

Effects of the human activities on the water level process of the Poyang Lake

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Abstract. The hydrological cycles in basin is profoundly affected by human activities. Yangtze River is a world class river with complex river-lake relations in the middle reaches. As the Three Gorges Reservoir (TGR) and other controlled reservoirs in the main stream and tributaries have been put into operation, the water regimes of the main stream in the middle reaches and Poyang Lake have been changed by water impounding and sediments trapping, clean water discharged from reservoirs, accelerating the evolution of the relationship of river and lake. After entering the 21st century, autumn droughts become more serious in Poyang Lake basin; the relationship between river and lake becomes tense. In light of the hydrological data in Poyang Lake since 2000s, this article made quantitative analyses of the influences of the human activities on the variation of the Poyang Lake level by authors. The results indicate that the main stream of Yangtze River, particularly the regulation of Three Gorges Reservoir, exerts a profound influence on the variation process of the Poyang Lake level. The regulation influence of the Upper Reach of the Yangtze River's Reservoir Group (URYRRG) could spread to Tangyin area in the middle of the lake in October.

1. Introduction

The enhancement of climate changes and human activities leads to the underlying surface change of the big river, altering basin runoff process [1]. It is surely that the evolution of the relationship between Yangtze River and Poyang Lake accelerated after the Three Gorges Reservoir (TGR) and other controlling reservoirs in the main stream and tributaries, which have been put into operation. Poyang Lake closely related with Yangtze River. The contrast relation of the total runoff from "Five Rivers" and the discharge at Hukou station adopted to define the interaction of Poyang Lake and Yangtze River [2]. The interaction intensity of Yangtze River and Poyang Lake is waxing and waning. From the perspective of seasons, Poyang Lake exerts a stronger effect on Yangtze River in April-June, whereas, Yangtze River yields a larger influence on Poyang Lake in July-September. It is used as the coefficient of water exchange between river and lake to express its intensity, that the ratio of the runoff from the tributaries into a lake to the runoff outlet from the lake, in order to make the analyses of the interaction process of Yangtze River and Poyang Lake in different years [3]. The scholars made the quantitative analyses of the conditions for Blocking Effect and Water Flowing Backward (WFB) effect of Yangtze River and the coefficient of the flood control effect of Poyang Lake [4]. In addition, the studies showed that how the evolution of river-lake relationship has been going on under the impacts of the variation of discharge capacity through the waterway of main stream of Yangtze River and the change of the inflowing water quantity and the water level of Poyang Lake [5].

As TGR and other controlled reservoirs in the upstream of Yangtze River put into operation progressively, the flood-prevention situations in middle-lower reaches have been improved significantly. Nonetheless, autumnal droughts occurred frequently in Poyang Lake region in recent years, thus it led to the changes of the material and energy exchange between Yangtze River and Poyang Lake,



the relationship between river and lake is growing increasingly tense. The decrease of the precipitation in “Five Rivers” basin, the low water level of the main stream of Yangtze River, the regulation of hydrological projects and the increase of industrial and agricultural water usage contribute to the relatively high frequency of the occurrence of droughts in Poyang Lake [6]. In addition, in normal years, autumn drought phenomenon in Poyang Lake caused by the less runoff from the upper reach of Yangtze River along with the low water level of the main stream and the increase of the discharge at Hukou station. The operation of Three Gorges Dam (TGD) has certain impact on the water level of Poyang Lake in dry season [7], whereas the results of the study using physical simulation models shows there is little influence [8]. Additionally, the lake basin enlarged by human sand excavation activities in Poyang Lake region; particularly the scouring is serious in the waterway region where the water flows into the river, it will certainly exert influence on the water level of Poyang Lake [9], and so forth. As is shown, the influence of the operation of TGD on the water level variation process of Poyang Lake should further researched in this paper.

2. Research area

Poyang Lake is the largest freshwater lake in China, situated in the north of Jiangxi Province. It is located at 115°49′ E~116°46′ E and 28°24′ N~29°46′ N, and at the junction of the middle-lower reaches of Yangtze River (Figure 1). Poyang Lake is an important lake of regulation and storage type in the middle-lower reaches of Yangtze River with single outlet connected to Yangtze River, flowing into Yangtze River at Hukou County. Poyang Lake absorbs runoff from “Five Rivers” (Gan River, Fu River, Xin River, Rao River, and Xiu River) and its own lake area, and discharges water into Yangtze River at Hukou. Poyang Lake basin, surrounded by mountains, with hills in the middle, is a complete water system. The south is higher than the north part, and the surrounding leans to the lake. The drainage area is $16.2 \times 10^4 \text{ km}^2$, accounting for 9% of Yangtze River and 94% of Jiangxi Province.

