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Runoff of the upper Yellow River above Tangnag: characteristics, evolution and changing trends

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Abstract: Runoff and its evolution, based on hydrometeorological data from surface measurement stations, are analyzed for the upper reaches of the Yellow River above Tangnag. Some mathematical statistical models, for example, Period Extrapolation-Gradual Regression Model, Grey Topology Forecast Model and Box-Jinkins Model, are applied in predicting changing trends on the runoff. The analysis indicates that the runoff volume in the upper Yellow River above Tangnag is ending a period of extended minimum flows. Increasing runoff is expected in the coming years.

Runoff of the upper Yellow River above Tangnag: characteristics, evolution and changing trends LAN Yong-chao1, KANG Er-si1, MA Quan-jie2, ZHANG Ji-shi1, CHEN Ren-sheng1 (1. Cold and Arid Regions Environmental and Engineering Research Institute, CAS, Lanzhou 730000, China; 2. Hydrology and Water Resources Bureau of the Upper Yellow River Basin, Lanzhou 730030, China) 1 Introduction The basin above Tangnag is the principal area for runoff formation in the upper reaches of the Yellow River. For example, the runoff from the Tangnag Station occupies 95% of the inflow into the Longyangxia Reservoir, the largest reservoir on the upper Yellow River. So variations on runoff in the upper Yellow River above Tangnag have been very important for the utilization of the water resources in the entire Yellow River Basin. However, the runoff in the upper Yellow River above the Tangnag has been decreasing recently due to consecutive droughts in the basin (Lan, 1999), which not only greatly influenced the economy and people´s living standard in the upper Yellow River areas, but also curbed the economic development of the whole Yellow River Basin. To solve these problems, accurate prediction of variations of runoff at the Tangnag Station is indispensable for adequate and reasonable exploitation of the water resources at the basin scale, as well as determining the amount of the water supplied by other basins. However, sophisticated methods are not available at present to determine the variability of water flows, due to complexity of their intrinsic evolutions, and close and complicated relationships to climatic changes. In addition, the precision of runoff prediction is greatly influenced by the difficulty in long-term weather and climate forecast. Therefore, it is essential to analyze the evolution of runoff and its relationships with climatic parameters. Hydro-meteorological data have been collected at the Tangnag Station since 1956. 2 Geographical and hydrological characteristics of upper Yellow River Basin The upper Yellow River above Tangnag is located in northeastern Qinghai-Tibet Plateau (95.50 -103.50 E, 32.50-36.00 N), with a drainage basin of 121972 km2, accounting for 1/6 of the total area of the Yellow River Basin. Magengangri (elevation of 6282 m.a.s.l.), the main peak in the A´ny?aq? Mountains, located at the headstream of the Yellow River, is the highest point of the whole Yellow River Basin. The Tangnag Station, located at the outlet of the study area (elevation of 2546 m.a.s.l), is the lowest point of the basin. Most of the basin has an elevation of above 3000 m. The study basin is characterized by cold and semi-arid or semi-humid alpine climate, with annual air temperature of -4.0 to 1.1 oC and annual precipitation of 300-750 mm[1]. The annual precipitation and relative air humidity decrease northwestwards. The annual variations of precipitation are small with coefficients of variation ranging from 0.10 to 0.25 (Table 1), the lowest in China[2]. Widespread frost-weathered debris is favorable to water infiltration and some areas are rich in groundwater, such as the Heihe River and the Baihe River basins in the Zoig?Peatlands in Sichuan Province. The tributaries with rich groundwater are very important for their strong moderation of floods in the upper Yellow River. The flows from the Heihe and Baihe rivers account for 27% of the annual runoff through Maqu Hydrometric Station. Forty glaciers in the A´ny?aq? Mountains, with an ice-snow covered area of about 120.57 km2, are known as the ´solid water reservoirs´ on the upper Yellow River. The Qushan Rivers and th e Qemqu Rivers, originating from glaciers, are the major branches between the Jungong and Tangnag section. The Tangnag Hydrometric Station, constructed for the downstream Longyangxia Hydropower Plant 134 km, is the observing station for the inflow into the Longyangxia Reservoir, the largest power generation project on the upper Yellow River. Per unit area runoff production in the Yellow River Basin is the lowest among the major rivers in China, because most parts of it are located in arid and semi-arid regions. Although the multi-year average