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Remote sensing-based monitoring of land cover changes along the expressway project in Da Nang using geospatial analysis and machine learning

Giám sát sự thay đổi lớp phủ đất dọc theo dự án đường cao tốc ở Đà Nẵng dựa trên ảnh viễn thám sử dụng phân tích không gian địa lý và thuật toán học máy

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Abstract

Infrastructure development significantly impacts the surrounding environment. This study utilizes geospatial and remote sensing methodologies to analyze land cover change detection along the La Son – Tuy Loan expressway in Hoa Bac commune, Hoa Vang district of Da Nang. The study focuses on the expressway section from Mui Trau tunnel to the Da Nang-Hue provincial boundary, a buffer zone of 1000 meters is established for analysis. Land cover statistics were derived from Sentinel-2 imagery for the years 2019 and 2024. Random forest classifiers were employed to construct detailed land cover maps, revealing notable patterns in the area. Geospatial analyses indicate a significant enhancement in greenness within the buffer zone, with vegetation area increasing from 18.27 km² to 20.91 km²—an increase of over 14%—while barren land decreased by 47%. These findings provide crucial insights for local government and urban planners, aiding in the sustainable development strategies of the city by highlighting the patterns of land cover changes in Da Nang over time.

Keywords: Land cover change; remote sensing; geospatial analysis; random forest.

Tóm tắt

Phát triển cơ sở hạ tầng có tác động đáng kể đến môi trường xung quanh. Nghiên cứu của chúng tôi sử dụng phương pháp không gian địa lý và ảnh viễn thám để phân tích sự thay đổi lớp phủ đất dọc theo đường cao tốc La Sơn – Túy Loan, tại xã Hòa Bắc, huyện Hòa Vang, Đà Nẵng. Chúng tôi tập trung vào đoạn đường cao tốc từ hầm Mũi Trâu đến ranh giới Đà Nẵng - Huế, vùng đệm 1000m được thiết lập để phân tích sự thay đổi của lớp phủ đất. Số liệu thống kê về độ che phủ đất được lấy từ hình ảnh Sentinel-2 trong năm 2019 và 2024. Các mô hình dựa trên thuật toán rừng ngẫu nhiên được sử dụng để xây dựng bản đồ che phủ đất chi tiết, giúp đưa ra các thông tin về sự thay đổi của bề mặt đất trong khu vực. Các phân tích không gian địa lý cho thấy sự cải thiện đáng kể về độ che phủ thực vật trong vùng nghiên cứu, với diện tích thảm thực vật tăng từ 18,27 km^2 lên 20,91 km^2 - tăng hơn 14%, trong khi đất cằn cỗi giảm 47%. Kết quả nghiên cứu này cung cấp thêm những thông tin quan trọng cho công tác quy hoạch đất, hỗ trợ các chiến lược phát triển bền vững của thành phố bằng cách thống kê sự thay đổi của lớp phủ đất ở Đà Nẵng theo thời gian.

Từ khóa: Thay đổi bề mặt đất; viễn thám; phân tích không gian địa lý; thuật toán rừng phân loại.

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1. Introduction

The rapid changes in land use and land cover, particularly in developing nations, are a significant concern. These changes are frequently characterized by the expansion of urban areas into surrounding natural or agricultural lands, a phenomenon known as urban sprawl. Additionally, land degradation and the transformation of natural landscapes into other uses, such as agriculture or infrastructure development, are common occurrences. These land use and land cover changes can lead to adverse effects on the natural environments [1].

The transformation of natural ecosystems into manmade landscapes, such as expressways, can have profound impacts on local and regional environments. The loss of natural habitats, fragmentation of ecosystems, and disruption of ecological processes can lead to a decline in biodiversity, soil degradation, and altered local hydrological characteristics. Hence, monitoring the patterns of land cover changes is essential for developing effective land use policies and management strategies that ensure environmental sustainability [2].

