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Temporal and spatial variations and statistical models of extreme runoff in Huaihe River Basin during 1956–2010

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Abstract: Based on the daily runoff data from 20 hydrological stations above the Bengbu Sluice in the Huaihe River Basin during 1956–2010, run test, trend test and Mann-Kendall test are used to analyze the variation trend of annual maximum runoff series. The annual maximum series (AM) and peaks over threshold series (POT) are selected to describe the extreme distributions of generalized extreme value distribution (GEV) and generalized Pareto distribution (GPD). Temporal and spatial variations of extreme runoff in the Huaihe River Basin are analyzed. The results show that during the period 1956–2010 in the Huaihe River Basin, annual maximum runoff at 10 stations have a decreasing trend, while the other 10 stations have an unobvious increasing trend. The maximum runoff events almost occurred in the flood period during the 1960s and 1970s. The extreme runoff events in the Huaihe River Basin mainly occurred in the mainstream of the Huaihe River, Huainan mountainous areas, and Funiu mountainous areas. Through Kolmogorov-Smirnov test, GEV and GPD distributions can be well fitted with AM and POT series respectively. Percentile value method, mean excess plot method and certain numbers of peaks over threshold method are used to select threshold, and it is found that percentile value method is the best of all for extreme runoff in the Huaihe River Basin.

Keywords: Huaihe River; extreme runoff; extreme distribution; threshold selection

1 Introduction

In the Intergovernmental Panel on Climate Change (IPCC), it is indicated that in the Fourth

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Assessment Report (AR4) that, under the background of global climate change, energy and water cycle characteristics of the underlying surface have undergone great changes, especially a severe impact on the occurrence of extreme weather events (IPCC, 2007). Climate change will change the status of the global hydrological cycle, resulting in the increasing trend of the frequency and intensity of high temperature, drought, heavy rain and floods and other extreme weather events (Trenberth *et al.*, 2007), which pose a serious threat to global and regional water security and become the major challenge for human survival and social sustainable development.

Extreme hydrological events have attracted the attention of many scholars at home and abroad, and have become the hot issue of climate change and hydrological scientific research in recent years. Kunkel *et al.* (1999), Manton *et al.* (2001), Nandintsetseg *et al.* (2007) and Rajeevan *et al.* (2008) made some research on extreme precipitation and temperature variation characteristics in the United States and Canada, Southeast Asia and the South Pacific region, area near lake Hövsgöl, Mongolia and India. Zhai *et al.* (1999), Cai *et al.* (2007), Zhang *et al.* (2009) and Su *et al.* (2008) made analysis in extreme precipitation characteristics in whole China, eastern China, South China and the Yangtze River Basin. Wang and Tian (2010) analyzed spatial and temporal variation trends and interannual variability of extreme precipitation in the Huaihe River Basin via trend analysis methods. Zhang *et al.* (2009) analyzed the temporal and spatial characteristics of extreme precipitation events in the Yangtze and Huaihe river basins through calculating six extreme precipitation indices. Xia *et al.* (2012) studied the trend analysis and statistical distribution of extreme rainfall events in the Huaihe River Basin during 1960–2009. Dong *et al.* (2009) fitted the extreme monthly precipitation and discharge series in the Huaihe River Basin by probability distributions and studied the relationship between extremes of precipitation and discharge in the Huaihe River Basin. However, the study of extreme runoff in the Huaihe River Basin is still limited.

In the past 20 years, the high incidence area of floods in China, such as the Huaihe River Basin, the extreme precipitation events trend to increase and flood disasters are severe (Xia *et al.*, 2011). Since the 20th century, basin-scale floods of the Huaihe River Basin happened in 1921, 1931, 1954 and 1991. Furthermore, large floods happened in the upstream of the Huaihe River in 1968, the Shipihe River in 1969, the Hongruhe River and Shayinghe River in 1975. In the 21th century, serious floods took place in 2003, 2005, 2007 and 2011 in the Huaihe River Basin, which brought serious threat and huge losses to the property and lives of people. Thus, research on spatial and temporal variation distribution and statistical probability characteristics of extreme runoff in the Huaihe River Basin is of great significance in disaster prevention and mitigation and regional water security. In this research, based on daily runoff data of 20 typical stations during 1956–2010, spatial and temporal variation distribution and statistical probability characteristics of extreme runoff in the Huaihe River Basin are analyzed, which lay the foundation of detecting and validating extreme floods in the Huaihe River Basin during recent years, forecasting the future variation of extreme runoff in the Huaihe River Basin and making further study of extreme runoff events under climate change.

2 Overview of the study basin

The Huaihe River Basin is located between 111°55'–121°25'E and 30°55'–36°36'N, with a drainage area of 270,000 km^2. The multi-year average precipitation of the basin is about 883 mm, which is generally decreasing from south to north. The Huaihe River Basin is located in the north-south climate transitional zone in China. Areas south of the Huaihe River belong to the subtropical zone, while areas north of it belong to the warm temperate zone. Because of its special geographical features, it is prone to floods (Wei and Zhang, 2009). In this paper, historical daily flow at 20 typical hydrological stations in the Huaihe River Basin are selected to analyze the temporal and spatial variation of extreme runoff events. Statistical probability models are used to simulate the observation data. The DEM and distribution of the hydrological stations above the Bengbu Sluice in the Huaihe River Basin are shown in Figure 1.

