land

MDPI

Article

Quantitative Assessment of the Contribution of Climate and Underlying Surface Change to Multiscale Runoff Variation in the Jinsha River Basin, China

Shuaijun Yue [1,2], Guangxing Ji [1,2], Junchang Huang [1,2,*], Mingyue Cheng [1,2], Yulong Guo [1,2] and Weiqiang Chen [1,2]

[1] College of Resources and Environment, Henan Agricultural University, Zhengzhou 450046, China; yueshuaijun@stu.henau.edu.cn (S.Y.)

[2] Henan Engineering Research Center of Land Consolidation and Ecological Restoration, Zhengzhou 450046, China

* Correspondence: huangjc1014@henau.edu.cn

Abstract: Many studies quantify the impact of climate change and human activities on runoff changes on an annual scale, but few studies have examined this on multiple time scales. This paper quantifies the contribution of different factors to the variability of Jinsha River runoff at multiple time scales (annual, seasonal and monthly). First, the trend analysis of Jinsha River runoff is carried out, and the Mann–Kendall mutation test was then applied to the runoff data for mutation analysis. According to the mutation year, the research period is divided into the base period and the mutation period. By constructing an ABCD hydrological model simulation and monthly scale Budyko model, the contribution rate of human and climate factors to the multitime-scale runoff of Jinsha River is calculated. The results showed that: (1) The sudden year of change in the Jinsha River runoff is 1978, and the Nash coefficients of the ABCD hydrological model in the base period and sudden change period were 0.85 and 0.86, respectively. (2) Climate factors were the dominant factor affecting annual runoff changes (98.62%), while human factors were the secondary factor affecting annual runoff changes (1.38%). (3) The contribution rates of climate factors in spring, summer, autumn, and winter to runoff were 91.68%, 74.08%, 95.30%, and 96.15%, respectively. The contribution rates of human factors in spring, summer, autumn, and winter to runoff were 8.32%, 25.92%, 4.70%, and 3.85%, respectively. (4) The contribution rates of climate factors to runoff in May, June, and July were 95.14%, 102.15%, and 87.79%, respectively. The contribution rates of human factors to runoff in May, June, and July were 4.86%, −2.15%, and 12.21%, respectively.

Keywords: Jinsha River; runoff; climate; human; ABCD model; Budyko model

Citation: Yue, S.; Ji, G.; Huang, J.; Cheng, M.; Guo, Y.; Chen, W. Quantitative Assessment of the Contribution of Climate and Underlying Surface Change to Multiscale Runoff Variation in the Jinsha River Basin, China. *Land* **2023**, *12*, 1564. https://doi.org/10.3390/land12081564

Academic Editors: Assefa M. Melesse, Omid Rahmati and Khabat Khosravi

Received: 30 June 2023
Revised: 3 August 2023
Accepted: 5 August 2023
Published: 7 August 2023

1. Introduction

Runoff is one of the main sources of water available to humans. Many runoffs have changed significantly [1,2], and an increasing number of studies have focused on the drivers of runoff changes, of which climate change and human activities are considered to be the two main factors [3]. Numerous studies in recent years have shown that runoff in some watersheds is no longer consistent under the coupled effects of climate change and human activities [4,5]. However, these effects are so coupled and intertwined that it is difficult to quantify the impact of a single factor. Studying the effects of climate change and human activities on runoff also involve separating and quantifying the contributions of both. On the one hand, it helps to understand the interrelationship between hydrological processes and climate and environmental change, and on the other hand it can provide a scientific basis for issues such as water resources management [6]. The upper Jinsha River is part of the Yangtze River region, ecologically fragile, the lower reaches are densely populated and have a well-developed industrial and agricultural sector. The Jinsha River basin is rich in water resources and is also the largest hydropower base in China. The study of factors influencing the runoff of the Jinsha River can further strengthen the integrated management of water resources in the Jinsha River basin. Much work has been conducted by many researchers to distinguish between quantifying the impact of climate change and human activities on runoff.

Kang et al. [7] analyzed the multitime-scale runoff evolution patterns of the Yellow River Huayuankou hydrological station from 1956 to 2017. Research has found that interannual runoff shows a decreasing trend, with uneven distribution of annual inner diameter flow, mainly from July to October. Su et al. [8] studied the characteristics of runoff complexity changes in the upper reaches of the Yellow River at multiple time scales. Research has found that human activities have a stronger impact on annual and non-flood season runoff at a single time scale than during flood season, and have a stronger impact on flood season runoff at multiple time scales than during annual and non-flood seasons. The impact on runoff varies greatly at different time scales and periods. Wu et al. [9] used Mann–Kendall test and sliding t-test methods to analyze the characteristics and evolution trends of runoff in the Mekong River at multiple time scales, including annual, high and low water periods, and extreme days. Ye et al. [10] studied the runoff of the Pengchongjian small watershed from 1983 to 2014. The comparative law of the cumulant slope change rate is used to calculate the contribution rate of precipitation change, evapotranspiration and vegetation restoration to runoff change on seasonal and annual scales. The results show that on a seasonal scale, precipitation changes and evapotranspiration in spring and summer are the main reasons for the reduction of runoff depth. In autumn and winter, vegetation restoration plays a dominant role. On a yearly scale, evapotranspiration contributes the most to the reduction of runoff depth.

There are many studies on attribution analysis of runoff [11–15], and some scholars use the Budyko model to conduct attribution analysis of runoff changes. Yan et al. [16–18] calculated the contribution of climate and vegetation to runoff changes based on the Budyko model. Ji et al. [19] conducted attribution analysis of runoff in the source area of the Yellow River based on the Budyko model. Yang et al. [20] took the Yihe River Basin in Shandong Province as the research object, and based on hydrological and meteorological data from 1960 to 2016, quantitatively calculated the contribution rate of climate change and human activities to runoff change using the Budyko water heat coupling equilibrium equation. Li et al. [21] first analyzed the evolution trend of multiple factors such as hydrology, meteorology, vegetation, and socioeconomic factors in the Baihe River Basin using trend testing method, and then quantified the contribution rate of multiple factors to runoff changes using the Budyko framework that considers the time-varying characteristics of multiple factors. Liang et al. [22] used the Danghe River Basin as the research area and analyzed the characteristics of meteorological, underlying surface, and hydrological changes in the basin using methods such as linear tendency estimation. Based on the Budyko water heat coupling balance equation, they quantified the contributions of climate change and human activities to runoff changes.

The ABCD water balance model was proposed by Thomas [23] in 1981. The ABCD model is composed of four parameters: a, b, c, and d, which clearly includes the main hydrological processes. It has the advantages of clear concepts, fewer parameters and easy optimization, simple structure, good application at annual and monthly scales, and high simulation accuracy. By inputting potential evapotranspiration and precipitation data through this model, it can be used to simulate changes in soil water, base flow, groundwater, and actual evapotranspiration [24]. It has been widely applied in the field of scientific research. Peng et al. [25] compared a 12-month scale hydrological model in 153 basins with different climatic conditions in China, and the ABCD hydrological model showed good applicability. Wu et al. [26] used the ABCD hydrological model for runoff simulation of the Xinan River basin, and conducted sensitivity analysis on model parameters, believing that the model has high simulation accuracy and high applicability, and can be widely used in small and medium-sized basins in China. Li et al. [27] simulated long-term runoff based on the structural framework of four-month water balance models of ABCD, TWBM, VWBM and DWBM. The results show that the annual runoff simulation methods based on the four models can obtain satisfactory simulation accuracy in most basins, and the ABCD model is the most accurate.

