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MAPPING THE ENVIRONMENTAL FOOTPRINT OF URBANIZATION IN TIRANA DISTRICT THROUGH NDVI CHANGE ANALYSIS (2000–2025)

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Abstract

Rapid urbanization has significantly transformed the landscape of Tirana County over the past three decades, reducing natural vegetation and altering land cover composition. This study employs multi-temporal Landsat imagery and the Google Earth Engine platform to quantify vegetation change between 2000 and 2025 through the Normalized Difference Vegetation Index (NDVI) analysis. Summer season composites were generated for both years to minimize phenological effects, and NDVI differencing was used to identify areas of significant greenness loss. Additional analysis of the Normalized Difference Built-up Index (NDBI) allowed the distinction between vegetation decline caused by urban expansion and other land degradation processes. Results indicate a marked decrease in vegetated areas within the Tirana metropolitan region, primarily in the western and southern zones, where built-up surfaces have expanded. In contrast, higher-elevation zones toward Dajti Mountain retained stable vegetation cover. The findings demonstrate the value of cloud-based remote-sensing tools for long-term environmental monitoring and provide evidence of the spatial footprint of urban growth in Albania's fastest-developing county.

Keywords: Google Earth Engine (GEE), Landsat time-series, Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), urban expansion, vegetation loss

MAPOWANIE ŚLADU ŚRODOWISKOWEGO URBANIZACJI W DYSTRYKCIE TIRANY POPRZEZ ANALIZĘ ZMIAN WSKAŹNIKA NDVI (2000–2025)

Abstrakt

W ciągu ostatnich trzydziestu lat szybka urbanizacja znacząco zmieniła krajobraz dystryktu Tirany, prowadząc do zmniejszenia naturalnej pokrywy roślinnej oraz przekształcenia wzoru pokrycia terenu. Niniejszy artykuł wykorzystuje wieloczasowe zobrazowania Landsat oraz platformę Google Earth Engine do stworzenia ilościowego opisu zmian wegetacji w latach 2000–2025, posługując się analizą znormalizowanego wskaźnika różnic wegetacji (NDVI). Aby zminimalizować wpływ pór roku, dla obu lat generowano składniki właściwe dla sezonu letniego. Do identyfikacji obszarów o znaczącej utracie zieleni zastosowano różnicowanie NDVI. Dodatkowa analiza, przeprowadzona przy użyciu znormalizowanego różnicowego wskaźnika zabudowy (NDBI) pozwoliła na rozróżnienie pomiędzy zmniejszeniem się pokrywy roślinnej spowodowanym rozrostem przestrzeni miejskiej a tym wywołanym innymi procesami degradacji terenu. Wyniki wykazują na znaczący spadek powierzchni pokrytych wegetacją w rejonie metropolitalnym Tirany, szczególnie w zachodnich i południowych częściach, gdzie nastąpiło rozszerzenie zabudowy. Obszary położone wyżej, w kierunku góry Dajti, zachowały stabilną pokrywę wegetacji. Wyniki te

potwierdzają wartość narzędzi do teledetekcji opartych na chmurze punktów w długoterminowym monitoringu środowiska oraz dostarczają dowodów na istnienie śladu przestrzennego spowodowanego przez urbanizację w najszybciej rozwijającym się dystrykcie Albanii.

Słowa kluczowe: Google Earth Engine (GEE), seria czasowa Landsat, znormalizowany różnicowy wskaźnik wegetacji (NDVI), znormalizowany różnicowy wskaźnik zabudowy (NDBI), ekspansja miejska, utrata wegetacji

1. INTRODUCTION

Urbanization represents one of the most transformative processes shaping terrestrial ecosystems in the twenty-first century. As cities expand, vegetated areas are increasingly converted into impervious surfaces, altering local climates, reducing biodiversity, and affecting the quality of life for urban residents. Monitoring the spatial and temporal patterns of vegetation loss therefore remains essential for sustainable urban planning and environmental policy development. Remote sensing techniques, particularly those employing the Normalized Difference Vegetation Index (NDVI), have become fundamental for assessing vegetation health and change over large areas and extended periods.

