Impact of mangrove degradation on biodiversity and land use in Togo (2014–2024)

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Summary

Faced with the threat of degradation of mangrove ecosystems, this study based on geomatics, field surveys and socio-economic surveys analyzes the spatio-temporal dynamics of mangroves in Bas-Togo from 2014 to 2024. Sentinel-2 MSI images (2014–2024) were used to calculate the Normalized Difference Vegetation Index (NDVI), unsupervised classification (Maximum Likelihood) and supervised classification (K - means) to better discriminate mangrove areas.

The results reveal a 35.8% decline in mangrove areas, from 1,150 ha in 2014 to 738 ha in 2024. This loss translates into a 35% decline in *Rhizophora racemosa populations* and a nearly 40% decrease in floristic diversity, signaling a process of ecological homogenization. At the same time, urban areas have expanded from 18 to 32%, while income from artisanal fishing has fallen by 50%.

This dynamic illustrates the growing impact of **direct anthropogenic pressures** : unplanned urbanization, massive harvesting of mangrove wood for domestic energy, uncontrolled discharges from human activities and disruption of hydrological exchanges between lagoons and the ocean.

Abstract

Faced with the threat of degradation of mangrove ecosystems, this study based on geomatics, field surveys and socio-economic surveys Analyzes the spatio -temporal dynamics of mangroves in Bas-Togo from 2014 to 2024. Sentinel-2 MSI images (2014–2024) were used to calculate the Normalized Difference Vegetation Index (NDVI), unsupervised classification (Maximum Likelihood) and supervised classification (K-means) to better discriminate mangrove areas.

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Introduction

Mangroves, intertidal coastal ecosystems dominated by halophilic woody species, play a central role in maintaining the ecological and socioeconomic balances of coastal regions. They act as buffer zones against erosion, nurseries for numerous marine species, and carbon sinks of global importance. In the context of climate change, their role in mitigating extreme effects (storms, floods, sea level rise) is even more critical.

In West Africa, these formations are undergoing accelerated degradation linked to population growth, land use changes and climate effects (UNEP, 2020; Alongi , 2015). In Togo, the Bas-Togo area – covering in particular the prefectures of Lacs and Vo – constitutes the main stronghold of these ecosystems. However, for three decades, these formations have been subject to multiple pressures: rapid urbanization, uncontrolled logging, agricultural intensification, unsustainable fishing, and direct and indirect impacts of climate change.

Estimates from previous work (Adjéhi , 1995; Kouassi et al., 2002; Essolakina et al., 2021) show a loss of more than 70% of mangrove cover since the 1990s, with notable consequences for biodiversity, coastal resilience and local food security.

In this context, this study is part of an **integrated coastal zone management approach** and pursues three main objectives:

1. Characterize the recent dynamics (2014–2024) of the mangroves of Bas-Togo by analyzing multi-source satellite images.
2. Assess the ecological and socio-economic implications of these changes.
3. Propose guidelines for sustainable management, based on the contribution of remote sensing and geographic information systems (GIS).

I - Materials and Methods

I.1. Description of the Study Area

The study area is located in Bas-Togo, in the extreme south of the country, between 6°05' and 6°20' North latitude and 1°15' and 1°40' East longitude. It extends mainly over the prefectures of **Lacs** and **Vo** , including localities such as Aného, Agbodrafo, Togoville, Avépozo and Aklakou . The spatial delimitation was carried out using **IGN/ORSTOM**

topographic maps (1: 200,000) and Sentinel-2 MSI images (2015, 2024 **)** , reprojected into the **WGS 84 / UTM Zone 31N geodetic system** to ensure georeferenced homogeneity of the analyses.

Biophysically, the area is characterized by a mosaic of coastal ecosystems including **Lake Togo** , the **Aného Lagoon** , and the **Mono** , **Haho** , **Zio** , **Boko** , and **Gbaga Rivers** . These hydrographic systems play a major role in freshwater supply, salinity regulation, and sediment transport, creating favorable conditions for the development of mangroves.

