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Three Possible Future Courses for the Sassandra-Dagbégo Ramsar Site (Côte d'Ivoire): Prospective Modelling and Implications for Restoration

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Abstract: The Sassandra-Dagbégo Ramsar Site, along the coast in southwestern Côte d'Ivoire, is a wetland of major ecological importance because of its forest ecosystems, associated wetlands, and hydrological regulation functions. This area is subject to increasingly intense anthropogenic pressures in connection with the exploitation of forest resources and local populations' needs for food and well-being, resulting in numerous spatial dynamics. In this line, prospective modeling appears to be an essential tool to understand these dynamics and anticipate possible future courses of the Sassandra-Dagbégo complex. This study aims at improving knowledge of changes that occur within the wetland by analyzing historical spatial dynamics and simulating future use of land and land-cover patterns up to 2040. So, this study is based on a multi-temporal analysis of Landsat imagery that covers the period 2015-2025, combined with Geographic Information System tools and predictive modeling of three scenarios based on Markov chains. The retrospective analysis results show a decreas in the formations of forest to the order of croplands and other anthropized areas. The projections of 2040 significantly show differentiated directions, presenting an increasing artificialization as if nothing has happened, considerably retracteted by conservation and restoration policies. The restoration scenario stands out through the recovery of the mangrove.

Keywords: *Sassandra-Dagbégo Complex; Remote Sensing; GIS; Spatial Dynamics; Prospective Modeling; Scenario; Wetland.*

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I. INTRODUCTION

Wetlands are biodiversity reservoirs and shelter for numerous species of floral and faunal in critical period of their existence. They provide a tremendous service to the populations who live by offering them in particular feeding for their resources, firewood, and nutrition building [1]. For those reasons, more than half of the world's population lives in coastal areas [2].

Among other services provided wetlands help regulate climate that can be registered in the most important ecosystem services, including the protection against the effects of climate change. Indeed, they sequester carbon and are part of the planet's major carbon reserves. So, it's one of the major proprieties in the world to limit future temperature increases, protecting wetlands from direct anthropogenic disturbances, for the sake of reducing additional warming through minimizing the emission of greenhouse gas from all possible sources [3]; hence the wetlands conservation and the creation of the Ramsar wetland network.

But, over too many years, the world is subject to change in the climate change and has a significant part as far as the coastal areas degradation is concerned. Indeed, Climate change affects hydrology, and its functionality is often altered by highest temperatures, droughts or floods, erosion, an increase in CO_2 / or a saline intrusion [4]. Those climate change contribute to affect critical function of coastal areas and their ecosystemic services, such as carbon storage, biodiversity sustain, faunal vivarium and water quality [4].

Other factors of stress, such as invasive species and soils use change by the populations, amplify management difficult and restoration of wetlands and risk of endemic species extinction [5].

Côte d'Ivoire is not in margin of that wetland's degradation. Conjugated action of population and climate change on those areas make them vulnerable [6]. This vulnerability of the environment grows as the time moves on and comes out by anthropogenic pression, but also by climatological phenomenon.

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Ramsar area of Sassandra-Dagbégo complex is a tangible example for coastal wetlands environment destruction. It is confronted with two hazards that are on the one hand the coastal flooding, a temporary coastal flooding caused by adverse meteorological and tidal conditions. Conversely, the coastline retreat has increased due to anthropogenic pression. That area retreats due to coastal erosion. These phenomena lead to the vegetation destruction, especially mangroves, but also decline and loss of animal's species. Indeed, the mangrove dead in the Dagbeo river led to crustaceans and fishes decline over the last past years [7].

That area is also confronted with the anthropogenic pression incessantly tied to the need for arable land, to the forest exploration and to the various territorial and environmental dynamics. Indeed, a predominantly rural population led to a high dependency to the natural resources to the wetland as well as ecosystem services that it provides. They fund their socio- economics activities on the richess of the wetland. Thus, the intensification of uses and the progressive transformation of natural landscape could have impacted the ecosystem functions of the Ramsar area.

Then, some Non-Governmental Organization having become aware of the wetlands benefits has invested themselves in Sassandra-Dagbégo mangrove reforestation, in order to restore it. Thus, several actions of mangrove restoration or projects of reforestations have been carried out in Sassandra-Dagbégo wetland area, some of which without studying the causes of their destruction. It would therefore be more judicious to understand first this environment evolvement and to model its possible futures so as to better guide our preservation or restoration projects; hence the interest of this study entitled "Three possible future trajectories for the Sassandra-Dagbégo Ramsar site" (Côte d'Ivoire): prospective modeling and implication for the restoration

This study aims to explore from remote sensing, Geographic information systems and prospective modeling, three trajectories future of land uses, in order to appreciate their involvement in the preserving the wetland.

