



Research Progress on the Impact of Land Use and Climate Change on Gully Runoff in Yan' an City

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ABSTRACT

The ArcSWAT model provides an effective tool for quantifying the responses of gully runoff in Yan'an City to land use and climate change. Returning farmland to forest and reclaiming land from gullies have significantly reduced soil erosion through vegetation restoration and engineering measures. However, climate change may offset some of the ecological benefits. The vegetation index of Yan'an City from 2000 to 2019 ranged from 0.54 to 0.75. In terms of time distribution, it showed a significant upward trend, with an overall upward rate of 0.095/(10a). From 2000 to 2019, 79.83% of the regional vegetation in Yan'an City showed an improving trend, mainly distributed in the loess ridges and gully areas in the north and east of Yan'an City. The degraded areas accounted for 0.34% of Yan'an City, mainly distributed in the urban area of Yan'an City and the suburban areas of county-level cities, presenting a point-like and strip-like distribution. From 2000 to 2012, human activities were the dominant factor determining the status of vegetation index. From 2013 to 2019, the main factors affecting the growth of vegetation in Yan'an were water and heat conditions. In the future, strategies for land use optimization, engineering maintenance and climate adaptability need to be comprehensively considered to achieve the coordinated goal of ecological protection and sustainable utilization of water resources.

KEYWORDS

Yan'an City; land use types; ArcSWAT; NDVI.

1. INTRODUCTION

The influence of climatic factors and land use/cover change on the hydrology and water resources of river basins is an important basis for adaptive river basin management [1-2]. It is extremely urgent to evaluate the impact of climate change, especially precipitation changes, on water resources and the water cycle. The research results are of great significance for the future regional water resources planning and rational development and utilization [3]. As one of the most vulnerable areas of the ecosystem in China, the Loess Plateau witnessed a significant decline in vegetation coverage due to excessive land reclamation in the early years, and problems such as soil erosion and land desertification became increasingly prominent [4-5]. After years of implementation of afforestation projects, the ecological environment of the Loess Plateau has been continuously improved [6]. Yan'an City is located in the central and southern part of the Loess Plateau and belongs to the hilly and gully area of the Loess Plateau. The northern part is mainly composed of loess mounds and gullies, accounting for 72% of the total area of the entire district. The southern part is mainly composed of loess tableland gullies, accounting for 19% of the total area. Rocky mountainous areas account for 9%

of the total area in the entire region [7]. Yan'an City was once one of the regions in China with the most severe soil erosion. Against the backdrop of environmental protection and economic development, Yan'an City has implemented projects such as returning farmland to forest and grassland, afforestation, closing mountains for afforestation, and treating gullies to create land. As a result, the land use/cover of Yan'an City has undergone tremendous changes. Moreover, with global warming, natural factors such as temperature and precipitation are constantly changing. This has led to changes in the climate of Yan'an City. Under the interaction of climatic factors and human activities, the water resources and hydrological processes in Yan'an City have also changed. Therefore, by analyzing the changing trends of historical meteorological and hydrological data of the gullies in Yan'an City, exploring the impact of land use/cover on the runoff of the gullies in Yan'an City, and revealing the responses of the hydrological processes of the gullies in Yan'an City to climate and human activities, It can provide a basis for the research on the coupling mechanism of hydrological processes such as vegetation change and evapotranspiration in Yan'an City, and at the same time offer theoretical references for reasonable water resources management and evaluation. It is of great significance for guiding the coordinated development of social economy and ecological environment in Yan'an City.

Current studies rarely involve the research on the hydrological effects of small-scale environmental changes such as channels. Therefore, with the help of ArcGIS software in this paper, by collecting meteorological, hydrological, DEM, soil and land use/cover data of the study area, analyzing the changing trends of historical meteorological and hydrological data of the gullies in Yan'an City, and creating standard databases such as meteorology and soil, a SWAT model is constructed, and the SEBAL model is used to invert surface evapotranspiration for model parameter calibration. Analyze the sensitivity of parameters and study the variations of gully runoff in Yan'an City under different scenarios such as climate and land use/cover. By setting up scenarios, the influences of both on the runoff generation in the basin were quantitatively analyzed, and the influences of a single land use type and different climate change scenarios on the runoff in the basin were analyzed respectively, with the expectation of providing an important scientific basis for water resource management and land use planning under the influence of climate change and human activities.

2. APPLICATION FRAMEWORK OF ARCSWAT MODEL

2.1. Data Preparation

The construction of the ArcSWAT model requires multi-source data support, including topography (DEM), land use, soil type, meteorological data and hydrological observation data. In the research in Yan'an City, the land use data mainly originated from the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences, covering five periods of data from 1980 to 2020, with a spatial resolution of 1 km. Meteorological data are obtained through the China Meteorological Data Network, including meteorological factors such as precipitation, temperature, relative humidity and wind speed, covering four national meteorological stations: Yan'an Station, Yanchang Station, Luochuan Station and Wuqi Station. The Soil data adopted Harmonized World Soil Database (HWSD), including parameters such as soil texture, organic carbon content, and saturated water conductivity, providing basic soil attribute information for the model.

