Study on Dynamic Changes of Soil Erosion in the North and South Mountains of Lanzhou

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Research Article

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Study on dynamic changes of soil erosion in the North and South Mountains of Lanzhou

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Abstract: This study takes the north and south mountains of Lanzhou as the study area, calculates the soil erosion modulus of the north and south mountains of Lanzhou based on the five major soil erosion factors in the RUSLE model and analyzes the temporal and spatial dynamic changes of soil erosion and the characteristics of soil erosion under different environmental factors. The results show that the soil erosion intensity of the north and south mountains of Lanzhou is mainly micro erosion in 1995, 2000, 2005, 2010, 2015 and 2018. They are distributed in the northwest and southeast of the north and south mountains. Under different environmental factors, the soil erosion modulus first increased and then decreased with the increase of altitude; the soil erosion modulus increased with the increase of slope; the average soil erosion modulus of grassland and woodland was larger, and the average soil erosion modulus of water area was the smallest; except for bare land, the average soil erosion modulus decreased with the increase of vegetation coverage. The soil erosion modulus in the greening range is lower than that outside the greening scope, mainly the result of the joint influence of precipitation, soil and vegetation.

Keywords: soil erosion; RUSLE model; erosion intensity; north and south mountains of Lanzhou

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.

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1. Introduction

Soil erosion refers to the destruction and loss of soil and water resources and land

productivity under the interference of natural forces and human activities, mainly including land surface erosion and water loss, which is also called soil and water loss in China (Wang et al., 2005; Jiang et al., 2014; Fang et al., 2019). Soil erosion will destroy the surface structure, reduce land fertility, raise the river bed, destroy water conservancy facilities, aggravate flood and drought, and pose a significant threat to agricultural production, river water quality and environment. At present, soil erosion has become one of the most extensive and complicated ecological problems in the world, and it has become the concern of many disciplines, such as soil science, agronomy, hydrology, environmental science and so on (Vrieling et al., 2006; Zhang et al., 2010; Zou et al., 2017; Youcef et al., 2019). China is one of the countries with the most severe soil erosion. Relevant data show that the area of soil erosion in China reached $2.73 \times 10^6 km^2$ in 2018, accounting for about 28.80% of the country's total area except for Taiwan Province. The amount of soil erosion is much higher than the allowable amount of soil loss (Ministry of Water Resources of the People's Republic of China, 2019). The area of soil erosion in Northwest China is $1.26 \times 10^6 km^2$, accounting for 40.95% of the total area of Northwest China. Soil erosion has become an essential environmental problem in Northwest China (Zheng et al., 2008). In 2018, the area of soil erosion in Gansu Province reached $1.86 \times 10^5 km^2$, accounting for about 40.66% of the total area of Gansu Province, which exerted significant pressure on soil and water conservation and the construction of ecological civilization in various regions of Gansu Province (Ministry of Water Resources of the People's Republic of China, 2019).

The north and south mountains of Lanzhou, located in the central part of Gansu Province, are not only the ecological protection barrier of Lanzhou, the capital city of Gansu Province, but also an essential part of the urban ecosystem of Lanzhou. It plays a significant role in water conservation, soil and water conservation, carbon fixation and oxygen release, environmental purification and biodiversity protection. Whether the ecosystem is stable or not has a significant impact on the urban environment of Lanzhou. The elevation of the north and south mountains in Lanzhou is between 1494 and 3625m, which belongs to the typical geomorphological features of the Loess Plateau, the gully is vertical and horizontal, the surface is broken, and most of the area is covered by deep loess. The precipitation resources in the north and south mountains of Lanzhou are low and uneven, the average annual precipitation is only 327mm, but the average yearly potential evaporation is 1468mm, and the rainfall is mainly concentrated from July to September, accounting for more than 60% of the yearly rainfall. The harsh natural conditions and frequent human production activities lead to the difficulty of vegetation growth, severe soil erosion and ecosystem deterioration in the north and south mountains of Lanzhou, which restricts the economic development of Lanzhou. Threatening the ecological security of Lanzhou (Zhao et al., 2006). After the founding of New China, local governments have invested many human and financial resources in afforestation in the north and south mountains of Lanzhou over the years. Since 1983, provincial and municipal party, government and military enterprises and institutions have contracted the barren mountains of the north and south mountains of Lanzhou to start afforestation. At present, the afforestation area of the north and south mountains of Lanzhou has reached $413 km^2$, and 1.6×10^8 trees have survived, forming a relatively perfect artificial

ecosystem and effectively slowing down the soil and water loss in the north and south mountains of Lanzhou (Wu, 2003; Li, 2009).

Soil erosion model is a common method for quantitative estimation of soil erosion. In 1986, based on the USLE model, the United States established a modified general soil loss equation (RUSLE). Compared with other soil erosion models, RUSLE model has the advantages of a simple formula, fewer parameter requirements and high estimation accuracy, so it has become a widely used quantitative estimation model of soil erosion all over the world. Therefore, to evaluate the ecosystem of the north and south mountains of Lanzhou, this study takes the north and south mountains of Lanzhou as the study area, takes soil erosion as the research content, based on the relevant measured data of soil samples, uses the RULSE model to calculate the soil erosion modulus of the north and south mountains of Lanzhou, and reveals the temporal and spatial variation characteristics of soil erosion in the north and south mountains of Lanzhou, to provide scientific reference for the control of soil and water conservation and the construction of ecological civilization in Lanzhou.

2. Data sources and research methods

2.1 General situation of the study area

The north and south mountains of Lanzhou span Anning District, Qilihe District, Chengguan District, Xigu District, Gaolan County and Yuzhong County within the jurisdiction of Lanzhou City, with geographical coordinates of 35°44′-36°19′N、103°21′-103°59′E. The total area is about 1940.08km^2 (Fig. 1). Among them, the green part accounts for 846.66 km^2, and the non-green region accounts for 1147.42km^2. The geological conditions of this area are involved, the topography is fragmented, and natural disasters are easy to occur. The climate type belongs to temperate semi-arid continental monsoon climate, with an annual average temperature of 9.1 ℃ and yearly average rainfall of 327.7mm, mostly concentrated from July to September, and the annual average potential evaporation is 1468mm, which is 4.4 times of precipitation. The vegetation type basically belongs to the transition type from typical steppe to desert steppe. At present, most of the existing forests in the north and south mountains of Lanzhou are artificial forests, mostly young and middle-aged forests. Artificial afforestation is mainly coniferous and broad-leaved mixed forest; Arbor shrub mixed forest and shrub forest. The soil types in this area are primarily grey calcareous soil, mostly dark grey calcareous soil and typical grey calcareous soil in Nanshan, and light grey calcareous soil and red sandy soil in the northern mountain, with a loose texture and weak anti-erosion ability.

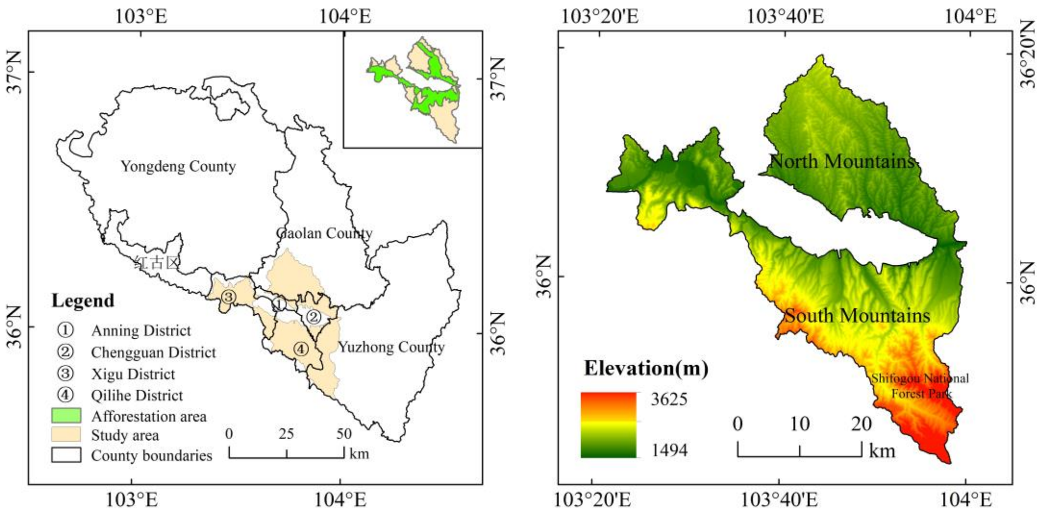

Fig.1 Overview of the study area

2.2 Data source

2.2.1 Soil texture and organic carbon data

(1) Soil sample sampling

Based on the 1: 1 million soil map of the north and south mountains of Lanzhou, it is planned to arrange about 1 million soil sampling sites according to the uniform distribution method 4km × 4km. Sampling was carried out in the north and south mountains of Lanzhou from July to August 2019. A sample of 10 m × 10 m was selected, and soil samples of 0-20cm in the surface layer of the center and four right corners of the sample plot were collected by a soil drill, which was evenly mixed and placed in a self-sealing bag for the determination of soil texture and soil organic carbon. The 0-20cm soil samples of the surface layer at the center and four right corners were collected with a ring knife, put into an aluminum box, and weighed fresh at the sampling site, which was used to determine the soil bulk density. Using GPS positioning, the elevation, longitude and latitude of the sampling points in the center were recorded and numbered sequentially. A total of 130 soil samples were actually collected (Fig. 2 and Fig. 3).

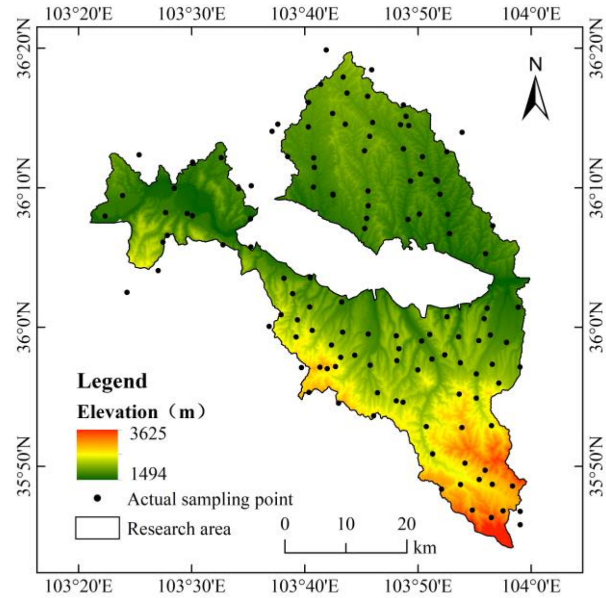

Fig.2 Distribution of soil sampling points

(2) Determination of soil samples

The determination of soil texture was carried out in the soil particle size laboratory of the School of Resources and Environment, Lanzhou University. The instrument was Mastersizer2000 laser particle size analyzer. The soil organic carbon content, soil salinity and pH value were determined in the soil laboratory of the School of Geography and Environmental Science of Northwest Normal University. The soil organic carbon content was determined by Qiulin method, the soil salinity was determined by "residue drying-mass method", and the pH value was determined by "potential method" (Fig. 3).

Fig.3 Photos of soil sampling and indoor soil experiment

2.2.2 Other data

(1). The meteorological data is based on the monthly precipitation data set of 0.5 °× 0.5 °in China from 1995 to 2018 (V2.0). The elevation data comes from the China Meteorological data sharing Network (http://data.cma.cn/). (2). The GDEMDEM 30m spatial resolution digital elevation is derived from the geospatial data cloud (http://www.gscloud.cn/). (3). The Landsat TM/OLI image from 1995 to 2018 is selected as the source of Google Earth engine cloud platform (Google Earth Engine, GEE) (https://earthengine.google.com/). The image is programmed in the platform to preprocess the image. (4). The land use with a spatial resolution of 30m in 1990, 2000, 2005, 2010, 2015 and 2018 is selected from the Resource and Environmental Science data Center of the Chinese Academy of Sciences (http://www.resdc.cn/).

2.3 Research methods

2.3.1 Soil erosion model

In this study, the RUSLE model was used to estimate the amount of soil erosion in Lanzhou (Renard, 1991; Chen et al., 2014; Kayet et al., 2018). The formula is as follows:

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{1}$$

Among them, ***A*** is the average soil erosion amount per unit area last year, the unit is [t / (hm^2 · a)], and ***R*** is the precipitation erosivity factor, the unit is [MJ mm/ (hm^2 · h ·a)]. ***K*** is the soil erodibility factor, in units[t·hm^2·h/(hm^2·MJ·mm)], ***LS*** is the slope length factor (dimensionless); ***C*** is the vegetation cover and management factor, and dimensionless); ***P*** is the soil and water conservation and measure factor (dimensionless).

