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Impact of Mangrove Degradation on Biodiversity and Land Use in Togo (2014-2024)

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Abstract

Mangrove ecosystems along the southern coast of Togo are undergoing rapid degradation under increasing anthropogenic and climatic pressures. This study investigates the spatio-temporal dynamics of mangrove cover in Lower-Togo between 2014 and 2024 by integrating remote sensing, field observations, and socio-economic surveys. Multi-temporal Sentinel-2 MSI imagery was processed to derive the Normalized Difference Vegetation Index (NDVI) and to perform land-use classification using unsupervised (K-means) and supervised (Maximum Likelihood) approaches, enabling accurate discrimination of mangrove formations and surrounding land-use classes. The results indicate a significant reduction in mangrove extent, with surface area decreasing by 35.8%, from 1,150 ha in 2014 to 738 ha in 2024. This spatial regression is accompanied by a marked decline in ecological integrity, reflected by a 35% reduction in Rhizophora racemosa populations and an overall loss of nearly 40% of floristic diversity, suggesting progressive ecological homogenization. Concurrently, urban land cover expanded from 18% to 32%, while socio-economic surveys reveal a 50% decrease in income from artisanal fishing, highlighting the close coupling between ecosystem degradation and community vulnerability. These trends underscore the dominant role of direct human pressures including unplanned urban expansion, intensive harvesting of mangrove wood for domestic energy, uncontrolled effluent discharge, and disruption of lagoon–ocean hydrological connectivity in driving mangrove loss in Lower-Togo. The study demonstrates the effectiveness of combining remote sensing, GIS, and socio-economic data for long-term coastal ecosystem monitoring and provides a robust scientific basis to support sustainable mangrove management and integrated coastal zone planning in West Africa.

Keywords: Water, Ecological Health, Urban Expansion, Socio Economic And Environmental Change

1. Introduction

Mangroves are intertidal coastal ecosystems dominated by halophilic woody species and play a fundamental role in maintaining the ecological and socio-economic balance of coastal regions. They function as natural buffers against coastal erosion, serve as nurseries for numerous marine and estuarine species, and constitute major carbon sinks of global importance. In the context of climate change, mangroves are increasingly recognized for their capacity to mitigate the impacts of extreme events such as storms, flooding, and sea-level rise. In West Africa, mangrove ecosystems are experiencing accelerated degradation driven by population growth, land-use change, and climate variability (UNEP, 2020; Alongi, 2015). In Togo, the Lower Togo coastal zone particularly within the prefectures of Lacs and Vo represents the country's principal mangrove stronghold. However, for more than three decades, these ecosystems have been subjected to intense anthropogenic pressures, including rapid and often unplanned urban expansion, uncontrolled logging for fuelwood, agricultural intensification, unsustainable fishing practices, and both direct and indirect impacts of climate change. Previous studies (Adjéhi, 1995; Kouassi et al., 2002; Essolakina et al., 2021) report a loss exceeding 70% of mangrove cover in southern Togo since the 1990s. This decline has resulted in significant consequences for biodiversity, coastal resilience, and local food security, particularly for communities that depend heavily on artisanal fisheries and mangrove-derived resources. Within this context, the present study adopts an integrated coastal zone management perspective and pursues three main objectives:

- To characterize recent mangrove dynamics (2014–2024) in Lower Togo through the analysis of multi-source satellite imagery.
- To assess the ecological and socio-economic implications associated with observed changes in mangrove extent and condition.
- To propose guidelines for sustainable mangrove management, highlighting the contribution of remote sensing and geographic information systems (GIS) as decision-support tools [1-3].

