Research Article

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Study on the changes in vegetation structural coverage and its response mechanism to hydrology

<https://doi.org/10.1515/geo-2020-0322>

received August 12, 2021; accepted November 25, 2021

Abstract: Vegetation is an important factor that affects the hydrological process of a watershed. In recent years, the vegetation in the hilly and gully regions of the Loess Plateau has undergone significant changes, which have greatly changed the relationship between rainfall and runoff and sediment in the region. A single vegetation cover index cannot represent the important impact of vegetation grade on the effectiveness of soil and water conservation. It is of great scientific significance to deeply study the influence of the vegetation structure change mechanism in the hilly and gully area on the hydrological process of the watershed. In this article, a typical watershed in the loess hilly and gully area is used as the research object, and the method of combining field sampling experiment and remote sensing inversion is used to establish a vegetation index remote sensing model reflecting the vegetation canopy cover and litter. The impact of changes in vegetation structure on hydrological processes is quantitatively assessed. The results show that the more annual precipitation in the basin, the more sensitive the runoff coefficient is to changes in structural vegetation index. The greater the rainfall intensity, the weaker the sensitivity of the sediment yield coefficient to changes in structural vegetation index. The use of remote sensing data to retrieve the underlying surface vegetation still has the problem of the scale effect. It is necessary to further use remote sensing

data with a higher spectral resolution to carry out field observations at different scales to improve the applicability of this method in a wider range of watersheds.

Keywords: loess hilly and gully area, structural vegetation coverage, remote sensing model, hydrological response relationship

1 Introduction

The ecological and environmental security problems are becoming more and more serious, and preventing soil erosion is an important part of the ecological environment construction in the Yellow River Basin [1–3]. Surface vegetation is an important factor affecting water and soil erosion in the watershed. The vegetation's function to prevent soil erosion is affected by its coverage and hierarchical structure. How to accurately reflect the soil and water conservation efficacy of vegetation has become a hotspot of research [4]. The ability of vegetation to prevent soil erosion is determined by its canopy structure and leaf shape, and different vegetation community structure levels also have an important impact on the soil and water conservation efficiency of vegetation. In the previous evaluation process of soil and water conservation, the litter layer directly covering the surface, which has an important impact on the vegetation community, has been neglected [5].

A single remote sensing vegetation index can only reflect the information of green vegetation coverage on the ground, while the information of the litter layer covered by green vegetation cannot be effectively reflected. Therefore, simply using the traditional vegetation index cannot accurately reflect the soil and water conservation effect of vegetation [6]. A large number of studies have found that to accurately reflect vegetation by remote sensing technology, the interaction between soil and vegetation must be considered [7–10]. The extraction and the use of the simple vegetation index are greatly affected by factors such as soil background brightness and

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atmospheric interference. The spectral characteristics of the litter layer of the vegetation community are similar to that of the background soil, and the traditional vegetation index is very difficult to extract decaying vegetation [11]. After comparing the spectral characteristics of crop residues with the soil background spectral characteristics, foreign scholars pointed out that the amplitude in the near-infrared band of the vegetation community litter layer and soil background are significantly different, and the spectral characteristics of the two in the short wave infrared band (1,100–2,400 nm) are unique [12]. On this basis, many decayed vegetation indexes that can reflect the information of litter layers of natural vegetation communities are proposed [13–17]. The most commonly used decayed vegetation indexes are the normalized difference index (NDI) and the normalized difference tillage index (NDTI) by normalizing the infrared and thermal infrared bands in remote sensing images [18], and NDTI can eliminate the influence of the atmosphere to a certain extent [19,20].

There is an inseparable relationship between the growth of vegetation and the process of water circulation. The hydrological processes under different vegetation community characteristics are different, and there are large differences in the characteristics of soil water use status and other characteristics [21,22]. Du selected the Fenhe River Basin as a research area to study the effects of vegetation on evapotranspiration [23]. The results showed that the amount of evapotranspiration decreased with the increase of vegetation coverage. Dunkel and Grob found that areas with a higher density of vegetation cover caused a decrease in evapotranspiration and runoff [24]. Anna and other researchers showed that increasing vegetation water use will reduce runoff and emphasize the importance of vegetation to the water cycle process [25].