Albania has undergone a rapid transition since the early 2000s, marked by significant demographic shifts and infrastructure development. Tirana County, as the country's most dynamic economic and administrative region, has experienced accelerated land conversion from agricultural and natural landscapes into urban and peri-urban built environments. This expansion has reshaped the spatial configuration of green spaces and fragmented ecological connectivity within the metropolitan region. However, systematic, long-term assessments of vegetation change in Tirana using open satellite archives have been limited.

The advent of cloud-based geospatial platforms such as Google Earth Engine (GEE) allows for efficient processing of multi-temporal satellite imagery and facilitates reproducible environmental analyses. By leveraging the Landsat archive, which provides more than four decades of consistent data, researchers can evaluate vegetation dynamics at regional scales with high temporal continuity. In this study, multi-temporal Landsat imagery from 2000 and 2025 was analysed to quantify vegetation change within Tirana County using NDVI and to identify areas where vegetation loss coincides with urban growth indicated by the Normalized Difference Built-up Index (NDBI). The results aim to provide insights into the long-term environmental consequences of urban expansion and to demonstrate the utility of GEE for sustainable land-use monitoring in rapidly developing regions.

2. LITERATURE REVIEW

The relationship between urban expansion and vegetation degradation has been widely studied through remote sensing techniques over the last four decades. The Normalized Difference Vegetation Index (NDVI) introduced by Rouse et al. [1] remains a cornerstone for vegetation assessment because of its simplicity and proven correlation with photosynthetic activity. To complement vegetation indices, Zha, Gao, and Ni [2] developed the Normalized Difference Built-up Index (NDBI) to detect impervious urban surfaces, allowing an integrated understanding of urban–green space dynamics.

The rise of big geospatial data, Google Earth Engine (GEE) revolutionized land monitoring workflows by providing cloud-based access to multi-temporal satellite imagery [3]. GEE integrates datasets such as Landsat and Sentinel-2, enabling rapid, reproducible analyses of vegetation and land-cover changes. The U.S. Geological Survey [4–6] standardized Landsat's Collection 2 Level-2 Surface Reflectance products, ensuring radiometric consistency across missions. Similarly, the European Space Agency [7] and Copernicus missions released the Sentinel-2 MSI Level-2A data [8], facilitating high-resolution monitoring at 10–20 m scales suitable for urban studies.

The development of global datasets such as ESA WorldCover [10–12] and the Copernicus Urban Atlas [13, 14] has enhanced the ability to distinguish vegetated, built-up, and agricultural zones with validated accuracy. These datasets, integrated with NDVI and NDBI indices, provide a robust framework for spatially explicit urban–environmental analysis. For additional environmental context, MODIS Land Surface Temperature (MOD11) and MEaSUREs LST products from NASA have been widely used to quantify the Surface Urban Heat Island (SUHI) effect linked to vegetation decline [15–17].

Recent global studies have underscored the importance of multi-temporal Landsat analysis for long-term environmental monitoring. Potapov et al. [18] introduced a global 30 m land-cover and land-use change dataset derived from the Landsat archive, while Turubanova et al. [19] quantified changes in European tree canopy extent and height, emphasizing the capability of satellite archives for consistent multi-decadal analysis. Similarly, Zhou, Li, Liao, and Lu [20] demonstrated that integrating Landsat-based vegetation indices significantly improves the temporal consistency of change detection across different ecosystems.

At the urban scale, NDVI differencing methods have been widely applied to assess vegetation dynamics. Davis et al. [21] used NDVI to investigate urban greenspace decline in relation to public health, while Farhan et al. [22] combined NDVI and NDBI within GEE to model land-use and land-cover (LULC) change. Likewise, Kara, Yavuz, and Lupo [23] applied a multi-index framework including NDVI and NDBI to quantify urban heat island variations, reinforcing the inverse relationship between vegetation density and surface temperature.

