

Strengthening the Protection and Management of Classified Forests and Agricultural Land in Senegal through the Combined Use of Remote Sensing and GIS

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Abstract

Senegal, like many developing countries, is facing rapid and often uncontrolled urbanization, particularly in areas with high economic stakes such as Dakar. This situation is putting increasing pressure on agricultural land and classified forests. This urban expansion therefore threatens food security, biodiversity, and the country's socio-economic balance and, as a result, does not promote the achievement of the Sustainable Development Goals (SDGs), in particular SDG 11 (Sustainable Cities and Communities), which aims to promote better spatial planning and urban resilience, and SDG 15 (Life on Land), which aims to preserve biodiversity and the sustainable management of terrestrial ecosystems. This article aims to analyze the effects of urbanization on agricultural land and classified forests using remote sensing and Geographic Information Systems (GISs) tools for the sustainable and proactive management of these vital land resources. The study is based on a methodological approach combining temporal analysis of satellite images (Landsat 7 and 8), spatial processing tools, grid modeling, and field surveys conducted with institutional and community stakeholders. It was applied in three areas of the Dakar region: the urban center of Diamniadio, the Tivaouane Peulh area, and the ecologically sensitive areas of the Mbao classified forest and the shores of Lake Rose. The results show a marked increase in built-up areas at the expense of agricultural and forest areas. These changes are often facilitated by a lack of rigorous planning, arbitrary declassifications, and opaque land governance. In response to this situation, the study proposes recommendations based on three pillars: technological innovation (GIS, remote sensing), legal reinforcement, and inclusive governance (community GIS, participatory tools). This

work is in line with the Sustainable Development Goals and shows how the tools used enable better monitoring of land use changes, better planning in land use policies, strengthened land governance, urban resilience, and biodiversity preservation to reconcile urban development and ecosystem preservation in Senegal.

Keywords

Urbanization, Land Management, Remote Sensing, GIS, Agricultural Land, Classified Forests, Senegal

1. Introduction

Urbanization is now a major global phenomenon. In most developing countries, such as Senegal, cities are expanding at an accelerated pace under the combined effects of population growth, internal migration, and the gradual integration of rural peripheries into the urban fabric [1]-[5]. While this dynamic promotes economic development and infrastructure expansion, it also brings about profound changes in land use and management. Urban expansion thus poses a growing threat to agricultural land and protected forests, which are gradually being encroached upon by real estate, road, and industrial infrastructure projects, especially in countries where legislation does not provide sufficient protection for these areas or is not rigorously enforced.

In Senegal, this trend is particularly evident around the Dakar region, the country's economic heartland, which has been undergoing rapid urbanization for more than two decades. Major projects such as the Dakar-Diamniadio toll highway, the Regional Express Train (TER), and the Diamniadio Urban Pole illustrate this desire for development and modernization. However, these initiatives are putting significant pressure on land, jeopardizing the sustainability of natural resources, particularly agricultural land, which is a source of food security, and classified forests, which are key to ecological balance.

In this context, geospatial tools, particularly remote sensing and Geographic Information Systems (GISs), offer interesting opportunities for analyzing land use dynamics, anticipating land conflicts, and supporting sustainable land management policies [6]-[15]. These technologies overcome the limitations of traditional approaches by providing a comprehensive, accurate, and scalable view of space [16] and [17]. In the face of rapid urbanization, how can remote sensing and Geographic Information Systems (GISs) tools be used to analyze changes in land use, identify emerging land conflicts, and propose solutions for the sustainable management of agricultural land and classified forests?

2. Presentation of the Study Areas

- **Diamniadio urban center**

The Diamniadio urban center, located 30 km east of Dakar in the department of Rufisque (Dakar Region), covers an area of 1750 hectares, 45% of which was urbanized between 2015 and 2023. Strategically positioned between the Senegalese capital and Blaise Diagne International Airport (AIBD), this area is served by the toll highway (Ila Touba) to the South, the RN-3 to the West, and the Regional Express Train (TER), enhancing its accessibility (Figure 1). It borders the municipalities of Bargny and Sendou to the North, Lac Rose, a sensitive ecological area, to the East, and agricultural land to the South. This positioning makes it a major hub for economic and urban development within the framework of the national land use planning policy. The area has a Sahelian climate, with a short rainy season (June to October).

Classified as a new city under the Emerging Senegal Plan (PSE), Diamniadio is a strategic response to the saturation of Dakar, with the goal of accommodating 500,000 inhabitants by 2030. Developed under the legal status of a Concerted Development Zone (ZAC), it is placed under the direct supervision of the state, which oversees its planning, coordination, and development. This status allows for centralized land management and consistent implementation of infrastructure, with a view to creating a compact, sustainable city that is well connected to the country's major centers [18].

