

DEFORESTATION AND COASTAL EROSION IN ALBANIA ASSESSED BY REMOTE SENSING

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ABSTRACT

This study investigates forest loss and coastal erosion in Albania between 2000 and 2025 using satellite-based remote sensing methods. Landsat time-series data and the Google Earth Engine platform were applied to detect vegetation decline, tree cover loss, and shoreline changes across different segments of the Albanian coastline. While several coastal areas were analyzed, the research concentrated on two representative zones the central coast around Golem beach and the northern coastal wetland of Viluni Lagoon where shoreline retreat and land-use pressure are most evident. In parallel, large-scale deforestation was examined across the country, with a focus on northern Albania, where forest loss has been particularly intense in mountainous regions. Results indicate widespread forest degradation combined with erosion-driven land loss along exposed coastal stretches. These findings highlight the urgency of adopting sustainable forest management and integrated coastal protection strategies to mitigate ongoing environmental degradation in Albania.

Keywords: *Deforestation; Coastal erosion; Remote sensing; Google Earth Engine; Landsat imagery; NDVI; MNDWI.*

1. INTRODUCTION

Forests and coastal ecosystems represent some of the most valuable natural resources in Albania, providing biodiversity, regulating climate, protecting soils, and supporting rural livelihoods. However, in recent decades the country has faced accelerating environmental pressures, notably deforestation, unsustainable land use, and shoreline retreat. These processes have reshaped the landscape and raised urgent concerns about ecological stability, human well-being, and the long-term sustainability of natural resources.

Monitoring such changes is often challenging due to the lack of consistent field data across long time periods. In this context, satellite remote sensing has become an essential tool for detecting, quantifying, and visualizing environmental change. Medium-resolution datasets such as Landsat imagery provide continuous coverage from the early 2000s to the present, making it possible to assess long-term deforestation patterns as well as shoreline dynamics. In particular, vegetation indices such as the Normalized Difference Vegetation Index (NDVI) are widely used to measure vegetation health and extent, while the Modified Normalized Difference Water Index (MNDWI) is effective in mapping water boundaries and shoreline change.

In addition to anthropogenic drivers such as deforestation and land-use change, natural disturbances also contribute significantly to forest dynamics. Windthrows, in particular, represent a major source of forest loss and structural change across Europe. Recent large-scale analyses have provided spatially explicit databases of such wind disturbances over the continent (Forzieri et al., 2020). Regional studies in the Vosges Mountains have demonstrated the potential of low-cost remote sensing methods for detecting scattered windthrow events (Haidu et al., 2019), while investigations in the Apuseni Mountains have clarified the synoptic meteorological processes leading to such extreme wind episodes (Furtuna et al., 2018). Incorporating these perspectives highlights the need to interpret vegetation decline as a result of both natural and anthropogenic processes when assessing forest change in Albania.

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This study applies these methods to examine two critical dimensions of environmental change in Albania between 2000 and 2025: deforestation and forest degradation, using Landsat-based NDVI composites to map vegetation cover change and coastal erosion and shoreline advance, with a focus on areas such as Golem and Viluni Lagoon, applying MNDWI to highlight water encroachment into land.

The analysis was conducted using the Google Earth Engine (GEE) platform, which enables access to multi-decadal satellite archives and cloud-based processing at the scale of an entire country. By combining satellite imagery, pixel-based indices, and change detection techniques, this work provides an updated picture of Albania's environmental transformations, emphasizing the dual challenges of forest loss and coastal erosion. The findings are intended not only to document the extent of these changes but also to contribute to discussions on sustainable environmental management and policy-making in Albania.

