Quantitative Evaluation of Soil and Water Loss in Black Soil Based on RS and GIS

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Abstract: With the development of society, people are making more and more intensive use of the land on which they live. However, natural resources are limited and cannot satisfy the endless possessive desire of people. It will lead to the frequent occurrence of natural disasters. This paper is mainly aimed at the black soil erosion in the area of the province, taking the area as the research object, taking meteorological data, soil data, DEM data, remote sensing images, Landsat TM images, and landsat8 OLI images, Based on the Yearbook of Statistical Yearbook and the official website of the provincial government, the RUSLE model, was used to analyze the temporal and spatial pattern of soil erosion intensity, and the soil erosion and soil erosion factors in the area. Finally, soil erosion in different slopes and different altitudes was obtained, and finally, the soil erosion condition in the study area was obtained. According to the actual situation, relevant soil protection measures and improvement programs are put forward.

1. Introduction

The black soil area of Song Liao Plain is one of the three largest black soil regions in Northeast China. It is mainly distributed in two provinces of Hebei and Henan provinces. A small number of them are distributed in the northern part of the province. After more than 100 years of reclamation, the soil quality deterioration is severe under the action of overexploitation and natural resources of black soil and has caused severe soil erosion. In the long-term development process, [1-3] people only pay attention to the speed of development but neglect the quality of construction. Various adverse problems frequently appear primarily environmental issues, [4-6] which have become the focus of academic research and aroused the widespread concern of the whole society [7-9].

As the largest province of black soil in Northeast China, the province is shouldering the critical mission of food security. With the increasingly serious situation of soil and water loss in the whole province, the black soil has also undergone a process of gradual degradation from thick to middle and thin layers to broken yellow-black soil, and finally to become a Loess fence.

How to protect the black land to ensure its sustainable and sustainable food production has attracted the attention of scientists and government departments. Using GIS to generate DEM (Digital Elevation Model) for geomorphological characteristics analysis, and using a GIS system to extract vegetation coverage, land use and surface material composition from remote sensing images, etc, using GPS (Global Positioning System, hereinafter referred to as GPS) to collect data, the interpretation results are checked. The whole process is mainly processed by computer, with less manual intervention, stronger objectivity, and higher efficiency, which makes it widely used in the study of soil erosion.

2. Survey of the research area and data processing

2.1 Survey of Research Areas

It is located in the middle and southwest part of the province and is an important transport hub in the Hualong River Basin of Songnen Plain. The northeast of the city is low in southwest and high in the west, from low mountain plain to low plain. The monsoon climate in the market is distinct, belonging to the continental monsoon climate in the cold temperate zone. The specific geographical location is 124 13 to 128 30 in the East, 45 3 to 48 02 in the North latitude, 135 - 247 m above sea level, 3.4 in the city, 511.2 mm in precipitation, and 2644.3 hours in the sunshine. The soil types in this area are mainly typical black soil, which is the nearest subspecies to the concept of black soil in the black soil subspecies. The parent material of black soil is yellowish-brown and dark yellowish-brown sub-clay. The surface layer of black soil is loose gray-black and black humus layer, which gradually transits downward to the leaching layer. Under the leaching layer is the depositional layer, and the depositional layer develops well.

2.2 Data Sources

(1) Population and economic data come from the Yearbook of statistical Yearbook and the official website of the provincial government.

(2) Soil data came from the soil map of Wan Wan City at 1:25.

(3) Slope and slope length factors are derived from DEM data of 30m, an international scientific data service platform of the Chinese Academy of Sciences.

(4) Vegetation cover and land use data were obtained from Landsat TM images in 2003 and Landsat 8 OLI images in 2015 of the International Scientific Data Service Platform of the Academy of Sciences Science Data Center.

(5) Other information is derived from the work report of the municipal government, the statistical Yearbook of the municipal market, and the territorial chronicles.

(6) The rainfall data in the study area are derived from the rainfall data of the ground stations on the meteorological data center website of the China Meteorological Administration.

2.3 Data Preprocessing

2.3.1 Remote Sensing Image Preprocessing

For taking the panchromatic orthophoto correction image as the reference image, the TM image in 2003 and the LANDSAT8 image in 2015 in the study area were radiation corrected and atmospherically corrected respectively to eliminate the geometric change of the image. Thirty control points were selected, and geometric correction was carried out using quadratic polynomial correction model. RMS error was controlled within one pixel, 0.473 and 0.497, respectively.

Soil type thematic map data are registered and vectorized; DEM data format is Metadata particular format, and the file header needs to be modified to be a format that can be read by GIS software. Batch modification of DEM data header file format, splicing, and tailoring. All data are converted to a unified projection (Xian_1980_GK_CM_129E).

2.3.2 Remote Sensing Image Interpretation

As an essential data source for remote sensing monitoring of soil erosion, remote sensing images can obtain practical monitoring factors of soil erosion. Land use is a vital monitoring content of soil erosion, which reflects human activities and soil and water conservation measures. In this study, the human-computer interactive interpretation method was used to interpret the land cover types of the two images in the study area. The interpretation results are shown in Fig. 1 and 2.