For attribution identification, the selection of natural stages is very important. The sudden change in the runoff series may be caused by human activities or climatic factors, and the examination of the sudden change point of the runoff series can help to reasonably judge the identification of the time point when significant changes in runoff occur. Scholars have conducted a series of studies on the selection of mutation points, commonly used methods include the Mann–Kendall mutation detection [28], ordered clustering [29], and double cumulative curve method [30].

Several scholars [31–33] have studied to quantify the influence of natural and human factors on runoff based on the Jinsha River basin. Precipitation was found to be the dominant factor affecting runoff variability. Human activities have a smaller impact on runoff at the annual scale. Song et al. [34] analyzed the precipitation runoff characteristics of the Jinsha River basin, the result showed that the precipitation distribution in the area was rather uneven, with the main intra-annual distribution happening from June to September in small variation. Zhang et al. [35] found that both human and climatic influences on the Jinsha River runoff had a significant impact on it. Wang et al. [36] used relative importance analysis to study the causes of runoff changes in the upper Jinsha River in terms of previous runoff and rainfall, found that the factors influencing runoff in the upper Jinsha River are complex and have significant spatial and temporal heterogeneity, the factors that influence runoff vary throughout the year, the main ones being snowfall, evaporation, rainfall and runoff from the previous month. Zhang et al. [37] used statistical methods to examine the characteristics of runoff changes in four subregions of the Jinsha River basin, and comprehensively evaluated the contributions of climate change and human activities to runoff changes based on methods such as the Budyko elasticity method and the cumulative slope change ratio, and found that climate change dominated runoff changes in the upper Jinsha River and human activities were the main force behind runoff changes in the middle and lower Jinsha River. Chen Hua et al. [38] simulated the runoff of Jinsha River in consideration of the impact of human reservoir construction on the runoff, and the simulation effect was good. Zhang et al. [39–41] used a combination of hydrological simulation and numerical analysis to identify the response of the Jinsha River runoff characteristics to climate change, and found that climate change is the dominant factor in runoff changes.

Although the above studies have quantified the impact of climate change and human activities on runoff, they have only quantified the impact of climate and human activities on runoff on an annual scale. There are few studies on the impact of climate and human factors on runoff of Jinsha River from multiple time scales (annual, seasonal and monthly), which cannot accurately understand the process of annual runoff distribution changes and is not conducive to the allocation and regulation of water resources under changing conditions. In recent years, floods and droughts frequently occur in Jinsha River basin [42,43], which has caused serious impact on economic and social development. Ensuring water security is of strategic importance to the construction of the upper Yangtze River economic belt. Therefore, this paper quantifies the contribution of different factors to the change of runoff on multiple time scales (annual, seasonal and monthly). This paper first analyses the trend of Jinsha River runoff, and then applies the Mann–Kendall mutation test to analyze the runoff data to find the mutation years of Jinsha River runoff from 1970 to 2016. The study period was divided into a base period and a mutation period according to the mutation years. The actual evaporation and soil water storage of Jinsha River are obtained through the ABCD hydrological model. Budyko model was constructed to calculate the contribution rate of human and climate to the multitime-scale runoff change of Jinsha River. The research results are expected to provide scientific reference for the comprehensive planning and utilization of hydrology in the Jinsha River basin.

2. Materials and Methods

2.1. Research Area

The Jinsha River basin is located in the upper reaches of the Yangtze River in China, originating in the Tanggula Mountains, with a global geographic location between 90°23′ E–104°37′ E and 24°28′ N–35°46′ N. The Jinsha River basin includes the eastern part of the Qinghai Tibet Plateau and the Hengduan Mountains. It extends southward to the northern Yunnan Plateau and eastward to the southwest edge of the Sichuan Basin. It is located in the north of Yunnan Province and the eastern side of the Qinghai Tibet Plateau. It is the largest basin in Yunnan Province, with a vast basin, numerous tributaries, and abundant and stable river runoff. Jinsha River has a drainage area of 49.5×10^4 km^2. It is generally divided into three river sections: the upper section starts at the mouth of the Yushu Batang River in Qinghai Province, with Shigu as the boundary; the section from Shigu to the mouth of the Yabi River is the middle section; and the lower section ends at Yichang. The hydro energy resources in the basin amount to 113 million kW, accounting for about 16.7% of the country's hydro energy resources, which are extremely abundant. It ranks among the top hydro power bases in the country.

2.2. Data Sources

The runoff data of Jinsha River basin come from Pingshan Hydrological Station, which was changed into a water level station in 2012. After 2012, the observation data of Pingshan Hydrological Station have come from Xiangjiaba Hydrological Station located 2 km downstream of Xiangjiaba Reservoir, which is collectively referred to as Pingshan Hydrological Station in this paper.

The climate station data of Jinsha River basin were obtained from China Meteorological Administration (http://www.cma.gov.cn/ accessed on 1 June 2023). The dataset contains the daily meteorological data of all stations in the study area from 1969 to 2016. Using the annual precipitation data of the meteorological stations in the study area from 1969 to 2016, the average annual precipitation of Jinsha River basin is obtained by Kriging interpolation. The reference evapotranspiration of each meteorological station from 1969 to 2016 is calculated by Penman Monteith formula recommended by FAO, and then the average annual reference evaporation of Jinsha River basin is obtained by Kriging interpolation.

2.3. Research Methods

2.3.1. Mann–Kendall Trend Analysis Method

Commonly used nonparametric tests include the Mann–Kendall trend analysis test proposed by Mann [44] and Kendall [45]. The Mann–Kendall trend analysis method is a nonparametric statistics test method, which is not affected by a few outliers, has strong applicability and simple calculation, and is one of the most commonly used methods to analyze the change trend of meteorological and hydrological elements [46]. In this study, the Mann–Kendall trend analysis method was used to analyze the trends of runoff, precipitation and evaporation capacity of the Jinsha River from 1970 to 2016.

2.3.2. Concentration and Concentration Period

This method treats a vector as the monthly runoff of all months within a year, with the length of the vector representing the magnitude of the monthly runoff and the direction of the vector representing the month in which it is located. This method represents the number of days (365 days) in a year with a circumference (360°), and the azimuth angles h from January to December are 0°, 30°, 60°... 330°. The method accumulates the monthly runoff in a vector manner, and the ratio of the combined amount of each component to the annual runoff is the concentration degree of annual runoff (*RCD* year). The annual runoff concentration period (*RCP* year) is the tangent angle of the ratio of the annual components and, which can objectively reflect the time when the maximum runoff occurs in a year [47]. These Equations (1)–(5) are shown as follows:

$$R_x = \sum_{i=1}^{12} R_i sinh \quad (1)$$

$$R_y = \sum_{i=1}^{12} R_i sinh \quad (2)$$

$$R_{year} = \sum_{i=1}^{12} R_i \quad (3)$$

$$RCD_{year} = \sqrt{{R_x}^2 + {R_y}^2} / R_{year} \quad (4)$$

$$RCP_{year} = \arctan\left(\frac{R_x}{R_y}\right) \quad (5)$$

where R_i is the runoff volume of month i, R_{year} is the annual runoff volume, and R_x and R_y are synthetic vectors in the x, y directions, respectively.

