Coupling effects of topography and the spatial distribution of cypress on surface runoff coefficient on a steep forested slope in southwest China

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Abstract

Interactions between topography and the spatial distribution of cypress give rise to the spatial heterogeneity of surface runoff on steep forested slopes in southwest China. To reduce surface runoff and improve the water conservation capacity of cypress forests, the coupling effects of topography and the spatial distribution of cypress on surface runoff coefficient were studied through the Structural Equation Modeling (SEM) and the Response Surface Method (RSM) based on twelve natural runoff plots. Results showed that the surface runoff coefficient increased monotonically with the increase of the composite index of topography (topographic relief× runoff path density/ surface roughness), and increased first and decreased later with the increase of the composite index of the spatial distribution of cypress (stand density of cypress× contagion index of cypress). To reduce surface runoff coefficient from a larger value (>0.5) to less than 0.3, two strategies of stand structure adjustment could be adopted, including only increasing the stand density of cypress or increasing both the stand density and the contagion index of cypress, and which strategy should be adopted depended on the initial stand density of cypress. When the initial stand density of cypress was relatively low (<20 ind/100m2), the first step was to increase the stand density of cypress, and until the stand density of cypress reached to a moderate level (20-50 ind/100m2), adjusting the spatial structure of cypress from relatively regular to relatively clumped could reduce surface runoff coefficient to a greater extent.

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Abstract

Interactions between topography and the spatial distribution of cypress give rise to the spatial heterogeneity of surface runoff on steep forested slopes in southwest China. To reduce surface runoff and improve the water conservation capacity of cypress forests, the coupling effects of topography and the spatial distribution of cypress on surface runoff coefficient were studied through the Structural Equation Modeling (SEM) and the Response Surface Method (RSM) based on twelve natural runoff plots. Results showed that the surface runoff coefficient increased monotonically with the increase of the composite index of topography (topographic relief× runoff path density/ surface roughness), and increased first and decreased later with the increase of the composite index of the spatial distribution of cypress (stand density of cypress× contagion index of cypress). To reduce surface runoff coefficient from a larger value (>0.5) to less than 0.3, two strategies of stand structure adjustment could be adopted, including only increasing the stand density of cypress or increasing both the stand density and the contagion index of cypress, and which strategy should be adopted

depended on the initial stand density of cypress. When the initial stand density of cypress was relatively low (<20 ind/100m^2), the first step was to increase the stand density of cypress, and until the stand density of cypress reached to a moderate level (20-50 ind/100m^2), adjusting the spatial structure of cypress from relatively regular to relatively clumped could reduce surface runoff coefficient to a greater extent.

Key words: Spatial distribution of cypress; topography; surface runoff coefficient; SEM (Structural equation modeling); coupling effects

1. Introduction

Surface runoff is a multi-factor combined process that happens in a complex underlying surface (Xu et al., 2019; Maria et al., 2018; Ochoa et al., 2016). Vegetation and topography are the basic elements that make up the underlying surface, as well as the main factors that affect surface runoff (El et al., 2013). Studies have demonstrated that the effects of vegetation and topography on surface runoff are manifested by jointly changing the upslope inflow of a certain slope unit, and these two factors are usually inseparable (Qin et al., 2015). Specifically, aboveground traits of vegetation constitute the main drivers for generating hydraulic roughness (Kervroedan et al., 2019), while the topography is the carrier for the occurrence and development of surface runoff generation (Sabzevari and Talebi, 2019).

Regarding on vegetation, topography, and surface runoff, most studies tend to analyze the impact and contribution of a single factor to the surface runoff process (Li et al., 2008; Bal et al., 2011; Bennett and Bridge, 2010). Related studies have shown that the surface runoff coefficient has a negative correlation as well as logarithmic function relationship with surface vegetation coverage, has a negative correlation as well as power function relationship with the thickness of the litter layer, and has a positive correlation as well as exponential function relationship with slope (Zhang et al., 2006; He et al., 2014; Duan et al., 2016). Some scholars have also paid attention to the coupling effects of vegetation and topography on surface runoff, but theoretical research is relatively few, mostly involved in other research topics. For example, Zhang (2018) studied the variation process of water erosion dynamics under different vegetation spatial configuration through indoor runoff scouring experiments and proposed that when grass strip was planted at about 80% of the slope length, it could better exert soil and water conservation function. Cao et al. (2017) analyzed the response of erosion and sediment yield characteristics to the interaction of slope and vegetation cover based on the field simulation test and proposed that the effect of vegetation coverage on surface runoff gradually weakened with the increase of slope, while the effect of slope on surface runoff gradually increased, and finally became the dominant factor affecting soil erosion. Ren et al. (2018) explored the response of water erosion dynamics to vegetation cover and slope allocation based on the WEPP (Water Erosion Prediction Project) model and proposed that the increase of vegetation canopy cover could significantly reduce soil loss and sediment yield, and the least soil loss occurred when vegetation was distributed in the lower slope conditions.

The main purpose of the above research was to determine the optimal configuration of vegetation under typical topography conditions. However, these studies had certain limitations in revealing the coupling effects of vegetation and topography on surface runoff. On the one hand, most studies had adopted simulation methods and defaulted the slope condition to a homogeneous slope, artificially setting or simplifying the combination of vegetation and topography features, ignoring the fact that the formation of the overlapping distribution of vegetation and topography was the result of their long-term interaction and co-evolution (Saco and Mariano, 2013; Kim and Kupfer, 2016). On the other hand, when it came to the coupling effects of vegetation and topography on surface runoff, most of the research objects focused on herbs or shrubs, rarely involved the spatial distribution of tree species.

When studying the coupling effect of complex topography and the spatial distribution of tree species on surface runoff generation, the causal relationship between multiple factors is involved. Structural equation modeling (SEM) is a statistical method based on confirmatory factor analysis and path analysis to reveal the structural theory of a certain phenomenon, which has advantages in simulating and verifying the complex relationship between multiple factors and has been widely used in the environmental and ecological research.

For example, Xi et al. (2018) built an SEM of three potential variables including terrain, stand structure, and soil characteristics to study the multi-factor coupling relationships between typical Robinia pseudoacacia L. and Pinus tabulaeformis Carr. mixed plantations. Hou et al. (2020) used SEM to reveal the relationships between vegetation coverage and the reduction rate of the runoff coefficient and the reduction rate of the sediment yield. Yang et al. (2018) used SEM to test the impacts of abiotic and biotic driving factors on plant biomass and root/shoot ratios.

In this study, cypress forests on a steep slope in southwestern China was taken as the research object, the SEM was used to simulate the causal relationship between the spatial distribution of cypress, topography, and surface runoff, and the response surface method (RSM) was used to further analyze the response of surface runoff to the spatial distribution of cypress and topography. Finally, the strategies of stand structure adjustment were proposed to reduce surface runoff, which would provide theoretical and technical support for the improvement of water conservation capacity of cypress forests on steep slopes in southwestern China.

2. Materials and methods

2.1. Site description

The study was carried out on a steep slope (slope angle>30deg) in Huaying County (30deg25'21"N, 106deg50'2"E), Sichuan Province, with an annual average precipitation of 1200 mm and an annual average temperature of 18 degrees Celsius. Most of the rainfall occurred between May and August, accounting for 70% of the annual precipitation. The slope was a bedding slope and the soil was limestone yellow soil. The vegetation conditions on the slope were composed of cypress and sparse weeds. The cypress on the slope originated from the Grain-for-Green Project at the beginning of the 21st century. Aerial-seeding afforestation was carried out on the degraded slope. After two decades of succession of vegetation communities, the slope had developed into an open-canopied cypress forest, with significant differences in stand density and distribution patterns.

2.2. Experiment design

2.2.1. Runoff plot setting

Twelve runoff plots (5 mx10 m) were built at the same slope position, and the relative height difference of each runoff plots was similar so that the influence of topography on surface runoff only depended on the internal topographic characteristics. The basic characteristics including the stand density of cypress, surface vegetation coverage, and the relative height difference of each runoff plot were shown in Tab.1. The statistical results showed that the standard deviations of the surface vegetation coverage and the relative height difference of the 12 runoff plots were 2.25% and 0.13m, respectively, which were not of the same order of magnitude as the sample data. Therefore, the interference of surface vegetation coverage and the relative height difference to this study could be eliminated.

2.2.2. Data collection

In each runoff plot, observation data including topography, the spatial distribution of cypress, rainfall, and surface runoff was collected. Specifically, Real-time kinematic GPS (RTK-GPS) was used to measure topography, while the spatial location of cypress was also determined. In the process of topographic measurement, spatial point data was measured at 0.2m intervals, and when encountering areas with large terrain variability, an intensive measurement was performed at 0.1m intervals. After each rainfall, the surface runoff was measured by the water-level gauge in the runoff storage pond, and the rainfall data monitored by the small weather station was recorded. No less than 20 rainfall and runoff data were observed during the rainy season.

