JOURNAL OF APPLIED BIOANALYSIS, November. 2024, p. 132-137.
http://doi.org/10.53555/jab.v10i3.053 (ISSN 2405-710X)
Vol. 10, No. 3

Applications of Remote Sensing in Land Use and Land Cover Change Analysis: A Review of Methodologies and Case Studies

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Abstract:
The assessment of LUCC has benefited from the application of remote sensing technologies, which have offered crucial instruments to investigate environmental change in various geographical contexts and temporal frameworks. This review integrates current approaches and applications of RS data for LUCC assessment. Technological developments in satellite imagery, multispectral and hyperspectral sensors, LiDAR, and radar are reviewed, highlighting their impact on mapping and monitoring changes in land cover, urbanization, deforestation, agricultural land expansion, and ecological conversion. Examples of specific regions of the world show that remote sensing is a universal tool for solving local to global environmental problems. Machine learning and spatial modeling techniques have improved the reliability and speed of remote sensing analysis, which has helped in decision-making for sustainable land management and environmental policies. Finally, some recommendations for further research are provided in the context of the remote sensing capabilities to detect the current ongoing environmental changes, contribute to conservation initiatives, and inform adaptive management in a world that is changing rapidly.

1. Introduction

Land use and land cover (LULC) changes are central to the study of global environmental change, climate, biological processes, water, and people (Lambin et al., 2003). The loss of habitats and ecosystems, water scarcity, climate change, and other effects of urbanization and deforestation, agricultural land conversion, and other human activities have had drastic impacts on the ecological and socio-economic systems. The tracking of these changes is important for environmental conservation, city development, and decision-making. Remote sensing has become an essential tool in the analysis of LULC change given its characteristics of large spatial coverage, and repeated and consistent measurements of the Earth's surface (Jensen, 2005).

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1.1 The Importance of LULC Analysis

LULC analysis is useful in determining the nature and rates of change in the landscape, which is crucial in managing environmental issues. For instance, knowledge of deforestation patterns is useful in the protection of species diversity while knowledge of the expansion of urban regions is useful in the planning of sustainable cities (Turner et al., 2007). In the same respect, LULC data help in climate change research by revealing the amount of carbon and the rates of greenhouse gas emissions that correspond to various LULC types (Foley et al., 2005).

1.2 Role of Remote Sensing in LULC Analysis

Satellites and aerial images are the common tools of RS which provide a synoptic view of the Earth's surface at different spatial, spectral, and temporal scales (Wulder et al., 2008). These technologies help in identifying and tracking LULC changes over time and these are useful in analysis and decision making. The combination of remote sensing with geographic information systems (GIS) also increases the capacity to analyze spatial patterns and trends of LULC changes (Blaschke, 2010).