2. Materials and Methods

2.1. Description of the Study Area

The study area is located in Lower Togo, in the extreme southern part of the country, between 6°05′ and 6°20′ N latitude and 1°15′ and 1°40′ E longitude. It mainly covers the prefectures of Lacs and Vo and includes the coastal localities of Aného, Agbodrafo, Togoville, Avépozo, and Aklakou. Spatial delimitation of the study area was carried out using IGN/ORSTOM topographic maps at a scale of 1:200,000 and Sentinel-2 MSI imagery (2015 and 2024). All spatial datasets were reprojected into the WGS 84 / UTM Zone 31N coordinate system to ensure geometric consistency and spatial comparability across analyses. From a biophysical perspective, the area is characterized by a complex mosaic of coastal and lagoon ecosystems, including Lake Togo, the Aného Lagoon, and several major river systems such as the Mono, Haho, Zio, Boko, and Gbaga rivers. These hydrographic networks play a key role in freshwater inputs, salinity regulation, and sediment transport, thereby creating favorable environmental conditions for mangrove development. he climate of Lower Togo is subequatorial, marked by two rainy seasons (March–July and September–November) and two dry seasons (August, followed by December–February). Mean annual rainfall ranges from 800 to 1,200 mm, while average temperatures are around 27 °C. These climatic conditions strongly influence mangrove productivity and the seasonal dynamics of lagoon–ocean exchanges. Vegetation within the study area is dominated by red mangroves (Rhizophora racemosa), white mangroves (Avicennia germinans), and gray mangroves (Conocarpus erectus), accompanied by halophytic and herbaceous species. These mangrove formations provide essential ecosystem services, including carbon sequestration, shoreline stabilization, and nursery habitats for fishery resources. From a socio-economic standpoint, Lower Togo exhibits high population densities, particularly around coastal towns and lagoon margins. Dominant human activities include artisanal fishing, peri-urban agriculture, mangrove wood exploitation, and largely unplanned urban expansion. Diachronic analysis of satellite imagery reveals a substantial increase in built-up areas and a progressive fragmentation of natural habitats, further increasing the vulnerability of mangrove ecosystems. Overall, the study area represents a strategic coastal zone that is both ecologically sensitive and socio-economically important, yet increasingly exposed to anthropogenic and climatic pressures. Its selection is justified by the need for multitemporal monitoring using Remote Sensing and GIS approaches, enabling the characterization, quantification, and interpretation of mangrove degradation dynamics in **Lower Togo** over the 2014–2024 period [2,3].

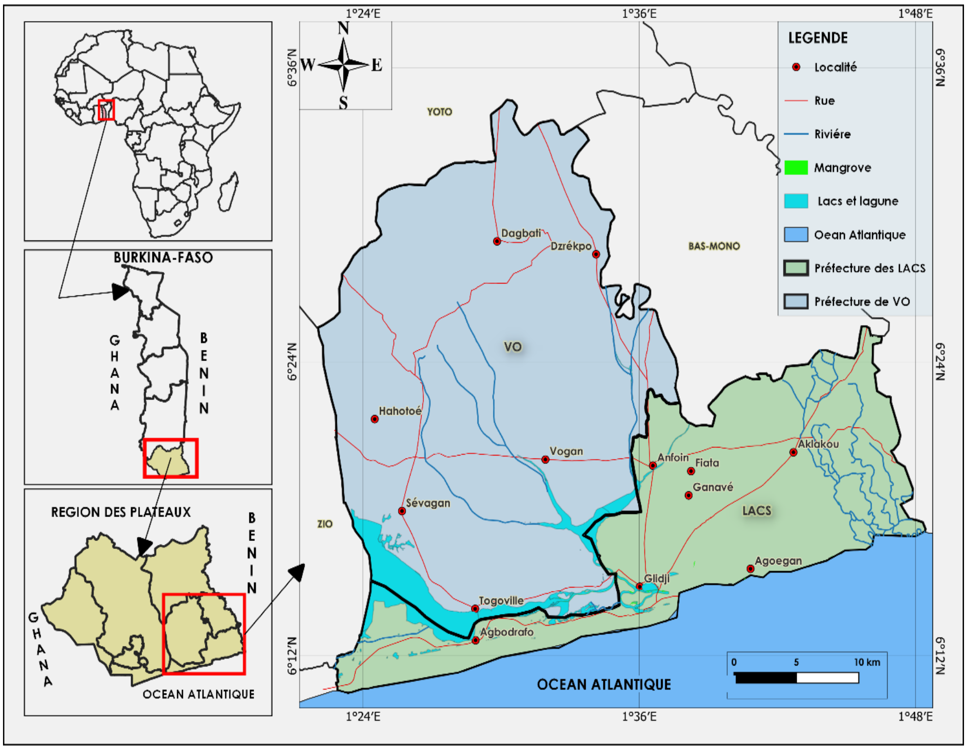

Figure 1 : Location of The Study Area

2.2. Data Acquisition

This study is based on the analysis of multi-temporal satellite imagery with medium to high spatial resolution, selected for their thematic relevance, temporal coverage, and free accessibility. The remote sensing data were acquired from two main satellite sensors