The water level of Poyang Lake is affected jointly by “Five Rivers” and the main stream of Yangtze River, the annual variation of the Poyang Lake level is complicated; nevertheless, there still have been rules to follow. The dry period of Poyang Lake is in October-next March; the wet period is in April-September. The annual maximum of the lake level usually occurs in July-August, the minimum is in January-February (Figure 2). After entering the every main flood season, the runoff from “Five Rivers” soars, leading to the increase of the lake level month by month. In July-September, Yangtze River enters main flood season, the water level of the main stream of Yangtze River is increased, even higher than the water level of Poyang Lake. The blocking effect of the water from the main stream in the middle reach of Yangtze River on the outflow from Poyang lake is ever increasing, which makes the outflow from the lake at Hukou decreased and sometime even makes the water from Yangtze River flow backward to Poyang Lake, hence the Poyang Lake level is rising and high. And the lake level is reduced gradually until “Five Rivers” basin enters dry season in September. Afterwards, the main stream of the Yangtze River also enters dry season, the water level of Poyang Lake falls rapidly.

3. Data and methods

3.1 Data collection

The paper collected hydrological data at Hukou, Xingzi, Duchang, Tangyin gauging stations. In light of these hydrological data since 2000, the effects of the human activities on the process of the Poyang Lake level will be studied to systematically explore the general principles of the interactions between river and lake.

