Urban Change Detection in Tirana, Albania (2000–2025) Using Remote Sensing and Open Geospatial Data

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Abstract

Tirana, the capital of Albania, has experienced rapid and often unregulated urbanization since the early 2000s, resulting in profound changes in land use, environmental conditions, and urban structure. This study examines the spatial and temporal dynamics of urban change in Tirana over the last 25 years by leveraging multi-temporal satellite imagery and open geospatial data to map and assess land cover transitions. The analysis utilizes freely available Landsat and Sentinel-2 satellite images acquired at multiple intervals, aiming for regular coverage throughout the period. Open data from the Urban Atlas is used to complement the classification and support a more detailed evaluation of land cover change. Change detection techniques are applied using key spectral indices—such as the Normalized Difference Vegetation Index (NDVI) to monitor vegetation loss and the Normalized Difference Built-up Index (NDBI) to identify the expansion of built-up areas. Urban change is assessed and modeled using the MOLUSCE plugin in QGIS, which enables both quantification and prediction of land use transformations based on historical trends and infrastructure development. The results indicate widespread urban expansion, considerable loss of vegetation, and increasing land consumption for built-up areas. These findings provide important insights for urban planning and sustainable development in Tirana, while also demonstrating the value of open geospatial data and free software tools for monitoring urban change in rapidly transforming cities.

1. Introduction

1.1 Urbanization and Informal Development in Tirana

Urbanization is one of the most significant drivers of environmental and socio-economic transformation in the 21st century, particularly in rapidly growing cities across Eastern Europe. Tirana, the capital of Albania, offers a striking case of accelerated and often unregulated urban expansion, reflecting the profound political, economic, and social changes that have shaped Albania since the early 1990s (Aliaj et al., 2003; CoPLAN, 2018).

The phenomenon of informality in Albania, particularly in Tirana, emerged in the early 1990s as a direct consequence of mass migration and the absence of effective urban management structures. Following the collapse of the communist regime, Tirana experienced intensive population growth and widespread informal development. During the 1990s, the city grew at an annual rate of 5–7%, resulting in a tripling of the population and a doubling of the built-up area within a decade (Aliaj, Lulo & Myftiu, 2003; Co-PLAN, 2018). This rapid, often unregulated expansion led to profound spatial transformations, as documented by successive studies (Co-PLAN, 2018; Aliaj, 2017).

In the subsequent years, Tirana continued to absorb a significant portion of the country’s population, with recent reforms further consolidating its administrative boundaries and its role as Albania’s dominant urban center (INSTAT, 2023). Such urban growth resulted in significant land use change, the loss of green spaces, increased urban sprawl, and emerging environmental challenges. Similar patterns have been observed in other Western Balkan capitals (Hyka et al., 2022).

1.2 Evolution of Spatial Documentation and Early Orthoimagery

Although the impacts of informality and rapid urbanization became apparent throughout the 1990s, the need for **systematic** spatial documentation and digital mapping was only recognized in the early 2000s. The first aerial photographs of Tirana were taken in 1994–95 by LMTF/ULMP under the Ministry of Construction, with technical assistance from USAID and Harvard University.

Nearly a decade later, Co-PLAN (Institute for Habitat Development) began experimenting with low-cost spatial documentation methods, such as the use of delta-planes and mosaicking images based on existing topographic maps. These innovative approaches enabled, for the first time, the detailed mapping of informal areas and provided a foundation for urban replanning in peri-urban municipalities like Kamëz (Co-PLAN 2002).

In 2007, Albania produced its first comprehensive national digital orthophoto, divided into three lots: the first with 8 cm/pixel resolution for urban areas (59 cities), the second with 20 cm/pixel, and the third with 35 cm/pixel. The responsible authority was ALUIZNI, and the product was delivered by Geofoto d.o.o. The 2007 orthophoto remains a foundational geospatial dataset and continues to serve as a key reference for land management, legalization processes, cadastral updates, and urban planning.