Specifically, the primary goal is to analyze the spatio-temporal dynamics between 2015 and 2026, then model possible trajectories future of land use in 2040, from observed dynamic and spatial explanatory factors and finally to compare futures possible scenarios in order to assess their spatial implications for the Ramsar area restoration and conservation; which would provide essential decision-aid arguments for efficient wetland management.

II. METHODOLOGY

This study methodology concerns the use of remote sensing and GIS associate to the modeling. To successfully carry out this work, it is first important to present and delaminate the study area.

A. Description of the Study Area

The study area is a major importance ecological site. It named Sassandra-Dagbégo complex. Located in the Southwest of Côte d'Ivoire around 300km from Abidjan between 4° 57' 42''north latitude and 6°02' west longitude, wetland of Sassandra-Dagbégo is located on the two sides Sassandra river's mouth. It's an important international wetland, registered on the Ramsar site lists since in October 2005.

The wetland so-called Sassandra-Dagbego complex rests on a mixed rocky and sandy coast line consisting of amphibole pyroxenite, migmatite, gneiss, and various granites. However, it stands on the edge of the coast, surrounded by hills with fairly steep slopes.

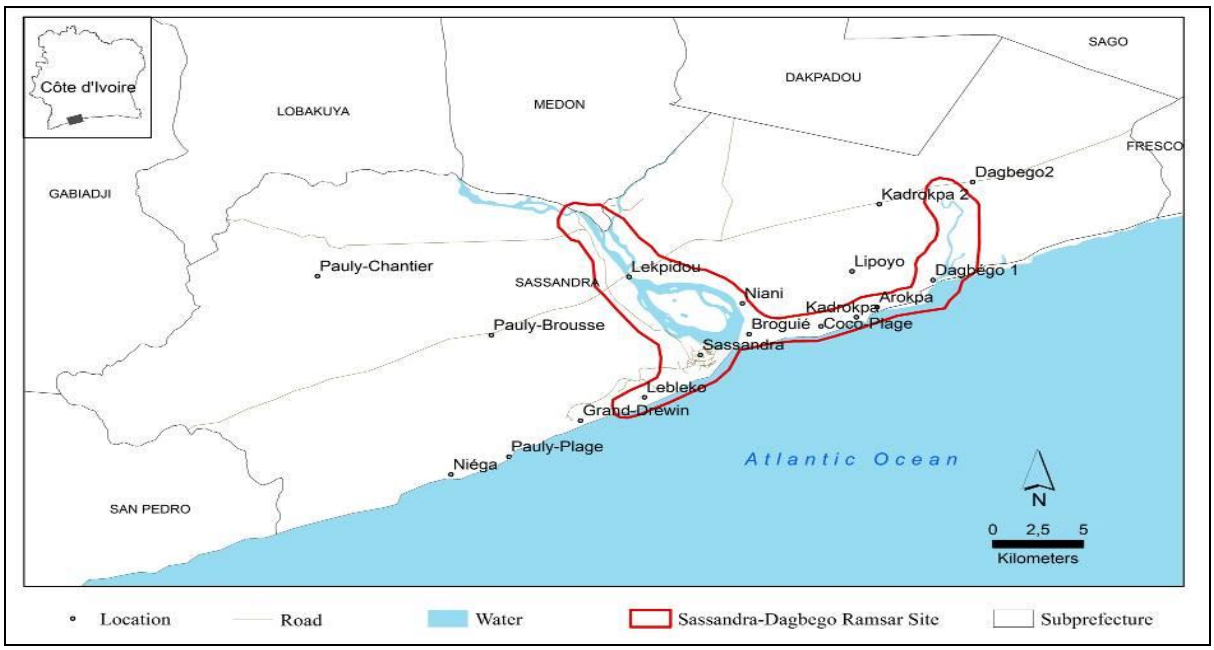


Fig 1 Description of the Study Area
Sources: OSM 2024 and Ramsar 2005

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It is a well- watered area with the Sassandra river to the west, the Dagbe river to the east, and the Atlantic Ocean to the south. This area's climate is tropical with four seasons, including two rainy season and two dry seasons. The rain that falls in a year is about 16000 mm. The temperature per year is about 26°C. The natural environment is very rich with a variety of ecosystems including mangrove, riparian forests, swampy or firm ground, marshes, thickets, and weltlands. Many rare species such as Drypetes aframensis, conocarpus erectus, Hibiscus comoensis, and Hexalobus salicifolus can be found there. There is also a great diversity faunal, including endangered speciessuch as the Diana monckey, peregrine falcon, leatherback turtle, or even olive ridley turtle, along with species of economic importance such as the royal antelope and the bushpig. It also shelters a rich variety of aquatic bird [8].

The department of Sassandra has a population of about 72.221 people [9]. Most of the population live in the rural areas and mainly consisted of fishermen, forest workers, and farmers who benefits from the local resources but also put a lot of pressure on them, leading to their degradation. This heavy reliance on natural resources makes the wetland a particularly sensitive area to change in land use. This pression can significantly change the landscape and ecosystem functions.