2.3.2 Determination of factors in RUSLE Model

(1) Determination of ***R***-value of precipitation erosivity factor.

Precipitation is one of the important exogenous forces causing soil erosion, which reflects the potential impact of annual average or maximum precipitation on soil erosion. This study adopts the method of estimating rainfall erosivity by using yearly and monthly precipitation data proposed by Wischmeier et al (1978). The formula is as follows:

$$R = \sum_{i=1}^{12} \left[1.735 \times 10^{\left(1.5 \times \log \frac{P_i^2}{p} - 0.8188\right)} \right] \tag{2}$$

In the formula, $\boldsymbol{P_i}$ is monthly precipitation (mm); ***P*** is annual precipitation (mm). This method has been applied in the western region, and good results have been obtained (Gao et al., 2015). The

average precipitation erosivity factors in 1995, 2000, 2005, 2010, 2015 and 2018 in Lanzhou were 110.06, 83.20, 71.09, 46.68, 56.97 and 198.61 [MJ·mm/(hm^2·h·a)] respectively. Spatially, the precipitation erosivity factors of the north and south mountains decreased from southeast to northwest in 1995, 2000, 2005 and 2010, and the precipitation erosivity factors of the south and south mountains decreased from the west to the east in 2015 and 2018, and the precipitation erosivity factor of the west was greater than that of the east. The erosivity factor of precipitation in 2018 is significantly higher than that in other years, mainly because 2018 is an abnormally rainy year. The precipitation is higher than that in previous years (Fig. 4).

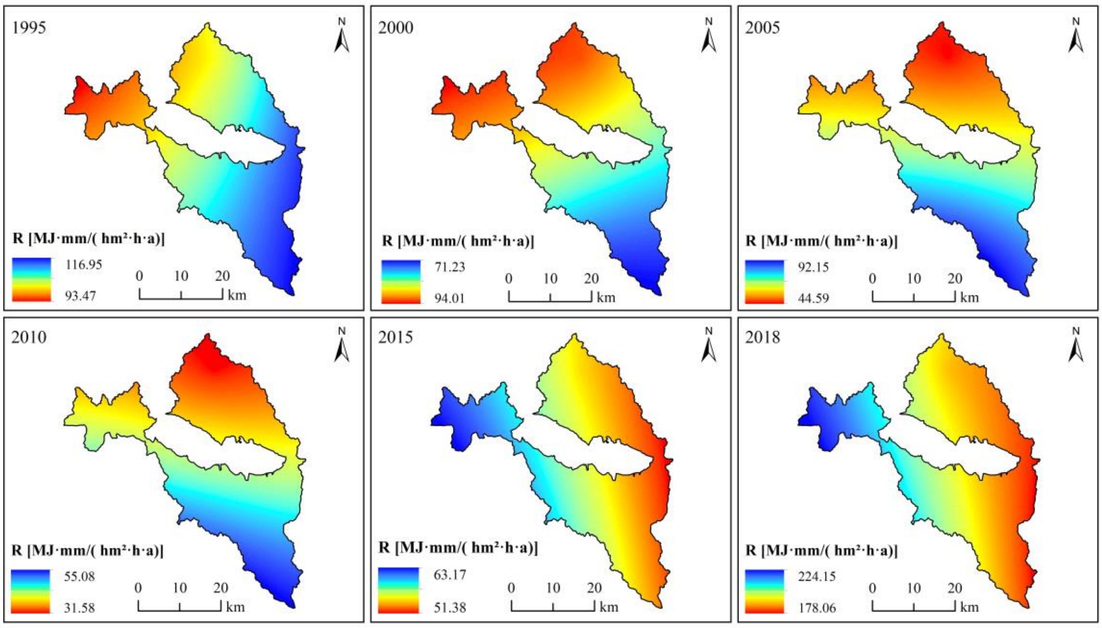

Fig.4 Spatial distribution of rainfall erosivity in the South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018

(2) Calculation of K value of soil erodibility factor

Soil erodibility factor refers to the soil loss rate under a given unit precipitation erosivity measured in a standard plot (Men et al., 2004; Jiang et al., 2004). In this study, Williams et al. (1983) calculation method of soil erodibility factor K in the EPIC model is adopted. The formula is as follows:

$$K = 0.1317 \times \left\{ 0.2 + 0.3 \exp\left[-0.0256 Sand\left(1 - \frac{Silt}{100}\right) \right] \right\} \times \left[\frac{Silt}{Clay + Silt} \right]^{0.3} \times \left[1 - \frac{0.25C}{C + \exp(3.72 - 2.95C)} \right] \times \left[1 - \frac{0.7Sn1}{Sn1 + \exp(-5.51 + 22.9Sn1)} \right] \quad (3)$$

Among them, ***Clay***, ***Silt*** and ***Sand*** represent the percentage of clay, silt and sand content in soil respectively (%); ***C*** is the percentage of soil organic carbon content (%); ***Sn1***=1-Sand/100.

Generally speaking, the higher the value of soil erodibility factor, the lower the soil erosion resistance and easy to be eroded; on the contrary, the soil is not easy to be eroded (Fu & Zha., 2008; Lu et al., 2011; Zhu et al., 2016; Cassim et al., 2019; Pavisorn et al., 2020).

According to the soil data measured by the laboratory, the spatial distribution of soil erodibility factors in the northern and southern mountains of Lanzhou City was calculated according to formula (3) (Fig. 5). The areas with a soil erodibility factor of 0.054-0.061 $t\cdot hm^2\cdot h/(hm^2\cdot MJ\cdot mm)$ are mainly distributed in the central and eastern regions, and the soil erodibility factor is 0.45-0.053 $t\cdot hm^2\cdot h/(hm^2\cdot MJ\cdot mm)$ areas are mainly distributed in the western, northwest and southern regions; the areas with a soil erodibility factor of 0.037-0.044 $t\cdot hm^2\cdot h/(hm^2\cdot MJ\cdot mm)$ are mainly distributed in parts of Beishan; soil can be The areas with an erodibility factor of 0.018-0.036 $t\cdot hm^2\cdot h/(hm^2\cdot MJ\cdot mm)$ are mainly distributed in the western part of Beishan.

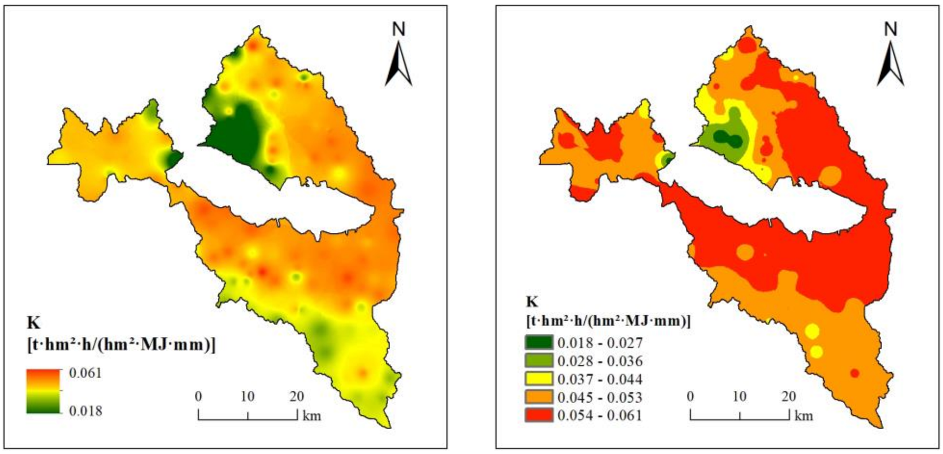

Fig.5 spatial distribution of soil erodibility factor K in the South and North Mountains of Lanzhou

(3) Calculation of LS value of slope length factor.

The slope length factor is the topographic factor, which determines the motion state and direction of surface runoff (Zingg,1940). The larger the slope is, and the longer the slope is, the greater the potential energy of surface runoff will be, which will have a stronger erosion effect on the soil. In this study, the slope and slope length factors are extracted by the formulas studied by McCool et al., (1989) and Liu Baoyuan et al., (2002). The calculation formulas of slope factors are as follows:

$$S=\begin{cases}10.8\cdot\sin\theta+0.03 & \theta<5\\ 16.8\cdot\sin\theta-0.50 & 5\le\theta<14\\ 21.91\cdot\sin\theta-0.90 & \theta<14\end{cases} \tag{4}$$

Where $\boldsymbol{S}$ is the slope factor (dimensionless), and $\boldsymbol{\theta}$ is the slope value (°), which can be extracted from DEM data.

The formula for calculating the slope length factor is as follows:

$$L=(\lambda / 22.13)^{\alpha} \tag{5}$$

$$\lambda = flowacc \times cellsize \tag{6}$$

$$\alpha = \beta / (1+\beta) \tag{7}$$

$$\beta = (\sin\theta / 0.089) / [3.0 \times (\sin\theta)^{0.8} + 0.56] \tag{8}$$

Among them, ***L*** is the slope length factor, and its value is the amount of soil erosion produced on the standard slope of 22.13m. The ***λ*** is the slope length, where ***flowacc*** is the catchment accumulation, ***cellsize*** is the size of the DEM data grid pixel, and ***α*** is the slope length, ***θ*** is the slope value, in units of (°).

The spatial distribution of the slope factor of the north and south mountains in Lanzhou (Fig.6) shows that the minimum value of the slope factor is 0, the maximum value is 58.98, the average value is 15.52, the minimum value of the slope factor is 0, the maximum value is 9.99, the average value is 4.76, the minimum value of the slope length factor is 0, the maximum value is 5.92, the average value is 2.22. The minimum value of the slope length factor is 0, the maximum value is 59.19, the average value is 12.20. The overall upper slope, slope factor, slope length factor and slope length factor are zonal distribution, and the slope length factor of the south mountain is obviously larger than that of the north mountain.

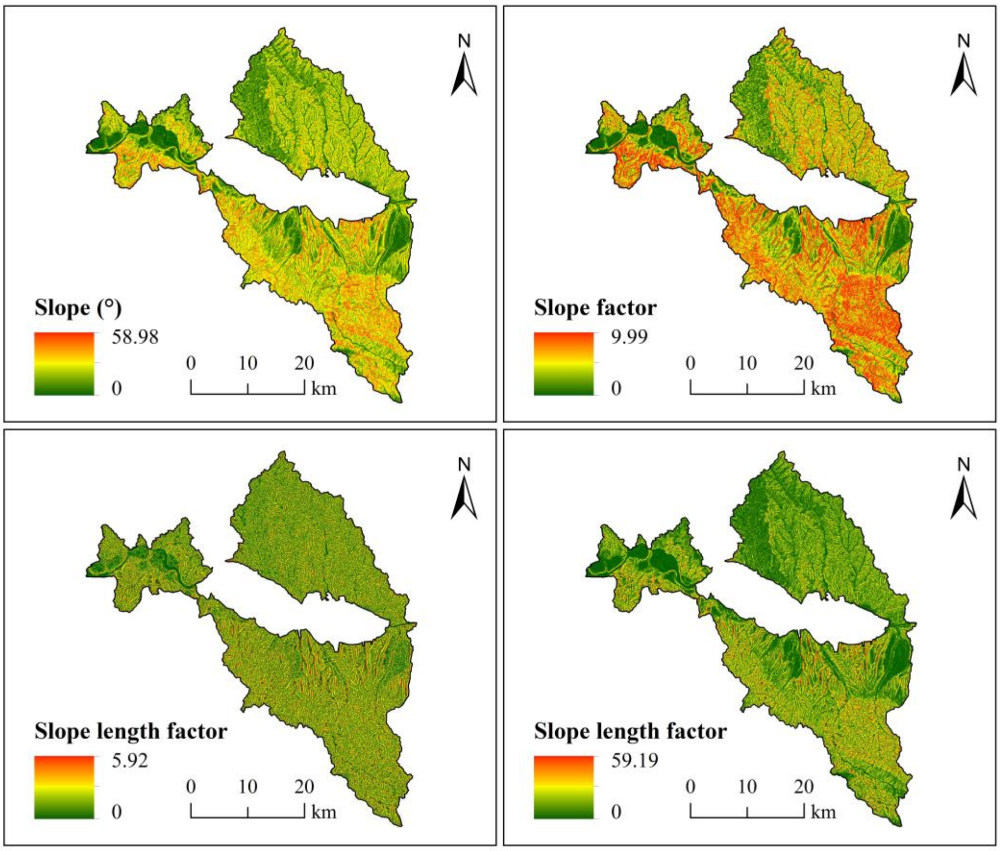

Fig.6 Spatial distribution of the gradient slope and slope length factor in the South and north of Lanzhou

(4) Determination of C value of vegetation cover and management factor

Vegetation can protect the surface soil and slow down the rate of soil erosion (Wang et al., 2018). NDVI is the most common data to calculate the C value of vegetation cover and management factor (Zha et al., 2015). The NDVI number 9 used in this study is derived from the Google Earth Engine cloud platform, and the formula proposed by VanderKnijff et al., (1999) is used to calculate the C value of vegetation cover and management factor. The formula is as follows:

$$C = \exp\left[-a \times \frac{NDVI}{b - NDVI}\right] \tag{9}$$

Among them, ***C*** is the vegetation cover and management factor (dimensionless); ***a*** and ***b*** are the parameters that determine the NDVI-C relationship curve. Through VanderKnijff experiments, it is found that the most appropriate values are a=2 and b=1. This method has been studied in China and achieved good results (Zha et al., 2015). According to the formula (9), if the C value is negative, the assignment is 0 for all negative values; if the C value is greater than 1, the assignment is 1 for all values greater than 1. The higher the C value, the worse the vegetation growth; on the contrary, the better the vegetation growth (Wang et al., 2018).

