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Research on Black Soil Spatiotemporal Changes in Hulin City Based on Sentinel -2 Remote Sensing Images

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Abstract: In order to find out the type, distribution range, quantity, quality and utilization of the surface substrate of the black soil in Hulin City, solve the problem of insufficient basic data of field investigation, and form a comprehensive index system suitable for the health status of the surface substrate of the black soil. In this paper, based on Sentinel-2 satellite remote sensing images, the black soil change detection in Hulin City was realized. Satellite remote sensing images in the same month of 2019 and 2024 were selected to classify land use based on the support vector machine method, and the dynamic trend of black soil land use in Hulin City in 5 years was discussed by combining the transfer matrix and spatial distribution. In 2019 and 2024, the classification accuracy is better than 90%, and the Kappa coefficient is above 86%. From 2019 to 2024, there will be both transfer in and out of black soil, among which there will be more mutual conversion between black soil and woodland, and the overall black soil area will increase. There are many black soil wetlands, and most of them are turned into black soil and woodland.

Keywords: Land Use; Change Detection; Hulin City; Black Soil

1. Introduction

In recent years, with the change of natural environment and policies, the black soil is also undergoing dynamic changes, in order to grasp the spatiotemporal evolution of the black soil. To achieve the sustainable development of regional black soil resources, many experts and scholars have done relevant research. Among them, the use of time-series satellite remote sensing images to realize land use classification and change detection has gradually become the mainstream method due to its advantages of rapid response and accurate judgment [1-4]. Based on the theory of the earth's critical zones, Yao et al. clarified the concept of black soil, combined with regional soil type data and land use/cover data in 1980, 2000, and 2020, and used the superposition analysis method and land use spatiotemporal change analysis method to reveal the spatiotemporal pattern evolution and driving factors of black soil change in Northeast China in the past 40 years [5]. Wu et al. pointed out that the decrease in cultivated land area is attributed to the great change in landscape pattern with the development of the economy and the increase of urbanization rate, and the conversion of cultivated land to non-agricultural land [6]. Li et al. used the land use transfer matrix to extract the amount of cultivated land transformation in four periods from 1980 to 2015, and the dynamic degree of cultivated land use determined the activity of cultivated land dynamic change in each period, providing suggestions for ensuring food security in Heilongjiang Province [7]. Combined with the concept of generalized black soil, this paper uses Sentinel-2 satellite remote sensing images to realize the study of land use classification and black soil transfer, so as to provide effective data support for land management and black soil loss prevention.

2. Data Sources and Methodology

2.1 Overview of the Study Area

Hulin City (132° 11'35"E ~ 133°56'32"E, 45°23'34"N~46°36'33"N). Heilongjiang Province is a county-level city, managed by Jixi City, located in the eastern part of Heilongjiang Province, at the southern foot of Wanda Mountain, with the Ussuri River as the boundary and the Russian Federation across the water. It has a cold temperate continental monsoon climate. Hulin City is a sparsely populated city with agriculture, green food

industry, border trade, tourism, medicine and other industries.

2.2 Data Sources

Satellite remote sensing images are derived from the Copernicus data space ecosystem, and two remote sensing images are selected from October 5, 2019 and October 22, 2024, and the cloud coverage does not affect the subsequent classification results. The 2018-year land use classification integration data in the annual China Land Cover Dataset (CLCD) were used as the baseline data to verify 2019 and 2024 land use classification accuracy.

2.3 Research Methodology

2.3.1 ROI construction and separability calculation

Based on the classification system of China's multi-period land use remote sensing monitoring dataset (CNLUCC) and combined with the national standard of "Classification of Land Use Status" (GB/T21010-2017), this paper divided black soil cultivated land into black soil cultivated land on the basis of soil layer, black soil woodland, black soil construction land, black soil wetland, and water body. In this paper, black soil cultivated land is defined as black soil. In order to ensure the accuracy and reliability of land use classification, the samples in the study area should meet the conditions of purity, uniform distribution, number and representativeness of each type of sample, as shown in Figure 1, (a) black soil; (b) black soil woodland; (c) for black soil construction land; (d) black soil wetlands; (e) is a body of water. The closer the sample separability coefficient is to 2, the purer the sample, usually the separability coefficient of the qualified sample is greater than 1.8, when the sample is less than 1.4, the sample needs to be re-selected or the category merged. The separability coefficient of all samples in this paper is greater than 1.8, which is a qualified sample.