Remote sensing technology can provide strong technical support for monitoring and evaluation of soil erosion at the basin scale. A single remote sensing vegetation index can only reflect the information of the vegetation coverage on the surface, while the information of the litter layer covered by the green vegetation cannot be effectively reflected. Therefore, simply using the traditional vegetation index cannot accurately reflect the effectiveness of vegetation in soil and water conservation. A large number of studies have found that to use remote sensing technology to accurately reflect vegetation, the interaction between soil and vegetation must be considered. The extraction and the use of the simple vegetation index are greatly affected by factors such as soil background brightness and atmospheric interference. Because the spectral characteristics of the litter layer of vegetation communities

are similar to the spectral characteristics of the background soil, it is very difficult for traditional vegetation indexes to extract decayed vegetation. Foreign scholars have conducted comparative studies on the spectral characteristics of crop residues and the soil background spectral characteristics and pointed out that there are obvious differences in the amplitude of the vegetation community litter layer and the soil background in the near-infrared band, and the spectral characteristics of the two are in the short-wave infrared. It is unique in the band (1,100–2,400 nm). Therefore, many decaying vegetation indices that can reflect the information of the litter layer of natural vegetation communities are proposed [26,27]. Among them, the most commonly used decay vegetation index includes the NDI; and the NDTI, which is normalized by the infrared band and thermal infrared band of remote sensing images, and the normalized tillage index can eliminate the influence of the atmosphere to a certain extent [28].

In this article, the vegetation coverage of different vegetation communities in the study area was measured, combined with soil and water conservation coefficients to calculate the coverage of green vegetation and litter layer at sampling points and to screen out the best vegetation greenness index and yellowness index to construct The structural vegetation index remote sensing model, and through the runoff index and other indicators, establishes the influence function relationship of the structural vegetation index on the hydrological process such as runoff and sediment.

2 Study area scope and data

The study area is located in Luoyugou watershed and Qiaozigou watershed in the northern part of Tianshui City, Gansu Province. The location ranges from 105° 30' E to 105° 45' E and 34° 34' N to 34° 40' N. The Luoyugou watershed, as a secondary branch gully of the Weihe River Basin, has unique regional representativeness and is a typical research area for soil erosion in the loess hilly region of my country. The distribution of watersheds and data sampling points in the study area is shown in Figure 1.

Luoyugou watershed has the following characteristics:

(1) Typical geographic location. The Luoyugou watershed is located in the hilly and gully regions of the Loess Plateau. It is located at the intersection of the two river basins in China, the Yellow River Basin and the Yangtze River Basin. The rainfall is unevenly distributed. The temperature difference between winter and summer is large. It has a continental climate in the transition zone of warm

Figure 1: Distribution map of sampling locations in Luoyugou watershed and Qiaozixigou.

temperate semi-humid and semi-arid climate. It is one of the birthplaces of the Wei River and Jialing River.

(2) Key prevention and control area for soil erosion in the Loess Plateau. In the 1990s, artificial felling of trees and reclamation of arable land in Luoyugou caused vegetation loss, and at the same time, the drainage ratio of Luoyugou itself was larger and there were fewer water and soil conservation projects. In addition, the rainfall distribution was uneven and the soil was loose. These have caused serious soil erosion problems in Luoyugou. A large amount of sediment was poured into the bottom of the Chuanba ditch, the farmland was cushioned, and the previous water conservancy facilities were also severely damaged. Therefore, taking Luoyugou as a key area for soil erosion research is not only conducive to the local ecological environment and social and economic construction and development of the basin but also important for the in-depth study of the mechanism of vegetation structure changes in the hilly and gully regions of the Loess Plateau on the hydrological process of the basin.

(3) A solid research foundation. As early as before the founding of the People’s Republic of China, the Tianshui Soil and Water Conservation Scientific Experimental Station has been established. Typical sites are selected throughout the Luoyugou Watershed to carry out experimental observations

of meteorological and hydrological projects of different scales [29–31]. This provides a solid data foundation and theoretical basis for this study.

This study adopts the measured sediment transport and runoff at the Beidao Hydrological Station from the hydrological yearbook of the hydrological department and the hydrological database of the Yellow River Conservancy Commission and Gansu Province. The basic information of the Beidao Hydrological Station is presented in Table 1. Based on the basic data of water and sediment in the North Hydrological Station, the runoff coefficient and sediment yield coefficient are calculated.