2.3. Data processing

2.3.1. Determination and calculation of factors that characterize the spatial distribution of cypress

The Ripley's K index (Ripley, 1977), the contagion index (Pommerening, 2002; Aguirre et al., 2003), and the stand density of cypress were used to reflect the spatial distribution of cypress in each runoff plot. In this study, Ripley's K index described the number of individual plants in a circle with a point as the center and r was the radius, which was typically used to compare a given point distribution with a random distribution:

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with

$I_r(u_{ij}) = \{$

$\begin{matrix} 1, & u_{ij} < r \\ 0, & u_{ij} > r \end{matrix}$ and $0[?]I_r(u_{ij})[?]1$ (1)

Where N is the total number of trees, and u_{ij} is the distance between i and j.

The K-function can be normalized as L-function proposed by Besag (1977):

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(2)

A positive value of L(r) indicates clustering over that spatial scale whereas a negative value indicates dispersion.

The contagion index W_i described the degree of regularity of the spatial distribution of the four trees nearest to a reference tree i.W_i was based on the classification of the angles between these four neighbors. A reference quantity was the standard angleα_0, which was expected in a regular point distribution. The binary random variable z_{ij} was determined by comparing each α_j with the standard angle $\alpha_0 = 90$, and the contagion index W_i was then defined as the proportion of angles α_j between the four neighboring trees which were smaller than the standard angleα_0:

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with

$z_{ij} = \{$

$\begin{matrix} 1, & \alpha_j < \alpha_0 \\ 0, & otherwise \end{matrix}$ and $0[?]W_i[?]1$ (3)

W_i=0 indicates that the trees in the vicinity of the reference tree are positioned in a regular manner, whereas W_i=1 points to an irregular or clumped distribution.

The value range and meaning of the contagion index W_i were further clarified in Fig.1. In this study, the average of the contagion index W calculated by each standard tree was used as the comprehensive contagion index of each runoff plot:

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(4)

2.3.2. Determination and calculation of factors that characterize the topography

Topographic relief (Normark and Spiess, 1976), surface roughness (Romkens et al., 2002), surface cutting depth (He et al., 2016), and runoff path density (Zhao and Govers, 2016) were used to describe internal topographic characteristics of each runoff plot. The above indicators were calculated based on the measured topography data.

Topographic relief was calculated based on change-point theory. Firstly, the average value X was calculated according to the elevation value of 0.2m grid points $\{X_1,X_2,X_3\ldots X_n\}$ in the runoff plot, and then the average topographic relief of the runoff plot could be calculated:

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(5)

Surface roughness was calculated by the ratio of the surface area and the projected area of the runoff plot which were extracted by 3D Analyst tool in ArcGIS:

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(6)

Where S_1 is the surface area of the runoff plot, $S_2$is the projected area of the runoff plot.

Runoff path referred to the shallow trench formed by surface runoff, while the runoff path density was the total length of the runoff path per unit area. In this study, RTK-GPS was used to measure the runoff path, and hydrological analysis tool in ArcGIS was used for secondary inspection:

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(7)

Where L_i is the length of the i-th groove in the runoff plot, A is the area of the runoff plot.

Surface cutting depth referred to the difference between the average elevation and the minimum elevation of a certain point on the ground. In this study, surface cutting depth was calculated with the elevation data of each point in the neighborhood of the runoff path:

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(8)

Where Y_i is the average elevation within the neighborhood of the i-th point on the bottom line of the runoff path, Y_{imin} is the minimum elevation of the i-th point on the bottom line of the runoff path, and m is the point on the bottom line of all runoff paths in the runoff plot.

2.3.3. Determination of runoff characteristics

Surface runoff coefficient was used to reflect the surface runoff characteristics of each runoff plot. When studying the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient, it was necessary to eliminate the interference of extreme rainfall events on surface runoff coefficient. Therefore, the rainfall intensity with the most frequent occurrence in this area was taken as the standard, and 10 groups of runoff and precipitation data with similar rainfall intensity were selected to calculate the surface runoff coefficient:

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(9)

Where F_i is the runoff yield of the i-th rainfall,$P_i$is the precipitation of the i-th rainfall.

2.4. Research method

2.4.1. Correlation analysis

The Pearson correlation coefficient method was used to test the correlation between each influencing factor and the surface runoff coefficient, and the influencing factors with significant differences to the surface runoff coefficient were screened out as the basic variables for SEM model construction.

2.4.2. Structural equation modeling

The essence of SEM was a confirmatory model analysis, which used measured data to confirm the possible causal relationships between variables. In this study, it was assumed that there was an interaction between the spatial distribution of cypress and the topography, which together affected the surface runoff coefficient. By constructing an SEM, the interaction between the spatial distribution of cypress and the topography, as well as the causal relationship between the characteristic parameters and the surface runoff coefficient was reflected.

2.4.3. Response surface method

The Response surface method (RSM) was used to analyze the response of surface runoff coefficient to the coupling of the spatial distribution of cypress and the topography, and the functional relationship between runoff coefficient and each factor would be identified.

3. Results

3.1. Correlation between surface runoff coefficient and the characteristic parameters of the spatial distribution of cypress and topography

The characteristic parameters of the spatial distribution of cypress and topography in each runoff plot were shown in Tab.2. When analyzing the coupling effects of multiple factors on surface runoff coefficient, it was necessary to assume that every single factor had a significant correlation with the surface runoff coefficient, so the irrelevant variables needed to be excluded in advance. Therefore, the Pearson correlation coefficient method was used to check the correlation between each characteristic parameter and the surface runoff coefficient, and the results were shown in Tab.3. The results of the correlation test showed that except for the surface cutting depth and L(d) index, other factors had significant correlations with the surface runoff coefficient. Besides, topographic relief and runoff path density were positively correlated with the surface runoff coefficient, while surface roughness, contagion index, and stand density of cypress were negatively correlated with the surface runoff coefficient.

3.2. Correlation between surface runoff coefficient and the characteristic parameters of the spatial distribution of cypress and topography

3.2.1. SEM construction

To construct an SEM to reflect the impact of the spatial distribution of cypress and topography on runoff coefficient, the first step was to clarify the independent and dependent variables, and the accuracy of the model depended on the significant differences of the correlation between the independent and dependent variables. According to Tab.3, three factors that characterizing topographical characteristics including topographic relief, surface roughness, and runoff path density, and two factors representing the spatial distribution of cypress including contagion index and stand density of cypress, were selected as independent variables, and surface runoff coefficient was used as the dependent variable for SEM construction.

In the construction of SEM, the relationship chains between variables were created in the form of a path diagram shown in Fig.2. The one-way arrow in the figure represented the effect of the independent variable on the dependent variable, and the two-way arrow represented the interaction between independent variables. The output results of the model included the fitness index of the model, the normalized path coefficient, and the corresponding significant differences between variables.

3.2.2. SEM simulation results

The simulation results of the model were presented in the form of a path diagram shown in Fig.3, the standardized path coefficients among the variables were shown in Tab.4, and the accuracy of the model was reflected in the form of the fitness index output by the model shown in Tab.5.

From Tab.5, the fit index values of the model were all within the acceptable range, indicating that the hypothetical structural model could simulate the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient in this study. The simulation results of the model showed that the five independent variables (topographic relief, surface roughness, runoff path density, contagion index, stand density of cypress) all had a significant impact on surface runoff coefficient, and the effects were 0.245, -0.272, 0.239, -0.311, -0.134, respectively. Among the five independent variables, there are significant interactions between stand density of cypress and surface roughness, between stand density of cypress and runoff path density, and between contagion index and topographic relief, and the interaction coefficients were 0.773, -0.491, -0.775, respectively.

3.3. Analysis of the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient

According to the output of SEM, the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient could be divided into three structures: The coupling effects of surface roughness, runoff path density, and stand density of cypress on surface runoff coefficient; The coupling effects of contagion index and topographic relief on surface runoff coefficient; and the coupling effects of all these five factors on surface runoff coefficient. The Response Surface Method (RSM) was used to analyze the response of surface runoff coefficient to each factor under three groups of structures.

3.3.1. Coupling effects of surface roughness, runoff path density and stand density of cypress on runoff coefficient

Runoff path density and surface roughness, as characteristic parameters of topography, had opposite effects on surface runoff coefficient. Taking the runoff path density/surface roughness as the composite index of surface roughness-runoff path density, the constructed nonlinear regression curve of the surface runoff coefficient to the composite index of surface roughness-runoff path density was shown in Fig.4. Fig.4 suggested that surface runoff coefficient had a positive correlation as well as exponential function relationship with the composite index of surface roughness-runoff path density (R^2=0.623).

The nonlinear regression curve of the surface runoff coefficient to the stand density of cypress was shown in Fig.5. Fig.5 suggested that surface runoff coefficient had a negative correlation as well as quadratic function relationship with the stand density of cypress (R^2=0.560).

The RSM was used to further analyze the response of the surface runoff coefficient to the coupling of stand density of cypress and the composite index of surface roughness-runoff path density. The response surface was shown in Fig.6, and the corresponding response surface regression equation was shown in Tab.7.