The climate is subequatorial **,** with two rainy seasons (March–July and September–November) and two dry seasons (August, then December–February). Annual rainfall varies between 800 and 1,200 mm, with an average temperature of around 27 °C. These climatic conditions strongly influence the biological productivity of mangroves and the seasonal dynamics of lagoon exchanges.

The vegetation cover is dominated by **red mangroves (** ***Rhizophora racemosa*** **)** , **white mangroves (** ***Avicennia germinans*** **)** and **gray mangroves (** ***Conocarpus erectus*** **)** , accompanied by halophytic and herbaceous species. These formations play a crucial ecological role in terms of carbon sequestration, protection against coastal erosion and nursery function for fishery resources.

Socio-economically, Bas-Togo has a **high population density** , concentrated around coastal towns and lagoon areas. Major human activities include artisanal fishing, peri-urban agriculture, mangrove timber exploitation and unplanned urbanization. Diachronic analysis of satellite images highlights a **notable increase in built-up areas** and fragmentation of natural spaces, accentuating the vulnerability of mangroves.

In summary, the study area constitutes a strategic coastal area, both **ecologically sensitive** and **socio-economically vital** , but subject to increasing anthropogenic and climatic pressures. Its choice is part of a perspective of **multitemporal monitoring by Remote Sensing and GIS** , making it possible to characterize, quantify and understand the dynamics of mangrove degradation over the period 2014–2024.

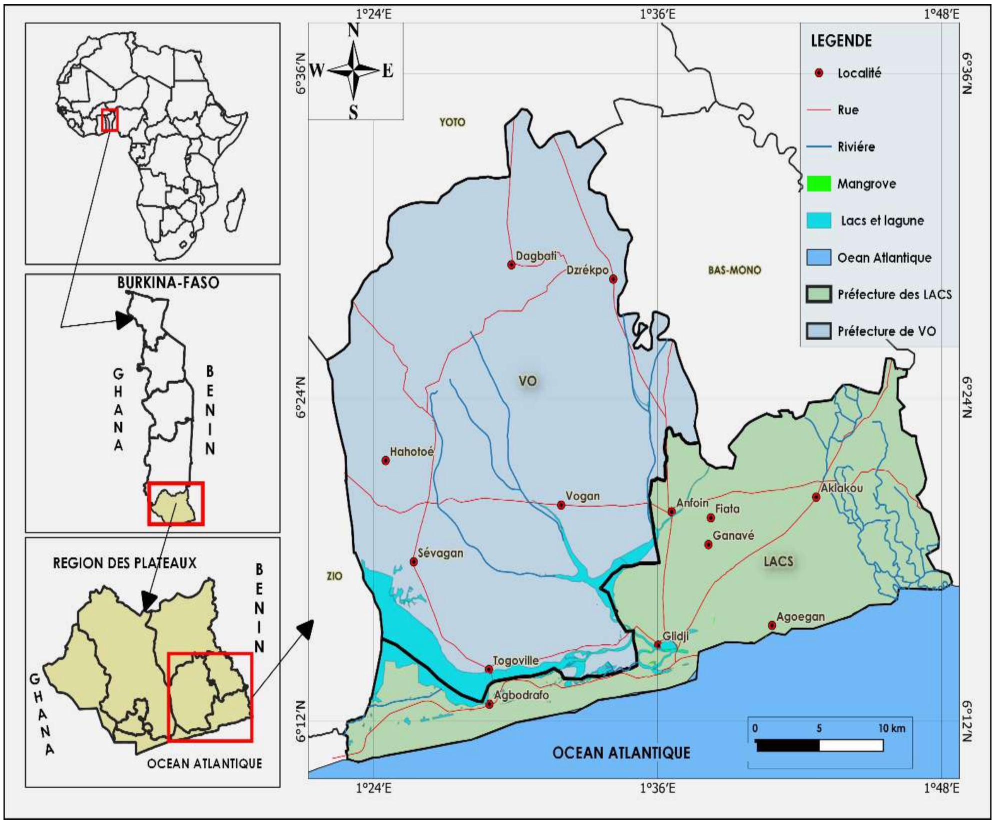

Figure 1: Location of the study area[1]