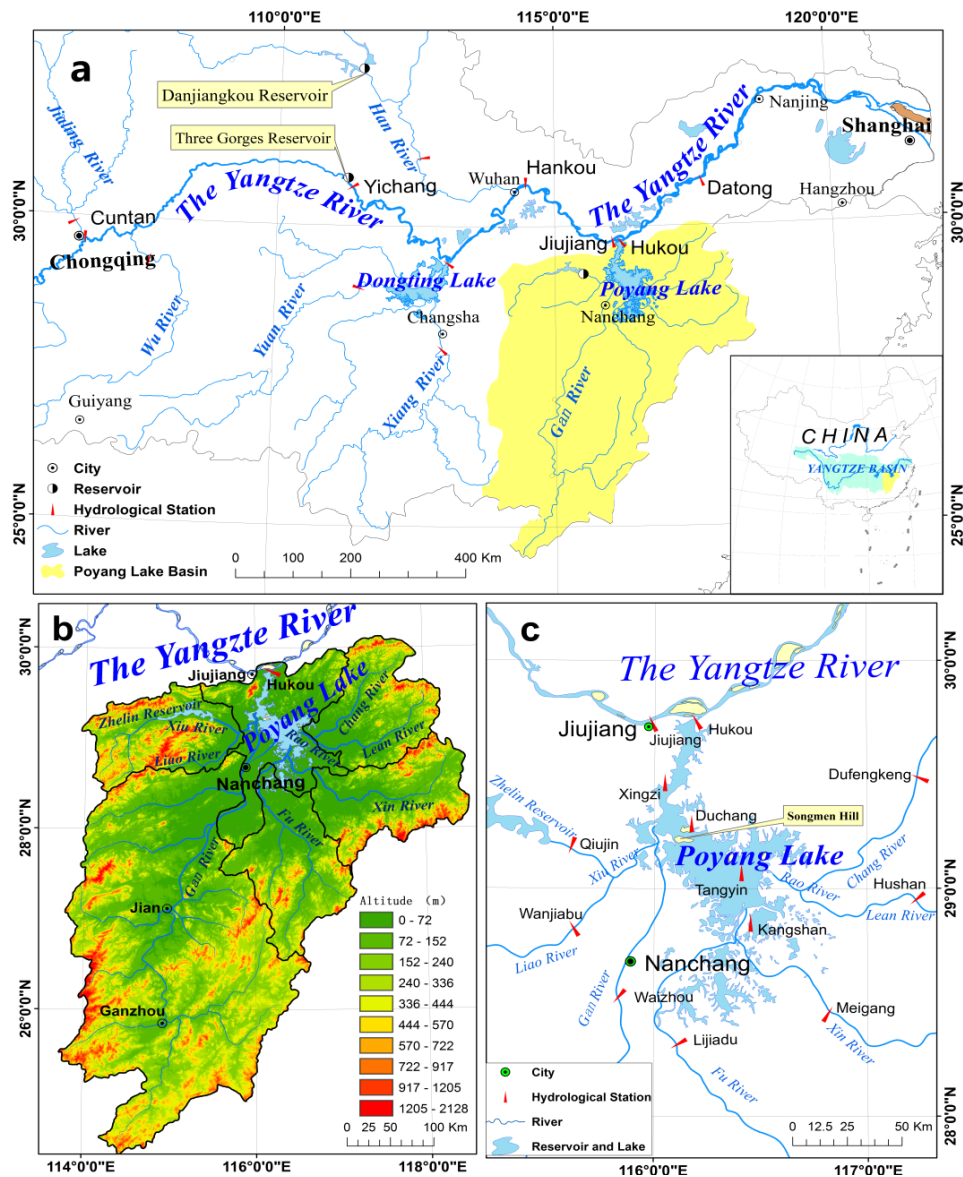


Figure 1. Diagram of Poyang Lake and Yangtze River Water System.

3.2 Main research methods

3.2.1 Mann-Kendall Statistical Method

As for a sequence with n samples x_1, x_2, \dots, x_n , M-K method defines the statistic S

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^n \text{sign}(x_k - x_j) \quad (1)$$

$$\text{sign}(x_k - x_j) = \begin{cases} 1 & x_k - x_j > 0 \\ 0 & x_k - x_j = 0 \\ -1 & x_k - x_j < 0 \end{cases} \quad (2)$$

thereinto $\text{sign}()$ is sign function, x_j, x_k are the corresponding variables of j, k respectively, and $k > j$,

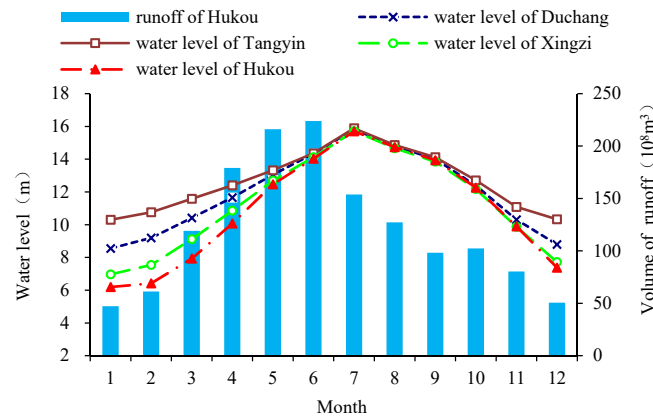


Figure 2. The annual variation processes of the Poyang Lake level and runoff at Hukou.

$$Var(s) = \frac{n(n-1)(2n+5)}{18} \quad (3)$$

$$M = \begin{cases} (s-1)/\sqrt{Var(s)} & s > 0 \\ 0 & s = 0 \\ (s+1)/\sqrt{Var(s)} & s < 0 \end{cases} \quad (4)$$

In formula (4), M is one statistic following normal distribution, positive value shows the original sequence is rising, and negative value indicates original sequence is declining. Significance test is carried out at the given significance level. When the absolute value of M is greater than or equal to 1.96 and 2.56, it expresses that the significance level tests at 95% and 99% confidence levels pass respectively [10].

3.2.2 Rescaled Range Analysis Method (R/S)

Considering a time series $\{t\}$, $t=1, 2, 3, \dots, n$, and any positive integer $\tau \geq 1$, define one means sequence

$$(E\xi)_\tau = \frac{1}{\tau} \sum_{t=1}^{\tau} \xi(t), \quad \tau = 1, 2, 3, \dots, n \quad (5)$$

$X(t)$ represents accumulative deviation,

$$X(i, \tau) = \sum_{t=1}^i \xi_t - i(E\xi)_\tau, \quad 1 \leq i \leq \tau \quad (6)$$

The range R is defined as

$$R(\tau) = \max_{1 \leq i \leq \tau} X(i, \tau) - \min_{1 \leq i \leq \tau} X(i, \tau), \quad \tau = 1, 2, 3, \dots, n \quad (7)$$

