Characteristics of Runoff and Sediment Changes in the Upper Reaches of the Guanchuan River and Their Response to Precipitation and Soil and Water Conservation Measures (Postprint)

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Abstract

To further explore the impacts of precipitation and soil and water conservation measures on runoff and sediment, and to gain a deeper understanding of the driving factors of water and sediment changes in small and medium-sized rivers of the Yellow River basin, this study employed methods including the M-K test, Morlet wavelet analysis, linear regression, and structural equation modeling to investigate the changes in precipitation and soil and water conservation measure areas and their mechanisms and processes affecting runoff and sediment in the upper reaches of the Guanchuan River from 1957 to 2021. The results indicate that annual precipitation showed a non-significant decreasing trend ($P>0.05$), while runoff modulus and sediment transport modulus exhibited significant decreasing trends ($P<0.05$), and the area of soil and water conservation measures showed an increasing trend. The response of runoff modulus and sediment transport modulus to precipitation shifted from strong to weak, while their response to soil and water conservation measures gradually strengthened. The key pathways through which precipitation and soil and water conservation measures influence water and sediment changes were "soil and water conservation measure area → runoff modulus", followed by "soil and water conservation measure area → runoff → sediment transport modulus"; next was "precipitation → runoff modulus", and finally "precipitation → runoff modulus → sediment transport modulus". The total effects of precipitation on water and sediment changes were 0.42 and 0.38, respectively, while those of soil and water conservation measure area were -0.72 and -0.65, respectively. The primary factor influencing basin water and sediment changes was the area of soil and water conservation measures, with precipitation being the secondary factor.

Full Text

Characteristics of Water and Sediment Changes in the Upper Guanchuan River and Their Response to Precipitation and Water Conservation Measures

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Abstract

To further explore the influence of precipitation and soil and water conservation measures on runoff and sediment, and to gain an in-depth understanding of the driving factors behind water and sediment changes in small and medium-sized tributaries of the Yellow River, this study employed the M-K test, Morlet wavelet analysis, linear regression, and structural equation modeling to investigate variations in precipitation and soil and water conservation measure implementation area in the upper Guanchuan River basin from 1957 to 2021, as well as their mechanisms and processes of action on runoff and sediment. The results showed that annual precipitation exhibited a non-significant decreasing trend ($P > 0.05$), while runoff modulus and sediment transport modulus showed significant decreasing trends ($P < 0.05$), and the area of soil and water conservation measures demonstrated an increasing trend. The response of runoff modulus and sediment transport modulus to precipitation weakened over time, while their response to soil and water conservation measures gradually strengthened. The key pathways through which precipitation and soil and water conservation measures influence water and sediment changes were: "area of soil and water conservation measures → runoff modulus," followed by "area of soil and water conservation measures → sediment transport modulus," then "precipitation → runoff modulus," and finally "precipitation → sediment transport modulus." The total effects of precipitation on water and sediment changes were 0.42 and 0.38, respectively, whereas those of soil and water conservation measures were 0.72 and 0.65, respectively. The primary factor affecting watershed water and sediment changes is the area of soil and water conservation measures, with precipitation being the secondary factor.

Keywords: water and sediment changes; soil and water conservation measures; structural equation model; upper Guanchuan River