B. Study Data

Many data have been necessary to implement this work.

- Satellite images: two satellite images from the Landsat sensor, with a resolution of 30 meters, were downloaded from the website https://glovis.usgs.gov/. They were used to map the land use of Ramsar area from 2015 and 2026

- Reference data: there are basic geographic elements used to locate and analyze other information. These vectors-types were taken from Open Street Map website. This includes the road network, watercourses, and buildings. The digital terrain model, on the other hand, was downloaded from the site https://glovis.usgs.gov/. All this data is used as input for predictive modeling.

C. Methods

- Treatment of images data: Several steps were necessary elaborated the land use mapping. The spectral bands of the Landsat images were enhanced by calculating spectral indices such as the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Moisture Index (NDMI), the Brightness Index (BI), including by way of Principal Component Analysis (PCA). These complementary indices were calculated to summarize the information contained in the bands to improve the discrimination of land use classes. The most relevant indices were selected for the classification.

- Land uses classification: Training plots were selected based on field knowledge and according to the nomenclature presented in Table 1.

Table 1 Land Use Nomenclature

Code	Class	Nature
1	Mangrove	Fringe halophytic vegetation
2	Water and swamps	Bodies of water, estuarine channels
3	Forest	Continental forest formations
4	Cropland and fallow land	Agricultural and human-occupied areas
5	Built-up land et bare soils	Built-up areas

Source: Our Investigations

Then, the land use maps for 2015 and 2026 were subsequently produced at the different dates using a supervised classification with the Support Vector Machine algorithm (SVM). This flowchart was selected because of its ability to effectively discriminate between the classes of use of land having common traits of spectral signatures, a condition particularly important in wetland areas.

The quality of the classifications was then evaluated using confusion matrices and accuracy indicators, notably the overall accuracy, which is over 80% for all years. This performance is confirmed by the kappa coefficient, which is 0.87 and 0.9 for the 2015 and 2026 classifications, respectively. According to the reference scale of [10], a kappa, greater than 0.80 indicates good agreement between the classifications and ground reality. Thus, the classification method used is reliable.

The maps obtained and deemed accurate thus constituted the basic data for analysis of spatio-temporal changes and prospective modeling.

- Analysis of spatio-temporal dynamics: the dynamics of land use were analyzed by comparing the maps produce for the years 2015 and 2026. The analysis is conducted of the basis of spatial and statistical evolution of land use classes, not forgetting the transitions that occurred. Environmental changes were then identified to highlight evolution trends. Subsequently, changes in the landscape were determined by cross-referencing the two land use maps for pinpointing the main exchange that occurred from 2015 to 2026.

- Analysis of transitions and transition probabilities: The transitions between all the classes related to the use of land were then quantified using transition matrix. This allowed for the identification, for each initial class, of the proportions of area that were retained or converted to other

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classes. The matrix established for the 2015-2026 period allowed the characterization of the intensity of the observed conversions. The transition probabilities thus obtained constitute the temporal component of the modeling. They allowed for the estimation of the amount of change to be reproduced during the simulation. In Dinamica EGO, this step was carried out by generating single- step and multi-step matrices, which respectively allow the overall transition rates to be expressed and converted into time steps usable in the simulation.

- Calibration of the prospective model: the prospective modeling concerning the use of land was conducted using Dinamica EGO, a spatial representation of the environment takes into account the representation and simulation of change processes. The calibration aims to establish a relationship between observed transitions and the factors likely to influence their spatial distribution. Several variables were therefore selected base on their ability to affect spatial dynamics and their distribution in Sassandra-Dagbego complex.

The following are the four variables that have been retained:

- The Digital Elevation Model, which accounts for the influence of topography on the distribution of land use units in a wetland, where altitude cold be associated with flooding conditions.
- The distance to water bodies, which provides information on the proximity of aquatic areas and spaces subject to particular hydric conditions.
- The distance to the road network, which serves as an indicator of territorial accessibility and might be associated with the intensification of human activities including changes related to land use.

The distance to built-up areas, which allows for the integration of the influence of spatial urbanization on spatial distribution.

These three Euclidean distances are derived from the 2015 land use status and all the four parameters have been discretized into intervals to allow the estimation of the weights of the Evidence for each transition.

The Weight of Evidence (WoE) method was then to estimate the influence of variables spatial probability of each transition. Thus, for each transition, a W^+ coefficient was calculated. A positive weight indicates a favorable association with the occurrence of the transition, whereas a negative point indicates an unfavorable relationship. The obtained coefficients were the combined to generate change probability surfaces

Cramer's Independence test was subsequently performed on each pair of variables to verify the correlation between variables and to eliminate redundant variables. Of the four retained variables, no variable pair exceeds the critical threshold, the maximum observed value being0.58. It follows that all the four variables are retained for the subsequent analysis.