As shown in Fig.6, higher surface runoff coefficient (M>0.5) corresponded to lower stand density of cypress (T<53 ind/100m^2) and higher composite index of surface roughness-runoff path density (Q>7.64), while lower surface runoff coefficient (M<0.3) corresponded to lower composite index of surface roughness-runoff path density (Q<6.44). According to Fig.6 and Tab.7, any value of Q in its value range always made [?]M/[?]Q>0, indicating that the surface runoff coefficient increased with the increase of Q value, and the increase rate gradually became flat. The surface runoff coefficient increased first and decreased later with the increase of T value, and the critical point of trend change appeared at [?]M/[?]T=0. The critical value of T that made [?]M/[?]T=0 decreased as the Q value gradually increased.

3.3.2. Coupling effects of contagion index and topographic relief on surface runoff coefficient

The nonlinear regression curve of the surface runoff coefficient to contagion index was shown in Fig.7. Fig.7 suggested that surface runoff coefficient had a negative correlation as well as exponential function relationship with contagion index (R^2=0.702).

The nonlinear regression curve of the surface runoff coefficient to topographic relief was shown in Fig.8. Fig.8 suggested that surface runoff coefficient had a positive correlation as well as exponential function relationship with topographic relief (R^2=0.493).

The RSM was used to further analyze the response of the surface runoff coefficient to the coupling of the contagion index and topographic relief. The response surface was shown in Fig.9, and the corresponding response surface regression equation was shown in Tab.9.

As shown in Fig.9, higher surface runoff coefficient (M>0.54) corresponded to lower contagion index (W<0.43) and higher topographic relief (S>1.48), while lower surface runoff coefficient (M<0.3) corresponded to higher contagion index (W>0.54). According to Fig.9 and Tab.9, any value of W in its value range always made [?]M/[?]W<0, indicating that the surface runoff coefficient decreased with the increase of W value. Any value of S in its value range always made [?]M/[?]S>0, indicating that the surface runoff coefficient increased with the increase of S value.

3.3.3. Coupling effects of five factors on surface runoff coefficient

Among the factors that characterize topographic features, the effect directions of runoff path density and topographic relief on runoff coefficient were opposite to that of surface roughness. Taking the topographic relief *runoff path density/surface roughness as the composite index of topography, the constructed nonlinear regression curve of the surface runoff coefficient to the composite index of topography was shown in Fig.10. Fig.10 suggested that surface runoff coefficient had a positive correlation as well as exponential function relationship with the composite index of topography (R^2=0.717).

Among the factors that characterized the spatial distribution of cypress, the effect direction of stand density of cypress and contagion index on runoff coefficient was the same. Taking the stand density of cypress* contagion index as the composite index of the spatial distribution of cypress, the constructed nonlinear regression curve of the surface runoff coefficient to the composite index of the spatial distribution of cypress was shown in Fig.11. Fig.11 suggested that surface runoff coefficient had a negative correlation as well as quadratic function relationship with the composite index of the spatial distribution of cypress (R^2=0.565).

The RSM was used to further analyze the response of the surface runoff coefficient to the coupling of the composite index of the spatial distribution of cypress and the composite index of topography. The response surface was shown in Fig.12, and the corresponding response surface regression equation and standardization effect of arrangement diagram were shown in Tab.11 and Fig.13.

As shown in Fig.12, higher surface runoff coefficient (M>0.6) corresponded to higher composite index of topography (U>11.4), while lower runoff coefficient (M<0.3) corresponded to lower composite index of topography (U<9.0). According to Fig.12 and Tab.11, any value of U in its value range always made [?]M/[?]U>0, indicating that the surface runoff coefficient increased with the increase of U value, and the increase rate gradually became steeper. The surface runoff coefficient increased first and decreased later with the increase of V value, and the critical point of trend change appeared at [?]M/[?]V=0. The critical value of V that made [?]M/[?]T=0 increased as the U value gradually increased. Fig.23 further illustrated the effect of each parameter in the regression equation on surface runoff coefficient. The parameters U and V^2 had a dominant effect on surface runoff coefficient, making the surface runoff coefficient increase monotonically with the change of U value, and change parabolic with the increase of V value, which was consistent with the nonlinear relationship shown in Fig.10 and Fig.11. According to Tab.11, the coefficient of VU was opposite to the coefficient of V^2, but the same as the coefficient of U, indicating that the interaction between the spatial distribution of cypress and the topography enhanced the influence of topography on the surface runoff coefficient, with an enhancement rate of 25.05%, and weakened the influence of the spatial distribution of cypress on the surface runoff coefficient, with a weakening rate of 40.74%.

4. Discussion

4.1. Strategy of stand structure adjustment to reduce surface runoff coefficient and improve water conservation capacity of cypress forest

According to the water balance method referred in the Standard for Evaluation of Forest Ecosystem Service Function (LY/T 1721-2008) and related research (Wang et al., 2013; Si et al., 2011), when the rainfall and evapotranspiration were close, the amount of water conservation depended on the surface runoff. In this study, every runoff plots were located on the same slope and at the same altitude, and the vegetation coverage and the growth of cypress were basically the same, so the rainfall and evapotranspiration were basically the same. Therefore, the smaller the surface runoff coefficient, the higher the water conservation capacity, and reducing the surface runoff coefficient would indirectly improve the water conservation capacity of cypress forest.

According to the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient, through the adjustment of the stand structure, the system structure of runoff generation in the terrain unit would be changed, thereby reducing the surface runoff coefficient and improving the water conservation capacity of cypress forest.

The actual observations of the runoff plots showed that the surface runoff coefficient of the study area was concentrated in the range of 0.3 to 0.4. When the surface runoff coefficient was large (M>0.5), the main characteristics of the spatial distribution of cypress could be divided into two categories. The first type had low stand density of cypress (T<20 ind/100m^2) and regular spatial structure (W<0.5), and the second type had moderate stand density of cypress (20 ind/100m^2< T<50 ind/100m^2) and regular spatial structure (W<0.5). In both cases, the composite index of topography was relatively high (U>12). According to the interaction coefficients between the independent variables determined by the SEM, the response of the composite index of topography to the spatial distribution of cypress could be determined. Combining the response regression equation of surface runoff coefficient to the composite index of the spatial distribution of cypress and the composite index of topography, the dynamic change curve of surface runoff coefficient with the change of the spatial distribution of cypress was constructed (Fig.14, Fig.15).

For different spatial distribution of cypress, two strategies of stand structure adjustment could be adopted to reduce surface runoff coefficient (The designed target surface runoff coefficient was within 0.3), including A) only increasing the stand density of cypress, or B) increasing both the stand density and the contagion index of cypress (The strategy of only increasing the contagion index of cypress shown in the figure could not achieve the goal of reducing the surface runoff coefficient to 0.3).

In the case of low stand density and regular spatial structure of cypress (Fig.14), the surface runoff coefficient could be reduced from 0.62 to less than 0.3 by A) increase the stand density of cypress from 14 ind/100m^2 to 24 ind/100m^2(corresponding to the composite index of topography reduced from 17.4 to 9.1) or B) increasing the stand density of cypress from 14 ind/100m^2 to 21 ind/100m^2 and the contagion index from 0.41 to 0.56 (corresponding to the composite index of topography reduced from 17.4 to 8.0). Comparing strategy A and strategy B in fig.24, it could be found that when the stand density of cypress was increased to the same value, strategy B reduced the surface runoff coefficient by 4%˜6.8% higher than strategy A.

In the case of moderate stand density and regular spatial structure of cypress (Fig.15), the surface runoff coefficient could be reduced from 0.57 to less than 0.3 by A) increase the stand density of cypress from 36 ind/100m^2 to 64 ind/100m^2(corresponding to the composite index of topography reduced from 12.3 to 6.0) or B) increasing the stand density of cypress from 36 ind/100m^2 to 52 ind/100m^2 and the contagion index from 0.46 to 0.58 (corresponding to the composite index of topography reduced from 12.3 to 6.3). Comparing strategy A and strategy B in fig.26, it could be found that as the stand density of cypress increased, the difference in the reduction of surface runoff coefficient between strategy B and strategy A gradually expanded. When the stand density of cypress increased to 55 ind/100m^2, strategy B could reduce the surface runoff coefficient by 23.9% higher than strategy A.

Comparing the reduction efficiency of the surface runoff coefficient by strategy A and strategy B under the two cases, it could be found that when the stand density of cypress was low (T<20 ind/100m^2), increasing the contagion index of cypress on the basis of increasing the stand density of cypress to a certain index could not significantly improve the reduction of surface runoff coefficient. However, when the stand density of cypress was moderate (20 ind/100m^2< T<50 ind/100m^2), increasing the contagion index of cypress on the basis of increasing the stand density of cypress to a certain index could greatly improve the reduction of surface runoff coefficient. Therefore, for the strategy of stand structure adjustment in the study area, when the initial stand density of cypress was relatively low (<20 ind/100m^2), the first step was to increase the stand density of cypress, and until the stand density of cypress reached to moderate level (20-50 ind/100m^2), adjusting the spatial structure of cypress from relatively regular to relatively clumped could reduce the surface runoff coefficient to a greater extent.