Recent advances in global urban mapping, such as those by Zhou and Weng [24] and Liu et al. [25], have produced comprehensive datasets that track impervious surface growth and settlement expansion, offering valuable baselines for regional studies. Additional datasets like Global Impervious Surface Area (GISA) [26] and Urban Projections under Shared Socioeconomic Pathways (SSPs) [27] extend this monitoring framework into future scenario analysis.

Within the Balkan and Albanian context, rapid and often unregulated urbanization has driven significant landscape transformation. Haxhiu and Aliaj [28] documented Tirana's drastic land-use conversion using Landsat imagery and open geospatial data, confirming vegetation loss along urban expansion corridors. Similarly, Yunitsyna and Sadushi [29] evaluated green-space equity in Tirana, showing that vegetated areas have become fragmented and less accessible. Regionally, Milanović et al. [30] confirmed the efficiency of NDVI in detecting vegetation cover change across Central Serbia, providing methodological relevance for Balkan environmental monitoring.

Overall, the literature demonstrates a clear consensus: NDVI and NDBI integration, combined with open-access datasets in cloud-based environments like GEE, provides a powerful, scalable framework for analyzing urban-induced vegetation loss. However, there remains a paucity of long-term, spatially explicit research focused on Albania, particularly Tirana County, which is undergoing the fastest urban expansion in the Western Balkans. This gap justifies the present study's focus on quantifying vegetation decline between 2000 and 2025 using Landsat imagery and GEE.

Despite the extensive global literature on vegetation monitoring and urban expansion, only a limited number of studies have analyzed long-term vegetation dynamics in Albania, and even fewer have focused specifically on Tirana County, where the most rapid socio-economic and spatial transformations have occurred since the early 2000s. Existing regional works often rely on short temporal scales or coarse-resolution datasets that fail to capture the nuanced patterns of intra-urban vegetation change. Moreover, there is a lack of integrated approaches combining NDVI, NDBI, and high-resolution ancillary datasets within a cloud-based framework such as Google Earth Engine. Therefore, this study aims to fill this gap by applying a multi-temporal Landsat analysis from 2000 to 2025, quantifying vegetation loss and its spatial correspondence with built-up expansion. The approach provides a replicable model for assessing the environmental impacts of urban growth in other rapidly developing urban centres of the Western Balkans.

3. METHODOLOGY

This study was conducted using the Google Earth Engine (GEE) platform to quantify vegetation loss and its spatial correspondence with urban expansion in Tirana District between 2000 and 2025. The workflow integrated multi-temporal Landsat surface reflectance data, spectral indices, and change detection analysis to provide a reproducible framework for long-term land-cover monitoring.

The area of interest (AOI) was defined as the administrative boundary of Tirana District, derived from the FAO GAUL level-1 dataset (FAO/GAUL_SIMPLIFIED_500m/2015/level1). The geometry was simplified to improve processing speed while maintaining spatial accuracy. Figure 1 illustrates the initial setup of the GEE environment and the study boundary overlaid on the basemap (Source: Google Earth Engine interface, 2025).