I.2. Data acquisition

The study is based on the exploitation of time series of medium and high resolution satellite images, selected for their thematic relevance and free availability. The data come from two sensors main :

- **Landsat 8 OLI (Operational Land Imager)** : scenes from 2014 and 2021, offering a spatial resolution of 30 m and a radiometric depth of 12 bits. These multispectral images, covering the spectral range from visible to near-infrared (0.43 – 2.29 µm), allow for robust diachronic analysis of changes in land cover and land use.
- **Sentinel-2 MSI (MultiSpectral Instrument)** : image from 2024, with a spatial resolution of 10 to 20 m depending on the spectral bands. Its set of 13 spectral bands, including vegetation-specific bands (red-edge), is particularly suitable for assessing the health and dynamics of plant formations.

Scenes were selected based on their **low cloud cover (<10%)** and seasonal relevance, to limit biases related to phenological variations. They were downloaded from the **USGS**

[1]The map illustrates the geographical position of Bas-Togo, showing the main bodies of water (lakes, lagoons), mangrove areas, the Atlantic Ocean, as well as major localities and road infrastructures. It also situates the study area in the regional context (West Africa, Togo, Plateaux Region).

Earth Explorer (Landsat) and **Copernicus Open Access Hub** (Sentinel-2) institutional portals.

In addition, **IGN/ORSTOM topographic maps (1/200,000)** as well as **ground truths collected by submetric GPS (200 control points)** were integrated to validate the results and improve geometric accuracy.

Photo 1: Mangrove trees in Abobo [2]

Photo 2: Mangrove trees in Vo[3]

I.3. Pretreatments

In order to ensure the temporal and spatial comparability of the data, several preprocessing operations were carried out using **ENVI 5.6** , **QGIS 3.28** and **ArcGIS 10.8 software** :

- **Radiometric correction** : Raw sensor values (Digital Numbers, DN) were converted to apparent surface reflectance using MTL (Landsat) and SAFE (Sentinel-2) metadata. This step ensures radiometric homogeneity and facilitates inter-sensor comparison.
- **Atmospheric correction** : The **DOS1 (Dark Object Subtraction) method** was applied to Landsat images to reduce the effect of atmospheric scattering. For Sentinel-2, the **Sen2Cor module** was used to obtain surface reflectances corrected for atmospheric and topographic effects.

[2]View of the stands of *Rhizophora racemosa* rooted in the Abobo area, characterized by their aerial stilts and their role in stabilizing the banks.
[3]Mangrove stands observed in the Vo area, illustrating the interface between the mangrove and the lagoon water bodies.

- **Geometric registration and projection** : all scenes were reprojected into the **WGS 84 / UTM Zone 31N coordinate system, with** sub-pixel accuracy (< 0.5 pixels). This registration ensures temporal superimposability and spatial consistency of the different data sources.
- **Clipping of the study area** : from a vector shapefile delimited on the basis of administrative maps of Togo, the scenes were restricted to the coastal zone of Bas-Togo, thus avoiding unnecessary processing of pixels outside the area **.**

These pre-processings constitute an essential step to reduce uncertainties linked to acquisition conditions and guarantee the reliability of subsequent analyses (NDVI, PCA, supervised and unsupervised classifications).

I.4. Vegetation analysis

The assessment of the state of mangroves was carried out using the **Normalized Difference Vegetation Index (NDVI, *Normalized Difference Vegetation Index*)** , calculated using the formula : NDVI = (NIR - RED)/ (NIR + RED)

Or **NIR** corresponds to near-infrared reflectance and **RED** to red reflectance. NDVI, sensitive to chlorophyll content, allows us to assess the density and vigor of the vegetation cover. High positive values (> 0.3) reflect dense and healthy vegetation, while low values (< 0.2) indicate degraded or absent vegetation. This index has been used as a key indicator of the vitality and dynamics of mangrove formations.