4.2. Selection of key factors when studying the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient using SEM

The SEM used in this study was a confirmatory model, not an exploratory model. It required the support of theory or empirical rules to construct a hypothetical model, and the consistency of the theoretical model and the actual observation was tested through sampled data. When using SEM to study the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient, the theoretical basis was that different spatial distribution of cypress were distributed in slope units with different topographical features, which changed the system structure of runoff generation in the unit, enhanced or weakened the water blocking capacity of the landscape system, thereby changing the distribution and intensity of surface runoff (Slattery and Burt, 2015).

In the selection of key factors, on the one hand, it was necessary to exclude the interference of factors other than characteristic parameters of the spatial distribution of cypress and topography. In this study, the disturbing factors that could have an impact on surface runoff coefficient included rainfall intensity, surface vegetation coverage, the relative height difference, etc. Therefore, in the process of experimental design and data collation, the above disturbing factors should be controlled or explained. On the other hand, the selected key factors should be able to fully reflect the characteristics of the spatial distribution of cypress and topography, while having a significant impact on surface runoff coefficient. Therefore, based on a large number of studies on the influencing factors of surface runoff, seven common independent factors were selected, and the correlation between each factor and surface runoff coefficient was analyzed, and finally five factors that had significant effects on surface runoff coefficient were screened out as independent variables for SEM construction. The theoretical model constructed therefrom had a high degree of fit and could simulate the causal relationship and coupling mechanism among the spatial distribution of cypress, topography and surface runoff coefficient.

5. Conclusions

The purpose of this research was to clarify the coupling effects of the spatial distribution of cypress and topography on surface runoff coefficient and propose a strategy of stand structure adjustment to reduce the surface runoff coefficient, and provide a theoretical basis and technical support for improving the water conservation function of cypress forests on steep slopes in southwestern China.

Among the key indicators reflecting the characteristics of the topography and the spatial distribution of cypress forest, topographic relief, surface roughness, runoff path density, contagion index, and stand density of cypress, all had a significant impact on surface runoff coefficient, and the impact effects were 0.245,-0.272, 0.239, -0.311, -0.134, respectively. Significant interactions were found between the stand density of cypress and surface roughness, the stand density of cypress and runoff path density, and the contagion index and topographic relief, and the interaction coefficients were 0.773, -0.491, -0.775, respectively; Under the condition of the coupling of topography and spatial distribution of cypress, the surface runoff coefficient increased monotonically with the increase of the composite index of topography (topographic relief*runoff path density/surface roughness), and increased first and decreased later with the increase of the composite index of the spatial distribution of cypress (stand density of cypress*contagion index of cypress); The interaction between the spatial distribution of cypress and the topography enhanced the influence of topography on surface runoff coefficient, with an enhancement rate of 25.05%, and weakened the influence of the spatial pattern of cypress on surface runoff coefficient, with a weakening rate of 40.74%.

To reduce the surface runoff coefficient from a larger value (>0.5) to less than 0.3, two strategies of stand structure adjustment could be adopted, including only increasing the stand density of cypress, or increasing both the stand density and the contagion index of cypress, and which strategy should be adopted depended on the initial stand density of cypress. When the initial stand density of cypress was relatively low (<20 ind/100m^2), the first step was to increase the stand density of cypress, and until the stand density of cypress reached to moderate level (20-50 ind/100m^2), adjusting the spatial structure of cypress from relatively regular to relatively clumped could reduce the surface runoff coefficient to a greater extent.

In this study, the constructed SEM was highly consistent with the actual observation data and could simulate the causal relationship as well as the coupling mechanism among the topography, the spatial pattern of cypress, and surface runoff coefficient. The next stage of the research would be based on the SEM constructed in this study, combined with the determination of sediment yield and ecosystem service functions to expand the model, so that the optimal allocation for the spatial distribution of cypress was more targeted.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Aguirre O., Hui G., Gadow K.V., et al. (2003). An analysis of spatial forest structure using neighbourhood-based variables. Forest Ecology & Management, 183(1-3):137-145.

Bai X.Y., Wang S.J., Xiong K.N. (2012). Assessing spatial-temporal evolution processes of karst rocky desertification land: Indications for restoration strategies. Land Degradation & Development, 24(1):47-56.

Bal K., Struyf E., Vereecken H., et al. (2011). How do macrophyte distribution patterns affect hydraulic resistances. Ecological Engineering, 37(3): 529-533.

Balázs Székely., Tamás Telbisz., Zsófia Koma., et al. (2015). Geomorphometric correlations of vegetation cover properties and topographic karst features based on high-resolution LiDAR DTM of Aggtelek Karst, NE Hungary[C]// Egu General Assembly Conference.

Bennett S.J., Bridge J.S. (2010). An experimental study of flow, bedload transport and bed topography under conditions of erosion and deposition and comparison with theoretical models. Sedimentology, 42(1):117-146.

Besag J.E. (1977). Contribution to the discussion on Dr. Ripley's paper. J. R. Stat. Soc. Ser, 39.

Cao Z.H., Zhao Q.H., Ding S.Y., et al. (2017). Influence of slope and vegetation coverage on the erosion and sediment yield characteristics of river bank slope. Journal of Natural Resources, 32(11): 1892-1904. (in Chinese)

Capmourteres V., Anand M. (2016). Assessing ecological integrity: A multi-scale structural and functional approach using Structural Equation Modeling. Ecological Indicators, 71:258-269.

Clark P.J., Evans F.C. (1954). Distance to Nearest Neighbor as a Measure of Spatial Relationships in Populations. Ecology, 35(4): 445-453.

Currence H.D., Lovely W.G. (1970) . The Analysis of Soil Surface Roughness. Amer Soc Agr Eng Trans Asae, 71(71):710-714.

Du H., Hu F., Zeng F., et al. (2017). Spatial distribution of tree species in evergreen-deciduous broadleaf karst forests in southwest China. Scientific Reports, 7(1):15664.

Du H., Peng W.X., Song T.Q., et al. (2015). Spatial distribution of woody plants and their environmental interpretation in the karst forest of southwest China. Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, 149(1):121-130.

Duan L., Huang M., Zhang L. (2016). Differences in hydrological responses for different vegetation types on a steep slope on the Loess Plateau, China. Journal of Hydrology, 537:356-366.

Efe, R. (2014). Ecological Properties of Vegetation Formations on Karst Terrains in the Central Taurus Mountains (Southern Turkey). Procedia - Social and Behavioral Sciences, 120:673-679.

El K.H., Zhang H., Zhang P., et al. (2013). Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China. Catena, 105:1-10.

Febles-Gonzalez J.M., Vega-Carreno M.B., Tolon-Becerra A., et al. (2012). Assessment of soil erosion in karst regions of Havana, Cuba. Land Degradation & Development, 23(5):465-474.

Gao J., Wang H. (2019). Temporal analysis on quantitative attribution of karst soil erosion: A case study of a peak-cluster depression basin in Southwest China. Catena, 172:369-377.

He J.J., Sun L.Y., Gong H.L., et al. (2016). The characteristics of rill development and their effects on runoff and sediment yield under different slope gradients. Journal of Mountain Science, 13(3):397-404.

He Y.H., Chen X H, Lin K R, et al. (2014). Temporal and spatial characteristics of runoff coefficient variations in the Dongjiang Basin during 1964-2012. Geographical Research, 33(6):1369-1376. (in Chinese)

Hou G.R., Bi H.X., Huo Y.M., et al. (2020). Determining the optimal vegetation coverage for controlling soil erosion in Cynodon dactylon grassland in North China, Journal of Cleaner Production,244,118771.

Jonsson M., Wardle D.A. (2010). Structural equation modelling reveals plant-community drivers of carbon storage in boreal forest ecosystems. Biology Letters, 6(1):116-119.

Kim D., Kupfer J.A. (2016). Tri-Variate Relationships among Vegetation, Soil, and Topography along Gradients of Fluvial Biogeomorphic Succession. Plos One, 11(9):e0163223.

Lea K., Armand R., Saunier M., et al. (2019). Effects of plant traits and their divergence on runoff and sediment retention in herbaceous vegetation. Plant and Soil, 441(1):511-524.

Li X.J., Li X.R., Song W.M., et al. (2008). Effects of crust and shrub patches on runoff, sedimentation, and related nutrient (C, N) redistribution in the desertified steppe zone of the Tengger Desert, Northern China. Geomorphology, 96(1-2):221-232.

Maria L.G.A., Armando N.S., Mendoza M.E. (2018). Modeling biophysical and anthropogenic effects on soil erosion over the last 2,000 years in central Mexico. Land Degradation & Development, 29(6):1885-1895.

MilisVa M., BelancVic A., KepcVija R.M., et al. (2010). Calcite deposition in karst waters is promoted by leaf litter breakdown and\r, vice versa. Annales de Limnologie - International Journal of Limnology, 46(4):225-232.