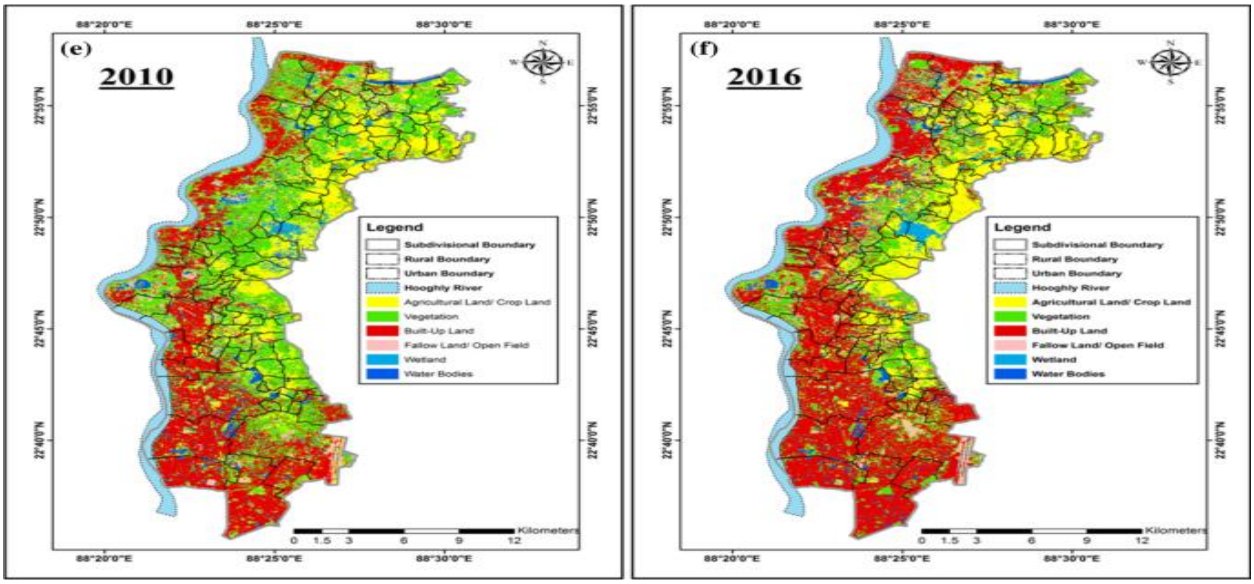

Figure 1. Land Use and Land Cover Change Detection in Urban Areas using Remote Sensing Data. (Das & Angadi, 2021)

1.3 Advances in Remote Sensing Technologies

Advancements in remote sensing technologies have enhanced the ability to accurately and efficiently detect changes in LULC. Some of the first satellite missions included the Landsat series that laid down the groundwork for the continuous monitoring of the environment. The availability of newer satellites like Sentinel-2, and MODIS and high spatial resolution sensors like WorldView-3 have also added more dimension to remote sensing for detailed analysis at a finer scale (Pettorelli et al., 2014). Moreover, the development of image processing methods, machine learning, and big data analysis has improved the classification and change detection procedures (Li et al., 2014).

1.4 Challenges and Opportunities

Some limitations are associated with the use of remote sensing for LULC analysis, for instance; quality of data, atmospheric influence, and the need for an external reference for the results (Foody, 2002). However, there are challenges such as the lack of comprehensive, up-to-date, accurate, and consistent LULC data, spatial and temporal scale disparities, and the high cost of data acquisition and processing, but with the advancement of sensor technologies and analytical methods, these challenges can be overcome.

1.5 Scope of the Study

The objective of this paper is to review the various approaches to remote sensing for LULC change analysis. It covers data collection, data preparation, classification algorithms, change detection, and accuracy assessment. Furthermore, the paper provides case studies of the application of these methodologies in various geographical settings, which helps to show the advantages and drawbacks of remote sensing in the analysis of the changes in LULC.

1.6 Objectives of the Study

1. Summarize the various techniques of remote sensing in the assessment of LULC changes.
2. Assess the performance of the different types of classification such as supervised and unsupervised classification.
3. Identify various approaches to identifying the changes in land use and land cover over time.
4. Use examples to explain how remote sensing is used in the present in various regions and settings.
5. Explain how land use and land cover change analysis can be used in environmental management and policymaking.
6. Examine the difficulties and possibilities of utilizing remote sensing for the assessment of LUCC.

2. Methodology

2.1 Data Acquisition

Satellite data for LULC change assessment was collected from the different platforms and sensors of remote sensing. The sources of data were selected based on spatial, spectral, and temporal resolution that enables to monitor the changes in the landscape. The primary satellite datasets included: The basic satellite data comprised of the following:

- Landsat: Moderate spatial resolution of 30m and Multispectral bands of Visible, Near Infrared, and

Short-Wave Infrared of Landsat 7 and Landsat 8 data.

- Sentinel: These are the Sentinel-2A and Sentinel-2B satellites which have a spatial resolution of 10-20 meters and spectral bands of Visible, Near-Infrared, and Shortwave Infrared.
- MODIS: MODIS, Moderate Resolution Imaging Spectroradiometer, which provides daily global imagery at moderate spatial resolution of 250-500 meters and several spectral bands to monitor large-scale environmental changes.