2.3.3. ABCD Water Balance Model

The ABCD model consists of two parts, the soil aquifer and the groundwater layer, and is based on the water balance principle. The water balance Equation (6) can be expressed as:

$$P_t - ET_t - DR_t - GR_t = S_t - S_{t1} \quad (6)$$

where P_t is the monthly rainfall, ET_t is the actual monthly evaporation, DR_t is the direct surface runoff, GR_t represents Groundwater recharge, and S_t and S_{t1} represent the soil moisture content of the current and previous months.

According to the above equation, the effective water quantity W_t and the possible evaporation Y_t can be obtained, shown in Equations (7) and (8):

$$W_t = S_{t1} + P_t = S_t + ET_t + GR_t + DR_t \quad (7)$$

$$Y_t = S_t + ET_t \quad (8)$$

The potential evapotranspiration Y_t is the maximum amount of water that can leave the basin in the form of evaporation, while the effective water W_t is the sum of the potential evapotranspiration and the outflow from the soil aquifer (including direct surface runoff and groundwater recharge). Possible evaporation Y_t can be expressed as a nonlinear function of effective water W_t, shown in Equation (9):

$$Y_t = \frac{W_t + b}{2a} - \sqrt{\frac{W_t + b^2}{2a} - \frac{bW_t}{a}} \quad (9)$$

where a is the probability of runoff formation before the soil is fully saturated, and parameter b is the upper limit of water storage in the unsaturated aquifer.

The ABCD model assumes that the ratio between the rate of decrease in soil water content S due to evapotranspiration and the potential evapotranspiration is S_t/b, shown in Equations (10) and (11):

$$\frac{d_{st}}{d_t} = -E_P \frac{S_t}{b} \quad (10)$$

$$S_t = Y_t exp(\frac{-E_p}{b}) \quad (11)$$

where E_p represents the potential evaporation. In this study, the potential evapotranspiration is calculated using Penman's equation.

For the groundwater layer component, the water balance Equation (12) is shown below:

$$G_t + GD_t = G_{t1} + GR_t \tag{12}$$

where GD_t is groundwater runoff, GR_t is groundwater recharge, groundwater storage for the current month and the previous month are G_t and G_{t1}, respectively, and groundwater recharge GR_t and groundwater runoff GD_t can be expressed as Equations (13) and (14), respectively:

$$GR_t = c(W_t - Y_t) \tag{13}$$

$$GD_t = dG_t \tag{14}$$

where Parameter c is the proportion of groundwater recharge to the soil aquifer, parameter d is the rate at which groundwater forms outflow, $GR_t + GD_t$ is the sum of surface runoff and subsurface runoff.

Due to hydrological observation errors, prediction model structure, and uncertainty in parameter estimation, errors in runoff forecasting are inevitable. The Nash certainty coefficient NSE is the most commonly used indicator to evaluate the degree of fitting between simulated and observed values. The ABCD model parameters in this paper refer to the study of Han [48].

2.3.4. Budyko Model

The water heat coupling balance equation based on Budyko's hypothesis analyzes the impact of climate change and human activities on runoff from the perspective of water and energy balance. Compared to other methods, this method can directly calculate the contribution of climate change and underlying surface change to runoff change, and the data are easy to obtain and the calculation method is simple, so it is widely used. Based on the seasonal scale Budyko model proposed by Chen et al. [49], the contribution rates of climate and humans to runoff are calculated, Equation (15) in Turc–Pike form is used as follows:

$$\frac{E}{P - \Delta S} = \left[1 + \left(\frac{E_P}{P - \Delta S} - \varphi\right)^{-\omega}\right]^{\frac{1}{\omega}} \tag{15}$$

where $\frac{E_P}{P-\Delta S}$ is the drought index, $\frac{E}{P-\Delta S}$ is the evaporation rate, φ is the lower bound of the drought index, ΔS represents the soil water storage variable (which cannot be ignored in the monthly time scale), and ω represents the parameters of the underlying surface (used to characterize the impact of human activities).

Solve the monthly Budyko model using the vertical decomposition method. The vertical decomposition method believes that climate change affects runoff by changing effective precipitation and potential evaporation, while human activities change the distribution ratio of effective precipitation between evaporation and runoff [50]. The impact of climate change can induce both horizontal and vertical components, both of which can affect runoff, but direct human interference can only induce vertical components.

Runoff can be obtained from Equation (16), and the change amount of runoff affected by human activities can be obtained from Equation (17). This model can calculate the contribution of direct human interference to runoff change. Equations (16) and (17) are as follows:

$$R = (P - \Delta S)\left(1 - \frac{E}{P - \Delta S}\right) \tag{16}$$

$$\Delta R_h = (P_2 - \Delta S_2)\left(\frac{E_2'}{P_2 - \Delta S_2} - \frac{E_2}{P_2 - \Delta S_2}\right) \tag{17}$$

where $\frac{E_2'}{P_2-\Delta S_2}$ and $\frac{E_2}{P_2-\Delta S_2}$ are the vertical coordinate values of B and C points with the same horizontal axis in the model.

The total diameter rheological amount Equation (18) is as follows:

$$\Delta R = R_2 - R_1 \tag{18}$$

where R_1 and R_2 represents the runoff of two periods. The amount of runoff caused by climate change is the difference between the total runoff and the runoff caused by human activities. Equation (19) is as follows:

$$\Delta R_c = \Delta R - \Delta R_h \tag{19}$$

On this basis, the contribution of human activities and climate change to the amount of runoff change can be calculated using Equations (20) and (21):

$$\eta_{R_h} = \frac{\Delta R_h}{\Delta R} \times 100\% \tag{20}$$

$$\eta_{R_c} = \frac{\Delta R_c}{\Delta R} \times 100\% \tag{21}$$

where η_{R_h} and η_{R_c} indicate the contribution of human activities and climate change to runoff changes, respectively.

3. Results

3.1. Mann–Kendall Trend Test

The regional monthly, seasonal and annual scale runoff was analyzed separately using the Mann-Kendall trend test and the results are as follows (Table 1):

Table 1. Runoff change of Jinsha River in different time scales from 1970 to 2016.

Month	β (mm/a)	Z Statistic	Significant Level
January	0.08	4.35	0.01
February	0.06	4.04	0.01
March	0.08	4.87	0.01
April	0.05	3.24	0.01
May	0.00	0.00	-
June	−0.10	−1.22	-
July	0.01	0.04	-
August	−0.07	−0.47	-
September	0.05	0.25	-
October	−0.05	−0.40	-
November	−0.01	−0.28	-
December	0.01	0.24	-
spring	0.14	2.98	0.01
summer	0.01	0.08	-
autumn	−0.10	−0.36	-
winter	0.14	3.60	0.01
year	0.45	0.83	-

Over the period 1970–2016, on a monthly scale, the runoff of the Jinsha River decreased at a rate of 0.10 mm/a in June, and the runoff of the Jinsha River increased significantly at a level of 0.01 in January and March, both at a rate of 0.08 mm/a. On a seasonal scale, the runoff of the Jinsha River increased significantly at a level of 0.01 in spring and winter, both at a rate of 0.14 mm/a. On an annual scale, the annual runoff rate (0.45 mm/a) was more variable than the other scales.

