Effects of Landscape Patterns on Runoff and Sediment in Danjiang River Basin

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Abstract. The Danjiang River being the main tributary of the Hanjiang river, is the main water source of the south-to-north water diversion project in China, which is benefit from the protection of ecological environment. As the main reasons for ecological degradation, the land use changing and severe soil erosion attracted considerable attention in recent years. Based on the land use data and measured runoff and sediment data, the landscape pattern index analysis method and statistical analysis method were employed to explore the relationship between landscape pattern indexes and runoff and sediment in Danjiang River Basin (DRB). The results show that the runoff and sediment of the river present a downward trend from 1985 to 2018. The forestland was the dominant type of land use, and the growth rate of grassland was the highest. Results also show that the patch density (PD), the interspersion and juxtaposition (IJI), the edge density (ED), CONTAG, DIVISION and the largest patches index (LPI) have the same trend, indicating that the fragmentation degree of landscape, the connectivity between landscapes, and the richness of landscape increased. In addition, the shannon’s diversity index (SHDI) and IJI were positively associated with the runoff at landscape level, number of patches (NP), PD, ED, and CONTAG were negatively associated with sediment, and CONTAG was positively correlated with sediment. At class level, the NP, PD, LSI, and IJI of forestland, the NP, PD, and DIVISION of cropland, the LPI of grassland, and the NP, PD, and LSI of construction land were negatively correlation with runoff. The LSI and ED of grassland and the LPI of construction land were positively correlation with runoff. And the LSI, IJI, and ED of forestland and the LSI, IJI, and ED were negatively correlation with sediment.

1. Introduction
The condition of water and soil erosion in the Danjiang River Basin is serious, and the water and soil erosion area accounts for 47.87% of the total area(Hu and Jixia, 2009). As an ecological process, water and soil erosion is not only associated with rainfall and soil, but also closely related to land use(Kaitao et al., 2019 , Wang et al., 2011). And the changes of land use caused by human activities can alter hydrological processes and landscape pattern, which can impact water supply(FU et al., 2005). As the water source of the Middle Route of the South-to-North Water Diversion project, the water and soil conservation and governance work in the Danjiang River Basin is highly regarded. The number of projects was constructed to control water and soil erosion(ZHANG, 2020; ZHU, et al., 2021). Moreover,
the quantity and quality of the delivered water will be influenced by the changes of runoff and sediment in the Danjiang River Basin (XU et al., 2019). It is crucial for developing comprehensive approach that is able to simulate and evaluate landscape pattern and their relationship with hydrological processes to land use and water resource planning and management.

In recent years, emphasis is put on the interaction between landscape pattern and ecohydrological process, and it becomes a critical field of Ecological hydrology and landscape ecology as well (Wang et al., 2009; Wilcox et al., 2003). The change of landscape pattern influences the spatial distribution of moisture and has an impact on the regulation of runoff and sediment yield and concentration (LV et al., 2007; MUYIBUL, et al., 2019). By analyzing the change of index, the temporal and spatial changes of the landscape pattern can be reflected (LI et al., 2020), so that the relationship between the landscape pattern and runoff and sediment can be found.

YAN (2020) found that, in the Fuhe River Basin, the runoff decreased with the fragmentation degree of the landscape reduced, the complexity of the patches’ shape added, and the uniformity of patches reduced. Xiaojun et al. (LIU et al., 2016) found that, in Huanghe River Basin, the diversity of landscape was extremely positively correlated with runoff, and the connectivity degree of landscape patches was significantly correlated with the sediment. MEI et al. (2020) found that, in Xunhe River Basin, the sediment reduced with the connectivity of patches increased and the concentration of patches increased. GAO et al. (2021) found that in Hanjiang River Basin, the more fragmented and the worse connectivity of the landscape patches, the soil was easier to erosion. Though the number of studies have found the relationship between landscape pattern and runoff and sediment, little research studied the relationship between the landscape pattern of different land uses and runoff and sediment. Moreover, previous studies did not closely combine the process of water and soil erosion with the landscape pattern as well (Saidi, 2012). The existing researches on the relationship between landscape pattern and water and soil erosion are mainly concentrated in the Loess Plateau (Khaledian et al., 2017, Montero, 2005), and there are few studies on the relationship between landscape pattern changes and runoff and sediment in Danjiang River Basin. Therefore, this article not only analyzed the change of rainfall and runoff, the change of land use and landscape pattern, but also researching the relationship between landscape and runoff and sediment at landscape level and class level. Aiming to provide the basis for preventing and controlling soil erosion.