annual runoff is 5.60?010m3, the mean specific runoff in the basin is only 2.2 ls-1km-2, the lowest among the major rivers in China. However, the specific runoff in the upper Yellow River Basin above Tangnag is much higher, 5.44 ls-1km-2[3]. Although the runoff above Tangnag accounts for only 38% of the entire Yellow River, it is very important for the basin´s socio-economic development. Table 1 shows the main meteorological characteristics in the upper Yellow River. Table 1 Main meteorological characteristics in the upper Yellow River Basin 3 Runoff formation in upper Yellow River The main source of the runoff in the upper Yellow River is precipitation, groundwater and snowmelt water. In the upper Yellow River, the rainy season which is also the warm season, consisting of summer and autumn, is short; the precipitation is scarce and in solid forms during winter and spring. The precipitation at the 10 meteorological observatories in Table 1 has been measured since 1958. Correlation analysis indicates that the each linear relationship between the precipitation at the three meteorological observatories (Jiuzhi, Tongde and Dawu) and runoff through Tangnag Station is high. Relatively, the above three relationships are higher than that of the precipitation at the each other station in Table 1 and runoff through Tangnag[4]. The rainy season mainly covers the period from mid-June to mid-September. As a result, each linear correlation between the precipitation at the above-mentioned three meteorological stations and the runoff during the period from June to October is high, and the correlation in September is the highest. Furthermore, it can be observed that if precipitation increases in September, runoff will increase apparently[4] not only in this month but also in the next month. According to the measured discharge data, mean annual runoff (1956-1997) at Tangnag is 206.88(108m3, of which snowmelt water supply, ground water supply, and rain supply is 20.0(108 m3, 53.6(108 m3, and 135(108 m3 respectively[3]. 4 Regional distribution for runoff Regional distribution of runoff is controlled and affected by precipitation, climate, topography, vegetation, soil, and geology and anthrosphere. In the upper Yellow River above Jimai, the elevation is above 3500 m, the evapotranspiration is low, and the annual runoff modulus is only 2.82 ls-1 km-2. The elevation is about 2500 m in the interzonal basin from Jimai to Tangnag, where snow cover in the alpine regions is seen throughout the year. Lakes and wetlands are widespread due to the flat terrain and abundant precipitation. Groundwater is rich in the Jimai, Maqu, Jiuzhi, Hongyuan, Zoig?and Guoluo areas. The Heihe River and Baihe River basins are the regional rainstorm centers in the upper Yellow River Basin. The annual specific runoff is 8.28 ls-1km-2 in the interzonal basin from Jimai to Tangnag whose runoff coefficient is maximum in the entire Yellow River Basin. The annual specific runoff along upper Yellow River Basin above Tanning can be seen in Table 2. Table 2 Runoff modulus of along upper Yellow River 5 Seasonal and yearly variations of runoff 5.1 Seasonal variations of runoff Seasonal runoff variations are decided by the supply conditions of river. The general features of runoff variations in the upper Yellow River are that late winter to early spring (from November to March next year) and early summer to late autumn (from mid June to late September) is low flow periods. After March, runoff begins to increase noticeably corresponding to snowmelt and solifluction along with air temperature rise. In summer and autumn, runoff is most abundant because of extensive and frequent rains formed by the summer monsoon, supplies of glacier, snowmelt water and groundwater. The floods also can occur in autumn if the rainy season persists. At the Tangnag Station the maximum flow occurs in July and September, and the minimum runoff occurs in February (Table 3). Table 3 Monthly mean flows at Tangnag Station 5.2 Yearly variations of runoff Although the runoff in the upper Yellow River is affected significantly by atmospheric circulation, yearly variations of runoff are lighter compared with other great rivers in China. Runoff coefficient variations of the upper Yellow River decrease along with the increase of catchment area[3]. The high, mean and low flow years in the upper Yellow River are classified according to reliability, P[5] (see Table 4). Table 4 The high, normal and low flow years in upper Yellow River classification The high, normal and low flow periods of annual runoff at Tangnag can be analyzed according to the corresponding normalized runoff of K. K presents the annual runoff volume in a certain year/the mean annual runoff (see Table 5) Table 5 Normalized runoff coefficient K of the annual runoff at Tangnag 5.3 Decadal runoff variations The 1950s is a low flow period, the 1960s and the 1970s are normal flows, the 