Normark W.R., Spiess F.N. (1976). Erosion on the Line Islands archipelagic apron: Effect of small-scale topographic relief. Geological Society of America Bulletin, 87(2):286.

Ochoa P.A., Fries A., Mejía D., et al. (2016). Effects of climate, land cover and topography on soil erosion risk in a semiarid basin of the Andes. Catena, 140, 31-42.

Peng W.X., Song T.Q., Zeng F.P., et al. (2010). The coupling relationships between vegetation, soil, and topography factors in karst mixed evergreen and deciduous broadleaf forest. Acta Ecologica Sinica.30(13):3472-3481.(in Chinese)

Pommerening A. (2002). Approaches to quantifying forest structures. Forestry (3):305-324.

Qin W., Cao W.H., Zuo C.Q., et al. (2015). Review on the coupling influences of vegetation and topography to soil erosion and sediment yield. Journal of Sediment Research, 000(003):74-80.(in Chinese)

Ren K.M., Wei W., Zhao X.N., et al. (2018). Simulation of the effect of slope vegetation cover and allocation distribution on water erosion in the loess hilly region. Acta Ecologica Sinica, 38(22): 8031-8039. (in Chinese)

Ripley B.D. (1977). Modeling spatial patterns. Journal of the Royal Statal Society Series B (Statal Methodology), 9:178-212.

Romkens M.J.M., Helming K., Prasad S.N. (2002). Soil erosion under different rainfall intensities, surface roughness, and soil water regimes. Catena, 46(2-3):103-123.

Sabzevari T., Talebi A. (2019). Effect of hillslope topography on soil erosion and sediment yield using USLE model. Acta Geophysica, 67(6):1587-1597.

Saco P.M., Mariano M.D.L.H. (2013). Ecogeomorphic coevolution of semiarid hillslopes: emergence of banded and striped vegetation patterns through interaction of biotic and abiotic processes. Water Resources Research, 49(1): 115-126.

Santibáñez-Andrade G., Castillo-Argüero S.,Vega-Peña E.V., et al. (2015). Structural equation modeling as a tool to develop conservation strategies using environmental indicators: The case of the forests of the Magdalena river basin in Mexico City. Ecological Indicators, 54:124-136.

Slattery M.C., Burt T.P . (2015). Particle size characteristics of suspended sediment in hillslope runoff and stream flow. Earth Surface Processes & Landforms, 22(8):705-719.

Wang P.J., Dai Q.H., Ding G.J., et al. (2014). Variation of soil anti-erodibility during restoration of degraded karst vegetation. Acta Pedologica Sinica , 51(4):806-815.(in Chinese)

Wei X., Bi H.X., Liang W.J., et al. (2018). Relationship between Soil Characteristics and Stand Structure of Robinia pseudoacacia L. and Pinus tabulaeformis Carr. Mixed Plantations in the Caijiachuan Watershed: An Application of Structural Equation Modeling. Forests, 9(3):124-139.

Xu C., Yang Z., Qian W., et al. (2019). Runoff and soil erosion responses to rainfall and vegetation cover under various afforestation management in subtropical montane forest. Land Degradation and Development, 2019.30(14):1711-1724

Xu X.L., Ma K.M., Fu B.J., et al. (2009). Soil and water erosion under different plant species in a semiarid river valley, SW China: the effects of plant morphology. Ecological Research, 24(1):37-46.

Yang Y., Dou Y., An S., et al. (2018). Abiotic and biotic factors modulate plant biomass and root/shoot (R/S) ratios in grassland on the Loess Plateau, China. Science of The Total Environment, 636:621-631.

Yoo K., Amundson R., Heimsath A.M., et al. (2006). Spatial patterns of soil organic carbon on hillslopes: Integrating geomorphic processes and the biological C cycle. Geoderma, 130(1-2):47-65.

Zhang H.J., Sun Y.H., Cheng Y., et al. (2006). Influence of Different Vegetation Types on Surface Runoff Coefficient in Jinyun Mountain, Chongqing. Journal of Soil and Water Conservation, 20(6):11-13. .(in Chinese)

Zhang X., Li P., Li Z.B., et al. (2018). Study on temporal and spatial variation of runoff velocity and sediment in the convex hillslope under different vegetation patterns. Journal of Soil and Water Conservation, 32(6):16-21. (in Chinese)

Zhao J.L., Govers G. (2016). Variations in vegetation cover and topography control gully density and sediment production on the Chinese Loess Plateau[C]// Egu General Assembly Conference. EGU General Assembly Conference Abstracts

Tab.1 Characteristics of each runoff plot

NO.	Stand density of cypress (ind/100m^2)	Surface vegetation coverage (%)	The relative height difference (m)
1	14	57.2	8.22
2	22	58.4	8.33
3	34	55.8	8.12
4	22	59.2	8.03
5	36	55.0	8.17
6	66	57.4	8.44
7	36	53.5	8.32
8	54	58.8	8.10
9	70	57.1	8.22
10	68	52.0	8.03
11	34	58.2	8.13
12	10	58.5	8.02

Tab.2 Characteristic parameters of the spatial distribution of cypress and topography in each runoff plot

NO	Topographic relief (m)	Surface roughness	Surface cutting depth (cm)	Runoff path density (m/100m^2)	L(r) index	Contagion index	Stand density of cypress (ind/100m^2)	Surface runoff coefficient
1	1.71	1.22	9.54	12.44	-0.10	0.41	14	0.62
2	1.54	1.23	8.71	9.64	0.22	0.48	22	0.51
3	1.44	1.35	10.32	11.22	0.08	0.42	34	0.56
4	1.36	1.21	3.49	10.08	-0.05	0.53	22	0.39
5	1.71	1.31	6.94	9.62	0.22	0.45	36	0.60
6	1.39	1.61	10.76	9.92	-0.13	0.54	66	0.32
7	1.61	1.72	6.95	8.02	0.16	0.43	36	0.35
8	1.31	1.62	5.94	6.96	0.26	0.64	54	0.21
9	1.66	1.45	8.73	6.52	0.03	0.47	70	0.33
10	1.31	1.73	6.32	10.08	0.19	0.60	68	0.20
11	1.51	1.65	7.43	7.9	0.03	0.40	34	0.33
12	1.55	1.46	4.76	9.3	0.08	0.47	10	0.41

Tab.3 Correlation between surface runoff coefficient and the characteristic parameters of the spatial distribution of cypress and topography

Variable	Topographic relief	Surface roughness	Surface cutting depth	Runoff path density	L(r) index	Contagion index	Stand density of cypress
Surface runoff coefficient	0.659**	-0.788***	0.344	0.634**	-0.152	-0.598**	-0.748***

** means significant differences at P < 0.05 level, and *** means significant differences at P < 0.01.

Tab.4 Normalized path coefficient between variables

Variable	Topographic relief	Surface roughness	Runoff path density	Contagion index	Stand density of cypress	Surface runoff coefficient
Topographic relief	-					
Surface roughness	-0.495	-				
Runoff path density	0.121	-0.517	-			
Contagion index	-0.775***	0.539	-0.509	-		
Stand density of cypress	-0.507	0.773***	-0.491**	0.521	-	
Surface runoff coefficient	0.245**	-0.272***	0.239**	-0.311**	-0.134***	-

** means significant differences at $P < 0.05$ level, and *** means significant differences at $P < 0.01$.

Tab.5 Normalized path coefficient between variables

	CMIN/DF	RMSEA	CFI	NFI	IFI
Index value	2.746	0.067	1.0	0.996	0.983
Accepted value	1~3	<0.08	>0.9	>0.9	>0.9

Tab.6 Nonlinear regression equation of the runoff coefficient to the stand density of cypress and the composite index of surface roughness-runoff path density

Impact factor	Nonlinear regression equation	R^2
Stand density of cypress (T)	$M=0.5254-0.001411*T-0.000036*T^2$	0.560
Composite index of Surface roughness-runoff path density (Q)	M=exp(-1.85368+0.139303*Q)	0.623

Tab.7 Response surface regression equation of the surface runoff coefficient to the coupling of the stand density of cypress and the composite index of surface roughness-runoff path density

Impact factor	Response surface regression equation	Partial derivative	P value
Stand density of cypress (T) and composite index of surface roughness-runoff path density (Q)	$M=-0.000098T^2-0.0035Q^2-0.00063T*Q+0.0103T+0.12Q-0.29$	$\partial M/\partial T=-0.000196T-0.00063Q+0.0103$ $\partial M/\partial Q=-0.007Q-0.00063T+0.12$	0.041

Tab.8 Nonlinear regression equation of surface runoff coefficient to contagion index and topographic relief

Impact factor	Nonlinear regression equation	R^2
Topographic relief (S)	M=exp(-3.72169+1.83457*S)	0.493
Contagion index (W)	M=exp(1.12364-4.10265*W)	0.702

Tab.9 Response surface regression equation of the surface runoff coefficient to the coupling of contagion index and topographic relief