3.2. Changes in Characteristics during the Year

The Jinsha River runoff data from 1970–2016 were divided into five chronological periods for analysis: 1970–1979, 1980–1989,1990–1999, 2000–2009 and 2010–2016 (Figure 1).

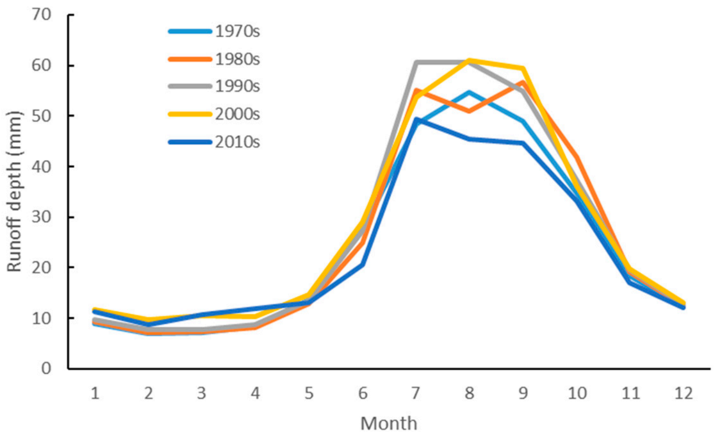

Figure 1. Changes in Runoff Trends by Age.

From 1970–2016, the overall trend in runoff is generally consistent across all years, with a slow increase from January to May and a sharp increase from May to a high in July. The runoff remains high from July until September, then drops sharply from September to December, with only the 2010s seeing a slow decline from July onwards. Overall, July to September is the high runoff period.

The concentration and concentration periods were calculated separately for the five decades from 1970 to 2016, and the results show (Table 2) that the inter-decade variation of the RCD of the Jinsha River runoff concentration is large, with the highest value being 49.96% (1990s) the lowest value being 41.30% (2010s), and the RCD shows an overall decreasing trend. In terms of the runoff concentration RCP during the year, there is little inter-decade variation, with a maximum value of 234.12° (1990s) and a minimum value of 229.93° (1980s), with the exception of the 1980s, which is generally relatively stable, with the runoff concentration period in August for all five decades.

Table 2. Results of RCD and RCP in Different Ages.

	RCD/%	RCP/(°)	Time of RCP Maximum Runoff
1970s	48.14	233.62	August
1980s	49.45	229.93	August
1990s	49.96	234.12	August
2000s	46.19	233.48	August
2010s	41.30	233.59	August

3.3. Mutation Analysis

Based on the Mann–Kendall trend analysis method to analyze the mutation of the Jinsha River runoff from 1970 to 2016, the Mann–Kendall mutation test is generally considered to be reliable at the 0.05 level of significance in practical applications. When the two lines intersect and the intersection point falls within the 0.05 level of significance, the time of the intersection point is considered to be the time of the mutation of the time series data.

The results of the study (Figure 2) showed that abrupt changes in Jinsha River runoff began to occur with 1978 as the inflection point, and 1978 was the year of abrupt change in Jinsha River runoff, so the study period was divided into two time periods for the study: the base period (1970–1978) and the abrupt change period (1979–2016).

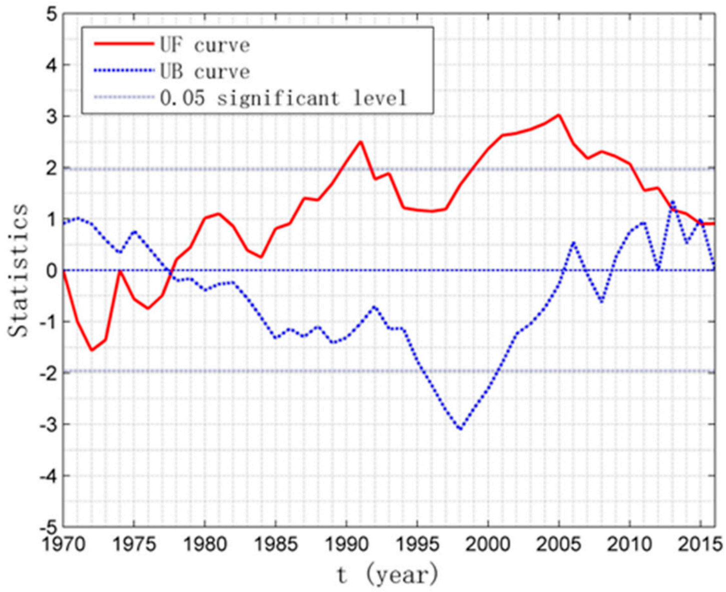

Figure 2. MK Mutation Analysis Results.

3.4. ABCD Hydrological Simulation

To eliminate data fluctuations in the initial years, a one-year warm-up period was added to each study period, and precipitation, reference evaporation, and runoff data were studied for two time periods, 1969–1978 and 1978–2016, based on the ABCD hydrological model.

The parameters for this study showed in Table 3, where the NSE values were all greater than 0.85. Figures 3 and 4 show that the observed and simulated values fit well, indicating good simulation accuracy. From this, the actual evaporation and soil water storage changes were obtained.

Table 3. NSE and parameters of ABCD model in different periods.

	NSE	a	b	c	d
Value ranges	$-\infty$~1	0~1	0~1000	0~1	0~1
Base period	0.85	0.89	449.78	0.10	0.70
Mutation period	0.86	0.89	449.99	0.10	0.69

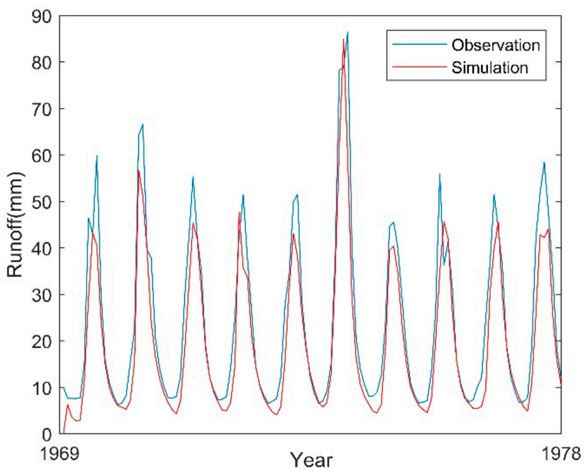

Figure 3. Runoff simulation from 1969 to 1978.

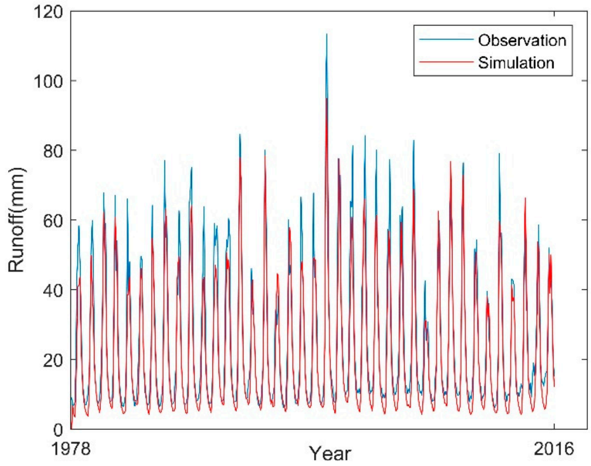

Figure 4. Runoff simulation from 1978 to 2016.