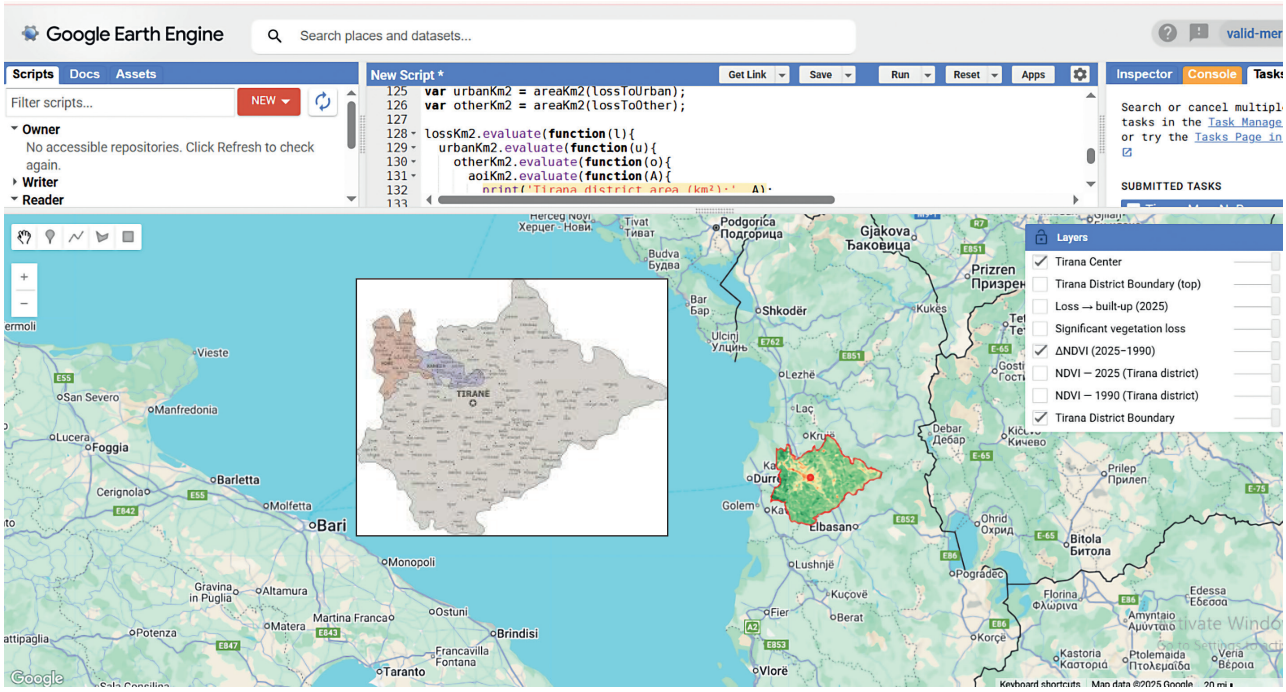

Fig. 1. Google Earth Engine interface showing the workflow for the Tirana District analysis. The script integrates Landsat surface reflectance data (2000–2025) and administrative boundaries from FAO GAUL to generate NDVI, NDBI, and vegetation loss layers used in the multi-temporal land-cover assessment

Ryc. 1. Interfejs Google Earth Engine pokazujący sekwencję zadań do analizy dystryktu Tirany. Skrypt integruje dane odbicia powierzchni otrzymane z Landsat (2000–2025) i granice administracyjne z FAO GAUL oraz generuje NDVI, NDBI i warstwy utraty wegetacji używane w wieloczasowej ocenie pokrycia terenu

The analysis used Landsat Collection 2 Level 2 Surface Reflectance (SR) products from multiple sensors: Landsat 5 TM, Landsat 7 ETM+, and Landsat 8-9 OLI. To ensure temporal and radiometric consistency, surface reflectance values were scaled following the USGS coefficients:

$$\text{Reflectance}=(\text{SR\_Band}\times 0.0000275)-0.2 \quad (1)$$

Clouds, shadows, and dilated areas were masked using the QA_PIXEL band through bitwise filtering. Median composites were generated for the summer season (June–November) of 2000 and 2025 to minimize phenological variation and ensure comparability of vegetation signals across years. Vegetation and built-up indices were derived from each composite. The Normalized Difference Vegetation Index (NDVI) was computed as:

$$NDVI = \frac{(SWIR1-NIR)}{(SWIR1+NIR)} \quad (2)$$

where NIR and RED represent the near-infrared and red spectral bands, respectively. Similarly, urban areas were identified using the Normalized Difference Built-up Index (NDBI) defined by Zha et al. (2003):