The average values of vegetation cover and management factors in the north and south mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018 were 0.34,0.43,0.56,0.50,0.40 and 0.57, respectively. Overall, the vegetation cover and management factor were the lowest in 1995 and the highest in 2018. The C value of the north mountain is obviously higher than that of the south mountain, indicating that the vegetation coverage of the north mountain is lower than that of the south mountain (Fig. 7).

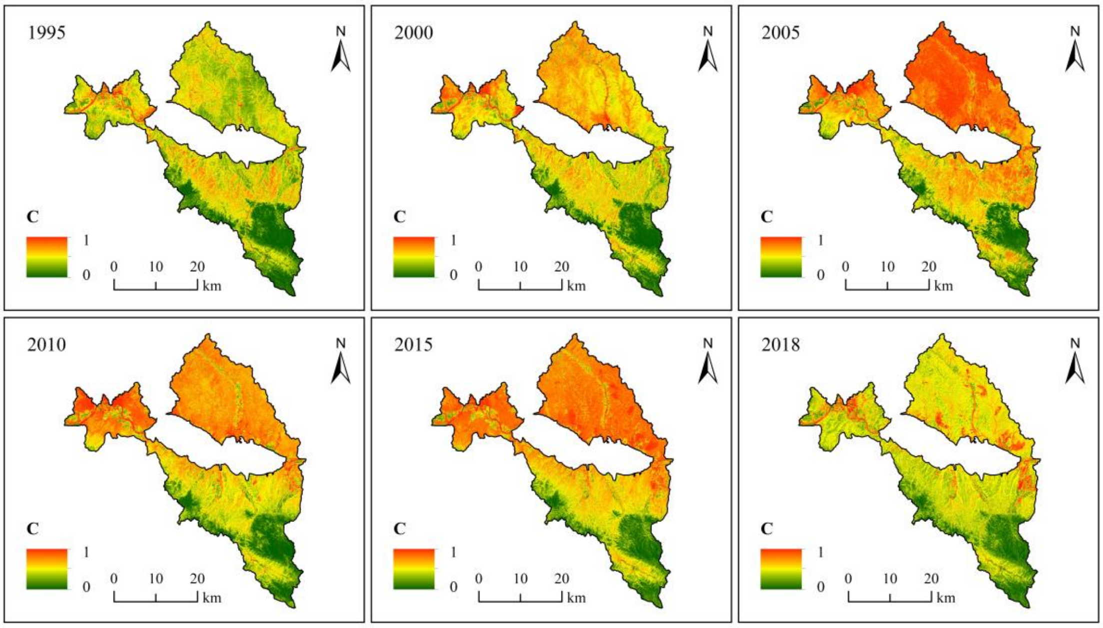

Fig.7 Spatial distribution of vegetation cover and management factors in the South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018

(5) Calculation of P-value of soil and water conservation measures

The factor of soil and water conservation and measures generally refers to the ratio of the amount of soil loss when certain engineering measures are taken in a certain area to the amount of soil loss without engineering measures under the same conditions. Its value ranges from 0 to 1, 0 means that soil erosion will not occur in this area, and 1 value means no soil and water conservation measures have been taken in this area (Lu et al., 2017). In this study, according to Table 1, the land use data of 1995, 2000, 2005, 2010, 2015 and 2018 were assigned, and the spatial distribution of P-value of soil and water conservation measure factors with 30m resolution was obtained (Fig. 8). As the land-use change in the north and south mountains of Lanzhou is not obvious, the spatial distribution of soil and water conservation measures in the north and south mountains is consistent, and the change is not obvious.

Tab. 1 P values of different land use types in the South and North Mountains of Lanzhou

Land-use type	Cultivated land	Forest land	Grassland	Water area	Construction land	Other

p	0.35	1.0	1.0	0.0	0.0	0.0

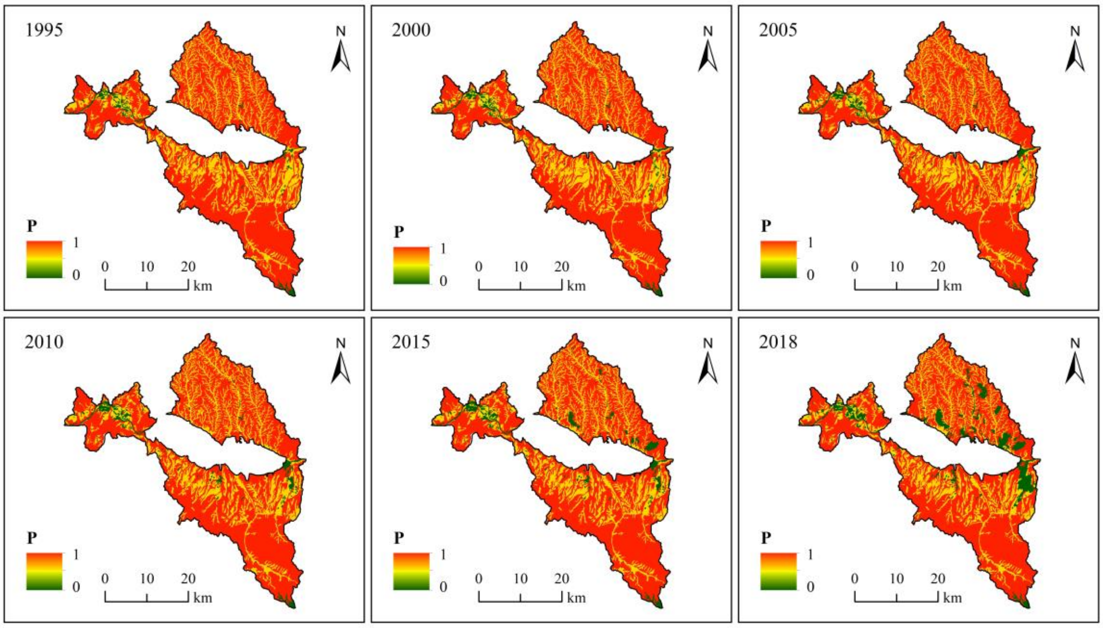

Fig.8 Spatial distribution of soil and water conservation measures factors in South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018

3 Analysis of dynamic changes of soil erosion in the north and south mountains of Lanzhou

3.1Spatio-temporal variation characteristics of soil erosion

According to the soil erosion modulus in different years, the average soil erosion modulus of 1995, 2000, 2005, 2010, 2015 and 2018 in the north and south mountains of Lanzhou are 16.59, 16.24, 17.16, 10.04, 15.77 and 25.83 t/(hm^2·a), respectively. The annual average soil erosion amount is 330.74 × 10^{4}t, 323.80 × 10^{4}t, 342.09 × 104t, 200.20 × 10^{4}t, 314.41 × 10^{4}t and 11515.14 × 10^{4}t. From 1995 to 2018, the average soil erosion modulus in the north and south mountains of Lanzhou was 15.95 t/(hm^2·a), soil erosion modulus was 25.83 t/(hm^2·a), appeared in 2018, and the minimum value was 10.04 t/(hm^2·a), appeared in 2010. In the past 24 years, the average soil erosion modulus showed a fluctuating downward trend (Fig. 9). According to the spatial distribution of soil erosion grades in the north and south mountains of Lanzhou (Fig. 10), the soil erosion intensity in the north and south mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018 is mainly slight erosion. It is mainly distributed in the northwest and southeast of the north and south mountains. The strong, extremely strong and severe soil erosion is mainly distributed in the middle of Nanshan Mountain and the middle of Beishan Mountain.

By using the spatial superposition analysis function of ArcGIS, the area and proportion of soil erosion intensity change in north and south mountains are obtained (Table 2): from 1995 to 2000,

the area with constant soil erosion intensity grade in Lanzhou is 1571.05 km^2, accounting for 78.79% of the total area, and the area of soil erosion grade decline is 207.66 km^2, accounting for 10.41% of the total area, which is mainly distributed in the middle of Beishan Mountain. The area with the increase of soil erosion grade is 215.37 km^2, accounting for 10.80% of the total area, which is mainly distributed in the middle of Nanshan Mountain. From 2000 to 2005, the area of constant soil erosion intensity in the north and south mountains of Lanzhou was 1627.29 km^2, accounting for 81.61% of the total area; the area of soil erosion grade decline was 150.55 km^2, accounting for 7.55% of the total area, mainly distributed in the western part of Nanshan; the area of soil erosion grade rising was 216.25 km^2, accounting for 10.84% of the total area, mainly distributed in the central and southern parts of Nanshan. From 2005 to 2010, the area with the same soil erosion intensity grade in the north and south mountains of Lanzhou was 1328.94 km^2, accounting for 66.64% of the total area; the area in which the soil erosion grade decreased was 645.64 km^2, accounting for 32.38% of the total area, and there was a large area distribution in both the north and south mountains; the area with the increase of soil erosion grade was 19.50 km^2, accounting for 0.98% of the total area. From 2010 to 2015, the area with the same soil erosion intensity grade in the north and south mountains of Lanzhou was 1386.15 km^2, accounting for 69.51% of the total area; the area in which the soil erosion grade decreased was 28.47 km^2, accounting for 1.43% of the total area; the area in which the soil erosion grade increased was 579.46 km^2, accounting for 29.06% of the total area; the soil erosion grade increased obviously, which was distributed in both the north and south mountains. From 2015 to 2018, the area with the same soil erosion intensity grade in the north and south mountains of Lanzhou was 868.62 km^2, accounting for 43.56% of the total area; the area in which the soil erosion grade decreased was 57.88 km^2, accounting for 2.90% of the total area; the area in which the soil erosion grade increased was 1067.59 km^2, accounting for 53.54% of the total area; the increase in soil erosion grade was more obvious, and there was a large area distribution in both the north and south mountains. From 1995 to 2018, the area with the same soil erosion intensity grade in the north and south mountains of Lanzhou was 915.73 km^2, accounting for 45.92% of the total area; the area in which the soil erosion grade decreased was 100.88 km^2, accounting for 5.06% of the total area; the area in which the soil erosion grade increased was 977.47 km^2, accounting for 49.02% of the total area. The grade of soil erosion has increased, and there is a large distribution in both the north and south mountains.

