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Dynamic Analysis of Soil Erosion in Songhua River Watershed

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Abstract. In this paper, based on RS and GIS technology and Revised Universal Soil Loss Equation (RUSLE), the soil erosion dynamic changes during the two periods of 1990 and 2010 in Bin County was analyzed by using the Landsat TM data of the two periods, so as to reveal the soil erosion spatial distribution pattern and spatial and temporal dynamic evolution rule in the region. The results showed that: the overall patterns of soil erosion were basically the same in both periods, mainly featuring slight erosion and mild erosion, with the area proportions of 80.68% and 74.71% respectively. The slight and extremely intensive erosion changing rates showed a narrowing trend; mild, moderate and intensive erosion was increasing, with a trend of increased soil erosion; mild and intensive erosion were developing towards moderate erosion and moderate and extremely intensive erosion were progressing towards intensive erosion.

1. Introduction

Erosion, as a major problem throughout the world[1], which is the result of the combined action of natural and human factors [2], and has become one of the major environmental and agricultural issues worldwide [3].It is not only the fundamental reason for land degradation, declining soil fertility, water quality pollution, as well as siltation of rivers and lakes, but also the important cause for the further deterioration of the ecological environment and disasters, constituting a serious threat to human survival and development[4]. Therefore, the monitoring of spatial and temporal dynamics of soil erosion represents a new research topic both at home and abroad [5]. Water erosion is the major type of physical land degradation in the global perspective [6], and Asia alone has almost half of the area of the total water-eroded land of the world [7]. China, as the largest country in Asia, has become one of the countries with the most serious soil erosion problem in the world.

Thus, soil erosion is one of the most critical environmental hazards of modern times [6]; however, the rapid development of spatial information technology, combined remote sensing with GIS technology as a means, not only provides a broad space and a strong data support for dynamic monitoring of soil erosion, but also reflects spatial and temporal dynamics of soil erosion [8] more accurately and objectively with real-time dynamics. What's more, it has become a hot research topic to conduct our country's soil erosion dynamic monitoring based on remote sensing and GIS technology [9]. Therefore, in this paper, an integrated approach using RS and GIS-based methods is proposed and the Landsat TM images in 1990 and 2010 were used as major data resource, combing DEM (Digital Elevation Model) and others data. The revised universal soil loss equation (RUSLE) [10] is used here for the estimation of soil erosion from watershed areas [11]. The change monitoring studies were conducted on the temporal and spatial pattern dynamics of soil erosion in the Songhua River Watershed (Bin County, Heilongjiang Province), revealing its spatial and temporal distribution rule, pattern and characteristics, and aiming at providing technical support and a theoretical basis [12] for conservation planning and erosion control of soil and water in the region, and prevention planning of agricultural land, water and soil erosion in the black soil area in the Northeast of China [12].

2. Study Area

Bin County is located in the middle Heilongjiang Province, with the specific geographical coordinates as follows: 126°55′41″-128°19′17″E and 45°30′37″-46°01′20″N. The administrative region of the county contains 17 villages and towns, with the annual average temperature of 2.5-4.0 ℃, the annual average frost-free period of 110-150 days and the annual precipitation of 400-600mm. In the aspect of natural environment, there is "55% Water and 45% Farmland", with Zhangguangcai Mountains extending throughout the county. The terrain is high in the south part and low in the north part, with the southern mountains extending in a strip shape along the southeast part of the county. The hills are distributed in the central part. The north part along the river is the valley plain area. The soil belongs to the mountain brown soil, mostly the black soil. Some regions are used for agricultural production. On the two sides of the valley, there are meadow soil and gley meadow soil. In this area, there is fertile land, vast territory, and relatively small population, which is suitable for the development of agricultural production and that's why it is an important grain production base with rich agricultural and sideline products.

3. Data Processing and Study Methods

3.1. Data Preparation and Processing

The data information available mainly includes LandsatTM remote sensing images in the two periods of 1990 and 2010, meteorological data, a 1:50, 000 topographic map, soil type distribution diagrams and some field survey data and the land use data in the study area, together with natural geographic data such as black soil area geological hazard maps and vegetation form distribution maps as well as social data such as population size and economic conditions in the study area.

With the support of ERDAS IMA GE 9.2, false color composite of remote sensing images 4, 5, 3 (R, G, B) was completed. The image geometric correction was completed with the reference to the 1:50, 000 topographic map. The land use interpretation in the study area was completed under the premise of ensuring accuracy by referring to some field survey data, considering the present land-use situation in the study area and making use of supervised classification and human-computer interaction methods,. Besides, the scanning, geometric correction, digital processing and vector data grid-conversion of the black soil area geological disasters map and the soil type distribution map were completed, which was stored in the Grid format. In addition, the interpolation calculation of meteorological data was completed with the support of ArcGIS according to the meteorological data collected.