1.3 Institutional Developments and Data Accessibility

Following important institutional developments, the State Authority for Geospatial Information (ASIG) was established in 2012 under Law No. 72/2012. ASIG was tasked with the centralization, standardization, and management of all geospatial information in Albania, supporting both national and local planning processes. The development of the National Geoportal provided a unified access point for official spatial datasets and services. However, the Geoportal currently allows users to download only the administrative boundaries dataset, with most other geospatial layers inaccessible to the public and researchers. This limited openness continues to hamper scientific research, evidence-based policy-making, and public transparency (ASIG, 2012).

1.4 Systematic Production of Orthoimagery after 2012

After the institutional consolidation with ASIG, the production of high-resolution, standardized orthophotos became a systematic process in Albania. Between 2015 and 2017, an RGB orthophoto with 20 cm/pixel resolution was produced for the entire territory of Albania, funded by the Albanian government under Decision KZHR Nr.14, dated 23.9.2014 (Official Gazette No. 147/2014), and in line with national technical standards (VKM Nr. 397, 19.06.2019). In 2018, a color (RGB) orthophoto covering 375 km² in the Tirana–Durrës high-growth corridor was produced at an 8 cm/pixel resolution with JICA support, specifically for large-scale mapping in this rapidly developing area. In 2019, 24 urban areas were surveyed by drone at 4 cm/pixel, conforming to the same technical standards. Most recently, the Satellite Orthophoto 2024 covers the whole country with high-frequency satellite imagery, providing advanced monitoring capabilities for Albania's territory.

1.5 The Need for Advanced Geospatial Analysis

Remote sensing and open geospatial data have emerged as powerful resources for tracking and analyzing land cover dynamics, enabling both retrospective and predictive modeling. With satellite imagery and spatial indices such as NDVI and NDBI, and by leveraging open-source GIS tools, it is now possible to objectively monitor and measure patterns of urban expansion and land cover change (Padma et al., 2022; Ramadan & Hidayati, 2022; Hafner et al., 2024). However, in Albania, the application of GIS and remote sensing remains limited, mostly confined to visualization, digitization, and routine cadastral updates, rather than systematic analysis of urban change. There is a critical need for studies that integrate advanced geospatial methods and open satellite data to provide a more complete and quantitative understanding of urban transformation.

Figure 1. Location of Tirana within Albania and Western Ballkan.

1.6 Aim of the Study

This study aims to provide a comprehensive assessment of urban change in Tirana over the last 25 years, utilizing multi-temporal satellite imagery and open data sources to map, detect, and model patterns of land cover transformation and urban expansion. The findings will contribute to a deeper understanding of Tirana's development and support decision-makers in promoting more sustainable and informed urban policies.

1.7 Study Area

Tirana is the capital and largest city by population in Albania. It is located in the central part of the country, at approximately 41.33° N latitude and 19.82° E longitude (Figure 1). The Municipality of Tirana shares its borders with the municipalities of Kamëz and Vorë to the north and northwest, Elbasan and Dibër to the east, and Kavajë and Rrogozhinë to the south and southwest. The city is bordered to the east by Mount Dajt and surrounded by low hills to the south and west. The average elevation of the urban area is about 110 meters above sea level, while Mount Dajt rises to 1,828 meters within the municipality's administrative boundaries.

The municipality of Tirana covers an area of approximately 1,110 square kilometers, making it the largest municipality in Albania by surface area. According to INSTAT, as of January 1, 2023, the population of the Municipality of Tirana was 598,176, while the urban area of the city proper had a population of 389,323. This indicates that around 65% of the municipality's residents live within the urban core, with the rest distributed across peri-urban and rural areas (Figure 2).

The area administered by the municipality was significantly expanded in 2015 during Albania's territorial reform, incorporating several former municipalities and a mix of urban, peri-urban, and rural landscapes. The territory of the municipality includes diverse land cover types—residential areas, green spaces, agricultural land, and water bodies—reflecting the variety of landscape characteristics across thearea.