2. Materials and methods

2.1. Study area

The Danjiang River Basin is a typical mountainous river which is located at the junction of Shaanxi province, Henan province, and Hubei province (Figure 1). The Danjiang River catchment area is 8,887 km² and the total length of the main steam is 280 km. It covers the geographical coordinates of 33°04’10” to 34°11’09” N and 109°30’08” to 111°15’51” E. With the relative elevation difference of 1,915m, the Danjiang River basin features western high and eastern low. The Danjiang River Basin is controlled by the monsoon-type continental climate with four distinct seasons. The rainfall concentrated from May to October, accounting for about 80% of the annual precipitation. The Jingziguan station is one of the hydrological stations in the watershed, which has complete runoff data from 1985 to 2018. In addition, there are 43 precipitation gauge in the study area, and the precipitation date from 1985 to 2018 can be collected from those stations.
2.2. Data sources and data analysis
The DEM used was the Shuttle Radar Topography Mission (SRTM) 30m, which was reprocessed by the National Aeronautics and Space Administration (NASA), and was available from the USGS Earth Explorer website (https://earthexplorer.usgs.gov/). To extract the watershed boundary, the DEM raster was mosaiced together firstly. After the DEM of the watershed was filled, the water flow direction was generated and the river network was extracted based on the DEM by using ArcGIS, the basin’s boundary can be got.

The 300m global land Cover data of 1992, 2010, 2015, and 2018 this research used was developed by European Space Agency Climate Change Initiative and could be download from its website (http://maps.elie.ucl.ac.be/CCI/). The data were reclassified into five categories by using ArcGIS, after being tailored to the watershed boundary. The five kinds of land use are cropland, grassland, forest land, construction land, and water.

Basing on the previous studies(Kaitao et al., 2019 , ZHANG, 2020, Zijun et al., 2020), Number of patches (NP), Patch density (PD), Largest patch index (LPI), Landscape shape index (LSI), Contagion index (CONTAG), COHESION, Shannon’s diversity index (SHDI), Interspersion and Juxtaposition (IJII), Edge density (ED), and DIVISION are chosen to analysis.

2.3. The relationship between landscape index and runoff and sediment
For the change of runoff needs time to respond to the land use and landscape pattern changes, 5 years were chosen to be response time, and the response periods of 1992, 2010, 2015, and 2018 were 1985-1990, 2006-2010, 2011-2015, and 2016-2018. In addition, the land transition matrixes were made by using ArcGIS, and the Pearson correlation coefficient method was used to analyze the relationship between landscape index and runoff and sediment.

3. Results and discussion
3.1. The characteristics of precipitation, runoff, and sediment on temporal scale
The inter-annual variation of the annual precipitation, annual mean runoff, and sediment of the Danjiang River Basin from 1985 to 2018 are shown in Fig 2. The annual mean rainfall of the Danjiang River Basin is 732.29mm. The minimum annual precipitation is 561.17 mm (1986), while the maximum annual rainfall is 945.44 mm (2017), and the coefficient of the variation is 15.84%. Besides, the precipitation shows a downward trend from 1985 to 2018.