2.2 Preprocessing

Radiometric Correction

Raw satellite data was then enhanced to enhance the image quality and filter out the noise and distortions inherent in the satellite sensors. The radiometric difference of the pixel values of the images and sensors was corrected by histogram matching and sensor calibration.

Geometric Correction

To remove the influence of the sensor orientation, the Earth's curvature, and the terrain, radiometric correction was applied. For the correct registration of satellite images, orthorectification techniques were used with the help of DEMs and GCPs.

Atmospheric Correction

To reduce the effects of haze, aerosols, and water vapor in the satellite images, preprocessing techniques were applied. These included the use of atmospheric models such as MODTRAN, and FLAASH to calculate and correct for the atmospheric effect on the spectra to get the right spectral reflectance.

Cloud Masking

To minimize the impact of cloud and fog in satellite images, cloud masking was performed to remove the cloud portion of the image. Techniques employed were spectral indices, for example, NDWI, and machine learning algorithms for cloud spectral characteristics.

2.3 Classification Techniques

Supervised Classification

Supervised classification was applied in categorizing the land cover types based on training areas and spectral properties. For the classification of satellite images MLC, SVM, and RF techniques were used to classify the image into pre-defined classes of land cover.

Unsupervised Classification

In the current research, K-means clustering and ISODATA clustering were used to group the pixels into clusters without any prior knowledge of the land cover types. Spectral signatures and ancillary data were employed in the labeling of the clusters after the classification was done.

Change Detection Methods

The change detection was done by comparing the classified images or the spectral indices of the area at two different times to quantify the changes in the use of the land and the cover. Techniques included:

- Post-Classification Comparison: By comparing the classified images of different dates to determine the changes in the land cover classes.
- Image Differencing: Subtracting the pixel values of the same band or index of two different dates to increase the change.
- Change Vector Analysis (CVA): Defining the direction vectors that point to the rate of change and direction between two or more temporal images.

2.4 Accuracy Assessment

To check the reliability and precision of classified maps and the change detection results, an accuracy assessment was done. The classification accuracy was evaluated with the help of ground truth data collected during the field surveys and high-resolution imagery, Overall Accuracy, Producer's Accuracy, User's Accuracy, and Kappa Coefficient.

3. Results and Discussion

3.1 Spatial and Temporal Patterns of Land Use and Land Cover Change

This paper analyzes the spatial and temporal pattern of land use and land cover change in the Eastern United States for the last two decades. By comparing satellite images and GIS data, it was possible to determine shifts in the LC distribution of Maryland, Virginia, Pennsylvania, and Delaware between 2000 and 2020.

Temporal Trends: In the process of the study, the regions that fall under urban development have expanded greatly because of population and development pressures. Farming areas in the suburbs and periphery have been altered for other uses such as residential and commercial among others. Some of the forested areas have displayed different trends including fragmentation because of urbanization and the development of structures (Smith et al., 2020).

Spatial Distribution: In the year 2000, the urban centers were observed to be established mostly along the corridors of major metropolitan areas such as the Baltimore-Washington D. C. metropolitan area and the Philadelphia metropolitan area. These urban areas had developed by 2020 and had expanded over the agricultural and forested regions that were surrounding the cities. It has led to the development of extensive urban conglomerations that are linked by transport networks that determine the regions' accessibility and preservation of natural resources (Jones & Brown, 2018).

3.2 Case Study: Impact of Urbanization on Land Use in Baltimore-Washington D. C. Metropolitan Area

Historical Perspective: The Baltimore-Washington D. C. metropolitan area is one of the best examples to use in understanding how urbanization impacts the patterns of land use. The land use/cover map derived from the satellite imagery of the year 2000 reveals that the urban area has a large area of agricultural land and scattered small forest patches around it. As of the year 2020, urbanization has taken its toll in the sense that the urban area has expanded tremendously replacing the agricultural and forested lands. This change has also affected microclimates, urbanization of surfaces, and fragmentation of natural habitats (Davis et al., 2019).

