Flood Variation Analysis based on Chézy-manning Formula and HADS

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Abstract. River training works and upstream reservoir regulation are used to control flood in city, which protect people against flood disasters, change the relationship of river channel and subject it to climate change. In this study, the flood variation form of Xuanen County was analyzed by hydrological alteration diagnosis system (HADS) and Chézy-manning formula. The results showed that: the annual maximum daily flow series from 1962-2013 jumped a downward moderate variation in 1999, which indicated that flow was decreasing. Xuanen county river canalization result in decrease of the flood flow, exacerbating the variation of flood, thereby the flood warning plan need to adapt to the changing environment.

Keywords: HADS; Chézy-manning formula; Variation; Flood; Xuanen.

1. Introduction

Flood control is always a significant issue which is related to people's safety and the prosperity and decline of the nation through the ages [1]. In order to resist against flood, reservoirs and other hydraulic engineering projects have come into being, so that the basin surface conditions changed. Due to the influence of climate change and human activities, the formation and variation in regularity are changed and the consistency of flood series is destroyed, affecting the frequency and intensity of floods [2].

Xuanen County in Hubei province is located in a large flat valley bordering on both sides of the Zhongjian River whose upstream has Tongziying medium reservoir and Longdong medium reservoir, which plays a role in regulation for the flood upstream. Its downstream has Dongping large reservoir, whose backwater has a certain influence to midstream and downstream of the river. In August 1995, maximum flood flow of Longdong reservoir was about $1400m^3/s$, which affected 600 people and caused millions worth of damage [3]. In recent years, Xuanen County suffered heavy rains attacks and frequent flood disasters [4]. Therefore, channel improvement project of Xuanen County started in 2005, left bank project completed in 2009, and both sides of the river bank completed in 2012. After years of treatment, natural river course of Zhongjian River district section has been transformed into nearly parallel and regular on both sides, and the trend of the river remain unchanged before and after the river canalization.

In order to better reveal flood variation regularity of Xuanen district from statistical meaning and physical meaning, by combining the hydrological variation diagnosis system [5] with the measured annual maximum flow series from 1962 to 2013 in Xuanen station and the average annual maximum monthly rainfall series of Xuanen County from 1956 to 2010, the variation form and the degree of the flood series was calculated. And its cause analysis was conducted using Chézy-manning formula. The results not only is beneficial for the local flood variation countermeasure and water resource utilization, but also has great reference value on water conservancy project construction and flood control and disaster mitigation planning.

2. Methodology

2.1. HADS

There are definite composition and stochastic composition contained in the hydrological series, and the definite composition could be decomposed as circle, tendency and jump elements. The hydrological series is stationary if the circle, tendency and jump elements have nothing to do with it, which means the physical causes have no change as time goes on. The statistical regulations, such as the distribution style and parameters (*Cv*, *Cs* etc.), are consistent with no alteration in the time scale of the hydrological series and the hydrological data fluctuates in random based on the mean value. Otherwise, the hydrological series is non-stationary and statistical regulations are inconsistent, the physical causes and hydrological parameters were changed in the time scale of the hydrological series. Therefore, the definition of hydrological alteration in the statistical scale is the distribution style and parameters are changed obviously within the hydrological series.

There are many different methods to diagnose the hydrological alteration, the methods that used to diagnose the jump alteration such as Sequential Cluster, Rank-Sum Test, Sliding T Test etc. and the Spearman Rank Correlation Test, Kendall Rank Correlation Test etc. used to diagnose the trend alteration. However, the alteration situation is complex in the hydrological series because the alteration may happened in the elements of circle, trend and jump, the methods above could not diagnose the alteration comprehensively. Meanwhile, the classification of alteration degree is not considered in the hydrological series with alteration. In order to improve the methods above, XIE put forward the Hydrological Alteration Diagnosis System (HADS). This system could diagnose the trend and jump alteration, and it is composed of three parts, i.e. preliminary diagnose, detailed diagnose and comprehensive diagnose.

The method of Hydrograph Analysis, Sliding Average Analysis and Hurst Coefficient Analysis are used to diagnose whether the hydrological alteration exist or not in the process of preliminary diagnose, and based on the relationship between Hurst coefficient and the parameter of Fractional Brownian Motion to classify the degree of hydrological alteration, the principles of diagnosis and classification as follows.