The annual mean runoff and sediment of the Danjiang River Basin are 27.21 m³/s and 80.51 m³/s respectively. The maximum annual mean runoff and sediment are 58.6 m³/s (1985) and 443 m³/s (2010)
respectively, while the minimum annual mean runoff and sediment are 2.37 m³/s (2007) and 0.332 m³/s (2008) respectively. The coefficients of the variation are 76.91% and 144.25% respectively, which means the inter-annual variation of the annual mean runoff and sediment are both great. Besides, a decreased trend of the annual mean runoff and sediment are shown from 1985 to 2018.

In addition, the Pearson correlation coefficient of rainfall and runoff is 0.711, the Pearson correlation coefficient of rainfall and sediment is 0.482, and the Pearson correlation coefficient of runoff and sediment is 0.541, which means precipitation and runoff are highly correlated, and runoff and sediment are correlated as well.

![Figure 2](image_url)  the temporal variation of the annual precipitation, annual mean runoff, and sediment

3.2. Spatiotemporal pattern of land transformation
The land use maps of 1992, 2010, 2015, and 2018 were overlaid in ArcGIS to get the land transition matrix.

![Figure 3](image_url)  The change of five kinds of land use
Figure 4  The area of every land use

As shown in figure 4, the area of cropland, forestland, and construction land had an increasing trend from 1992 to 2015 and a decreasing trend was shown from 2015 to 2018. The grassland witnessed a sharp fall from 1992 to 2010 and then it increased from 2010 to 2018. Moreover, during the period of 26 years, cropland and grassland altogether reduced 31.46 km² and 124.22 km² respectively. And the area of forestland and construction land increased 109.82 km² and 41.16 km² from 1992 to 2018, respectively. But the water area almost unchanged in 26 years.

| Land class | Grassland | Cropland | Construction land | Forest land | Water | Loss |
|------------|------------|----------|-------------------|-------------|-------|------|
| Grassland  | 253.101    | 70.315   | 8.1907            | 70.235      |       | 401.841 |
| Cropland   | 0.268      | 1412.801 | 19.727            | 14.373      |       | 1447.169 |
| Construction land | 7.789 |           |                    |             |       | 7.789 |
| Forest land| 12.821     | 22.537   | 5196.980          | 5232.339    |       | 5232.339 |
| Water      | 1.499      | 1.499    |                   |             |       | 1.499 |
| Gain       | 266.190    | 1505.653 | 35.706            | 5281.588    | 1.499 | 7090.636 |

Table 2  The land transition matrix 2010-2015 (km²)

| Land class | Grassland | Cropland | Construction land | Forest land | Water | Loss |
|------------|------------|----------|-------------------|-------------|-------|------|
| Grassland  | 265.226    | 0.214    | 0.107             | 0.642       |       | 266.19 |
| Cropland   | 1498.372   | 7.280    |                   |             |       | 1505.653 |
| Construction land | 35.706 |           |                    |             |       | 35.706 |
| Forest land| 5.086      | 2.57     | 5273.933          | 5281.588    |       | 5281.588 |
| Water      |           |          |                   |             | 1.499 | 1.499 |
| Gain       | 270.312    | 1501.156 | 43.094            | 5274.576    | 1.499 | 7090.636 |
Table 3  The land transition matrix 2010-2015 (km²)

| Land class | Grassland | Cropland | Construction land | Forest land | Water | Loss |
|------------|-----------|----------|-------------------|-------------|-------|------|
| Grassland  | 164.773   | 15.647   | 3.964             | 85.241      | 0.171 | 269.796 |
| Crop land  | 12.462    | 1183.660 | 16.351            | 286.150     | 0.134 | 1498.756 |
| Construction land | 0.530   | 8.905   | 33.429            | 0.191       |        | 43.056 |
| Forest land | 98.945    | 205.171  | 0.190             | 4952.208    | 0.137 | 5256.650 |
| Water      | 0.186     | 0.058    |                   | 0.408       | 0.847 | 1.499 |
| Gain       | 276.896   | 1413.441 | 53.934            | 5324.199    | 1.288 | 7069.757 |