The multispectral remote sensing data used in this research include the remote sensing data acquired by Thematic Mapper (TM) carried by the US Land Resources Satellite Landsat5 from 1990 to 2011 and remote sensing data obtained from the operation of the Land Imager (OLI) Landsat8 carried out from 2013 to 2017. The preprocessing of remote sensing image data includes radiation calibration and atmospheric correction. Landsat data can only truly reflect the true spectral features of ground features after completing the radiation calibration and atmospheric correction process (Figure 2).

Two yellowness indexes, normalized decay vegetation index (NDSVI) and NDTI, and three greenness indexes, modified soil adjustment vegetation index (MSAVI),

Table 1: Basic information of North Station

River name	Site name	Site category	Catchment area (km ²)	Observation location	Longitude	Latitude
Weihe	BeiDao	Hydrology	24871	Weihe Bridge Head, Maiji District, Tianshui City, Gansu Province	105.54°	34.34°

Figure 2: The result of remote sensing data preprocessing.

normalized vegetation index (NDVI), and atmospheric impedance vegetation index (ARVI), respectively, reflect the accumulation of vegetation litter layer and the coverage of tree layer and grass layer. These indexes can be calculated based on the calculation formula of each index using ENVI software to calculate the band.

2.1 NDSVI

NDSVI normalizes the red and short-wave infrared bands of LANDSAT image data. Since the human short-wave infrared band is added, the index is more sensitive to the moisture content of vegetation. Compared with healthy vegetation, the water content of the litter layer is very small, and the reflection in the short-wave infrared band will be enhanced. NDSVI can be calculated as follows:

$$\text{NDSVI} = \frac{P_{\text{TM5}} - P_{\text{TM3}}}{P_{\text{TM5}} + P_{\text{TM3}}}, \quad (1)$$

where P_{TM5} and P_{TM3} , respectively, refer to the mid-infrared and red light band of Landsat remote sensing images.

2.2 NDTI

NDTI is calculated by normalizing the mid-infrared and thermal infrared bands of LANDSAT image data, which not only has a strong sensitivity to soil moisture texture but also can effectively reflect the water content in vegetation leaves, thereby characterizing covering information of the litter layer. NDTI can be calculated as follows:

$$\text{NDTI} = \frac{P_{\text{TM5}} - P_{\text{TM7}}}{P_{\text{TM5}} + P_{\text{TM7}}}, \quad (2)$$

where P_{TM7} and P_{TM5} , respectively, refer to the mid-infrared and short-wave infrared of Landsat remote sensing images.

2.3 MSAVI

In the application of the vegetation index, the influence of the soil background is very obvious. Qi et al. developed the MSAVI. The effect of the soil background can be effectively reduced, and the vegetation status in the study area can be more accurately reflected. MSAVI can be calculated as follows:

$$\begin{aligned} \text{MSAVI} \\ = \frac{2P_{\text{TM4}} + 1 - \sqrt{(2P_{\text{TM4}} + 1)^2 - 8(P_{\text{TM4}} - P_{\text{TM3}})}}{2}, \end{aligned} \quad (3)$$

where P_{TM4} and P_{TM3} , respectively, refer to the near-infrared and red light band of Landsat remote sensing images.

2.4 NDVI

The NDVI is obtained by normalizing the red light band and the near-infrared band of LANDSAT image data. Currently, it is the most widely used vegetation index. NDVI can be calculated as follows:

$$\text{NDVI} = \frac{P_{\text{TM4}} - P_{\text{TM3}}}{P_{\text{TM4}} + P_{\text{TM3}}}, \quad (4)$$

where P_{TM4} and P_{TM3} , respectively, refer to the near-infrared and red light band of Landsat remote sensing images.

NDVI is the most commonly used indicator to reflect changes in the vegetation and ecological environment. However, NDVI is not sensitive to areas with high vegetation coverage and is easily affected by the soil background. It should be used reasonably in characterizing green vegetation information.

2.5 ARVI

The atmosphere has a great influence on the use of remote sensing data. The ARVI improves the NDV to eliminate atmospheric effects and corrects the atmospheric effects by scattering the blue band in the LANDSAT image in the atmosphere. The combination of the red and blue bands in the LANDSAT image replaces the red band in NDVI. ARVI can be calculated as follows:

$$\text{ARVI} = \frac{P_{\text{TM4}} - (2P_{\text{TM3}} - P_{\text{TM1}})}{P_{\text{TM4}} + (2P_{\text{TM3}} - P_{\text{TM1}})}, \quad (5)$$

where P_{TM4} , P_{TM3} , and P_{TM1} , respectively, refer to the near-infrared, red, and blue light band of Landsat remote sensing images.