The long-term relativity characteristics of temporal series could be described by the Hurst coefficient h. If h=0.5, the temporal series is random and the variation tendency is not impacted by now; if h is approaching to 1.0, it means the variation tendency of future is same to now and the durative of temporal series is positive; if h is approaching to 0.0, the situation is reverse. The stochastic feature of temporal series is disturbed by the long-term relativity and the alteration happens, and the farther the h deviated from 0.5, the more apparent the alteration is. Therefore, based on the Hurst coefficient h, the stochastic feature and alteration of temporal series could be diagnosed, and with the observation temporal series, the h could be calculated by the Rescaled Range Analysis method [6]. Fractional Brownian motion [7] was born with the combination of random process and fractal theory and it was put forward by Mandelbrot from the ordinary Brownian motion. The long-term relativity could be described by the motion parameter H, the relationship between H and correlation function $C(t)$ as follows [8]:

$$C(t) = -\frac{E\left[B_H(-t)B_H(t)\right]}{E\left[B_H(t)\right]^2} = 2^{2H-1} - 1 \tag{1}$$

XU et al. indicated that the motion parameter H is equivalent to Hurst coefficient h in logic and definition, so the correlation function $C(t)$ of temporal series could be calculated with the h already known [9]. The hypothesis testing of $C(t)$ could be carried out under a certain confidence degree α: if $C(t)$ is smaller than the critical value r_α, the long-term relativity is not significant and there is no alteration happens in the temporal series; else the long-term relativity is significant and the alteration exists. There is a situation existing in the application of $C(t)$, even if the hypothesis testing passed the testing with the confidence degree α, it may not passed the testing with the confidence degree $\beta(\alpha>\beta)$, that means $r_\alpha<C(t)<r_\beta$. In this situation, the alteration is significant with the confidence degree α and not significant with the confidence degree β, it is named weak alteration in this paper. If $C(t)$ is more than and equal to r_β, the alteration is obvious and the classification could be considered based on the correlation degree.

If there is no alteration in the hydrological series by the result of preliminary diagnose, the analysis and investigation of causes should be carried out to confirm the result; else the process of detailed diagnose will be activated.

In the process of detailed diagnose, much more methods are considered to detect the trend alteration and jump alteration. In order to detect the trend alteration, the methods of Linear Correlation Coefficient, Spearman Rank Correlation Test and Kendall Rank Correlation Test are used. In order to detect the jump alteration, the methods of Sequential Cluster, Lee-Heghinian, Rank-Sum Test, Sliding F Test, Sliding T Test, Runs Test, R/S Analysis, Brown-Forsythe, Mann-Kendall and Bayesian are used [10-13]. After the trend alteration and jump alteration diagnose, the process of comprehensive diagnose will be activated.

In the process of comprehensive diagnose, the comprehensive results of trend diagnose and jump diagnose will be achieved based on the results of detailed diagnose. The fitting degree of hydrological series and the proportion of trend or jump will be estimated by the coefficient of efficiency, and the bigger one will be accepted as the result of hydrological alteration. With the investigation and analysis of the actual conditions, the conclusion and the style of alteration will be confirmed at last [14].

Compared with the traditional simplex alteration diagnosis methods, HADS could diagnose the alteration comprehensively and considered the alteration degree classification in the hydrological series, it is comprehensive in the indexes and the alteration analysis result is credible. Therefore, the HADS was used to diagnose the hydrological alteration in this paper.

2.2 Chézy-manning Formula

According to the Chézy-manning formula in the hydraulic, the runoff can be calculated from the following formula [15]:

$$Q = \frac{wR^{2/3}I^{1/2}}{n} \tag{2}$$

Where Q is volume of runoff, w is the discharge section area, R is the hydraulic radius, n is the roughness coefficient and I is the water surface slope.