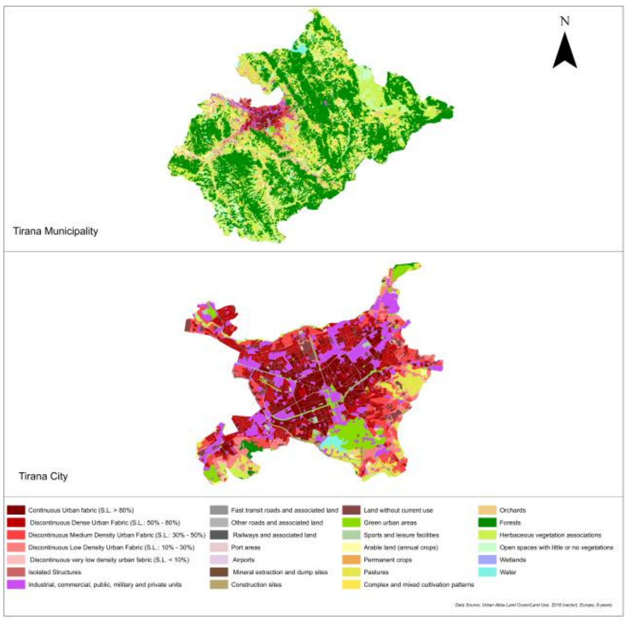

Figure 2. Location of Tirana and land use/land cover (Urban Atlas).

2. Data and Methods

2.1 Data sources

This study utilizes a combination of satellite remote sensing data, open-access land cover products, demographic statistics, and administrative boundaries to analyze urban change in Tirana from 2000 to 2025. The main datasets, sources, formats, and periods of use are summarized in Table 1.

Data Type	Source	Format	Years Used
Landsat 5, 8 Satellite Imagery	USGS Earth Explorer	Raster (GeoTIFF)	2000, 2006, 2010
Sentinel-2A L2A Satellite Imagery	Copernicus Open Access Hub	Raster (GeoTIFF)	2016, 2020, 2025
Land Use/ Land Cover	Urban Atlas/ Copernicus Land Cover	Vector (Shapefile)	2006, 2012, 2018
Population Data	INSTAT (Albanian Institute of Statistics)	Tabular (CSV)	2001, 2011, 2023
Administrative Boundaries	OpenStreetMap / National sources	Vector (Shapefile)	Current

Table 1. Overview of datasets used in this study.

Year	Population	Source / Reference
2001	343,078	INSTAT, 2001 Census
2011	418,495	INSTAT, 2011 Census
2023	598,176	INSTAT, Estimate 2023

Table 2. Population of Tirana Municipality (INSTAT).

2.2 Data Pre-processing and Index Calculation

All remote sensing images were obtained as atmospherically corrected products, ensuring comparability across sensors and time periods. Only scenes with minimal cloud cover were selected (less than 4% for Landsat and 0% for Sentinel-2A). Each image was clipped to the extent of Tirana's administrative boundaries, and all raster data were reprojected to a unified spatial reference system (EPSG: 32634, UTM Zone 34N).

For each image, the relevant spectral bands were extracted and used to compute the Normalized Difference Vegetation Index (NDVI) as an indicator of vegetative cover, and the Normalized Difference Built-up Index (NDBI) to highlight built-up and impervious surfaces. The indices were calculated directly in QGIS, following a standardized workflow for all years. Thresholds for index interpretation were established based on both existing literature and exploratory data analysis specific to the local urban context. Resulting raster layers were harmonized in terms of spatial resolution and extent, ensuring the reliability of change detection across all analyzed years. A detailed description of the NDVI and NDBI calculation process—including the specific bands used for each sensor—is provided in the accompanying repository's README file (see Appendix).

2.3 Land Cover Change Detection and Urban Growth Modeling

Temporal change detection was performed by comparing NDVI and NDBI results across all time steps, aiming to identify and map the spatial and quantitative patterns of land cover transformation. Raster maps were produced for each year, illustrating urban expansion and vegetation loss within the study area.

