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Application and Challenges of Remote Sensing Technology in Ecological Effect Assessment of Mining Area Reclamation

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Abstract

While promoting social and economic development, the development of mineral resources has also caused serious land damage and ecological degradation, making land reclamation and ecological restoration in mining areas a global issue. Accurate assessment of restoration effect is the key to measure the effectiveness of reclamation. However, the traditional ground survey method has high cost and low efficiency, and it is difficult to achieve large-scale dynamic monitoring. Remote sensing technology provides a revolutionary means for the evaluation of ecological effects of reclamation in mining areas by virtue of its macro, rapid and dynamic non-contact advantages. This paper systematically reviewed the application and effectiveness of remote sensing technology in vegetation restoration, soil quality, soil and water conservation and landscape pattern evolution, analyzed the current challenges in technical limitations, model uncertainty and data fusion complexity, and prospected the future development trend of quantification, intelligence and multi-platform collaboration, in order to provide theoretical reference for the deepening application of remote sensing technology in ecological restoration of mining areas.

Keywords

Remote Sensing; Mining Area Reclamation; Ecological Effect Assessment; Vegetation Monitoring; Soil Quality.

1. Introduction

Mining activities, especially open-pit mining and underground mining subsidence, seriously disturb the surface landscape and ecosystem, resulting in land excavation, occupation and collapse, causing soil erosion, vegetation destruction and biodiversity decline and other ecological and environmental problems[1]. The implementation of land reclamation and ecological restoration in mining areas is an inevitable requirement for restoring regional ecosystem functions and achieving sustainable development. However, how to scientifically and effectively evaluate the long-term ecological effects of reclamation projects has always been a difficult point in management and scientific research practice. Traditional ecological assessment mainly relies on field sampling and ground investigation. Although this method can obtain accurate point data, its limitations are significant : First, it is difficult to reflect the spatial heterogeneity of the reclamation area ; second, it is costly and inefficient, and is not suitable for large-scale long-term dynamic monitoring. Thirdly, the results are easily affected by the subjective experience of the investigators. The rise of remote sensing technology provides a powerful tool to break through the above bottlenecks. The development of multi-source remote sensing platforms such as multi-spectral, hyperspectral, optical and radar has realized multi-dimensional and multi-scale surface information acquisition[2]. By retrieving eco-physical parameters, remote sensing can quantitatively, objectively and dynamically evaluate the effect

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of large-scale reclamation, which has become a key technical means in this field. This paper systematically reviews the application status of remote sensing technology in the evaluation of ecological effects of mining area reclamation, analyzes the current challenges, and looks forward to the future development trend, so as to promote the further maturity and application of this technology.

2. The Main Application of Remote Sensing Technology in the Evaluation of Ecological Effect of Reclamation

2.1. Dynamic Monitoring of Vegetation Restoration

Vegetation restoration is the most intuitive and core indicator to measure the success of reclamation ecology. Remote sensing constructs a series of vegetation indices through the spectral characteristics of vegetation, especially the response to red and near-infrared band reflectance, and realizes the long-term tracking of vegetation coverage, growth and biomass.

(1) Vegetation coverage and growth assessment: Normalized Difference Vegetation Index (NDVI) is the most classic and widely used index, which can effectively reflect the vegetation coverage and green biomass. By analyzing the time-series NDVI data of the reclamation area, the recovery trajectory of vegetation from scratch and from inferior to superior can be clearly revealed[3]. For example, the effectiveness of reclamation projects can be quantitatively evaluated by comparing the trend of NDVI mean values for many years before and after reclamation. In addition, the enhanced vegetation index (EVI) has better performance in dense vegetation areas by introducing blue light bands to correct the effects of atmosphere and aerosols ; advanced products such as leaf area index (LAI) and net primary productivity (NPP) of vegetation can reveal the recovery status of ecosystems more profoundly from the structural and functional levels.

(2) Species identification and succession monitoring: Hyperspectral remote sensing can capture the unique spectral ' fingerprint ' information of different plant species by virtue of its dozens to hundreds of continuous narrow bands. This makes it possible to identify pioneer plants, invasive species and even target plant communities in reclamation areas by using classifiers such as spectral angle mapping (SAM) and support vector machine (SVM), which provides an unprecedented perspective for monitoring the succession process of vegetation communities[4].