I.5. Image classification

Two complementary approaches were used for land use mapping:

- **Supervised classification (Maximum Likelihood)** : applied to recent images (2021 and 2024), based on training samples collected **in situ** using submetric GPS and enriched by visual verifications on Google Earth . This probabilistic method is based on the maximum likelihood function, guaranteeing a good separation of thematic classes.
- **Unsupervised classification (K- means)** : applied to the 2014 image, in order to automatically group pixels into homogeneous classes. This non-parametric approach made it possible to identify the main land use types without contemporary reference data, and then to interpret the classes based on available topographic maps and secondary data.

The combined use of these two methods ensures both **temporal comparability** and **thematic robustness** of the results.

I.6. Validation of classifications

The quality of the results was verified by:

- **A confusion matrix** , allowing the classes resulting from the classification to be compared with the reference data.
- **The Kappa coefficient** , measuring the degree of agreement above chance between the classification and the ground truths.

Validations were performed based on **200 georeferenced control points collected in the field** , supplemented by very high-resolution image observations. The results show an overall accuracy greater than 85% and a Kappa coefficient > 0.80, demonstrating the reliability of the classifications.

I.7. Software tools

The processing and analyses were carried out using the following software:

- **ArcGIS 10.8** : image processing, spatial analysis and cartographic production;
- **QGIS 3.28** : spatial database management, reprojections and thematic analyses;
- **R 4.3** : advanced statistical analyses, calculation of precision indices and graphical representations.

This combination of tools made it possible to ensure an integrated **GIS – Remote Sensing – Statistics approach** , guaranteeing the scientific rigor and reproducibility of the study.

II. Results

II.1. Evolution of mangrove areas

Diachronic analysis from Landsat (2014, 2021) and Sentinel-2 (2024) images reveals a **clear regression in mangrove areas** in Bas-Togo. In 2014, they covered approximately **1,150 hectares** compared to only **738 hectares in 2024** , a net loss of **412 hectares** corresponding to a regression of **-35.8%** over the period considered (Figure 4, Table 2).

This decrease is accompanied by a **sharp increase in urbanized areas** , which increased from **18% to 32%** (+14 percentage points), to the detriment of agricultural land and natural spaces. The latter have been gradually converted into housing or infrastructure, reflecting unplanned urbanization and increasing land pressure in the coastal zone.