3.5. Attribution Analysis

The vertical decomposition method based on seasonal scales distinguishes between quantifying the effects of climate change and human activities on runoff depth, fitting Budyko curves for annual, four seasons, and the months of May, June and July. Table 4 shows the parameter values for fitting Budyko curves at each time scale.

Table 4. Parameters Results of Base Period Extended Budykyo Model Fitting.

Timescale	Parameter	
	ω	ϕ
spring	0.9225	−0.4295
summer	1.1608	0.0880
autumn	1.1730	0.1811
winter	0.7789	−0.5840
5	0.8215	−1.4782
6	1.1642	0.1469
7	1.2253	0.1108
year	1.0418	0.1907

Analyzing the changes of precipitation, evaporation and water storage in the base period and the mutation period of the Jinsha River, it can be seen from Table 5 that for precipitation, the spring precipitation of the Jinsha River increased from 109.3 mm in the base period to 112.82 mm in the mutation period, an increase of 3.52 mm. Summer precipitation increased from 292.76 mm in the base period to 297.04 mm in the mutation period, an increase of 4.28 mm. The precipitation in autumn increased from 193.06 mm in the base period to 207.14 mm in the mutation period, an increase of 14.08 mm. The winter precipitation increased from 73.25 mm in the base period to 75.94 mm in the mutation period, an increase of 2.69 mm. Precipitation in May increased from 46.56 mm in the base period to 46.67 mm in the mutation period, an increase of 0.10 mm. Precipitation in June decreased by 2.27 mm from 72.69 mm in the base period to 70.42 mm in the mutation period. Precipitation in July increased from 107.55 mm in the base period to 112.93 mm in the mutation period, an increase of 5.38 mm. The annual precipitation increased from 668.37 mm in the base period to 692.95 mm in the mutation period, an increase of 24.57 mm. In terms of seasons, the Jinsha River has the highest precipitation in summer and the least precipitation in winter, and the precipitation in the two periods changes the most in autumn and the least in winter. In terms of months, the Jinsha River receives the most precipitation in July, and the most significant change in precipitation in the two periods is also in July. Precipitation changes were least significant in May.

Table 5. Characteristic values of meteorological and hydrological data in different periods.

Time Scale	Base Period *P*/mm	Mutation Period *P*/mm	Change Value *P*/mm	Base Period *Ep*/mm	Mutation Period *Ep*/mm	Change Value *Ep*/mm	Base Period △*S*/mm	Mutation Period △*S*/mm	Change Value △*S*/mm
Spring	109.30	112.82	3.52	79.74	80.86	1.12	17.56	23.18	5.62
Summer	292.76	297.04	4.28	158.95	161.68	2.73	−84.07	−108.65	−24.58
Autumn	193.06	207.14	14.08	93.64	95.51	1.87	48.51	60.26	11.76
Winter	73.25	75.94	2.69	45.18	44.57	−0.61	57.53	58.41	0.88
May	46.56	46.67	0.10	32.59	33.18	0.59	−10.53	−6.53	4.00
June	72.69	70.42	−2.27	43.81	44.82	1.01	−38.02	−47.99	−9.97
July	107.55	112.93	5.38	57.50	58.37	0.87	−41.59	−40.57	1.02
Year	668.37	692.95	24.57	377.50	382.62	5.12	39.53	33.20	−6.32

In terms of evaporation, the spring evaporation of Jinsha River increased from 79.74 mm in the base period to 80.86 mm in the mutation period, an increase of 1.12 mm. The evaporation in summer increased from 158.95 mm in the base period to 161.68 mm in the mutation period, an increase of 2.73 mm. The evaporation in autumn increased from 93.64 mm in the base period to 95.51 mm in the mutation period, an increase of 1.87 mm. The evaporation in winter decreased from 45.18 mm in the base period to 44.57 mm in the mutation period, a decrease of 0.61 mm. The evaporation in May increased from 32.59 mm in the base period to 33.18 mm in the mutation period, an increase of 0.59 mm. The evaporation in June increased from 43.81 mm in the base period to 44.82 mm in the mutation period, an increase of 1.01 mm. The evaporation in July increased from 57.50 mm in the base period to 58.37 mm in the mutation period, an increase of 0.87 mm. The annual evaporation increased from 377.50 mm in the base period to 382.62 mm in the mutation period, an increase of 5.12 mm. In terms of seasons, Jinsha River has the largest evaporation in summer, three times the evaporation in summer, the largest change in evaporation in the two periods in summer, and the smallest change in winter. In terms of months, the Jinsha River evaporation was the largest in July, and the difference between the two periods of evaporation was largest in June.

In terms of soil water storage, the spring water storage of Jinsha River increased from 17.56 mm in the base period to 23.18 mm in the mutation period, an increase of 5.62 mm. The water storage in summer was reduced from −84.07 mm in the base period to −108.65 mm in the mutation period, a decrease of 24.58 mm. The water storage in autumn increased from 48.51 mm in the base period to 60.26 mm in the mutation period, an increase of 11.76 mm. The water storage in winter increased from 57.53 mm in the base period to 58.41 mm in the mutation period, an increase of 0.88 mm. The water storage in June decreased from −38.02 mm in the base period to −47.99 mm in the mutation period, a decrease of 9.97 mm. The water storage in July increased from −41.59 mm in the base period to −40.57 mm in the mutation period, an increase of 1.02 mm. The annual water storage decreased from 39.53 mm in the base period to 33.20 mm in the mutation period, a decrease of 6.32 mm. In terms of seasons, the two periods of the Jinsha River have the greatest variation in summer and the smallest change in winter. In terms of months, June saw the largest change in water storage and the smallest change in July.

Based on the vertical decomposition method, the contribution rate of climate factors and human factors to runoff can be obtained by quantifying the impact of climate change and human activities on runoff (Table 6). On the seasonal scale, in spring, climatic factors increased the runoff of Jinsha River by 2.20 mm, with a contribution rate of 91.68%, and human factors increased the runoff by 0.20 mm, with a contribution rate of 8.32%. In summer, climatic factors increased the runoff of Jinsha River by 1.15 mm, with a contribution rate of 74.08%, and human factors increased the runoff by 0.40 mm, with a contribution rate of 25.92%. In autumn, climatic factors increased the runoff of Jinsha River by 11.63 mm, with a contribution rate of 95.30%, and human factors increased the runoff by 0.57 mm, with a contribution rate of 4.70%. In winter, climatic factors increased the runoff of Jinsha River by 3.18 mm, with a contribution rate of 96.15%, and human factors increased the runoff by 0.13 mm, with a contribution rate of 3.85%. Climatic factors have a greater impact on runoff in autumn than in the other three seasons, and climatic factors contribute more to runoff in winter than in the other three seasons. Human factors contribute more to runoff in summer than in the other three seasons, and human factors have a greater impact on runoff in autumn than in the other three seasons.

Table 6. Climate and human contribution to runoff at different timescales.