For each transition, a map of probability is then produced. Each map highlights the likelihood of each pixel undergoing the considered mutation. The probabilities are spatially coherent. All transitions related to mangroves are located on the estuarine fringe, while forest and agricultural dynamics are more in the hinterland. The spatial simulation of transitions is then carried out using the Expander and Patcher mechanisms, which respectively promote the expansion of change from existing patches and the formation of new patches, their allocation being managed by the Allocate Transitions module. Finally, the land use for 2026 is simulated from the 2015 state. The simulation is base on the observed rate of mutations, applied without any posterior correction. Priority is given to scientific integrity; that is say, the most important is not reproduction mandatory of a known result, as any discrepancies constitute potential information.

- Model validation: the validation of the modal was conducted so as to determine its ability to reproduce the observed spatial dynamics before its use for future projections. the simulated 2026 map was compared with the land use map actually observed at that same date. This step allows for evaluation of the model's ability to reproduce the quantity of changes and their spatial organization. The Fuzzy spatial similarity measure with multiple windows implemented by [11] was used for this purpose. This method aims to account for minor location shifts between simulated and observed changes and evaluate their concordance at different spatial structure of the level of similarity obtained becomes an indicator of the model's ability to reproduce the spatial structures of the observed dynamics.

The model, once calibrated and validated, was then used to generate projections according to three scenarios:

- ✓ The trend scenario (BAU) is the reference scenario. It extends observed trends, maintaining transition probabilities as well as existing spatial relationships. It allows estimating the future trajectory of land use in the wetland area under the assumption that current dynamics continue.

- ✓ The conservation scenario (CONS) simulates a land use trajectory in measure to protect natural areas are strengthened. Thus, all transitions unfavorable to the maintenance of natural ecosystems are constrained in order to limit or to prevent their production. Indeed, the transitions "mangroves and forest being transformed into bult-up areas or agricultural land" are constrained. The scenario aims to explore the effects of limiting the conversion of natural formations into anthropized areas, while maintaining the other mechanisms of historical dynamic changes.

- ✓ The Restoration scenario (REST), on the other hand, explore a trajectory where conservation measures are complemented by restoration actions. In addition to the

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conversion limits of the conservation scenario, it promotes certain transitions, thus allowing natural formations to reclaim anthropized or degraded spaces. Two restoration trajectories are considered: the conversion of croplands into forest and the conversion of croplands into mangroves.

III. RESULTS

A. These Studies have Led to Various Results

➢ *Evolution of the Areas of the Classes*

In 2015, the natural environment was characterized by 1, 246.1 ha of forest, mostly located in the southern part of the wetland, and 140.5 ha of mangrove, representing 1,66% of the land cover and located around the mouth of the Sassandra river (fig. 2).