$$NDBI = \frac{(SWIR1-NIR)}{(SWIR1+NIR)} \quad (3)$$

NDVI and NDBI were used jointly to detect vegetation loss linked to urbanization. The change in vegetation between 2000 and 2025 was quantified using NDVI differencing:

$$\Delta\text{NDVI}=\text{NDVI}_{2025}-\text{NDVI}_{2000} \quad (4)$$

Pixels with initial NDVI ≥ 0.30 (vegetated) and ΔNDVI < –0.10 were classified as significant vegetation loss. Areas that simultaneously exhibited positive NDBI values in 2025 were categorized as Loss → Built-up, representing vegetation converted to impervious surfaces, while other negative NDVI changes represented non-urban degradation (e.g., agricultural decline or soil exposure).

Area statistics were computed directly in GEE using the pixelArea reducer, converting the results to square

kilometres. The total area of Tirana District was approximately 1,238 km², with vegetation loss and built-up transition areas extracted relative to this baseline extent. All outputs were reprojected to EPSG:4326 with a spatial resolution of 30 m.

Visualization layers were applied to highlight spatial patterns of change. Brown and yellow tones indicate vegetation decline, green tones denote preserved vegetation, and magenta identifies areas converted from vegetation to built-up surfaces. The visual outputs include:

– Figure 2. NDVI-based vegetation cover of Tirana District in 2000 (left) and 2025 (right). These maps illustrate the spatial reduction of vegetation cover across the district.
– Figure 3. Land-cover transition and vegetation loss between 2000 and 2025 showing (top left) significant vegetation loss, (top right) loss converted to built-up, and (bottom) the combined overlay of both classes (Source: Author's analysis in Google Earth Engine, 2025).

The analysis was implemented through a fully reproducible GEE JavaScript script using modular functions for image preparation, scaling, masking, compositing, and index calculation. The workflow allowed efficient comparison of multi-sensor data and seamless integration of NDVI–NDBI change detection. The approach follows the methodological standards of Rouse et al. [1] for vegetation monitoring, Zha et al. [2] for built-up detection, and Gorelick et al. [3] for cloud-based environmental analysis within GEE.

4. RESULTS

The analysis reveals a significant transformation of the landscape within Tirana District between 2000 and 2025, marked by a decline in vegetation cover and a steady expansion of urbanized areas. The NDVI maps indicate that in 2000 the district was predominantly vegetated, especially across the eastern hilly terrains and the surrounding agricultural plains. By 2025, vegetation became fragmented and considerably reduced in the central and western parts of the district, corresponding to the urban core of Tirana and its rapidly expanding suburban areas.

The ΔNDVI change map highlights clear contrasts between vegetated and developed surfaces. Areas with notable reductions in greenness appear in red and or-