3. Analyzed the Flood Variation based on HADS

Table 1 The alteration diagnosis results of Xuanen station

<table>
<tr><td colspan="4">Hydrological elements</td><td>flow series (m3/s)</td></tr>
<tr><td colspan="2" rowspan="2">Preliminary diagnose</td><td colspan="2">Hurst coefficient</td><td>0.749</td></tr>
<tr><td colspan="2">Ateration degree</td><td>moderate</td></tr>
<tr><td rowspan="14">Detailed diagnose</td><td rowspan="11">Jump Diagnose</td><td colspan="2">Sliding F Test</td><td>1999(+)</td></tr>
<tr><td colspan="2">Sliding T Test</td><td>1999(+)</td></tr>
<tr><td colspan="2">Lee-Heghinian</td><td>1999(0)</td></tr>
<tr><td colspan="2">Sequential Cluster</td><td>1999(0)</td></tr>
<tr><td colspan="2">R/S Analysis</td><td>1991(0)</td></tr>
<tr><td colspan="2">Brown-Forsvthe</td><td>1999(+)</td></tr>
<tr><td colspan="2">Runs Test</td><td>2004(+)</td></tr>
<tr><td colspan="2">Rank-Sum Test</td><td>1999(+)</td></tr>
<tr><td colspan="2">Optimal information two degmentation</td><td>1968(0)</td></tr>
<tr><td colspan="2">Mann-kendall</td><td>1999(+)</td></tr>
<tr><td colspan="2">Bayesian analysis</td><td>1999(+)</td></tr>
<tr><td rowspan="3">Trend Comprehensive</td><td colspan="2">Linear Correlation Coefficient</td><td>+</td></tr>
<tr><td colspan="2">Spearman Rank Correlation</td><td>+</td></tr>
<tr><td colspan="2">Kendall Rank Correlation</td><td>+</td></tr>
<tr><td rowspan="6">Comprehensive diagnose</td><td rowspan="3">Jump Comprehensive</td><td colspan="2">Jump Point</td><td>1999</td></tr>
<tr><td colspan="2">Comprehensive weight</td><td>0.78</td></tr>
<tr><td colspan="2">Comprehensive significant</td><td>6(+)</td></tr>
<tr><td>Trend Comprehensive</td><td colspan="2">Comprehensive significant</td><td>3(+)</td></tr>
<tr><td rowspan="2">Compare</td><td rowspan="2">Efficiency coefficient(%)</td><td>Jump</td><td>22.82</td></tr>
<tr><td>Trend</td><td>12.68</td></tr>
<tr><td colspan="4">Diagnose Conclusion</td><td>1999(+)↓</td></tr>
</table>

Note: "+" means significant, "-" means not significant, "0" means the significant test could not be tested

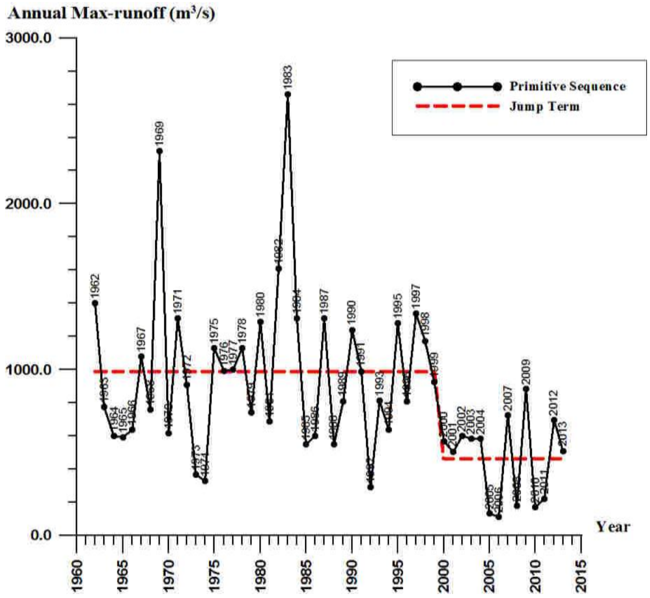

Fig. 1 Jump alteration of annual max-runoff series at Xuanen station

Under the condition of the first degree of confidence α=0.05 and the second degree of confidence β=0.01, the HADS was used to analyze the alteration of the average annual maximum monthly rainfall series from 1956-2010 (the calculation for the arithmetic mean of the average annual maximum monthly rainfall at Xianfeng, Xiaoguan, Xuanen, Longping, Xicaoba and Tongziying station) and the annual maximum daily flow series of Xuanen station from 1962-2013.