	Runoff(mm)		**Contribute**	
	Climate	**Human**	**Climate**	**Human**
Spring	2.20	0.20	91.68%	8.32%
Summer	1.15	0.40	74.08%	25.92%
Autumn	11.63	0.57	95.30%	4.70%
Winter	3.18	0.13	96.15%	3.85%
May	−0.46	−0.02	95.14%	4.86%
June	−3.36	0.07	102.15%	−2.15%
July	3.96	0.55	87.79%	12.21%
Year	19.19	0.27	98.62%	1.38%

On the monthly scale, in May, climatic factors reduced the runoff of Jinsha River by 0.46 mm, with a contribution rate of 95.14%, and human factors reduced the runoff by 0.02 mm, with a contribution rate of 4.86%. In June, climatic factors reduced the runoff of the Jinsha River by 3.36 mm, contributing 102.15%, and human factors increased the runoff by 0.07 mm, contributing −2.15%. In July, climatic factors increased the runoff of Jinsha River by 3.96 mm, with a contribution rate of 87.79%, and human factors reduced the runoff by 0.55 mm, with a contribution rate of 12.21%. Climatic factors had a greater impact on runoff in July than in the other two months, and climatic factors contributed more to runoff in June than in the other two months. Human factors contributed more to runoff in July than in the other two months, and had a greater impact on runoff in July than in the other two months.

On the year scale, climatic factors increased the runoff of Jinsha River by 19.19 mm, with a contribution rate of 98.62%, and human factors reduced the runoff by 0.27 mm, with a contribution rate of 1.38%. On the whole, the influence of climatic factors on the change of runoff is the dominant factor, the influence of human factors on the change of runoff accounts for a secondary factor, and the large impact of human factors is mainly in summer and July, which may be due to human regulation and storage of river water, irrigation of farmland, and hydroelectric power generation during the period of high water.

4. Discussion

The sixth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) pointed out that the rapid development of the global economy has aggravated the magnitude of climate change. The series of global environmental issues caused by global climate change are seriously troubling human society, posing a serious threat to the security of ecosystems and socioeconomic development. Climate change, as the main driving factor of the water cycle, has a direct impact on all aspects of the hydrological cycle. Zhang et al. [31] found in their research on the influencing factors of runoff in the middle reaches of Jinsha River that on an annual scale, human activities have less impact on runoff than climate factors, and climate is still the main influencing factor of runoff change. This article is consistent with Zhang et al.'s research.

The Jinsha River belongs to the upper reaches of the Yangtze River. Previous studies mainly focused on the interannual variation of the runoff of the Jinsha River, but this was insufficient to reveal the specific characteristics of the runoff of the Jinsha River. It can be seen from Figure 1 that the runoff of the Jinsha River is the greatest from July to September. Bian et al. [51] found that the main flood season of the middle and lower reaches of the

Yangtze River mainly occurs from July to September, which is consistent with this study. If a large flood occurs in the Jinsha River in the upper reaches of the Yangtze River, the flooding in the middle and lower reaches of the Yangtze River will be more serious, helping to further understand the flood season hydrological change characteristics of Jinsha River basin. It will help the government to make accurate, timely and effective decisions. In order to avoid the harm of flood to human life and property, it is necessary to study the runoff of Jinsha River from multiple time scales. For the months with large runoff, on the one hand, there is a certain amount of glaciers and snow cover in the Jinsha River Basin. Due to the high temperature from July to September, the rising temperature not only increases the evaporation loss, but also causes the rapid melting of glaciers, which can further supplement the runoff to a certain extent. On the other hand, due to the abundant rainfall period from July to September, the runoff from July to September was supplemented. Months with less runoff may be due to increased evaporation due to higher watershed temperatures, which consumes more water and reduces runoff. As the main carrier of water resources in the basin, runoff can be directly used by people for industrial and agricultural production and drinking. Population increase and industrial and agricultural development will lead to a reduction of runoff. The water demand of wheat crops in spring is large, and agricultural water diversion irrigation and groundwater exploitation will affect the development and utilization of water resources in the basin. The water conservancy projects constructed by humans will change the natural path of water circulation and, to some extent, increase evaporation. Hydropower stations and other facilities have a great influence on the regulation of river runoff [52,53], especially when hydropower stations operate at full load for power generation and flood control, and the runoff will be reduced. According to the contribution and influence of climate and human on runoff, the runoff of Jinsha River shows the characteristics of summer > autumn > spring > winter.

Lu et al. [54] believed that the annual temperature and flow of the Jinsha River had no significant correlation, but the seasonal temperature and runoff showed a good positive correlation. This also indirectly confirms the necessity of studying runoff at the seasonal scale. The contribution of climate factors to the runoff of Jinsha River in summer has significantly decreased, while the contribution of human beings to the runoff in summer has significantly increased. This may be due to the high temperature in summer, resulting in the greatest evaporation. At the same time, human intervention in runoff is relatively large in summer. Human use water conservancy facilities to regulate runoff in dry and flood seasons, reduce floods, and ensure people's production and living water in dry seasons. Humans may also carry out cloud seeding for irrigation.

In the quantitative calculations of this article, we used runoff data from a hydrological station for research, which may not fully represent the actual situation of the entire river. In addition, due to the fact that precipitation, evaporation, and soil water storage are classified as climate factors in this article, while other factors are classified as human activities, there may be insufficient accuracy in the calculation and analysis. This study assumes that climate change and the impact of human activities on runoff are two independent variables, while, in fact, human activities also have a mutual impact on climate change. The intensification of drought and enhanced evaporation will reduce runoff, which means a decrease in groundwater level and soil moisture. It will inevitably limit the amount of water used for regional agricultural irrigation and manual extraction, thereby having adverse effects on industrial and agricultural production and social development. Vegetation factors are also important factors affecting runoff. The Chinese government has implemented a large number of large-scale ecological restoration projects, such as the Grain for Green and grassland project, which has improved the vegetation coverage in the Jinsha River basin. The interception effect of vegetation can weaken runoff, and vegetation factors can be considered in subsequent research.

5. Conclusions

This paper quantitatively analyzed the contribution rate of different factors to the runoff change of Jinsha River at multiple time scales (year, season, month). First, the trend analysis of Jinsha River runoff was carried out, and then the Mann–Kendall catastrophe test method was used to find the abrupt year of change of Jinsha River runoff from 1970 to 2016. The research period was divided into the baseline period and mutation period based on the year of mutation. The actual evaporation and precipitation of Jinsha River were obtained through the ABCD hydrological model, and the data of Jinsha River were divided by year, month and season. The Budyko model was used to calculate the impact and contribution rate of human and climate on the runoff of Jinsha River at multiple time scales (year, season and month). Research showed that:

(1) The Nash coefficients of the ABCD hydrological model in the base period and catastrophe period were 0.85 and 0.86, respectively, indicating that the ABCD hydrological model simulates the runoff changes of the Jinsha River well.

(2) Climate factors were the dominant factor affecting annual runoff changes (98.62%), while human factors were the secondary factor affecting annual runoff changes (1.38%).

(3) The contribution rates of climate factors in spring, summer, autumn, and winter to runoff were 91.68%, 74.08%, 95.30%, and 96.15%, respectively. The contribution rates of human factors in spring, summer, autumn, and winter to runoff were 8.32%, 25.92%, 4.70%, and 3.85%, respectively.

(4) The contribution rates of climate factors to runoff in May, June, and July were 95.14%, 102.15%, and 87.79%, respectively. The contribution rates of human factors to runoff in May, June, and July were 4.86%, −2.15%, and 12.21%, respectively.