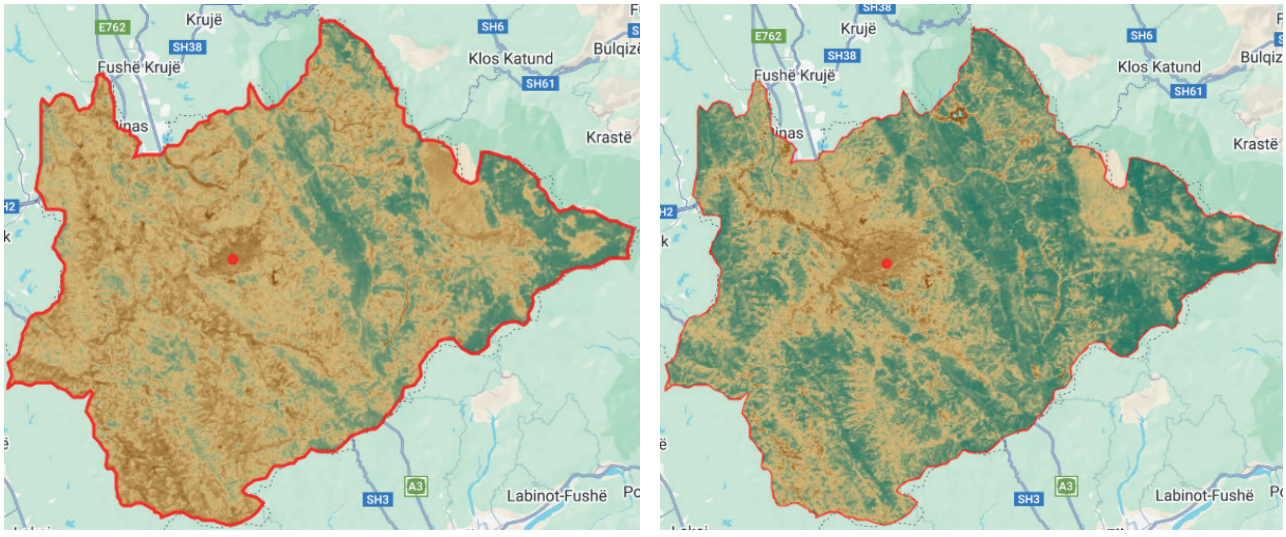

Fig. 2. NDVI-based vegetation cover of Tirana District in 2000 (left) and 2025 (right).
The maps visualize the spatial decline of vegetation and the corresponding expansion of built-up areas across the district. Brown and light-yellow tones represent areas with reduced greenness or conversion to impervious surfaces, while green tones indicate preserved vegetation

Ryc. 2. Pokrywa roślinna dystryktu Tirana oparta na NDVI w roku 2000 (z lewej) i 2025 (z prawej).
Mapy wizualizują zmniejszanie się powierzchni pokrytej roślinnością i związaną z tym ekspansję obszarów zabudowanych. Barwy brązowe i jasnozielone reprezentują obszary o zredukowanej ilości zieleni lub obszary przekształcone w powierzchnie nieprzepuszczalne, a barwa zielona oznacza obszary z zachowaną roślinnością