In recent years, geospatial technologies, including remote sensing and geographic information systems (GIS), have emerged as invaluable tools for the monitoring, mapping, and analysis of land cover changes [3]. Satellite remote sensing, in particular, offers a powerful approach to tracking land-use changes with high temporal resolution and at a lower cost compared to traditional methods. The utility of remote sensing data lies in its ability to provide a comprehensive overview, consistent coverage, and real-time data collection. Consequently, digital data derived from satellite imagery allows for precise calculations of various land cover and land use categories as well as effectively monitoring changes in land cover [4].

Expressways play a crucial role in providing essential social and economic functions and services to local communities, including transportation, travel, cultural exchange, and the movement of materials. However, they also lead to a variety of negative ecological impacts, such as ecosystem deterioration and landscape fragmentation. These adverse effects arise from factors like landscape segmentation, noise disturbances, and edge effects. Hence, understanding the spatial and temporal changes in land cover caused by the infrastructure development projects is an urgent need in developing countries [5,6].

This research employs geospatial and remote sensing methodologies to investigate land cover change detection along the La Son – Tuy Loan expressway, specifically within the Hoa Bac commune of the Hoa Vang district in Da Nang. The study focuses on a segment of the expressway, extending from the Mui Trau tunnel to the boundary between Da Nang and Hue provinces. A buffer zone of 1000 meters is used for land cover change analysis. Utilizing Sentinel-2 satellite imagery from the years 2019 and 2024, this study aims to derive land cover comparisons that reveal changes over this period of time. To facilitate the analysis, random forest classifiers are utilized to create detailed land cover maps, which helps highlight important patterns and trends in land cover changes in the area.

2. Research methodology

The research methodology employed in this study (refer to Figure 1) integrates geospatial and remote sensing techniques to analyze land cover changes along the La Son – Tuy Loan expressway. Initially, Sentinel-2 satellite imagery from 2019 and 2024 is utilized to capture the temporal dynamics of land cover in the designated study area. To classify and map the land cover categories, random forest classifiers are applied, leveraging its robustness and accuracy in handling complex datasets. The acquisitions of the Sentinel-2 images and random forest-based pattern classifications are performed in Google Earth Engine (GEE) code editor (https://earthengine.google.com/). Additionally, the resulting maps are prepared in QGIS (https://qgis.org/).

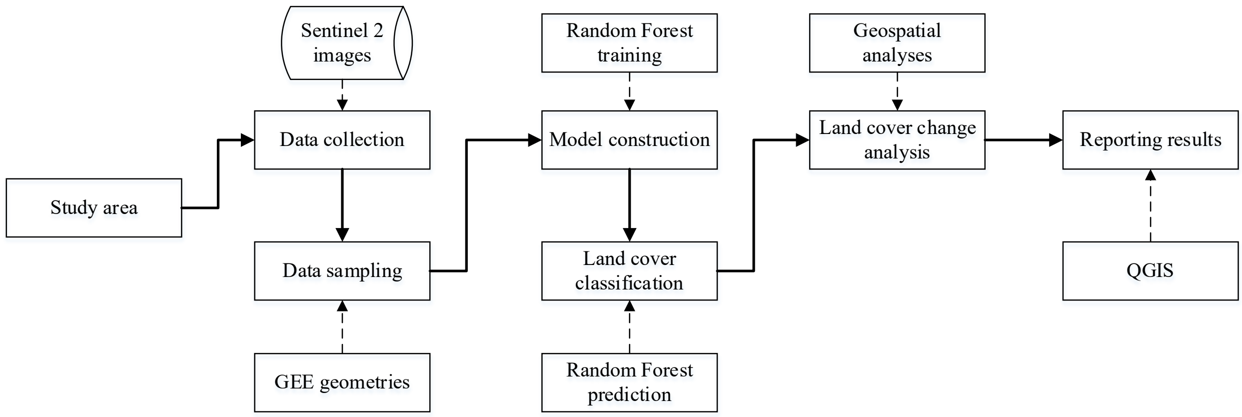

Figure 1. Framework for research methodology

2.1. The study area and data collection

Da Nang, located in central Vietnam, is a vibrant city renowned for its strategic geographic position along the coast of the East Sea. Da Nang serves as a significant hub for urbanization and economic development, acting as a crucial link between the northern and southern regions of the country. Da Nang has experienced rapid economic growth and landscape transformation. The city is also recognized for its commitment to sustainability and urban planning, aiming to balance economic growth with environmental preservation. The city possesses a modern infrastructure and is allocating significant resources to infrastructure developments through various large scale projects, including the La Son – Tuy Loan expressway.