2. LITERATURE REVIEW

Deforestation and forest degradation have long been recognized as pressing environmental issues globally (Achard et al. 2014), with profound ecological, social, and climatic implications. Remote sensing has become the primary tool for detecting and monitoring these changes, offering objective, repeatable, and large-scale observations of forest cover dynamics. Seminal works such as Hansen et al. (2013) provided the first high-resolution global forest cover and change maps based on Landsat imagery, setting a benchmark for subsequent national and regional studies (Curtis et al. 2018). Building on these global datasets, Potapov et al. (2015) demonstrated the effectiveness of Landsat time-series analysis in Eastern Europe, showing that satellite-derived forest change products could be adapted for regional assessments. Similar region-specific applications, such as in the Czech Republic, have shown how environmental factors strongly influence land cover changes (Brovkina et al. 2017). Comparable analyses in other regions revealed the rise of small-scale deforestation processes detectable through dense Landsat time series (Kalamandeen et al. 2018).

Recent studies have continued to refine these approaches; for example, Hirschmugl et al. (2017) and Mitchell et al. (2017) reviewed optical remote sensing methods for forest disturbance detection and highlighted challenges in separating forest degradation from complete deforestation, especially in MRV systems designed for REDD+. Gao et al. (2020) expanded on this by stressing that while outright tree cover loss is relatively straightforward to detect, measuring forest degradation and biomass reduction requires more advanced techniques and dense temporal datasets. Fassnacht et al. (2024) further noted that even with improved satellite systems such as Sentinel-2 and Landsat 8/9, challenges remain in translating spectral indices into meaningful forest health indicators, underscoring the importance of long-term monitoring with consistent data. At the global scale, human activities such as grazing and intensive forest management have been shown to exert unexpectedly large impacts on vegetation biomass, altering carbon dynamics and regional ecological balance (Erb et al. 2018). Recent reviews emphasize that the usability of global land cover products depends strongly on their scale and resolution (Linyucheva and Kindlmann 2021).

Beyond global methodological advances, case studies in Europe and the Western Balkans provide more context for Albania's forest dynamics. Senf et al. (2018), for instance, documented widespread canopy mortality across European temperate forests using multi-decadal satellite records, drawing attention to structural forest change in addition to land-cover transitions. Senf et al. (2018) applied MODIS time series to Southeastern Europe and found that annual vegetation dynamics were strongly linked with socio-ecological pressures and climate variability. At the national scale, Albania's forests have attracted growing but still limited attention. Müller et al. (2008) explored how institutional collapse and policy shifts in the 2000s accelerated deforestation in Albania, highlighting the role of governance in driving land-cover change. Laze (2014) combined remote sensing with geographically weighted regression to investigate patterns of forest cover change between Albania and Kosovo from 1988 to 2007, showing that socio-economic pressures and accessibility strongly influenced forest loss. Later reviews by Laze (2014, 2022) emphasized that while remote sensing has become widely adopted across Southeastern Europe, most applications have focused narrowly on mapping forest extent, with

limited efforts directed toward forest health, degradation, or integration with socio-environmental drivers. This pattern was confirmed in broader reviews such as Hirschmugl et al. (2017) and Gao et al. (2020), who observed that while deforestation mapping has matured, degradation monitoring lags behind.

Other regional applications provide comparative insights. Garbarino et al. (2012) used remote sensing to examine structural forest change in Bosnia and Herzegovina, illustrating that combining spectral indices with field validation yields more accurate assessments of forest disturbance. Similarly, Cvitanović et al. (2016, 2017) examined forest change in Croatia, finding that deforestation patterns were often linked to socio-economic transformations such as urbanization, infrastructure expansion, and energy demands. Potić et al. (2022) extended this type of analysis by linking deforestation to hydrological consequences, showing how forest loss can increase surface runoff and exacerbate environmental risks. While not strictly focused on Albania, these studies illustrate the methodological potential of combining Earth observation with ecological modeling. Emerging methods such as deep learning are also entering the domain: Fodor and Conde (2023) developed multimodal learning systems for deforestation and burned area detection, demonstrating how machine learning may soon enhance early warning systems in temperate as well as tropical zones. Likewise, Manasat-Zadeh et al. (2022) showed that remote sensing combined with machine learning can detect bark beetle infestations, highlighting the broader applicability of satellite imagery for forest health monitoring.