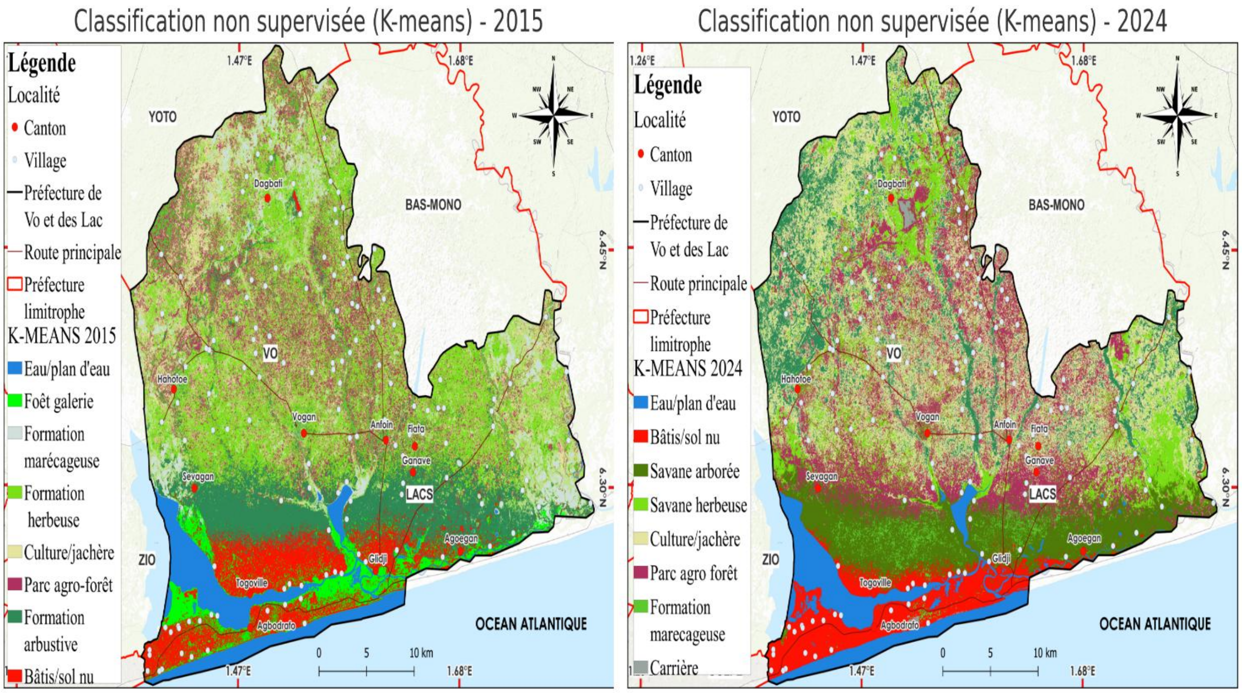

Figure 2: Unsupervised classification maps (K- means) of the study area in 2015 and 2024[4]

II.2. Variation of the vegetation index (NDVI)

The evolution of the **average NDVI** (Figure 5) confirms the **decrease in plant biomass** over the period 2014–2024. The average value fell from **0.21 in 2014** to **0.14 in 2024** , reflecting a loss of vigor and density of the plant cover.

Areas with an NDVI greater than 0.3, indicative of **dense and healthy mangroves** , are now limited to a few isolated nuclei, particularly around **Togoville** and **Avépozo** . This fragmented spatial distribution reflects a **widespread and heterogeneous degradation** of the ecosystem.

[4]These maps illustrate the spatio-temporal dynamics of land use in Bas-Togo, obtained by unsupervised classification (K- means) from satellite images from 2015 (Landsat 8 OLI) and 2024 (Sentinel-2 MSI). They highlight the regression of marshland and mangrove formations in favor of built-up areas and agricultural land.
Source: Author's processing, 2024

II.3. Floristic composition

The floristic study highlights a **marked decline in populations of *Rhizophora racemosa*** (–35%), a species historically dominant in Togolese mangroves. This regression is accompanied by a relative expansion of sparse populations of **Avicennia germinans** , but also the appearance of **bare areas** indicating a loss of ecological resilience.

Overall, floristic diversity fell by **40%** , indicating a **homogenization of the plant landscape** and a reduction in the adaptive capacity of the ecosystem in the face of anthropogenic and climatic pressures.

II.4. Socio-economic impacts

Socio-economic surveys conducted among **50 riverside households** show a **sharp decline in fishery resources** . Pelagic fish catches have fallen by **60% in ten years** , leading to an average 50% drop **in fishermen's income** (Table 4).

This loss of resources further weakens communities already exposed to **food insecurity** and increased dependence on mangroves for fuelwood collection and subsistence. The results thus highlight a **direct correlation between ecological degradation and the socio-economic vulnerability** of local populations.

II.5. Dynamics of land use classes (2015–2024)

Diachronic analysis of satellite images from 2015 and 2024 (Table 3, Figure 6) highlights profound transformations in land use in the study area.

Maps from 2015 and 2024 show:

Table 1: Land use classes

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%

The graph below illustrates this evolution:

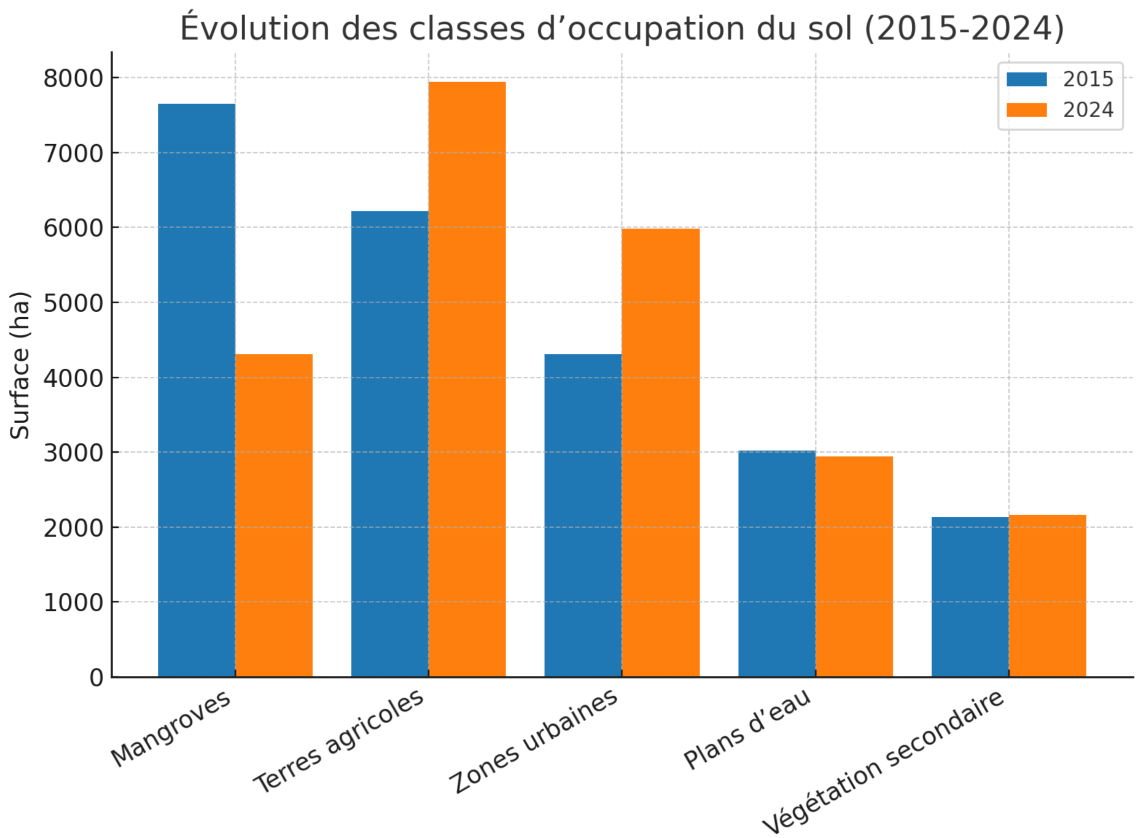

Figure 3: Occupancy classes[5]

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.

III. Discussion

III.1. Degradation factors

The results obtained confirm that the regression of mangroves in Bas-Togo is mainly attributable to anthropogenic pressures. Unplanned urbanization, particularly marked around Aného, Agbodrafo and Avépozo , causes the filling of wetlands and the fragmentation of habitats. Similarly, the exploitation of mangrove wood, particularly **Rhizophora racemosa** , for domestic energy and fish smoking, is a major cause of deforestation (FAO, 2020). Agricultural expansion, supported by population growth, accentuates soil conversion and disrupts water regimes. These findings are consistent with those reported by **Diop et al. (2014)** in Senegal and **Nwilo et al. (2016)** in Nigeria, where

[5]This graph highlights the dynamics of the main land use classes in Bas-Togo between 2015 and 2024. We observe a strong regression of mangroves (−43.8%), a significant expansion of urban areas (+38.8%) and agricultural land (+27.7%), as well as a relative stability of water bodies (−2.5%) and secondary vegetation (+1.2%).

urbanization and agriculture are among the main drivers of degradation of mangrove ecosystems.

III.2. Influence of climate change

Climate change acts as an aggravating factor, altering salinity regimes and promoting saltwater intrusion into lagoons, which exacerbates coastal erosion (IPCC, 2021). Rising sea levels and intensified storms are leading to the partial submersion of some mangroves and the salinization of agricultural soils. These findings are consistent with the work of **Alongi (2015)** and **Friess et al. (2019)** , which highlight the increased vulnerability of mangroves to climate pressures.