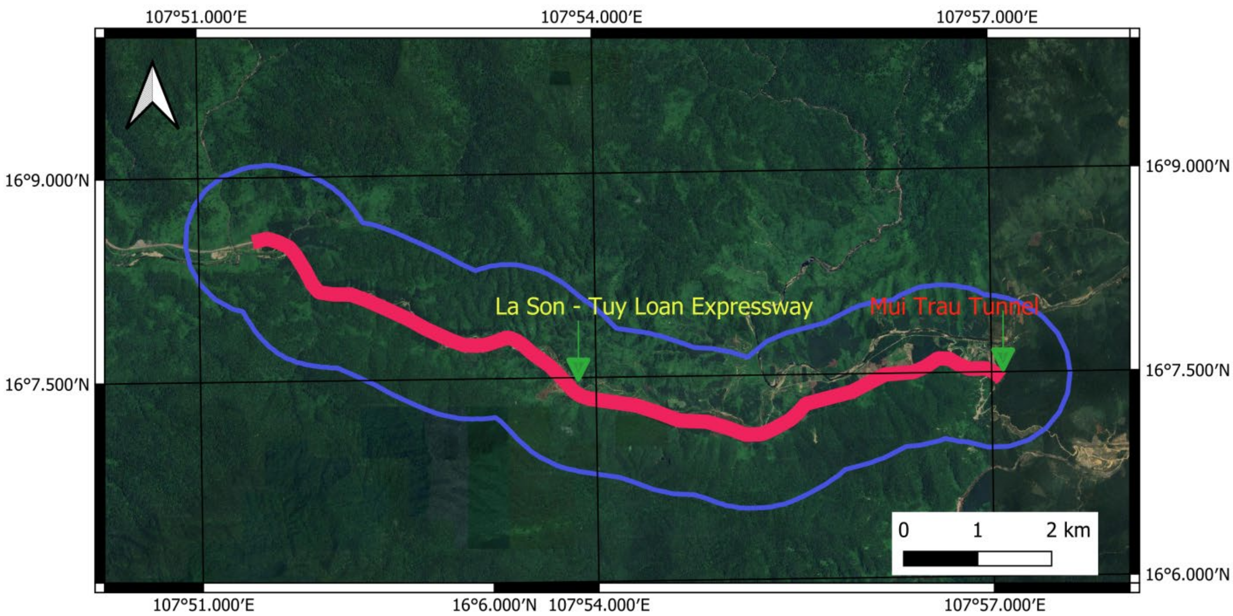

Figure 2. The study area

The La Son – Tuy Loan expressway is a significant infrastructure project in Da Nang, designed to enhance connectivity and promote economic development in the region. Spanning approximately 77 kilometers, this expressway begins at the La Son junction in Thua Thien-Hue Province and extends to the Tuy Loan intersection in Hoa Vang District, Da Nang. The expressway features a modern design that includes four lanes and multiple overpasses, facilitating smooth and efficient transportation. The study focuses on a segment of the expressway that extends from the Mui Trau tunnel to the boundary between Da Nang and Hue provinces (refer to Figure 2). The total length of this segment is about 11.3 km. For analyzing the land cover change, a buffer zone of 1000 meters is employed.

Moreover, to generate land cover maps, this study relies on Sentinel-2's images. Sentinel-2 imagery is openly distributed by the European Space Agency and the European Commission, making it highly accessible for a wide range of users, especially those in developing countries. Sentinel-2 data facilitates quick and easy access to high-resolution multispectral imagery for various applications, including land use and land cover analyses [7]. Sentinel-2 provides high-resolution multispectral imagery, making it an invaluable resource for land cover analysis. Equipped with a multispectral imager, Sentinel-2 captures data across different spectral bands at spatial resolutions of 10, 20, and 60 meters, allowing for detailed observation of various land features, including vegetation, water bodies, barren, and built-up areas. The study area captured by the Sentinel-2's true color composite in 2024 (from 01/01/2024 to 08/30/2024) is presented in Figure 3.

