Variation of runoff between southern and northern China and their attribution in the Qinling Mountains, China

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Abstract Climate and underlying surface changes have a profound impact on runoff in the Qinling Mountains. This study attempts to identify the difference in runoff changes of two rivers in the south and north of China's south-north transitional zone under climate change. The Pettit test and Mann-Kendall test were used to investigate the abrupt change and trend analysis on runoff in the Ba River watershed and Jinqian River watershed from 1960 to 2014. The coupled energy-water balance equation based on the Budyko hypothesis estimated the climate and landscape elasticity of runoff followed by attribution analysis of runoff in these two watersheds. The results showed that annual runoff in the Jinqian River (in the southern Qinling Mountains) and the Ba River (in the northern Qinling Mountains) exhibited a significant decreasing trend at P<0.05 and P<0.01, respectively. Abrupt runoff changes occurred in 1989 and 1992 in the Ba River and Jinqian River, respectively. The attribution analysis showed that the change in potential evapotranspiration had little impact on runoff in the southern and northern Qinling Mountains. In contrast, the dominant factors leading to runoff reduction were the change in precipitation and catchment landscape. The contributions of climate change and land surface alteration to runoff changes in the Ba River watershed and Jinqian watershed were 38.08% and 61.92%, and 23.95% and 76.05%, respectively. This study can provide a scientific reference for water resource protection in the south-north transitional zone.

KEYWORDS

Budyko framework, runoff, climate change, human activities, Qinling Mountains

1 | INTRODUCTION

Global warming will intensify the hydrological cycle of precipitation, evaporation and runoff, change the temporal and spatial distribution of water resources, and change the utilization of water resources. Runoff is the main link associated with the water cycle (Oki and Kanae, 2006). Attribution identification of river and river runoff is the basis for formulating climate change response strategies and sustainable use of water resources (Zeng *et al*., 2020). Under the combined effect of global climate change and human activities on runoff in basins, significant runoff changes have occurred in many basins worldwide (Best, 2019).

Climate change and underlying surface change are the two main driving factors of runoff change. An increasing number of scholars have begun to focus on the influence and attribution of climate change and human activities on runoff change, e.g., Iran (Solaimani *et al*., 2020), China (Yang *et al*., 2015; Zheng *et al*., 2018; Li *et al*., 2019; Huo *et al*., 2020; Li *et al*., 2020), India (Saha *et al*., 2020), the United States (Zhang *et al*., 2019; Young *et al*., 2019), and European regions (Giovanna and Francesco, 2020). There are many methods to evaluate runoff changes (Zeng *et al*., 2020), such as hydrologic models (Wang *et al*., 2020), paired catchments (Brown *et al*., 2005), empirical statistics (He *et al*., 2017), and the Budyko framework (Yang *et al*., 2015; He *et al*., 2019a; Bai *et al*., 2020). As there are many parameters in the hydrologic model, it is difficult to model and calibrate parameters with strong uncertainty (Renard *et al*., 2010). The paired catchment method is often used in the comparative study of two small-scale catchments (usually < 1 km^2) in which the climate, soil, topography and underlying surface conditions are similar. Due to the lack of a physical mechanism, the application of empirical statistical models is limited to a region. The Budyko framework considers the interaction among various factors in the basin, and it is easy to calculate and widely used in relevant studies.

The Qinling Mountains, the watershed between the Yangtze River basin and Yellow River basin, is a transitional zone between northern and southern China that is highly sensitive to climate change and is also the birthplace of many rivers in China. The Jinqian River basin is located in the southern Qinling Mountains, belongs to the Han River basin and is an important source of water for the middle route of the south-to-north water diversion project in the Yangtze River basin. In contrast, the Ba River basin in the northern Qinling Mountains belongs to the Wei River basin, and it is the largest tributary of the Yellow River basin. To date, research has mainly been based on empirical statistical methods and hydrological models to analyse the characteristics and driving factors of runoff changes in different basins, but there are relatively few comparative studies on river runoff changes in different basins in the north-south transition zone. He *et al.* (2019b) analysed the runoff change in the Ba River watershed from 1958 to 2015 and pointed out that the underlying surface change was the main aspect affecting runoff (74.5%). Ma *et al*. (2013) used an empirical statistical method to suggest that runoff changes in the Ba River basin and Jinqian River watershed were the comprehensive effects of climate factors and human activities. Bai *et al*. (2012) used statistical methods to analyse the hydrological characteristics of the

Jinqian River watershed and concluded that the contribution of human activities to the reduction of runoff in the Qianqian River Basin was 46.6%. Compared with traditional empirical statistical methods, hydrologic models have a good physical basis, but their structure and parameters are uncertain, which reduces the credibility of the research results. Due to the limited number of parameters and clear physical significance, the Budyko framework is often used for quantitative analysis and the evaluation of the impact of climate change and underlying surface change on runoff change.