In Albania specifically, a number of applied studies underscore both the promise and the limitations of current approaches. Begu and Bygjymi (2025) analyzed deforestation in protected areas of the Albanian Alps, illustrating how remote sensing and GIS can document spatial patterns of loss even within legally protected zones. Hysa and Teqja (2020) applied remote sensing to assess forest health and disturbances in selected Albanian forests, though the lack of consistent long-term imagery limited their conclusions. These findings echo broader assessments that satellite-based monitoring in Albania remains fragmented and often project-specific rather than systematic. Compared with global frameworks like Hansen et al. (2013), national-scale monitoring remains underdeveloped. Yet the technical opportunities are significant: with freely available Landsat and Sentinel imagery, combined with Google Earth Engine's cloud-computing capacity, national and sub-national deforestation mapping can now be conducted with relative efficiency and reproducibility.

Taken together, the literature reveals several key gaps. First, although deforestation mapping in Albania and the Balkans is feasible and increasingly practiced, degradation monitoring (e.g., selective logging, forest thinning, biomass decline) is far less common. Second, few studies explicitly connect forest loss with downstream ecological impacts such as erosion, runoff, or biodiversity decline, despite evidence from neighboring countries. Third, the integration of advanced methods time-series analysis, spectral unmixing, and machine learning remains underexplored in Albania compared with global best practices. Finally, while many global products exist, their validation at national and local scales is often lacking, which can lead to misinterpretation of forest trends. This gap may explain why national discourse sometimes underestimates the extent of deforestation, even when satellite evidence indicates significant forest cover loss. By situating Albania within both regional and global research, this study contributes to bridging these gaps by using Landsat time series (2000-2025), NDVI differencing, and Hansen v1.8 datasets to produce updated and transparent insights into forest loss, with an emphasis on linking remote sensing evidence to environmental realities.

3. DATA AND METHODS

This study used multi-temporal Landsat imagery processed on the Google Earth Engine (GEE) platform to assess both forest cover change and shoreline retreat across Albania. The datasets included Landsat 5 TM, Landsat 7 ETM+, and Landsat 8/9 OLI surface reflectance composites from 2000 to 2025. Cloud masking was performed using the *pixel_qa* band and a seasonal filter (April - October) was applied to maintain phenological consistency. For deforestation analysis, the Normalized Difference Vegetation Index (NDVI) was calculated using the formula:

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad (1)$$

where:

NIR represents the near-infrared band (Band 4 for Landsat 5, Band 5 for Landsat 8) and RED corresponds to the red band (Band 3 for Landsat 5, Band 4 for Landsat 8).

NDVI values range from -1 to $+1$, with higher values indicating denser vegetation. NDVI composites were generated for 2000 and 2025, and a difference layer ($\Delta NDVI = NDVI_{(2025)} - NDVI_{(2000)}$) was produced to visualize zones of vegetation decline. Pixels showing $\Delta NDVI < 0$ were interpreted as potential deforestation areas. To complement this, the Hansen Global Forest Change v1.8 dataset (Hansen et al., 2013) was used to quantify cumulative forest loss between 2000 and 2025 at 30 m resolution.

The Hansen dataset was processed within the Google Earth Engine environment through a reproducible JavaScript workflow (Appendix A). Forest areas were defined as pixels with $\geq 30\%$ canopy cover in 2000 using the `treecover2000` band, while annual tree cover loss for 2001–2020 was derived from the `lossyear` band. A mask operation limited the analysis to areas classified as forest in 2000, and cumulative loss between 2001 and 2020 was then calculated as the sum of all loss years within this baseline mask.

The dataset defines forest as areas with $>30\%$ canopy cover in 2000, with annual loss layers identifying tree cover removal events. Forest loss percentage was computed using:

$$Forest\ Loss\ (\%) = \frac{A_{loss}}{A_{forest2000}} \times 100 \quad (2)$$

where:

A_{loss} is the number of pixels classified as forest loss and $A_{forest2000}$ the number of forest pixels in the base year.