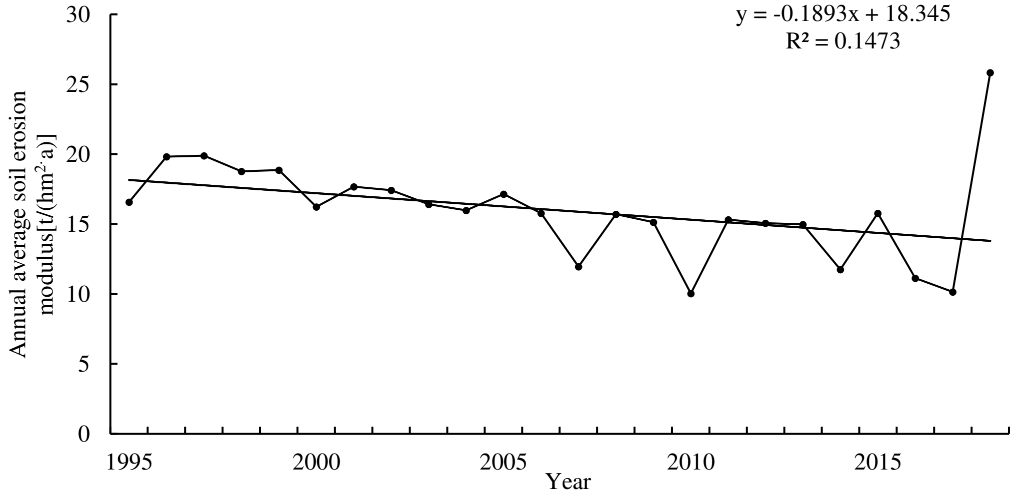

Fig.9 Time change of annual soil erosion modulus in the South and North Mountains of Lanzhou from 1995 to 2018

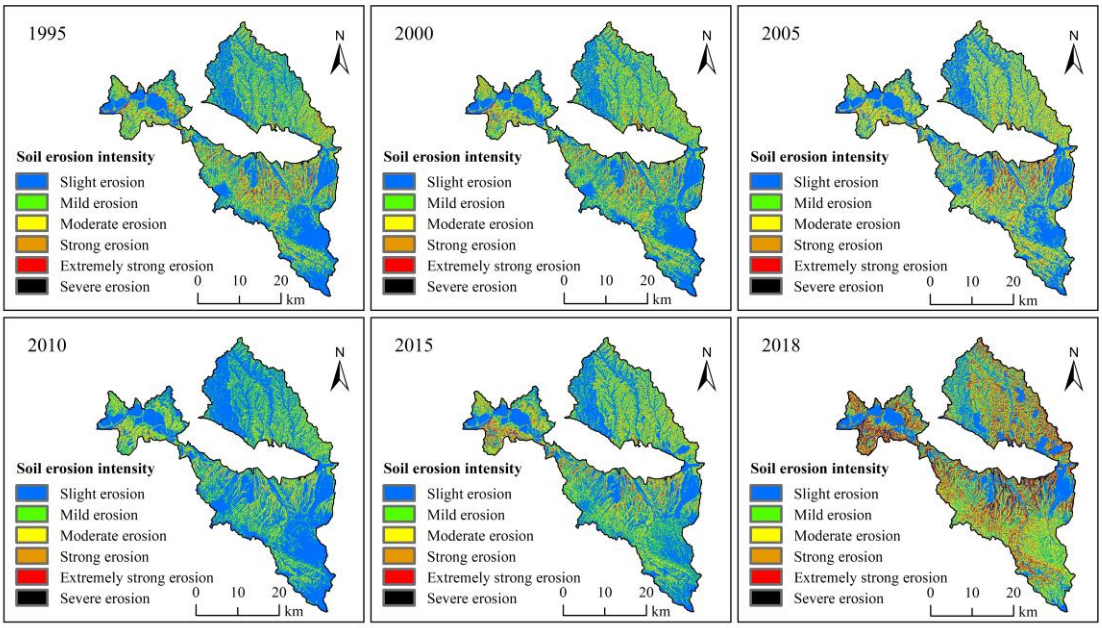

Fig.10 Spatial distribution of soil erosion intensity in the South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018

Tab. 2 Soil erosion intensity grade change area (km^2) and proportion (%) in the north and south mountains of Lanzhou.

Grade change	Lower		No change		Rise	
	Area	Proportion	Area	Proportion	Area	Proportion

1995-2000	207.66	10.41	1571.05	78.79	215.37	10.8
2000-2005	150.55	7.55	1627.29	81.61	216.25	10.84
2005-2010	645.64	32.38	1328.94	66.64	19.5	0.98
2010-2015	28.47	1.43	1386.15	69.51	579.46	29.06
2015-2018	57.88	2.9	868.62	43.56	1067.59	53.54
1995-2018	100.88	5.06	915.73	45.92	977.47	49.02

3.2 Area transfer characteristics of soil erosion intensity

Based on the statistical analysis of the data of different erosion intensity area, the transfer chord diagram of soil erosion intensity is obtained. From 1995 to 2000, the unchanged area of micro soil erosion was 1020.17 km^2, and the areas transferred to mild, moderate, strong and very strong were 79.58, 2.52, 0.07 and 0.01 km^2, respectively. The unchanged area of slight erosion was 279.41 km^2, and the areas of micro, moderate, strong and extremely strong transfer were 63.69, 78.10, 2.63 and 0.06 km^2, respectively. The unchanged area of moderate soil erosion was 186.28 km^2 and the areas transferred to micro, mild, strong, extremely strong and severe erosion were 4.24, 62.21, 40.88, 2.02 and 0.01 km^2, respectively. The unchanged area of strong soil erosion was 63.11 km^2, and the area of transfer to micro, mild, moderate, extremely strong and severe was 0.31, 4.37, 43.52, 9.31 and 0.03 km^2, respectively. The unchanged area of extremely strong soil erosion was 21.89 km^2, and the areas transferred to slight, mild, moderate, strong and severe were 0.03, 0.86, 3.82, 22.64 and 0.14 km^2, respectively. The unchanged area of severe soil erosion was 0.19 km^2, and the areas of transfer to mild, moderate, strong and extremely strong were 0.01, 0.06, 0.19 and 0.170 km^2, respectively. The stability rates of soil micro, mild, moderate, strong, extremely strong and severe erosion in 1995-2000 were 51.16%, 14.01%, 9.34%, 3.16%, 1.10% and 0.01%, respectively (Fig. 11a).

From 2000 to 2005, the unchanged area of micro soil erosion was 1008.99 km^2, and the areas of mild, moderate, strong and very strong transfer were 73.72, 5.46, 0.27 and 0.02 km^2, respectively. The unchanged area of slight soil erosion was 307.54 km^2, and the areas of slight, moderate, strong and extremely strong transfer were 51.65, 64.08, 3.01, 0.15 km^2, respectively. The unchanged area of moderate soil erosion was 215.41 km^2, and the areas of slight, mild, strong, extremely strong and severe transfer were 1.79, 49.36, 44.75, 2.99 and 0.11 km^2, respectively. The unchanged area of strong soil erosion was 73.50 km^2, and the areas of slight, mild, moderate, extremely strong and severe transfer were 0.21, 1.10, 33.60, 20.99 and 0.11 km^2, respectively. The unchanged area of extremely strong soil erosion was 21.75 km^2, and the areas of slight, mild, moderate, strong and severe soil erosion were 0.11, 0.06, 0.72, 11.67 and 0.69 km^2, respectively.

The unchanged area of severe soil erosion was 0.09 km^2, and the areas of strong and very strong soil erosion were 0.01 km^2 and 0.25 km^2, respectively. The stability rates of soil micro, mild, moderate, strong, extremely strong and severe erosion in 2000-2005 were 50.60%、15.42%、10.80%、3.69%、1.09% and 0.00% respectively (Fig. 11b).

From 2005 to 2010, the unchanged area of micro soil erosion was 1052.71 km^2, and the areas transferred to mild, moderate and strong erosion were 9.63, 0.41 and 0.01 km^2, respectively. The unchanged area of slight soil erosion was 174.28 km^2, and the areas transferred to micro, moderate and strong erosion were 250.43, 6.92 and 0.15 km^2, respectively. The unchanged area of moderate soil erosion was 86.00 km^2, and the area of transfer to micro, mild, strong and extremely strong soil erosion was 22.67, 208.37, 2.212 and 0.04 km^2, respectively. The unchanged area of strong soil erosion was 14.55 km^2, and the area of transfer to micro, mild, moderate and extremely strong soil erosion was 1.39, 19.23, 97.85 and 0.18 km^2, respectively. The unchanged area of extremely strong soil erosion was 1.37 km^2, and the areas transferred to micro, mild, moderate and strong erosion were 0.09, 1.01, 20.57 and 23.12 km^2, respectively. The unchanged areas of severe soil erosion to moderate, strong and extremely strong erosion were 0.03, 0.69, 0.19 km^2, respectively. The stability rates of soil micro, mild, moderate, strong, extremely strong and severe erosion in 2005-2010 were 52.79%, 8.74%, 4.31%, 0.73%, 0.07% and 0.005%, respectively (Fig. 11c).

From 2010 to 2015, the constant area of micro soil erosion was 1073.06 km^2, and the areas of mild, moderate, strong and extremely strong transfer were 242.64, 11.11, 0.41 and 0.07 km^2, respectively. The unchanged area of slight soil erosion was 203.33 km^2, and the areas of slight, moderate, strong and extremely strong transfer were17.01, 186.57, 5.07 and 0.53 km^2, respectively. The unchanged area of moderate soil erosion was 94.74 km^2, and the areas of slight, mild, strong and extremely strong soil erosion were 3.24,6.84,101.94 and 5.02 km^2, respectively. The unchanged area of strong soil erosion was 13.33 km^2, and the areas of slight, mild, moderate and extremely strong soil erosion were 0.26,0.18,0.87 and 26.09 km^2, respectively. The unchanged area of extremely strong soil erosion was 1.68 km^2, and the areas of micro, mild, moderate, strong and severe transfer were 0.01, 0.01, 0.03, 0.04 and 0.02 km^2, respectively. The stability rates of soil micro, mild, moderate, strong, extremely strong and severe erosion in 2010-2015 were 53.81%, 10.20%, 4.75%, 0.67%, 0.08% and 0.005%, respectively (Fig. 11d).

From 2015 to 2018, the unchanged area of micro soil erosion was 753.12 km^2, and the area of transfer to mild, moderate, strong, extremely strong and violent was 250.79, 73.16,13.18,2.67 and 0.65 km^2, respectively. From 2015 to 2018, the unchanged area of mild soil erosion was 69.55 km^2, and the areas of slight, moderate, strong, extremely strong and severe transfer were 24.50,237.13, 93.37, 25.77 and 2.67 km^2, respectively. The unchanged area of moderate soil erosion was 33.73 km^2, and the area of transfer to micro, light, strong, extremely strong and severe erosion was 10.78,

11.29, 111.48, 120.77 and 5.29 km^2, respectively. The unchanged area of strong soil erosion was 6.87 km^2, and the area to micro, mild, moderate, extremely strong and severe transfer was 4.09, 0.09, 5.41, 71.59 and 32.74 km^2, respectively. The unchanged area of extremely strong soil erosion was 5.33 km^2, and the area of transfer to micro, moderate, strong and severe erosion was 0.74, 0.20, 0.79 and 26.31 km^2, respectively. The unchanged area of severe soil erosion was 0.02 km^2. The stability rates of soil micro, mild, moderate, strong, extremely strong and severe erosion in 2015-2018 were 37.77%, 3.49%, 1.69%, 0.34%, 0.27% and 0.005%, respectively (Fig. 11e).

From 1995 to 2018, the unchanged area of micro soil erosion was 735.92 km^2, and the areas transferred to mild, moderate, strong, extremely strong and severe erosion were 37.85, 13.43, 4.42, 1.49 and 0.13 km^2, respectively. The unchanged area of slight soil erosion was 95.44 km^2, and the areas of slight, moderate, strong and extremely strong transfer were 215.14, 21.42, 2.52 and 15 km^2, respectively. The unchanged area of moderate soil erosion was 54.64 km^2, and the areas transferred to micro, mild, strong, extremely strong and severe erosion were 115.44, 164.35, 12.29, 2.87 and 0.02 km^2, respectively. The unchanged area of strong erosion was 15.71 km^2, and the areas of micro, mild, moderate, extremely strong and severe transfer were 29.72, 87.66, 88.63, 3.83 and 0.13 km^2, respectively. The unchanged area of extremely strong soil erosion was 15.44 km^2, and the areas of slight, mild, moderate, strong and severe erosion were 5.64, 38.24, 106.20, 60.35 and 0.28 km^2, respectively. The unchanged area of severe soil erosion was 1.58 km^2, and the areas of slight, mild, moderate, strong and extremely strong soil erosion were 0.50, 3.36, 11.32, 25.38 and 25.56 km^2, respectively. The stability rates of soil micro, mild, moderate, strong, extremely strong and severe erosion in 1995-2018 were 36.91%, 4.64%, 2.74%, 0.79%, 0.77% and 0.08%, respectively (Fig. 11f).