This paper aimed to compare and analyse runoff variation characteristics and the main influencing factors of the Ba River and Jinqian River in the southern and northern Qinling Mountains. The Budyko framework was used to reveal the response of runoff from typical watersheds in the southern and northern Qinling Mountains to climate change. The results provided a basis for water resource management in the Qinling Mountains under the background of climate change.

2 | STUDY AREA AND DATA

2.1 | Study region

The Jinqian River is in the southern Qinling Mountains and is a tributary of the Han River, the second tributary of the Yangtze River. The vegetation coverage in the Jinqian River watershed is high, and its population density is low. There are no large water conservation facilities in the watershed, and the natural environment is not substantially affected by humans. The hydrologic control station is the Nan Kuan Ping (NKP) hydrologic station (Figure 1).

The Ba River is the largest tributary of the Wei River in the northern Qinling Mountains. With a total length of 104 km, it is the second tributary of the Yellow River basin. The Ma Du Wang (MDW) hydrological station is the upstream control station of the Ba River watershed (Figure. 1).

FIGURE 1 The map of the watershed in the study area

2.2 | Data

The Nan Kuan Ping (NKP) hydrological station in the Jinqian River watershed south of the Qinling Mountains, the Ma Du Wang (MDW) hydrological station in the Ba River watershed north of the Qinling Mountains and 16 representative meteorological stations were selected for the accuracy, completeness and continuity of the data (Figure 1). The runoff of the two hydrological stations from 1960 to 2014 was obtained from the Yangtze River Hydrological Yearbook and the Yellow River Hydrological Yearbook. Data from the 16 meteorological stations for the same period included monthly precipitation, average maximum temperature, average minimum temperature, sunshine duration, average wind speed and relative humidity. The Penman-Monteith method (Allen *et al*., 1998) was used to calculate the potential evapotranspiration (ET_0). The areal mean rainfall and ET_0 were calculated by using the simple kriging spatial interpolation method (He *et al*., 2015).

The normalized difference vegetation index (NDVI) is the best indicator of the vegetation growth and vegetation coverage. The NDVI can reflect the underlying surface of the region under changes in climate and human factors. In this study, the NDVI used GIMMS NDVI3g data from 1982 to 2015 (https://ecocast.arc.nasa.gov/data/pub/gimms/3g.v1/), and the spatial resolution of the data was 8 km.

3 | METHODOLOGY

3.1 | Trend analysis and abrupt detection

The Mann-Kendall (MK) (Mann, 1945; Kendall, 1975) test was used to analyse the rainfall trend, ET_0, runoff and underlying surface parameters, and the Pettit test was used to perform abrupt tests on runoff (Pettitt, 1979). If the Z value of the statistic tested by the MK method is positive, it indicates an increasing trend of the sequence; and if the value is negative, it shows a decreasing trend. The critical values were ± 1.96 when the significance level was 0. 05 ± 2.58 at a significance level of 0. 01.

3.2 | Sensitivity analysis of the influencing factors on the runoff change

The actual evapotranspiration can be deduced from the water balance equation of the basin:

$$AET = P - R - \Delta W \qquad (1)$$

where P is precipitation (mm), R is runoff depth (mm), AET is actual evapotranspiration (mm), and ΔW represents the change in water storage in the watershed. On average, ΔW is negligible over man years; then, equation (1) can be expressed as:

$$AET = P - R \tag{2}$$

By combining equation (2) with the coupled energy-water balance equation of the basin deduced by Choudhury (1999), Roderick and Farquhar (2011), and Yang *et al*. (2015) that is based on the Budyko hypothesis, the following equation can be obtained:

$$\frac{AET}{P} = \frac{PET}{\left(P^{\omega} + PET^{\omega}\right)^{1/\omega}} \tag{3}$$

where PET is the annual ET_0 (mm) and ω is the underlying surface feature parameter. Combined with equations (2) and (3), the runoff depth is calculated as follows.

$$R = P - \frac{P \times PET}{\left(P^{\omega} + PET^{\omega}\right)^{1/\omega}} \tag{4}$$

where, R, P and PET are known, and ω can be deduced.