Landsat 8 Operational Land Imager (OLI)

Landsat 8 OLI scenes acquired in 2014 and 2021 were used to analyze long-term changes in land cover and land use. These images provide a spatial resolution of 30 m and a radiometric resolution of 12 bits, with spectral bands covering the visible, near-infrared, and shortwave infrared regions (0.43–2.29 µm). Their temporal consistency makes them suitable for diachronic analysis at regional scale.

A Sentinel-2 MSI image acquired in 2024 was used to characterize recent land-cover conditions. Sentinel-2 provides a spatial resolution ranging from 10 to 20 m depending on the spectral band and includes 13 spectral bands, notably red-edge bands that are particularly effective for vegetation analysis and assessment of plant health. All satellite scenes were selected based on low cloud cover (<10%) and comparable seasonal acquisition periods in order to minimize the effects of phenological variability. Landsat images were downloaded from the USGS EarthExplorer platform, while Sentinel-2 data were obtained from the Copernicus Open Access Hub. In addition to satellite data, IGN/ORSTOM topographic maps at a scale of 1:200,000 were used to support spatial delimitation and interpretation. Field data consisting of 200 ground control points collected using sub-metric GPS were integrated to support validation procedures and improve the geometric accuracy of the analyses [4-7].

Figure 2 : Mangrove Trees In Abobo[5]

Figure 3 : Mangrove Trees in Vo[6]

2.3. Preprocessing

To ensure temporal and spatial comparability of the multi-source satellite data, a series of standard preprocessing steps were applied prior to analysis. All preprocessing operations were carried out using ENVI 5.6, QGIS 3.28, and ArcGIS 10.8 software.

2.4. Radio Metricorrection

Raw digital numbers (DNs) were converted to top-of-atmosphere reflectance using the metadata provided with each dataset. For Landsat 8 images, radiometric calibration was performed using the MTL metadata file, while Sentinel-2 images were processed using SAFE metadata. This step ensured radiometric consistency and facilitated comparison between sensors.

2.5. Atmospheric Correction

Atmospheric effects were reduced using sensor-specific approaches. The Dark Object Subtraction (DOS1) method was applied to Landsat 8 images to minimize atmospheric scattering. For Sentinel-2 imagery, atmospheric and topographic corrections were performed using the Sen2Cor processor to derive surface reflectance products.

2.6. Geometric Correction And Projection

All images were geometrically corrected and reprojected into the WGS 84 / UTM Zone 31N coordinate system. Image co-registration achieved sub-pixel accuracy (error < 0.5 pixel), ensuring precise spatial alignment and temporal superimposability of the datasets.

2.7. Spatial Clipping

Using a vector shapefile derived from administrative maps of Togo, all scenes were clipped to the coastal zone of Lower Togo. This operation limited the analysis to the area of interest and reduced computational redundancy associated with processing pixels outside the study area. These preprocessing steps were essential to minimize uncertainties related to acquisition conditions and to ensure the reliability of subsequent analyses, including NDVI computation, principal component analysis (PCA), and supervised and unsupervised image classification [7-10].

2.8. Vegetation Analysis

The condition and spatial dynamics of mangrove vegetation were assessed using the Normalized Difference Vegetation Index (NDVI). NDVI was calculated according to the standard formulation:

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

where **NIR** represents near-infrared reflectance and **RED** corresponds to red-band reflectance. NDVI is sensitive to chlorophyll content and vegetation structure and is widely used to evaluate vegetation density and vigor. Higher NDVI values (> 0.3) generally indicate dense and healthy vegetation, whereas lower values (< 0.2) are associated with sparse, stressed, or degraded vegetation cover. In this study, NDVI was used as a key indicator to characterize the condition, vitality, and temporal evolution of mangrove formations in **Lower Togo**.