The result of preliminary diagnose for the annual maximum daily flow series of Xuanen station showed that moderate alteration existed from the results of Table 1: the Hurst coefficient h=0.749, the first Hurst coefficient confidence limit h_α=0.676 and the second Hurst coefficient confidence limit h_β=0.720, $h>h_\beta$, which did not meet the consistent demand. Detailed diagnose revealed that jump and tendency of the annual maximum daily flow series were both significant, then entered the process of comprehensive diagnose. The larger of the jump efficiency coefficient or the trend efficiency coefficient (jump efficiency coefficient 28%) was selected as final variation form through jump comprehensive and trend comprehensive in the comprehensive diagnose. The final diagnose conclusion was the annual maximum daily flow series from 1962-2013 jumped a downward moderate variation in 1999, and its jump form was shown in Fig. 1.

4. Cause Analysis based on the Chézy-manning Formula

River regulation and bank canalization have changed natural texture and shape of bank artificially, which causes the river hydraulic characteristics to change, and then causes the river course characteristics to change. The following will analyze the major factors affecting stage-discharge relation, such as the discharge section area and the roughness reflecting the size of resistance, and the variation situation of maximum flow series of Xuanen station was analyzed using the formula of Chézy-manning.

Xuanen station which was built in May 1958, 1.5km away from the downstream Longdong reservoir, is a national base station. The relation curve of water level and discharge of this station is always a single curving line recent years, which reflects that this river has a proper operation condition and a stable section. The measured data of cross-section before and after Xuanen Urban river canalization were compared and analyzed. The cross-section shapes changed greatly before and after Xuanen Urban river canalization as shown in Figure 2.

Under the same water level, the channel section area after Xuanen Urban river canalization was decreased than before from Fig.4 the relation diagram of water level and area before and after Xuanen Urban river canalization, and the ralative reduction was 37.3% according to the Table 2. The result of

Table 2 was also showed that the higher water level (the closer to shore), the larger difference of the channel section area before and after Xuanen Urban river canalization, but the relative reduction of the channel section area was just decreased.

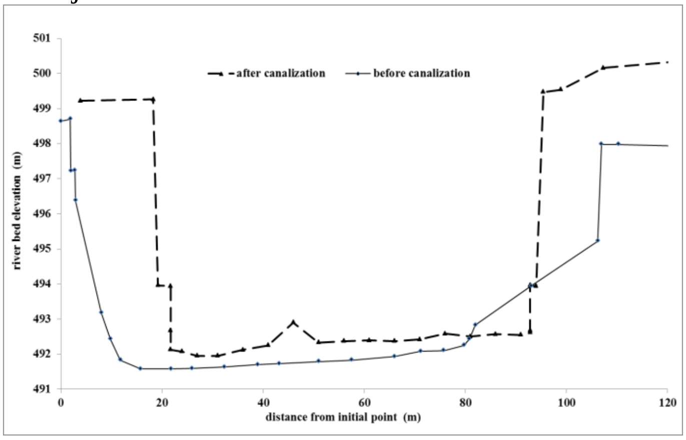

Fig.2 Comparison diagram of cross-section Variation before and after Urban river canalization

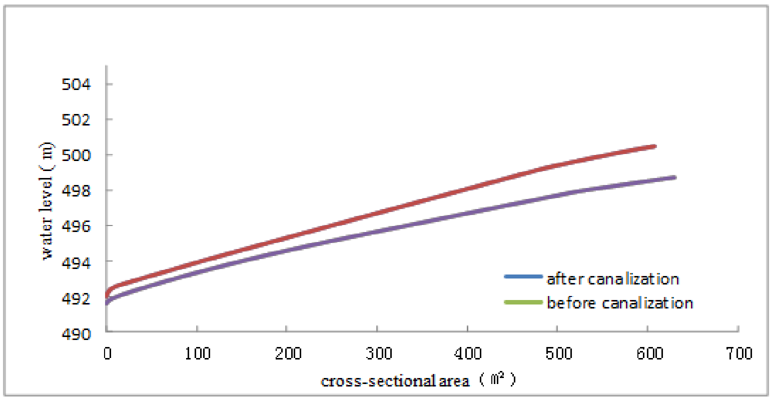

Fig.3 The relation diagram of water level and area before and after Xuanen Urban river canalization