3 Calculation of community structural vegetation coverage based on field samples

Structural vegetation coverage (c_s) is defined on the basis of calculating the vegetation coverage of different layers and combining with the corresponding levels of soil and water conservation capacity. c_s can be calculated as follows:

$$c_s = \sum_{i=1}^n a_i \times c_i. \quad (6)$$

In the earlier equation, a_i is the soil and water conservation coefficient of each structural level of vegetation distributed vertically, and c_i is the actual vegetation coverage of each structural level in the vertical direction. The soil and water conservation coefficients presented in Table 2 are derived from the previous research results [32]. Using this coefficient can more accurately characterize the vegetation's ability to prevent soil erosion in different community structures and provide data basis and theoretical basis for the calculation of structural vegetation coverage.

The field test of structural vegetation coverage was carried out at the Qiaozixigou slope test site at the Tianshui Soil and Water Conservation Test Station of the Yellow River Conservancy Commission. After many years of natural closure of Qiaozixigou and without implementation of water and soil conservation measures, the impact of silt dams and terraces can be avoided. According to the actual situation in the Luoyugou watershed, a total of 45 plots of green vegetation coverage were measured in summer, and the litter cover in the corresponding plots was measured in winter. These plots are divided into two categories: one is tree + herbaceous structure, such as cherry forest and black locust forest; the other is a single grass structure, such as returning farmland to grasslands.

The photo coverage of the tree canopy, the ground herb layer, and the litter layer was measured by the photo method to obtain the photo coverage of the vegetation structure level. Finally, the ratio of tree vegetation coverage is

calculated based on the number of corresponding tree vegetation and the canopy radius. Combined with the soil and water conservation coefficients of each layer, the green vegetation coverage and litter layer coverage of the plot were obtained. The structural vegetation coverage of the corresponding plot was calculated according to formula (6).

4 Remote sensing model construction and verification

By using Landsat remote sensing image data of the study area near the date of the actual measurement of vegetation coverage, three vegetation indexes reflecting green vegetation coverage, NDVI, ARVI, and MSAVI, and two vegetation indexes reflecting the coverage of litter layer, NDTI and NDSVI, were calculated and used. The coordinate information of the plot is used to extract the vegetation index of the plot. Taking the extracted vegetation index as the dependent variable and the actual measurement as the independent variable, the SPSS software was used to analyze the correlation between the measured green vegetation coverage and litter layer coverage of the sample site and the vegetation index of the corresponding sample site. A correlation test is a statistical test on whether the variables are correlated and how relevant. The value of the correlation coefficient indicates the degree of correlation between variables. The results are presented in Table 3.

The correlation coefficient between the green vegetation coverage of ARVI and the corresponding samples is the highest. ARVI is applied to the structural vegetation index (Csl) remote sensing model as the optimal greenness index. NDSVI has the highest correlation coefficient with the litter cover information of corresponding samples, so NDSVI is applied to the (Csl) remote sensing model as the best yellowness index.

Using SPSS software, based on the actual measurement data of ARVI and NDSVI and structural vegetation coverage of the corresponding sample points, conducting

Table 2: Soil and water conservation coefficients of different layers of vegetation in different community types

Community type	Arbor	Herb layer	Litter
Tree + herbaceous (coniferous)	0.0150	0.591	0.394
Tree + herbaceous (Broadleaf)	0.0608	0.828	0.112
Herbaceous		0.38	0.62

Table 3: Correlation analysis of vegetation index and measured coverage

	Green vegetation coverage		Litter coverage	
NDVI	0.791		NDTI	0.732
ARVI	0.862		NDSVI	0.831
MSAVI	0.817

Figure 3: Validation diagram of remote sensing model of structural vegetation index.

multiple regression analysis, establishing regression equations, and establishing a structural vegetation index (CsI) remote sensing can comprehensively reflect the information of green vegetation and litter layer coverage Model.

$$\text{CsI} = 0.790 \times \text{NDSVI} + 0.882 \times \text{ARVI}. \quad (7)$$

When constructing the model, 15 sample plot data were excluded in the construction of the model, but to be used as verification data to evaluate the suitability of the established structural vegetation index CsI remote sensing model. Correlation analysis between the measured structural vegetation coverage in the field in 15 plots and the structural vegetation index at the corresponding position calculated by the structural vegetation index model is shown in Figure 3. The values of the measured structural vegetation coverage and the structural vegetation index of the corresponding sample points are basically the same. The correlation coefficient between the measured structural vegetation coverage and the structural

Figure 4: Change trend of structural vegetation index and NDVI in Luoyugou watershed.

vegetation index exceeds 80%, which can prove that the structural vegetation index remote sensing model can reflect the structural coverage of the vegetation community more accurately.