The elasticity coefficient ε_x of factor x is defined by the elasticity coefficient, which is the ratio of the change rate of runoff to the change rate of the factor.

$$\xi_x = \frac{\partial R}{\partial x} \times \frac{x}{R} \tag{5}$$

where x is the main factor affecting runoff change, and ε_x is the elastic coefficient of the factor.

The elasticity coefficient ε_x is positive, indicating that the runoff depth increases with the increase in this factor, whereas a negative value demonstrates the opposite trend. According to Equation (5), ε_P, ε_{PET} and ε_ω can be obtained.

3.3 | Contribution of different factors to runoff changes

The study sequence was divided into two periods according to the abrupt change points of runoff in the watershed, and the runoff change dR was the annual average runoff depth R2 in the latter period minus R1 in the previous period:

$$\mathrm{d}R = R_2 - R_1 \qquad (6)$$

Similarly, the precipitation change dP, potential evapotranspiration change dPET and underlying surface feature parameter change dω are calculated.

The sum of runoff change dR_P, dR_{PET} and dR_ω caused by the change in P, PET or ω is the calculated runoff depth change dR', which is expressed by the sum of the product of its change amount and partial derivative.

$$\mathrm{d}R' = \frac{\partial R}{\partial P}\mathrm{d}P + \frac{\partial R}{\partial PET}\mathrm{d}PET + \frac{\partial R}{\partial \omega}\mathrm{d}\omega \qquad (7)$$

Equation (7) can be simplified as:

$$\mathrm{d}R' = \mathrm{d}P + \mathrm{d}PET + \mathrm{d}\omega \qquad (8)$$

Substituting equation (5) into equation (8) can be expressed as:

$$\mathrm{d}R_x = \xi_x \frac{R}{x} dx \qquad (9)$$

The relative contribution of each factor to runoff change is

$$C_x = \frac{\mathrm{d}R_x}{\mathrm{d}R'} \times 100\% \qquad (10)$$

where C_x is the contribution rate of P, PET or ω to runoff change.

4 | RESULTS

4.1 | Changes in Runoff and Environmental Factors

During the study period, the average annual runoff, rainfall, ET_0 and ω of the northern Qinling Mountains were 4.62×10^8 m^3, 670.6 mm, 948.9 mm and 1.027, respectively. The annual average runoff, rainfall, ET_0 and ω of the southern Qinling Mountains were 9.50×10^8 m^3, 723.4 mm, 923.6 and 1.462, respectively. The changes in runoff, rainfall, ET_0 and ω in the southern and northern Qinling Mountains were synchronized, and runoff, rainfall, and ET_0 all showed a downward trend except that ω showed an upward trend (Figure 2-5). The annual average runoff, rainfall and ω in the northern Qinling Mountains are smaller than those in the southern Qinling Mountains, whereas ET_0 in the northern Qinling Mountains is greater than that in the southern Qinling Mountains. In both the northern and southern Qinling Mountains, the coefficients of variation (CV) of runoff are greater than those of other environmental factors, indicating that the change in environmental factors is more stable than runoff. The MK test shows that the runoff on the southern and northern Qinling Mountains has a significant decreasing trend, ω has a significant increasing trend, and rainfall and ET_0 have insignificant trends (Table 1). According to the Budyko framework, an increase in ω will decrease runoff, and a decrease in rainfall will also reduce runoff. In the southern and northern Qinling Mountains, the changing trend of ω shows a significant increase and the changing trend of rainfall is insignificant, suggesting that ω may play a major role in decreasing the runoff.

The abrupt change point of runoff at the MDW hydrological station in the northern Qinling Mountains occurred in 1989 (Figure 6). Similarly, the abrupt change point of runoff at the NKP hydrological station in the southern Qinling Mountains occurred in 1992 (Figure 7). Therefore, for the MDW hydrological station, the study period is divided into two periods: 1960-1989 and 1990-2014. For the NKP hydrological station, the study period is divided into two periods: 1960-1992 and 1993-2014.