The land transition matrices are demonstrated in Table 1, Table 2, and Table 3, and it can be noticed that the change of water was the smallest. It also can be known that, during the periods of 1992-2010, 2010-2015, and 2015-2018, the gain rate and the loss rate of forest were the most, which were 74.49% and 73.79%, 74.39% and 74.49%, 76.29% and 74.25%, respectively. And the area of cropland gained and lost were the second largest, which were 1505.653km² and 1447.17 km², 1501.16 km² and 1505.65 km², 1413.44 km² and 1498.756 km² respectively in three periods. In addition, the lost area of grassland (401.841km²) was larger than the gained area (266.190 km²) except in the period 1992-2010. The lost area of cropland was larger than the gained area during 2010 to 2015 and 2015 to 2018. However, from 1992 to 2010, the gained area was larger than the lost area. During the periods of 1992-2010, 2010-2015, and 2015-2018, the lost area of construction land was smaller than the gained area.

The project of “returning farmland to forests” has been carried out since 2006(ZHANG, 2020). A lot of areas of cropland transformed to forestland and grassland from 2010 to 2018. Meanwhile, with the repaid development of society and economy, the area of construction land increased.

3.3. Landscape pattern analysis

The landscape indexes can be used to illustrate the landscape change characteristics of the whole basin(XU et al., 2018). From figure 5, NP, PD, LSI, and ED firstly showed downward trends in 1990-2010, and then increased from 2010 to 2018, while CONTAG and COHESION firstly increased in 1990-2010, and then decreased in 2010-2018. This indicates that the fragmentation and connectivity degree of landscape increased from 1990 to 2010, and decreased from 2010 to 2018. That is because the intensity of human activities has increased since 2010, and part of cropland transformed into construction land. As a result, large cultivated land was divided into many small patches and caused the increasing of landscape fragmentation. Besides, with the area of construction adds, the connectivity becomes better. It is also noticeable that in figure 5 the SHDI and IJI declined from 1990 to 2010 and from 2015 to 2018, while they raised from 2010 to 2015. And DIVISION kept falling in 1990-2018, while LPI raised continuously. That means, the kinds of patches reduced in 1990-2010 and 2015-2018, while the diversity of land use type increased in 2010-2015. For the impaction of human activities became more serious, the diversity of landscape increased correspondingly.

In summary, the fragmentation degree of the Danjiang River basin increased, while the degree of connectivity and the complexity of shape reduced, and the landscape heterogeneity reduced.
3.4. The relationship between landscape index and runoff at a landscape level

The Pearson correlation coefficients of landscape index and runoff was shown in Fig 6. IJI and SHDI had a positive correlation with runoff, and their correlation coefficients were 0.922 and 0.681 respectively, which means as the land use increased and adjacent patch types increased, it is easier to form the runoff. Because the whole plot of cropland, forestland, and grassland partly transformed to urban land, which reduces the connectivity of vegetation and reduces the retardation transpiration rate of vegetation to rainfall.

![Figure 5: The variation of landscape indexes 1992-2018](image)

![Figure 6: The correlation between landscape index and runoff](image)

The relationship between landscape and runoff was shown in Fig 7. The $R^2$ of PD and NP were both 0.23, which means the fragmentation degree of the landscape had a weak correlation. By contrast, the $R^2$ of CONTAG and COHESION were 0.778 and 0.927 respectively. That means runoff showed a significantly increasing trend when CONTAG<66.34 and COHESION<99.58, while when CONTAG>66.34 and COHESION>99.58, runoff decreased as CONTAG and COHESION increased. In other words, it is easier for runoff to form when the connectivity is weak. However, with the connectivity increasing to a certain extent, the formation of runoff became difficult. In addition, LSI also showed a strong connection with runoff, whose $R^2$ was 0.800. Runoff decreased with the complexity of patches’ shape increasing when LSI<23.30. however, it was easier for runoff to form when LSI>23.30.
LPI, SHDI, ED, and DIVISION had strong connectivity with runoff as well, for their $R^2$ were 0.990, 0.899, 0.972, and 0.985 respectively. Moreover, it is noticed that when LPI<66.28, SHDI<0.71, ED<10.12, and DIVISION<0.54, the runoff decreased as LPI, SHDI, ED, and DIVISION increased, while when LPI, SHDI, ED, and DIVISION increased, the runoff increased as LPI, SHDI, ED, and DIVISION decreased. That means when the impact of human activities, the landscape richness, and the degree of division add to a certain extent, it is easier to produce runoff.