Table 1. The used spectral bands of the Sentinel-2

Spectral bands	Resolution (m)	Wavelength (nm)	Notes
B2	10	496.6 (S2A) / 492.1 (S2B)	Blue
B3	10	560 (S2A) / 559 (S2B)	Green
B4	10	664.5 (S2A) / 665 (S2B)	Red
B5	20	703.9 (S2A) / 703.8 (S2B)	Red Edge 1
B6	20	740.2 (S2A) / 739.1 (S2B)	Red Edge 2
B7	20	782.5 (S2A) / 779.7 (S2B)	Red Edge 3
B8	10	835.1 (S2A) / 833 (S2B)	NIR
B8A	20	864.8 (S2A) / 864 (S2B)	Red Edge 4
B11	20	1613.7 (S2A) / 1610.4 (S2B)	SWIR 1
B12	20	2202.4 (S2A) / 2185.7 (S2B)	SWIR 2

Notably, Sentinel-2's images can be conveniently accessed via GEE code editor. This capability significantly enhances land cover classification and change detection efforts, enabling quick assess land use patterns. Furthermore, by integrating Sentinel-2 imagery with advanced analytical techniques, such as machine learning algorithms (e.g., random forests), the accuracy and efficiency of land cover assessments are greatly improved [8]. The spectral bands of the satellite are used as input features for the random forest classifiers. This study uses nine spectral bands obtained from the Sentinel-2; they are summarized in Table 1.

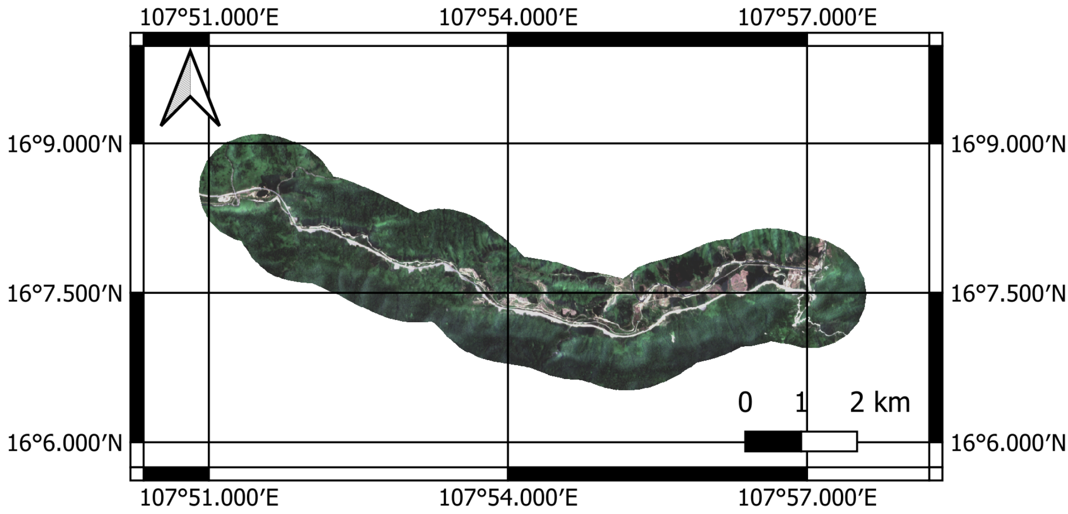

Figure 3. True color composite of the study area in 2024

2.2. Random forest classification

Random Forest [9] is a powerful machine learning algorithm that has gained widespread popularity in land use and land cover mapping using remote sensing data. It operates by constructing an ensemble of decision trees, each trained on a random subset of features and samples, and then aggregating their predictions to make a final classification [10,11]. This ensemble approach makes Random Forest highly robust to overfitting and noise in the data, while also allowing it to capture complex non-linear relationships between the input features and the target classes [12,13].