2.2. Parameter Calibration and Verification

Parameter calibration is a key step to ensure the accuracy of the ArcSWAT model. In the research, tools such as SWAT-CUP are usually adopted to conduct sensitivity analysis and automatic calibration of model parameters, with a focus on adjusting key parameters such as CN2 (number of runoff curves), SURLAG (surface runoff delay time), and OV_N (slope drift Manning coefficient). For example, in the research of the Jing River Basin, the SUFI-2 algorithm has been proved to be

able to effectively reduce parameter uncertainty and improve the simulation accuracy of the model. By comparing the measured runoff data with the model simulation results, the applicability of the model at the channel scale in Yan'an City is verified. For example, in the research of the Yan River Basin, the simulation of monthly runoff and sediment by the SWAT model has met the model accuracy requirements, indicating that this model has good applicability in the simulation of channel hydrological processes in Yan'an City.

2.3. Scenario Simulation

To analyze the impact of land use and climate change on ditch runoff, multiple scenarios were designed in the study. Land use scenarios include returning farmland to forest, urbanization expansion, etc., while climate change scenarios are based on different emission paths such as RCP2.6 and RCP8.5. For instance, in the study of the Xin'anjiang River Basin, returning farmland to forest can reduce sediment production but lower water production, while climate change may intensify non-flood season runoff fluctuations. In the research in Yan'an City, by setting up extreme land use scenarios (such as grassland, forest land, cultivated land, etc.) and climate change scenarios (precipitation increase/decrease by 10%-30%, temperature rise by 1°C), the responses of channel runoff under different scenarios were simulated to reveal the interaction mechanism between the two.

3. THE INFLUENCING MECHANISM OF LAND USE CHANGE

3.1. The hydrological regulation role of vegetation restoration

The project of returning farmland to forest and grassland has significantly changed the land use pattern in Yan'an City. The vegetation coverage rate has increased from 46% in 1999 to 81.3% in 2023. The areas and proportions of different NDVI intervals in each year were statistically analyzed (Table 1). It can be seen from the table that the vegetation index of Yan'an City shows an upward trend. Compared with 2000, the areas with NDVI values less than 0.5 significantly decreased in 2010, and the vegetation index of the entire Yan'an City shows an improving trend. Compared with 2010, the vegetation index of Yan'an City continued to grow in 2019. Some areas with moderate vegetation coverage turned into areas with high vegetation coverage, but the areas with vegetation coverage below 0.3 increased, mainly distributed in the urban area of Yan'an and the urban-rural fringe. Mainly affected by urban construction, the land cover type changed from grassland and cultivated land to construction land, reducing the vegetation coverage.

Table 1 The area and proportion of different NDVI intervals in Yan'an City in 2000, 2010 and 2019

NDVI	2000		2010		2019	
	Area/km ²	Proportion	Area /km ²	Proportion	Area /km ²	Proportion
< 0.3	1 685.2	4.55%	22.2	0.06%	33.3	0.09%
0.3 - 0.4	9 888.9	26.70%	170.4	0.46%	100.0	0.27%
0.4 - 0.5	8 077.8	21.81%	2 744.4	7.41%	737.0	1.99%
0.5 - 0.6	4 400.0	11.88%	9 418.5	25.43%	4 459.3	12.04%
0.6 - 0.7	3 877.8	10.47%	8 063.0	21.77%	10 429.6	28.16%
0.7 - 0.8	6 155.6	16.62%	7 225.9	19.51%	9 233.3	24.93%
0.8 - 1.0	3 322.2	8.97%	9 392.6	25.36%	12 048.1	32.53%

The increase in vegetation coverage affects gully runoff through the following pathways:

(1) Reduced runoff: The root systems of vegetation increase soil porosity, enhance infiltration capacity, and reduce surface runoff. For instance, data from the Zhidan Hydrological Station shows that after returning farmland to forest, the reduction in sediment transport (96%) is much greater than that in runoff (57%), indicating that vegetation has a more significant effect on sediment interception.

(2) Enhanced soil water-holding capacity: The soil available water capacity (SOL_AWC) of forest land and grassland is relatively high, which can increase soil moisture content and reduce slope runoff. Studies in the Yan River Basin show that returning farmland to grassland can significantly increase soil moisture content, while returning farmland to forest has a relatively small impact on soil water.

(3) Enhanced evapotranspiration: The increase in vegetation coverage leads to an increase in evapotranspiration (ET), thereby reducing the water production in the basin. The ET in the Jing River Basin has shown a fluctuating downward trend in the past 41 years. However, the contribution of ET is greater in areas with high vegetation coverage.