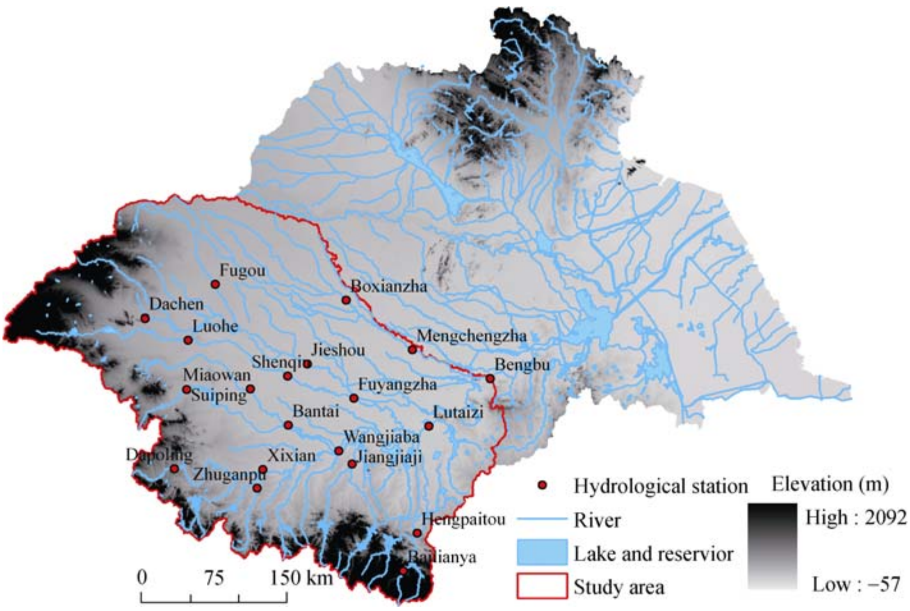

Figure 1 The DEM, location of hydrological stations and water system in the Huaihe River Basin

3 Data and methodology

3.1 Data processing and preparation

There are some missing values in the daily runoff data series at the 20 stations during 1956–2010 in the Huaihe River Basin, which are replaced with NA (no data). Replace the minus values of the data (This situation is most likely affected by the backwater during the water storage time) with the minimum flow in dry season.

Extreme runoff analysis in this paper is based on the sample sequences selected via annual maximum (AM) method and peaks over threshold (POT) method. Selection of the AM and POT series is to compare the fitting results of the two sequences fitted by GEV and GPD models. AM method is the standard method of flood calculation specifications in China. Nowadays, AM sequences have been widely used in the engineering design and experimentation. However, extreme runoff information in AM series is limited, and the annual maximum runoff only has relative significance. But POT method has the advantage of greatly increasing the sample size, to maximize the use of useful extreme information and solve the lack of historical hydrological data to some extent. Some methods such as percentile value method, mean excess plot method, goodness of fit test and bootstrap method etc. are commonly used to select POT series at present. In this study, percentile value method, mean excess plot method and three peaks over threshold per year in average are used to select thresholds. Runoff that exceeds 99th percentile of the data sequence compose POT1, while runoff exceeds the thresholds selected via mean excess plot compose POT2. And selection of three peaks over threshold per year in average is to compose POT3. Using the three threshold selection methods to compose three POT series is to explore the effects on the model fitting with different methods of threshold selection. Taking Lutaizi station as an example, the mean excess plot method is illustrated.

The mean excess function (Shi, 2006) of the GPD distribution is shown as follows.

$$e(\mu) = E(X - \mu | X > \mu) = \frac{\sigma + \xi\mu}{1 - \xi} \qquad \xi < 1 \tag{1}$$

where μ is threshold; ξ is shape parameter; σ is scale parameter.

For a threshold μ_0, the distribution of mean excess approximately follows the GPD with parameters σ_{μ_0} and ξ. Then for μ which is greater than μ_0, the mean excess function should fluctuate around a straight line. If the slope $e_n(\mu)$ remains unchanged when $\mu>\mu_0$, μ_0 can be selected as the threshold. It can be seen from Figure 2a that the mean excess function is ap-

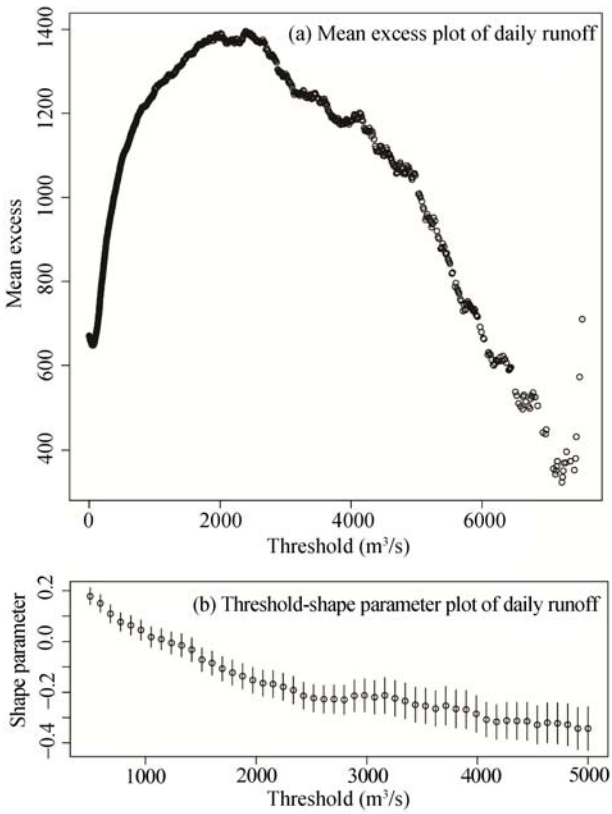

Figure 2 The threshold selection of daily runoff at Lutaizi station

proximately linear for the threshold which is greater than 2000 m^3/s, so the proper threshold is nearly 2000 m^3/s. Meanwhile, in the range of threshold values, if the series selected by the initial threshold μ_0 obeys GPD distribution approximately, the estimated parameter ξ should remain unchanged for series selected by the threshold which is greater than μ_0.