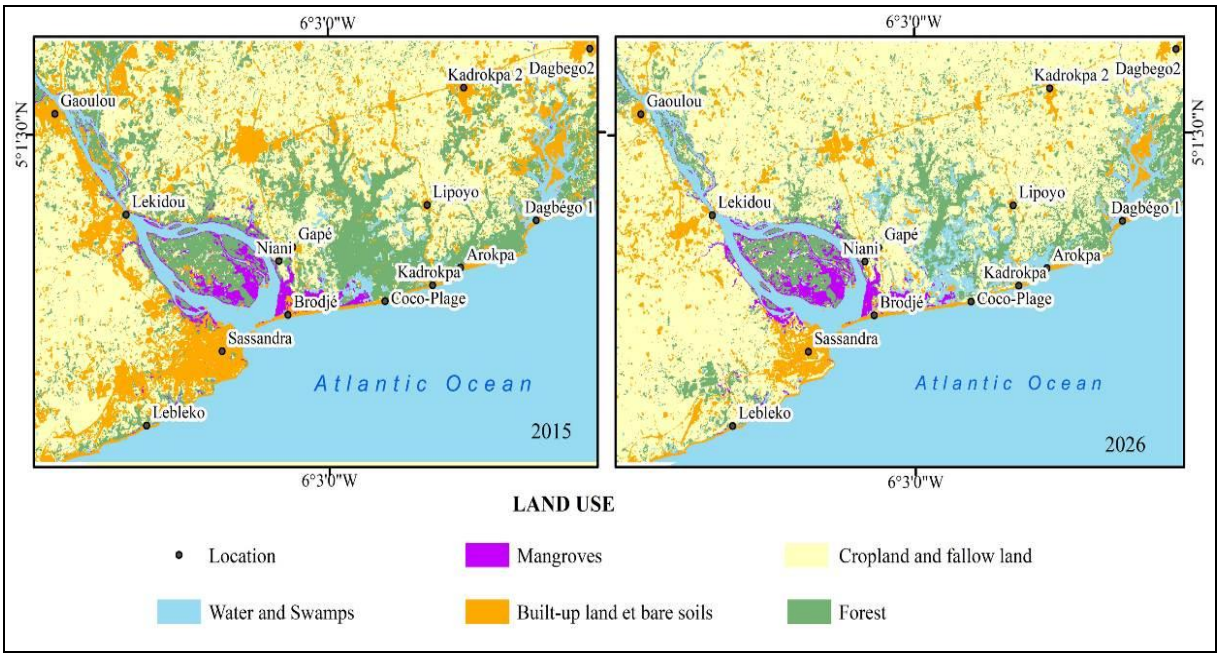


Fig 2 Land Use in 2015 and 2026
Source: Landsat Image of 2015 and 2025

Crops constitute the most important type of land use in the area, with 3 044,4 ha or 35,94%.

They cover the extent of the zone. Build-up land and bare soil, meanwhile occupy 111,8 ha of the wetland's total surface area (table 2).

Table 2 Statistics of Land Use Types for 2015 and 2016

	Area in 2015		Area in 2026	
Class	**In ha**	**In %**	**In ha**	**In %**
Mangrove	140,5	1,66	139,80	1,65
Water and swamps	2923,4	34,51	3 114,60	36,77
Forest	1246,1	14,71	801,80	9,47
Cropland and fallow land	3044,4	35,94	3 813,10	45,01
Built-up land et bare soils	1116,8	13,18	601,90	7,11
TOTALS	8471,2	100,00	8 471,20	100,00

Source: Land Use of the Wetland in 2015 and 2026.

In 2026, the same spatial configuration remains, with a few slight changes. Indeed, forests have shrunk a third of their surface area. They now represent only 9,47% of the area with 801,8 ha.

Mangrove's areas are relatively stable with 139,8 ha. Converly, cultivated areas occupy 139,8 ha. They have gained 768 ha and cover almost half of the wetland, reflecting agricultural expension in this area which is cultivated area. Built-up and bare soil have lost some ground, now covering only 601.9ha., which is 13.18% of Sassandra Dagbego. This drop of 514 has could be explained by the conversion of bare soils into farmland or for construction.

➢ *Transitions Analysis*

Between 2015 and 2026, the different land use classes show contrasting trends (fig. 3).

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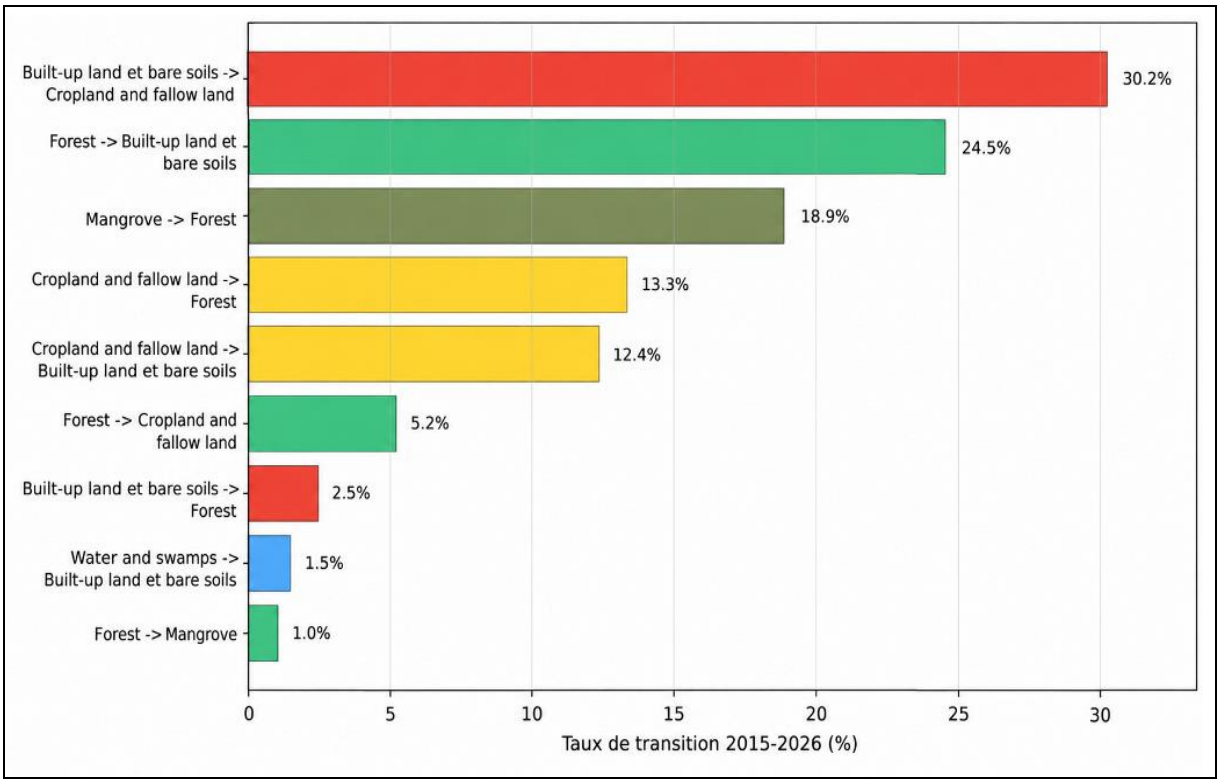