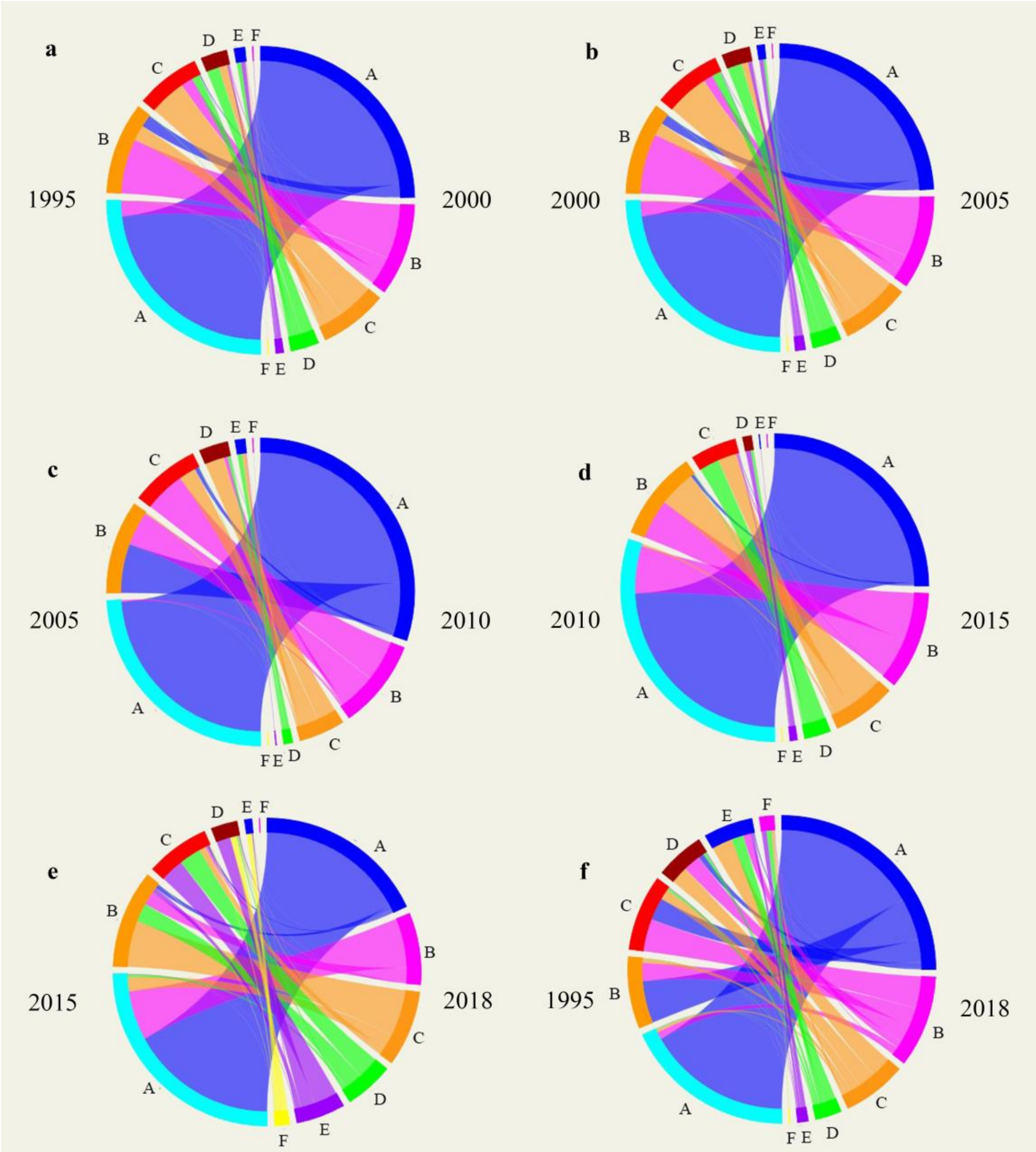

Fig.11 Chordal graph of soil erosion intensity in South and North Mountains of Lanzhou from 1995 to 2018（Note: a: slight erosion; B: mild erosion; C: moderate erosion; D: strong erosion; E: extremely strong erosion; F: severe erosion)

3.3 Characteristics of soil erosion under different environmental factors

3.3.1 Characteristics of soil erosion at different elevations

The soil erosion modulus in 1995, 2000, 2005, 2010, 2015 and 2018 was superimposed and analyzed according to different elevations, and the average soil erosion modulus at different elevations was obtained (Table 3). It can be seen from the table that the soil erosion modulus first

increases and then decreases with the increase of altitude, at the height of 1494-1800m, the slope length factor is lower, so the soil erosion modulus is lower; at the height of 1800-2100m, there are more gullies, and the slope length factor is high, coupled with human interference, the soil erosion modulus is the largest. 2100-2400m, 2400-2700m, 2700-3000m, 3000-3300m and 3300-3625m, with the increase of altitude, the growth of vegetation is better, the role of vegetation makes the vegetation cover and management factors lower, coupled with the reduction of human activities, the degree of soil intervention is low, so the average soil erosion modulus decreases with altitude.

Tab.3 Modulus of soil erosion in different years at different altitudes in the South and North Mountains of Lanzhou (unit: t/(hm2·a))

Elevation（m）	1995	2000	2005	2010	2015	2018	Average value
1494-1800	15.05	15.40	15.35	9.92	15.11	31.86	17.11
1800-2100	20.82	19.73	20.44	12.00	19.03	41.21	22.21
2100-2400	18.21	16.58	17.95	9.48	15.07	40.28	19.59
2400-2700	10.36	11.25	14.51	6.98	11.13	32.45	14.45
2700-3000	6.81	7.66	11.03	4.88	8.41	24.02	10.47
3000-3300	2.92	3.95	8.20	3.07	6.52	19.35	7.33
3300-3625	1.26	1.83	3.46	1.56	2.60	6.73	2.91

3.3.2 Characteristics of soil erosion under different slopes

The soil erosion modulus in 1995, 2000, 2005, 2010, 2015 and 2018 was analyzed according to different slope grades, and the average soil erosion modulus under different slope was obtained (Table 4). On the whole, the average soil erosion modulus under 0-5°, 5-8°, 8-15°, 15-25°, 25-35°and > 35°slopes were 4.27, 7.32, 14.43, 24.14, 32.75 and 38.20 t/(hm^2·a), respectively. The average soil erosion modulus is the highest on the slope of > 35 °and the lowest on the slope of 0-5 °. The 17 modulus of soil erosion increases with the increase of slope. This is mainly because the higher the slope is, the greater the slope factor is, and the rapid erosion of the runoff velocity caused by surface water is serious.

Tab.4 Modulus of soil erosion in different years under different slopes in the South and North Mountains of Lanzhou (unit: t/(hm2·a))

Slope	1995	2000	2005	2010	2015	2018	Average value
0-5°	4.19	3.85	3.82	2.20	3.47	8.08	4.27
5-8°	7.09	6.65	6.62	3.82	5.98	13.74	7.32
8-15°	13.55	13.07	13.28	7.66	11.94	27.10	14.43
15-25°	21.40	21.13	22.32	13.08	20.45	46.46	24.14
25-35°	27.44	27.31	30.17	17.95	28.58	65.04	32.75
35-60°	31.46	31.07	35.47	20.90	33.40	76.90	38.20

3.3.3 Characteristics of soil erosion under different land-use types

Based on the regional statistical analysis of land use classification and soil erosion modulus in 1995, 2000, 2005, 2010, 2015 and 2018, the average soil erosion modulus under different land-use types was obtained (Table 5). On the whole, the average soil erosion modulus of grassland and woodland is larger, which is 24.76 t/ (hm^2·a) and 23.43 t/ (hm^2·a),), respectively. The average soil erosion modulus of cultivated land is 7.48 t/ (hm^2·a),), which is the smallest, which is 0.27 t/ (hm^2·a). Although grassland and woodland are covered by vegetation, grassland and woodland are relatively high above sea level, generally distributed in areas with high mountains and steep slopes, and soil erosion is more serious under the action of running water and gravity.

Tab.5 Modulus of soil erosion in different years under different land-use types in the South and North Mountains of Lanzhou (unit: t/(hm2·a))

Land-use type	1995	2000	2005	2010	2015	2018	Average value
Cultivated land	7.51	6.87	6.83	3.71	5.71	14.26	7.48
Grassland	21.12	22.37	22.42	13.30	21.09	48.25	24.76
Woodland	19.31	20.87	20.97	11.52	19.38	48.53	23.43
Water area	0.32	0.24	0.13	0.11	0.23	0.57	0.27
Construction land	0.47	0.37	0.32	0.19	0.22	0.60	0.36

Unused land	1.18	1.20	1.32	0.58	0.48	2.68	1.24

3.3.4 Characteristics of soil erosion under different vegetation coverage

Based on the regional statistical analysis of soil erosion modulus in 1995, 2000, 2005, 2010, 2015 and 2018 according to different vegetation coverage, the average soil erosion modulus under different land-use types was obtained (Table 6). On the whole, the soil erosion modulus is the largest under low mulch. Except for bare land, the average soil erosion modulus decreases with the increase of vegetation coverage. The rise of vegetation coverage will reduce Rain Water's splashing and running water scouring. The roots of vegetation will maintain the soil and play a role in slowing down soil erosion. The average soil erosion modulus of bare land ranks third, mainly because according to the vegetation coverage of less than 10%, generally mainly construction land and unused land, construction land is generally cement hardened and difficult to erode; unused land generally has poor soil texture and relatively weak erosion.

Tab.6 Modulus of soil erosion in different years under different vegetation coverage in the South and North Mountains of Lanzhou (unit: t/(hm^2·a))

Vegetation coverage	1995	2000	2005	2010	2015	2018	Average value
Bare land	21.67	17.29	16.52	11.31	19.66	21.05	15.50
Low vegetation cover	21.21	19.70	21.90	12.92	18.78	43.90	20.06
Medium and low vegetation cover	19.03	19.71	20.82	11.12	15.48	44.21	19.05
Medium vegetation cover	14.42	12.68	16.60	7.58	11.19	38.34	14.97
Medium and high vegetation cover	9.19	7.88	12.35	5.51	9.55	31.47	11.56
High vegetation cover	3.36	3.16	5.16	2.73	7.18	21.64	7.03

3.3.5 Characteristics of soil erosion inside and outside the scope of Environmental Greening Project

Based on the regional statistics of soil erosion modulus inside and outside the scope of environmental greening project in the north and south mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018, the average soil erosion modulus inside and outside the scope of environmental greening project was obtained (Table 7). And the average area of different soil erosion intensity inside and outside the scope of environmental greening project (Table 8). In order to make the data comparable, the Shifogou National Forest Park in the north and south mountains

of Lanzhou is divided into the environmental greening project.

The average soil erosion modulus inside and outside the scope of the environmental greening project is 21.27 and 23.56 t/(hm^2·a), respectively, and environmental greening project is larger than that within the environmental greening project. The area of soil micro erosion inside and outside the greening area is the largest, accounting for 21.60% and 32.28% of the total area of 430.76 km^2 and 643.68 km^2, respectively, followed by light erosion, with an area of 166.40 km^2 and 245.11 km^2, accounting for 8.34% and 12.29%, respectively, and the area of moderate soil erosion is 132.88 km^2 and 163.25 km^2, accounting for 6.66% and 8.19% of the total area, respectively. The area of strong soil erosion was 65.28 km^2 and 62.60 km^2, accounting for 3.27% and 3.14% of the total area respectively; the area of extremely strong soil erosion was 43.61 km^2 and 28.68 km^2, accounting for 2.19% and 1.44% of the total area respectively; and the area of severe soil erosion was 7.72 km^2 and 4.11 km^2, accounting for 0.39% and 0.21% of the total area, respectively. Inside and outside the greening area, the area of soil erosion intensity from large to small is slight, mild, moderate, strong, extremely strong and severe.

Table.7 Modulus of soil erosion in different years under green and no green areas in the South and North Mountains of Lanzhou (unit: t/(hm^2·a))

Range	1995	2000	2005	2010	2015	2018	Average value
Within the greening area	18.81	18.55	19.74	11.98	18.36	40.19	21.27
Outside the greening area	22.28	21.79	22.19	15.29	20.57	39.23	23.56

Table.8 Average area of soil erosion intensity under green and no green areas of South and North Mountains in Lanzhou (unit: km^2)

Range	Slight	Mild	Moderate	Strong	Extremely strong	Violent
Within the greening area	430.76	166.40	132.88	65.28	43.61	7.72
Outside the greening area	643.68	245.11	163.25	62.60	28.68	4.11

4 Conclusion

(1) The study of soil erosion factors shows that the average precipitation erosivity factors of the north and south mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018 are 110.06, 83.20,71.09,46.68,56.97 and 198.61MJ·mm/(hm^2·h), respectively. Spatially, the precipitation erosivity of the north and south mountains decreased from southeast to northwest in 1995, 2000, 2005 and 2010, and decreased from west to east in 2015 and 2018.

(2) The analysis of the temporal and spatial variation of soil erosion shows that the average soil erosion modulus of the north and south mountains of Lanzhou fluctuates and decreases from 1995 to 2018. The intensity of soil erosion in 1995, 2000, 2005, 2010, 2015 and 2018 is mainly slight erosion, which is mainly distributed in the northwest and southeast of the north and south mountains. Strong, extremely strong and severe soil erosion is mainly distributed in the middle of Nanshan Mountain and a small amount in the middle of Beishan Mountain.