For the threshold greater than 2500 m^3/s, shape parameter shows the basic stability. For the relative error, the disturbance of Figure 2b is smaller. Through Kolmogorov-Smirnov (K-S) goodness of fit test analysis and comparison (Table 1), K-S test value is the smallest and the fit is the best with 2400 m^3/s as the runoff threshold at Lutaizi station. So we select 2400 m^3/s as the runoff threshold at Lutaizi station. Combined with the mean excess plot, threshold-shape parameter plot and goodness of fit test to select the runoff threshold, it can reduce the error caused by subjective reasons, so as to select the appropriate threshold, providing some basis for further parameter estimates.

Table 1 Parameters estimation and goodness of fit in threshold selection via mean excess plot

Threshold (m^3/s)	Number over the threshold	Shape parameter	Scale parameter	K-S test
1800	1908	–0.130	1553.343	0.038
2000	1639	–0.160	1605.095	0.036
2200	1425	–0.178	1621.657	0.033
2400	1212	–0.220	1706.028	0.025
2500	1154	–0.222	1694.079	0.026
2600	1068	–0.228	1684.540	0.029

3.2 Methodology

3.2.1 Statistical model of extreme value distribution

(1) Generalized extreme value distribution, GEV

In the 1930s, Fisher and Tipett (1928) put forward three extreme value distributions in the study of the maximum asymptotic distribution theory, which are the Gumbel distribution, Fréchet distribution and Weibull distribution. According to extreme value distribution theory, Jenkinson (1955) and Coles (2001) unified the three extreme value distributions as an extreme value distribution with three parameters, which is the generalized extreme value distribution (GEV). The distribution function is given as follows.

$$F(x)=\exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\},\qquad \left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]>0 \tag{2}$$

where σ and μ are scale parameter and position parameter; ξ is shape parameter.

When ξ=0, it is Gumbel distribution; when ξ>0, it is Fréchet distribution; when ξ<0, it is Weibull distribution.

Without considering the original distribution types, the unification of the three distributions can avoid shortcomings of a single distribution (Dong, 2001; Ding, 2006).

(2) Generalized Pareto distribution, GPD

Generalized Pareto distribution (GPD) is the “peaks over the threshold” (POT) stable distribution, which selects extreme data according to a given threshold, and then establishes extreme value distribution. This distribution describes the probability characteristics of all the observations over the threshold.

The distribution function of GPD (Shi, 2006; Brabson and Palutikof, 2000) is given as follows.

$$F(x)=1-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}} \quad , \quad x\geq\mu, 1+\xi\left(\frac{x-\mu}{\sigma}\right)>0 \tag{3}$$

where μ is threshold; $\sigma>0$ is scale parameter; ξ is shape parameter.

3.2.2 Method for parameters estimating

There are many methods for parameters estimating in extreme distributions, such as moments method, probability weighted moments method (PWM), L-moments method, Bayes estimation method and maximum likelihood estimation method (MLE) and so on. Each parameters estimating method has its advantages and disadvantages, but MLE is the method of best versatility of all, which can adapt to different parameters estimating of extreme models. MLE is put forward by British statistician R.A. Fisher in 1912 (Fisher, 1925). Because it can be used for every population and has good asymptotic property in the case of large sample, it becomes one of the most commonly used and most important methods for parameters estimating. The estimates obtained via MLE have consistency and effectiveness. If not unbiased, it can be modified to be unbiased. Under certain conditions, difference between maximum likelihood estimation of the unknown parameters and its true value can be made arbitrarily small. MLE method is a good, easy to be adaptable to complex models (Shi, 2006), so parameters were estimated through MLE method in this study. Supposed that $\{x_1, x_2, \ldots \ldots, x_n\}$ is independent and identically distributed (i.i.d.) with the probability distribution function F(x).

The parameters estimation of GEV by MLE method can be obtained from the following log-likelihood function.

$$L(\theta)=L(\mu,\sigma,\xi)=-n\ln\sigma-\sum_{i=1}^{n}\left[1+\xi\left(\frac{x_i-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}-\left(1+\frac{1}{\xi}\right)\sum_{i=1}^{n}\ln\left[1+\xi\left(\frac{x_i-\mu}{\sigma}\right)\right] \tag{4}$$

where $\theta=(\mu,\sigma,\xi)$; point (μ,σ,ξ) reaches the MLE when the function reaches the maximum point. There is no analytical expression of $\hat{\mu},\hat{\sigma},\hat{\xi}$, so numerical methods are needed to solve the function.

The parameter estimation of GPD by MLE can be obtained from the following log-likelihood function.

$$L(\theta)=L(\sigma,\xi)=n\ln\xi-n\ln\sigma-\left(\frac{1}{\xi}+1\right)\sum_{i=1}^{n}\ln\left(1+\frac{\xi}{\sigma}x_i\right) \tag{5}$$

where $\theta=(\sigma,\xi)$; point (σ,ξ) reaches the MLE when the function reaches the maximum point. There is no analytical expression of $\hat{\sigma},\hat{\xi}$, so numerical methods are needed to solve the function.

3.2.3 Goodness of model fit test

There are many methods to test the goodness of distribution fit. In this study, Kolmogorov-Smirnov (K-S) test method which is commonly used is selected to test the model goodness of fit. K-S test is a non-parametric test method. It compares the empirical distribution of the sample data with the specific theoretical distribution. If the difference between the two is small, we can infer that the sample is taken from the theoretical distribution. Assume that a specific theoretical distribution is F(x), the sample distribution is Fn(x), and the test statistic is D = max | F(x) – Fn(x) |. $D_\alpha(n)$ is the critical value of K-S test with the sample size of n at the significance level of α, which can be obtained from K-S test critical values table. If $D < D_\alpha(n)$, the distribution of the sample has no significant difference with the theoretical distribution F(x) at a significant level α, and the sample data has a good fit of the theoretical distribution.