5 Comparison of structural vegetation index and NDVI

From the CsI and NDVI change trend graphs (Figure 4), it can be seen that the structural vegetation index and the NDVI change trend are basically the same, but there was a big difference in 2003. The structural vegetation index decreased significantly, while the NDVI continued to grow steadily. It can be seen from the change trend chart of Luoyugou yellowness index (Figure 5) that the yellowness index of Luoyugou area dropped significantly in 2003, which was caused by land use change. Due to the increase in population, policy guidance, and economic benefits, 73% of the slope farmland in the Luoyugou

Figure 5: Change trend of yellowness index in Luoyugou watershed.

watershed has been converted into terraces, and the area of economic crop forest land has also increased to a large extent. In this process, the previously accumulated litter layer was destroyed, which resulted in a significant decrease in the yellowness index of the litter layer covering the Luoyugou area during this period. However, the NDVI alone cannot well reflect the actual changes of the litter layer on the underlying surface.

The correlation test analysis of the NDVI and structural vegetation index of the study area from 1996 to 2017 with the runoff coefficient of the study area of the same time series was conducted, as presented in Table 4.

The structural vegetation index Csl has a significantly negative correlation with the runoff coefficient, while the NDVI has a poor correlation with the runoff coefficient. A single vegetation index can only reflect the projected coverage of surface vegetation such as canopy or grass cover. The important influence of different levels of vegetation community on preventing soil erosion cannot be correctly reflected by a single vegetation index like the NDVI. With the comprehensive management and protection of the Luoyugou watershed for more than 20 years, the vegetation situation, especially the litter layer on the underlying surface, has continued to improve, resulting in a decrease in the runoff coefficient, which is of great significance for local soil and water conservation.

6 Responses of structural vegetation index changes to hydrological processes

6.1 River runoff response

According to the rainfall and runoff mechanism of the Loess Plateau, the effects of changes in forest and grass vegetation on river runoff are mainly through the interception of

Table 4: Correlation between structural vegetation index and NDVI and runoff coefficient in Luoyugou watershed

		Runoff coefficient
(Csl)	Correlation	−0.527
	Significance (double tail)	0.078
NDVI	Correlation	0.164
	Significance (double tail)	0.61

vegetation canopy and litter on rainfall and may change the effect of land transpiration.

The amount of runoff reduction is largely independent of surface material composition but it is deeply affected by local climatic conditions and is related to vegetation type.

To study the changes in water and sediment at the basin scale in depth, this study uses runoff coefficients to characterize the water production capacity of the basin, and it can be calculated as follows:

$$R = \frac{W}{A} \times \frac{1}{P}. \quad (8)$$

In the aforementioned formula, R is the runoff coefficient, W is the annual runoff of the basin, A is the catchment area of the basin, and P is the annual precipitation.

In this study, based on the measured runoff and precipitation from 1990 to 2017 in the Luokou Valley watershed, the runoff coefficients of the watershed above the North Hydrological Station were calculated, and the structural vegetation index of the watershed above the hydrological station was obtained. The relationship between runoff coefficient and structural vegetation index at different precipitation levels above the hydrological station is shown in Figure 6.

The average rainfall level from 1990 to 2017 was 450 mm, so the annual precipitation of 450 mm was used as the standard to distinguish different precipitation levels. From Figure 6, it can be seen that under the same precipitation conditions, the larger the structural vegetation index, the smaller the runoff coefficient of the watershed. When the rainfall is greater than 450 mm, the quantitative relationship between the runoff coefficient y and the structural vegetation index x is $y = 0.0431x - 0.579$. When the rainfall is less than 450 mm, the quantitative relationship between the runoff coefficient y and the structural

Figure 6: Relationship between structural vegetation index and runoff coefficient.

vegetation index x is $y = 0.0266x - 0.423$. The amount of runoff generated is more sensitive to the structural vegetation index. This conclusion is consistent with the conclusions obtained by Liu Changming and Zhong Junxiang in the study of the Loess Plateau watershed and is consistent with the actual situation in other watersheds of the Loess Plateau [33,34].

