Proceedings of ICEGEE 2025 Symposium: Sensor Technology and Multimodal Data Analysis 2025
DOI: 10.54254/2753-8818/2025.AU24806

Research on the Ecological Impact of Land Use Change Based on Remote Sensing Technology: A Review of Process Identification and Monitoring Applications

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Abstract. Land use change is a key factor triggering ecosystem changes. Activities such as urbanization, deforestation and agricultural expansion are constantly changing the surface pattern, leading to the decline of biodiversity, enhanced climate feedback and the degradation of ecosystem service capacity. This paper takes remote sensing technology as the entry point, systematically sorts out the main ecological impacts caused by land use changes, and focuses on analyzing the monitoring and evaluation functions of remote sensing in the processes of urban expansion, forest loss, soil degradation and green space reduction. Studies have found that remote sensing indices (such as NDVI, EVI, LAI) and classification techniques (such as OBIA, random forest) can effectively identify ecological change trends and enhance the scientific nature of ecological restoration effect assessment and policy response. This paper emphasizes the future potential of the integration of remote sensing and multi-source data, the development of intelligent algorithms, and the integration of interdisciplinary models, aiming to provide technical support and methodological references for regional sustainable land management and environmental governance. .

Keywords: Remote sensing monitoring, Ecosystem services, Urban expansion, Biodiversity, Land use

1. Introduction

Land use change is one of the most concerning environmental issues in the Anthropocene. With the intensification of human activities such as urbanization, agricultural expansion and deforestation, the surface landscape is changing at an unprecedented speed. These changes have had a profound impact on the structure and function of ecosystems, including the loss of biodiversity, enhanced climate feedback, and the decline in ecosystem service capacity [1,2]. Therefore, timely and effective monitoring of these changes has become the key to achieving sustainable development.

This article aims to explore the ecological impacts caused by land use changes from the perspective of remote sensing. The article first reviews the main damages caused to the ecosystem by activities such as urbanization, deforestation and agricultural intensification, and then focuses on introducing the specific applications of remote sensing technology in ecological impact monitoring.

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Finally, based on the existing achievements, suggestions and prospects for future research and policy-making are put forward.

2. Overview of remote sensing technology

Remote sensing technology is an efficient monitoring method to obtain ground object information from a long ditance by using sensors. The basic principle is to retrieve the surface characteristic information by receiving the electromagnetic wave signal reflected or radiated by the ground object. In the research of land use change, remote sensing technology has been widely used to extract land use/land cover (LU/LC) type, monitor change trends and assess ecological impact due to its advantages such as wide coverage, high updating frequency and rich data types. Common sources of remote sensing data include the Landsat series (United States Geological Survey), Sentinel-2 (European Space Agency), and MODIS (NASA). Common remote sensing data sources include Landsat (United States Geological Survey), Sentinel-2 (European Space Agency) and MODIS (NASA). Landsat provides continuous observation data since 1972, with a spatial resolution of 30 meters and a coverage period of 16 days, making it suitable for long-term dynamic monitoring of land use. Sentinel-2 has a spatial resolution of 10 meters and a revisit cycle of 5 days, and is capable of capturing details such as urban expansion and vegetation changes more accurately [3,4].