3.2.4 Estimations with different return periods

The return period is the average interval time of hydrological elements occurring once which is greater or equal to a magnitude during the period with records. It is the transfer cycle in the sense of probability. In essence, it is the right side of the probability distribution with the small probability (Ding and Jiang, 2009).

For GEV, estimation of extreme runoff with return period T is calculated as

$$X_p = \mu - \frac{\sigma}{\xi}\left\{1-\left[-\ln\left(1-\frac{1}{T}\right)\right]^{-\xi}\right\} \tag{6}$$

For GPD, estimation of extreme runoff with return period T is calculated as

$$X_p = \mu - \frac{\sigma}{\xi}\left[1-\left(\frac{1}{T}\right)^{-\xi}\right] \tag{7}$$

Through the substitution of the obtained parameters by MLE into the above equations, estimation of extremes X_p with return period T years can be obtained.

4 Results and analysis

4.1 Trend analysis of extreme runoff in the Huaihe River Basin

Trend analyses of extreme runoff are carried out by calculation of the basic moments, run test, trend analysis, and Mann-Kendall (M-K) test of the annual maximum daily flow at 20 hydrological stations above Bengbu Sluice in the Huaihe River Basin. The details are explained by taking typical stations in "75.8" storm flood such as Suiping, and Wangjiaba and Lutaizi stations in the mainstream of the Huaihe River as an example. The results are shown in Table 2 and Figure 3.

Table 2 Basic moments and tests of annual maximum runoff at Suiping, Wangjiaba and Lutaizi stations

Station name	Mean	Standard deviation	Coefficient of variance	Coefficient of skewness	Coefficient of Kurtosis	Run test	Trend test	M-K test
Suiping	577.780	726.142	1.257	2.903	14.343	0	0	0.131
Wangjiaba	3647.917	2686.844	0.737	1.976	10.096	*	0	0.377
Lutaizi	3905.546	2104.425	0.539	0.446	2.288	0	0	0.152

Note: 0 means the null hypothesis is accepted at a significant level of 0.05. The null hypothesis is that the data series is independent and identically distributed (i.i.d).

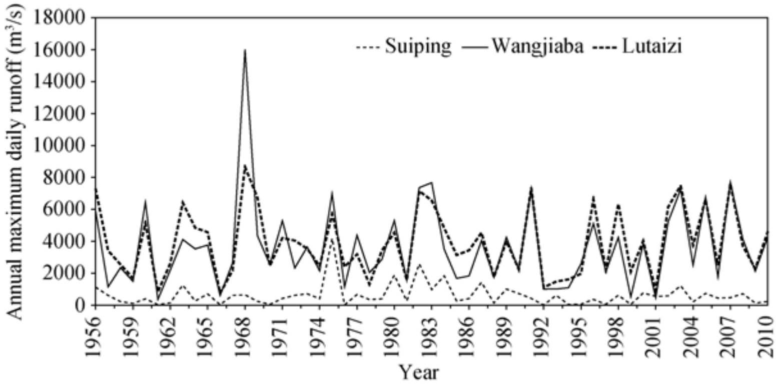

Figure 3 The anuual maximum runoff at Suiping, Wangjiaba and Lutaizi stations during 1956–2010

The maximum daily runoff at Suiping, Wangjiaba and Lutaizi station occurred in August, 1975, July, 1968 and July, 1968. Wangjiaba and Lutaizi stations are located in the mainstream of the Huaihe River, so the correlation of the maximum daily runoff variation between the two stations is good. The maximum daily runoff at the three stations are consistent when "75.8" storm flood occurred. The AM series of Suiping and Lutaizi stations are i.i.d, and that of Wangjiaba is not i.i.d tested but by run test. Through M-K test, |Z|<1.96 occurs at three stations, not passing the significance test at a significant level of 0.05, which indicates that the AM runoff series have an upward trend at the three stations, but it is not significant.

Through exploratory analysis of runoff at 20 typical stations in the Huaihe River Basin, we know that during1956–2010, the maximum runoff events almost occurred in the flooding season during the 1960s and 1970s (Figure 4). Runoff of 10 typical stations show a downward trend, two stations of which pass significant test at the significance level of 0.05. The left 10 stations show an upward trend which is not significant. And stations on the mainstream of the Huaihe River show an upward trend (Figure 5). There are six stations which