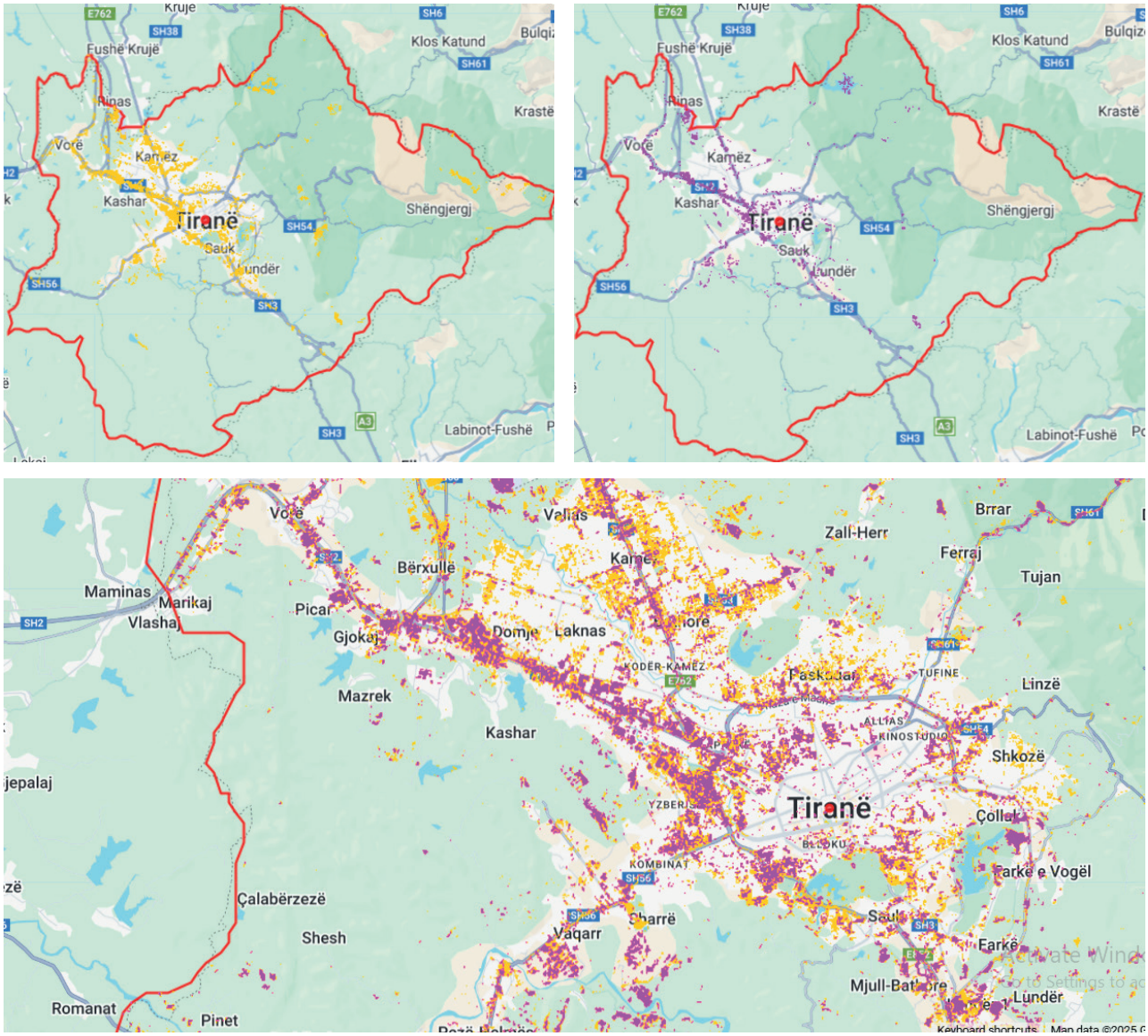

Fig 3. Land cover transition and vegetation loss in Tirana District between 2000 and 2025, (top left) areas of significant vegetation loss, (top right) vegetation loss converted to built-up zones, and (bottom) combined spatial overlay showing loss-to-urban (magenta) and non-urban vegetation decline (orange). The maps highlight the densification of the Tirana metropolitan area and the spread of urbanization along main transport corridors

Ryc. 3. Zmiana pokrycia terenu i utraty roślinności w dystrykcie Tirany od 2000 do 2025 roku, (u góry z lewej) obszary o znaczącej utracie roślinności, (u góry z prawej) utrata wegetacji w wyniku powstania zabudowy, oraz (u dołu) złożona mapa pokazująca utratę roślinności na rzecz terenów zurbanizowanych (amarant) oraz utratę roślinności niezwiązaną z urbanizacją (pomarańczowy). Mapy pokazują zagęszczenie w obszarze metropolitalnym Tirany i rozprzestrzenienie się urbanizacji wzdłuż korytarzy transportowych

ange tones, mainly concentrated around the city centre --//**and along the major suburban axes leading toward Kamëz, Kashar, and the Tirana-Durrës corridor. Conversely, areas with stable or slightly improved vegetation are found in the eastern and mountainous parts of the district, where urban pressure remains low and forest recovery is more evident.

The integration of NDVI and NDBI indices confirms that most vegetation loss is associated with urban growth. The “Loss → Built-up” class marks the

zones converted from vegetation to impervious surfaces, while the "Significant vegetation loss" class includes non-urban areas affected by soil exposure, agricultural decline, or land degradation. These patterns show that urbanization has been the primary factor driving vegetation reduction, especially in the lowland and peri-urban sectors of the district.

Overall, the results demonstrate a clear spatial gradient between the densely urbanized lowlands and the greener highlands. The central and western areas of Tirana District exhibit the strongest vegetation decline, whereas the eastern uplands maintain a more stable vegetative structure. This distribution reflects the impact of prolonged urban expansion and underscores the necessity for sustainable spatial planning and green infrastructure to preserve ecological balance within the district.