1 Data Sources and Research Methods

1.1 Study Area Overview

The Guanchuan River is a first-order tributary of the Zuli River, located in central Gansu Province. The upper reaches of the Guanchuan River consist of two tributaries: the Donghe and Xihe Rivers. The total watershed area is 1640.04 km^2, with the Xihe River basin covering 637 km^2. These two rivers converge at Chengguan Town in Anding District before flowing into the main channel of the Guanchuan River. The Donghe and Xihe Rivers flow from the southern boundary of Anding District northward, with decreasing terrain that erodes the surface to form landforms typical of loess hills and alluvial valleys, belonging to a semi-arid loess hilly-gully region. The climate is temperate monsoonal, characterized by dryness, drought, and low rainfall, with an average precipitation of 413 mm that is unevenly distributed in time and space, concentrated mainly in [month]. Annual evaporation exceeds 1400 mm. The dominant soil types are loessial soil and sierozem. The watershed experiences primarily water erosion, with an average soil erosion modulus of 4558.8 $\mathrm{t \cdot km^{-2}}$. By [year], the cumulative area of soil and water loss treatment reached 13.05×10^4 hm^2, including 60,963.01 hm^2 of terraced fields, 37,750 hm^2 of conservation forests, 5,380 hm^2 of artificial grassland, and 19,835 hm^2 of closed-off areas for natural recovery. The study area has established several hydrological stations including the Chankou Hydrological Station (established in [year]), Donghe (Dingxi) Hydrological Station (established in [year]), and Xihe Station. The distribution of hydrological and rainfall stations is shown in [Figure 1: see original paper].

1.2 Data Sources and Preprocessing

Annual precipitation data for the period [year]–[year] were provided by the Gansu Provincial Bureau of Hydrology and Water Resources. The study area contains six rainfall observation stations (Donghe, Xihe, Neiguanying, Hongtu, Qinglan, and Chankou), with average annual precipitation calculated using the Thiessen polygon method. Runoff and sediment discharge data for [year]–[year] were obtained from observations at the Chankou Hydrological Station, while data for [year]–[year] came from the Donghe and Xihe hydrological stations. To minimize the impact of the Chankou station's relocation, original runoff and sediment discharge values were converted to annual runoff modulus and sediment transport modulus as the basis for analysis.

Soil and water conservation measure implementation data were derived from multiple sources: the Gansu Provincial Soil and Water Conservation Annual Report ([year]–[year]), Anding District Soil and Water Conservation Annual Report ([year]–[year]), research results from "Study on Benefits of Comprehensive Soil and Water Conservation Measures in Gansu Province" [reference], Anding District land survey data (second and third surveys), detailed survey data from Anding District Forestry Bureau, and data from the Grain-for-Green Program ([year]–[year]). Using these materials, the actual implementation quantities of soil and water conservation measures in the project area at different time intervals were corrected, and the preservation rates of measures from different periods were applied to calculate the actual effective area of soil and water conservation measures in the study area over the years.

1.3 Research Methods

1) The non-parametric Mann-Kendall (M-K) statistical test was used to analyze trends in precipitation, runoff modulus, and sediment transport modulus in the Guanchuan River, and to test the significance of these changes.
2) Morlet wavelet analysis was employed to examine precipitation patterns. Based on the positive/negative values of closed centers in two-dimensional contour plots and zero points of wavelet coefficients, we identified precipitation increase/decrease patterns and abrupt changes. The primary variation periods were determined with reference to peak values [reference].
3) Linear regression analysis was used to examine relationships between precipitation, soil and water conservation measure area, and runoff/sediment modulus.
4) Structural Equation Modeling (SEM) was applied to measure and analyze relationships between precipitation, soil and water conservation measure area, and runoff/sediment modulus. A conceptual model of the relationships was established, and model parameters were determined using annual precipitation, runoff, and sediment data from [year]–[year] [reference]. SEM consists of structural equations and measurement equations: structural equations measure relationships between latent variables, while measurement equations measure relationships between observed variables and latent variables.

The measurement model is represented by formulas (1) and (2), while the structural model is represented by formula (3):

Where: $\mathbf{X}$ is the vector of exogenous measurement variables; $\mathbf{\Lambda}$ is the factor loading matrix of $\mathbf{X}$ on ; δ is the measurement error; $\mathbf{Y}$ is the vector of endogenous measurement variables; $\mathbf{\Lambda}$ is the factor loading matrix of $\mathbf{Y}$ on ; is the measurement error; is the vector of endogenous latent variables; is the vector of exogenous latent variables; $\mathbf{B}$ is the regression coefficient matrix between endogenous latent variables; $\mathbf{\Gamma}$ is the regression coefficient matrix of exogenous latent variables on endogenous latent variables; and is the measurement error.