(a) Black Soil

(b) Woodland

(c) Water

(d) Meadow

(e) Construction

Figure 1. Sample Example of Study Area

2.3.2 Support vector machines

Support vector machine (SVM), as a commonly used method in supervised classification, has strong robustness and generalization ability [8]. SVM maximizes the interval between different categories by automatically finding the largest region classification vector, thereby improving the reliability of classification results. The SVM algorithm mainly seeks a hyperplane between classes to achieve more accurate classification. When the study area is classified as class m, for class i (i=1, 2, ..., m), the decision function is:

$$f_i(X) = \sum_{j=1}^{N_i} a_{ij} y_{ij} K(X_j^{(i)}, X) + b_i \qquad (1)$$

where X is the input eigenvector. N is the number of class I support vectors. a_{ij} is the j-th support vector Lagrange multiplier in class I. y_{ij} is the label of the j-th support vector in class i. is a kernel function. b is a bias for class i.

Given the input eigenvector X, its predicted category is:

$$C(X) = \arg \max_{i \in (1,2,...m)} f_i(X) \qquad (2)$$

The category classification process is completed by selecting the maximum value of the decision function. Among them, there are many kinds of kernel functions, such as linear kernel functions, polynomial kernel functions, sigmoid kernel functions, etc.

2.3.3 Analysis of land use change

In this paper, the land use transition matrix is used to explore the changes of various types of

transfer [9-11], and the specific calculation formula is as follows:

$$T_{ij} = \begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1n} \\ T_{21} & T_{22} & \cdots & T_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ T_{n1} & T_{n2} & \cdots & T_{nn} \end{bmatrix} \quad (3)$$

where: T_{ij} is the area of the land class conversion; i and j represent pre-temporal type and post-temporal type, respectively; n is the number of land types.

3. Results and Analysis

3.1 Land Use Classification Results and Analysis

According to the concept of generalized black soil, the land use types in the study area were classified into five categories: black soil, black soil woodland, black soil construction land, black soil wetland and water body. Firstly, the samples in the study area were selected, and the separability coefficient of the calculated samples was greater than 1.8, which belonged to the qualified samples and could be used for subsequent classification. Then, the land use classification of Hulin City in 2019 and 2024 was completed based on the support vector machine method by using the qualified samples, and the land use classification results of Hulin City were obtained after classification and processing, as shown in Figure 2, Figure 3, where Figure 2 was the land use classification results of Hulin City in 2019; Figure 3 was the results of land use classification in Hulin City in 2024. In order to verify the accuracy and reliability of the classification results, the overall classification accuracy and Kappa coefficient are used to evaluate the classification accuracy. In 2019, the overall classification accuracy and Kappa coefficients of land use classification in Hulin City were 90.67% and 0.8661, and in 2024, the overall classification accuracy and Kappa coefficients of land use classification in Hulin City were 96.16% and 0.9401, indicating reliable classification results.

According to the land use classification results of Hulin City in 2019 and 2024, the land cover types of Hulin City are mainly black soil, black soil woodland and black soil wetland, and the area of the three types of land types accounts for about 96% of the total area of the research area, and the area of black soil construction land and water is small, accounting for about 4% of the total area of the research area. The black soil is concentrated in the middle and south of the research area, and the results of the classification of the two temporal phases show that the black soil in the northeast of the research area shows an increasing trend, and most of the black soil in this area is transferred from the black soil wetland. There is also an increasing trend in the black soil in the west, and most of it is transferred from black soil woodland. In 2019, the area of black soil was about 2495.19km^2, and in 2024, the area of black soil will be about 3164.51km^2, and the area of black soil will increase by about 669.32 km^2 in five years. The area of woodland increased to a certain extent, and the local area was reflected in the transfer of black soil and black soil wetland, and the area of black soil woodland increased by about 259.59km^2 in five years. This is related to the local forest protection and afforestation policy, and the increase of green space area has a promoting effect on the local natural ecological environment. From 2019 to 2024, there will be more transfers of black soil wetlands, including cultivated land and woodland. Most of the black soil construction land is distributed in the middle of the gentle terrain, and there is a tendency to extend to the northeast, and the area also increases to a certain extent, among which the proportion of black soil transfer is relatively high, and the black soil is converted into black soil construction land about 152.31km^2 within five years. The change in the area of water is not obvious, but the overall area is still decreasing.