(3) The study on the characteristics of soil erosion under different environmental factors shows that the soil erosion modulus of the north and south mountains of Lanzhou increases at first and then decreases with the increase of height, and increases with the increase of slope and decreases with the increase of vegetation coverage. among the land use types, the average soil erosion modulus of grassland and woodland is larger, and that of water area is the lowest. The soil erosion modulus in the greening range is lower than that outside the greening range, which is mainly the result of the joint influence of precipitation, soil and vegetation.

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Figures

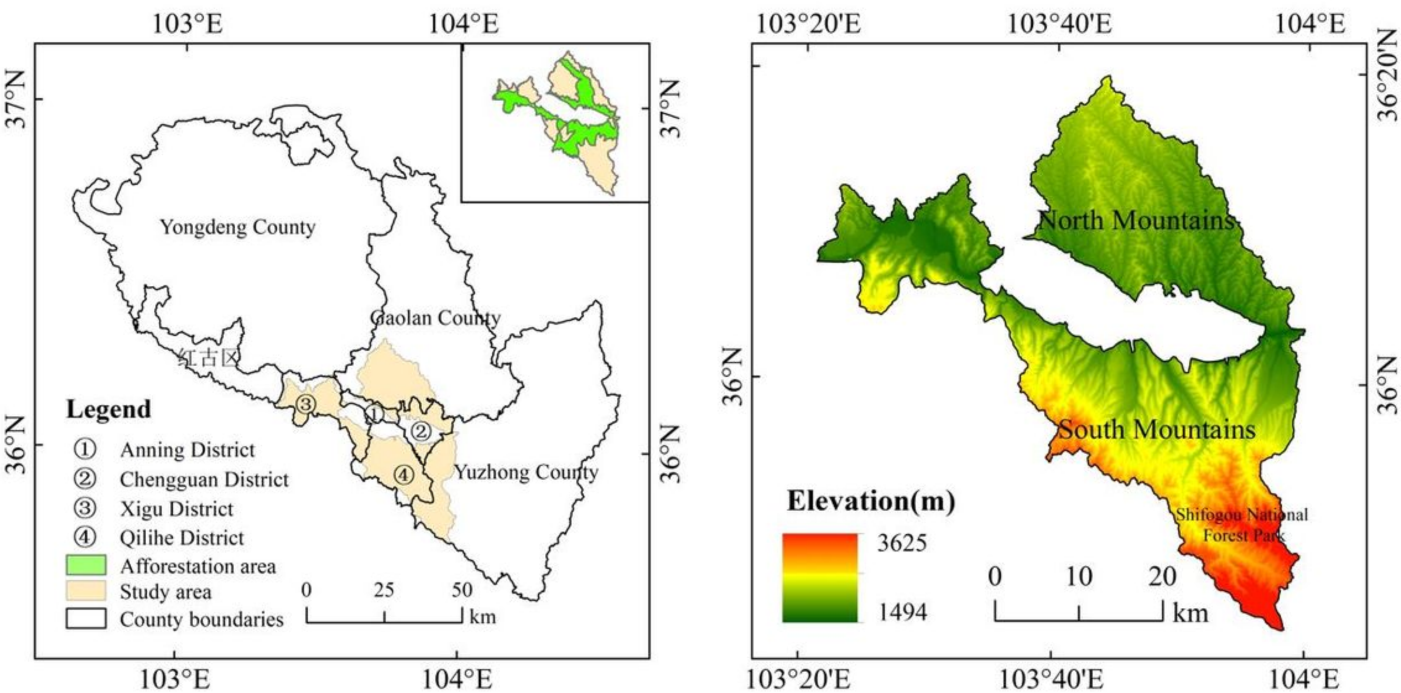

Figure 1

Overview of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

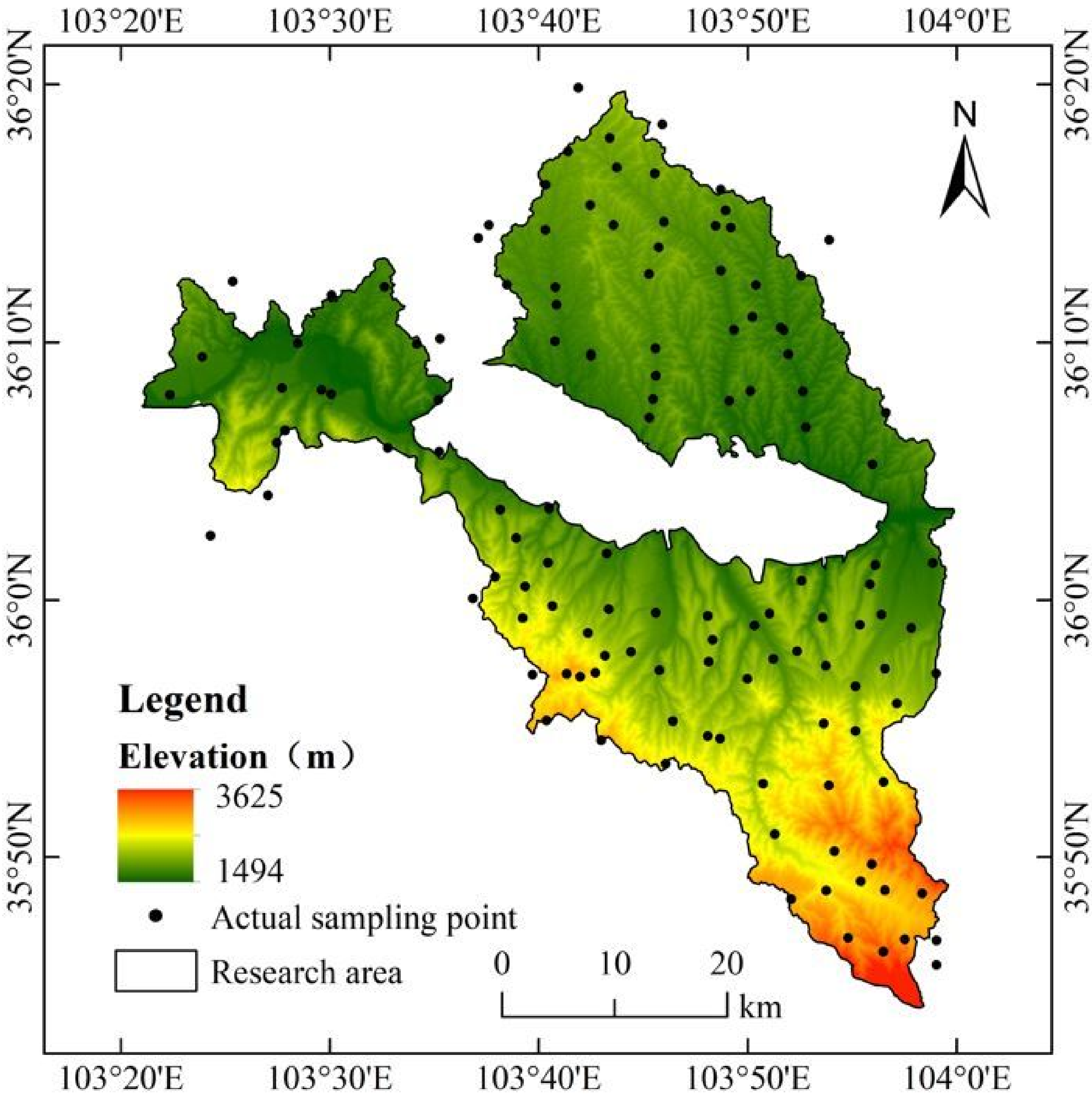

Figure 2

Distribution of soil sampling points. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

Photos of soil sampling and indoor soil experiment

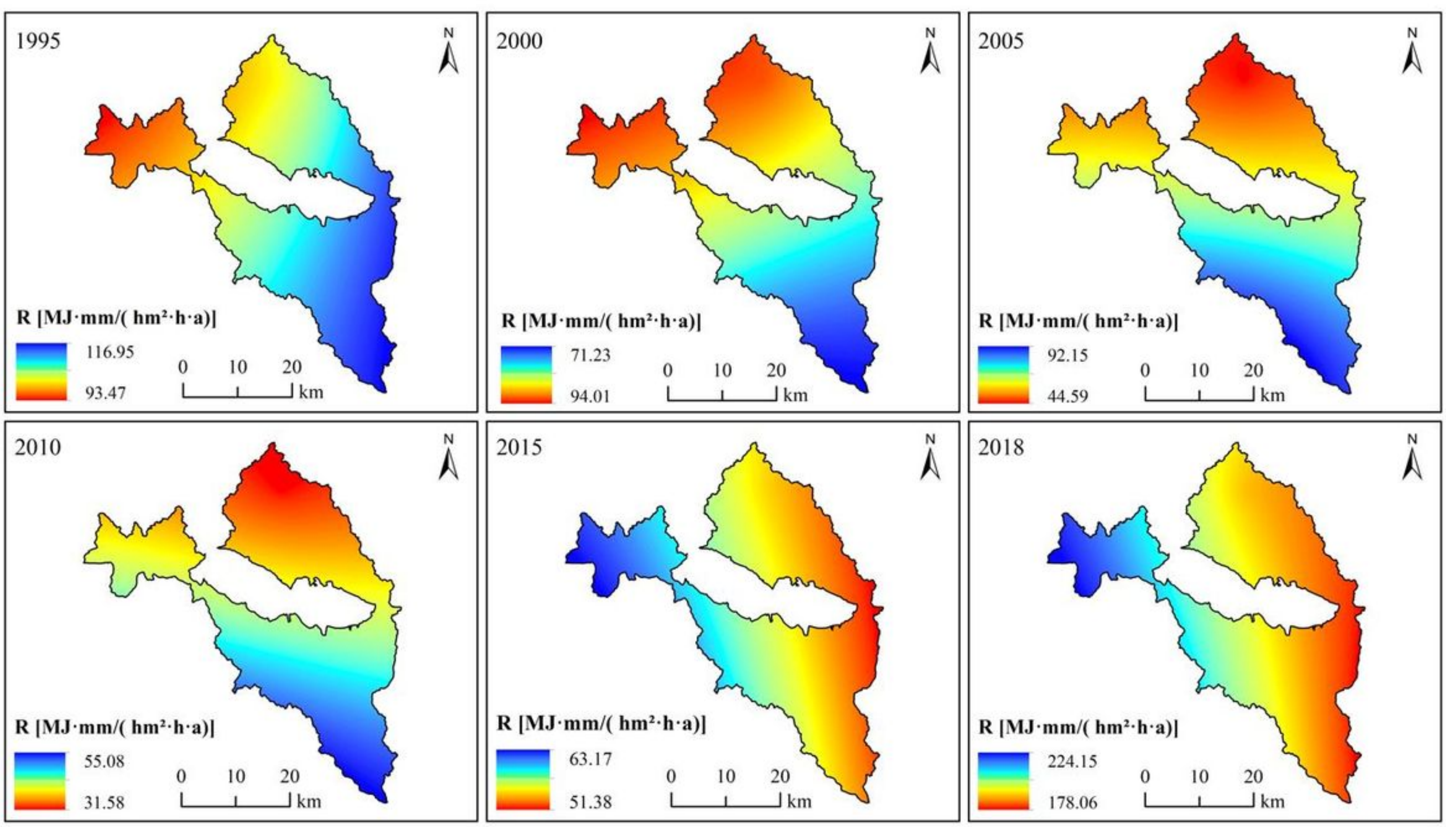

Figure 4

Spatial distribution of rainfall erosivity in the South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