2.9. Image Classification

Land-use and land-cover mapping was carried out using two complementary image classification approaches, selected according to data availability and reference information for each period.

2.10. Supervised Classification (Maximum Likelihood)

Supervised classification was applied to the most recent images (2021 and 2024), for which reliable reference data were available. Training samples were collected in situ using sub-metric GPS and complemented by visual interpretation of very high-resolution imagery from Google Earth. The Maximum Likelihood algorithm, a probabilistic classifier based on class-specific statistical distributions, was used to assign pixels to thematic classes. This method is well suited for detailed land-cover discrimination when representative training data are available and ensures robust separation of thematic classes.

2.11. Unsupervised Classification (K-Means)

For the 2014 image, an unsupervised classification using the K-means algorithm was implemented due to the limited availability of contemporary reference data for that period. This non-parametric approach automatically groups pixels into spectrally homogeneous clusters without prior class definition. The resulting clusters were subsequently interpreted and labeled based on ancillary information, including topographic maps, historical land-use data, and visual analysis. The combined use of supervised and unsupervised classification methods enabled consistent diachronic analysis while accounting for variations in data availability across the study period, thereby enhancing both temporal comparability and thematic robustness of the results.

2.12. Validation of classifications

The accuracy of the land-use and land-cover classifications was assessed using standard validation procedures. Classification results were evaluated through the construction of a confusion matrix, which compares classified pixels with independent reference data, allowing the computation of accuracy metrics for each thematic class. In addition, the Kappa coefficient was calculated to quantify the level of agreement between the classified maps and the reference data beyond that expected by chance. Validation was performed using a dataset of 200 georeferenced control points collected during field surveys and complemented by visual interpretation of very high-resolution imagery. The results indicate an overall classification accuracy exceeding 85% and a Kappa coefficient greater than 0.80, confirming the reliability and robustness of the classification outcomes.

2.13. Software Tools

All data processing, spatial analyses, and statistical computations were conducted using a combination of specialized software packages. ArcGIS 10.8 was used for image processing, spatial analysis, and cartographic production. QGIS 3.28 supported spatial database management, coordinate reprojection, and thematic mapping. Statistical analyses, including the calculation of accuracy metrics and graphical representation of results, were performed using R version 4.3. The combined use of these tools enabled an integrated GIS, remote sensing, and statistical analysis framework, ensuring methodological rigor and reproducibility of the study.

3. Results

3.1. Evolution of Mangrove Areas

Diachronic analysis based on Landsat imagery (2014 and 2021) and Sentinel-2 data (2024) reveals a pronounced regression of mangrove areas in Lower Togo. In 2014, mangroves covered approximately 1,150 ha, whereas in 2024 their extent had decreased to 738 ha. This represents a net loss of 412 ha, corresponding to a decline of 35.8% over the study period (Figure 4; Table 2). This regression is accompanied by a substantial expansion of urbanized areas, which increased from 18% to 32% of the total land surface (+14 percentage points). The growth of built-up areas occurred primarily at the expense of agricultural land and natural ecosystems, which were progressively converted into residential zones and infrastructure. These spatial changes reflect increasing land pressure and unplanned urban expansion along the coastal zone of Lower Togo.