The standard deviation S is defined as

$$S(\tau) = \left\{ \frac{1}{\tau} \sum_{i=1}^{\tau} [\xi_i - (E\xi)_\tau]^2 \right\}^{\frac{1}{2}}, \quad \tau = 1, 2, 3, \dots, n \quad (8)$$

$$\frac{R(\tau)}{S(\tau)} = (a\tau)^H \quad (9)$$

In Hurst studies, the range of H belongs to $[0, 1]$. When $H=0.5$, the sequence is random and uncorrelated, the future won't be affected by the past and the present, and the original sequence has no trend. When $H>0.5$, means that the trend of the future sequence will be the same as the past, the closer to 1 the value of H is, the stronger the persistence will be. When $0 \leq H < 0.5$, the time sequence has counter-trend, namely, the overall trend of the future variation is opposite to the past, and the closer to 0 the value of H is, the stronger the anti-persistence will be [11].

4. Interannual variation characteristics of the Poyang Lake level

The authors focus on the characteristics of the variations of the Poyang Lake level to reveal the effects of the regulation of the Upper Reach of the Yangtze River's Reservoir Group (URYRRG), of course, the main reservoir is TGR, and human sand excavation activities on the water level of Poyang Lake after entering the 21st century in this paper.

4.1 Interannual variation process of observed water level

Xingzi station is taken as an instance to make the analyses of the interannual variation process of the water level of Poyang Lake. Firstly, the interannual process of the Poyang Lake level in 1955-2015 fluctuated, with the maximum of the annual averaged water level higher than 13.5m (1988), and the minimum lower than 9.0m (2011), differing by more than 4m. There was no obvious trend before 2000, and there has been an apparent decrease trend of the water level since 2000 (Figure 3 (a)). Secondly, the water levels decrease in stages in 1955-2015 (Figure 3 (a)). The average was 11.47m before 2000, 10.43m in 2006-2015, which was a large difference. The water levels in flood and dry seasons had similar variation process and phase characteristic (Figure 3(b)). In a word, the interannual variation of the Poyang Lake level has a decrease trend in whole year, flood and dry seasons ever since 2000, particularly significant in 2006-2015, there may be relations with the regulation of URYRRG and the blocking influence of the main stream of Yangtze River.

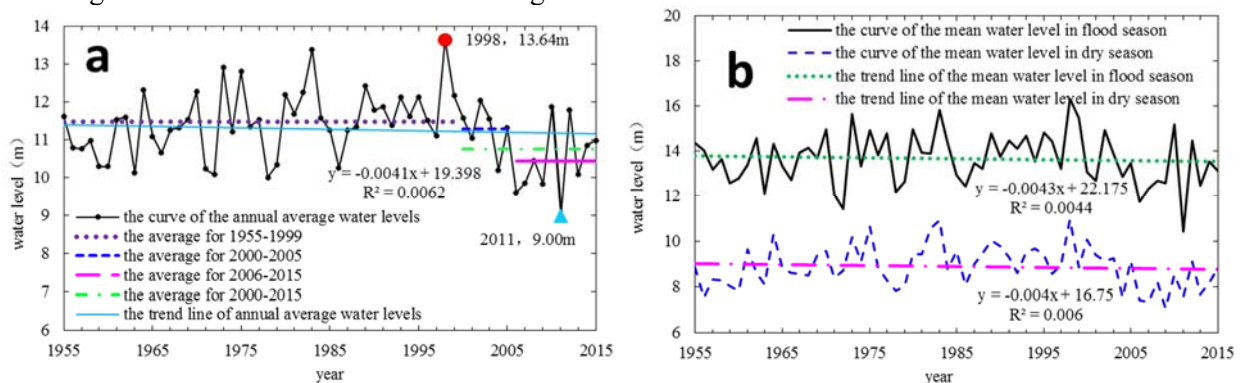


Figure 3. The interannual variation process of the water level at Xingzi station.

4.2 Trends of the interannual variation of water level

The research focuses on the water levels of the interior lake and Waterway of Runoff into the Yangtze River (WRYR) at different periods during 1950s-2015 in order to make a more comprehensive and accurate analysis of the variation continuity of the Poyang Lake level. The averages of water levels in January (lowest water level month), July (highest water level month), October (impounding period of TGR), whole year, flood season and dry season, spring, summer, autumn and winter are analyzed. The results were showed in Table 1.