Table 2 The results of channel section area change before and after Urban river canalization

Water level(m)	Area (m2)		Area Reduction	
	After canalization	Before canalization	Absolute value (m2)	Relative value (%)
492.00	0.1	13.1	-13.0	-99.2
492.50	9.2	43.7	-34.5	-78.9
493.00	40.5	77.2	-36.7	-47.5
493.50	74.1	113.3	-39.2	-34.6
494.00	107.8	152.3	-44.5	-29.2
494.50	143.3	194.2	-50.9	-26.2
495.00	178.9	239.2	-60.3	-25.2
495.50	214.5	286.7	-72.2	-25.2
496.00	250.3	334.9	-84.6	-25.3
496.50	286.2	383.6	-97.4	-25.4
497.00	322.2	432.4	-110.2	-25.5
497.50	358.3	481.6	-123.3	-25.6
498.00	394.5	533.8	-139.3	-26.1
498.50	430.8	601.7	-170.9	-28.4
	Average		-76.9	-37.3

River regulation works used stone blocks with cement mortar for revetment and curve cut-off to harden and canalized the natural slope and the river morphology of the original natural river course. The measured discharge data revealed that river canalization made roughness coefficient form two distinct distributing ranges, and the smaller the roughness coefficient, the higher the flow velocity. Before canalization (1990), the mean roughness coefficient was 0.033, ranging from 0.027 to 0.042.

After canalization (2013), the relationship between the roughness coefficient *n* and the width and depth ratio *B*/*h* developed steadily, but the mean roughness coefficient reduced to 0.029, ranging from 0.025 to 0.035, and the relation curve was showed in Figure 4.

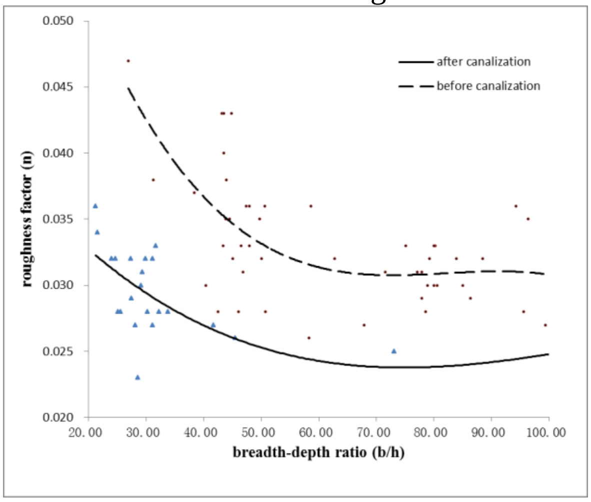

Fig. 4 The relation curve between the roughness coefficient n and the width and depth ratio B/h before and after Xuanen Urban river canalization

The greatest change point of the roughness coefficient before and after Xuanen Urban river canalization was in areas of high width and depth ratio (away from the shore) as shown in Figure 5, reduced from 0.045 to 0.03 by 50%. As the width and depth ratio *B/h* increased (close to the shore), the change of the roughness coefficient was reduced gradually, and after 50, the roughness coefficient was tending towards stability, reduced from 0.03 to 0.025 by 20%.

After canalization, natural river course of Zhongjian River district section has been transformed into nearly parallel and regular on both sides, and the trend of the river remain unchanged before and after the river canalization, so the water surface slope I could be considered to change little before and after the river canalization. Under the same water level, river bed base was raised 0.5m at most, which showed marked difference campared with the at least 5m flood depths, so the hydraulic radius R can be considered to be a constant. After the flood level rising to 495.0m, discharge section area was relatively reduced by 25% to 28% from the data listed in table 2. And when the flood level was rised to a certain position (the width and depth ratio *B/h* was greater than 50), the roughness coefficient n was relatively reduced by 20%. So Relative reduction of the numerator was greater than the denominator in Formula 2, and the conclusion that the river flood discharge was reduced after channelizing reconstruction can be inferred, which was consistent with the results obtained by the hydrological alteration diagnosis system. A fainal conclusion that flood variation was exacerbated by channelizing reconstruction to some extent.