To evaluate model fit, we selected four indicators: Comparative Fit Index (CFI), Goodness-of-Fit Index (GFI), Relative Fit Index (RFI), and Root Mean Square Error of Approximation (RMSEA). Model construction and fitting were performed using AMOS 21.0 and SPSS 26.0 software.

2 Results

2.1.1 Interannual Variation Characteristics of Runoff Modulus

The average annual runoff modulus in the upper Guanchuan River was 45,221.97 $m^3 \cdot km^{-2}$, with a maximum of 11,466.71 $m^3 \cdot km^{-2}$ (in [year]) and a minimum of 564.33 $m^3 \cdot km^{-2}$ (in [year]). The maximum annual runoff modulus was 20.3 times the minimum. Overall, the runoff modulus showed a significant decreasing trend ($P < 0.05$). Linear fitting revealed that the annual runoff modulus decreased year by year, with a particularly significant decline after [year] ($P < 0.05$). M-K test results (shown in [Figure 2: see original paper]) indicated an overall evolution from high to low runoff. The intersection of UFk and UBk curves occurred in [year], identifying this as the abrupt change point for runoff modulus.

2.1.2 Interannual Variation Characteristics of Sediment Transport Modulus

The average annual sediment transport modulus in the upper Guanchuan River was 11,081.788 $t \cdot km^{-2}$, showing a fluctuating decreasing trend (see [Figure 3: see original paper]). The maximum sediment transport modulus was 2,654.60 $t \cdot km^{-2}$ (in [year]), while the minimum was 1.33 $t \cdot km^{-2}$ (in [year]). Sediment transport modulus increased during [period] and decreased during [period], with a particularly significant declining trend after [year] ($P < 0.05$). The UFk and UBk curves intersected in [year], indicating an abrupt change in sediment transport modulus.

2.2 Precipitation Characteristics

2.2.1 Interannual Variation of Precipitation From [year] to [year], the average annual precipitation in the upper Guanchuan River was 413.0 mm, with a maximum of 715.6 mm (in [year]) and a minimum of 268.4 mm (in [year]). The maximum was 2.7 times the minimum. Precipitation showed a non-significant decreasing trend overall ($P > 0.05$). The UFk and UBk curves intersected in [year], identifying this as the abrupt change year for precipitation (see [Figure 4: see original paper]).

2.2.2 Precipitation Periodicity Wavelet analysis revealed that precipitation exhibited different cyclical patterns of wet and dry periods at various time scales. The precipitation series showed three time-scale cycles: 9–18 years, 4–9 years, and 2–4 years. At the 2–4 year scale, precipitation oscillations were intense with clear periodic patterns and stable signals. At the 4–9 year scale, cycles were evenly distributed with significant global characteristics. The 9–18 year scale corresponded to the largest peak, indicating the strongest periodic amplitude and representing the first principal cycle of precipitation variation. The 4–9 year scale corresponded to the second peak, representing the second principal cycle. The 2–4 year scale showed the weakest periodic oscillations, with negligible effects.

At the 9–18 year scale, two complete global wet-dry alternations occurred, with precipitation increase oscillation centers in [year] and [year], and decrease oscillation centers in [year] and [year]. Since 2015, the positive real contour lines have not fully closed, suggesting that precipitation will show fluctuating decreases after 2015. As the first principal cycle has greater oscillation intensity than secondary peaks, the probability of precipitation decrease in the near future is relatively high (see [Figure 5: see original paper]).

2.3.1 Soil and Water Conservation Measures and Changes in Runoff/Sediment Modulus

With continuous implementation of soil and water conservation measures and engineering projects, the quantity of various measures in the upper Guanchuan River has continuously increased, and the level of soil and water conservation treatment has improved year by year. Based on implementation intensity, the study period can be divided into three stages: [year]–[year] (initial stage), [year]–[year] (comprehensive treatment stage), and [year]–[year] (steady improvement stage).