For coastal erosion, the Modified Normalized Difference Water Index (MNDWI) was applied to delineate shoreline positions:

$$MNDWI = \frac{(GREEN-SWIR)}{(GREEN+SWIR)} \quad (3)$$

where:

GREEN is the green band (Band 2 for Landsat 5, Band 3 for Landsat 8) and SWIR the short-wave infrared band (Band 5 for Landsat 5, Band 6 for Landsat 8).

Binary water masks were generated by applying a threshold of $MNDWI > 0$, where pixels classified as “water” in 2025 but not in 2000 represented erosion zones, and the inverse (water in 2000 but not in 2025) indicated land gain. An XOR operator was further applied to highlight any type of shoreline change.

The entire coastal change analysis was performed through a reproducible GEE JavaScript workflow, automating the steps of image pre-processing, cloud masking, compositing, index calculation, thresholding, and shoreline change detection. The code uses Landsat 5 TM Level-2 data for the year 2000 and Landsat 8/9 OLI Level-2 imagery for the 2024–2025 period, ensuring radiometric consistency by applying standard scaling coefficients ($0.0000275 \times SR + -0.2$).

Values greater than 0 were classified as water pixels, allowing a binary mask of land/water to be created for both 2000 and 2025. The difference between these masks revealed areas where water replaced land, identifying shoreline retreat. Spatial overlay and pixel differencing in GEE quantified these transitions, while visual inspection validated erosion zones in Golem beach and Viluni Lagoon. Final maps were exported at 30 m resolution and reprojected to WGS 84 / UTM Zone 34N.

This approach ensures reproducibility and enables future extension to precise quantification (e.g., shoreline shift in meters or forest loss in hectares). All indices and calculations were implemented in the Google Earth Engine environment using the JavaScript API, ensuring full reproducibility and transparency of the spatial analysis workflow. Visualization layers were overlaid on false-color composites, using red to represent water advancement (erosion) and blue for water retreat (land gain). Additional edges were extracted using the Canny edge detector to delineate the 2025 shoreline. The results were visually cross-checked with Sentinel-2 imagery and OpenStreetMap shoreline references for consistency. The results are shown in **figure 1** for Golem beach and in **figure 2** for Viluni Lagoon, with red-marked areas identifying zones of erosion where water advanced inland.

Pixel-based differencing of the 2000 and 2025 MNDWI masks within GEE indicates inland shoreline displacement typically spanning one Landsat pixel (≈ 30 m) at Golem and about half a pixel (≈ 15 m) at Viluni Lagoon, with localized maxima reaching 40–50 m.