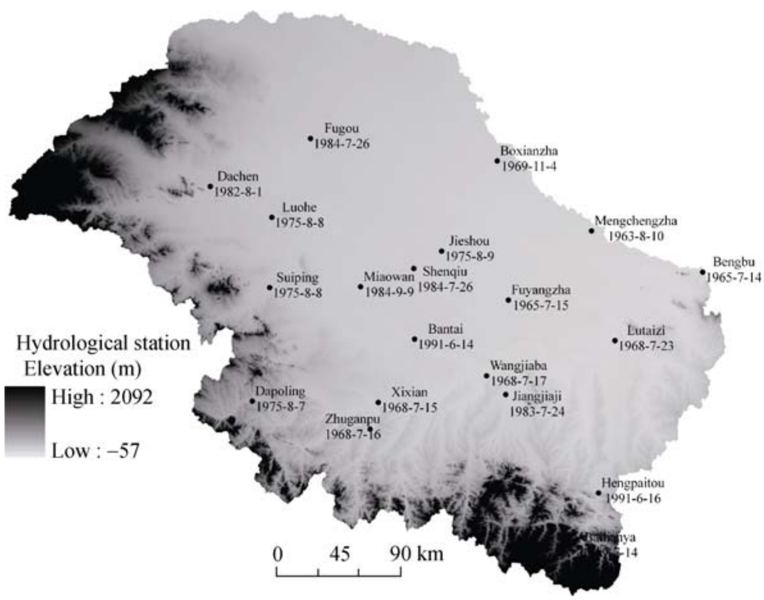

Figure 4 Occurrence date of the maximum runoff in the Huaihe River Basin

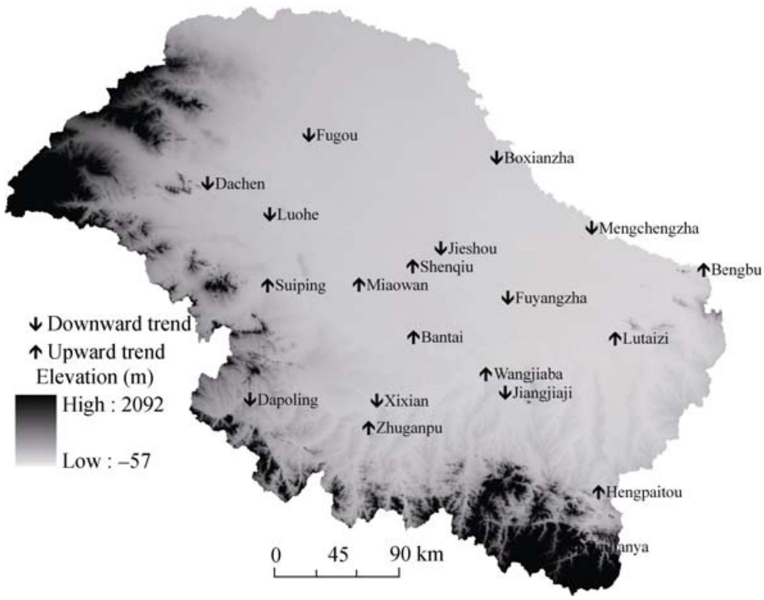

Figure 5 M-K test of the annual runoff in the Huaihe River Basin

reject i.i.d via run test, while two stations reject i.i.d via trend test. But it does not affect the use of statistic models because we can rarely obtain the independent and identically distributed samples in practice. It is more accurate to say that the standard samples approximately follow the GPD or GEV distribution.

L-moments method is used for the AM sequence and POT1 sequence of each station to calculate L-skewness and L-kurtosis. The exploratory analysis of the suitable extreme value distribution for extreme runoff in the Huaihe River Basin is shown in Figure 6.

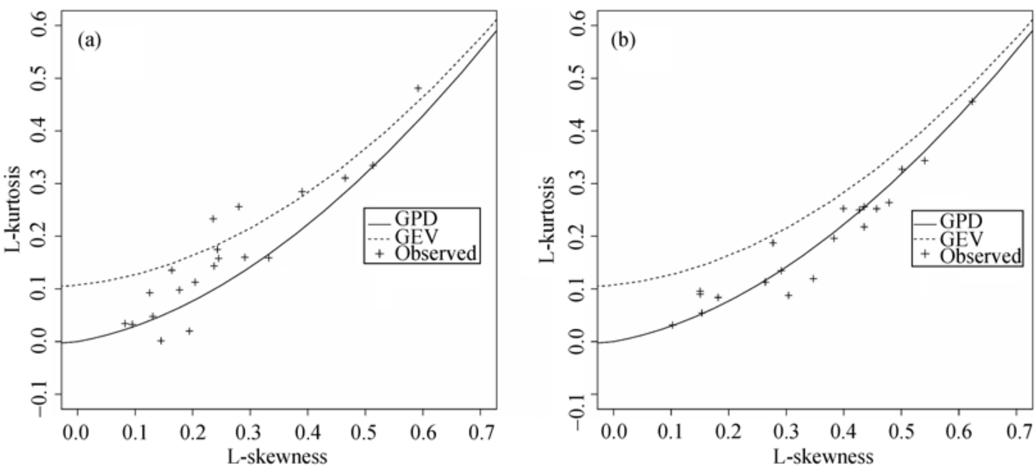

Figure 6 Empirical and theoretical L-skewness and L-kurtosis for (a) AM and (b) POT1 series in the Huaihe River Basin

It can be seen from Figure 6 that for AM series, points are scattered near the GEV and GPD distribution, there is no obvious aggregation. However, for POT1 series, most of the points are clustered near the GPD distribution. Thus, for most stations in the Huaihe River

Basin, empirical and theoretical L-skewness and L-kurtosis of POT1 series are close relatively, which indicates that the GPD distribution fits POT1 series better than GEV distribution.

4.2 Extreme statistical model for AM and POT series

GEV and GPD distributions are used to fit the AM and POT1 series, then K-S test is selected to test the goodness of the model fit. The results are shown in Table 3.

Table 3 The K-S test value for AM and POT1 series of extreme runoff in the Huaihe River Basin

Station	AM series			POT1 series		
	GEV	GPD	Better distribution	GEV	GPD	Better distribution
Dapoling	0.125	0.098	GPD	0.076	0.041	GPD
Zhuganpu	0.087	0.125	GEV	0.072	0.053	GPD
Xixian	0.093	0.082	GPD	0.072	0.055	GPD
Suiping	0.093	0.096	GEV	0.070	0.041	GPD
Miaowan	0.075	0.094	GEV	0.076	0.041	GPD
Bantai	0.121	0.102	GPD	0.066	0.055	GPD
Wangjiaba	0.084	0.105	GEV	0.064	0.050	GPD
Jiangjiaji	0.113	0.127	GEV	0.086	0.080	GPD
Bailianya	0.082	0.129	GEV	0.074	0.032	GPD
Hengpaitou	0.089	0.073	GPD	**0.328**	0.039	GPD
Dachen	0.103	0.074	GPD	0.076	0.047	GPD
Luohe	0.107	0.124	GEV	0.091	0.042	GPD
Fugou	0.078	0.108	GEV	0.057	0.042	GPD
Shenqiu	0.080	0.136	GEV	0.061	0.049	GPD
Jieshou	0.130	0.114	GPD	0.072	0.056	GPD
Fuyangzha	0.085	0.087	GEV	0.095	0.047	GPD
Lutaizi	0.102	0.065	GPD	0.066	0.091	GEV
Boxianzha	0.142	0.108	GPD	0.044	0.033	GPD
Bengbu	0.088	0.146	GEV	0.053	0.062	GEV
Mengchengzha	0.120	0.134	GEV	0.086	0.084	GPD

Note: Bold font in Table 3 represents that the distribution has not passed the K-S test at the confidence level of 95%.