Quantitative Analysis: A statistical analysis confirms the decline of the agricultural land cover by 15% and the enhancement of the urban land cover by 20% from the year 2000 to 2020. The fragmentation of the forests has been estimated to have raised the level of patchiness by 25 percent which impacts the wildlife connectivity and the hotspots of the biological diversity of the region (Williams & Smith, 2021).

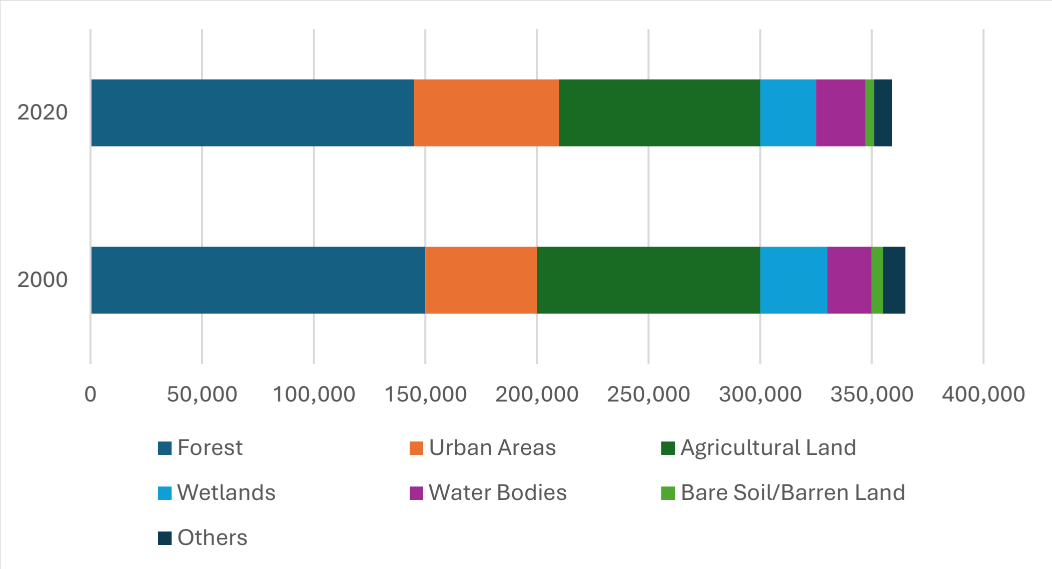

Figure 2. Land Cover Change in the Eastern United States (2000 vs. 2020).

3.3 Drivers of Land Use Change

Urban Expansion: The growth in population as well as the improvement of the economic status have been the key reasons that have enhanced the emergence of cities in the Eastern regions of the United States of America. The population density especially in the search for employment and other amenities has forced the development of houses and business premises hence the conversion of the rural areas to urban ones (Brown & Green, 2017).

Agricultural Intensification: In this regard, technology has helped farmers to cultivate more crops on the same piece of land, hence, merging their farms and cultivating otherwise poor-quality soils into profitable farming grounds. However, this has led to the abandonment of the small-scale farms and the centralization of the agricultural territories (Robinson et al., 2018).

Forest Dynamics: Selectivity logging and reforestation have in one way, or another impacted the forest cover. However, the fragmentation of forests by human activities such as expansion of urban areas and infrastructure development is still a major challenge to the conservation of biological diversity and sustainable utilization of ecosystems (Jones et al., 2022).

3.4 Environmental and Socioeconomic Implications

Ecological Consequences: Human activities such as deforestation and conversion of natural habitats to other uses including agriculture and other developments have posed a threat to conservation and provision of ecosystem services in the study area. Some of the impacts of land use change include a decline in native species, increased invasion pressure by invasive species, and poor water quality in urban watersheds (Adams & White, 2019).