III.3. Ecological consequences

The loss of mangrove cover has direct effects on ecosystem services. It results in a reduction in the capacity to sequester blue carbon, a reduction in the protective role against coastal erosion, and a decline in marine nurseries essential for artisanal fisheries productivity. These results are consistent with observations made in Southeast Asia and West Africa, where the disappearance of mangroves compromises both climate regulation and biodiversity (Alongi , 2015 ; Friess et al., 2019).

III.4. Socio-economic impacts

Socio-economic surveys conducted in the study area reveal a drastic decline in fish catches (–60%) and a significant reduction in fishermen's income (–50%). These dynamics weaken coastal communities and increase their dependence on other resources, sometimes exploited unsustainably. Similar situations have been reported in Senegal (Diop et al., 2014) and Nigeria (Nwilo et al., 2016), where mangrove degradation has exacerbated poverty and reduced the resilience of local populations.

III.5. Methodological contributions

The integration of multi-source and multi-date remote sensing data, coupled with field surveys and socio-economic surveys, provided a comprehensive and reliable view of mangrove evolution. The combined use of supervised (Maximum Likelihood) and unsupervised (K - means) classification, as well as validation by confusion matrix and Kappa coefficient, reinforced the robustness of the results. This methodological protocol is in line with the approaches of **Friess et al. (2019)** and **FAO (2020)** , who recommend data triangulation to improve the accuracy of analyses.

III.6. Limits and perspectives

The main limitations of this study concern the spatial resolution of historical data (30 m for Landsat), which limits the detection of small mangrove fragments, as well as the limited availability of longitudinal socio-economic data. In the future, the integration of high-resolution data (PlanetScope , 3 m) and complementary tools such as drones or radar (Sentinel-1, Radarsat) could improve fine-grained change detection.

III.7. Recommendations for sustainable management

To reverse the current trend, several measures are necessary:

- **Large-scale reforestation** with native species (Rhizophora racemosa , Avicennia germinans).
- **Creation and participatory management of community protected areas** , promoting the involvement of local populations.
- **Strengthening and strict enforcement of regulations** on resource exploitation.
- **Diversification of sources of income** (ecotourism, sustainable aquaculture, promotion of non-timber products), in order to reduce pressure on ecosystems.

Conclusion

The spatio-temporal analysis conducted over the period 2014–2024 highlights a worrying regression of the mangroves of Bas-Togo, with an estimated net loss of nearly **36%** of the vegetation cover. This dynamic reflects the combined effect of anthropogenic pressures (urbanization, exploitation of mangrove wood, agricultural expansion) and constraints linked to climate change (rising sea level, coastal erosion, soil salinization).

The observed impacts go beyond a simple reduction in surface area: they result in an **erosion of floral biodiversity** , a **reduction in ecosystem services** (carbon sequestration, coastal protection) and a **weakening of the socio-economic resilience** of communities dependent on fisheries resources.

Methodologically, the integration of multi-source data from remote sensing and GIS has made it possible to draw up a robust diagnosis, despite certain limitations inherent in the spatial resolution of the Landsat images used for previous years. These limitations open up perspectives for future studies integrating higher resolution data (PlanetScope , Sentinel-1/2, drones).

Given the seriousness of the observed trends, it appears necessary to implement **urgent and integrated actions** , including:

- THE **large-scale reforestation** with native species (Rhizophora racemosa , Avicennia germinans);
- there **creation of community management zones** ensuring participatory governance;
- there **diversification of livelihoods** (ecotourism, sustainable aquaculture, promotion of non-timber products);
- THE **strengthening the regulatory framework** relating to the exploitation of resources.

Ultimately, this work provides a **solid scientific basis** to support decision-making regarding the conservation and sustainable management of mangroves in Togo. It also contributes to the understanding of coastal dynamics in West Africa, and calls for **enhanced regional cooperation** to preserve these critical ecosystems in a context of global change.

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Ethics and Consent to Participate declarations**:** not applicable.

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