From the above table, except POT1 series at Hengpaitou station fitted by GEV distribution did not pass the K-S test with the confidence level of 95%, others satisfied $D < D_{\alpha}(n)$. It indicates that the model fitting passes the K-S test with a confidence level of 95%, and the distribution of samples follows the theoretical distribution. For AM series, 12 stations can be better fitted by GEV distribution while 8 stations can be better fitted by GPD distribution. For POT1 series, 18 stations can be better fitted by GPD distribution while two stations can be better fitted by GEV distribution. Therefore, it can explain using GEV distribution to fit AM series is better and using GPD distribution to fit POT series is better relatively to some extent. For the Huaihe River Basin, GPD distribution is the most appropriate distribution to fit POT1 sequence, which is consistent with the analysis of empirical and theoretical L-skewness and L-kurtosis (Figure 6b).

Different threshold selecting methods are used to select three POT series POT1, POT2 and POT3. Because POT series can be better fitted by GPD distribution in comparison, GPD distribution is chosen to fit the three POT series and K-S test method is chosen to test the goodness of fit, as shown in Table 4.

Table 4 The K-S test values for POT1, POT2 and POT3 series of extreme runoff in the Huaihe River Basin

Station name	POT1	POT2	POT3	Best	Better	Worst
Dapoling	0.041	0.057	0.040	POT3	POT1	POT2
Zhuganpu	0.053	0.048	0.184	POT2	POT1	POT3
Xixian	0.055	0.036	0.076	POT2	POT1	POT3
Suiping	0.041	0.043	0.065	POT1	POT2	POT3
Miaowan	0.041	0.040	0.062	POT2	POT1	POT3
Bantai	0.055	0.030	0.068	POT2	POT1	POT3
Wangjiaba	0.050	0.030	0.096	POT2	POT1	POT3
Jiangjiaji	0.080	0.056	0.084	POT2	POT1	POT3
Bailianya	0.032	0.031	0.143	POT2	POT1	POT3
Hengpaitou	0.039	0.038	0.055	POT2	POT1	POT3
Dachen	0.047	0.040	0.046	POT2	POT3	POT1
Luohe	0.042	0.043	0.067	POT1	POT2	POT3
Fugou	0.042	0.066	0.104	POT1	POT2	POT3
Shenqiu	0.049	0.047	0.098	POT2	POT1	POT3
Jieshou	0.056	0.046	0.084	POT2	POT1	POT3
Fuyangzha	0.047	0.051	0.077	POT1	POT2	POT3
Lutaizi	0.091	0.025	0.111	POT2	POT1	POT3
Boxianzha	0.033	0.062	0.097	POT1	POT2	POT3
Bengbu	0.062	0.014	0.215	POT2	POT1	POT3
Mengchengzha	0.084	0.028	0.137	POT2	POT1	POT3

It can be seen from Table 4, for most stations, POT2 selected by mean excess plot is best fitted by GPD, and POT1 selected by percentile value method is better fitted by GPD, while POT3 is not so good. The reasons lay in that, the mean excess plot takes goodness of fit test into consideration, so it has the best fitting. From the complexity of the threshold selection methods, the methods of POT1 and POT3 are simpler than that of POT2. From the comparison of GPD distribution fitting effect of POT1 and POT2, although POT2 is better than POT1, both fitting effects are almost the same for most stations. So considering the method complexity and fitting results, the percentile value method is better for selecting the threshold.

4.3 Spatial characteristics of parameters in extreme distribution

Parameters (shape parameter, scale parameter etc.) in extreme probability distributions have significant physical meanings, which reflect some change characteristics of extreme runoff. The above analysis shows that AM series is better fitted by GEV distribution and that POT series is better fitted by GPD distribution. Percentile value method is better for threshold selection. So AM series is fitted by GEV distribution and POT1 series is fitted by GPD distribution, then spatial characteristics of the parameters in GEV and GPD distributions will be