Although MODIS has a relatively low spatial resolution (250-1000 meters), it has a wide coverage and a high imaging frequency (1-2 times a day), making it highly suitable for monitoring large-scale ecological processes, such as seasonal vegetation changes and droughts. In terms of data processing, the classification methods of remote sensing images are mainly divided into three categories: supervised classification, unsupervised classification and Object-Oriented Classification (OBIA) [5]. Supervised classification requires artificially providing training samples. Common methods include the maximum likelihood method (MLC) and random forest (RF) [6-8]. The former classifies pixels based on statistical probability and is suitable for regularly distributed land types. The latter is based on the combination of decision trees, performs well in processing large data sets, has strong anti-noise ability, and is suitable for multi-source data fusion. The advantage of supervised classification lies in its high accuracy, but it relies on high-quality samples and human participation, and there is a certain degree of subjectivity. Unsupervised classifications such as K-means clustering do not rely on prior sample data and automatically group pixels through algorithms. This method has high computational efficiency and is suitable for areas with insufficient prior information. However, the classification results may not conform to the types of real ground objects and require manual correction in the later stage. Object-oriented Classification (OBIA) combines the spectral features and spatial information (such as texture and shape) of an image. It first segments the image into several patches and then performs classification. Compared with traditional pixel classification, OBIA is more suitable for high-resolution images, can reduce the "salt-and-pepper effect", and is widely used in urban construction and land subdivision research [9,10]. According to the purpose of the study, appropriate phase images can be selected for change detection. The selection of spatial and temporal resolution of remote sensing images has an important influence on the research results, which are generally determined according to the spatial scale of the research area and the time requirement of the research object.

In addition, remote sensing can also quantitatively characterize land use type change through vegetation index (such as NDVI), water body index (NDWI), and building index (NDBI) to assist ecological change assessment. Combined with GIS spatial analysis, remote sensing technology has increased its potential in land use change research, and has become an important tool in global change, urban expansion, biodiversity conservation and other fields.

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3. Ecological impacts of land use change based on remote sensing

Land use change is widely regarded as one of the most crucial driving forces for ecosystem transformation in the Anthropocene. Whether it is urban expansion, deforestation, or agricultural intensification, changes in land use patterns have had a profound impact on the environmental system. This section will review the main ecological impacts brought about by land use change, including the effects on vegetation, climate, biodiversity and ecosystem services, and at the same time explore how remote sensing technology can monitor, quantify and interpret these impacts at multiple scales.

3.1. Ecological consequences of land use change

Driven by rapid urbanization, agricultural expansion and deforestation, land use change has become an important driver of global ecological degradation. Over the past few decades, natural landscapes have been replaced by man-made land use, significantly altering the structure of ecosystems, reducing biodiversity, and disrupting the carbon cycle and hydrological cycle.

3.1.1. Urban expansion and ecological disruption

Urbanization is one of the most significant land use changes in remote sensing monitoring. In recent years, in regions such as Asia, Africa and Latin America, remote sensing images show that the impermeable surface area of cities has increased rapidly. This change has caused a series of adverse effects on the urban ecosystem.

Firstly, impermeable surfaces (such as concrete roads and buildings) replace vegetation coverage, reducing the surface's evapotranspiration capacity and heat absorption capacity, thereby causing the surface temperature to rise and forming the urban heat island effect (UHI). This effect has exacerbated the warming of the local climate in cities and increased the demand for energy consumption. Secondly, the fragmentation of green Spaces hinders ecological connectivity, affects species migration routes, leads to habitat loss, and reduces the biodiversity of cities. Furthermore, impermeable surfaces reduce the infiltration space for rainwater, increase surface runoff, and thereby raise the risk of urban flooding. Some studies have also found that these urban ecological degradation problems show a certain correlation trend with the health conditions of residents (such as respiratory diseases).

Therefore, the environmental problems brought about by urban expansion urgently need to be identified and quantified in a timely manner. Against this background, remote sensing technology has played a key role. By classifying and analyzing satellite images from different periods, remote sensing can effectively monitor the expansion of urban construction scope, the reduction of green Spaces, and the spatial distribution of the heat island effect, thereby providing data support for urban planning and environmental governance.

3.1.2. Deforestation and biodiversity loss

Deforestation is an important driver of global ecosystem degradation, especially prominent in tropical regions such as the Amazon, Southeast Asia and Central Africa. Remote sensing observation results show that the forest coverage rate in these areas has been continuously declining, bringing multiple ecological impacts.

The reduction of forests directly destroys the habitats of a large number of species and weakens the key service functions provided by the ecosystem, such as carbon sink capacity, soil conservation

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and water conservation. Studies show that after forests are artificially divided, ecological patches become smaller and marginal effects intensify, thereby limiting the living space of core species, leading to a decline in the number of endangered species and changes in the structure of biological communities. Furthermore, forest degradation is also closely related to regional climate anomalies, such as reduced precipitation.