In the context of land cover mapping, Random Forest can effectively handle the high-dimensional and multi-temporal nature of remote sensing data, such as Sentinel-2 imagery, to produce accurate and detailed land cover maps [14]. Its ability to handle multivariate and nonlinear further enhances its suitability for land cover analysis applications. Additionally, Random Forest is computationally efficient and can be easily implemented in GEE, making it scalable to large datasets and suitable for mapping tasks.

3. Result and discussion

The research methodology for this study employs Random Forest classifiers utilizing the ten spectral bands of Sentinel-2 as features for land cover classification. In the study area, four land cover classes—vegetation, built-up areas, barren land, and water—are considered. To create a dataset for model training, 100 data points are sampled from each class within a 1000-meter buffer zone surrounding the La Son – Tuy Loan expressway, resulting in a total of 400 samples. This dataset is used for training the Random Forest models to perform land use recognition for the years 2019 and 2024.

The Random Forest models are constructed using the Google Earth Engine (GEE) code editor. Each model is built with 100 individual decision trees, leveraging the ensemble learning approach that characterizes the Random Forest algorithm. This method enhances classification accuracy by aggregating the predictions of multiple trees. The classification outcomes are presented in Figure 4 and Figure 5. These maps illustrate the spatial distributions of the vegetation, built-up areas, barren land, and water categories in the area of interest. More detailed information of the land cover types is provided in Table 2 and Table 3.