3.2. Quantitative study of Soil Erosion

In view that the soil erosion type in Bin County is mainly formed due to the water erosion, the most widely used and improved Universal Soil Loss Equation (Revised UniversalSoil Loss Equation, RUSLE) is therefore used to complete soil erosion calculations in the study area, thus obtaining the average soil erosion intensity map in the study area.

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

In the equation (1): A represents soil erosion amount (t / (hm2 • a)); R represents rainfall erosion factor (MJ • mm / (hm2 • h • a)); K represents soil erodibility factor (t • hm2 • h / (hm2 • MJ • mm)); LS represents slope length slope factor; C represents vegetation cover factor; and P represents soil conservation measures factor.

R-factor: Fournier index is revised according to the monthly precipitation and annual precipitation data of the study area; the value of R is calculated through a universal R-factor equation; C factor: with the database reference provided by Heilongjiang Water Conservation Institute, it is determined by using the relationship between Cai Chongfa vegetation coverage (fg) and C factor[13]; LS factor: with the support of ArcGIS9.2, the slope and slope aspect and other terrain data are derived based on DEM, which is calculated with the reference to Zhang Xiankui formula[14]; K factor: the empirical method is used to obtain the value of K factor by setting parameters on Nomo figure according to soil type distribution map of the study area; P factor:, it is obtained with the reference to the relevant literature [15] according to current land use. Based on the Third National Soil Erosion Remote Sensing Survey by Ministry of Water Resources and water erosion intensity grading standards provided by Institute of Water and Soil Conservation of Heilongjiang Province, soil erosion results are divided into five levels: slight erosion, mild erosion, moderate invasion, intensive erosion and extremely intensive erosion.

4. Analysis of Results

4.1. Soil Erosion Area Change

Seen from the statistics of table 1 and figure 1, the overall patterns of soil erosion were basically the same in the study area during the two periods, which were mainly affected by slight erosion and mild erosion, respectively accounting for 80.68% and 74.71% of the total soil erosion area each year. Specifically, the slight erosion was mainly distributed in the northern river valley plain along the river and southern mountain area in Bin County; the mild erosion was mainly concentrated in the development area and some of the arable land in western part of Bin County; and the intensive and extremely intensive erosion was mainly distributed in a shallow hill and hilly area with the transition from arable land to mountains, which was mainly related to the characteristics and topography of the study area. During 1990-2010, the area of slight and extremely intensive soil erosion was reduced by 339.85km2 and 37.41 km2, in which the reduction in the extremely intensive erosion area was mainly due to such ecological projects as “returning grain plots to forestry” and “returning farmland to grassland” implemented in 1998, making the vegetation cover rate of some shallow mountains and hilly region increase and reducing soil erosion situation in the region; but the area of mild, moderate and intensive erosion was increased by 110.88 km2, 210.97 km2 and 55.41 km2; the moderate erosion area increased significantly, indicating that the soil erosion situation was getting worse. With the continuous expansion of the city size and population growth, people, driven by economic interests, have increased land reclamation, resulting in the destruction of vegetation on the earth surface, deterioration of ecological environment and serious soil erosion. Though the soil erosion situation is somewhat constrained in the local area, the erosion situation in most of areas is still not optimistic. On the other hand, it also shows that nearly 20 years’ soil erosion control has been mainly focused on the land class with higher soil erosion intensity, while ignoring other land classes which are less difficult to deal with.

Table 1. Different intensity soil erosion areas in the study area.

Soil erosion type	1990a		2010a		1990-2010
Slight	2155.35	56.09	1815.50	47.24	-339.85
Mild	944.86	24.59	1055.74	27.47	110.88
Moderate	476.65	12.40	687.62	17.89	210.97
Intensive	196.03	5.10	251.44	6.54	55.41
Extremely intensive	69.93	1.82	32.52	0.86	-37.41