1980s is a general high flow at the Tangnag, and the 1990s is another low flow period (see Table 6). Table 6 Decadal runoff variations at the Tangnag in 1956-1997 6 Periodic oscillation of annual runoff There are periodic fluctuations in the long-term changes on hydrologic and meteorological variables, and atmospheric circulations[6]. Spectral analysis using Fourier analysis is a useful method for researching these fluctuations. Spectral analysis corresponds with a nonlinear autoregression model in time series analysis[7-8], which can be used for extracting and forecasting p eriodic components on the basis of periodic extrapolation. Annual runoff data in upper Yellow River above Tangnag are analyzed and tested by means of power spectrum and variance analysis methods based on this one, the prominent cycles in annual runoff series which are T= 2y, 3y, 6y, 13y, 17y and so on are obtained. The curve in Figure 1 is Power Spectrum Curve of periodic oscillation of annual runoff sequence at Tangnag. The coarse line in 2 is ´Red noise´ testing curve whose confidence α=0.05. As shown in 2, the Power spectrum density possess the maximum at where k=4, 6, 12.5, 16, 21, 24, 28, 32.5 and 38 (namely periods Tk≈17 y, 13y, 6y, 5y, 4y, 3y and 2y corresponding with apexes on curve, Tk= 2m / k, m =N / 2, and N=68 is the length of extended time sequence according to the downriver measured data of the Lanzhou Station), and spectrum estimation values S (k) are larger than ´Red noise´ spectrum Sk (k) at where T ≈17y, 13y, 6y, 3y and 2y . First, the 2-year and 3-year cycles on runoff are accordant to 3y quasi-cycles on Pacific subtropic high ridge´s positions[9], which are an important weather system for affecting regional precipitation in western China. Cycles oscillation above even influences other hydrologic variables through bringing the variations on the earth ecstaltic forces variations on atmospheric circulations, air mass, and moistureshus transportation. Pacific subtropic high is one of the major weather systems affecting the precipitation in Yellow River Basin. Therefore, presence of the 2-3y cycles on runoff sequence in upper Yellow River may reflect interaction between ocean and atmosphere. The presence of the 2y or 3y cycles has been verified well in the upper Yellow River basin above Tangnag by many hydrologists and meteorologists[10]. The 17y cycles may be related to mid- and short-term periodical variations of sunspot activities and the movements low of celestial bodies[11]. Large-scale droughts and floods are closely related to fluctuations of sunspots and the variations of other climatic variables in China. So runoff in the upper Yellow River is also influenced frequently by the fluctuations of sunspots. Sunspots increasing generally correspond to longitudinal strengthening circulations (E-type) and to latitudinal circulations (W-type) weakening. The former can favor latitudinal air mass movements and precipitation formation. The latter generally strengthens hot lows over the Qinghai-Tibet Plateau (QTP), resulting in the increase of precipitation and runoff in the headwaters of the Yellow River situated in northeastern QTP. Conversely, runoff in the upper Yellow River will be reduced when radial winds abate and zonal winds develop. Sunspot activity reached a maximum value in 1990 (Lai, 1992)[10], so precipitation and runoff in northeastern Qinghai-Tibet Plateau have been decreasing ever since due to the gradual decline of the radial winds and the gradual buildup of the zonal winds. 7 Periods extension and forecast of runoff in upper Yellow River above Tangnag 7.1 Calculating model There are periodicity and randomicity in either case for long-term variation on hydrological factors. So there are generally two methods for the long-term forecast. One is multi-element comprehensive forecast, in which only the dominant meteorological and astronomical factors are considered and the others are neglected. Then, a statistical correlation can be established between antecedent hydro-meteorological factors and runoff. The other is the periodic-analytical method, in which only runoff change is considered, and the runoff series is regarded as a time sequence composed of fixed periodic waves. Several main cycles are extracted, extended and added to predict future runoff variation trends. Both of the above two aspects of runoff processes are important in the forecast models. We consider both aspects, as a Periodical Extrapolation and Stepwise Regression Coupling Model, to forecast annual runoff in the upper Yellow River above Tangnag. The runoff forecast model contains three variables as follows: where Q (t) is the forecast target series; QP (t) is the extracted main periodic waves series from runoff series by variance analysis method; Mj (t) is antecedent factor series; αi andβj are weight coefficients; and ε(t) is stochastic error. In this paper, ε(t) is treated as the forecast error, and $|\varepsilon(t)|$ is made as small as possible for forecasting. In the above model, the key is how to extract Pi (t), and how to determineαi andβj. 