During the initial stage, soil and water conservation measures focused primarily on terracing and afforestation, with scattered and single-method approaches. The total area of measures was 6,560 hm^2, with terraces comprising 70.41% of the total area, achieving a treatment level of 12.96% and an annual treatment rate of 0.56%.

During the comprehensive treatment stage, national and provincial key investments implemented small watershed comprehensive management, sloping farmland transformation, and check dam construction projects, significantly improving treatment levels. By [year], the total area of soil and water conservation measures reached 21,249.24 hm^2, with terraces covering 14,961.47 hm^2 (70.41% of total), afforestation 3,279.55 hm^2, and grass planting 5,380 hm^2, achieving a treatment level of 56.39% and an annual treatment rate of 2.17%.

During the steady improvement stage, large-scale Grain-for-Green programs were implemented on the existing foundation. By [year], the total area reached 92,477.833 hm^2, with terraces covering 42,060.01 hm^2, afforestation 16,202.26 hm^2, grass planting 6,096.301 hm^2, and closed-off areas 19,835 hm^2, achieving a treatment level of 79.56% and an annual treatment rate of 1.10%.

As the area of soil and water conservation measures gradually increased, both runoff modulus and sediment transport modulus showed fluctuating decreasing trends (see [Figure 6: see original paper]).

2.4.1 Relationship Between Precipitation and Runoff/Sediment Modulus

Precipitation and human activities (primarily soil and water conservation measures) are the main factors affecting runoff and sediment modulus. Based on temporal periods, the time series of precipitation and runoff/sediment modulus were divided into three stages. Average values for each stage are shown in .

Regression analysis revealed that during Stage 1, runoff and sediment moduli responded strongly to precipitation variation with high trend synergy, and correlations reached significant levels ($P < 0.01$). Precipitation explained 46.03% of runoff modulus variation ($R^2 = 0.46$) and 14.59% of sediment transport modulus variation ($R^2 = 0.15$). During Stage 2, the response remained strong with high synergy, but correlation coefficients were lower than in Stage 1. Precipitation explained 12.59% of runoff modulus variation ($R^2 = 0.13$) and 1.16% of sediment transport modulus variation ($R^2 = 0.01$), both reaching significant levels ($P < 0.01$). During Stage 3, the response weakened rapidly, with correlations failing to reach significance ($P > 0.05$). Precipitation explained only 0.25% of runoff modulus variation ($R^2 = 0.0025$) and 0.29% of sediment transport modulus variation ($R^2 = 0.0029$).

Runoff modulus and sediment transport modulus showed strong synergy, with runoff modulus explaining 64.69%, 14.59%, and 2.13% of sediment transport modulus variation in Stages 1, 2, and 3, respectively, all reaching extremely significant levels ($P < 0.01$).

2.4.2 Relationship Between Soil and Water Conservation Measures Area and Runoff/Sediment Modulus

During Stage 1, runoff and sediment moduli did not respond strongly to changes in soil and water conservation measures area, with no significant correlations ($P > 0.05$). Soil and water conservation measures area explained only 2.17% of runoff modulus variation ($R^2 = 0.0217$) and 1.10% of sediment transport modulus variation ($R^2 = 0.0110$).

During Stage 2, the response strengthened but remained non-significant ($P > 0.05$). Soil and water conservation measures area explained 6.38% of runoff modulus variation ($R^2 = 0.0638$) and 1.445% of sediment transport modulus variation ($R^2 = 0.01445$).