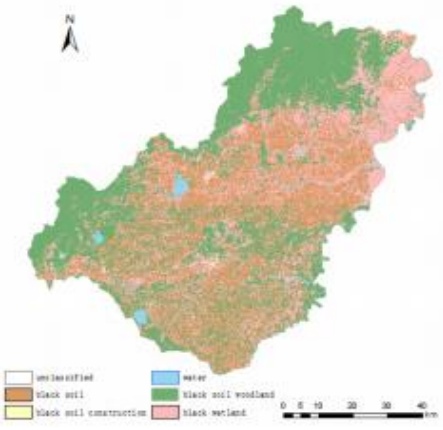

Figure 2. Classification Results of 2019

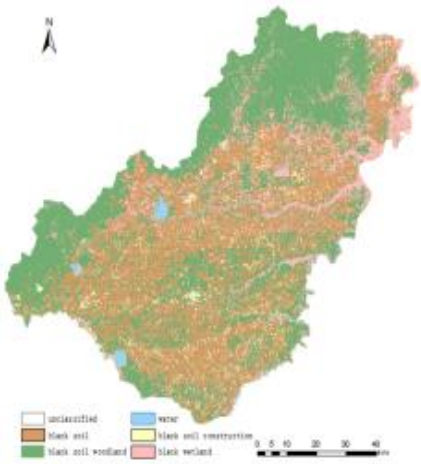

Figure 3. Classification Results of 2024

3.2 Analysis of Land Use Change

In this paper, the land use transition matrix is obtained by comparing and analyzing the land use classification results of Hulin City in 2019 and 2024, as shown in Table 1, where (a) black soil; (b) black soil woodland; (c) is water; (d) for black soil construction land; (e) is a black soil wetland. In Table 1, the row direction represents the land use type in 2019 and the column direction represents the land use type in 2024. As shown in Table 1, from 2019 to 2024, the transfer in and out of black soil existed at the same time, which was manifested in the transfer of black soil woodland and black soil wetland, and the transfer of black soil woodland and black soil construction land. The wetland was converted into black soil about 905km^2, which was concentrated in the northeast of the study area, and the wetland resources in this area were lost. In 2019, the area of black soil was about 2495.19km^2, and in 2024, the area of black soil was about 3164.51km^2, the area of black soil increased by about 669.32km^2in five years. The total amount of black soil woodland was 3968.77km^2 in 2019 and 4264.36km^2 in 2024, an increase of about 295.58km^2. Among them, black soil and wetlands are more transferred. The total amount of black soil wetland was 2649.99km^2 in 2019 and 1401.86 km^2 in 2024, a decrease of about 1248.13km^2. As a non-renewable land type, black soil wetland is the "giant panda" of natural resources, and excessive loss of black soil wetland will cause certain harm to the natural ecology. Therefore, it is imperative to strengthen the protection of black soil wetlands. The change in the water is not obvious, but it still decreases by about 69.26km^2.

Table 1. Land Use Type Transfer Matrix in the HuLin from 2021 to 2024 (Unit: km^2)

Use Types	black soil	woodland	water	construction land	wetland	Total
black soil	1602.0861	647.0284	2.6371	6.8348	905.8793	3164.5084
woodland	426.4856	2891.7352	4.39	3.0238	938.088	4264.3608
water	0.2364	6.5011	51.6707	0.7787	5.5689	64.7673
construction land	152.3077	63.8209	16.5952	27.6687	139.795	400.304
wetland	314.0599	359.3615	58.5361	9.2928	660.6101	1401.8604
Total	2495.1896	3968.7776	134.0305	47.8825	2649.9936	

4. Conclusion

The land use classification of the remote sensing images of Hulin City in 2019 and 2024 was carried out respectively, and the classification results were analyzed in combination with the transfer matrix to realize the black of Hulin City Transfer of land use types. The conclusions are as follows: (1) In general, the area of black soil, black soil woodland and black soil construction land in Hulin City increased, and the area of black soil increased by about 669.32km2. The area of black soil wetlands and water decreased, and the loss of black soil wetlands was more. (2) Through the transfer matrix analysis, most of the black soil in Hulin City flowed to the black soil woodland from 2019 to 2024. At the same time, the protection of black soil wetlands is imperative.

Acknowledgments

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