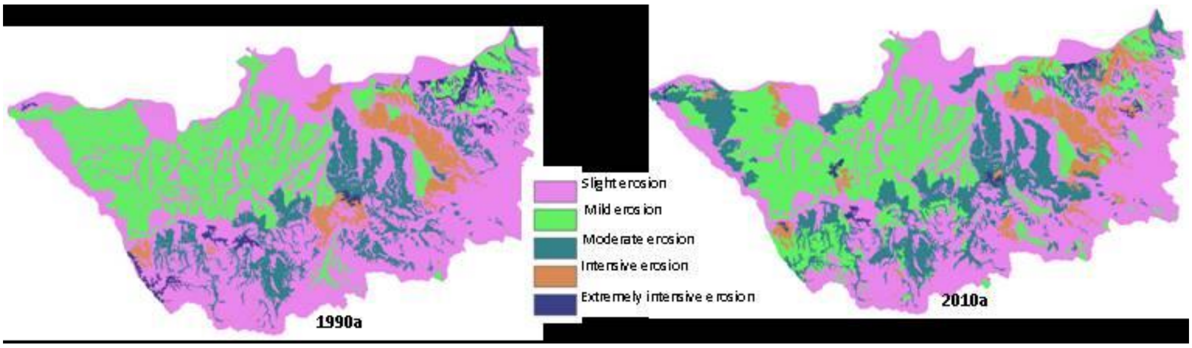

Figure 1. Soil erosion type distribution in the study area (1990 and 2010).

4.2. Soil Erosion Rate Changes

Single land use dynamic degree refers to a certain land-use velocity change in quantity in a region within a certain period of time [16], which can be used to make a good measure of land-use net change velocity. As to soil erosion rate, the model can also be used to make the quantified calculation, with the expression as equation (2):

$$R_s = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100 \tag{2}$$

In the equation (2): U_a and U_b represent the area of a type of erosion in the early and late study period. T represents the study period. When T is set to represent a year, Rs rerpesents annual change rate of a particular erosion type within a study period.

From the statistics in Table 2, it can be seen that the change rate of slight erosion and extremely intensive erosion is in a reduced tendency, both soil erosion areas show a decreasing trend and the extremely intensive erosion has the greatest reduction. Mild, moderate and intensive erosion shows an increasing trend. Moderate erosion has the greatest increase, which develops towards to a large scale. The mild erosion is the smallest.

4.3. Analysis of Changes in Soil Erosion

Based on ArcGIS 9.2 spatial analysis, the soil erosion data spatial overlay operations in the two periods as well as the calculation of the transfer matrix of soil erosion were completed. Then, the soil erosion transition probability model was built, so as to make quantitative analysis on the transformation between different types of soil erosion.

$$D_{ij} = \frac{S_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} S_{ij}} \tag{3}$$

In the equation (3), D_{ij} represents the transition probability from type i soil erosion into type j soil erosion, S_{ij} indicates the area of soil erosion transferring from type i into type j, and n represents the number of types of soil erosion.

Table 2. 1990-2010 Soil erosion transition matrix in the study area

1990 \ 2010	Slight	Mild	Moderate	Intensive	Extremely
Slight	83.21	11.71	4.14	0.66	0.28
Mild	0.76	80.67	14.79	3.18	0.60
Moderate	2.22	6.12	81.14	10.30	0.22
Intensive	1.70	0.33	30.83	67.06	0.08
Extremely	1.25	16.29	16.36	38.15	27.95

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Table 2 shows that, there was a certain amount of mutual conversion throughout the study period. The greatest one was slight erosion retention rate (probability of no erosion transition), which was 83.21%; followed by moderate erosion. The extremely intensive erosion was the smallest, which was only 27.95%. For slight erosion, its main flow was mild erosion, it was mainly transformed into moderate erosion, and the changes in the level span were relatively large, indicating that the ecological environment in the region showed some improvement. For intensive and extremely intensive soil erosion, they would develop toward the direction of slowing the soil erosion rate and intensity; the majority occurs in mountainous regions with the slopes of more than 25°. It is partly due to the implementation of ecological protection projects like "returning the farmland to the forest and grasslands", coupled with the constraint from the terrain and other natural conditions, relatively few human disturbance activities and some rationalization trends in land use. The regional ecological environment showed some improvement, but the occurrence area was relatively small. We will continue to increase the intensity of foresting in barren mountains and returning farmland to forestry, so as to recover and protect native vegetation.

5. Conclusions and Discussion

Bin County in Heilongjiang Province ranks among the top 500 major grain-producing counties in China, so the paper takes it as an example, making the analysis on soil erosion dynamic change during the two periods of 1990 and 2010 in Bin County by making use of the Landsat TM data of the two periods and applying the RS and GIS technology and Revised Universal Soil Loss Equation (RUSLE), so as to reveal the soil erosion spatial distribution pattern and spatial and temporal dynamic evolution rule in the region. The study was conducted on soil erosion dynamics and the temporal and spatial patterns in the area, aiming at providing important basis for the regional soil and water conservation planning, water and soil erosion control, the prevention planning of agricultural land water and soil erosion in the black soil area in the Northeast of China as well as the decision-making of regional sustainable development. It is also of great importance to the forecast and prevention of soil erosion in the study area in the future.

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