Firstly, from H values in Table 1, H values show that whether the sequences have persistence, H values at Hukou, Xingzi and Duchang stations in winter are relatively larger, higher than 0.8, namely, $0.846 < H_{Hukou} < H_{Xingzi} < H_{Duchang}$. The annual variation of H values at three stations follows one common rule: The value in winter is largest followed by the $0.737 < H_{Dry\ season} < H_{January} < H_{Winter}$. We can see that the value value in January, with that in dry season behind, that is, of the average water level in whole year is above 0.7, which shows that the annual average water level of Poyang Lake has certain continuity. It is strongest in winter.

Secondly, from the M values in Table 1, the M values, flood and dry seasons, spring, autumn and October at four stations (Hukou, Xingzi, Duchang and Tangyin gauging station) are negative, which indicate the water levels have a decrease trend during the corresponding periods. M values in October at four stations are negative, reaching the significance level, $\alpha = 0.01$. It indicates the water level in October has an obvious decrease trend, which might relate to the impounding of URYRRG (TGR). The

M value at Hukou in autumn is negative and achieves the significance level, $\alpha=0.05$, manifesting the water level at Hukou in autumn has a significant decrease trend. M values at Hukou and Xingzi stations are positive in the driest time: in winter and in January, whereas, the values at Duchang and Tangyin stations are negative in the same periods. This difference illustrates WRYR level of Poyang Lake has an increase trend. The decline trend of the interior lake level is less obvious in winter and in January, inversely. The situation shows there are opposite trends of the water level variations of WRYR and interior lakes in Poyang Lake in winter and in January. We know that the water levels of Poyang Lake influenced jointly by Five Rivers, the main stream of Yangtze River, and other factors. In winter and January, the regulation of URYRRG leads to the corresponding increase of the volume of runoff and the elevated water level in lower reach, hence the hindering effect of Yangtze River is stronger at Hukou, resulting in the increase trend of the WRYR level of Poyang Lake after entering the 21st century. In contrast, the water levels at Duchang and Tangyin stations in the interior lake has the opposite tendency, it is possibly related to human sand excavation activities and the coming water of Five River.

Table1. The trends statistics of the interannual variation of the Poyang Lake level

Gauging station	Statistical Item	January	July	October	Whole Year	Flood Season	Dry Season	Spring	Summer	Autumn	Winter
Hukou	H value	0.7507	0.7087	0.7076	0.7340	0.6747	0.7374	0.6876	0.7039	0.5994	0.8462
	M value	2.25	0.66	-3.21	-0.59	-0.54	-0.17	-0.43	0.23	-2.24	1.75
	Trend	↑*	↑	↓**	↓	↓	↓	↓	↑	↓*	↑
Xingzi	H value	0.8028	0.6968	0.7183	0.7651	0.7065	0.7759	0.7167	0.6858	0.6101	0.9048
	M value	1.15	0.36	-2.56	-0.34	-0.45	-0.29	-0.50	0.11	-1.33	1.19
	Trend	↑	↑	↓**	↓	↓	↓	↓	↑	↓	↑
Duchang	H value	0.8207	0.6929	0.6986	0.7848	0.7082	0.7808	0.6855	0.6849	0.5863	0.9256
	M value	-0.95	-0.09	-3.02	-1.24	-0.91	-1.72	-1.68	-0.28	-1.71	-1.02
	Trend	↓	↓	↓**	↓	↓	↓	↓	↓	↓	↓
Tangyin	H value	0.7642	0.7343	0.6151	0.7142	0.6582	0.6254	0.6989	0.6834	0.5525	0.6949
	M value	-0.68	-0.74	-3.6	-1.1	-0.56	-1.85	-0.15	-0.2	-1.9	-0.24
	Trend	↓	↓	↓**	↓	↓	↓	↓	↓	↓	↓

Annotation: The sequence has a increase trend when M value is positive, representing it with the red symbol “↑”, and it has a decline trend when M value is negative, representing it with the blue symbol “↓”. When the absolute value of M is greater than or equal to 1.96 and 2.56, it expresses that the significance level tests that α equals 0.05 and 0.01 pass respectively; the sign * and ** indicates that the significance tests at 95% and 99% confidence levels pass respectively.

4.3 Spatial differences of the interannual variation

The spatial difference of the interannual change of the Poyang Lake level and its characteristics in the internal lake and WRYR are revealed at different gauging stations. Hence, it illustrates the spatial unbalanced situation of the impact factors of the water level, making a further introduction to the impacts of the main stream of Yangtze River and regulation of URYRRG on the water level of Poyang Lake.