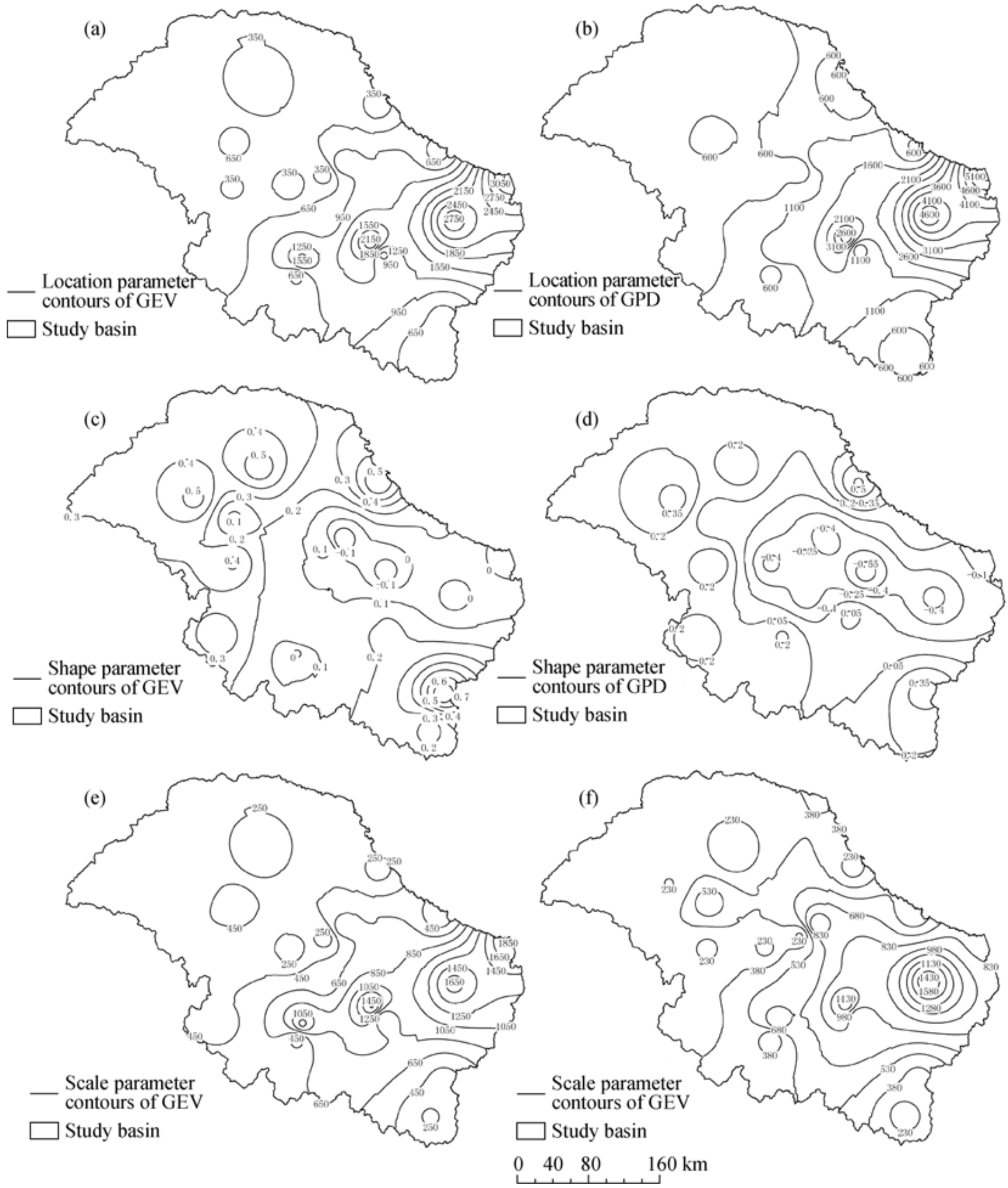

Figure 7 Spatial variations of estimated parameters in GEV and GPD distributions for extreme runoff series in the Huaihe River Basin

analyzed. The results are shown in Figure 7.

For GEV distribution, shape parameter determines the shape of the density curve and the type of the distribution. It can be seen from Figure 7b that AM series of extreme runoff at most of the stations in the Huaihe River Basin follow Fréchet distribution, and a few of them such as Jieshou and Fuyang stations follow Weibull distribution. Scale parameter controls the range of the distribution, and plays a role of zooming in or out the distribution area, but does not affect the pattern of the distribution. Location parameter describes the center of the extremes (Wan *et al.*, 2010). Figures 7a and 7e show the similarity of spatial characteristics for location and scale parameters, and the location and scale parameters for the mainstream of the Huaihe River and Huainan mountainous areas are large.

For GPD distribution, scale parameter describes the frequency and intensity characteristics of the extremes; shape parameter describes the distribution characteristics of high percentile value in extreme distribution; while location parameter is the lower limit (threshold) of the distribution. From the analysis of Figures 7b and 7f, the variability and threshold are relatively large in the mainstream of the Huaihe River and Huainan mountainous areas.

4.4 The estimated extreme runoff with different return periods

Fit AM and POT1 series with the optimal distribution for each station, and fit POT2 and POT3 series with the GPD distribution, then estimate extreme runoff with return periods of 20 and 50 years. The results are shown in Figure 8.

It can be seen from Figure 8 that, for AM and POT1 sequence, with return periods of 20 and 50 years, the spatial distribution of extreme runoff showed their similarity respectively, so are the cases for POT2 and POT3. From Figure 8, extreme runoff in the Huaihe River Basin estimated from AM series shows that it is mainly from the mainstream of the Huaihe River, Huainan mountainous areas and Funiu mountainous areas. With similarity of AM sequence, extreme runoff estimated from POT1 series is mainly from the mainstream of the Huaihe River and Huainan mountainous areas. However, extreme runoff estimated from POT2 and POT3 series is mainly from the mainstream of the Huaihe River and Wohe River. The results from AM and POT1 series are more consistent with the flood characteristics and the geographical features of the Huaihe River Basin, indicating that it is reasonable to use AM and POT series to model extreme runoff in the Huaihe River Basin. Furthermore, in the same return period, the estimated extreme runoff based on AM sequence is larger than that from POT1 at most stations.

5 Conclusions and discussion

Based on the daily runoff data at 20 hydrological stations during 1956–2010 in the Huaihe River Basin, the annual maximum series (AM) and peaks over threshold series (POT) are selected to fit the extreme distributions of GEV and GPD. Temporal and spatial variations of extreme runoff in the Huaihe River Basin are analyzed. The main conclusions are as follows:

(1) The maximum runoff events almost occurred in the flood period during the 1960s and 1970s in the Huaihe River Basin. Runoff of 10 stations show a downward trend, two of which are significant. The left 10 stations (Figure 5) show an upward trend which is not significant. Stations on the mainstream of the Huaihe River showed an upward trend.

(2) Using GEV and GPD distributions to fit AM and POT1 series, through K-S test, the extreme runoff fits well with GEV and GPD, in which AM series fit GEV distribution better and POT series fit GPD distribution better relatively for most stations in the Huaihe River Basin.