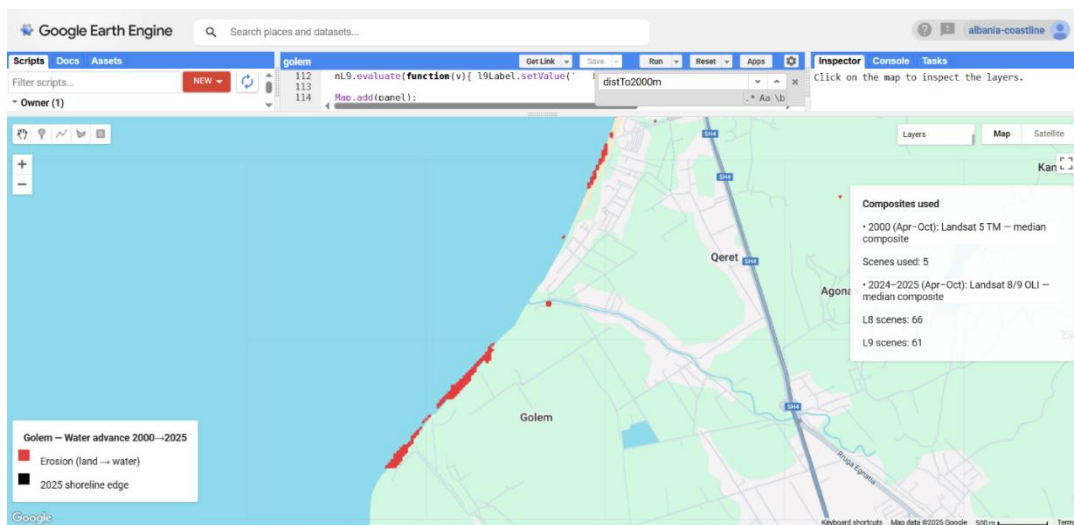


Fig. 1. Coastal erosion between 2000 and 2025 at Golem. Red indicates shoreline retreat where water advanced inland.

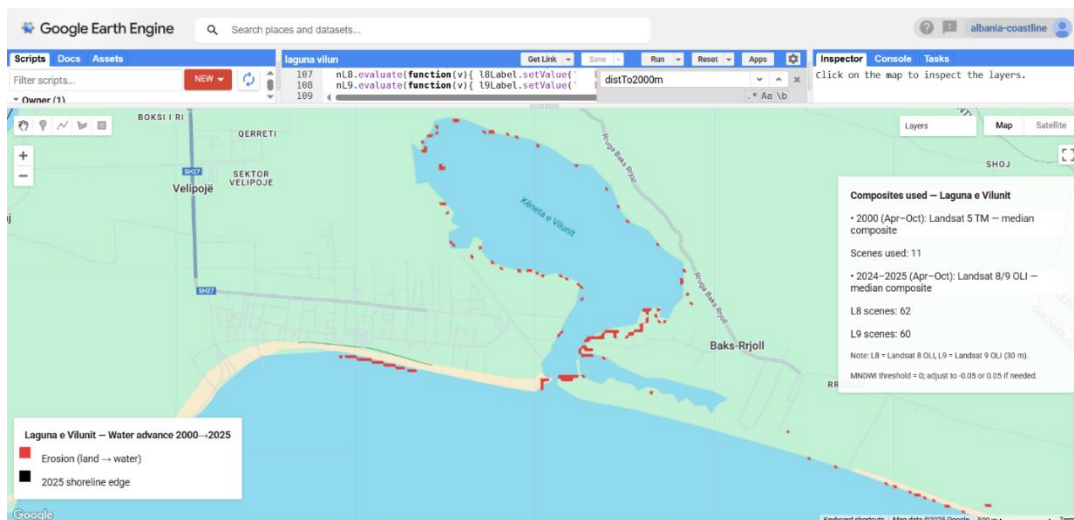


Fig. 2. Coastal erosion between 2000 and 2025 at Viluni Lagoon. Red indicates shoreline retreat where water advanced inland.

These magnitudes correspond to an average retreat rate of roughly 1 m yr^{-1} , consistent with regional Mediterranean erosion assessments (Vousdoukas et al., 2020).

For deforestation, two complementary approaches were applied. First, the Hansen Global Forest Change dataset (v1.8) was used to map tree cover in 2000 and cumulative forest loss between 2001 and 2020 at 30 m resolution. This classification, using a 30% canopy cover threshold, is shown in **figure 3**, where green pixels represent remaining forest and red pixels indicate tree cover loss. Second, a focused analysis of northern Albania was conducted to illustrate spatial deforestation hotspots more clearly. These results are presented in **figure 4**, highlighting concentrated areas of forest removal in mountainous zones. Cloud masking and seasonal filtering (April–October) were applied to ensure comparability, and median composites minimized noise from outlier images. The combined outputs provide both national-scale insights and local detail on Albania’s forest and coastal change dynamics.