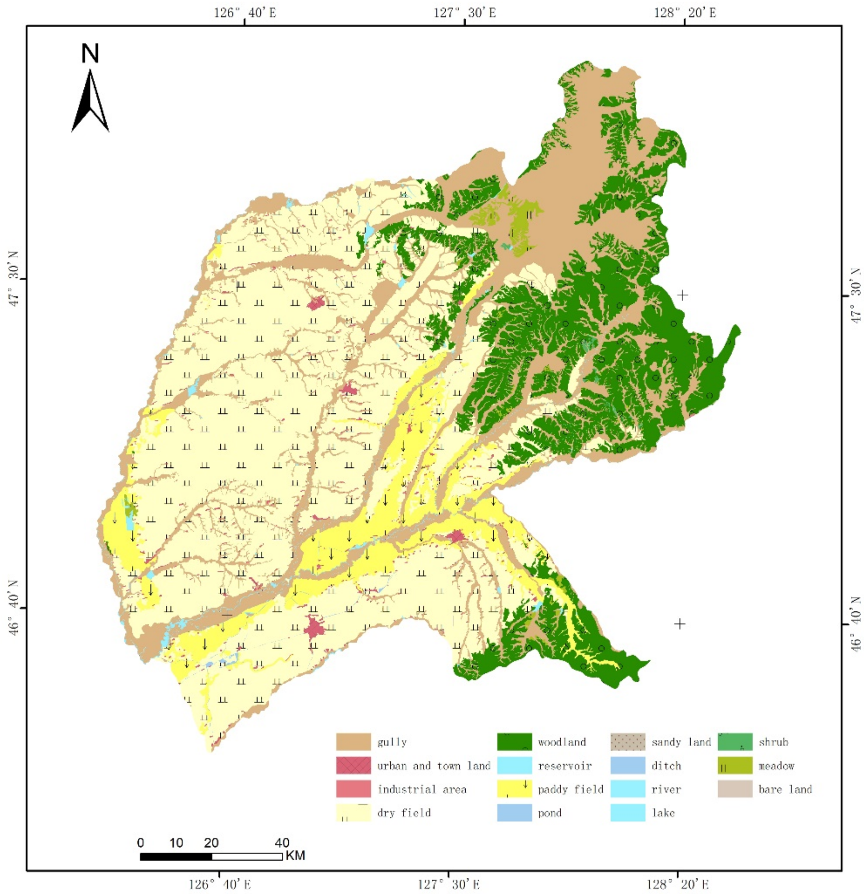


Figure 1. Research Area 2003 Remote Sensing Interpretation Map

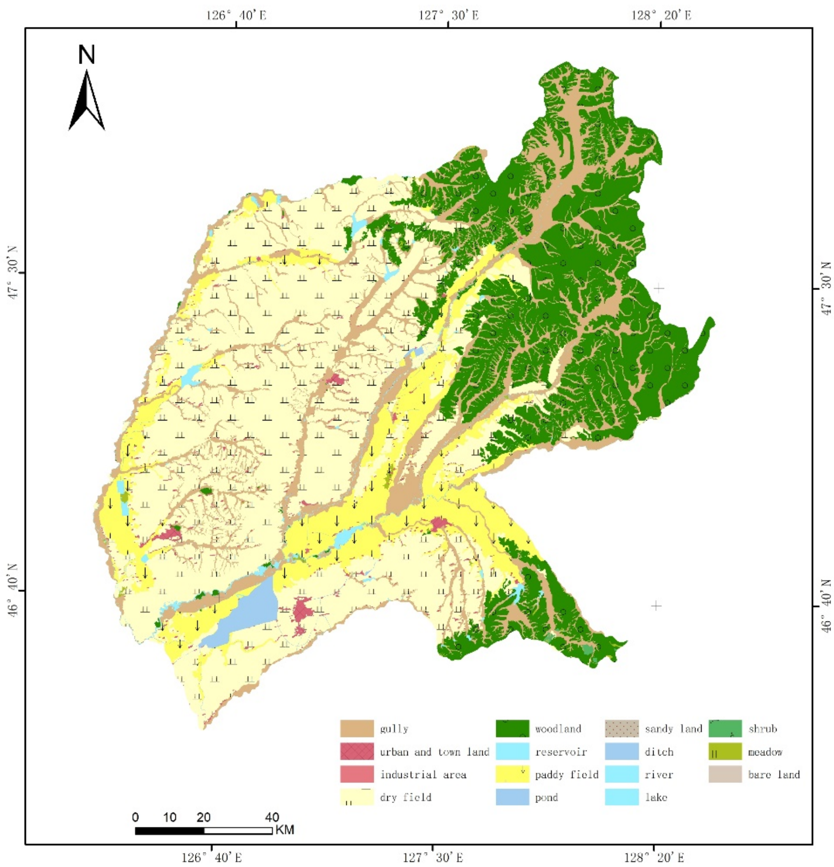


Figure 2. Research Area 2015 Remote Sensing Interpretation Map

3. Survey of research area and data processing

3.1 Soil and Water Loss Erosion Model

Soil erosion and the degradation of land quality are some of the essential reasons for the deterioration of the ecological environment of black soil. The reason is complex human and geographical processes, which are influenced by many factors, such as precipitation, underlying basement lithology, topographic gradient, land cover type, and management mode [10-12]. Through remote sensing information technology, soil, and water information in black soil areas can be quickly obtained. Meanwhile, soil erosion in black soil can be quantitatively estimated, which provides a way for soil and water monitoring, ecological environment construction and soil erosion prevention and control of black soil. According to the RUSLE model, the soil erosion and soil erosion of black soil can be studied, and the soil erosion of different slopes and altitudes can be obtained [13-15].

The soil loss model (RUSLE) is shown in Fig. 3

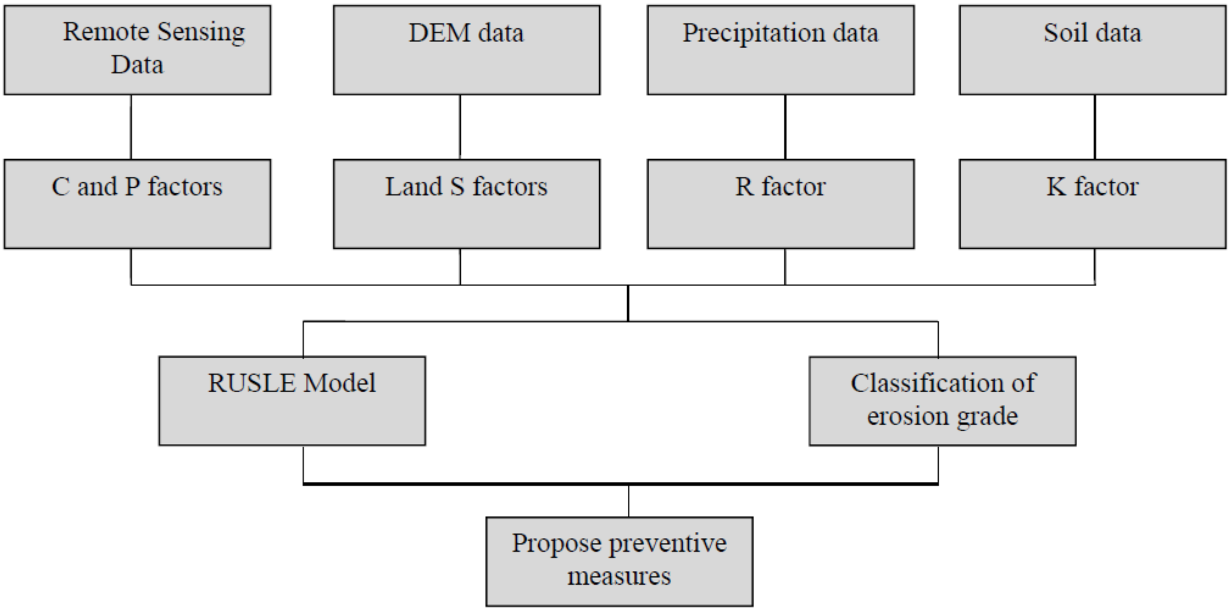


Figure 3. Technical flow chart of RUSLE model

The model expression is as follows 1:

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