7.2 Calculating processes 1) Potential periods and amplitudes of hydrological series are determined by means of variance analysis. To determine their future possible values, these cycle sequences are extrapolated based on major cycle superposition. Then two or three significant cycle sequences whose length is n+1 are obtained usually through a significance F test under a confidence (, and significant cycle sequence factors are taken as the new forecasts F i (i ??3) in a final stepwise regression analysis equation; 2) Correlative degree analysis of grey system theory[12-13] is applied to determine the correlation with the antecedent factors and runoff. The antecedent factors with higher correlative degree to the runoff (correlation R>0.5) are used in the next stepwise regression analysis. Thus, the work on stepwise regression can be greatly reduced. This procedure can be neglected if the antecedent factors have been chosen manually; 3) Under a given level of ´F-test´, the method of stepwise regression analysis is used for introducing or eliminating variables one by one for the antecedent meteorological and hydrological, and the periodic wave factors. The procedure does not stop until there no more variables can be introduced or eliminated. Meanwhile the weight coefficients and sequence number of the introduced variables are recorded to establish the forecast equation. Variables with j > k are the antecedent factors; and that j≤k index the major cycles contained in the original hydrologic element series. On the basis of above pr inciples and procedures, the model for forecasting annual mean runoff in the upper Yellow River through Tangnag can be obtained as follows where Q is the predicted value of the annual mean runoff through the Tangnag Station (m3/s), Pd,. Pj , and Pt are respectively the annual precipitation at the Dawu, Jiuzhi and Tongde meteorological observatories, and Q17 and Q13 are respectively the extended values of the 17y and 13y prominent cycles waves series extracted from the annual mean runoff series through the Tangnag. Forecasting values of the annual precipitation at the Jiuzhi, Tongde and Dawu meteorological observatories can also be obtained by extending their main cycles waves series and applying Box-Jenkins Model[14]. Forecasting and measured values of the annual mean runoff in the upper Yellow River through Tangnag are listed in Table 7. It can be observed from Table 7 that most of precision of calculated values of the Periodical Extrapolation and Stepwise Regression Coupling Model is over 80%, which is satisfying and in accord with needs for the accuracy of a long-term runoff forecast. So this model can be used for forecasting changing trend of mean annual runoff through the Tangnag, and the forecasting result can be seen in Table 8. Figure 2 Contrast on the forecasted and calculated values with the measured values of annual mean runoff at the Tangnag Station, where Qf and Qc are respectively the predicted value, the calculated and the measured value of annual mean runoff at Tangnag Station Table 7 Testing and verifying for periodical extrapolation and stepwise regression coupling model Table 8 Forecasted values of annual mean runoff (m3/s) through the Tangnag It can be observed from Table 8 that the mean of the prediction values of the runoff during 1998 to 2007 will be close to or slightly exceed to the runoff amount at the Tangnag during 1956 to 1997, which means the following ten years will be a normal flow period for annual mean runoff in the upper Yellow River through Tangnag, and runoff amount in the period will increase compared with that in the previous decade. 8 Conclusions 1) Runoff in the upper Yellow River above Tangnag has experienced couple significant decadal variations: the 1950s is a low flow period, the 1960s and the 1970s are normal flow periods; the 1980s is a general high flow period at the Tangnag. The 1990s is another a low flow period. The possibility of low flow periods occurrence is the largest generally for runoff through Tangnag; 2) Runoff in the upper Yellow River above Tangnag displays significant periodical variations of 2y, 3y, 6y, 13y, 17y cycles; 3) Runoff in the upper Yellow River above Tangnag can be divided into two complete high-low flow periods in variation hitherto and one incomplete low flow period. The Kp averages of each period are close to the multi-year average. The present period is at the minimum of the third low flow period; 4) The period from 1998 to 2007 will be a normal flow period for annual mean runoff in the upper Yellow River through Tangnag, in which the runoff amount will close to the runoff amount during the period from 1988 to 1997. References

关键词： runoff; upper Yellow River; trend; forecast