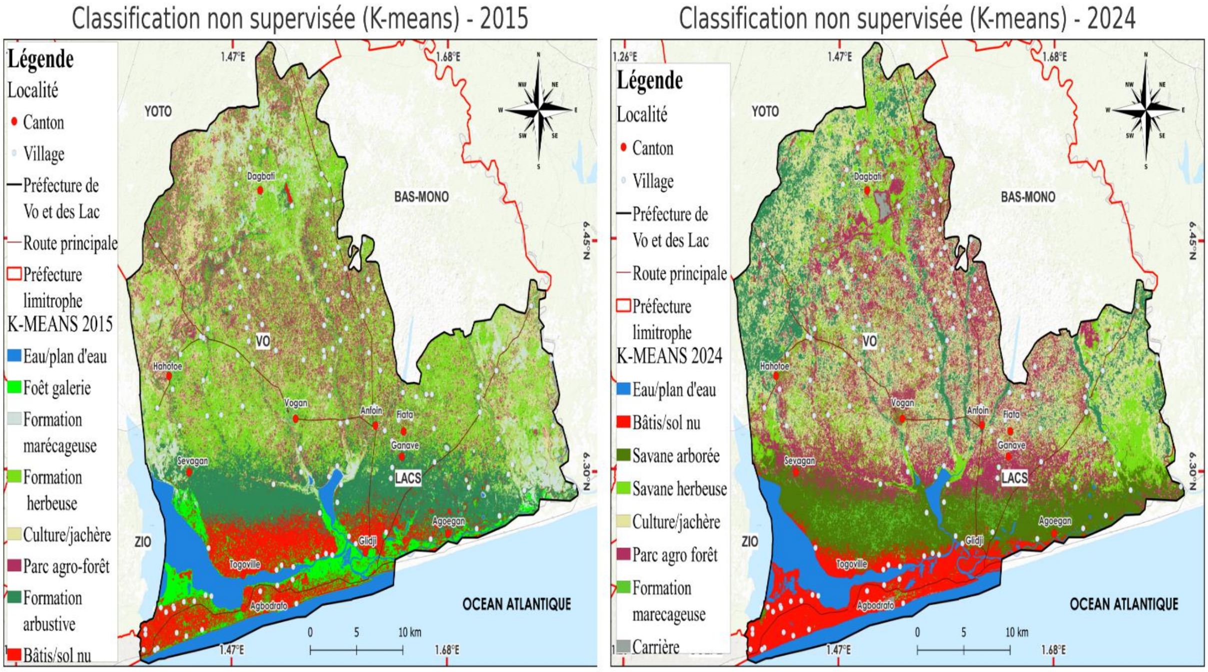

Figure 3 : Unsupervised Classification Maps (K- Means) of the Study Area in 2015 and 2024 [7]

3.2. Variation Of The Vegetation Index NDVI

The temporal evolution of mean NDVI values (Figure 5) indicates a progressive decline in vegetation biomass between 2014 and 2024. The average NDVI decreased from 0.21 in 2014 to 0.14 in 2024, reflecting a reduction in vegetation density and vigor across the study area. Areas exhibiting NDVI values greater than 0.3, characteristic of dense and relatively healthy mangrove stands, are currently restricted to a limited number of isolated patches, notably around Togoville and Avépozo. The spatial fragmentation of these high-NDVI zones highlights the heterogeneous distribution of remaining mangrove vegetation in **Lower Togo**.

3.3. Floristic Composition

The floristic analysis reveals a marked decline in populations of Rhizophora racemosa, with an estimated reduction of 35% over the study period. This species, historically dominant in the mangrove ecosystems of Lower Togo, shows a clear contraction in spatial extent and abundance. In contrast, *Avicennia germinans* exhibits a relative increase in occurrence, primarily in the form of sparse and discontinuous stands, accompanied by the emergence of bare or weakly vegetated areas. Overall, floristic diversity decreased by approximately 40% between 2014 and 2024. This decline is reflected in a simplified vegetation structure and reduced heterogeneity of mangrove plant assemblages across the study area.

3.4. Socio-Economic Impacts

Socio-economic surveys conducted among 50 riverside households indicate a substantial decline in fishery resources over the study period. Reported pelagic fish catches decreased by approximately 60% over the last decade, resulting in an average reduction of about 50% in fishermen's income (Table 4). In parallel, survey responses show increased reliance on mangrove resources for fuelwood and subsistence activities among local households. These findings document a measurable association between changes in mangrove ecosystems and the socio-economic conditions of coastal communities in Lower Togo.

3.5. Dynamics of Land Use Classes 2015–2024

Diachronic analysis of satellite images acquired in 2015 and 2024 highlights substantial transformations in land-use patterns across the study area (Table 3; Figure 6). Unlike previous sections focusing specifically on mangrove cover, this analysis considers all major land-use and land-cover classes within the entire coastal zone of **Lower Togo**.