C is a cover and management factor (cover-management factor)(dimensionless), which refers to the ratio of soil loss under a specific crop or vegetation cover to that of continuous fallow land after cultivation under the same conditions as other factors. This factor measures the inhibition of vegetation cover and management on soil erosion. Its value ranged from 0 to 1, and the closer it approached, the higher its inhibition effect on soil erosion.

P is a dimensionless factor of soil and water conservation measures. (Support practice factor) (Dimensionless)It refers to the ratio of soil loss after taking soil and water conservation measures to the amount of soil loss planted along the slope. Its value is between 0 and 1. When its value is 0, the probability of soil erosion in this area is 0, and when its value is 1, it means that the area has not taken any measures to prevent soil erosion.

LS is the slope length factor (L=slope length factor, s=slope steepness factor) (dimensionless), and L is the slope length factor, which is defined as the power function of slope length. S is the slope factor. LS indicates the ratio of soil loss on a given slope length and gradient to that on a typical slope in a standard runoff area under other conditions, which accelerates soil erosion. In practice, L and S factors can be measured to obtain data, but in the case of the extensive watershed and large slope, the terrain factors L and S can be collected based on DEM (digital elevation model) and ArcGIS spatial analysis.

R is the factor of rainfall erosivity (rainfall-runoff erosivity factor)

(MJ•mm•hm-2•h-1•a-1) and rainfall is the driving force of soil erosion. R reflects the potential ability of rainfall to cause soil erosion. In RUSLE, it is defined as the product of rainfall kinetic energy and maximum rainfall intensity of 30 minutes.