2.2. Inversion of Soil Quality Parameters

(1) Soil organic matter (SOM): SOM has specific absorption characteristics in the near-infrared band, which is the physical basis of its remote sensing inversion. By constructing the quantitative relationship between SOM content and spectral reflectance and its transformation form, machine learning algorithms such as partial least squares regression (PLSR) and random forest (RF) were used to realize the spatial mapping of SOM at regional scale and provide key data for evaluating soil fertility restoration[5].

(2) Soil moisture and land surface temperature: Optical remote sensing can retrieve land surface temperature (LST) through thermal infrared band, and LST is closely related to soil moisture content. In areas with low vegetation coverage, LST is an effective indicator for assessing soil water stress and evapotranspiration. The backscattering coefficient of microwave remote sensing, especially synthetic aperture radar (SAR), is very sensitive to the dielectric constant of soil, and has the ability to penetrate clouds and certain vegetation coverage. It provides a reliable means of soil moisture monitoring for cloudy and rainy mining areas.

(3) Soil pollution and erosion: Hyperspectral remote sensing shows a unique spectral response to soils rich in iron ions, clay minerals or organic pollutants, which can be used to preliminarily

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delineate the scope and extent of heavy metal pollution. In addition, by monitoring vegetation cover changes and surface exposure, combined with rainfall data, remote sensing can indirectly evaluate the effect of reclamation measures on soil erosion control.

2.3. Assessment of Soil and Water Conservation Effect

The reclamation project aims to control soil erosion through measures such as terrain remodeling and vegetation restoration. The evaluation of remote sensing technology in this area is mainly reflected in : terrain change monitoring, the use of airborne laser radar (LiDAR) or UAV photogrammetry, can generate high-precision digital elevation model (DEM). By comparing the DEM before and after reclamation, the earthwork volume can be accurately calculated, the slope and aspect changes can be analyzed, and the stability and rationality of terrain remodeling can be evaluated. In the simulation of surface runoff and soil erosion, the parameters such as vegetation coverage, land use type, soil type and topography obtained by remote sensing are used as input data to drive the hydrological model, which can realize the simulation of soil erosion intensity and risk assessment at the regional scale, and quantify the soil and water conservation benefits of reclamation projects.

2.4. Analysis of Landscape Pattern Evolution

The ultimate goal of ecological restoration is to restore a healthy and stable ecosystem, and the landscape pattern is the spatial embodiment of the structure and function of the ecosystem. Remote sensing provides a basis for landscape pattern analysis by providing a long-term sequence of land use/land cover classification maps. Through the calculation and analysis of landscape pattern indexes (such as patch density, edge density, aggregation degree, Shannon diversity index, etc.), the evolution process of landscape in reclamation area from fragmentation and disorder to integrity and order can be quantitatively described.

3. Challenges and Limitations

3.1. Limitations of the Technology Itself

(1) The trade-off of spatial-temporal-spectral resolution: High spatial resolution images usually have long revisit period and high cost, which is difficult to meet the needs of high-frequency dynamic monitoring. Although the free medium and low resolution data can meet the time series analysis, the recognition ability of small reclaimed land or linear features is insufficient. Hyperspectral data is rich in information, but the amount of data is large, the processing is complex, and it is susceptible to atmosphere and noise.

(2) Lack of 'perspective' ability: Optical remote sensing mainly detects surface information and is powerless to 'underground' ecological processes such as soil profile configuration, underground biomass, and root development. This limits its ability to reveal the core mechanism of reclamation ecological effects.

(3) Atmospheric and cloud interference: Optical remote sensing relies heavily on sunny weather. In cloudy and rainy tropical and subtropical mining areas, data missing problems are prominent, affecting the continuity of time series monitoring.

3.2. Uncertainty of Inversion Model and Accuracy Verification

(1) Poor universality of the model: The accuracy of remote sensing inversion models (such as SOM inversion model) based on specific regions and specific time-phase data often decreases significantly when applied to other regions or different periods. The migration ability of the model is a major challenge.