3.5. The relationship between landscape index and sediment at a landscape level

Figure 8 shows the correlation between landscape index and sediment. The Pearson correlation coefficient of NP, PD, and ED were -0.913, -0.849, and -0.753 respectively, which indicates the fragmentation degree of the landscape has a strong negative correlation with sediment yield. Besides, the Pearson correlation coefficient of LSI and CONTAG were -0.706 and 0.609 respectively. That means the complexity of shapes has a strong negative correlation with sediment and the aggregation degree of patches has a positive correlation with sediment. Because with the cropland transform into construction land and forestland, the formation degree of landscape increase, and the migration capacity of sediment become weaker.
The relationship between landscape index and sediment is shown in figure 9. The $R^2$ of LPI, COHESION, DIVISION, CONTAG, and SHDI were 0.324, 0.309, 0.325, 0.411, and 0.332 respectively, which means they only have a weak connection with sediment. However, NP and PD show a strong connection with sediment, for their $R^2$ were 0.864 and 0.860 respectively. The sediment reduced as the NP and PD increase till NP=1638 and PD=0.21, and after NP>1638 and PD>0.21, the sediment reduced as they increased. That means when the fragmentation degree of the landscape is low, it is easier to produce sediment, while the sediment production will be inhibited when fragmentation increases to a certain degree. Additionally, LSI had the strongest correlation with sediment among all of these indexes, for its $R^2$ was 1. That means the complexity of patches’ shape influences sediment greatly. IJI and ED correlated with sediment as well, whose $R^2$ were 0.779 and 0.895 respectively. When IJI <53.65, ED<10.15, the degree of different kinds of patches connected negatively correlated with sediment. When IJI>53.65 and ED>10.15, sediment increased as they increased.

3.6. The relationship between landscape index and runoff, landscape index and sediment at class level

Based on Table 4, it is noticeable that the NP, PD, LSI, and IJI of forest land negatively correlate to runoff, which is the same as the finding in WANG’s research(2021). In addition, the ED of forest land negatively correlated to sediment. From Table 1-3 and Table 4, it can be noticed that the added area of forestland is mainly transformed from cropland, and forestland distribute around the cropland. As a result, the fragmentation increased, the landscape dominance reduced, and the connectivity with other landscape patches increased. Therefore, the capacity of forest interception and soil infiltration add, which makes it difficult for runoff to form and sediment to transform.

Besides, the NP, PD, and DIVISION of cropland negative correlated to runoff, and the LSI, IJI, and ED of cropland negatively correlated to sediment. With the large area of crop transformed into forestland, cropland, and construction land, the landscape dominance of cropland reduced, the fragmentation increased, and the division increased, resulting in an increase in runoff yield capacity and a weakening of the capacity to transform sediment of cropland become weaker.

Moreover, the LPI of grassland negatively correlated to runoff, while the LSI and ED of grassland positively correlated with runoff, which is consistent with the finding in Xuang’s research(2018). Besides, the LPI and LSI of grassland both passed the 0.05 level test. The result also indicates that the increase of landscape dominance and the complexity of shape have a negative impact on the formation of runoff negatively. Because after “Returning cropland to forestland and grassland”, small pieces of
grass were gradually connected into a large area, which increased precipitation retention and transpiration rate. Therefore, it had a significant effect on runoff reduction.