6.2 River sediment response

Under other circumstances where the underlying surface is certain, the impact of changes in forest and grass vegetation on sediment yield in the watershed mainly depends on the degree of protection of forest and grass vegetation on erodible land. To more reasonably evaluate the effect of structural vegetation index on the restoration of sediment reduction, this study used the index of sediment yield index that can be calculated as follows:

$$S = \frac{D}{A} \times \frac{1}{P}. \quad (9)$$

In the aforementioned formula, S is the sediment yield index of the basin above the North Road, D is the actual sediment yield measured by the Watershed Control Hydrological Station, A is the catchment area of the basin, and P is the precipitation data.

A large number of measured data show that most rainfall in the Loess Plateau does not produce sediment. According to the statistics of scholars, the daily precipitation standard that can cause erosion on the Loess Plateau is 8.1, 10.9, and 14.6 mm on slope farmland, artificial grassland, and woodland, respectively, and the daily rainfall of 10 mm is proposed as the critical rainfall standard. Some scholars have analyzed 210 heavy rains that caused soil erosion on the Loess Plateau and found that more serious soil erosion was generally caused by rainfall with a daily rainfall of 40–60 mm. Therefore, this study focuses on the total annual precipitation greater than 10 mm and greater than 50 mm in the measured data of rainfall stations. These magnitudes of rainfall indicators not only reflect the rainfall factors but also fully reflect the rainfall intensity factors. P10 and P50 are used to characterize the total annual precipitation of daily precipitation greater than 10 mm and greater than 50 mm in the basin rainfall data, respectively. Sensitivity analysis of P10, P50, and P50/P10 and the measured sediments of hydrological stations are carried out. The results show that P50/P10 as the rain intensity index is more in line with reality.

Figure 7: Relationship between structural vegetation index and sand production index.

Therefore, this article calculates the sediment yield index of the watershed above the hydrological station based on the data of the measured sand and precipitation from 1990 to 2017 from the Watershed Control hydrological station and obtains the structural vegetation index of the watershed above the hydrological station. The relationship between the sediment yield index of the watershed above the hydrological station and the structural vegetation index of the watershed by different rain intensity levels is shown in Figure 7.

The average rainfall intensity P50/P10 index for the past three decades from 1990 to 2017 is 0.06, so P50/P10 equal to 0.06 is used as the standard to distinguish different rain intensity levels.

Figure 7 shows that under the same rainfall intensity, the greater the structural vegetation index, the lower the sediment yield index or the sediment yield rate of the watershed. When the rain intensity P50/P10 is greater than 0.06, the quantitative relationship between the sediment yield index y and the structural vegetation index x is $y = 2.7111x - 2.404$. When the rainfall intensity P50/P10 is less than 0.06, the quantitative relationship between the sediment yield index y and the structural vegetation index x is $y = 0.8577x - 4.298$. The greater the rainfall intensity in the watershed, the weaker the amount of sediment produced to the change of structural vegetation index. This conclusion is also consistent with the actual situation in other watersheds of the Loess Plateau.

7 Discussion and conclusion

In this study, on the basis of different action mechanisms of vegetation with different structures in preventing soil

erosion, we explored the use of remote sensing technology to reflect the coverage of structural vegetation and constructed a remote sensing model of structural vegetation index, which provided a comparison for the evaluation and monitoring of soil erosion in Luoyugou watershed. Reasonable vegetation factor indicators, combined with watershed-scale hydrological data, establish a functional relationship between the changes in vegetation structure and runoff and sediment production at the watershed scale, and the effects of changes in watershed vegetation structure on water and soil conservation effects such as sediment and flow reduction are investigated. The following conclusions are drawn:

(1) NDVI, MSAVI, ARVI, NDSVI, NDTI, and other vegetation indices in Luoyugou watershed were extracted according to Landsat images. By comparing the correlation coefficient of different greenness index and yellowness index with the measured green vegetation coverage and litter vegetation coverage, ARVI and NDSVI as the best yellowness and greenness index are selected for constructing structural vegetation index Csl. A structural vegetation index (Csl) remote sensing model $Csl = 0.790 \times NDSVI + 0.882 \times ARVI$ was constructed, and the relationship between the measured structural vegetation coverage verification data and Csl was established, and the corresponding r^2 exceeds 80%.