Future urban growth was modeled using the MOLUSCE (Modules for Land Use Change Evaluation) plugin in QGIS. MOLUSCE utilizes a series of historical land cover raster layers and explanatory factors—including spectral indices and proximity to urban infrastructure—to simulate and predict possible land use changes. In this study, MOLUSCE was applied to analyze transitions observed from satellite imagery and to generate spatial projections for potential urban expansion by 2030 (NextGIS, 2024). The modeling was based on land cover rasters from Urban Atlas for the years 2006 and 2018, while the prediction was generated for the year 2030. NDVI and NDBI raster layers were included as supporting factors in the model to ensure that the simulation reflected the physical landscape dynamics.

3. Results

3.1 Vegetation Dynamics and Urban Expansion (NDVI Analysis)

The multi-temporal NDVI analysis, utilizing both Landsat 5 imagery for 2000, 2006, and 2010 and Sentinel-2 imagery for 2016, 2020, and 2025, reveals clear trends of vegetation loss and urban expansion across Tirana during the last 25 years. For the Landsat period (2000–2010), NDVI maps display a progressive decline in high-value areas, especially in the city's periphery and previously vegetated zones. Maximum NDVI values decreased from 0.72 in 2000 to 0.58 in 2010, while the minimum values fell from 0.07 to 0.03. This downward shift signals both the direct conversion of green spaces into built-up land and the gradual fragmentation of the remaining vegetated patches (Figure 3). Urban expansion, characterized by the spread of impervious surfaces, is visible through the encroachment of low-NDVI zones (yellow to red) over the urban fringe and formerly rural plots. The reduction in both minimum and maximum NDVI further reflects an intensification of construction and densification, especially in newly developing administrative units.

With the introduction of Sentinel-2 data for the period 2016–2025, a different trend emerges. The higher spatial and spectral resolution of Sentinel-2 enables a more nuanced detection of vegetative features. Maximum NDVI values for this interval are notably higher, rising from 0.81 in 2016 to 0.64 in 2025, while minimum values also increase from 0.04 to 0.06. These elevated values, in part, reflect the sensor's improved ability to detect small green patches or managed urban vegetation—such as parks, roadside trees, and new landscaping projects—within the rapidly urbanizing matrix (Figure 4)

However, the overall spatial distribution of NDVI still highlights a continuing loss of large, contiguous vegetated zones. The gradual increase in both minimum and maximum NDVI values from 2016 to 2025 may suggest local stabilization or even partial recovery of greenery, potentially due to urban greening efforts, reforestation initiatives, or stricter land use controls in certain areas. Nonetheless, the expansion of low-NDVI regions near the city's edge—visible as intensifying yellow and red zones on the maps—demonstrates that urban growth remains the dominant driver of landscape change. The integration of Landsat and Sentinel-2 NDVI datasets, while requiring cautious comparison due to sensor differences, confirms that Tirana has experienced both a net decline and a fragmentation of vegetated land as urbanization has accelerated.

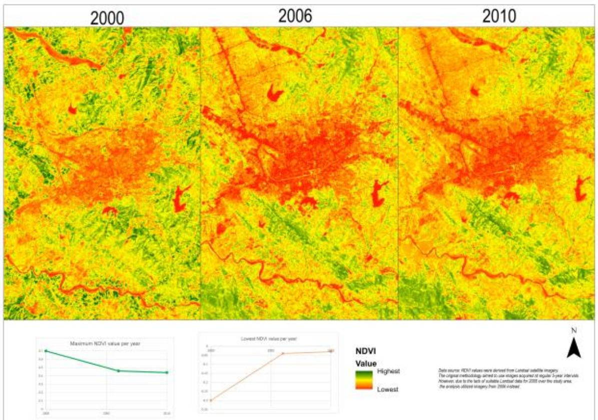

Figure 3. NDVI maps for 2000, 2006, 2010 (Landsat).