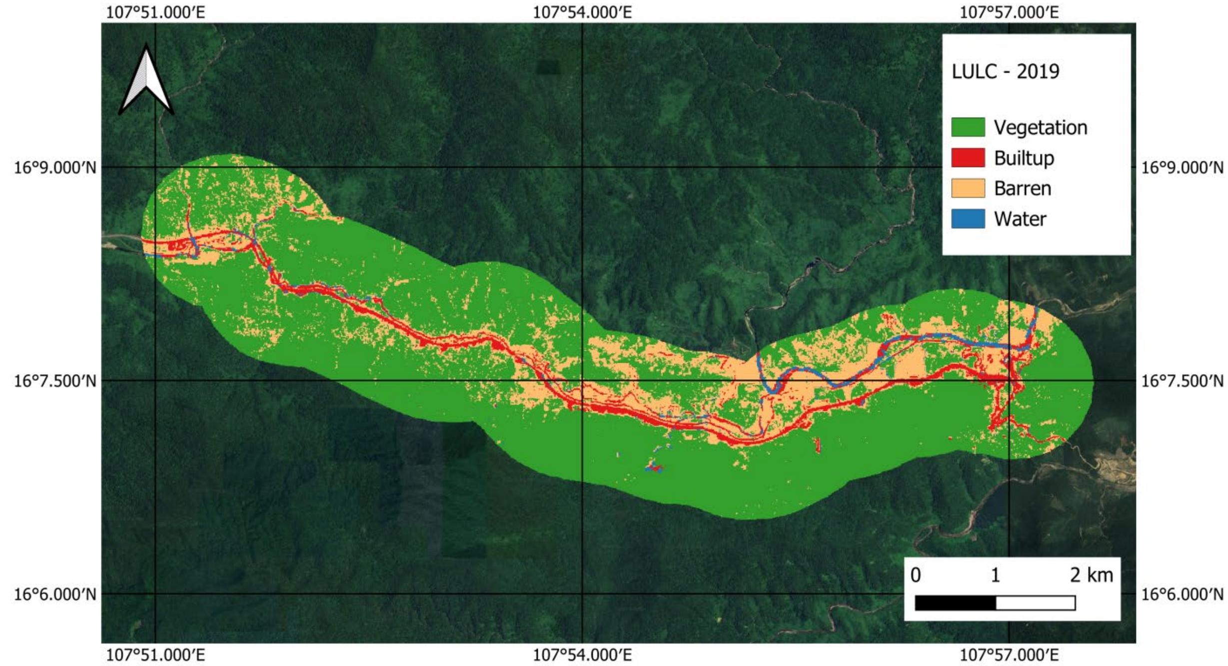

Figure 4. Land use land cover (LULC) classification in 2019

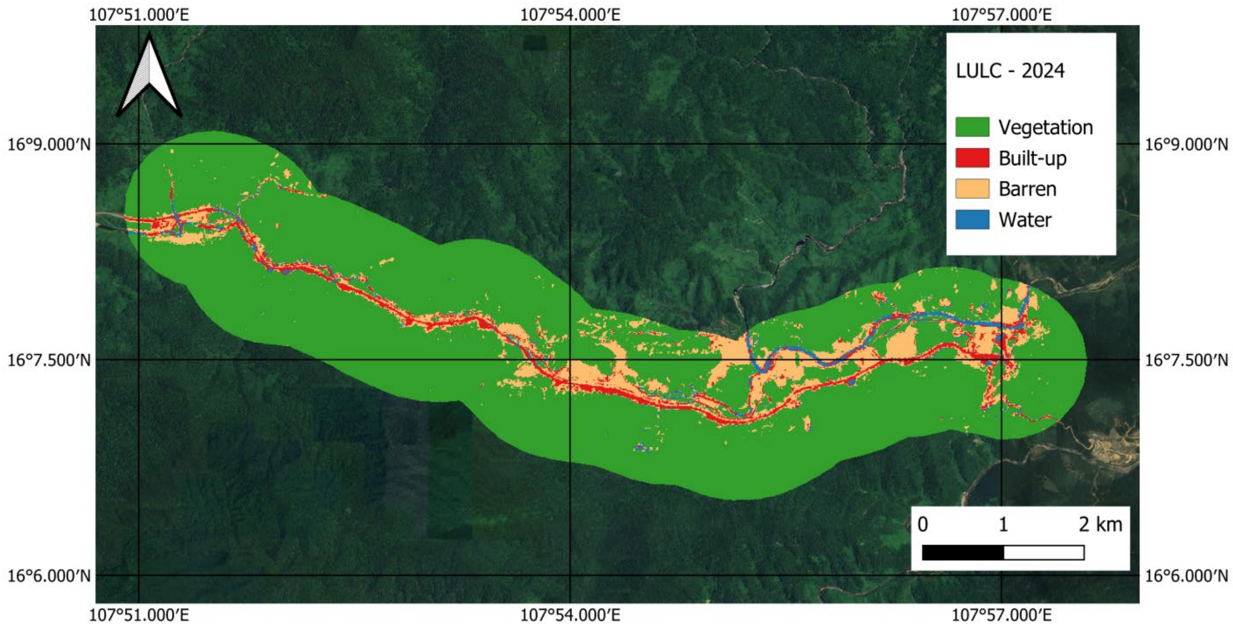

Figure 5. Land use land cover (LULC) classification in 2024

The area classified as vegetation increased from 18.27 km² in 2019 to 20.91 km² in 2024, which corresponds to a rise in proportion from 72.50% to 82.98%. This notable increase suggests a positive trend in vegetation cover, potentially indicating successful reforestation efforts, improved land management practices, or natural recovery of ecosystems in the area. The built-up category experienced a minor decrease in area from 1.45 km² (5.75%) in 2019 to 1.12 km² (4.44%) in 2024. This decline may imply the conversion of previously developed land back to green spaces or agricultural land. The area designated as barren decreased from 5.12 km² (20.31%) in 2019 to 2.71 km² (10.75%) in 2024. This reduction indicates a significant transformation in land use, where barren lands may have been converted to vegetation. Moreover, the area classified as water increased slightly from 0.36 km² (1.44%) in 2019 to 0.46 km² (1.83%) in 2024. The area of water surface is virtually unchanged and only occupies a minor proportion of the study area.