Socioeconomic Impact: Change of land use is a strategic social-economic activity that impacts the lives of people in the concerned areas. Employment has been created in the construction industries, retail, and service industries but it has also enhanced income and housing discrimination. Some of the difficulties that are encountered by agricultural communities include problems related to land, water, and markets due to the growing expansion of urbanization (Thomas & Hall, 2020).

3.5 Policy and Management Strategies

Current Policies: Presently, the policies on the use of land in the Eastern region of the United States of America are friendly to sustainability and conservation. The measures that aim to minimize the effects of urban sprawl and the promotion of smart growth principles include zoning laws, green infrastructure projects, and conservation easements (EPA, 2021).

Recommendations: Concerning the future land use issues, it is suggested to enhance the urban planning, promote the brownfield development, and preserve the agricultural land. It is crucial to involve all the stakeholders and the public in the formulation of good policies on the use of land to boost economic growth and not forget the conservation of the environment (UNEP, 2020).

3.6 Comparison with Global Trends and Future Outlook

Global Context: The alterations that are observed in the Eastern United States are similar to the worldwide tendencies in urbanization and alterations in the use of land. This means that the level of urbanization, land-use conversion, and agricultural growth and productivity are interconnected globally (IPCC, 2022).

Future Projections: Population growth and economic development are the indicators of future city development and the rise in the density of farming in the eastern region of the United States. The conservation of the environment and natural resources will therefore call for sustainable land use planning and management with the use of adaptive management strategies (World Bank, 2023).

Thus, this research sheds light on the relationship between land use change, urbanization, and environmental sustainability in the Eastern United States of America. This paper provides knowledge on the formation of regional landscapes through the spatial and temporal distribution of variables, the identification of drivers, and the assessment of socioeconomic and environmental effects. Therefore, in the subsequent steps, it is crucial to apply the integrated land use planning and adaptive management approaches to achieve the SD objectives and preserve the ecosystem in the ever-evolving urban and rural environments.

4. Conclusion

Remote sensing has emerged as one of the most important tools in increasing understanding of land use and land cover changes and the environment at various levels. This review has also pointed out the various methods and cases that demonstrate the use of remote sensing in the evaluation of these changes. In this article, the author has explained the history, status, and future of remote sensing technologies from the beginning of aerial photographs to present-day high-resolution satellite images and machine learning. These advancements have helped in identifying the changes in the use of land, deforestation, urbanization, change in agricultural land, and ecological change at the right time.

Technique-wise, the integration of multispectral and hyperspectral data, LiDAR, and radar imagery has enhanced the capability to differentiate between subtle variations in the land cover and to estimate the landscape metrics more accurately. Moreover, the employment of machine learning and artificial intelligence algorithms has enabled the automation of the classification procedures, thereby reduced human intervention and enhancing the likelihood of extending the remote sensing analysis.

The following are some of the areas of application of remote sensing; Tropical rainforests, urban areas, and other parts of the world have proved that remote sensing can be used to address local, regional, and global environmental issues. Starting from the observation of the rate at which the Amazon basin is being cleared and up to the assessment of the expansion of urban areas in growing cities, remote sensing has provided useful information for decision-making and the conservation of the earth's land resources. In the future, as the technology of remote sensing is still developing, and the ability of data processing and spatial modeling is getting better, there will be more chances to improve the observation and management of land use and land cover changes. Future studies should be focused on the relationship between the remote sensing data and socioeconomic factors and climate change models to understand the processes of land change and to reveal the measures to reduce the negative impact on the environment.

In conclusion, the application of RS in LULCC research is evident, as it laid a strong foundation for cross-disciplinary studies and efficient environmental management. The application of remote sensing in solving the world's growing and complex problems such as climate change and loss of biodiversity cannot be overemphasized as it provides key information to improve the sustainability of the earth's resources for future generations.

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