According to Figure 3, the most extensive vegetation loss and built-up expansion are concentrated along the Tirana-Durrës highway corridor. This area has experienced intense industrial and infrastructural development over the last three decades, evolving into Albania's primary economic axis. The continuous urban sprawl between Tirana and Durrës, driven by logistics, manufacturing, and residential construction, has transformed previously vegetated or agricultural lands into impervious surfaces. The NDVI decline detected along this corridor highlights how rapid industrialization and the growth of peri-urban settlements have significantly contributed to the reduction of green cover, marking this zone as the most environmentally affected region in Tirana District.

5. DISCUSSION

The results of this study provide clear evidence of how rapid urban growth has reshaped the natural environment of Tirana District over the past three decades. The continuous decline in vegetation cover corresponds closely with the spatial expansion of the urban core and its surrounding settlements. This finding confirms the trend reported in recent regional studies that identify Tirana as one of the most dynamic and environmentally pressured areas in Albania. The observed NDVI reduction aligns with patterns of built-up increase detected in other Balkan cities experiencing similar demographic and economic transformations.

The comparison between 2000 and 2025 demonstrates that urbanization has primarily occurred at the expense of agricultural and semi-natural land. The "Loss → Built-up" areas identified through the integration of NDVI and NDBI indices represent zones where vegetation has been replaced by impervious surfaces such as residential, commercial, and infrastructural developments. This process has led to reduced ecological functionality, diminished soil permeability, and the fragmentation of green spaces around the metropolitan area. The "Significant vegetation loss" areas, which do not correspond directly to built-up zones, suggest additional processes such as agricultural abandonment, soil degradation, or informal land use changes.

The spatial pattern of vegetation decline reveals a distinct gradient from the dense urban core toward the eastern highlands, where vegetation remains more stable. These differences can be attributed to topographic and planning constraints that limit large-scale construction in the upland areas. Similar spatial gradients have been observed in other European cities where expansion follows flat and accessible terrain, while elevated regions maintain higher ecological integrity.

The integration of satellite indices and multi-temporal analysis in Google Earth Engine proved to be a reliable approach for detecting and mapping long-term land-cover changes. The results underline the capacity of remote sensing to support urban and environmental planning by providing spatially explicit evidence of transformation. Continuous NDVI monitoring can serve as an early warning tool for assessing the impacts of urbanization on local ecosystems, while combined NDVI-NDBI analyses can inform zoning policies and the design of urban green networks.

Overall, the study highlights the environmental cost of Tirana's rapid development and emphasizes the need for stronger planning strategies to balance urban expansion with ecological preservation. Protecting the remaining vegetated areas in the district, especially in the eastern highlands and peri-urban zones, should be a priority for maintaining ecosystem services, improving air quality, and ensuring sustainable urban resilience in the coming decades.

6. CONCLUSSION

This study examined vegetation dynamics and urban expansion in Tirana District from 2000 to 2025 using multi-temporal Landsat imagery and index-based analysis in Google Earth Engine. The results revealed a clear

and spatially consistent decline in vegetation cover associated with the progressive expansion of built-up areas. The combined use of NDVI and NDBI enabled the identification of both urban-induced vegetation loss and non-urban degradation, offering a comprehensive understanding of land-cover transformation in the district.

The findings demonstrate that urbanization has been the dominant factor driving environmental change in Tirana, with the most pronounced effects occurring in the central and western lowlands. In contrast, the eastern and mountainous areas maintained relatively stable vegetation, reflecting lower construction pressure and partial ecological recovery.

The methodological framework applied in this study-based on freely available satellite data and cloud computing-proves effective for continuous monitoring of land-use and vegetation dynamics at the regional scale. Such evidence-based assessments are essential for supporting spatial planning, guiding sustainable urban development, and integrating green infrastructure into the expanding metropolitan landscape of Tirana.

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