Fig 3 Land Change Transitions Categorized by Intensity (2015–2026)

The analysis of transitions by class highlights different behaviours. The waters class is the most stable class, with 87% persistence, reflects the permanence of estuarine channels. Croplands and fallow land also show high stability at 70%. Build-up areas bare soils, however, show a particular dynamic. Although 58% of build-up areas and bare soils remain stable, a significant proportion is converted into cropland. This situation could partly be explained by the effects related to the spatial resolution of 30 m or the present of mixed pixel in peri-urban areas, but also by the agricultural soils included in the studies area.

The sharp decrease in build-up areas and bare soils (-46 %) could be interpreted by the composition of this class: a large part corresponds to bare soils that, when put into crops, shift towards the crop class. This analysis is consistent with an agricultural cycle where fallow lands, temporarily bare, are then used for cultivation.

Mangroves and forests appear to be the most dynamic classes. Mangroves retaining only (46 %) of their other hand, are heavily affected by conversion into crop land. This shows an important agricultural pressure on the formations of forest. All transitions pinpoint different directions according to the class. They also reveal the vulnerability of natural formations to changes based on human actions (fig. 3).

These dynamics form the historical basis for calibrating the prospective model and exploring the three future directions. The transitions' ranking, by intensity, pinpoints the predominance of the conservation of 'forest to cropland' trend. It by far the most active transition in the 2015-206 period, followed dynamics from "Built-up and Bare soil" to "Cropland" and "Cropland to "Built-up and Bare Soil" characteristic of an active urbanization front.

➢ *Scenarios of Possible Future Land Use in 2040*

The figure below shows from the space the distribution of projected land use in 2040 for each of the three scenarios, allowing us to visualize where changes will occur on the territory (fig. 4). The projections reveal clearly distinct trajectories.

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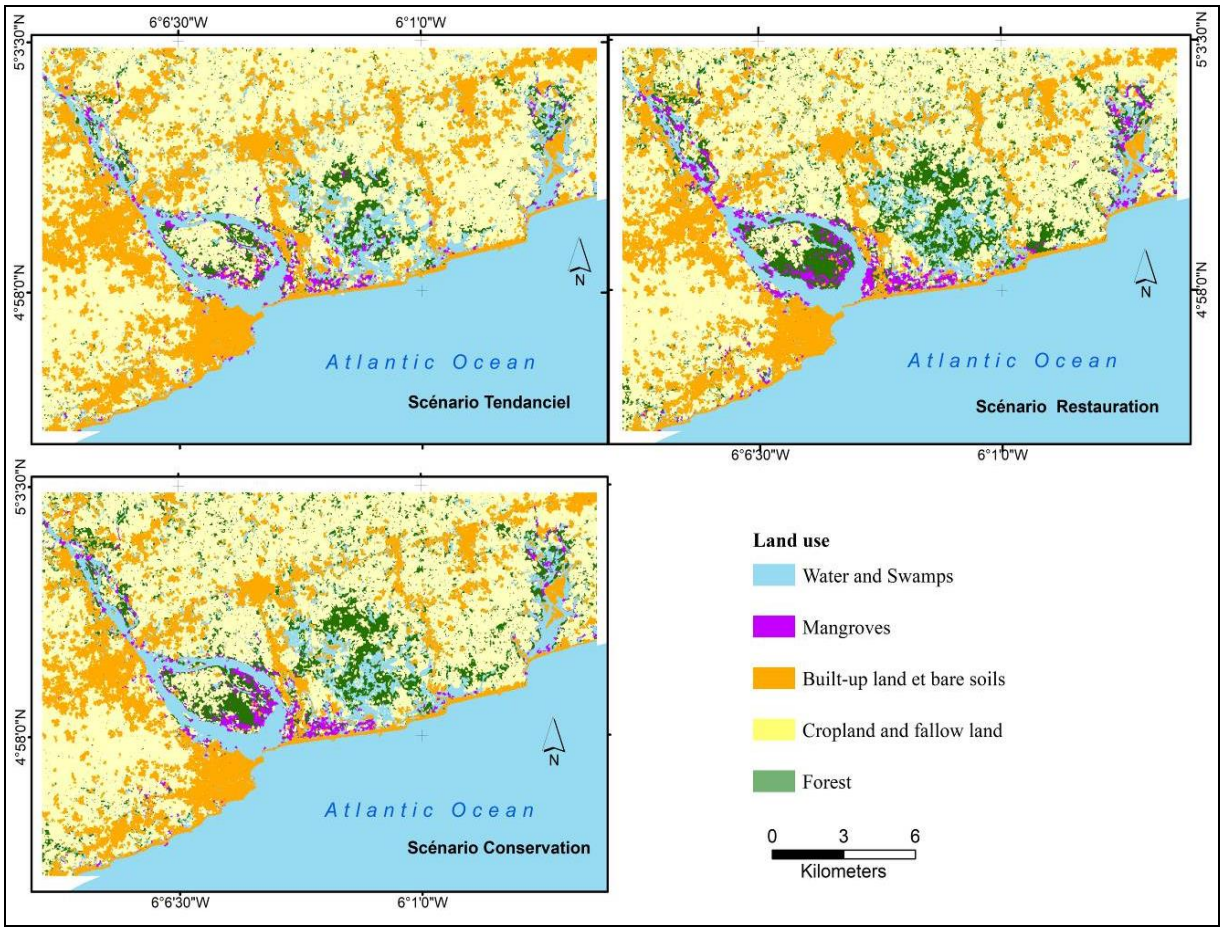