(2) Mixed pixel problem: In low-resolution images, a pixel may contain vegetation, soil, shadows and other ground objects at the same time, and its spectrum is a mixture of these components, which brings difficulties to the accurate inversion of target parameters.

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(3) Scale effect and verification difficulty: Remote sensing inversion is the average value of pixel scale, while ground measurement is point data. The two do not match on scale, resulting in uncertainty of verification results. Obtaining enough ground truth data with reasonable spatial distribution is also a difficult task in itself.

3.3. Complexity of Multi-source Data Fusion and Information Extraction

(1) Data fusion technology challenges: How to effectively integrate multi-source remote sensing data such as optical, radar, hyperspectral, and data with different spatial and temporal resolutions to give full play to their respective advantages is still a technical difficulty.
(2) Dependence of intelligent interpretation model: Efficient remote sensing information extraction is highly dependent on intelligent algorithms such as machine learning and deep learning. The training of these models requires a large number of high-quality labeled samples, and the production of samples is expensive, and the 'black box' characteristics of the model sometimes weaken the interpretability of the results.

4. Future Prospect

In order to meet the above challenges, the application of remote sensing technology in the evaluation of ecological effects of mining area reclamation in the future will show the following development trends :
(1) Deepening to quantification and mechanism: future research will no longer be satisfied with the apparent monitoring of ecological parameters, but will be committed to coupling the multi-parameters of remote sensing inversion with the ecological process model, simulating and predicting the evolution of reclaimed ecosystems from the mechanism, and realizing the leap from 'what' to 'why' and 'how' in the future.
(2) Multi-platform collaboration and space-ground integrated monitoring: It is an inevitable trend to build a three-in-one space-ground integrated collaborative observation network of 'satellite-UAV-ground sensor'. The satellite provides macro and continuous background data, the UAV flexibly responds to local fine monitoring requirements, and the ground sensor provides in-situ, high-frequency verification data. This collaborative model will overcome the limitations of a single platform to the greatest extent.
(3) Deep empowerment of artificial intelligence: AI technologies such as deep learning will play a central role in automatic classification, change detection, and parameter inversion of remote sensing images. By constructing a more powerful model, it is expected to solve the traditional problems such as mixed pixel decomposition, complex scene recognition and model migration, and greatly improve the automation level and accuracy of information extraction.
(4) Service-oriented business applications: With the development of cloud computing platform and the increasing abundance of data resources, it will be possible to develop an online, near real-time, integrated mining area ecological monitoring and evaluation system for mining enterprises and government management departments, and promote remote sensing technology from research to conventional business applications.

5. Conclusion

Remote sensing technology has become an indispensable and powerful tool in the evaluation of ecological effects of reclamation in mining areas. It has achieved remarkable results in the monitoring and application of vegetation dynamics, soil properties, soil and water processes and landscape patterns, and has realized the revolutionary transformation of evaluation work from 'point' to 'surface' and from 'static' to 'dynamic'. However, we must clearly recognize that this technology still faces challenges such as resolution trade-offs, poor model universality, and complex multi-source data fusion. The future development should focus on quantitative

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mechanism research, multi-platform collaborative observation, deep application of artificial intelligence and business system development. Through multidisciplinary integration, the monitoring ability and application value of remote sensing technology should be continuously improved, so as to provide more solid scientific support for the precise restoration and sustainable management of the ecological environment in global mining areas.

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References

[1] Bian, Z., et al. (2020). The impact of open-cut coal mining on the environment and its restoration: A review. Journal of Cleaner Production.

[2] Wulder, M. A., et al. (2020). Remote sensing of environment: Current applications and future directions. Remote Sensing of Environment.

[3] Zhang, Z., et al. (2019). Monitoring vegetation recovery after coal mining in China using time-series NDVI. Ecological Indicators.

[4] Govender, M., et al. (2019). A review of hyperspectral remote sensing for the detection and mapping of invasive alien plants. ISPRS Journal of Photogrammetry and Remote Sensing.

[5] Viscarra Rossel, R. A., et al. (2016). A global spectral library to characterize the world's soil. Earth-Science Reviews.