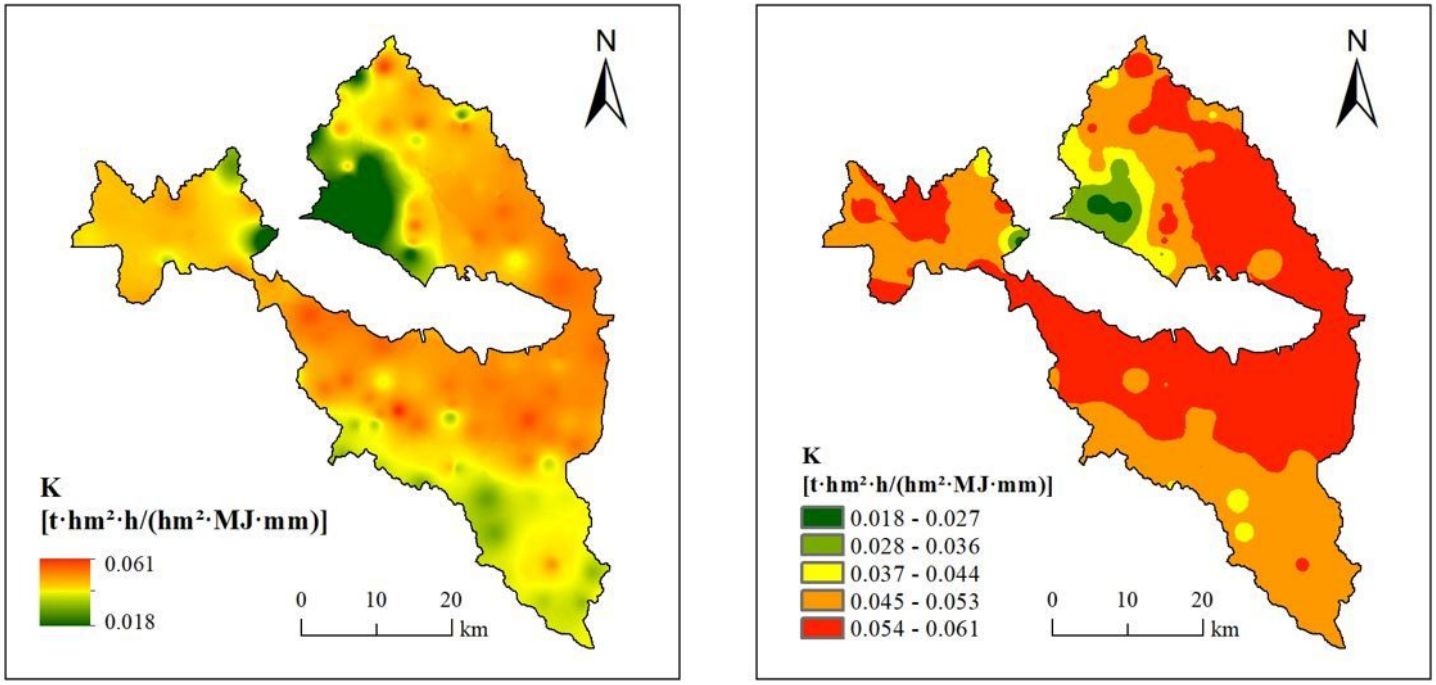

Figure 5

spatial distribution of soil erodibility factor K in the South and North Mountains of Lanzhou. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

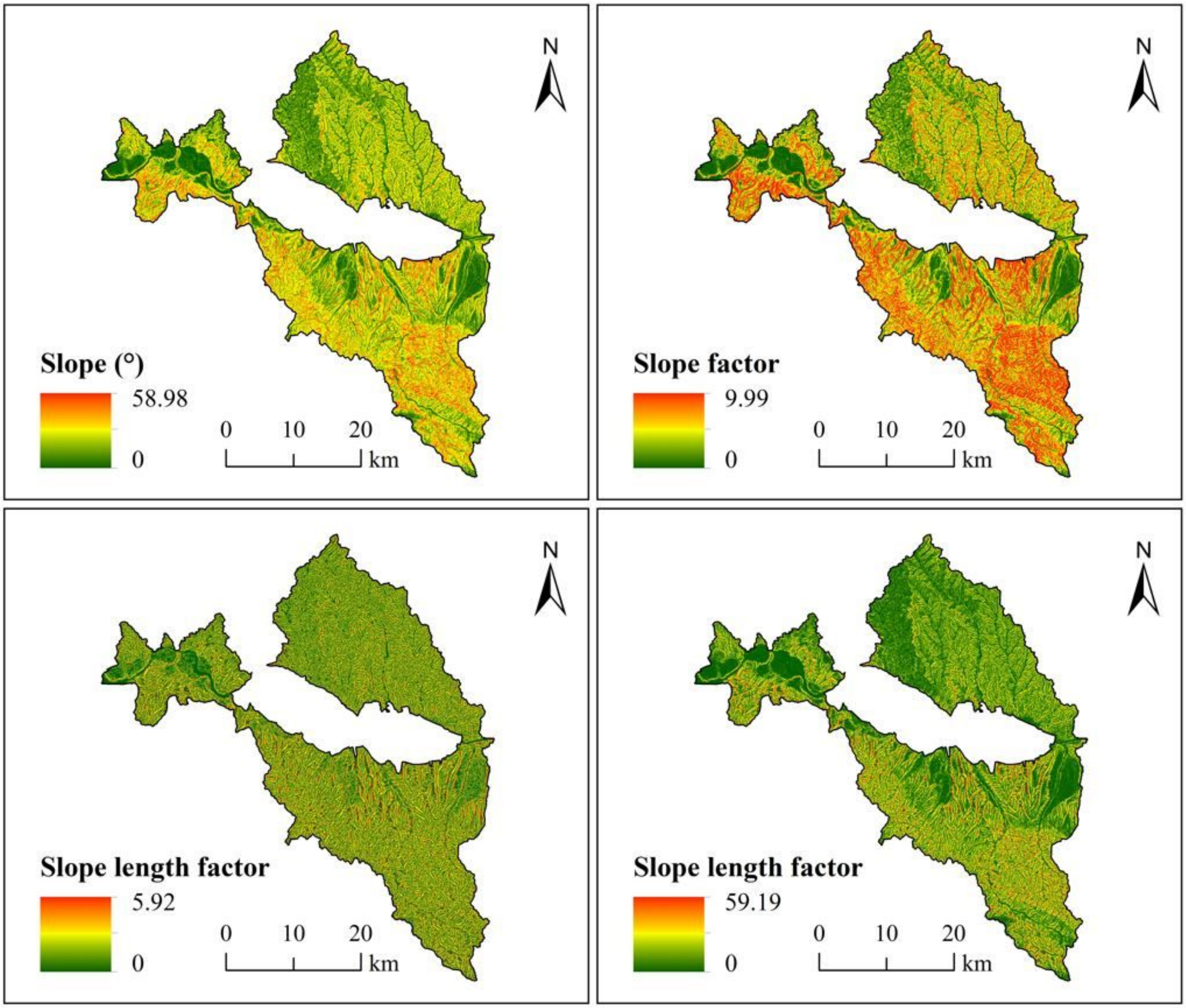

Figure 6

Spatial distribution of the gradient slope and slope length factor in the South and north of Lanzhou. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

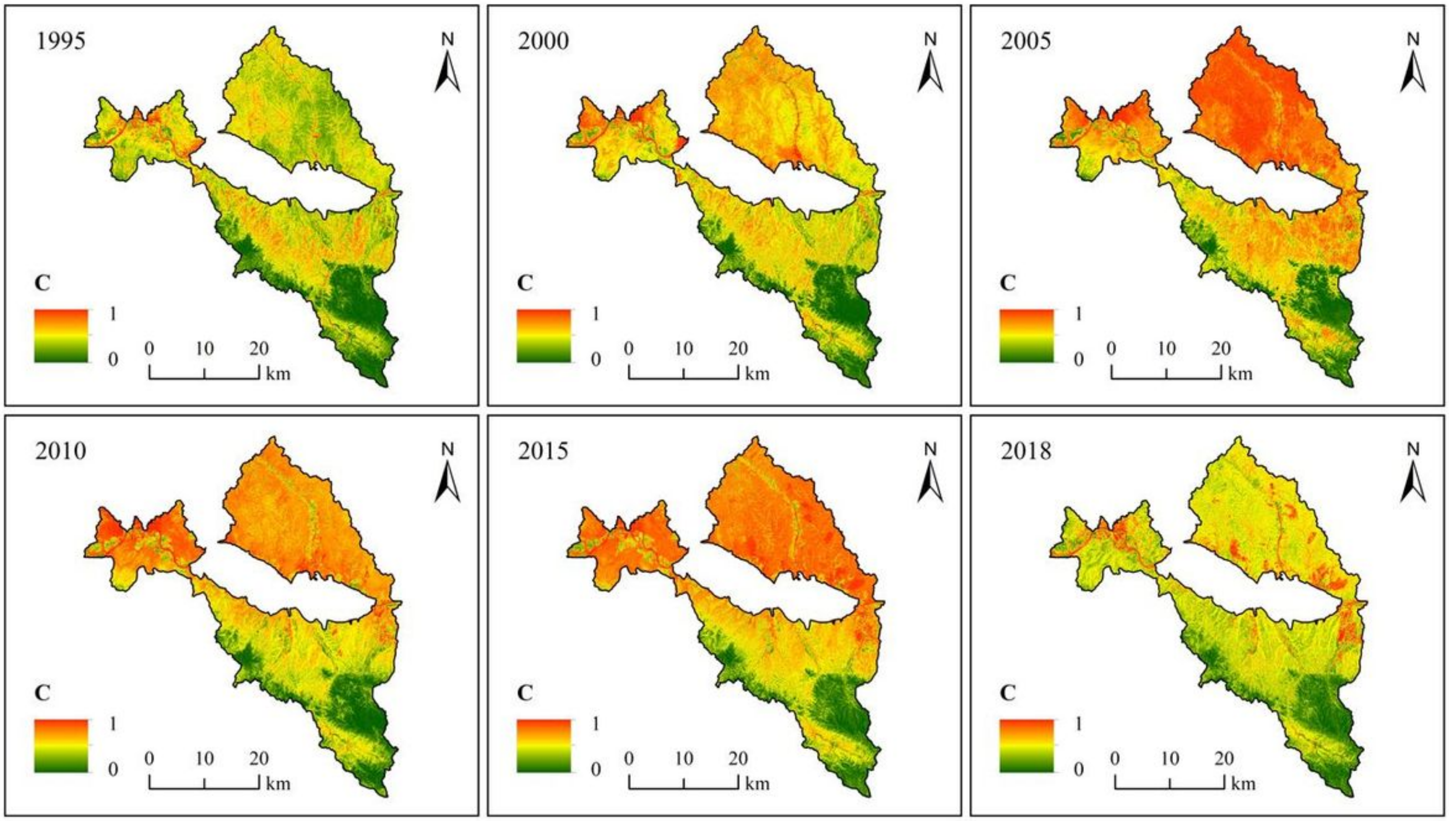

Figure 7

Spatial distribution of vegetation cover and management factors in the South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

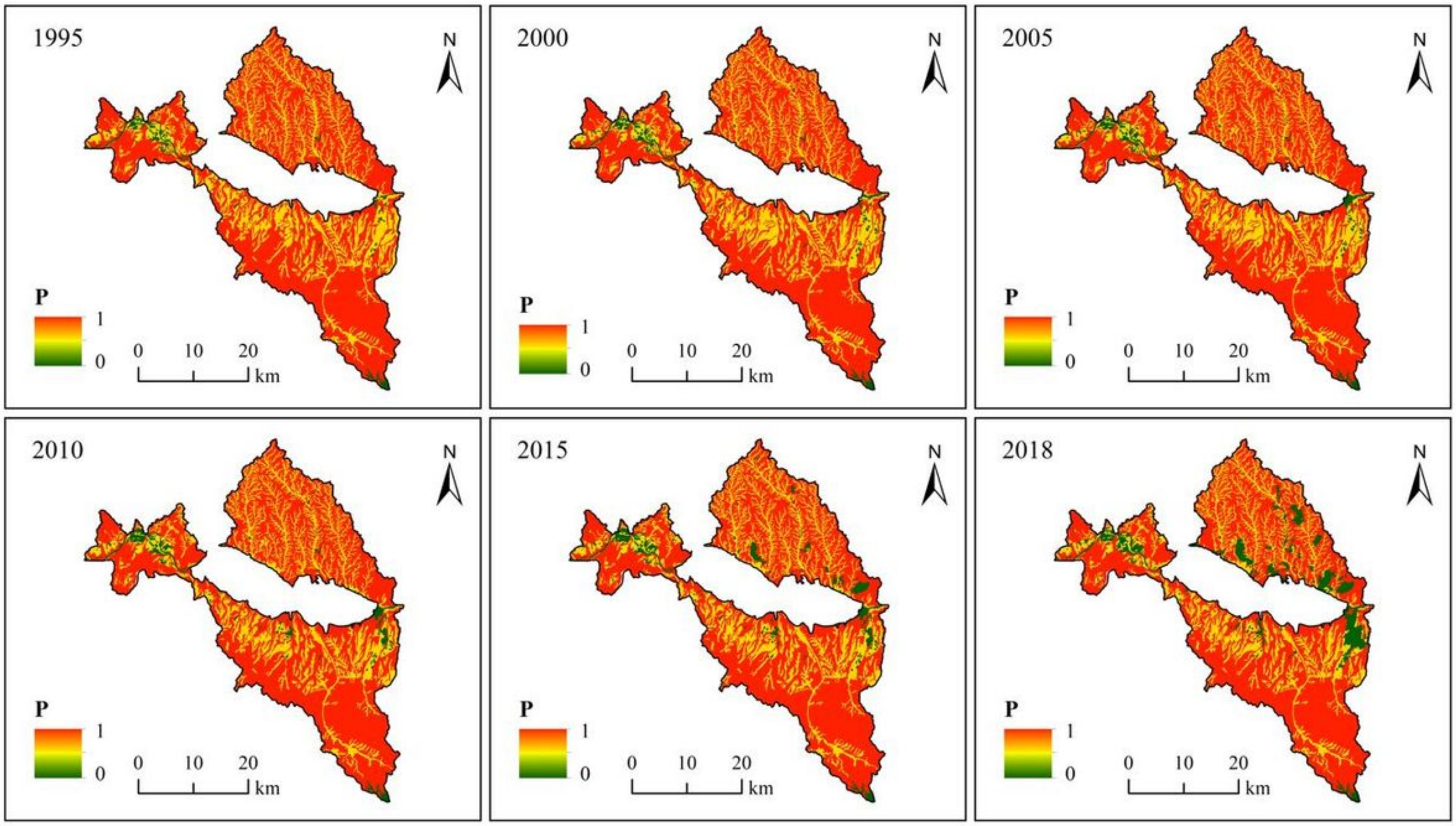

Figure 8

Spatial distribution of soil and water conservation measures factors in South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