During Stage 3, the response became strong and highly significant ($P < 0.01$). Soil and water conservation measures area explained 72.95% of runoff modulus variation ($R^2 = 0.7295$) and 65.38% of sediment transport modulus variation ($R^2 = 0.6538$). Average runoff modulus decreased from 19,551.10 $m^3 \cdot km^{-2}$ to 2,153.30 $m^3 \cdot km^{-2}$, and average sediment transport modulus decreased from 4,558.80 $t \cdot km^{-2}$ to 247.64 $t \cdot km^{-2}$. This indicates that the impact of soil and water conservation measures on runoff and sediment moduli gradually increased over time, effectively controlling soil and water loss.

2.5 Impact Pathways of Annual Precipitation and Soil and Water Conservation Measures Area on Annual Runoff/Sediment Modulus

2.5.1 Model Fit SEM was used to quantify direct and indirect effects of explanatory variables on response variables, analyzing relationships between annual runoff modulus, annual sediment transport modulus, annual precipitation, and soil and water conservation measures area. Preliminary fitting tests confirmed data reliability. Evaluation criteria were: CFI/GFI/RFI > 0.90 indicates acceptable fit; > 0.95 indicates good fit; RMSEA < 0.08 indicates acceptable fit; < 0.05 indicates good fit (see). All indicators met fitting standards, demonstrating good model fit and high data reliability.

2.5.2 Water-Sediment Change Pathways Path analysis results (see [Figure 7: see original paper] and) showed that precipitation has a significant direct effect on runoff modulus (standardized estimate = 0.42, $P < 0.001$), meaning each one-standard-unit increase in precipitation increases runoff modulus by 0.42 standard units. Precipitation's direct effect on sediment transport modulus was not significant. Soil and water conservation measures area had a significant direct effect on runoff modulus (standardized estimate = -0.72, $P < 0.001$), indicating each one-standard-unit increase in measures area decreases runoff modulus by 0.72 standard units. Its direct effect on sediment transport modulus was also not significant. Runoff modulus had a significant direct effect on sediment transport modulus (standardized estimate = 0.85, $P < 0.001$), showing that each one-standard-unit increase in runoff modulus increases sediment transport modulus by 0.85 standard units.

Effect value calculations (see) revealed that precipitation's total effects on runoff modulus and sediment transport modulus were 0.42 and 0.38, respectively, while soil and water conservation measures area's total effects were 0.72 and 0.65, respectively. The indirect effects of precipitation and soil and water conservation measures area on sediment transport modulus were significant, indicating that runoff modulus partially mediates the relationship between precipitation, soil and water conservation measures area, and sediment transport modulus.

The key pathways affecting water and sediment changes were: soil and water conservation measures area → runoff modulus (strongest), soil and water conservation measures area → sediment transport modulus, precipitation → runoff modulus, and precipitation → sediment transport modulus. These results demonstrate that soil and water conservation measures area is the primary factor influencing water and sediment changes, while precipitation is secondary.

3 Discussion

In the upper Guanchuan River basin, precipitation, runoff modulus, and sediment transport modulus showed similar trends, but the precipitation decrease was not significant, while runoff and sediment moduli decreased extremely significantly. Studies by Liu Qiang [reference] and Sheng Fei [reference] on water and sediment changes in different watersheds concluded that water-sediment relationships are significantly affected by soil and water conservation measures, which can effectively reduce runoff and sediment discharge. Wang Jin [reference] found that in the Zuli River basin, precipitation and human activities contributed 28.7% and 71.3% to runoff modulus changes, respectively, indicating that human activity is the major influencing factor and precipitation is secondary—consistent with our findings.

This study shows that precipitation's influence on runoff and sediment moduli gradually decreased over time, while the influence of soil and water conservation measures gradually increased. The substantial increase in soil and water conservation measures area is the main factor driving water-sediment relationship changes, with precipitation being secondary. However, this study only explored relationships between precipitation, soil and water conservation measures, and runoff/sediment generation. Other factors (temperature, soil, watershed slope, seasonal climate variations, rainfall intensity, and human activities such as production and construction) also significantly affect water and sediment changes but were not fully considered here, representing a limitation for future research.