TABLE 1 Changes in runoff and environmental factors at the MDW and NKP hydrological stations in the northern and southern Qinling Mountains during 1960-2014

FIGURE. 2 Changes in the runoff in the northern and southern Qinling Mountains during 1960-2014

FIGURE 3 Changes in rainfall in the northern and southern Qinling Mountains during 1960-2014

FIGURE 4 Changes in ET_0 in the northern and southern Qinling Mountains during 1960-2014

FIGURE 5 Changes in ω in the northern and southern Qinling Mountains during 1960-2014

FIGURE 6 Abrupt change in runoff at the MDW hydrological station in the northern Qinling Mountains during 1960-2014

FIGURE 7 Abrupt change in runoff at the NKP hydrological station in the southern Qinling Mountains during 1960-2014

4.2 | Elasticity of runoff for environmental factors

The environmental factors, underlying surface feature parameters and elastic coefficients of the southern and northern Qinling Mountains in each period are shown in Table 2. Compared with the baseline period (period I), the environmental factors and R/P of the southern and northern Qinling Mountains decreased, whereas ω and ET_0/P increased. Runoff was positively correlated with P, but it was negatively correlated with ET_0 and ω. In the northern Qinling Mountains, the environmental factors and underlying surface feature parameters on runoff of absolute values of the elastic coefficient are $|\xi_P| > |\xi_\omega| > |\xi_{ET0}|$, and they ranged from 1.46~1.71, 0.84~1.08, and 0.46~0.71, respectively. The elastic coefficient values indicate that a 1 % increase in P, ω or ET_0 will result in a 1.46%~1.71% increase, and 0.84%~1.08% or 0.46%~1.71% decrease in runoff and vice versa. In the southern Qinling Mountains, the environmental factors and ω for the absolute value of elastic coefficient of runoff are $|\xi_P| > |\xi_\omega| > |\xi_{ET0}|$, and their values ranged from 1.71~ 2.10, 0.71~1.10, and 0.94~1.16, respectively. The elastic coefficient values suggested that a 1 % increase in P, ω or ET_0 will lead to 1.71% ~ 2.10% increase, and 0.71% ~ 1.10% or 0.94%~1.16% decrease in runoff and vice versa. In addition, the elasticity coefficient of the environmental factors and the elasticity coefficient of ω for runoff were greater in the southern Qinling Mountains than in the northern Qinling Mountains in each period. Moreover, the sum of $|\xi_P|$ and $|\xi_{ET0}|$ in the northern Qinling Mountains is smaller than that in the southern Qinling Mountains, indicating that the sensitivity of runoff to climate change in the northern Qinling Mountains is lower than that in the southern Qinling Mountains.

TABLE 2 Climate hydrological characteristic values and elastic coefficients in the southern and northern Qinling Mountains

4.3 | Attribution recognition of the runoff change

The contribution rates of environmental factors and underlying surface changes to the runoff in the southern and northern Qinling Mountains are shown in Table 3. The difference between the runoff depth calculated (dR') by the Budyko framework and the actual runoff depth is very small (Table 3), which indicates that this method is reliable. In the northern Qinling Mountains, the contributions of P, ET_0 and ω changes to the runoff change in the Ba River are 38.12%, -0.03% and 61.92%, respectively, whereas in the southern Qinling Mountains, the contributions of P, ET_0 andωchanges to the runoff change in the Jinqian River are 26.73%, -2.76% and 76.02%, respectively. The change in the underlying surface is the main factor causing the decrease in runoff in both the northern and southern Qinling Mountains. The contribution of underlying surface change to runoff change in the southern Qinling Mountains is greater than that in the northern Qinling Mountains.

TABLE 3 Contributions of climate (precipitation, ET_0) and ω to runoff change in the southern and northern Qinling Mountains