K is a factor of soil erodibility (soil erodibility factor) (t•hm2•h•MJ-1•mm-1•hm-2). It is an index to measure soil erosion resistance. It is used to reflect the sensitivity of soil to erosion. It is a comprehensive reflection of soil permeability, permeability, water capacity, and the ability of soil particles to resist dispersion and transportation. K represents the amount of soil erosion per unit area caused by rainfall erosivity in a standard plot.

A is used to predict soil erosion (estimated average soil loss in tons per acre per year), which mainly refers to the annual average soil loss caused by rainfall and runoff.

3.2 Calculation of Soil and Water Loss Factor in RUSLE

3.2.1 Vegetation Coverage Factor C and Water Conservation Measures Factor P

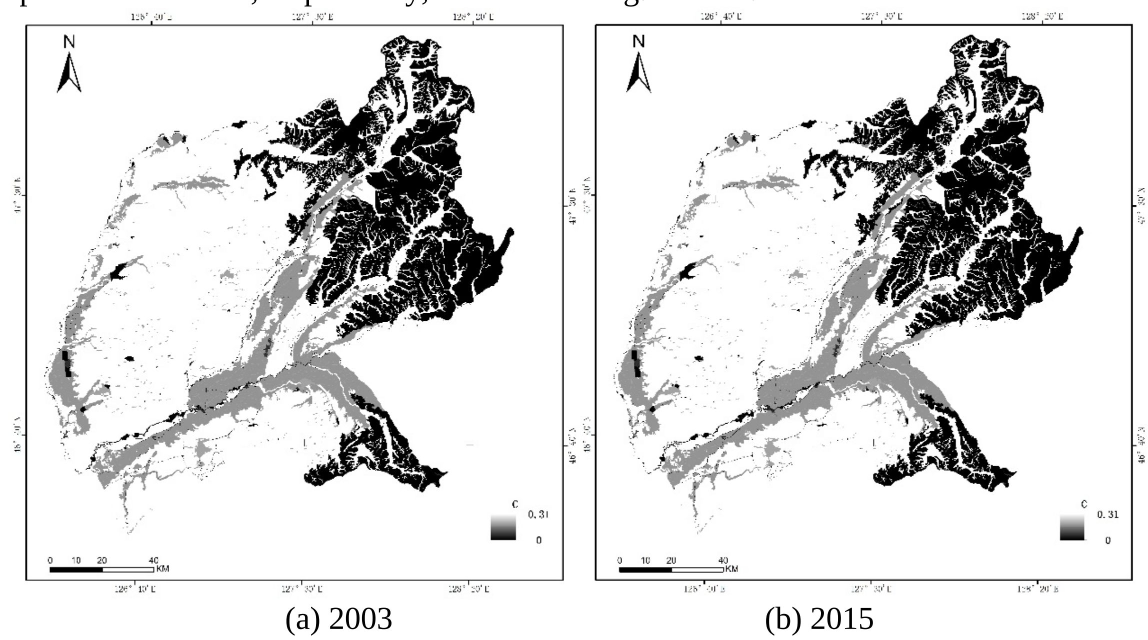
Vegetation coverage factor is also called material management factor. Experience shows that vegetation coverage has a great relationship with soil erosion. Under the same value of other geographic, environmental factors, the higher the vegetation coverage, the smaller the amount of soil loss; conversely, the more significant the amount of soil loss. The value assignment of factor C in the basin is shown in Table 1.

Table 1. C Factor Values of Different Land Use

Land use types	dry land	paddy field	Transportation land and water body	Grassland	Residential areas	woodland
Factor C	0. 31	0.18	0	0.06	0.2	0.006