Fig 4 Land Use Simulation in 2040

- The trend scenario: it causes the evolvement of an artificial development of the area. Indeed, on the basis of this scenario, the mangrove would decrease by 147 ha and would cover only 486.92 ha (Table 3).

Table 3 Land Use Statistics Under Possible Futures in 2040

Class	Observed en 2026 (ha)	Scenario BAU (ha)	Scenario CONS (ha)	Scenario REST (ha)
Mangrove	634,00	486,92	570,94	795,06
Water/swamp	13326,00	13940,01	13944,75	13614,62
Forests	3423,00	1242,02	2266,76	2511,60
Cropland and fallow land	16247,00	13600,19	13601,04	13519,73
Built-up/ Bare soils	2569,00	6910,48	5796,52	5739,10

Source: Land Use Simulation in 2040

Forests areas would also decline to reach 1,242 ha by 2040, as would the crop areas, which shrink by nearly 2,646 ha to occupy only 13,600.19 ha. Built-up areas and bare soils would double in size, reaching 6,910.48 ha.

- Conservation scenario: The scenario is marked by a loss of natural areas, but also of crop areas. Indeed, forest and mangrove areas would decrease. Thus, forest areas, which cover 3,423 ha in 2026, would drop to 2,266.76 ha, and mangrove areas would shrink to 570.94 ha. Similarly, crop areas would decrease by more than 2,645 ha, representing only 13,601.04 ha. Nonetheless, built-up areas and bare soils would gain 3,227 ha, spreading over more than 5,796.52 ha by 2040.
- The restauration scenario: This scenario leads to an increase in mangroves, which would grow by 161 ha to reach 795.06 ha. Forest areas would decrease, covering 2,511.6 ha, which is a loss of 911ha. The same goes for cropland, which would decrease shrink by 27.27 ha to cover 13,519 ha. Built-up areas and bare soils would move in the opposite direction, increasing by over 3,170 ha to reach 5,739.1 ha. Comparing the possible scenarios in 2040 shows clearly different trajectories.

➢ *Effect of Managemennt Policies on Land Use in the Sassandra-Dagbego Wetland*

The prospective modeling highlights different trajectories of land use changes by 2040. We can see a marked change in natural formation, agricultural spaces, and artificial areas. The trend scenario appears associated with significant human impact on the area, while the conservation and restoration scenarios reduce certain dynamics without actually

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reversing them. This is the case for the built-up and bare soil class, whose areas would increase sharply under the BAU scenario, by more than 100%, reaching 6, 910.48ha. this increase would be less significant in the CONS and REST scenarios, with 5,796.52 ha and 5,739.1 ha respectively, although still very high. The modeling therefore highlights the persistence of strong human pressure, even in land-use projections with conservation or restoration goals.

Forest formations, whereas, show a tendency to decline in all three scenarios, with a very significant projected loss in the trend scenario and more limited losses in the other hand two. This simulated reflects the vulnerability of forest formations to the future changes.

The projected changes for the mangrove are very contrasting. While mangrove would decrease in the BAU (by 23.2%) and CONS (9.9%) scenarios compared to 2026, they would increase by 25.4% in the Restoration scenario. The restoration trajectory seems likely to promote the spatial recolonization of mangroves. So, this result is an important element in differentiating between the scenarios; however, it should be interpreted as a simulated development and not as actual ecological restoration.