Maps from 2015 and 2024 show:

Class	Area in 2015 (ha)	Area in 2024 (ha)	Evolution (%)
Mangroves	7,652	4,304	-43.8%
Farmland	6,218	7,942	+27.7%
Urban areas	4,312	5,986	+38.8%
Bodies of water	3,021	2,945	-2.5%
Secondary vegetation	2,134	2,160	+1.2%

Table 1: Land Use Classes

Citation: Kassi, B. J., Gaglo, K., Mobio, B. A. (2026). Impact of Mangrove Degradation on Biodiversity and Land Use in Togo (2014-2024). *J Epidemiol Public Health, 4*(2), 1-8.

The land-use maps for 2015 and 2024 reveal a marked regression of mangrove areas, which decreased from 7,652 ha in 2015 to 4,304 ha in 2024, corresponding to a decline of 43.8% (Table 3). Over the same period, agricultural land expanded from 6,218 ha to 7,942 ha (+27.7%), while urban areas increased substantially from 4,312 ha to 5,986 ha (+38.8%). In contrast, water bodies exhibited only minor variation (–2.5%), and secondary vegetation showed a slight increase (+1.2%).

The graph below illustrates this evolution:
Figure 6 illustrates these changes and highlights a progressive reorganization of land-use patterns, characterized by the conversion of natural ecosystems—particularly mangroves nto agricultural and built-up areas. This land-use dynamic reflects increasing human pressure on coastal ecosystems and contributes to the spatial fragmentation observed across the study area.

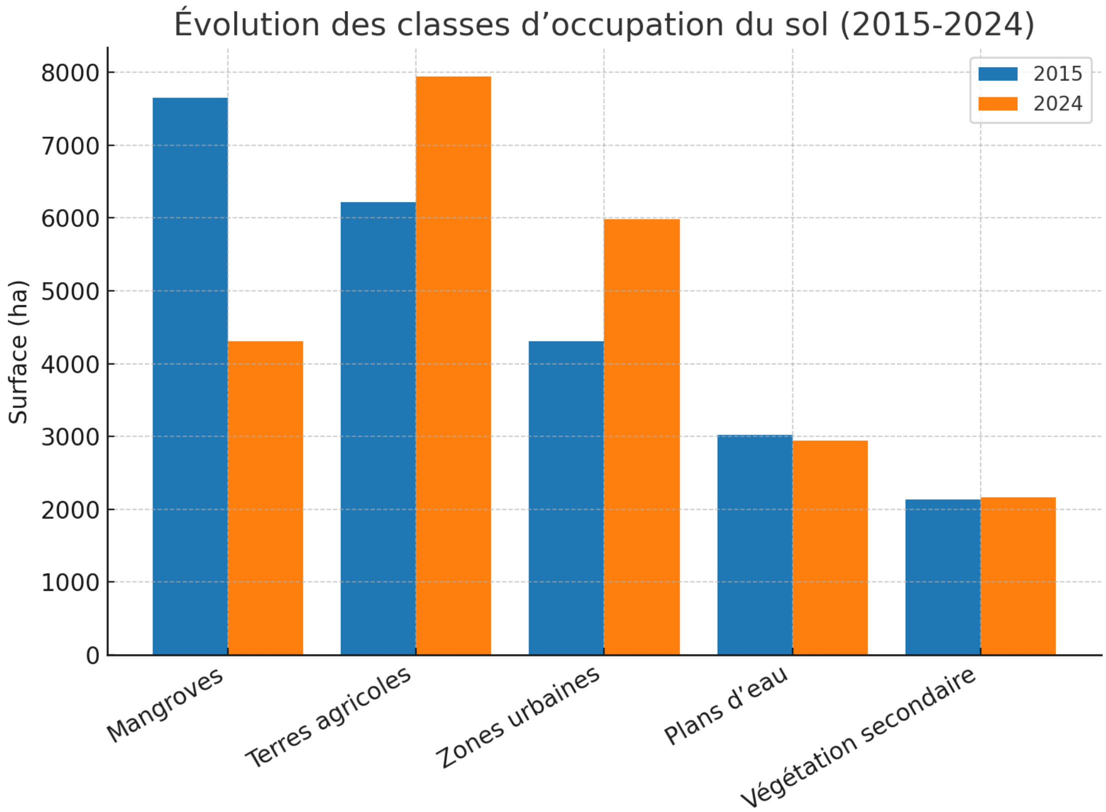

Figure 4 : Occupancy classes

Overall, these results reflect a dynamic of ecological erosion and socio-spatial transformation, dominated by the regression of mangroves in favor of agriculture and urbanization. The contraction of mangroves, coupled with the expansion of built-up areas, illustrates a process of increasing anthropogenic pressure on coastal ecosystems.