Facing this continuous damage, remote sensing technology has become an efficient tool for achieving large-scale and long-term forest change monitoring. By using high-resolution images and vegetation indices (such as NDVI), the scope, frequency and ecological consequences of deforestation can be accurately detected, providing a scientific basis for biodiversity conservation, forestry policy assessment and the implementation of international emission reduction agreements.

3.1.3. Agricultural intensification and soil degradation

Although agriculture is an important foundation for ensuring food security, its expansion often comes at the expense of ecological stability. Monoculture and excessive reclamation can lead to soil erosion, nutrient loss and groundwater pollution. Remote sensing tools (such as NDVI and SAVI) are often used to assess the impact of planting intensity on vegetation health and land degradation.

In addition, agricultural intensification is also accompanied by excessive use of pesticides and chemical fertilizers. These chemical substances seep into water bodies, causing eutrophication and threatening aquatic biodiversity. In irrigation areas, excessive extraction of groundwater can also disrupt the hydrological balance. This process can be monitored through time series remote sensing data of vegetation humidity and surface subsidence.

3.1.4. Green space decline and ecosystem service reduction

Urban green Spaces are crucial for regulating the microclimate, purifying the air and water bodies, and maintaining the mental health of residents. However, with the change of land use, the area of green space has continued to decrease, resulting in a significant decline in the ecosystem service function. The NDVI time series research based on MODIS and Sentinel-2 shows that the vegetation health in high-density urban areas is on a downward trend, and this trend is closely related to the rise in surface temperature and the decline in air quality.

Overall, land use change seriously threatens the long-term sustainability of ecosystems through the combined effect of direct pathways (such as habitat loss and soil erosion) and indirect pathways (such as climate feedback and biogeochemical cycle changes).

3.2. Applications of remote sensing in monitoring ecological impact

Remote sensing technology, due to its ability to monitor landscape dynamics across temporal and spatial scales, has become a core tool for assessing the ecological consequences of land use changes. Multiple application directions are constantly deepening, which is conducive to a comprehensive understanding of how geomorphic changes affect ecosystem health.

3.2.1. Urban dynamics detection

Urban expansion is one of the most widely applied fields in remote sensing technology. By classifying satellite images from different periods, researchers can draw urban expansion maps and quantify the speed of land transformation. Built-up area indices such as NDBI and impermeable

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surface estimation algorithms can effectively identify newly developed areas and encroachment on agriculture or forest land.

By introducing advanced classification techniques (such as OBIA), the identification accuracy of heterogeneous built environments in cities has been significantly improved. When combined with the thermal infrared band, the intensity and distribution range of the heat island effect can also be detected, providing a basis for urban climate resilience planning.

3.2.2. Vegetation health monitoring

Remote sensing vegetation indices (such as NDVI, EVI and LAI) are important means for ecosystem health monitoring. NDVI can reflect the photosynthesis and coverage degree of vegetation, and is applicable to deforestation, drought stress and agricultural yield monitoring. EVI has more advantages in areas with dense vegetation or those disturbed by the atmosphere. LAI reflects the total leaf area per unit ground surface and is a key parameter for evaluating canopy structure, water evapotranspiration and carbon cycle.

Through the time series analysis of MODIS and Sentinel-2, the seasonal and long-term vegetation succession trends can be identified. These indicators are also often used to evaluate the effect of ecological restoration. For instance, the NDVI value of the Loess Plateau in China has been continuously rising over the past 20 years, indicating that the "Returning farmland to Forest" project has achieved positive results. The decline of NDVI at the urban edge reflects the degradation pressure caused by human activities, providing remote sensing support for ecological management and policy-making.