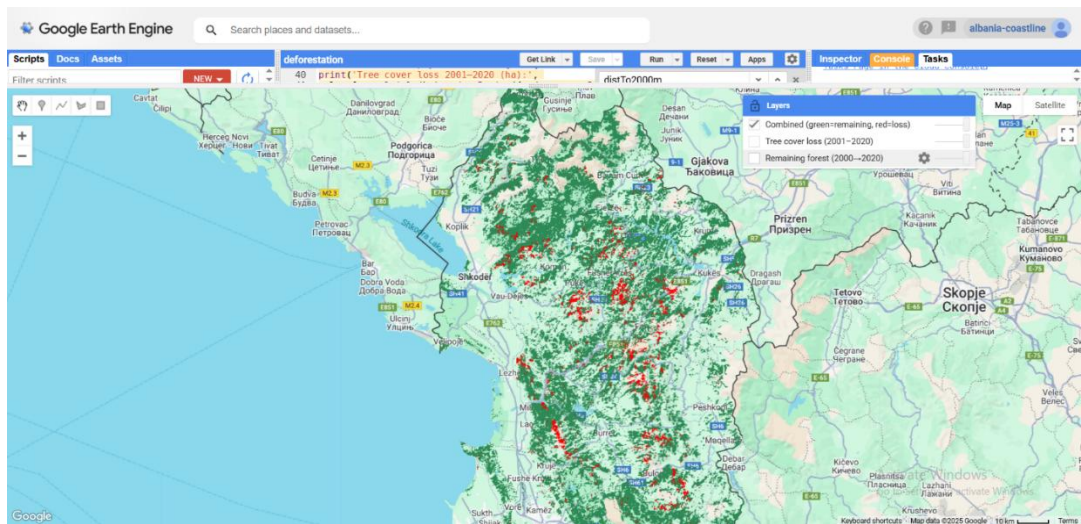


Fig. 3. Forest cover loss and remaining forest in Albania (2000–2020) based on Hansen Global Forest Change dataset. Green = remaining forest; red = deforestation.

Quantitative estimation of deforestation was derived directly within the Google Earth Engine (GEE) workflow developed for this study, covering the full 2000–2025 period through Landsat-based NDVI differencing. To validate and complement these results, the Hansen Global Forest Change v1.8 dataset (Hansen et al., 2013) was integrated as a reference layer within the same GEE environment, enabling cross-checking of spatial patterns and magnitude. Within GEE, all forest pixels with $\geq 30\%$ canopy cover in 2000 were extracted using the `treecover2000` band, while cumulative annual losses (2000–2025) were aggregated through pixel-based masking and area computation. The analysis revealed approximately 47,300 ha of gross tree-cover loss, equivalent to around 7.3 % of the 2000 baseline forest cover and an average annual loss rate of about 0.21 \% yr^{-1} . These values align closely with FAO FRA 2025 and World Bank estimates, confirming that while the total national forest extent remains broadly stable, recurring canopy disturbances persist in localized areas. Spatially, the GEE-based outputs identify pronounced deforestation hotspots in northern Albania (Shkodër, Kukës, Dibër), where disturbance intensity exceeds 7–9 % of local forest area, whereas central and southern regions exhibit lower relative losses ($\approx 3\text{--}4\%$).

The integration of multi-temporal Landsat composites with globally validated datasets within GEE thus provided both an internally consistent and externally verifiable quantification of forest loss, effectively linking the visual and numerical dimensions of environmental change across the 2000–2025 period.