Table 2. Classes of land cover in 2019

Category	Area (km^2)	Proportion (%)
Vegetation	18.27	72.50
Built-up	1.45	5.75
Barren	5.12	20.31
Water	0.36	1.44

Table 3. Classes of land cover in 2024

Category	Area (km^2)	Proportion (%)
Vegetation	20.91	82.98
Built-up	1.12	4.44
Barren	2.71	10.75
Water	0.46	1.83

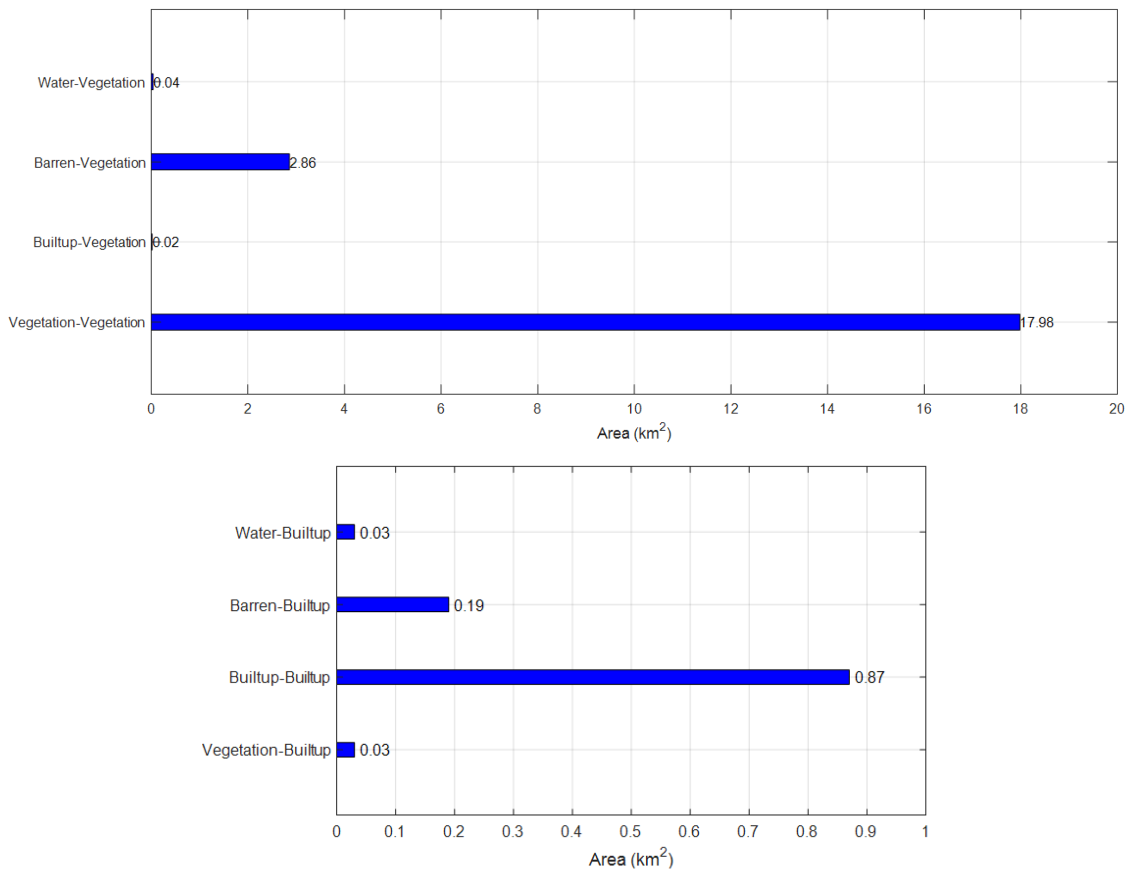

Figure 6. Analysis of land use changes

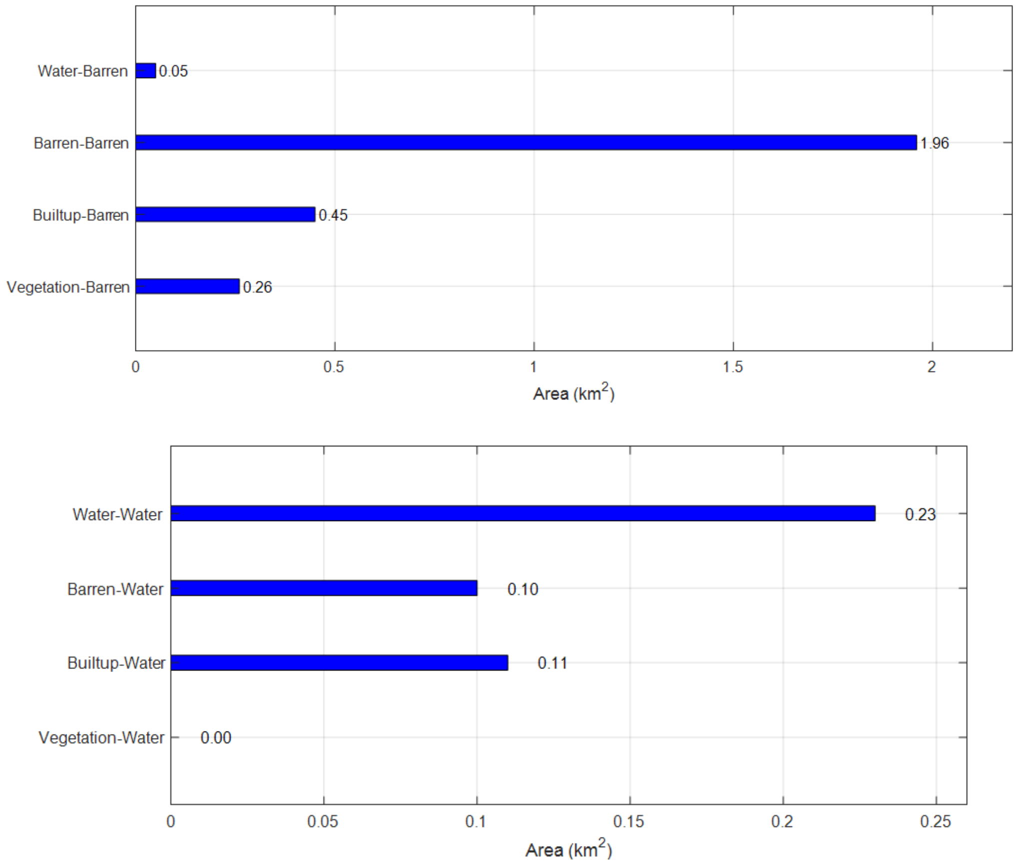

Figure 6. (Cont.)

More details about the land cover changes are demonstrated in Figure 6. Notably, a substantial portion of the existing vegetation cover (17.98 km²) remained stable over the period. This stability suggests effective conservation practices or a favorable environmental condition that supports the persistence of vegetated areas. Since 2.86 km² of barren was converted to vegetation, it is apparent that successful reforestation efforts, natural recovery, or improved land management practices have been carried out. Overall, the data illustrates the interplay of changes among the various land cover classes. The data shows a strong retention of vegetated areas, while the notable conversion of barren land to vegetation highlights positive ecological changes.

4. Conclusion

This study has conducted analyses on the land cover changes along the La Son – Tuy Loan expressway within the Hoa Bac commune of Da Nang, Vietnam. By employing geospatial methodologies, including Random Forest classifiers and Sentinel-2 imagery, this paper has mapped and analyzed the patterns of land cover variations from 2019 to 2024. The findings highlight significant trends, including an increase in vegetation cover and a decrease in barren land, which suggest positive ecological responses in the region.

However, it is important to acknowledge certain limitations that may have influenced the results. One significant limitation is the reliance on ground truth data points obtained through the interpretation of satellite images. The subjectivity and errors in visual interpretation may have led to some misclassification of land cover types. Moreover, the selection of a 1000-meter buffer zone around the expressway may not fully capture the extent of the highway's influence, as some impacts may extend beyond this boundary.

Therefore, future work should perform further analyses with different buffer zones. Moreover, the incorporation of vegetation indices and land surface temperature analyses should be considered to further enhance the understanding of the ecological impacts associated with the expressway. These additional metrics will provide deeper insights into vegetation health, thermal dynamics, and the overall characteristics of the landscape in response to infrastructural developments. Additionally, the current work can also be extended to monitor land cover changes in other segments of the expressway that pass through areas of natural forests.

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