5 | DISCUSSION

In the areas where human activities have little influence, climate and land vegetation change are the dominant factors affecting regional runoff. The change in land vegetation directly affects the evolution of runoff by changing the hydraulic parameters and hydrological factors such as plant interception, evapotranspiration, infiltration and groundwater recharge. The NDVI is an important index to monitor land vegetation change (Verbesselt *et al*., 2010). Many scholars have studied how vegetation change affects watershed runoff based on the NDVI (Zhang *et al*., 2015; Albarakat *et al*., 2018; He *et al*., 2019c; Zhao *et al*., 2019; Wang and Sun, 2021). The Ba River watershed and Jinqian River watershed are areas where human activities have little influence, so the change in land surface vegetation is one of the leading factors affecting runoff. The abrupt change points of runoff in the Ba River watershed and Jinqian River watershed are very close. Therefore, we analysed the vegetation changes in these two watersheds based on the GIMMS-NDVI data set from 1982 to 2014. The results show that the NDVI of both the southern and northern Qinling Mountains present an upward trend from 1982 to 2014, and the upward trend of NDVI of the southern Qinling Mountains is higher than that of the northern Qinling Mountains (Figure 8). The MK test also showed that the NDVI of both the northern and southern Qinling Mountains showed an upward trend, and the NDVI of the south showed a significant upward trend ($P < 0.05$). In contrast, the upward trend of the NDVI of the north was insignificant ($P > 0.1$). In this study, the annual variation trend of the average NDVI of the southern and northern Qinling Mountains was combined to explain the relationship between the vegetation change and runoff reduction. The method proposed by Yang *et al.* (2015) was adopted to perform a superposition analysis of the change rate and significance of NDVI. The results showed that the areas where vegetation coverage improved in the Ba River watershed and Jinqian River watershed accounted for 47.83% and 83.02% of the watershed area, respectively (Table 4-5). In other words, the increase in vegetation cover may be the main reason for the decrease in the runoff, especially in the Jinqian River watershed in the southern Qinling Mountains.

FIGURE 8 Variation characteristics of the NDVI in the southern and northern Qinling Mountains from 1982 to 2014

TABLE 4 Variation in the NDVI in the Ba River watershed from 1990 to 2014

TABLE 5 Variation in the NDVI in the Jinqian River watershed from 1990 to 2014

In addition, ω is related to the NDVI calculated above as well as the topography (Kadmon and Carmel, 1999; Munoz-Villers *et al.*, 2016; Ning *et al.*, 2019), soil properties (Potter *et al.*, 2005; Tang and Wang, 2017) and climate of the watershed. ω is a comprehensive index that reflects multiple factors of the underlying surface (Ning *et al.*, 2016).

In this study, the variation trend and abrupt change point of runoff in the Ba River watershed in the northern Qinling Mountains occurred in 1989, which is the same as the research result obtained by He *et al*. (2019b). The runoff trend and abrupt change point results in the Jinqian River watershed in the southern Qinling Mountains are consistent with the results obtained by Bai *et al*. (2012) and Ma *et a*l. (2013). Based on the differences between the contribution of climate change and human activities, the results in the Ba River watershed are different from the 74.5% runoff impact of the underlying surface obtained by He *et al*. (2019b), which is mainly caused by different study periods. The results obtained in the Jinqian River watershed are different from the results obtained by Bai *et al*. (2012), indicating that human activities account for 46.6% of the runoff. These discrepancies in the results are due to differences in the study periods and research methods.

6 | CONCLUSIONS

This paper quantified the contribution of climate and human activities to runoff change in the northern and southern Qinling Mountains taking the Ba River and Jinqian River as study areas. This study used the elastic coefficient method based on the Budyko framework. The main conclusions are summarized as follows:

The runoff of the Ba River watershed and Jinqian River watershed showed a decreasing trend during 1960-2014. The decreasing trend of the Ba River watershed was more significant. Abrupt changes in annual runoff in the Ba River watershed and Jinqian River watershed occurred in 1989 and 1992, respectively.

According to the elastic coefficient method-based the Budyko framework, runoff in both the northern and southern Qinling Mountains is most sensitive to underlying surface change. The sensitivity of runoff in the Jinqian River watershed to underlying surface change is higher than that in the Ba River watershed. The contributions of precipitation, ET_0 and the underlying surface to runoff change in the Ba River watershed are 38.12%, -0.03% and 61.92%, respectively, whereas the contributions of the Jinqian River watershed are 26.73%, -2.76% and 76.02%, respectively. The variation in the underlying surface is the main factor of runoff reduction in the northern and southern Qinling Mountains.

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REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper No. 56. Food and Agriculture Organization, Rome.

Albarakat, R., Lakshmi, V., & Tucker, C. (2018). Using Satellite Remote Sensing to Study the Impact of Climate and Anthropogenic Changes in the Mesopotamian Marshlands, Iraq. Remote

Sens (Basel), 10(10), 1524.