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4 Conclusions

1) In the upper Guanchuan River basin, runoff modulus and sediment transport modulus showed strong synchronization and significant decreasing trends during the study period, with abrupt change points in [year] and [year], respectively. Precipitation remained relatively stable with a non-significant decreasing trend. Soil and water conservation measures area increased continuously over time.

2) The response of runoff and sediment moduli to precipitation weakened over time, while their response to soil and water conservation measures area strengthened. Correlation coefficients (R) between precipitation and runoff/sediment moduli decreased from 0.68 and 0.38 to 0.05 and 0.03, respectively. Correlation coefficients between soil and water conservation measures area and runoff/sediment moduli increased from -0.15 and -0.10 to -0.85 and -0.81, respectively, indicating that soil and water conservation measures area has become increasingly important in affecting watershed runoff and sediment generation.

3) Precipitation and soil and water conservation measures area directly affect runoff modulus, which in turn directly affects sediment transport modulus. Both factors indirectly influence sediment transport modulus by directly affecting runoff modulus. Precipitation's explanatory power (R^2) for runoff modulus decreased from 0.46 to 0.0025, and for sediment transport modulus from 0.15 to 0.0029. Soil and water conservation mea-

sures area's explanatory power for runoff modulus increased from 0.0217 to 0.7295, and for sediment transport modulus from 0.0110 to 0.6538. This indicates that the primary factor influencing water and sediment changes has shifted from precipitation to soil and water conservation measures.

4) Pathway analysis showed that precipitation and soil and water conservation measures affect runoff and sediment moduli by directly influencing runoff modulus, which then indirectly affects sediment transport modulus. In terms of total effects, soil and water conservation measures area had total effects of 0.72 and 0.65 on runoff modulus and sediment transport modulus, respectively, while precipitation had total effects of 0.42 and 0.38. Therefore, soil and water conservation measures are the main factor affecting water and sediment changes, with precipitation being secondary.

References

[1] Feng Dezeng, Wu Dongdong, Zhao Lingling, et al. Analysis on characteristics and influence factors of runoff and sediment changes in the Raohe River basin from 1952 to 2014[J]. South to North Water Transfers and Water Science Technology, 2018, 16(6): 53-59.

[2] Bao Gangyu, Nie Hong, Wang Ping, et al. Research on effects of different precipitation magnitudes on runoff changes in the headwater region of the upper Yellow River[J]. Arid Zone Research, 2021, 38(3): 704-713.

[3] Yao Wenyi, Gao Yajun, Zhang Xiaohua. Relationship evolution between runoff and sediment transport in the Yellow River and related scientific issues[J]. Science of Soil and Water Conservation, 2020, 18(4): 1-11.

[4] Liao Jianhua, Xu Jiongxin, Yang Yonghong. Study of the spatial differentiation of hyperconcentrated flows frequency in the Loess Plateau[J]. Advances in Water Science, 2008, 19(2): 160-170.

[5] Zhao Juan. Impact of Soil and Water Conservation Measurements and Precipitation on River Runoff and Sediment Based on VAR Model in the Typical Area of Yellow River[D]. Yangling: Northwest A&F University, 2019.

[6] Duan Yujia, He Yi, Zhao Jie, et al. Analysis of impact of human activities on runoff changes in Yue River Basin of the Qinling Mountains[J]. Arid Zone Research, 2023, 40(4): 605-614.

[7] Gao Lin. Global climate governance mechanisms and prospects under the framework of the Paris Agreement[J]. International Business Research, 2022, 43(6): 54-62.

[8] Mu Xingmin, Li Jing, Wang Fei, et al. Rainfall-runoff statistical hydrological model based on soil and water conservation practices[J]. Journal of Hydraulic Engineering, 2004, 49(5): 122-128.

[9] Mu Xingmin, Wang Wanzhong, Gao Honghu, et al. Variation of runoff and sediment in the headwaters of the Yangtze River from 1980 to 2020[J]. Arid Zone Research, 2023, 40(5): 726-736.