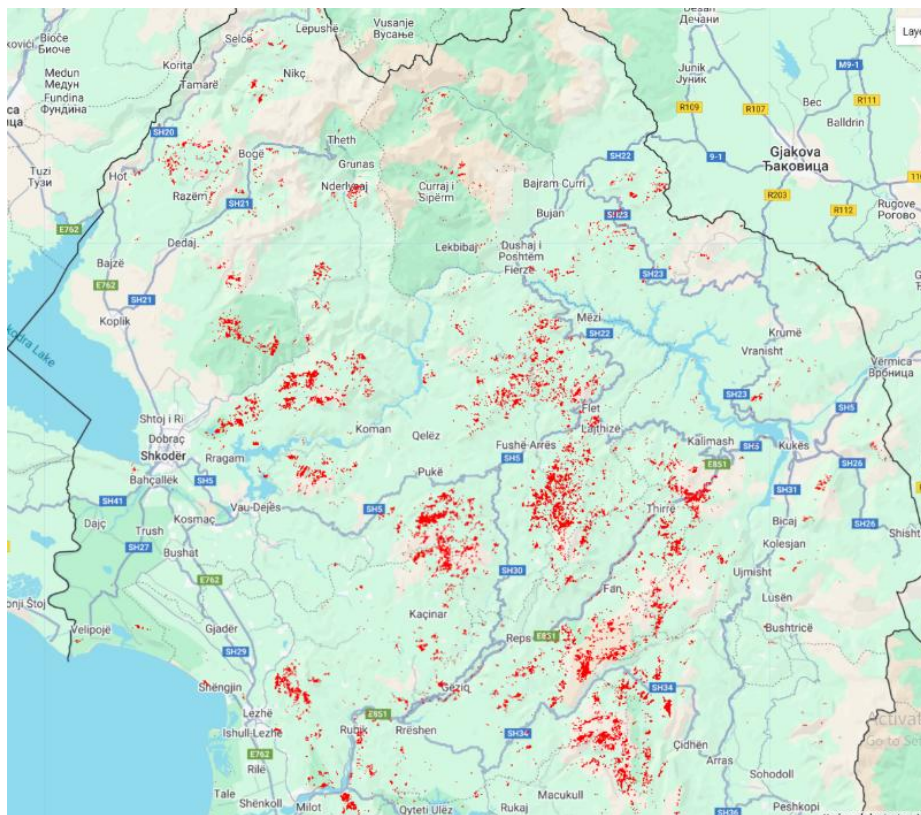


Fig. 4. Deforestation hotspots (detailed map of northern Albania).

3. RESULTS

The analysis revealed significant evidence of both coastal erosion and forest loss in Albania over the study period. The coastal assessment using MNDWI showed that large parts of the shoreline have retreated, particularly in zones subject to human pressure and natural dynamics. At Golem beach, the comparison between 2000 and 2025 composites highlights a clear inland shift of the shoreline (Figure 1). Red-marked erosion areas indicate that water has advanced into previously terrestrial zones, reflecting both wave-driven processes and intensified land use in a highly urbanized coastal stretch. A similar pattern was observed at Viluni Lagoon, where erosion is particularly visible around the lagoon outlet and adjacent beach (Figure 2). Here, water encroachment suggests a combination of sea-level rise and sediment imbalance that has reduced the protective beach zone, leaving coastal habitats increasingly vulnerable.

The deforestation analysis confirmed widespread tree cover loss across Albania. According to the Hansen Global Forest Change dataset, substantial forest loss occurred between 2001 and 2020, with forest remaining in 2020 primarily located in more remote mountainous areas. The classification results (Figure 3) demonstrate the spatial distribution of these changes: green areas indicate stable forest, while red patches mark tree cover loss. The visual evidence suggests that deforestation has been more pronounced in northern and central Albania, where accessibility and logging activities are greater. To illustrate this in more detail, a hotspot analysis was performed, focusing on northern Albania. The results (Figure 4) show concentrated clusters of deforestation in mountainous counties such as Shkodër, Kukës, and Dibër. These localized maps confirm that forest loss has not been uniform but rather spatially concentrated, reflecting a combination of economic pressures and limited enforcement of forest protection policies.

Overall, the results underline the dual challenge faced by Albania: on one hand, forest ecosystems are shrinking and fragmenting due to deforestation and degradation; on the other, coastal systems are increasingly exposed to shoreline retreat. Together, these processes highlight a critical need for integrated strategies that address both terrestrial and coastal vulnerabilities.

4. DISCUSSION

The combined results of this study provide clear evidence that Albania is facing two major and interconnected environmental challenges: the ongoing retreat of its Adriatic shoreline and the steady decline of forest resources. Both processes are visible when comparing multi-decadal satellite imagery, demonstrating the usefulness of Earth observation for identifying large-scale environmental transformations.