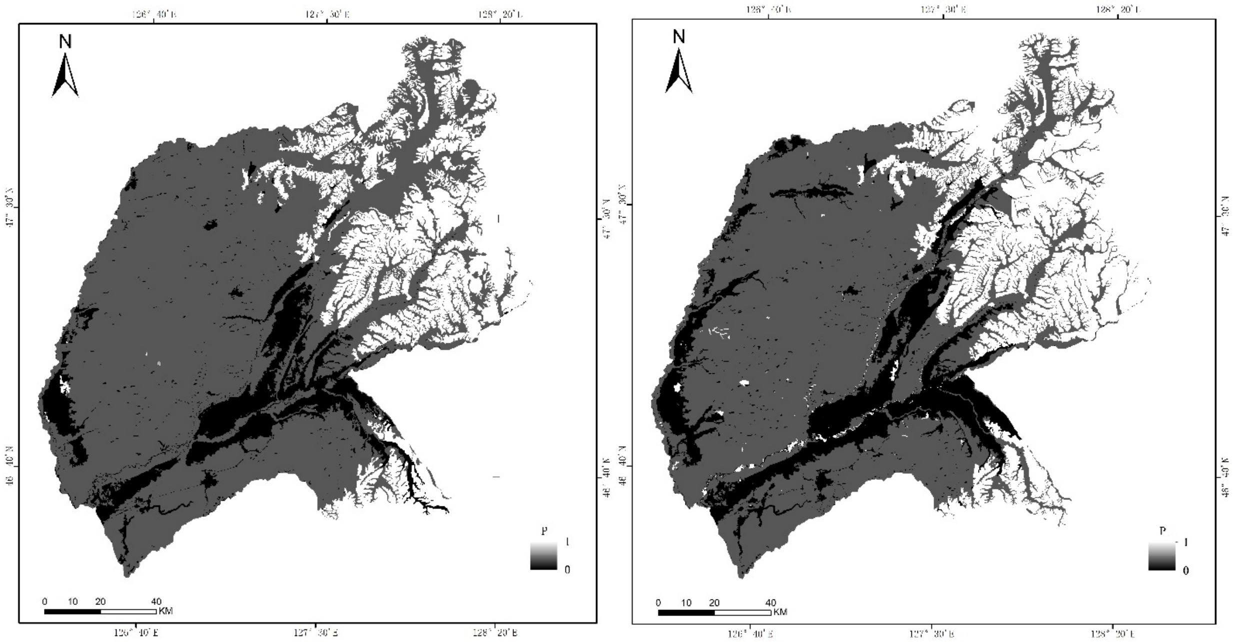
The factor of soil and water conservation measures is the ratio of the amount of soil loss to the amount of soil loss when planted along the slope after taking water and soil conservation measures. Usually, the control measures included in this factor are contour tillage, contour belt planting, and terrace construction. With the P factor of natural vegetation as 1, slope farmland as 0.35, rice is the best land use for terrace construction, and the P-value is 0.01.

According to the interpretation results of the two phases of images, the C factor and P factor of the two aspects are obtained, respectively, as shown in Fig. 4 and 5.



(a) 2003 (b) 2015

Figure 4. C Factor Thematic Map



(a) 2003 (b) 2015

Figure 5. P Factor Thematic Map

3.2.2 Terrain Factor LS

The ridgeline is extracted from DEM data of the working area, and then the vertical distance from each grid to the ridgeline is calculated as the approximate slope length of each grid.

The formula for calculating slope length factor:

$$L=\left(\frac{\lambda}{22.13}\right)^{\alpha} \quad (2)$$

$$\alpha=\frac{\beta}{\beta+1} \quad (3)$$

$$\beta=\frac{\sin\theta / 0.0896}{3.0\cdot(\sin\theta)^{0.8}+0.56} \quad (4)$$

Among the above formulas, lambda is the horizontal slope length, alpha is the slope length index, 22.13 is the slope length (m) of the standard plot, and theta is the slope extracted by DEM.

Formula 3-5 is used for factor S.

$$S=\begin{cases}10.8\sin\alpha+0.03, \theta<5^{\circ} \\ 16.8\sin\alpha-0.5, \theta\geq 5^{\circ}\end{cases} \quad (5)$$

Using the DEM data of the working area, the slope map is extracted and converted into radian units, and then the L and S factor layers of the basin are calculated, as shown in Figures. 6 and 7.