From Table 1, we can see that in autumn, particularly in October, the interannual variation of the Poyang Lake level at Hukou, Xingzi, and Duchang has an obvious decrease and all reach to the significance level $\alpha=0.01$. The trends of the water level variation in the interior lake and WRYR are not consistent in winter, especially in January. These phenomena are involved with the main stream of Yangtze River and the regulation of URYRRG, and so forth.

5. The influence of human activities on water level of Poyang Lake

In recent decades, there is no decrease trend occurring to the precipitations and the runoffs in the upper-middle reaches of Yangtze River and in Poyang Lake basin, yielding no change of the trend variation of the Poyang Lake level [12]. Hence, this paper focuses on the discussion of the effects of human activities on the water level of Poyang Lake, including the regulation of URYRRG and human sand excavation.

5.1 The regulation of URYRRG

The construction of TGD was set up in 1994, with the water level increased to 135m in the initial impounding period in 2003, and the water level up to 156m on the second impounding period in 2006. TGD was completed in 2009 with the water level up to 175m in the experimental storage stage. In recent years, many reservoirs were completed in upper reach along the main trunk of the Yangtze River. It will exert influence on the water and sediment exchange between the river and the lake in the middle-lower reaches of Yangtze River. Water is impounded by URYRRG (including TGR) in September–October every year, and the discharge is increased in November–next April (the dry season), and the discharge will be enhanced in early June to spare capacity for flood prevention. The water level of Poyang Lake will be influenced by the regulation of URYRRG definitely.

5.2 Activities of human sand excavation

Since sand excavation activities forbidden in the main stream of Yangtze River, many dredging vessels entered Poyang Lake. According to the researches, under the impacts of human interventions such as massive afforestation and dam constructions in Poyang Lake basin, the water and sediment flowing into the lake decreased significantly. Sand excavation activities were concentrated in the WRYR area in 2001–2007 and converged in the internal lake afterward [13]. Under the influences of continuous sand excavation and water erosion, the average elevation of the WRYR has been reduced to 3.69m until 2010 [14]. Thus, the average of the Poyang Lake basin is declined by the unordered sand excavation activities, the lake capacity is increased, and the decline of the WRYR is particularly getting more serious. These factors are bound to affect the lake level, leading to the decrease trend of the water level in recent years.

5.3 Quantitative discussion the human activities effect on the Poyang Lake water level

According to the trends of the interannual variation of the Poyang Lake level discussed in the previous parts, the period 1950–2015 is divided into two stages: 1950–1999 and 2000–2015. In accord with the regulation effect of URYRRG, it is divided into two phases: 2000–2005 and 2006–2015. In 2000–2005, the construction of TGR project had not yet been completed. In 2006–2015, from the second phase water impounding of TGR until its completion, TGR has a stronger effect on the runoff regulation. Hence, URYRRG exerts a certain influence on the water level of Poyang Lake. For convenience, we use *I, II, III* and *IV* stands for the four phases 1950–1999, 2000–2015, 2000–2005 and 2006–2015 respectively.

There are two primary elements influencing the trend of Poyang Lake level since 2000, that is, human sand excavation activities in the lake region and the regulation effect of URYRRG. The water level of Poyang Lake is affected by human sand excavation activities in the whole year, whereas, the regulation of URYRRG on the water level is seasonal, and it has spatial difference; it primarily exerts effect on WRYR but has little influence in the interior lake area. The mean decreased value of the water level in dry season could be approximately regarded as the impacts of human sand excavation activities on the water level in recent years.

Thus the following formula is established.

$$\mu_{ij} = \begin{cases} \frac{II_i - I_i - M_{ij}}{N_{ij}} \times 100\% & (j = 1) \\ \frac{IV_i - I_i - M_{ij}}{N_{ij}} \times 100\% & (j = 2) \end{cases} \quad (10)$$

where μ_{ij} is the influence degree of the main stream of Yangtze River and the regulation effect of URYRRG on the Poyang Lake level. N_{ij} is the annual mean water level at i gauging station in Period j . M_{ij} is the decreased value of the water level caused by human sand excavation activities at i gauging station in Period j . Which M stands for the difference of the mean water levels in Period II and I in dry seasons. Where i stands for gauging station, $i = 1, 2, 3, 4$ stands for Hukou, Xingzi, Duchang and Tangyin gauging stations respectively. Where j is the period, $j = 1, 2$ are Period II and Period IV respectively.