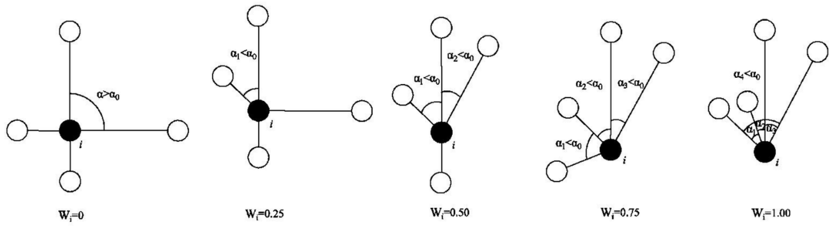
Impact factor	Response surface regression equation	Partial derivative	P value
Contagion index (W)and topographic relief (S)	$M=2.9W^2-0.23S^2+0.3W*S-4.7W+0.8S+1.2$	$\partial M/\partial W=5.8W+0.3S-4.7$ $\partial M/\partial S=-0.46S+0.3W+0.8$	0.033

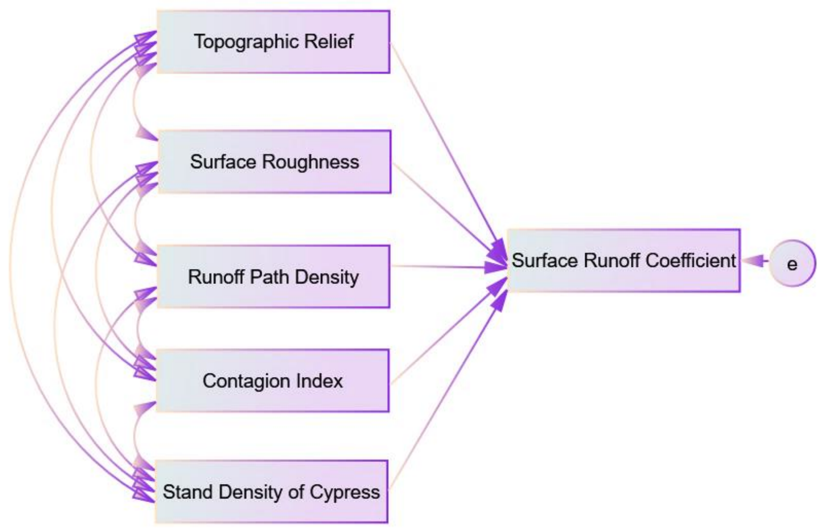
Tab.10 Nonlinear regression equation of the surface runoff coefficient to the composite index of the spatial distribution of cypress and the composite index of topography

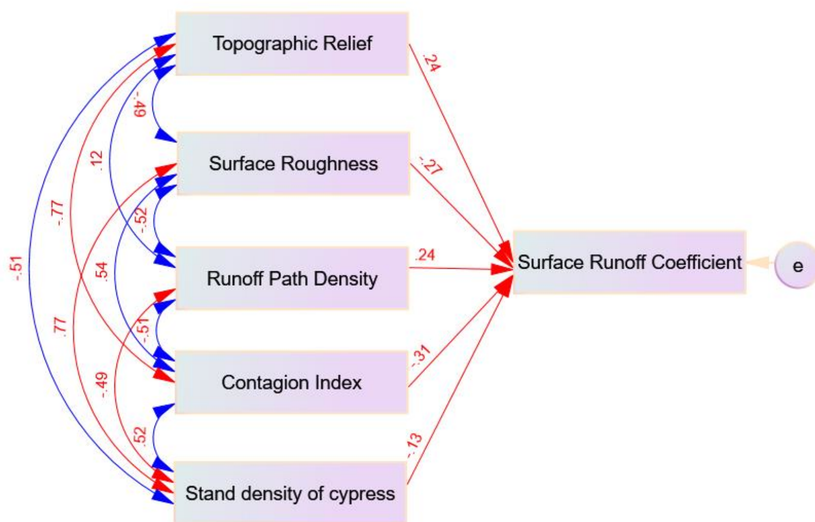
Impact factor	Nonlinear regression equation	R^2
Composite index of topography (U)	M=exp(-1.71125+0.0770892*U)	0.717
Composite index of the spatial distribution of cypress (V)	M=0.5205-0.00194*V-0.000138*V2	0.565

Tab.11 Response surface regression equation of the surface runoff coefficient to the coupling of the composite index of the spatial distribution of cypress and the composite index of topography

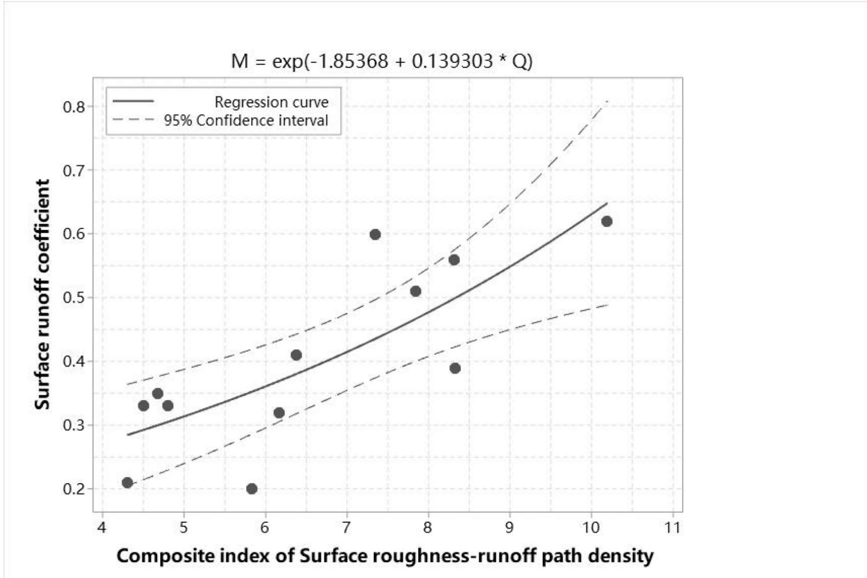
Impact factor	Response surface regression equation	Partial derivative	P value
Composite index of the spatial distribution of cypress (V) and composite index of topography (U)	$M=0.0041U^2-0.000613V^2+0.00126U*V-0.053U+0.0198V+0.19$	$\partial M/\partial U=0.0082U+0.00126V-0.053$ $\partial M/\partial V=-0.001226V+0.00126U+0.0198$	0.022

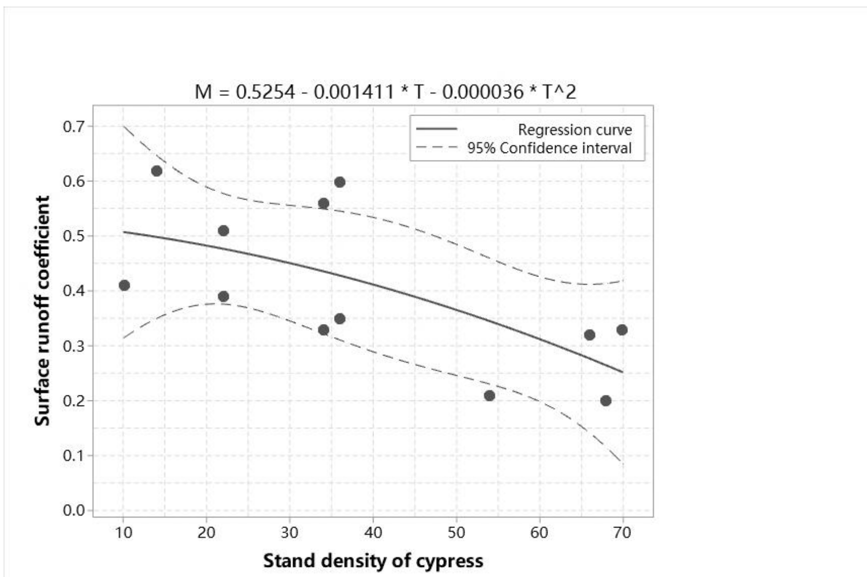

α>α0
i
Wi=0
α1<α0
i
Wi=0.25
α1<α0
α2<α0
i
Wi=0.50
α2<α0
α3<α0
α1<α0
i
Wi=0.75
α4<α0
i
Wi=1.00

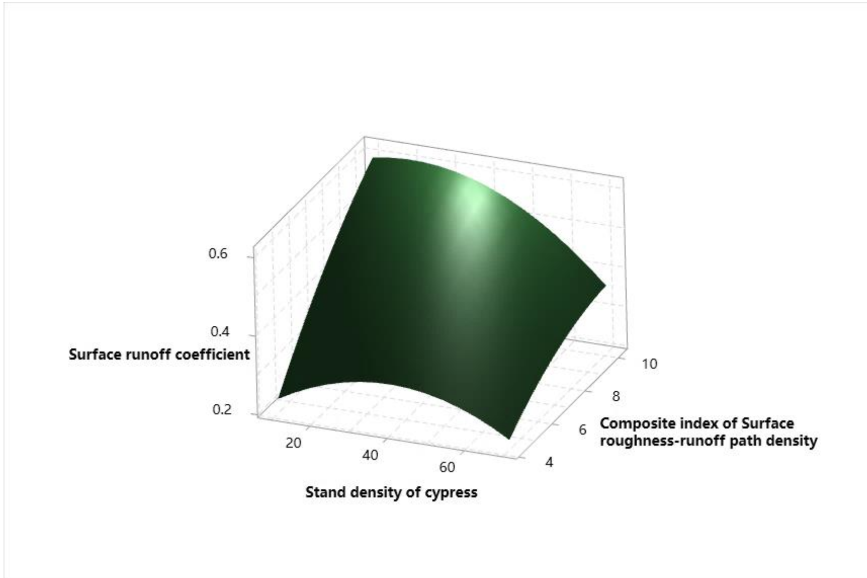

Topographic Relief
Surface Roughness
Runoff Path Density
Contagion Index
Stand Density of Cypress
Surface Runoff Coefficient
e