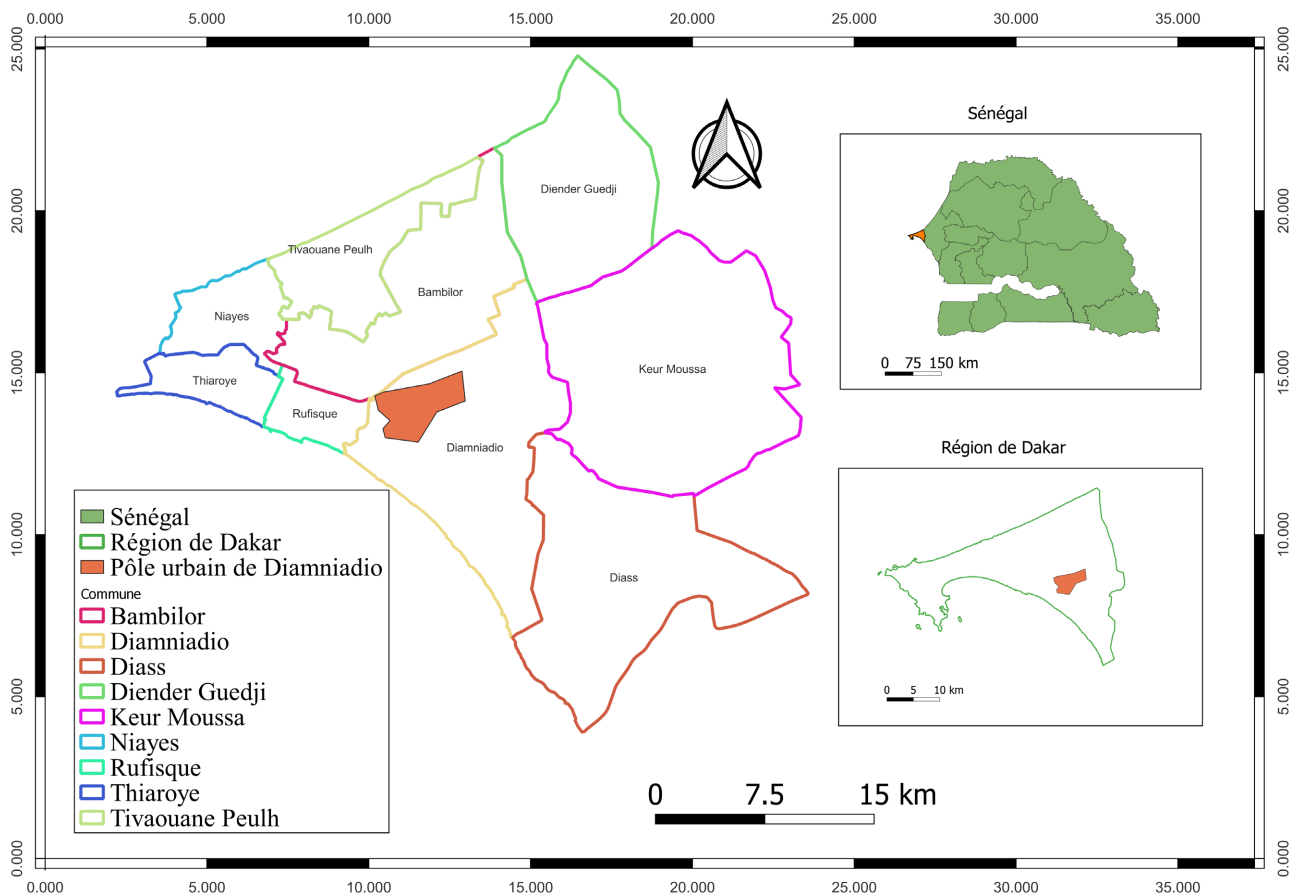


Figure 1. Map of the Diamniadio urban center.

- **Tivaouane Peulh**

Located East of Dakar in the commune of Rufisque, Tivaouane Peulh is a peri-urban area that is experiencing increasing land pressure due to its proximity to the capital and the development of social housing projects. This traditional agro-sylvo-pastoral area covers 12,500 hectares, 18% of which has been urbanized over the last decade. It is bordered to the North by the rural community of Pambal, to the South by the municipality of Jaxaay-Parcelles (Niakoul Rab), to the East by the municipalities of Bambilor and Sangalkam, and to the West by the municipality of Keur Massar (Figure 2). Its role as a buffer zone makes it a pivotal territory between urban dynamics and rural vocations, at the heart of regional planning issues.

Classified as an agro-sylvo-pastoral zone in the Local Urban Development Plan, Tivaouane Peulh has historically been populated by a traditional Fulani community, mainly composed of transhumant herders. This territory is characterized by high seasonal mobility, dictated by pastoral cycles and climatic variations, making it a dynamic but fragile space. In terms of land tenure, it is particularly complex, with the coexistence of state-owned land, plots governed by customary rights, and informal ancestral uses, making land management and security particularly sensitive in a context of increasing urbanization, which exposes it to informal urbanization and growing tensions over access to land.