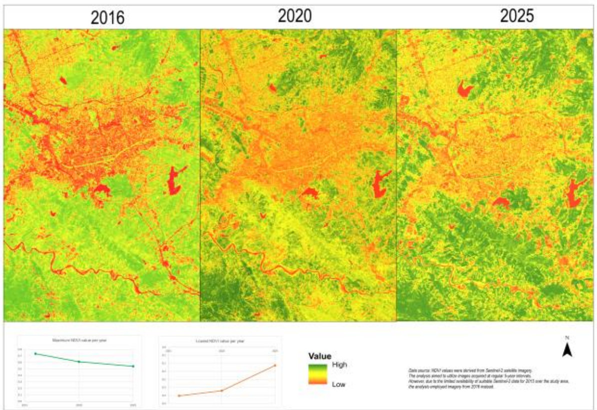

Figure 4. NDVI maps for 2016, 2020, 2025 (Sentinel-2).

3.2 Land Use Change According to Urban Atlas

Supporting the NDVI analysis, the spatial and quantitative transformation of land use in Tirana is explicitly illustrated by the Copernicus Land Cover and Urban Atlas datasets (2006, 2012, 2018). Figures 5, present both the spatial distribution of land use categories and the corresponding percentage breakdown for each year.

In 2006, based on CLC, urban land accounted for about 55% of the study area, agriculture for 30%, green areas for 11%, and the remainder for water, infrastructure, and other uses (Figure 5). For the purposes of this analysis, the original CLC subcategories were aggregated into these broader land cover classes in order to ensure a more comprehensive and interpretable result. This structure reflects a city in transition, with significant portions of land still devoted to agriculture and open spaces, even as urbanization intensified.

By 2012, Urban Atlas data show a significant increase in the urban class to 69%**,** while agriculture declines dramatically to 6%, and green areas remain at 11%. The increase in "infrastructure" and "other" categories signals further development and land conversion for roads, utilities, and mixed urban functions.

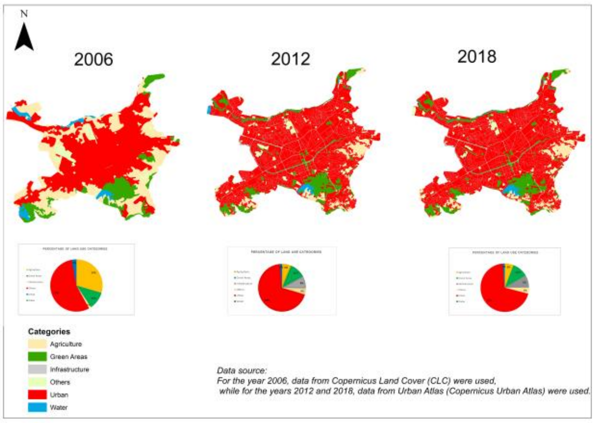

Figure 5. Land use maps and categories in % for 2006, 2012 and 2018.

In 2018**,** the urban category reaches its peak at 70% of the mapped area, confirming the rapid and near-continuous expansion of built-up land in just six years. Agriculture remains very limited at 6%**,** while green areas and infrastructure hold at 10% and 8%**,** respectively (Figure 7). These data reveal the dominance of urbanization as the defining land use process in Tirana, with most new development occurring at the expense of peri-urban agricultural land.

The pie charts accompanying each map visually confirm this process: urban land expands at the expense of both cultivated and natural areas, while the share of green space appears stable in percentage terms but is increasingly fragmented. The decline in agriculture is particularly evident, signaling the conversion of rural landscapes into urban fabric and supporting infrastructure.

The findings from Urban Atlas not only confirm the patterns detected in NDVI analysis, but also provide quantitative context to the loss of non-urban land and the growing dominance of the built environment.