4. Discussion

4.1. Drivers of Mangrove Degradation

The results of this study indicate that the regression of mangrove ecosystems in Lower Togo is primarily driven by anthropogenic pressures. Unplanned urban expansion, particularly pronounced around Aného, Agbodrafo, and Avépozo, has led to the infilling of wetlands and progressive fragmentation of mangrove habitats. These spatial changes are consistent with the observed increase in built-up areas documented in the Results section.

In addition, the intensive exploitation of mangrove wood—especially Rhizophora racemosa—for domestic energy and fish smoking constitutes a major driver of deforestation in the study area (FAO, 2020). Agricultural expansion, reinforced by population growth and increasing land demand, further accelerates the conversion of natural ecosystems and disrupts local hydrological regimes essential for mangrove sustainability. These findings are consistent with regional studies conducted in West Africa. Similar patterns have been reported in Senegal (Diop et al., 2014) and Nigeria (Nwilo et al., 2016), where rapid urbanization, agricultural encroachment, and resource exploitation have been identified as the dominant factors contributing to mangrove degradation. The convergence of these results highlights the regional nature of anthropogenic pressures affecting mangrove ecosystems along the West African coast.

4.2. Influence of Climate Change

Climate change acts as an aggravating factor in the degradation of mangrove ecosystems by modifying hydrological and salinity regimes and enhancing saltwater intrusion into lagoon systems, thereby intensifying coastal erosion processes (IPCC, 2021). Rising sea levels and the increasing frequency and intensity of storm events contribute to the partial submersion of low-lying mangrove zones and the progressive salinization of adjacent agricultural soils. Although anthropogenic pressures remain the dominant drivers of mangrove regression in Lower Togo, the observed climatic trends likely amplify ecosystem vulnerability and reduce the capacity of mangroves to recover from disturbance. Similar interactions between climate stressors and human-induced pressures have been documented in other mangrove regions worldwide. Studies by Alongi (2015) and Friess et al. (2019) emphasize that sea-level rise, altered sediment dynamics, and extreme climatic events significantly increase the susceptibility of mangrove ecosystems to degradation, particularly in densely populated coastal zones.

4.3. Ecological Consequences

The observed reduction in mangrove cover has significant implications for ecosystem functioning and the provision of ecosystem services in Lower Togo. Mangrove loss is associated with a decline in blue carbon sequestration capacity, a weakening of natural coastal protection against erosion, and a reduction in the availability of nursery habitats that support marine and estuarine species critical to artisanal fisheries. The contraction and fragmentation of mangrove habitats documented in this study are likely to reduce ecosystem resilience and disrupt trophic interactions within coastal environments. Similar ecological consequences have been widely reported in other mangrove regions of Southeast Asia and West Africa, where mangrove degradation has led to diminished biodiversity, increased shoreline instability, and reduced ecosystem-based climate regulation (Alongi, 2015; Friess et al., 2019).

4.4. Socio Economic Impacts

The socio-economic surveys conducted in the study area indicate a substantial decline in fishery productivity, with reported fish catches decreasing by approximately 60% and fishermen's income declining by about 50%. These trends contribute to increased economic vulnerability among coastal households and intensify reliance on alternative natural resources, some of which are exploited in an unsustainable manner. Comparable socio-economic consequences of mangrove degradation have been documented elsewhere in West Africa. Studies from Senegal (Diop et al., 2014) and Nigeria (Nwilo et al., 2016) similarly report declining fishery yields, heightened poverty levels, and reduced adaptive capacity among coastal communities. Together, these findings underscore the strong linkage between mangrove ecosystem degradation and the socio-economic resilience of populations dependent on coastal resources.