Then,

$$\omega_{ij} = \frac{M_{ij}}{N_{ij}} \times 100\% \quad (11)$$

where ω_{ij} is the influence degree of human sand excavation activities on the water level of Poyang Lake.

We could use the formula (10) to calculate the influence of the main stream of Yangtze River and URYRRG on the water level of Poyang Lake as showed in Table 2. We could see that $|\mu_{11}| > |\mu_{21}| > |\mu_{31}|$ and $|\mu_{12}| > |\mu_{22}|$ in January, July, October, and in “high water level period”, and there is a rule of $|\mu_{12}| > |\mu_{22}| > |\mu_{32}|$ in January and October. Secondly, October is the water impounding time of URYRRG (including TGR), it is seen that there is the law $\mu_{i2} > \mu_{i1}$ at each station with the maximum of the absolute value of μ_{ij} reaching to 21.5%. There is the rule $\mu_{i2} > \mu_{i1}$ in the WRYR in January. It indicates that URYRRG yields a larger regulation effect on the Poyang Lake level, the regulation effect on the water level is particularly much larger in WRYR, even stretching to Tangyin, the middle of the lake (the influence degree reaches to -11.69%). Thirdly, the values of μ_{ij} at four gauging stations are positive in January, and while it is not as the same as Duchang station. The former shows the water level in January increased after 2000. In WRYR area, due to the regulation of URYRRG in January, the runoff of Yangtze River increased, and it exerts a stronger blocking effect at Hukou, causing the elevated water level. As for the latter one, under the influence of massive human sand excavation activities, the lake basin was decreased in Poyang Lake, leading to the decrease trend of the water level of the entire lake in “high water level period”, flood season, “highest-water-level month (July)”. While the outflow from the interior lake to WRYR was increased, the water level at Duchang is high and the flow here is large.

ω_{ij} is calculated by the formula (11), we use 2×4 matrix to express $[\omega_{ij}]$

$$\omega_{ij} = \begin{bmatrix} -3.43 & -6.13 & -9.06 & -4.42 \\ -6.42 & -10.26 & -14.87 & -6.76 \end{bmatrix}$$

The matrix $[\omega_{ij}]$ means the influence degree of human sand excavation activities on the water level of Poyang Lake. The data in the matrix shows ① $\omega_{ij} < 0$, ② $|\omega_{i2}| > |\omega_{i1}|$, ③ $|\omega_{1j}| < |\omega_{4j}| < |\omega_{2j}| < |\omega_{3j}|$. It is seen that firstly the effect of human sand excavation activities on the Poyang Lake level spreads to the whole lake region, only the degree is difference. Secondly, the influence degree on the water level is increasing with the accumulation of the human sand excavation amount after 2000. Thirdly, the effects of human sand excavation activities on the water level have spatial discrepancy in distribution. This phenomenon might be involved with the randomness and the control of artificial sand-excavating activities. According to the studies, in early stage, the sand excavation activities were in random, it was mainly concentrated in WRYR, later it has been primarily concentrated in the interior lake region under the interruption of the government. What's more, the phenomenon is associated with the flow scouring on the lake basin. Generally speaking, in recent years, human sand excavation activities exert a certain effect on the variation of the water level, and it covers the whole lake region, and the influence degree is different in local area. Except for the effects of artificial sand excavation activities, the influences of the main stream of Yangtze River and the regulation of URYRRG still play a leading role in the trend variation of the Poyang Lake level.

Table2. The influence degree of the main stream of Yangtze River on the variation of the Poyang Lake level (%)

Station	Period	January	July	October	High water level period	Average in flood season	Average in dry season	Annual average
Hukou	μ_{11}	6.57	-4.38	-15.98	-4.85	-3.62	/	-1.81
	μ_{12}	8.28	-3.31	-21.15	-5.26	-3.12	/	-1.56

Xingzi	μ_{21}	4.65	-1.95	-12.08	-1.67	-1.02	/	-0.46
	μ_{22}	5.56	0.48	-15.63	-0.67	0.67	/	0.29
Duchang	μ_{31}	1.42	0.44	-8.26	0.80	1.60	/	0.80
	μ_{32}	0.83	4.52	-10.34	3.42	4.62	/	2.31
Tangyin	μ_{41}	1.47	-5.07	-8.75	-2.62	-0.74	/	-0.33
	μ_{42}	1.75	-4.67	-11.69	-2.75	-0.25	/	-0.17

6. Conclusions

Under the combined impacts of the regulation of URYRRG and human sand excavation activities in Poyang Lake, the interannual variation of the water level of Poyang Lake has a decrease trend in phased during 2000-2015. The results of MK tests indicate there is an obvious increase trend of the water level at Hukou in January but the water level of the whole lake has a highly significant decrease trend in October.