3.3 Built-up Surface Expansion and NDBI Interpretation

The Normalized Difference Built-up Index (NDBI) provides further confirmation of Tirana's accelerating urbanization. Analysis of NDBI maps from both Landsat and Sentinel-2 data demonstrates a clear and consistent growth in high-index (built-up) areas from 2000 to 2025. Initially, high NDBI values are concentrated in the historical urban core and major arterial corridors. Over time, these values spread outward, enveloping peri-urban neighborhoods and gradually converting former agricultural and open land into continuous built-up fabric.

By 2025, as revealed in the most recent NDBI maps, nearly the entire central and inner suburban belt is characterized by elevated built-up values, with only a few scattered green spaces or water bodies interrupting the urban matrix. The densification trend is most apparent along transportation axes and in zones targeted for new development, as mandated by post-2015 urban plans.

Taken together, the NDVI, Urban Atlas, and NDBI analyses provide a coherent, multi-scalar perspective on Tirana's urban transformation: a pronounced loss and fragmentation of vegetated land, rapid conversion of non-urban land uses into built-up areas, and increasing urban density, especially at the city's edge. The use of high-resolution remote sensing (Sentinel-2) in recent years further reveals emerging patterns of urban greening within the consolidated urban area, yet these gains remain modest compared to the overall scale of urban expansion.

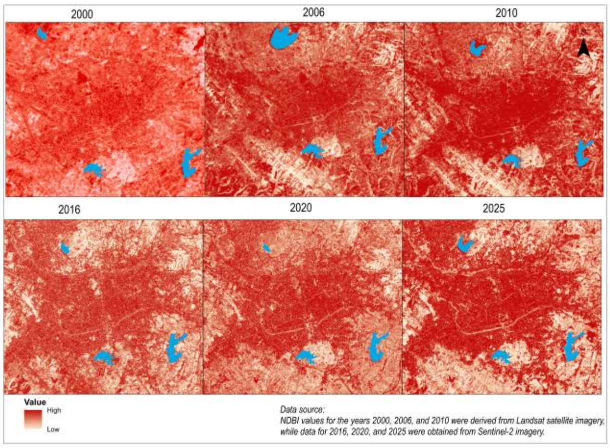

Figure 6. NDBI maps (Landsat & Sentinel-2).

In 2000, the minimum NDBI value is around 0.11**,** reflecting the presence of non-urban land covers such as vegetation, water, and bare soil, primarily located in Tirana's rural periphery and agricultural areas. By 2025, the maximum NDBI value reaches 1, corresponding to highly urbanized zones—mainly in the city center and dense residential districts—where almost all vegetative cover has been replaced by built-up surfaces. This change from low NDBI values in 2000 to the maximum possible value in 2025 highlights the dramatic expansion and densification of built-up areas across Tirana, aligning closely with the patterns seen in both NDVI and land use analyse (Figure 6).

3.4 Interpretation of Land Cover Change Prediction and Model Validation

The land cover prediction for 2030, as illustrated in Figure 7, highlights a continued trend of urban expansion in the Tirana region, with built-up areas expected to extend further into previously agricultural and natural landscapes.

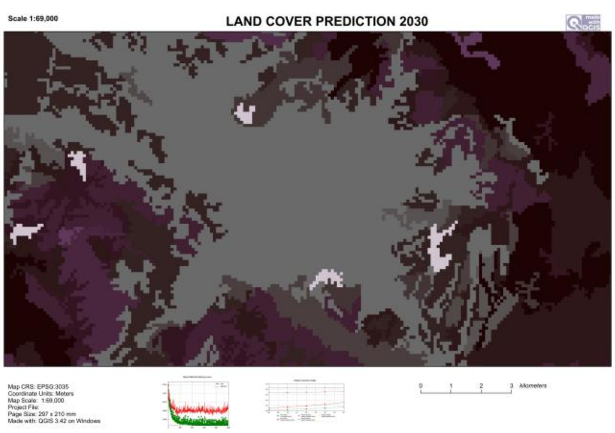

Figure 7. Land Cover Prediction Map.