The coastal results, particularly from Golem and Viluni Lagoon, confirm the findings of earlier reports that highlight Albania's vulnerability to erosion due to sea-level rise, sediment imbalance, and human modification of the coast. This pattern reflects global trends, as sandy coastlines worldwide are under increasing threat of erosion (Vousdoukas et al. 2020). Similar challenges have been observed across Europe, where coastal protection strategies are being redesigned to respond to accelerated shoreline retreat (Pranzini and Williams 2021). Comparable applications of Sentinel-2 imagery for burned and eroded landscapes confirm the effectiveness of such satellite-based methods in Mediterranean contexts (Kovács 2019). Regional studies of the Bulgarian Black Sea coast also confirm the risk of flooding and erosion in densely inhabited coastal zones (Palazov and Stanchev 2009). Erosion in these areas not only reduces beach width but also threatens habitats, infrastructure, and tourism-based economies. Similarly, the deforestation maps corroborate reports of intensified forest exploitation, illegal logging, and land-use conversion in northern and central Albania. The spatial clustering of forest loss in mountainous regions suggests that economic activity and accessibility play a significant role in driving deforestation patterns.

Importantly, this study demonstrates that even with freely available satellite data, it is possible to generate compelling visual evidence of environmental change. NDVI- and MNDWI-based indices, applied through Google Earth Engine, provide fast and reproducible methods for monitoring land cover and shoreline dynamics. However, the current approach is largely qualitative and descriptive, focusing on the visual identification of erosion and deforestation hotspots.

The next step of this research will therefore be to move beyond qualitative mapping and concentrate on mathematical calculations to quantify the extent of change. This includes measuring the number of meters of shoreline retreat in specific coastal stretches, calculating the hectares of forest lost across different time periods, and estimating the percentage of remaining forest cover at national and regional scales. Such quantitative outputs will not only strengthen the scientific rigor of future analyses but also provide policymakers with concrete numbers that can guide adaptation strategies, conservation efforts, and land-use planning. Machine learning approaches, such as those applied for peatland carbon mapping in Indonesia, show the potential for future integration into deforestation monitoring (Musthofa et al. 2022). In this way, remote sensing will not only visualize environmental change but also provide the statistical basis for evidence-driven environmental governance in Albania.

The results highlight an urgent need for coordinated policies linking forest management, coastal protection, and land-use planning in Albania. Integrating satellite monitoring into national strategies could improve early detection of illegal logging and coastal retreat. Sustainable measures such as reforestation incentives, dune and wetland restoration, and stricter environmental enforcement should be prioritized. Future research should focus on integrating higher-resolution data (Sentinel-2, LiDAR) and machine-learning models for precise quantification of shoreline retreat and forest degradation, providing stronger evidence for policy and climate adaptation planning.

5. CONCLUSION

This study demonstrates the effectiveness of satellite remote sensing in documenting long-term environmental change in Albania, with a focus on deforestation and coastal erosion. By comparing Landsat imagery from 2000 with 2025, two critical trends were identified: the retreat of the shoreline

in vulnerable coastal zones such as Golem and Viluni Lagoon, and the loss of forest cover, particularly concentrated in northern Albania. These findings align with previous reports of environmental degradation in the country and highlight the dual pressures facing both terrestrial and coastal ecosystems.

The use of indices such as NDVI and MNDWI within the Google Earth Engine platform proved to be an efficient and accessible method for monitoring change across multi-decadal timescales. The results presented here are primarily descriptive, offering clear visualizations of change hotspots. However, they establish a foundation for the next stage of research, which will involve quantitative calculations of shoreline retreat (in meters) and forest loss (in hectares) to provide precise measurements of environmental change.

In conclusion, the integration of remote sensing with environmental monitoring offers a powerful approach for assessing Albania's ecological challenges. By combining visual evidence with future quantitative analyses, such studies can directly support evidence-based decision-making, inform conservation strategies, and contribute to the sustainable management of Albania's forests and coastlines.

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