Through the quantitative research of the effects of the main stream of Yangtze River and human sand excavation activities on the water level of Poyang Lake, the authors found that the decrease trend of the Poyang Lake level in recent years is mainly caused by the regulation of URYRRG. The regulation effect of URYRRG on the trend of water level is seasonal. It affects primarily the trend of water level of WRYR and it can spread to the middle lake area in the impounding period.

Acknowledgments

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References

- [1] S. Joshi and Y. J. Xu, Assessment of Suspended Sand Availability under Different Flow Conditions of the Lowermost Mississippi River at Tarbert Landing during 1973-2013. *Water*, vol.7, pp. 7022-7044, 2015.
- [2] Q. Zhang and A. D. Werner, Hysteretic relationships in inundation dynamics for a large lake–floodplain system. *Journal of Hydrology*, vol. 527, pp. 160-171, 2015.
- [3] J.K. Zhao, C.J. Jiang, G.H. Hua, et al., Quantitative Analysis on the Water Exchange between River and Lake: A Case Study in the Middle and Lower Reaches of the Yangtze River. FEEM 2013, 24-25 December 2013 Hong Kong, China. WIT Press, vol, 88, pp. 759-768, 2014.
- [4] Z.X. Zhang, X. Chen, C.Y. Xu, et al., Examining the influence of river–lake interaction on the drought and water resources in the Poyang Lake basin. *Journal of Hydrology*, vol. 522, pp. 510–521, 2015.
- [5] Q. Zhang, X.C. Ye, A.D. Werner, et al., An investigation of enhanced recessions in Poyang Lake: Comparison of Yangtze River and local catchment impacts. *Journal of Hydrology*, vol. 517, pp. 425–434, 2014.
- [6] X.J. Lai, J.H. Jiang, Q.H. Liang, Large-scale hydrodynamic modeling of the middle Yangtze River Basin with complex river–lake interactions. *Journal of Hydrology*, vol. 492, pp. 228–243, 2013.
- [7] L. Feng, X.X. Han, C.M. Hu, et al., Four decades of wetland changes of the largest freshwater lake in China: Possible linkage to the Three Gorges Dam? *Remote Sensing of Environment*, vol.176, pp. 43–55, 2016.
- [8] Huang X., et al., 2014. Forward stratigraphic modelling of the shallow-water delta system in the Poyang Lake, southern China. *Journal of Geochemical Exploration*, 144, 74–83.
- [9] J.H. Gao, J.I. Jia, A.J. Kettner, et al., Changes in water and sediment exchange between the Changjiang River and Poyang Lake under natural and anthropogenic conditions, China. *Science of the Total Environment*, vol. 481, pp. 542–553, 2014.
- [10] C.B. Fu and Q. Wang, The definition and detection of the abrupt climatic change. *Chinese Journal of Atmospheric Sciences*, vol. 16, pp. 482-493, 1992. (In Chinese)

- [11] H.Y. Bai, Q.L. Hou, X.P. Ma, J. Zhang, Hydrological Characteristic and Its Responses to Precipitation Change in Jinqian River Basin of Qinling Moutains During the Last 50 Years. *Scientia Geographica Sinica*, vol. 32, pp. 1229-1235, 2012. (In Chinese)
- [12] X.C. Ye, Q. Zhang, J. Liu, X.H. Li, C.Y. Xu, Distinguishing the relative impacts of climate change and human activities on variation of stream flow in the Poyang Lake catchment, China. *Journal of Hydrology*, vol. 494, pp. 83–95, 2013.
- [13] F. Jiang, S.H. Qi, F.Q. Liao, et al., Hydrological and sediment effects from sand mining in Poyang Lake during 2001-2010. *Acta Geographica Sinica*, vol. 70, pp. 837-845, 2015. (In Chinese)
- [14] G.P. Wu, Y.B. Liu, X.W. Fan, Bottom topography change patterns of the Lake Poyang and their influence mechanisms in recent 30 years. *Journal of Lake Sciences*, vol. 27, pp. 1168-1176, 2015. (In Chinese)