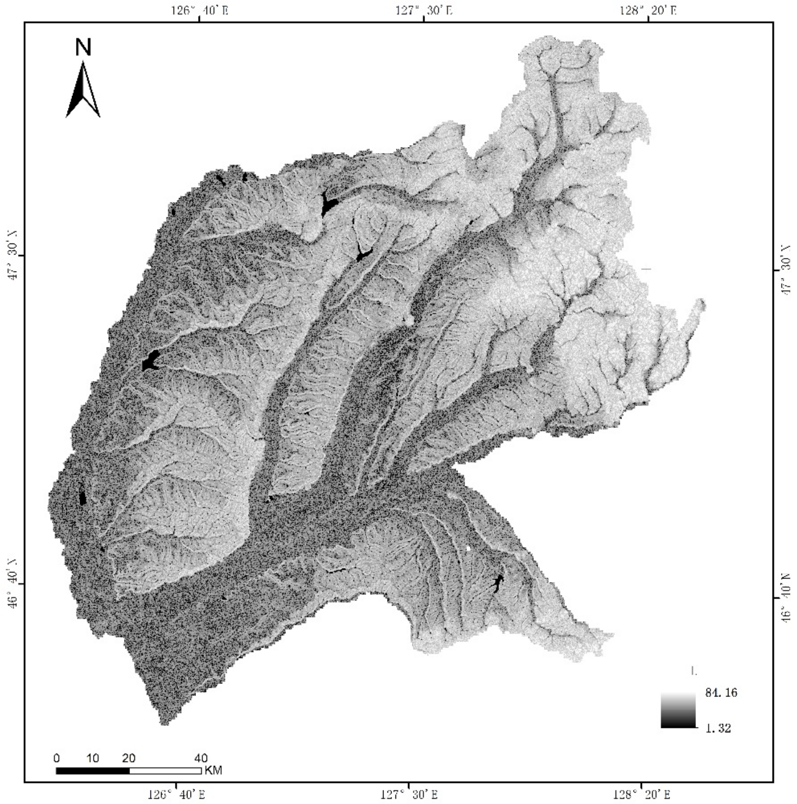


Figure 6. Factor L Map

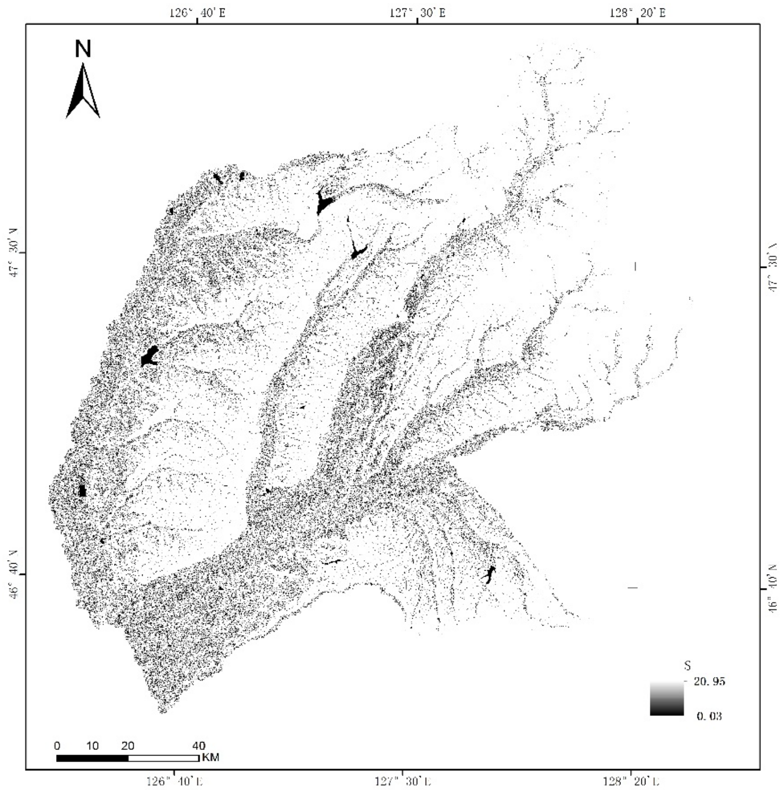


Figure 7. S Factor S Map

3.2.3 Rainfall Erosion Factor R

Rain droplets splash the surface soil layer. Soil fragmentation, separation, and splash cause soil erosion. The degree of soil erosion is affected by rainfall characteristics. Rainfall erosivity Factor R indicates the potential of soil erosion caused by rainfall. The calculation of the R factor is based on the formula of monthly average rainfall and annual average rainfall:

$$R = \sum_{i=1}^{12}(-1.15527 + 0.1792Pi) \quad (6)$$

PI and Pare monthly and annual precipitation (mm), respectively. The raster diagram of the R factor is shown in Fig. 8.

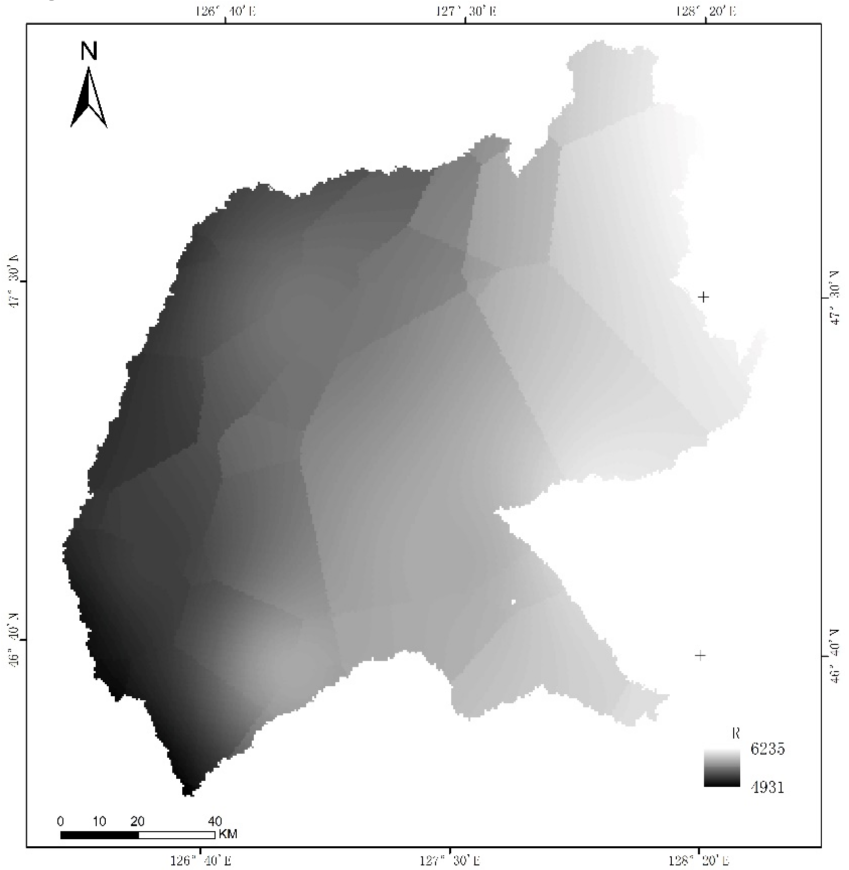


Figure 8. R factor Thematic Map

3.2.4 Soil erosion factor K

The estimation formula of K varies according to soil composition and the amount of data collected. Combined with the soil type map of the market, the study assessed the different soil types of the city and estimated the soil erosion. According to the formula of calculation:

$$K = \frac{[2.1 \times 10^{4} \cdot M^{1.14}(12 - OM) + 3.35 \cdot (S - 2) + 2.5 \cdot (p - 3)]}{100} \quad (7)$$

Among them, M= (Silt%+Very fine sand %)-(1-Clay %) (According to the U.S. particle size classification system);

OM = soil organic matter content; S = structure coefficient; P = permeability grade. Soil organic matter content was retrieved by the inversion of soil organic matter content in this project. Other data were obtained by querying common profile interpolation in the soil database. The K factor of the study area is calculated, as shown in Fig. 9.

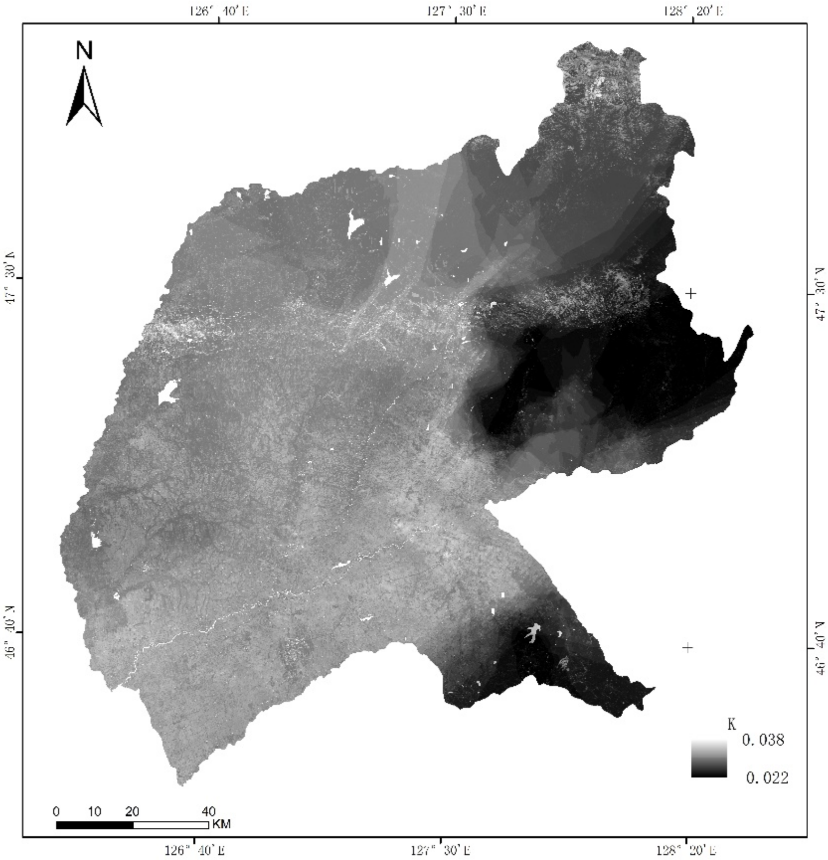


Figure 9. K Factor Thematic Map

3.3 Analysis of Soil and Water Loss Patterns

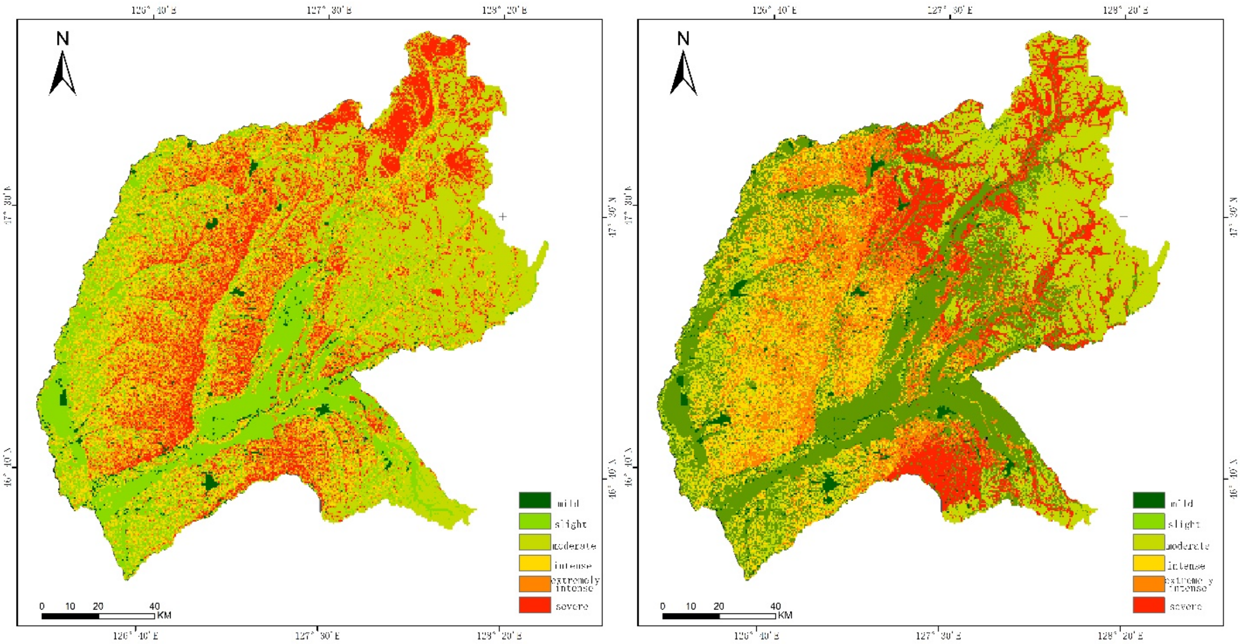
3.3.1 Soil Erosion

The slope length factor LS, rainfall erodibility factor R, soil erodibility factor K, W, water conservation measure factor P and vegetation cover management factor C above are calculated by the RUSLE model. The soil erosion modulus a value is multiplied by the conversion coefficient, and the unit is converted into the metric unit. In the 1990s, soil erosion classification standards were published in China. In 2007, the Ministry of Water Resources promulgated the revised Soil Erosion Classification Standards (SL190-2007). According to the amount of soil erosion, the degree of soil erosion can be divided into six grades: mild erosion, slight erosion, moderate erosion, intense erosion, extremely severe erosion, and — erosion. It is suitable for the whole country and provides a reference standard for the study of soil erosion in China.

As shown in Table 2, the spatial distribution is shown in Figures 10.

Table 2. Classification Table of Soil Erosion Intensity in Working Area

classification	soil erosion modulus ($t \cdot km^{-2} \cdot a^{-1}$)	2003		2015	
		area (km^2)	Percentage (%)	area (km^2)	Percentage (%)
mild	< 500	375.75	1.93	454.5	2.33
slight	500~2500	4728.25	24.25	5758	29.56
moderate	2500~5000	5002.25	25.66	4762	24.44
intense	5000~8000	3344.5	17.15	2821.75	14.48
extremely intense	800~15000	3123.5	16.02	2914	14.96
severe	> 15000	2922.75	14.99	2772	14.23



(a) Soil Erosion Intensity Classification Map 2003.
(b) Soil Erosion Intensity Classification Map 2015

Figure 10. Soil Erosion Intensity Classification Map

3.3.2 Analysis of the Overall Characteristics of Soil and Water Loss in the Research Area