Brown, A. E., Zhang, L., McMahon, T. A., Western, A. W., & Vertessy, R. A. (2005). A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. Journal of Hydrology, 310(1-4), 28-61.

Bai, H. Y., Hou, Q. L., Ma, X. P., Zhang, J., & Yuan, B. (2012). Hydrological Characteristic and Its Responses to Precipitation Change in Jinqian River Basin of Qinling Moutains During the Last 50 Years. Scientia Geographica Sinica, 32(10), 1229-1235 (in Chinese).

Best, J. (2019). Anthropogenic stresses on the world's big rivers. Nature Geoscience, 12(1), 7-12.

Bai, P., Liu, X. M., Zhang, D., & Liu, C. M. (2020). Estimation of the Budyko model parameter for small basins in China. Hydrological Processes, 34(1), 125-138.

Choudhury, B. (1999). Evaluation of an empirical equation for annual evaporation using field observations and results from a biophysical model. Journal of Hydrology, 216(1), 99-110.

Giovanna, D., & Francesco, M. (2020). Assessment of the impact of climate variability and human activities on the runoff in five catchments of the Adriatic Coast of south-central Italy. Journal of Hydrology: Regional Studies, 31, 100712.

He, Y., Wang, F., Mu, X. M., Yan, H. T., & Zhao, G. J. (2015). An Assessment of Human versus Climatic Impacts on Jing River Basin, Loess Plateau, China. Advances in Meteorology, 478739.

He, Y., Wang, F., Mu, X. M., Guo, L. Q., Gao, P., & Zhao, G. J. (2017). Human activity and climate variability impacts on sediment discharge and runoff in the Yellow River of China. Theoretical and Applied Climatology, 129(1-2), 645-654.

He, Y., Song, J. X., Hu, Y. Y., Tu, X., & Zhao, Y. (2019a). Impacts of different weather conditions and landuse change on runoff variations in the Beiluo River Watershed, China. Sustainable Cities and Society, 50, 101674.

He, Y., Qiu, H. J., Song, J. X., Zhao, Y., Zhang, L. M., Hu, S., & Hu, Y. Y. (2019b). Quantitative contribution of climate change and human activities to runoff changes in the Bahe River watershed of the Qinling Mountains, China. Sustainable Cities and Society, 51, 101729.

He, Y., Jiang, X. H., Wang, N. L., Zhang, S. Q., Ning, T. T., Zhao, Y., & Hu, Y. Y. (2019c). Changes in mountainous runoff in three inland river basins in the arid Hexi Corridor, China, and its influencing factors. Sustainable Cities and Society, 50, 101703.

Huo, J., Liu, C. J., Yu, X. X., Jia, G. D., & Chen, L. H. (2020). Effects of watershed char and climate variables on annual runoff in different climatic zones in China. The Science of the total environment, 754, 142157.

Kendall, M. (1975). Rank correlation measures. Charles Griffin, London.

Kadmon, R., & Carmel, Y. (1999). Effects of Grazing and Topography on Long-Term Vegetation Changes in a Mediterranean Ecosystem in Israel. Plant Ecology, 145(2), 243-254.

Li, Y. Z., Liu, C. M., Yu, W. J., Tian, D., & Bai, P. (2019). Response of streamflow to environmental changes: A Budyko-type analysis based on 144 river basins over China. The Science of the total environment, 664, 824-833.

Li, D. F., Li, Z. W., Zhou, Y. J, & Lu, X. X. (2020). Substantial increases in the water and sediment fluxes in the headwater region of the Tibetan Plateau in response to global warming. Geophysical Research Letters, 47, e2020GL087745.

Mann, H.B. (1945). Non-parametric test against trend. Econometrika, 13(3), 245-259.

Ma, X. P., Bai, H. Y., Feng, H. P., Li, P. X., & Mi, Y. Y. (2013). Runoff variation and its influencing factors compared between south and north of Qinling Mountains during 50 years. Arid Land Geography, 36(6), 1032-1040 (in Chinese).

Munoz-Villers, L. E., Geissert, D. R., Holwerda, F., & McDonnell, J. J. (2016). Factors influencing stream baseflow transit times in tropical montane watersheds. Hydrology and Earth System Sciences, 20, 1621-1635.

Ning, T. T., Li, Z., & Liu, W. Z. (2016). Separating the impacts of climate change and land surface alteration on runoff reduction in the Jing River catchment of China. Catena, 147, 80-86.