This study quantitatively distinguished the impacts of climate change and human activities on runoff at different time scales, providing valuable reference for the scientific and refined management and sustainable utilization of regional water resources. It is suggested that from July to November, lakes and depressions can be used for flood storage, or embankments can be reinforced, river channels can be dredged, and river channels can be regulated to regulate water volume and do a good job in flood control. In basins with large drops, reservoirs can be built to develop hydropower. We should further strengthen people's awareness of water conservation, improve the utilization rate of water resources, continuously promote the construction of a water-saving society, do a good job in afforestation, and prevent soil erosion. Ensure the coordinated and sustainable development of the socioeconomic and ecological environment in the watershed.

Author Contributions: Conceptualization: J.H.; methodology: G.J.; data curation: G.J.; writing-original draft preparation and review and editing: S.Y. and M.C.; project administration: Y.G. and W.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Henan Soft Science Research Project (232400410328), the Research Project of Henan Federation of Social Sciences (2023-ZZJH-189) and the National Key R&D Program of China (2021YFD1700900).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wang, G.Q.; Zhang, J.Y.; Guan, X.X.; Bao, Z.X.; Liu, Y.L.; He, R.M.; Jin, J.L.; Liu, C.S. Quantifying attribution of runoff change for major riversin China. *Adv. Water Sci.* **2020**, *31*, 313–323.
2. Zhang, J.Y.; Wang, G.Q.; Jin, J.L.; He, R.M.; Liu, C.S. Evolution and variation characteristics of the recorded runoff for the major rivers in China during 1956–2018. *Adv. Water Sci.* **2020**, *31*, 153–161.
3. Piao, S.L.; Ciais, P.; Huang, Y.; Shen, Z.H.; Peng, S.S.; Li, J.S.; Zhou, L.; Liu, H.; Ma, Y.; Ding, Y.; et al. The impacts of climate change on water resources and agriculture in China. *Nature* **2010**, *467*, 43–51. [CrossRef]
4. Milly, P.C.D.; Dunne, K.A.; Vecchia, A.V. Global pattern of trends in streamflow and water availability in a changing climate. *Nature* **2005**, *438*, 7066. [CrossRef] [PubMed]

5. Field, C.B.; Barros, V.R.; Dokken, D.J.; Mach, K.J.; Mastrandrea, M.D. *Climate Change 2014 Impacts, Adaptation, and Vulnerability*; Cambridge University Press: Cambridge, UK, 2014.
6. He, Y.f.; Yang, H.B.; Tang, L.H.; Lei, H.M.; Yang, D.W. Attribution analysis of runoff change in Beidasha River Basin. *Water Resour. Prot.* **2022**, *38*, 95–101.
7. Kang, M.; Xiao, W.; Lu, F.; Wang, Y.; Hou, B.; Zhang, X. Analysis of Multitemporal Scale Runoff Evolution Regularity at Huayuankou Hydrological Station on the Yellow River. *People's Yellow River* **2022**, *44*, 25–29.
8. Su, X.; Li, X.; Wang, Y.; Lu, C.; Wang, N. Research on the Characteristics of Runoff Complexity Changes in the Upper Yellow River at Multiple Time Scales. *J. Water Resour. Water Eng.* **2021**, *32*, 1–10.
9. Wu, Y.; Guo, L.; Zeng, T.; Li, Q.; Jing, P. Study on the Characteristics of Multitemporal Scale Variations of Mekong River Runoff. *China Rural. Water Resour. Hydropower* **2021**, *468*, 42–49.
10. Ye, J.; Liu, Z.; Ouyang, L.; Sheng, F.; Liu, S. Analysis of runoff changes and their attribution in small watersheds at different time scales. *J. Ecol.* **2019**, *39*, 4478–4487.
11. Ji, G.; Lai, Z.; Xia, H.; Liu, H.; Wang, Z. Future Runoff Variation and Flood Disaster Prediction of the Yellow River Basin Based on CA-Markov and SWAT. *Land* **2021**, *10*, 421. [CrossRef]
12. Ji, G.; Lai, Z.; Yan, D.; Wu, L.; Wang, Z. Spatiotemporal patterns of future meteorological drought in the Yellow River Basin based on SPEI under RCP scenarios. *Int. J. Clim. Chang. Strateg. Manag.* **2022**, *14*, 39–53. [CrossRef]
13. Ji, G.; Song, H.; Wei, H.; Wu, L. Attribution Analysis of Climate and Anthropic Factors on Runoff and Vegetation Changes in the Source Area of the Yangtze River from 1982 to 2016. *Land* **2021**, *10*, 612. [CrossRef]
14. Wang, Y.; Liu, Z.; Qian, B.; He, Z.; Ji, G. Quantitatively Computing the Influence of Vegetation Changes on Surface Discharge in the Middle-Upper Reaches of the Huaihe River, China. *Forests* **2022**, *13*, 2000. [CrossRef]
15. Liu, Y.; Chen, W.; Li, L.; Huang, J.; Wang, X.; Guo, Y.; Ji, G. Assessing the contribution of vegetation variation to streamflow variation in the Lancang River Basin, China. *Front. Ecol. Evol.* **2023**, *10*, 1058055. [CrossRef]
16. Yan, D.; Lai, Z.; Ji, G. Using Budyko-Type Equations for Separating the Impacts of Climate and Vegetation Change on Runoff in the Source Area of the Yellow River. *Water* **2020**, *12*, 3418. [CrossRef]
17. Ji, G.; Huang, J.; Guo, Y.; Yan, D. Quantitatively Calculating the Contribution of Vegetation Variation to Runoff in the Middle Reaches of Yellow River Using an Adjusted Budyko Formula. *Land* **2022**, *11*, 535. [CrossRef]
18. Ji, G.; Yue, S.; Zhang, J.; Huang, J.; Guo, Y.; Chen, W. Assessing the Impact of Vegetation Variation, Climate and Human Factors on the Streamflow Variation of Yarlung Zangbo River with the Corrected Budyko Equation. *Forests* **2023**, *14*, 1312. [CrossRef]
19. Ji, G.; Wu, L.; Wang, L.; Yan, D.; Lai, Z. Attribution Analysis of Seasonal Runoff in the Source Region of the Yellow River Using Seasonal Budyko Hypothesis. *Land* **2021**, *10*, 542. [CrossRef]
20. Yang, X.; Wu, W.; Zheng, C.; Wang, Q. Identification of attribution of runoff changes in the Yi River Basin based on the Budyko hypothesis. *Res. Soil Water Conserv.* **2023**, *30*, 100–106.
21. Li, M.; Zou, L.; Xia, J.; Wang, F.; Wang, Z. Analysis of the Evolution and Attribution of Runoff in the Baihe River Basin under the Budyko Framework. *Resour. Environ. Yangtze River Basin* **2023**, *32*, 774–782.
22. Liang, P.; Xin, H.; Li, Z.; Nan, F.; Tang, B.; Zhang, W. Attribution of runoff changes in Danghe River based on the Budyko hypothesis. *Desert China* **2023**, *43*, 210–219.
23. Thomas, H.A., Jr. *Improved Methods for National Water Assessment, Water Resources Contract: WR15249270*; Center for Integrated Data Analytics Wisconsin Science Center: Madison, WI, USA, 1981.
24. Zhao, S.T. *Characteristics of Runoff Variation and Quantitative Separation in Karst Area*; Guangxi University: Nanning, China, 2022.
25. Bai, P.; Liu, X.; Liang, K.; Liu, C. Comparison of performance of twelve monthly water balance models in different climatic catchments of China. *J. Hydrol.* **2015**, *529*, 1030–1040. [CrossRef]
26. Wu, G.; Xu, J.; Hoshin, G.; Zhang, X. The abcd water balance model and parameter sensitivity analysis in the Xin'an River Basin. *J. Yangtze River Acad. Sci.* **2019**, *36*, 23–27+40.
27. Li, S.; Du, T. Design and application of annual runoff simulation method based on monthly water balance model. *J. Yangtze River Acad. Sci.* **2022**, *39*, 21–26.
28. Li, B.M.; Zhang, J.Z.; Wu, X.; Li, S. Research on variation characteristics of runoff based on mann-kendall and orderly clustering method. *Haihe Water Resour.* **2012**, *02*, 37–38.
29. Cao, M.L.; Zhang, C.; Zhou, H.C.; Li, H.Y. Change trend of rainfall and runoff in upstream of Fengman basin under influence of human activities. *Hydrology* **2008**, *28*, 86–89.
30. Mu, X.M.; Zhang, X.Q.; Gao, P.; Wang, F. Theory of double mass curves and its application in hydrology and meteorology. *J. China Hydrol.* **2010**, *30*, 47–51.
31. Zhang, M.; Huang, X.R.; Wang, Y.J. Evolution process and influencing factors of runoff in Jinsha River Basin. *Water Resour. Sci.* **2022**, *40*, 27–31.
32. Zhang, X.F.; Yan, H.C.; Yue, Y.; Lu, Y.T. Changes and analysis of annual runoff in various sections of Jinsha River in the past 50 years. *Resour. Environ. Yangtze Basin* **2018**, *27*, 2283–2292.
33. Wei, X.Y.; Huang, X.R.; Pan, X.; Zhang, L. Response of runoff changes in the upper reaches of Jinsha River to climate in the past 60 years. *Hydroelectr. Power* **2019**, *45*, 12–17.
34. Song, M.B.; Li, T.X.; Chen, J.Q. Preliminary Analysis of Precipitation Runoff Features in the Jinsha River Basin. *Procedia Eng.* **2012**, *28*, 688–695.