This ongoing process is projected to cause further reduction and fragmentation of green spaces, which may compromise ecological connectivity and the delivery of key ecosystem services.

The neural network learning curve supports the robustness of the simulation, showing stable performance during both training and validation phases and indicating that the model is capable of generalizing to new spatial patterns. The multiple-resolution budget analysis reinforces the crucial role of comprehensive and accurate input data in achieving reliable predictions, in line with previous findings in the literature (Wang et al., 2020).

Together, these results confirm the validity of using MOLUSCE for future land cover scenario modeling in Tirana (NextGIS, 2024), while underscoring the importance of integrated urban and environmental planning to manage ongoing urbanization pressures and to safeguard remaining green areas.

4. Discussions

The discussion of these findings underscores the transformative impact of rapid urbanization on Tirana's spatial structure and land use configuration. As the capital has expanded, urban development has not only consumed large areas of agricultural and peri-urban land, but has also altered the city's internal organization—driving increased density, infill construction, and a more fragmented urban fabric. This pattern reflects a broader trend observed in many fast-growing cities of Eastern Europe and the Western Balkans, where market-driven development and limited regulatory oversight often lead to sprawling, uncoordinated growth.

The results from this study reveal how urban expansion in Tirana has progressed primarily through horizontal extension into peripheral zones, converting productive landscapes and reshaping the urban edge. Such expansion has frequently outpaced the capacity of planning institutions and infrastructure networks, resulting in challenges related to congestion, access to public services, and sustainable mobility. Furthermore, the application of multi-temporal remote sensing and GIS-based analysis offers valuable insights for monitoring these urban dynamics, providing spatial evidence that can inform targeted interventions and policy responses.

By demonstrating the effectiveness of open-source tools like QGIS and the integration of diverse spatial datasets, this research highlights the potential for data-driven planning in rapidly changing urban environments. The methodology adopted here can serve as a practical model for other cities in the region facing similar pressures from urbanization, supporting more systematic approaches to land management, zoning, and urban design. Ultimately, the case of Tirana illustrates the necessity of coupling technological advances with robust urban governance to address the complex challenges posed by fast-paced, and often unregulated, urban growth.

5. Conclusions

This study provides clear evidence of major urban transformation of Tirana over the past 25 years, characterized by rapid expansion of built-up areas and a significant reduction and fragmentation of green and agricultural land. The integration of open-source remote sensing data (Landsat, Sentinel-2) and land use datasets (Urban Atlas) allowed for a robust, multi-temporal analysis of these trends.

The results demonstrate that urban land has grown significantly from 2006 to 2018, while agricultural areas have nearly disappeared, and green space have become increasingly isolated within the urban matrix. These patterns underscore the environmental and social challenges facing Tirana as it continues to grow.

Despite some methodological limitations, such as differences in data resolution and classification systems—this approach highlights the value of combining open data and spatial analysis for urban monitoring. The findings stress the urgent need for integrated planning strategies focused on protecting and reconnecting green areas, promoting sustainable land use, and mitigating the negative impacts of uncontrolled urban expansion.

Furthermore, the use of the MOLUSCE plugin in QGIS enabled the spatial prediction of future land cover scenarios, offering critical insight into the likely trajectory of urban expansion in Tirana by 2030. Scenario-based modeling with MOLUSCE proved to be a valuable tool for anticipating future land use changes and for supporting data-driven planning decisions. Incorporating predictive modeling tools such as MOLUSCE is essential for urban planners and policymakers aiming to promote urban resilience and proactively address the ongoing challenges of rapid urbanization.

Further research should focus on higher-resolution monitoring, and comparative analyses with other rapidly urbanizing cities in the region, to inform more effective urban policy and resilience strategies.

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Appendix

Data and Workflow Availability

The QGIS workflow, input datasets, and all resulting data products (including classified rasters and final maps) used in this study are publicly available in the following repository: https://github.com/Leonora94/QGIS-Workflow-and-Dataset.