Ning, T. T., Zhou, S., Chang, F. Y., Shen, H., Li, Z., & Liu, W. Z. (2019). Interaction of vegetation, climate and topography on evapotranspiration modelling at different time scales within the Budyko framework. Agricultural and Forest Meteorology, 275, 59-68.

Oki, T., & Kanae, S. (2006). Global hydrological cycles and world water resources. Science, 313, 1068-1072.

Pettitt, N. A. (1979). A non-parametric approach to the change-point problem. Journal of the Royal Statistical Society. Series C: Applied Statistics, 28(2), 126-135.

Potter, N. J., Zhang, L., Milly, P. C. D., McMahon, T. A., & Jakeman, A. J. (2005). Effects of rainfall seasonality and soil moisture capacity on mean annual water balance for Australian catchments. Water Resources Research, 41, 11.

Renard, B., Kavetski, D., Kuczera, G., Thyer, M., & Franks, S. W. (2010). Understanding predictive uncertainty in hydrologic modeling: The challenge of identifying input and structural errors. Water Resources Research, 46(5), W05521.

Roderick, M. L., & Farquhar, G. D. (2011). A simple framework for relating variations in runoff to variations in climatic conditions and catchment properties. Water Resources Research, 47(12), W00G07.

Solaimani, K., Habaibnejad, M., & Pirnia, A. (2020). Temporal trends of hydro-climatic variables and their relevance in water resource management. International Journal of Sediment Research, 36(1), 63-75.

Saha, A., Joseph, J., & Ghosh, S. (2020). Climate controls on the terrestrial water balance: Influence of aridity on the basin characteristics parameter in the Budyko framework. The Science of the total environment, 739, 139863.

Tang, Y., & Wang, D. B. (2017). Evaluating the role of watershed properties in long-term water balance through a Budyko equation based on two-stage partitioning of precipitation. Water Resources Research, 53(5), 4142-4157.

Verbesselt, J., Hyndman, R., Newnham, G., & Culvenor, D. (2010). Detecting trend and seasonal changes in satellite image time series. Remote Sensing of Environment, 114(1), 106-115.

Wang, W., Zhang, Y., & Tang, Q. H. (2020). Impact assessment of climate change and human activities on streamflow signatures in the Yellow River Basin using the Budyko hypothesis and derived differential equation. Journal of Hydrology, 591, 125460.

Wang, H., & Sun, F. B. (2021). Variability of annual sediment load and runoff in the Yellow River for the last 100years (1919–2018). The Science of the total environment, 758, 143715.

Yang, D. W., Zhang, S. L., & Xu, X. Y. (2015). Attribution analysis for runoff decline in Yellow River Basin during past fifty years based on Budyko hypothesis. Scientia Sinica (Technologica), 45(10), 1024-1034 (in Chinse).

Young, D., Zégre, N., Edwards, P., & Fernandez, R. (2019). Assessing streamflow sensitivity of forested headwater catchments to disturbance and climate change in the central Appalachian Mountains region, USA. The Science of the total environment, 694, 133382.

Zhang, S. L., Yang, H. B., Yang, D. W., & Jayawardena, A. W. (2015). Quantifying the effect of vegetation change on the regional water balance within the Budyko Framework. Geophysical

Research Letters, 43(3), 1140-1148.

Zheng, Y. T., Huang, Y. F., Zhou, S., Wang, K. Y., & Wang, G. Q. (2018). Effect partition of climate and catchment changes on runoff variation at the headwater region of the Yellow River based on the Budyko complementary relationship. The Science of the total environment, 643, 1166-1177.

Zhang, X., Dong, Q. J., Cheng, L., & Xia, J. (2019). A Budyko-based framework for quantifying the impacts of aridity index and other factors on annual runoff. Journal of Hydrology, 579, 124224.

Zhao, J., Huang, S. Z., Huang, Q., Wang, H., Leng, G. Y., Peng, J., & Dong, H. X. (2019). Copula-Based Abrupt Variations Detection in the Relationship of Seasonal Vegetation-Climate in the Jing River Basin, China. Remote Sens (Basel), 11(13), 1628.

Zeng, F., Ma, M. G., Di, D. R., & Shi, W. Y. (2020). Separating the Impacts of Climate Change and Human Activities on Runoff: A Review of Method and Application. Water, 12(2201), 2201.