Eng. 32 24-30
[11] Xie P, Chen G C, Lei H F et al 2010 Hydrological alteration diagnosis system J. Hydr. Eng. 1 85-91