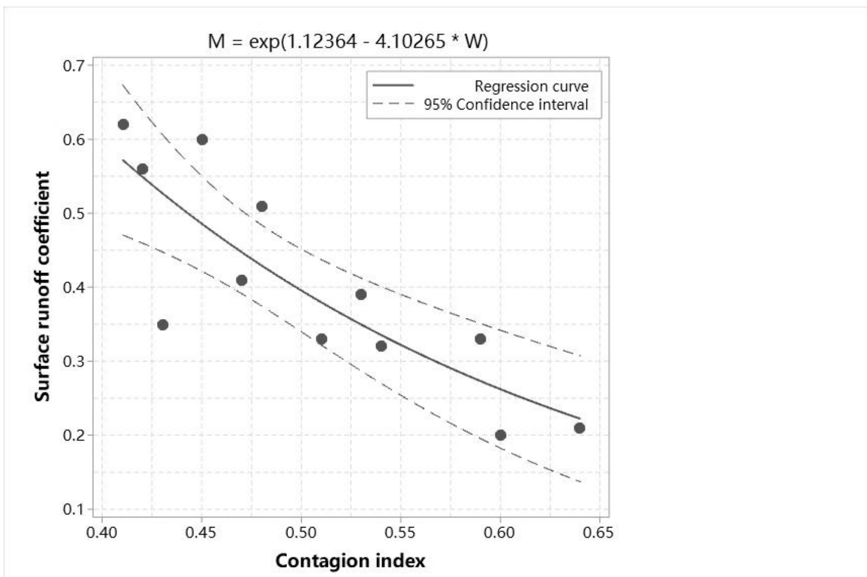


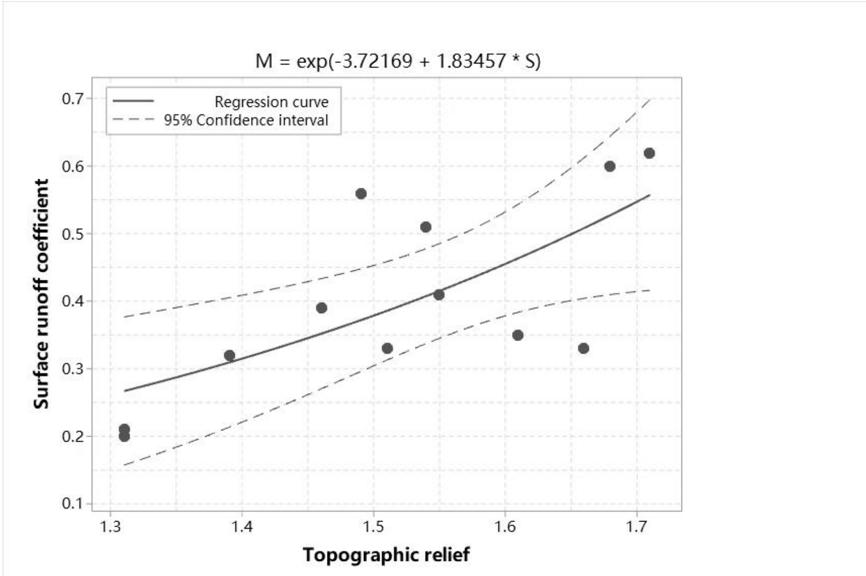
Topographic Relief
Surface Roughness
Runoff Path Density
Contagion Index
Stand density of cypress
Surface Runoff Coefficient
e
.24
-.27
.24
-.31
-.13
-.49
.12
-.52
-.77
.54
-.51
.77
-.49
-.51
.52


M = exp(-1.85368 + 0.139303 * Q)
Regression curve
95% Confidence interval
Surface runoff coefficient
0.8
0.7
0.6
0.5
0.4
0.3
0.2
4
5
6
7
8
9
10
11
Composite index of Surface roughness-runoff path density

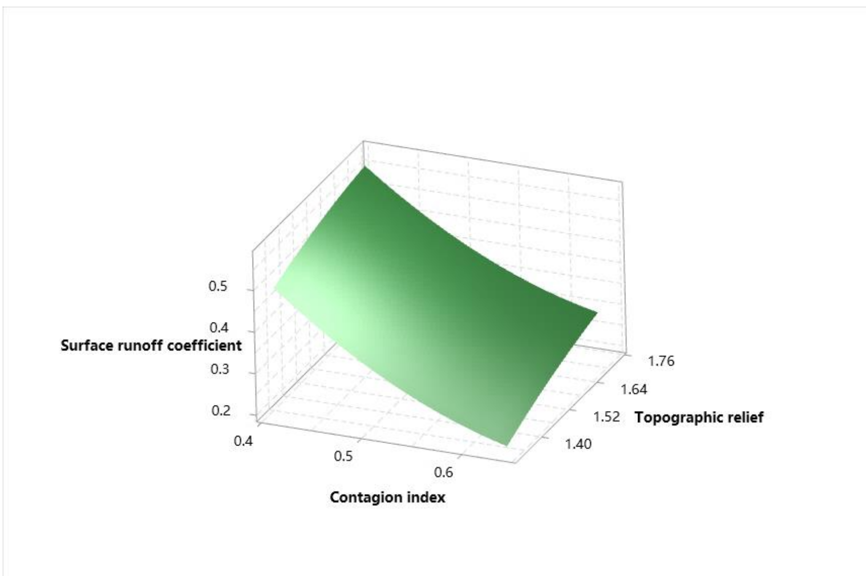

M = 0.5254 - 0.001411 * T - 0.000036 * T^2
Regression curve
95% Confidence interval
Surface runoff coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
10
20
30
40
50
60
70
Stand density of cypress


0.6
0.4
0.2
Surface runoff coefficient
20
40
60
Stand density of cypress
4
6
8
10
Composite index of Surface roughness-runoff path density

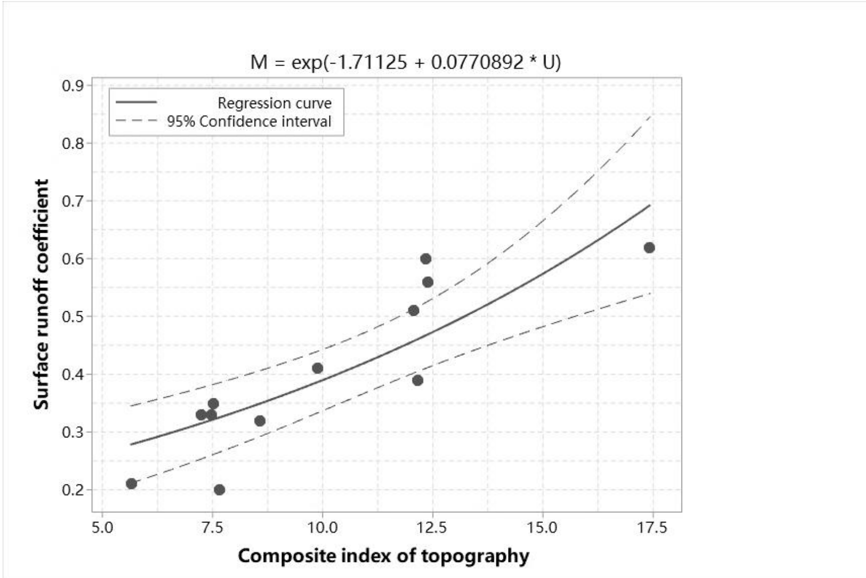

M = exp(1.12364 - 4.10265 * W)
Regression curve
95% Confidence interval
Surface runoff coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.40
0.45
0.50
0.55
0.60
0.65
Contagion index