Soil erosion in the working area is mainly mild and moderate, distributed primarily on the East and west sides of the working area, the terrain is relatively flat, the primary land use type is arable land. The northeastern part of China is a woodland with high vegetation coverage, and the erosion is mostly mild to moderate. The moderate and intensive erosion distributes in the central and northern parts of the work area, which is mainly affected by the topography and vegetation coverage. Very intense and intense soil erosion mostly concentrated in gully development areas, while the rest of the scattered areas with extraordinarily excellent and extraordinary grades were sparsely covered or bare.

The numerical characteristics of soil erosion in 2003 and 2015 were analyzed. Overall, the proportion of soil erosion at all levels in 2003 and 2015 is similar. Mild and moderate is the primary grade of soil erosion in the work area, and the proportion of the slight area is the smallest, which is less than 3%.

From 2003 to 2015, soil and water conservation measures increased, and soil erosion tended to be better. Statistical results show that the proportion of strength and extreme strength area decreases, while the relative area increases slightly and slightly. In 2015, the area of soil erosion in intensity erosion grade decreased by 522.75 km2 compared with 2003 and increased slightly by nearly 1000 km2. From the interpretation results, in 2003 and 2015, the gully area decreased of almost 1800 km2, the area of cultivated land and forest land increased, and the soil and water conservation measures were appropriate, which reduced the soil erosion grade.

4. Conclusion

In this study, the extraction and calculation of soil erosion factor K require relevant parameters such as soil organic matter content and soil texture. For the content of soil organic matter, since geochemical data do not cover the whole working area, the inversion value of soil organic matter content is directly used instead of interpolation calculation based on geochemical results, from the effects of K value calculation, it is feasible to use the inversion results to extract soil erosion factors. For soil texture parameters, because the soil texture distribution map of the working area is not obtained in this study, only some soil profile data in the soil database can be interpolated and calculated, which may affect the accuracy of K value to a certain extent.

In future research, the accuracy of soil organic matter content in black soil area should be improved, and the data of soil profile and soil texture that can cover black soil area should be collected to improve the evaluation accuracy of the model.

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