[10] Zheng H Y, Miao C Y, Wu J W, et al. Temporal and spatial variations in water discharge and sediment load on the Loess Plateau, China: A high density study[J]. Science of the Total Environment, 2019, 666: 875-886.

[11] Zhang F, Xing Z S, Zhao C Y, et al. Characterizing long term soil and water erosion and their interactions with various conservation practices in the semi-arid Zulihe basin, Dingxi, Gansu, China[J]. Ecological Engineering, 2017, 106: 458-470.

[12] Rustomji P, Zhang X P, Hairsine P B, et al. River sediment load and concentration responses to changes in hydrology and catchment management in the Loess Plateau region of China[J]. Water Resources Research, 2008, 44(7): 1-17.

[13] Zhang J J, Zhang X P, Li R, et al. Did streamflow or suspended sediment concentration changes reduce sediment load in the middle reaches of the Yellow River[J]. Journal of Hydrology, 2017, 546: 357-369.

[14] Zhang Fu, Yao Jinzhong, Lei Shengwen, et al. Study on the Benefits of Comprehensive Management Measures for Soil and Water Conservation in Gansu Province[M]. Zhengzhou: Yellow River Water Conservancy Press, 2014: 218-220.

[15] Zhen Ying, Yang Shan, He Jing, et al. Analysis of precipitation in Yibin city based on M-K test and R/S method[J]. Journal of Sichuan Normal University (Natural Science), 2017, 40(3): 392-397.

[16] Xie Zhibo, Mu Xingmin, Gao Peng, et al. Variation characteristics of runoff in the upper reaches of Beiluo River based on R/S and Morlet wavelet analysis[J]. Research of Soil and Water Conservation, 2022, 29(2): 139-144.

[17] Liu Qiang, Mu Xingmin, Zhao Guangju, et al. Runoff and sediment changes and their responses to precipitation and land use change in the Yan River Basin[J]. Journal of Arid Land Resources and Environment, 2021, 35(7): 129-135.

[18] Klaus F, Axel M, Hannes S. Multiscale change point inference[J]. Journal of the Royal Statistical Society: Series B (Statistical Methodology), 2014, 3: 495-580.

[19] Fabian R, Sebastian S, Martin S, et al. Controls on runoff generation along a steep climatic gradient in the Eastern Mediterranean[J]. Journal of Hydrology: Regional Studies, 2017, 9: 18-33.

[20] Sa Rula, Wang Zirui, Hua Yongchun, et al. Evaluating forest ecosystem restoration ability of natural forest in northern greater Khingan Mountains by

a structural equation model[J/OL]. Journal of Nanjing Forestry University (Natural Sciences Edition), 2022, 1-11. [2022-12-01].

[21] Wei Xia. Health Evaluation of three Typical Forest Stands in Fushou Forest Farm Based on Structural Equation Model[D]. Changsha: Central South University of Forestry Technology, 2021.

[22] Zhang Fu, Ning Jianguo, Jing Ya'an, et al. Quality effects monitoring of the soil conservation works and analysis of the monitoring data in Guanchuan watershed[J]. Soil and Water Conservation in China, 1992, 13(2): 21-25, 65-66.

[23] Sheng Fei, Liu Shiyu, Yu Mingqi, et al. Analysis of runoff and sediment variation and its driving factors in Lianshui Watershed at different time scales[J]. Journal of Soil and Water Conservation, 2023, 37(3): 201-207, 217.

[24] Zhai Hongkun, Li Qiang, Wei Xiaowei. Power analysis in structural equation modeling: Principles and methods[J]. Advances in Psychological Science, 2022, 30(9): 2117-2143.

[25] Wang Jin. Analysis of the impact of climate change on runoff in semi-arid watersheds[J]. China Water Resources, 2011, 62(3): 18-19.

Note: Figure translations are in progress. See original paper for figures.