4.5. Methodological Contributions

The integration of multi-source and multi-temporal remote sensing data with field observations and socio-economic surveys provided a comprehensive and reliable assessment of mangrove dynamics in Lower Togo. This combined approach enabled the analysis of both spatial patterns and socio-environmental implications of mangrove degradation over a decadal timescale. Methodological robustness was strengthened through the complementary use of supervised (Maximum Likelihood) and unsupervised (K-means) classification techniques, selected according to data availability and reference conditions for each period. Classification accuracy was further ensured through validation using confusion matrices and the Kappa coefficient. This triangulated methodological framework is consistent with recommended best practices in mangrove and coastal ecosystem monitoring and aligns with approaches advocated by Friess et al. (2019) and FAO (2020), which emphasize the importance of combining remote sensing, field data, and socio-economic information to improve analytical accuracy and interpretability.

4.6. Limits and Perspectives

The main limitations of this study are related to the spatial resolution of historical satellite data, particularly the 30 m resolution of Landsat imagery, which constrains the detection of small and fragmented mangrove patches. In addition, the availability of long-term, continuous socio-economic data remains limited, restricting more detailed temporal analyses of livelihood dynamics. Future research could address these limitations through the integration of very high-resolution satellite imagery, such as PlanetScope data (3 m), as well as complementary observation tools including unmanned aerial vehicles (UAVs) and radar data (e.g., Sentinel-1, RADARSAT). The combined use of optical and radar sensors would enhance fine-scale change detection and improve monitoring capabilities under variable atmospheric conditions, thereby providing a more detailed understanding of mangrove dynamics and resilience.

4.7. Recommendations for sustainable management

In light of the observed trends, several measures are required to promote the sustainable management and restoration of mangrove ecosystems in Lower Togo. Priority actions include large-scale reforestation programs using native mangrove species such as Rhizophora racemosa and Avicennia germinans, which are essential for restoring ecosystem structure and function. The establishment and participatory management of community-based protected areas should be strengthened to enhance local stewardship and improve compliance with conservation objectives. In parallel, regulatory frameworks governing mangrove exploitation need to be reinforced and more effectively enforced to limit unsustainable resource use. Finally, the diversification of local livelihood opportunities including ecotourism, sustainable aquaculture, and the promotion of non-timber mangrove products represents a key strategy for reducing pressure on mangrove ecosystems while improving socio-economic resilience among coastal communities.

5. Conclusion

The spatio-temporal analysis conducted over the period 2014–2024 reveals a pronounced regression of mangrove ecosystems in Lower Togo, with an estimated net loss of nearly 36% of mangrove cover. This decline reflects the combined influence of increasing anthropogenic pressures particularly unplanned urban expansion, mangrove wood exploitation, and agricultural encroachment together with climate-related stressors such as sea-level rise, coastal erosion, and soil salinization. The impacts of mangrove degradation extend beyond a simple reduction in surface area. They include a significant loss of floristic diversity, a decline in key ecosystem services such as blue carbon sequestration and coastal protection, and a weakening of the socio-economic resilience of communities that depend heavily on fisheries and mangrove-related resources for their livelihoods. From a methodological perspective, the integration of multi-source remote sensing data with GIS analysis, field observations, and socio-economic surveys enabled a robust assessment of mangrove dynamics over a decade. Although the spatial resolution of historical Landsat imagery imposed certain limitations on the detection of fine-scale changes, these constraints highlight opportunities for future research incorporating higher-resolution data sources such as PlanetScope imagery, radar data (Sentinel-1), and unmanned aerial systems. Given the severity of the observed trends, the implementation of coordinated and urgent management actions is essential. Priority measures include large-scale reforestation using native mangrove species (Rhizophora racemosa and Avicennia germinans), the establishment of community-based management zones to strengthen participatory governance, diversification of local livelihoods through sustainable economic alternatives, and the reinforcement of regulatory frameworks governing resource exploitation. Overall, this study provides a solid scientific basis to support decision-making aimed at the conservation and sustainable management of mangrove ecosystems in Togo. By combining spatial, ecological, and socio-economic perspectives, it also contributes to a broader understanding of coastal ecosystem dynamics in West Africa and underscores the need for enhanced regional cooperation to safeguard mangroves in the context of ongoing global environmental change.

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