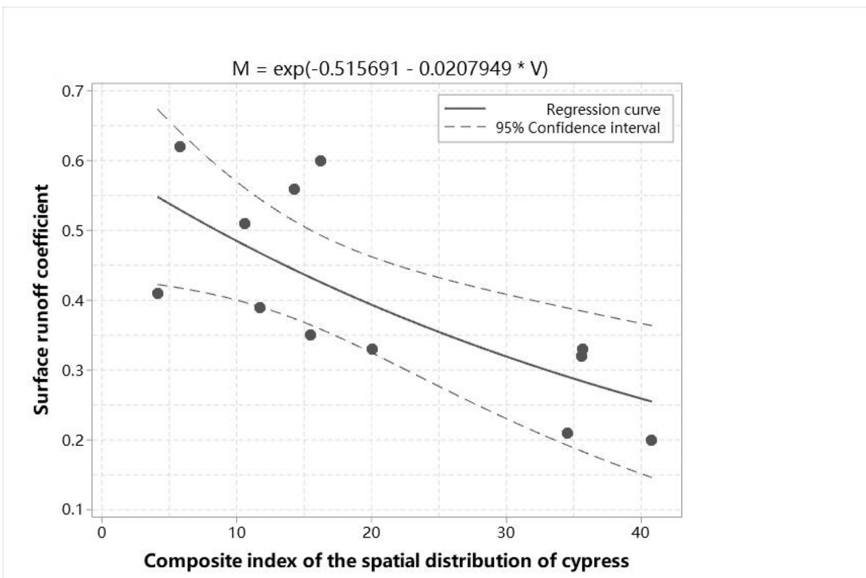


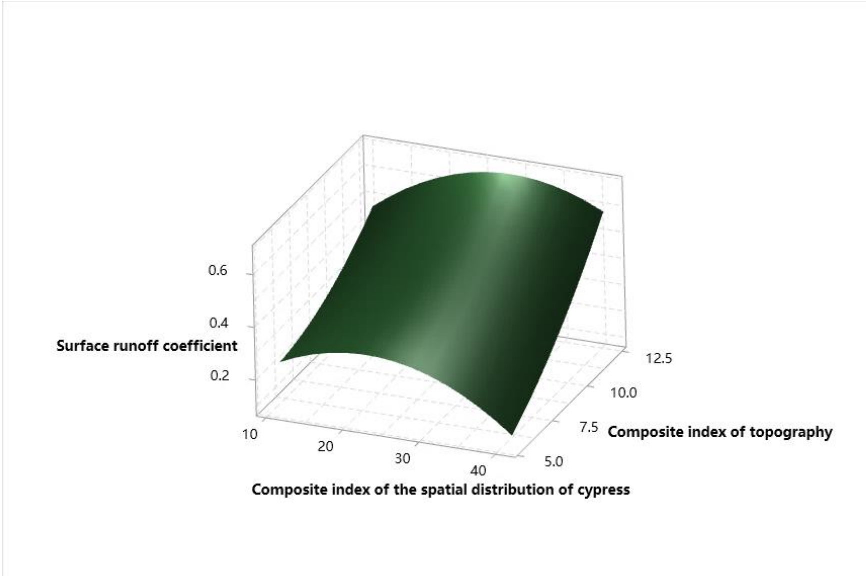
M = exp(-3.72169 + 1.83457 * S)
Regression curve
95% Confidence interval
Surface runoff coefficient
Topographic relief
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.3
1.4
1.5
1.6
1.7

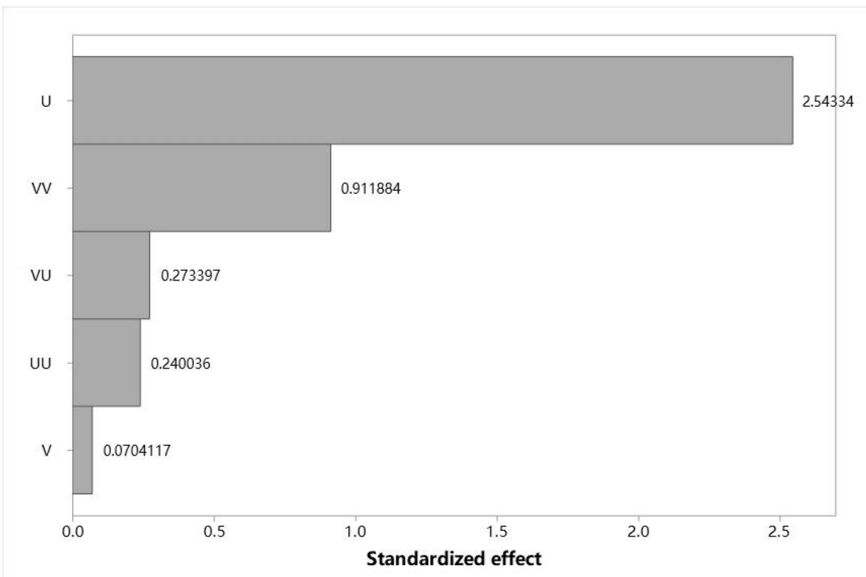


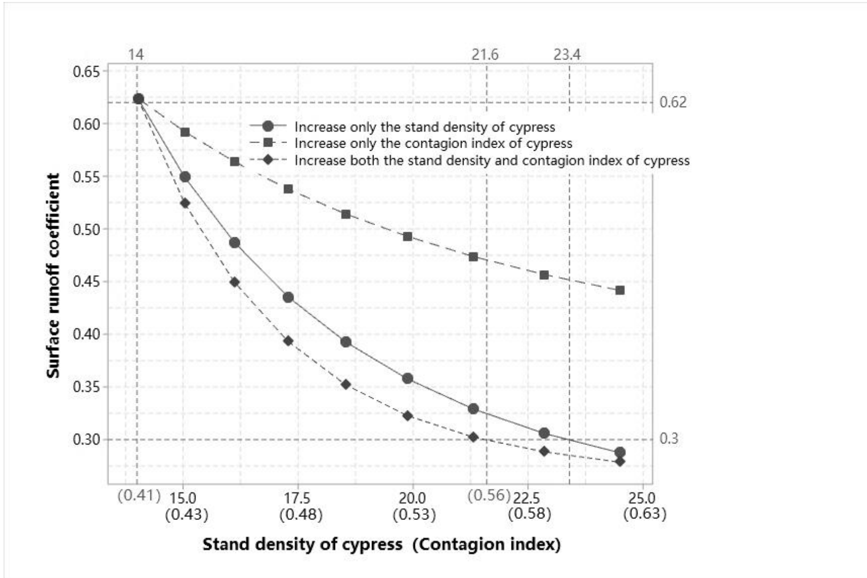
Surface runoff coefficient
0.5
0.4
0.3
0.2
0.4
0.5
0.6
Contagion index
1.76
1.64
1.52
1.40
Topographic relief

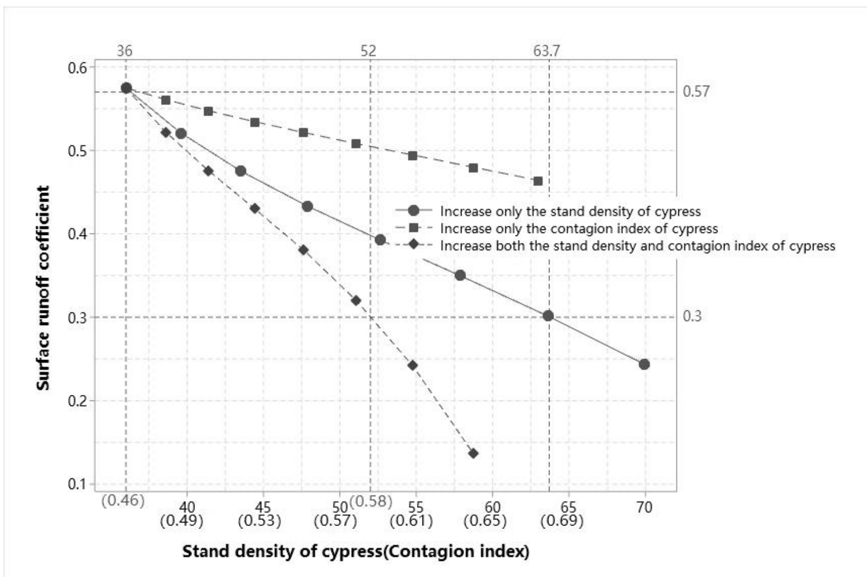

M = exp(-1.71125 + 0.0770892 * U)
Regression curve
95% Confidence interval
Surface runoff coefficient
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
5.0
7.5
10.0
12.5
15.0
17.5
Composite index of topography


M = exp(-0.515691 - 0.0207949 * V)
Regression curve
95% Confidence interval
Surface runoff coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
Composite index of the spatial distribution of cypress


0.6
0.4
Surface runoff coefficient
0.2
10
20
30
40
Composite index of the spatial distribution of cypress
12.5
10.0
7.5
Composite index of topography
5.0


U
2.54334
VV
0.911884
VU
0.273397
UU
0.240036
V
0.0704117
0.0
0.5
1.0
1.5
2.0
2.5
Standardized effect


Increase only the stand density of cypress
Increase only the contagion index of cypress
Increase both the stand density and contagion index of cypress
Surface runoff coefficient
Stand density of cypress (Contagion index)
14
21.6
23.4
0.62
0.3
(0.41)
(0.56)


Increase only the stand density of cypress
Increase only the contagion index of cypress
Increase both the stand density and contagion index of cypress
Surface runoff coefficient
Stand density of cypress(Contagion index)
36
52
63.7
0.57
0.3
(0.46)
(0.58)