3.2.3. Landscape fragmentation and ecological connectivity

Landscape indicators extracted based on remote sensing classification data (such as patch density, edge density, and connectivity index) can be used to quantify the degree of fragmentation. With the help of tools such as Fragstats or GIS models, the spatial structure of ecosystems can be evaluated, supporting habitat suitability modeling and biodiversity conservation planning.

Fragmented maps reveal that even if the total area of green Spaces remains unchanged, their spatial distribution may still become more fragmented during urban expansion, weakening the functional connectivity required for wildlife migration.

3.2.4. Ecosystem services and carbon assessment

Remote sensing data provide the necessary biophysical parameters for ecosystem service modeling and can be input into spatial modeling tools such as InVEST and ARIES. For example, aboveground biomass can be estimated by using vegetation index and heterologous growth equation, thereby conducting dynamic simulation of carbon storage.

Furthermore, the study also quantified the decline in service functions such as flood regulation and water quality purification caused by the reduction of wetlands by using the Landsat land cover classification results. The surface temperature (LST) obtained by remote sensing has also been used for the assessment of urban ecological services, confirming that it is highly correlated with the decline in cooling service capacity.

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4. Recommendations and future directions

As the compound impact of land use change on the ecosystem intensifies increasingly, there is an urgent need to optimize monitoring strategies and promote sustainable land management. Although remote sensing technology has been widely applied, it still faces challenges in terms of accuracy, efficiency and applicability.

First of all, the integration ability of multi-source remote sensing data should be given priority for development. Combining optical images (such as Sentinel-2), radar data (such as Sentinel-1) with high-resolution commercial images can make up for the limitations of a single sensor in cloud coverage seasons or complex terrains, improve classification accuracy and enhance ecological modeling capabilities.

Secondly, it is crucial to promote the development of intelligent classification and change detection algorithms (especially those based on machine learning and deep learning). These methods can handle large-scale time series data and identify ecological micro-changes that are difficult to detect by traditional techniques. However, its implementation effect depends on the support of high-quality samples and powerful computing resources.

Thirdly, remote sensing data should be integrated with socio-economic and ecosystem models to promote interdisciplinary research. By introducing variables such as population, policies and climate, it is possible to move from descriptive analysis to causal inference and scenario simulation, which is particularly suitable for evaluating the policy effects such as conservation zoning and vegetation restoration subsidies.

In addition, a long-term ecological monitoring framework based on remote sensing needs to be established. Regular assessment of standardized indicators (such as NDVI, LST, and fragmentation index) helps track ecological trends, evaluate restoration effects, and provide a basis for adaptive management at the regional and national levels.

Finally, the collaboration among scientific researchers, policymakers and local communities should be strengthened to transform remote sensing achievements into operational strategies. Platforms such as Google Earth Engine can enhance the convenience of obtaining and processing remote sensing data and support multi-party participatory ecological planning processes.

Against the backdrop of accelerated land transformation, remote sensing technology will continue to play a key role in ecological research and environmental governance. Future development needs to focus on technological innovation, data integration, platform accessibility and policy relevance to achieve more effective ecological response solutions.

5. Conclusion

This paper studies the ecological impacts brought about by land use change by using remote sensing technology. Through the analysis of phenomena such as urban expansion, deforestation and agricultural intensification, the transformation of the ecosystem on spatial and temporal scales is revealed.

Studies show that land use change can lead to a decline in biodiversity, enhanced climate feedback and the deterioration of ecosystem service functions. Urbanization leads to an increase in surface temperature and a decline in green connectivity. Deforestation weakens carbon storage and the quality of habitats, while agricultural activities damage the soil and water environment. Remote sensing tools such as NDVI, LST, OBIA, etc. can effectively identify these ecological disturbances and provide data support for long-term monitoring.

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Looking forward to the future, the integration of multi-source remote sensing data and machine learning algorithms should be strengthened to improve the monitoring accuracy. Meanwhile, integrating remote sensing data with socio-economic models is conducive to carrying out more targeted ecological management. Collaboration among scientific research, policies and the public will also become an important guarantee for promoting sustainable land management.

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