In addition, the NP, PD, and LSI of construction land negatively correlated to runoff, and the LPI of construction land positively correlated to runoff. It can be noticed from the result that with the socio-economic development and acceleration of urbanization, the construction land tends to centralize. The increase of impervious areas is beneficial to increase runoff. However, the area of construction land is small, whose area only accounts for 0.6% of the total area. Therefore, its impact on runoff is weak. Moreover, the construction land is mostly distributed around the cropland, and the population is relatively concentrated, leading to a great demand for water resources. Therefore, as the area of construction land increases, the runoff is reduced.

| Table 4 | The relationship between landscape class level and runoff and sediment |
|---------|----------------------------------------------------------------------------|
|         | NP  | PD  | LPI | LSI | LJI | COHESION | ED  | DIVISION |
| Forestland Runoff | 0.717 | 0.740 | 0.017 | 0.926 | 0.976 | 0.010 | 0.577 | -0.013 |
| Sediment | 0.395 | 0.381 | -0.569 | 0.166 | -0.114 | -0.563 | - | 0.569 |
| Cropland Runoff | 0.769 | 0.771 | -0.989* | 0.146 | 0.520 | -0.477 | - | 0.938 |
| Sediment | -0.422 | - | 0.077 | - | - | 0.499 | - | -0.226 |
| Grassland Runoff | 0.401 | 0.418 | - | 0.977 | 0.540 | 0.291 | 0.939 | - |
| Sediment | 0.061 | 0.072 | 0.029 | - | 0.471 | 0.544 | 0.119 | - |
| Construction (land) Runoff | -0.848 | - | 0.608 | - | 0.770 | -0.919 | - | - |
| Sediment | -0.578 | - | -0.502 | - | 0.451 | 0.290 | - | - |
| Water Runoff | -0.045 | - | -0.546 | - | 0.450 | -0.045 | - | - |
| Sediment | 0.570 | 0.570 | -0.492 | 0.569 | 0.570 | 0.570 | 0.570 | - |

**At 0.01 level (two-tailed), the correlation was significant.
*At 0.05 level (two-tailed), the correlation was significant.
- One of the data is lack.

To sum up, the change of the land use and landscape pattern of the Danjiang River Basin from 1990 to 2018 are analyzed in this study. Besides, the impact of landscape pattern changes on runoff from 1990 to 2018 is also studied, which provides an important reference for further exploring the influence of human activities on runoff and sediment. However, there are still some limitations in this study. Although this study analyzes the impact of land use changes on the Danjiang River Basin on runoff and sediment from the macroscopic perspective, it hasn’t been researched from the micro perspective, which is worthy of further research. In addition, the relationship between landscape pattern and runoff and the relationship between landscape pattern at different watershed-scale leave room for further study.

4. Conclusion

Both the runoff and sediment show a downward trend from 1985 to 2018. Though the forestland was the dominant in the study area, the growth rate of grassland was the highest. In addition, the change of landscape indices from 1985 to 2018 indicated that the degree of landscape fragmentation increased while the land use connectivity decreased. The above results are mainly due to the implementation of the conversion of farmland to forest and the increase of human activities.
At landscape level, SHDI and IJI positively associated to runoff. Besides, NP, PD, and ED negatively associated to sediment, while CONTAG positively correlated to sediment. That means the diversity and convergence of landscape positively associated to runoff. Additionally, the fragmentation of landscape negatively associated to sediment, while the convergence of landscape positively associated to sediment.

At class level, the NP, PD, LSI, and IJI of forestland, the NP, PD, and DIVISION of cropland, the LPI of grassland, and the NP, PD, and LSI of construction land negatively correlated to runoff. The LSI and ED of grassland and the LPI of construction land positively correlated to runoff. And the LSI, IJI, and ED of forestland and the LSI, IJI, and ED negatively correlated with sediment.

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