(3) POT1, POT2 and POT3 series are selected by the percentile value method, mean excess plot method and three peaks over threshold method, and then they were fitted by the GPD distribution. For most stations, the fitting effects from best to bad is POT2, POT1 and

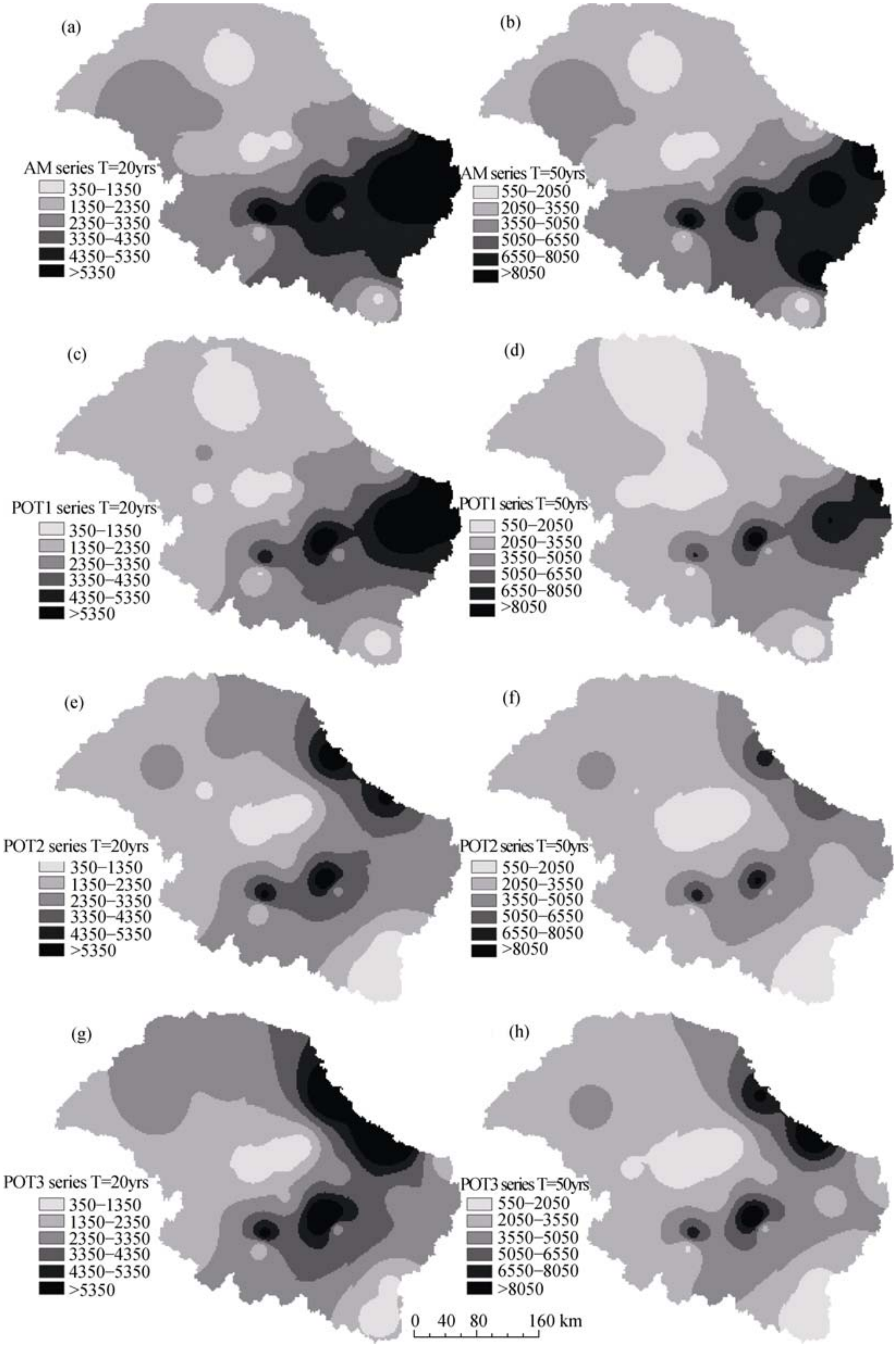

Figure 8 Extreme runoff amount for different return periods of AM, POT1, POT2 and POT3 series in the Huaihe River Basin

POT3. Taking the complexity of the methods, fitting effects and the extent of consistence with the flood characteristics and the geographical features of the Huaihe River Basin, the percentile value method is the best of the three methods.

(4) From the analysis of spatial characteristics of parameters in the extreme distributions, AM series of extreme runoff at most stations in the Huaihe River Basin follow Fréchet distribution, and a few areas such as Jieshou and Fuyang stations follow Weibull distribution. For AM series fitted by GEV distribution, the location and scale parameters for the mainstream of the Huaihe River and Huainan mountainous areas are large. While for POT1 series fitted by GPD distribution, the variability and threshold are relatively large in the mainstream of the Huaihe River and Huainan mountainous areas.

(5) With return periods of 20 and 50 years, spatial distribution of extreme runoff estimated from AM and POT1 series showed their similarity respectively, so is the case for POT2 and POT3 series. The Huaihe River Basin extreme runoff estimated from AM and POT1 series is mainly from the mainstream of the Huaihe River, Huainan mountainous areas and Funiu mountainous areas. This is more consistent with the flood characteristics and the geographical features of the Huaihe River Basin than that estimated from POT2 and POT3 series, indicating that it is reasonable to use AM and POT1 to describe extreme runoff. In the same return period, the estimated extreme runoff from AM sequence is larger than that from POT1 sequence at most of the stations.

(6) Extreme runoff in the Huaihe River Basin is mainly from the mainstream of the Huaihe River, Huainan mountainous areas and Funiu mountainous areas, and the variability and threshold are relatively large in the mainstream of the Huaihe River and Huainan mountainous areas. Thus, for these areas, floods control and management should be strengthened. The flood control projects ought to be under rational management and the regulation role of the water conservancy ought to be played fully in order to ensure the water security of the Huaihe River Basin.

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