3.2. The interception effect of trench engineering

Yan'an City has built 649 main DAMS and 9,002 small DAMS, forming a complete mud retention and flood control system. These projects have significantly reduced the amount of sediment flowing into the Yellow River by intercepting sediment and regulating floods. The gully control and land reclamation project, through the design of "seepage first, then overflow", effectively controlled floods and improved the local hydrological cycle, reducing the amount of sediment flowing into the Yellow River from an average of 258 million tons per year to 31 million tons, a decrease of 88%. In addition, the land reclamation by treating gullies has increased the area of cultivated land, achieving a win-win situation for ecological protection and land resource utilization.

4. THE IMPACT MECHANISMS OF CLIMATE CHANGE

4.1. The leading role of precipitation changes

The average annual rainfall in Yan'an City has increased by approximately 100 millimeters compared to before the land was returned to farmland. The concentration of precipitation during the flood season (July - September) has increased, which may lead to an increase in the peak flood flow. For example, the average annual runoff of the Yanhe River is 141 million cubic meters, among which the runoff from July to August accounts for more than 40% of the annual total. Extreme precipitation events (such as the measured peak flood flow of 389 m³/s at the Yan 'an Hydrological Station in August 2020) have intensified channel erosion and sediment transport, posing a threat to flood control safety.

4.2. Indirect effects of rising temperature

The increase in temperature accelerates the evaporation of soil moisture, which may reduce soil moisture content and base flow replenishment. For example, under the future climate scenarios of the Jing River Basin, the increase in temperature may lead to a further increase in evapotranspiration, thereby affecting the seasonal distribution of runoff. The increase in temperature may also change the snow-melting process. Although there is less snow accumulation in Yan'an City, the earlier snow-melting in spring may have an impact on the runoff in some local gullies.

5. EMPIRICAL RESULTS AND REGIONAL DIFFERENCES

5.1. Spatial heterogeneity of runoff response

The lower reaches of the Yan River Basin have a greater reduction in runoff than the upper reaches due to high vegetation coverage and dense silt DAMS. For instance, in the Zhou River Basin where

the Zhidan Hydrological Station is located, the runoff volume decreased by 57% and the sediment transport volume decreased by 96% after the land was returned to farmland. The regulatory effects of different land use types on runoff also vary. Forest land and grassland have a stronger regulatory effect on runoff than farmland. For example, farmland in the Jing River Basin contributes the most (29.9%) to the interannual fluctuation of water production, while grassland contributes the highest (55.0%) to evapotranspiration.

5.2. Future Scenario Prediction

Under the RCP8.5 scenario, the runoff volume in Yan'an City may increase by 3.7% by the end of this century, but the flow in summer will significantly decrease, intensifying the pressure on water resources. In terms of land use scenarios, returning farmland to forest can enhance carbon sink capacity (increase NPP and SOC), but it may reduce water production. Returning farmland to grassland has a limited effect on enhancing carbon sinks, but it can increase soil moisture content. Therefore, a balance needs to be sought between ecological protection and the sustainable utilization of water resources.

6. CONCLUSION

The vegetation index of Yan'an City from 2000 to 2019 ranged from 0.54 to 0.75. In terms of time distribution, it showed a significant upward trend. Its NDVI value increased from 0.54 in 2000 to 0.73 in 2019, and the overall upward rate was 0.095/(10a). The dynamic changes of vegetation index in Yan'an City from 2000 to 2019 showed an overall upward trend. Among them, 79.83% of the regional vegetation showed an improving trend, mainly distributed in the loess ridges and gully areas in the north and east of Yan'an City. The degraded areas account for 0.34% of Yan'an City, mainly distributed in the urban area of Yan'an City and the suburban areas of county-level cities, presenting a point-like and strip-like distribution. The vegetation index of Yan'an City is jointly influenced by natural factors and human activities. Among them, from 2000 to 2012, affected by the government's project of returning farmland to forest and grassland, the growth rate of NDVI was relatively fast. During this period, human activities were the dominant factor determining the status of the vegetation index. From 2013 to 2019, the vegetation index in Yan'an City fluctuated greatly. Its changing trend curve was basically consistent with temperature and precipitation. The main factors affecting the growth of vegetation in Yan'an were water and heat conditions. The ArcSWAT model provides an effective tool for quantifying the responses of gully runoff in Yan'an City to land use and climate change. Returning farmland to forest and reclaiming land from gullies have significantly reduced soil erosion through vegetation restoration and engineering measures. However, climate change may offset some of the ecological benefits. In the future, strategies for land use optimization, engineering maintenance and climate adaptability need to be comprehensively considered to achieve the coordinated goal of ecological protection and sustainable utilization of water resources. With the deepening of research, multi-model coupling and refined simulation should be further strengthened to provide more accurate scientific support for water resource management and ecological security in Yan'an City.

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