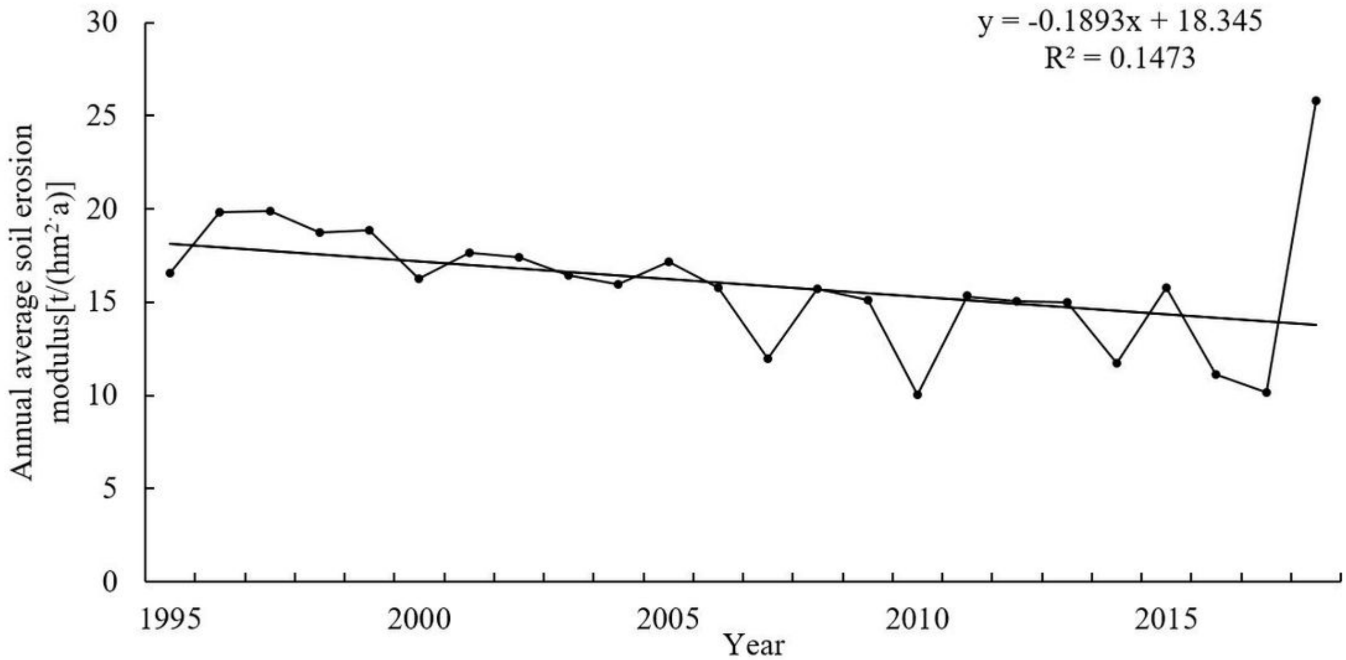

Figure 9

Time change of annual soil erosion modulus in the South and North Mountains of Lanzhou from 1995 to 2018

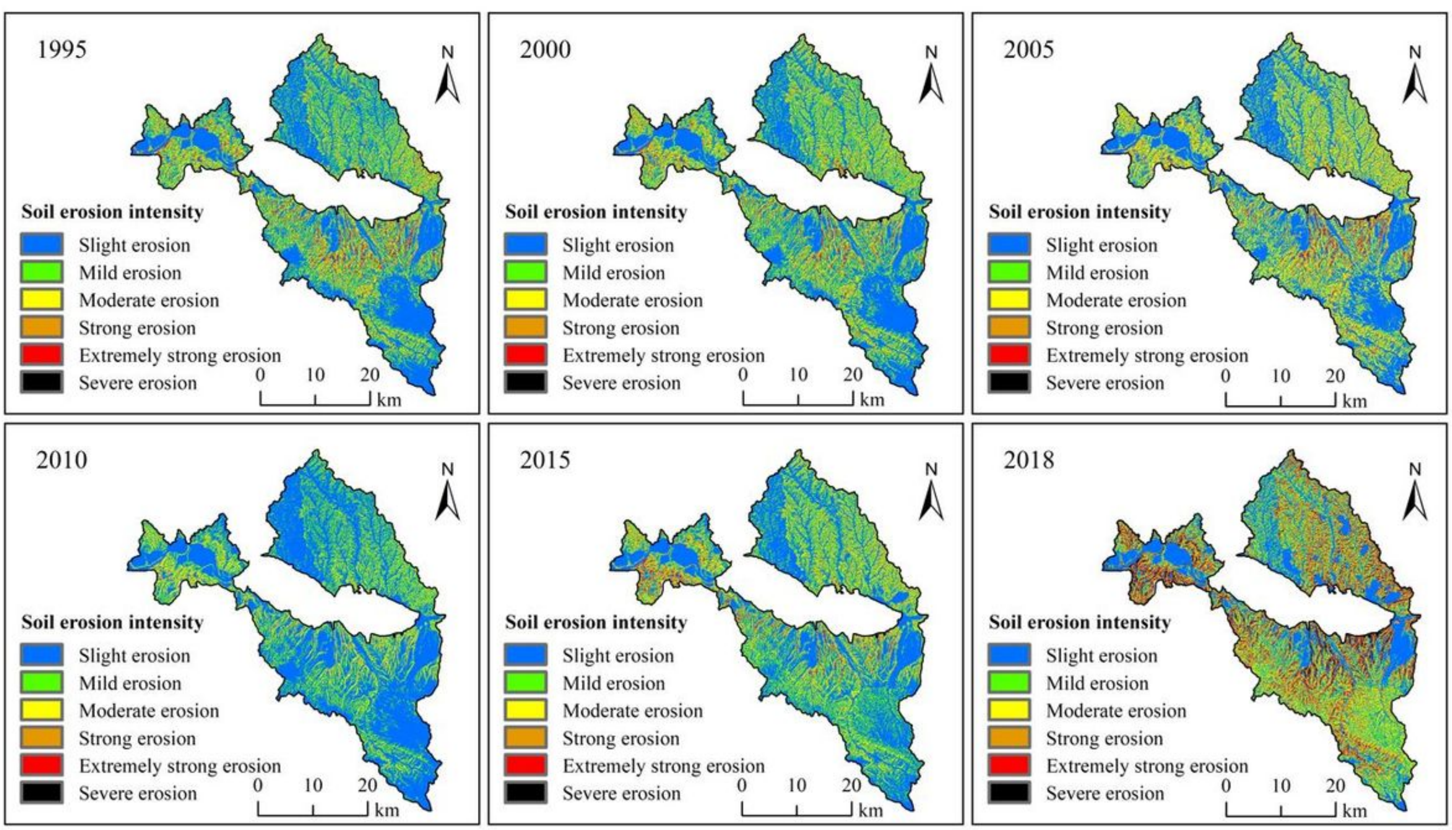

Figure 10

Spatial distribution of soil erosion intensity in the South and North Mountains of Lanzhou in 1995, 2000, 2005, 2010, 2015 and 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

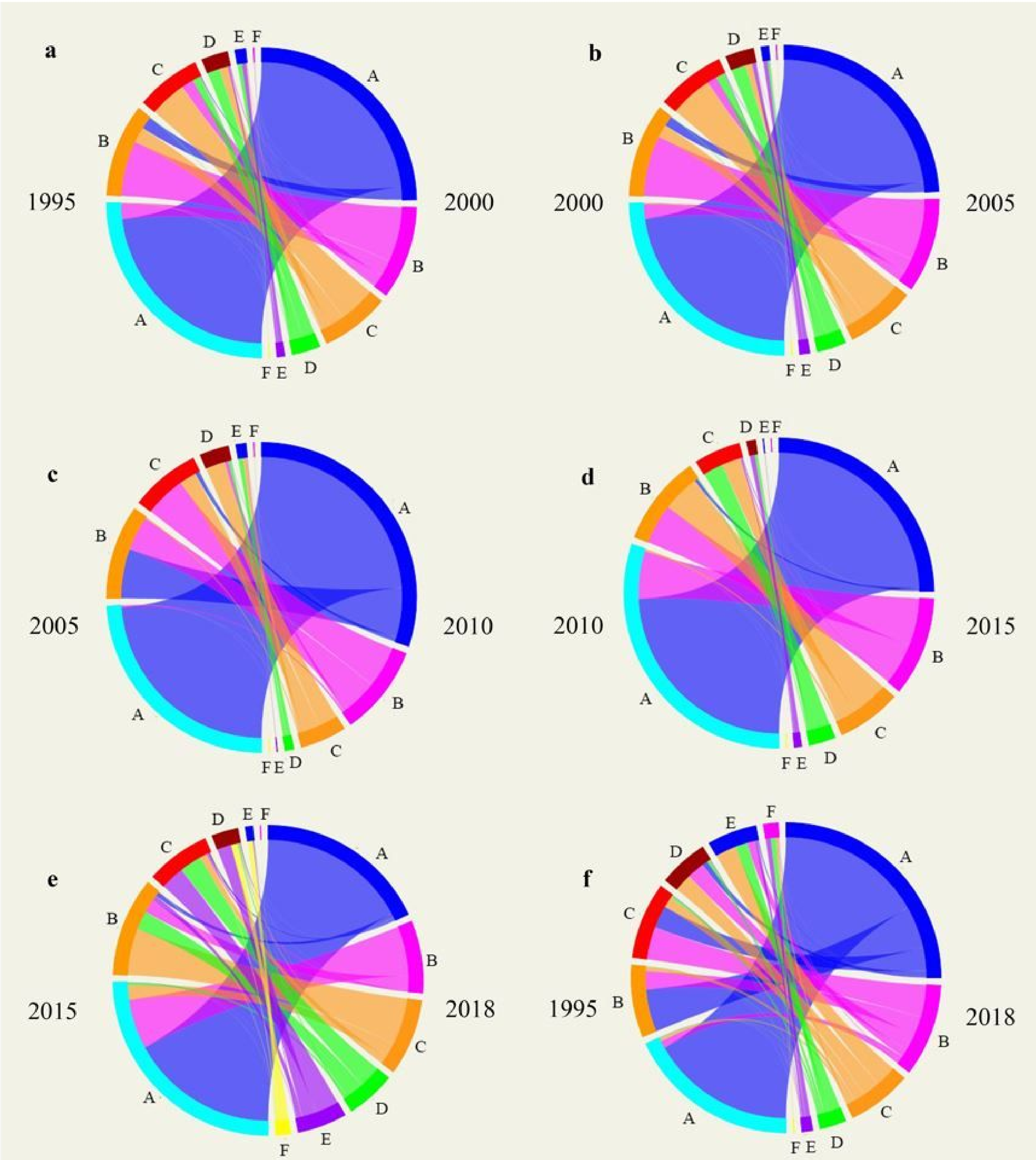

Figure 11

Chordal graph of soil erosion intensity in South and North Mountains of Lanzhou from 1995 to 2018 (Note: a: slight erosion; B: mild erosion; C: moderate erosion; D: strong erosion; E: extremely strong erosion; F: severe erosion)

Supplementary Files

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