(2) Use indicators such as runoff coefficients to establish the functional relationship between changes in vegetation structure and runoff at the river basin scale. When the rainfall is greater than 450 mm, the quantitative relationship between the runoff coefficient y and the structural vegetation index x is $y = 0.0431x - 0.579$. When the rainfall is less than 450 mm, the quantitative relationship between runoff coefficient y and structural vegetation index x is $y = 0.0266x - 0.423$. At the same structural vegetation index level, the more annual precipitation in the basin, the greater the sensitivity of runoff generation to the coverage of structural vegetation.

(3) Use indicators such as the sediment yield coefficient to establish the functional relationship between changes in the vegetation structure and the sediment yield at the river basin scale. When the rainfall intensity P50/P10 is greater than 0.06, the quantitative relationship between the sediment yield index y and the structural vegetation index x is $y = 2.7111x - 2.404$. When the rainfall intensity P50/P10 is less than 0.06, the quantitative relationship between the sediment yield index y and the structural vegetation index x is $y = 0.8577x - 4.298$. The greater the rainfall intensity in the river basin, the weaker the sensitivity of the sediment yield index to structural vegetation index changes.

Hyperspectral remote sensing data can reflect vegetation features more accurately due to the narrower band. The use of remote sensing index to reflect the scale effect of the underlying vegetation and its applicability to the larger watershed range needs further analysis. It is also necessary to apply more high-spectral and high-spatial-resolution remote sensing data combined with field vegetation surveys at different scales for better applying structural vegetation index to a larger watershed area. In the future, more effective data collection technology is needed to explore the mechanism of vegetation changes affecting hydrological processes that more accurately reflect the structural levels of different vegetation communities.

Funding information: The study was financially supported by the National Key Research and Development Program (Grant No. 2018YFC0407905), the Science Fund for Distinguished Young Scholars of Henan Province (Grant No. 202300410539), the Science Fund for Excellent Young Scholars of Henan Province (Grant No. 212300410059), the Major scientific and technological special project of Henan Province (Grant No. 201400211000), the National Natural Science Fund of China (Grant No. 51779100 and 51679103), Central Public-interest Scientific Institution Basal Research Fund (Grant No. HKY-JBYW-2020-21 and HKY-JBYW-2020-07).

Conflict of interest: Author states no conflict of interest.

References

- [1] Gao Y, Li Z, Liu X. Construction of land use classification system for remote sensing monitoring of soil and water erosion in yellow river basin. *Water Soil Conserv Bull.* 2018;38(01):111–5.
- [2] Zhang Z, Liu W, Gao Z, Chang Y. Discussion on ecological environment construction with soil and water conservation in the yellow river basin. *Shaanxi For Sci Technol.* 2017;3:64–70.
- [3] Shi Z, Liu Q, Zhang H, Wang L, Huang X, Fang N, et al. Study on soil erosion and conservation in the past 10 years: progress and prospects. *Acta Pedologica Sin.* 2020;57(5):1117–27.
- [4] Song X. Analysis of law of soil and water loss in different land use modes. *Heilongjiang Hydraulic Sci Technol.* 2020;48(06):22–4 + 230.
- [5] Bourgoin C, Betbeder J, Coutron P, Blanc L, Dessard H, Oszwald J, et al. UAV-based canopy textures assess changes in forest structure from long-term degradation. *Ecol Indic.* 2020;115:115.
- [6] Leng Z. Application of GIS and remote sensing technology in soil and water loss quantitative evaluation. *Water Resour Plan Des.* 2018;10:28–30 + 52.