35. Zhang, K.Y.; Yuan, X.; Lu, Y.; Guo, Z.P.; Wang, J.H.; Luo, H.M. Quantifying the Impact of Cascade Reservoirs on Streamflow, Drought, and Flood in the Jinsha River Basin. *Sustainability* **2023**, *15*, 4989. [CrossRef]
36. Wang, L.; Cao, H.; Li, Y.R.; Feng, B.F.; Qiu, H.; Zhang, H.R. Attribution Analysis of Runoff in the Upper Reaches of Jinsha River, China. *Water* **2022**, *14*, 2768. [CrossRef]
37. Zhang, D.; Wang, W.S.; Yu, S.Y.; Liang, S.Q.; Hu, Q.F. Assessment of the Contributions of Climate Change and Human Activities to Runoff Variation: Case Study in Four Subregions of the Jinsha River Basin, China. *J. Hydrol. Eng.* **2021**, *26*, 05021024. [CrossRef]
38. Chen, H.; Zhu, D.; Chen, Q.H.; Chen, J.H.; Guo, S.L. Simulation study on runoff of Jinsha River considering reservoir transfer and storage. *Geomat. Wuhan Univ. (Eng. Sci.)* **2022**, *55*, 13–21.
39. Zhang, X.F.; Yan, H.C.; Yue, Y.; Xu, Q.X. Quantifying natural and anthropogenic impacts on runoff and sediment load: An investigation on the middle and lower reaches of the Jinsha River Basin. *J. Hydrol. Reg. Stud.* **2019**, *25*, 100617. [CrossRef]
40. Wu, Y.Y.; Fang, H.W.; Huang, L.; Ouyang, W. Changing runoff due to temperature and precipitation variations in the dammed Jinsha River. *J. Hydrol.* **2020**, *582*, 124500. [CrossRef]
41. Jia, W.H.; Wu, Y.W.; Wang, S.; Chen, M.F.; Liu, X. Combined Impacts of ENSO and IOD on Streamflow: A Case Study of the Jinsha River Basin, China. *Water* **2022**, *15*, 45. [CrossRef]
42. Wu, G.Y.; Chen, J.; Chen, Q.H.; Gu, L.; Wang, H.M. Spatiotemporal variation of hydro-meteorological drought in Jinsha River Basin in recent 50 years. *Yangtze River* **2019**, *50*, 84–90.
43. Shen, J.H.; Yang, H.B.; Liu, Z.W.; Yang, D.W. Sensitivity analysis of annual runoff to annual variation of meteorological elements in upper reaches of the Yangtze River. *Water Resour. Prot.* **2023**, *39*, 119–126.
44. Mann, H.B. Nonparametric tests against trend. *Econometrica* **1945**, *13*, 246–259. [CrossRef]
45. Kendall, M.G. Rank Correlation Methods. *Br. J. Psychol.* **1990**, *25*, 86–91. [CrossRef]
46. Shi, H.L.; Hu, C.H.; Wang, Y.G.; Tian, Q.Q. Water and sediment change trend and its genesis analysis in Huaihe River Basin. *J. Hydraul. Eng.* **2012**, *43*, 9.
47. Liu, X.Z.; Li, J.Z.; Su, Q.; Wang, C.Z.; Li, X.G. Research on intra-annual distribution of runoff based on concentration degree and concentration period. *Sci. Geogr.* **2007**, *06*, 791–795.
48. Han, P.F. *Application and Parameter Characteristics of ABCD of Climate and Hydrological Model*; China University of Geosciences (Beijing): Beijing, China, 2016.
49. Chen, X.; Negin, A.; Wang, D. Modeling interannual variability of seasonal evaporation and storage change based on the extended Budyko framework. *Water Resour. Res.* **2013**, *49*, 6067–6078. [CrossRef]
50. Wang, D.; Alimohammadi, N. Responses of annual runoff, evaporation, and storage change to climate variability at the watershed scale. *Water Resour. Res.* **2012**, *48*, W05546. [CrossRef]
51. Bian, W.; Zhang, X. Analysis of flood encounter in Jinsha River and the middle and lower reaches of the Yangtze River. *Water Resour. Hydropower Bull.* **2002**, *23*, 8–10.
52. Huang, X.R.; Gao, L.Y.; Yang, P.P.; Xi, Y.Y. Cumulative impact of dam constructions on streamflow and sediment regime in lower reaches of the Jinsha River, China. *J. Mt. Sci.* **2018**, *15*, 2752–2765. [CrossRef]
53. Chen, Q.H.; Chen, H.; Zhang, J.; Hou, Y.K.; Shen, M.X.; Chen, J.; Xu, C.Y. Impacts of climate change and LULC change on runoff in the Jinsha River Basin. *J. Geogr. Sci.* **2020**, *30*, 85–102. [CrossRef]
54. Lu, L.; Wang, Q.; Wang, G.; Liu, Y.; Liu, C. Climate change trend and runoff response relationship of Jinsha River basin in recent 60 years. *J. N. China Univ. Water Resour. Electr. Power* **2016**, *37*, 16–21.