Crop areas also experience a decrease in size across all three scenarios. This decline reflects a reorganization of agricultural spaces and should be consider alongside the simultaneous increase in built-up and bare soils. Water and marsh areas would remain fairly stable in all three scenarios. This leads to an overall maintenance of weltlands across all the simulated trajectories

Overall, the modeling highlights a profound reorganization of the wetland characterized by the progression of human activity in the areas and the decline of natural formations and cultivated areas, as well as a contrasting evolution of the mangroves. The CONS and REST scenarios help mitigate certain trends without, however, stopping their progression.

IV. DISCUSSION

➢ *Choice of the Calibration Period*

Calibration is based on the analysis of land use dynamics during the recent period 2015-2026. This choice is based on three considerations established by the Fuzzy similarity of [11]. First, the assumption of stationary transition is better respected the closer the calibration period is to the projected period. Next, historical data may not reflect current dynamics and may be outdated. Moreover, it is difficult to faithfully reproduce the explanatory variables for this area (built environment, hydrology, road network).

Finally, the use of non-current explanatory variables can lead to biases in projections. Therefore, the calibration period from 2015 to 2026 provides a coherent historical basis by 2040. Nevertheless, the hypothesis of the continuity of historical trends does not imply future conditions similar to those observed during the calibration period, as they can be altered by management or planning policies, and socio-economic dynamics.

➢ *Prospective Trajectories and Conservation Challenges*

The results of predicative modeling of land use in the Sassandra-Dagbego complex, looking ahead to 2040, highlight significant landscape transformation. the business-as-usual scenario is most unfavorable to natural formation, with the regression of forest and mangrove and the increase of built-up areas and bare soil. It extends the dynamics observed between 2015 and 2026, characterized by the conversion of forest formations into agricultural areas. This trend is also observed in many wetlands in Africa, notably in the Densu Delta in Ghana [12]. This study, along with many others, highlights the transformative power of agriculture, including urbanization [13].

Furthermore, the comparison of the three scenarios demonstrates that conservation or restoration measure could influence certain trajectories, as is the case with mangroves, whose areas would decrease by 23.2% in BAU scenarios and by 99.9% in the CONS scenario, but would increase by 25.4% in the REST scenarios would be very useful in halting the degradation of certain dynamics. It is therefore in the perspective that [12] emphasized the importance of implementing mangrove conservation and restoration policies to restore ecosystem functions.

The results also show an increase in built-up areas and bare soil for the three scenarios, but differentiated according to the type of scenario. It can therefore be concluded that conservation and restoration policies are likely to mitigate certain transformations without, however, curbing the anthropogenic pressures affecting the landscape, particularly urbanization, as their effect are conditioned by the control of the expansion of artificialized areas [14]. However, the reduction in the cultivated areas in all three scenarios should be interpreted with caution. It appears to correspond to a spatial recomposition of bare soil.

Thus, the conservation of the wetland area would require an integrated approach combining the protection of natural formations, the restoration of mangroves, the control of artificialization, and the management of agricultural spaces.

➢ *Limits and Uncertainties of Modeling*

Land use projections are possible trajectories, not definite predictions of land use in 2040. The reliability of the projections depends on various factors that include the quality of classifications, observed transition matrices, and the assumption of the way observed dynamics contribute to future changes.

The uncertainty first source concerns the satellite image classification. A classification that contains errors can underestimate or overestimate the classes. These errors could affect the transitions used as an assumption of modeling.

The second important limitation concerns the transition matrix. It serves as the historical basis for projections. The transitions used assume a important representation of the

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spatial behaviours observed during the period is related to environmental and socio-economic conditions specific to that period, whereas the conditions themselves could change as time passes. In addition, errors of classification could spread through the matrix and influence the projections.

Finally, the assumptions specific to each scenario on which the projections are based are simplified representations of possible futures. They do not take into account the entirety and complexity of the changes affecting the territory. All these results should be considered as possible trajectories rather than certain predications.

V. CONCLUSION

This study let to analyzing the dynamics of land use in the wetland of Sassandra-Dagbego complex between 2015 and 2026, as well as the passible future trajectories through three prospective scenarios. The result highlights a profound transformation of the wetland environment, characterized by the conversion of forest formation areas into agricultural zones and an increase in built-up and soil.

The comparison of scenarios show that the business-as-usual scenario would be conducive to the degradation of forest formation, whereas the conservation and restoration scenarios would mitigate certain transformations, specifically the restoration scenario, which would increase mangrove areas. However, the persistent progression of artificialization underlines the limitations of approach based solely on ecological restoration.

Thus, this study highlights the necessity of implementing integrated management of wetlands with the preservation of forest and mangroves, the restoration of degraded environments, and the control of the expansion of artificialized areas.

Therefore, despite the uncertainties related to classifications, the transition matrix, and projection assumptions, this prospective approach constitutes a decision-making tool to guide conservation strategies in the wetland areas.

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