- [7] Zhao Y. Application of remote sensing technology to the soil and water conservation monitoring and supervision of Beijing. *Soil Water Conserv China*. 2018;3:15–8.
- [8] Gao J, Ai Q, Hao L, Dang W, Liu Z. Research on influencing factors of gravity erosion based on UAV technology. *Yellow River*. 2020;42(10):100–3.
- [9] Wang X, Wang M, Wang S, Wu Y. Extraction of vegetation information from visible unmanned aerial vehicle images. *Trans Chin Soc Agric Eng*. 2015;31(05):152–7+ 159 + 158.
- [10] Miao Q, Min X. Advances in study on vegetation indices indices. *Adv Earth Sci*. 1998;13(4):327–33.
- [11] Wu Y, Zeng Y, Zhao Y, Wu B, Wu W. Monitoring and dynamic analysis of fractional vegetation cover in the hai river basin based on MODIS data. *Resour Sci*. 2010;32(7):1417–24.
- [12] Feng L, Yue D, Guo X. A review on application of normal different vegetation index. *For Inventory Plan*. 2009;34(2):48–52.
- [13] Chen Z, Chen Y, Guo Z. Research on the application of vegetation factor calculation in soil erosion quantitative monitoring. *Subtropical Soil Water Conserv*. 2000;3:42–6.
- [14] Deventer V, Ward AD, Gowda PH, Lyonnet JG. Using thematic mapper data to identify contrasting soil plains and tillage practices. *Photogrammetric Eng Remote Sens*. 1997;63(1):87–93.
- [15] Daughtry CS, Hunt Jr ER, McMurtrey III JE. Assessing crop residue cover using shortwave infrared reflectance. *Remote Sens Environ*. 2004;90(1):126–34.
- [16] Marsett RC, Qi J, Heilman P, Biedenbender SH, Carolyn Watson M, Amer S, et al. Remote sensing for grassland management in the arid southwest. *Rangel Ecol Manag*. 2006;59(5):530–40.
- [17] Pacheco A, McNairn H. Evaluating multispectral remote sensing and spectral unmixing analysis for crop residue mapping. *Remote Sens Environ*. 2010;114(10):2219–28.
- [18] Guo T. Study on the variation of crop normalized difference vegetation index. Northwest A&F University; 2019.
- [19] Wang J, Ma C, Zhang N. Monitoring and evaluation of ecological environmental damage and recovery capability based on remote sensing image normalization index. *J Shenyang Jianzhu University(Natural Sci)*. 2018;34(04):676–83.
- [20] Hunt ER, Daughtry CST, Eitel JUH, Long DS. Remote sensing leaf chlorophyll content using a visible band index. *Agron J*. 2011;103(4):1090–9.
- [21] Dan Y, Du L, Wang L, Ma L, Qiao C, Wu H, et al. Effects of planted shrub encroachment on evapotranspiration and its components in desert steppe: a case study in Yanchi county, Ningxia Hui Autonomous Region. *Acta Ecologica Sin*. 2020;2020(16):1–11.
- [22] Chen H, Wu X. Impact of vegetation interannual variability on evapotranspiration. *Acta Ecologica Sin*. 2013;33(14):4343–53.
- [23] Du Q. Effects of vegetation restoration on evapotranspiration in fenhe river basin of shanxi province. *Pearl River*. 2018;39(01):10–2+39 .
- [24] Dunkel Z, Grob S. A simple method for estimation of evapotranspiration using remotely sensed data during vegetation period in Hungary. *Phys Chem Earth*. 2002;27(23–24):1109–111.
- [25] Anna U, Albert VD. River flows drop as carbon dioxide creates thirstier plants. *Irrig Aust: Off J Irrig Australia*. 2016;32(1):8–8.
- [26] Zou B. Temporal and spatial dynamic changes and risk analysis of cold spot and hot spot in vegetation coverage in Xi'an. *J Xi'an Univ Technol*. 2020;36(2):197–204.
- [27] Li DA. Processing System for Greenness Meteorological Image of NOAA/AV HRR. *Monthly*. 1996;10:13–8.
- [28] Zhang S, Wang T, Li Z, Mou P, Kou X, Ge J. Dynamic correlation analysis of the relationship between xinjiang vegetation remote sensing greenness index and water and heat. *J Ecol Rural Environ*. 2009;25(2):16–9.
- [29] Zhang L. Study of comprehensive management of luoyugou watershed and its effectiveness. *Yellow River*. 2012;34(12):96–9.
- [30] Zhu N, Ma C, Wang Y, Zhang H, Zhu J. Effects of varied land use structures on runoff-sediment yield. *Sci Soil Water Conserv*. 2016;14(4):105–12.
- [31] Yang C. Catchment-scale simulation study on soil erosion in the loess Hilly Region – a case study of Luoyugou watershed. Lanzhou University; 2017.
- [32] Ning LW, Zhong Ming W. Extraction of structured vegetation factor index based on TM remote sensing image in loess region of northern Shaanxi. *J Appl Ecol*. 2009;20(11):2736–42.
- [33] Liu C, Zhang X. Causal analysis on actual water flow reduction in the mainstream of the yellow river. *Acta Geographica Sinica*. 2004;59(3):323–330.
- [34] Liu C, Zhong J. The influence of forest cover upon annual runoff in the loess plateau of china. *Acta Geograph Sin*. 1978;02:112–27.