Eenvironmental change contains climate change and human activity, runoff mainly reflects the response of human activity. A moderate variation occurred for the runoff in Xuanen according to the alteration diagnosis of the annual maximum daily flow series, which indicated that this area was controlled by the influence of human activities. In addition, the runoff series jumped a downward in 1999, and the Longdong reservoir in this area was completed in 1995, which played a role in flood cotrolling for natural floods, which indicated that water conservancy project could be primed for the runoff variation. Meanwhile, river canalization has started in 2005, exacerbating impact of human activities, which made amade a new demand for revising the plan of flood-earlying warning.

5. Conclusion

With the data of the annual maximum daily flow series, the Hydrological Alteration Diagnosis System was used to estimate the consistency of the series. Using the formula of Chézy-manning, the flood variation characteristics was discovered according to effect of changing environment on urban water bodies of Xuanen. The main conclusions in this paper are as follows: Firstly, the annual maximum daily flow series jumped a downward moderate variation in 1999, which indicated that the influence of human activities leaded to the variation of the annual maximum daily flow. Secondly, river canalization has started in 2005 and completed in 2012, which has reduced the flood discharge at equal water level, aggravating the flood variation to a certain extent. Finaly, human activities have great influence on the flood control abilities of urban water bodies of Xuanen. So the flood warning plan needs to adapt to the changing environment, which makes river flood prevention decision more scientific and feasible.

References

[1] FANG G H., ZHONG L J., MIAO M. Research on urban flood control and waterlogged drainage safety of our country. Journal of Catasterophology, Vol. 23 (2008) No.3, p. 119-123.
[2] Xu B., Xie P., Tang Y. Y., et al, Analysis of flood returning to main channel influence on the flood control ability of Xijiang River. Journal of Hydroelectric Engineering, Vol. 33 (2014) No.2, p. 65-72.
[3] Hydrology and water resources survey bureau of Enshi. The report of Xuanen urban area flood control ability at present [R]. 2014.
[4] SUN Y X. The documentary of preparedness work for storm floods during the Meiyu period in Hubei province in 2013. China's flood control and drought relief, Vol. 23 (2013) No.4, p. 75-79.
[5] XIE P., CHEN G C., LEI H. F., et al. Hydrological alteration diagnosis system. Journal of Hydroelectric Engineering, Vol. 29 (2010) No.1, p. 85-91.
[6] Hurst H E, Black R P, Simaika Y M. Long-term Storage:An Experimental Study, London: Constable, 1965.
[7] Mandelbrot B B, Wallis J R. Computer experiments with fractional Gaussian noises, (Part 1 and Part 2) Water Resources Research, Vol. (1969) No.1, p. 228-259.
[8] Li H Q., Wang F Q., Fractional theory and its Applications in molecular Science, Science Press, Beijing, (1993), p. 41-59.
[9] Xu X S., Ma L L. i, Cheng Y B. Theoretical Basis of R/S Analysis: Fractional Brownian motion. Wuhan University Journal (Natural Science Edition), Vol. 50 (2004) No.5, p. 547-550.
[10] Chebana, F., et al., Testing for multivariate trends in hydrologic frequency analysis. Journal of Hydrology, Vol. 488 (2013), p. 519-530.
[11] Zhang Q., Gu X H., Vijay P. S. and Xiao M. Z., Flood frequency analysis with consideration of hydrological alterations: Changing properties, causes and implications, Journal of Hydrology, Vol. 519 (2014) Part A, p. 803-813.
[12] Sang Y F., Wang Z G. and Liu C M., Comparison of the MK test and EMD method for trend identification in hydrological time series, Journal of Hydrology, Vol. 510 (2014), p. 293-298.
[13] Machiwal, D., Jha, M.K., Hydrologic Time Series Analysis: Theory and Practice. Berlin: Springer-Verlag, 2012
[14] Xie P., Chen G C., Lei H F., et al. Surface water resources evaluation methods on changing environment. Beijing: science press, 2009.
[15] Ye S Z., Hydrological and hydraulic calculation. Beijing: China Waterpower Press, 2005.