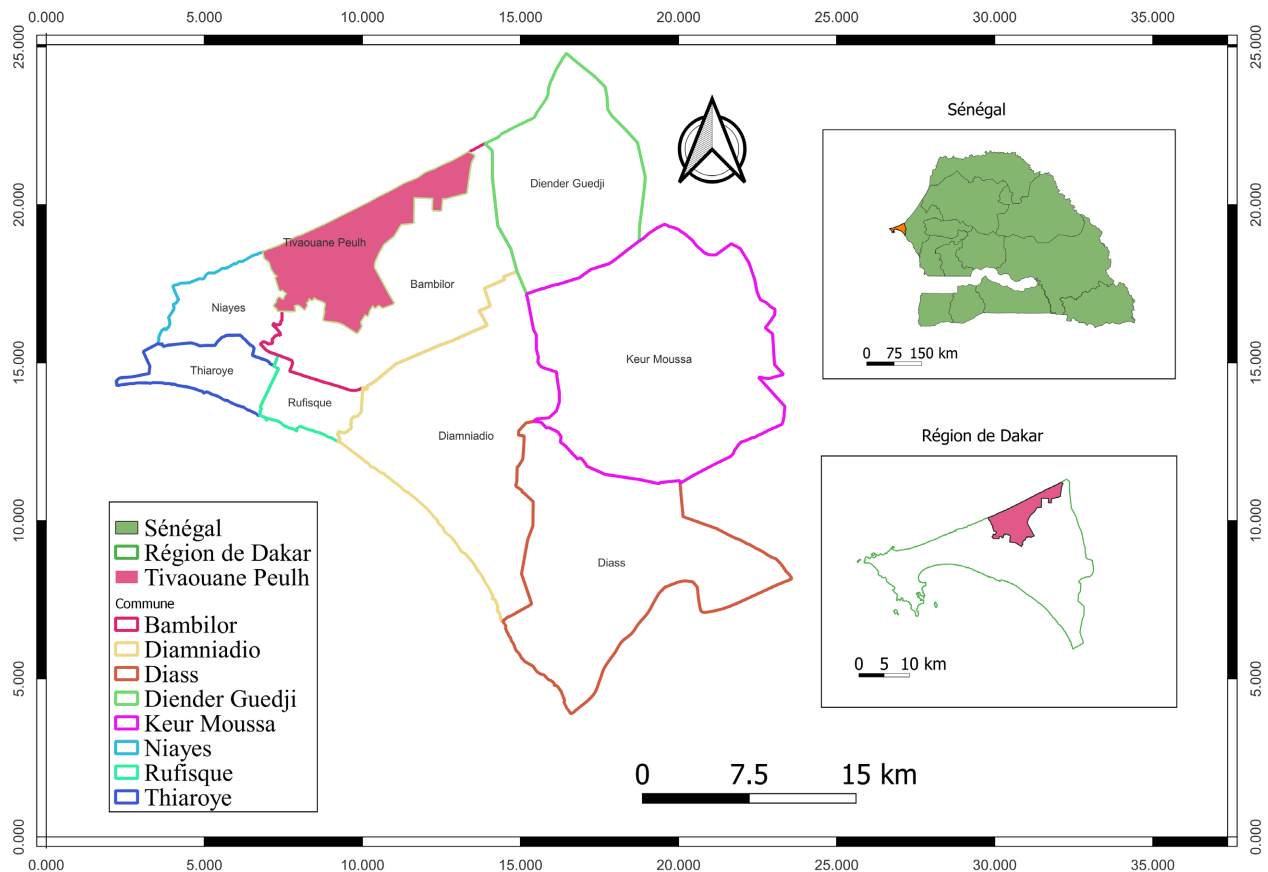


Figure 2. Map of the Tivaouane Peulh area.

- Mbao classified forest

The Mbao classified forest, covering an area of approximately 700 hectares, is one of the last remaining classified forests in the immediate vicinity of Dakar. It is located in the Pikine department in the municipality of Mbao, within the Dakar region. This ecological heritage is now threatened by rapid and uncontrolled urbanization, marked by illegal occupation, unregulated real estate projects, and the growing development of infrastructure and facilities (roads, public buildings, technical networks) that are gradually encroaching on its boundaries. The forest is bordered to the North by the neighborhoods of Boune, Darou Misseth, and Medina Kell. To the South, it is bordered by the municipalities of Petit Mbao and Grand Mbao, to the East by Kamb and Keur Mbaye Fall, and finally to the West by National Highway n° 1 and the Petit Mbao and Fass Mbao ramps (Figure 3).

Also running from West to East, the toll highway has also crossed the classified forest, which will help improve accessibility while also creating factors that could undermine its integrity. The forest is also crossed from North to South by the road connecting Keur Massar to the RN1 [19].

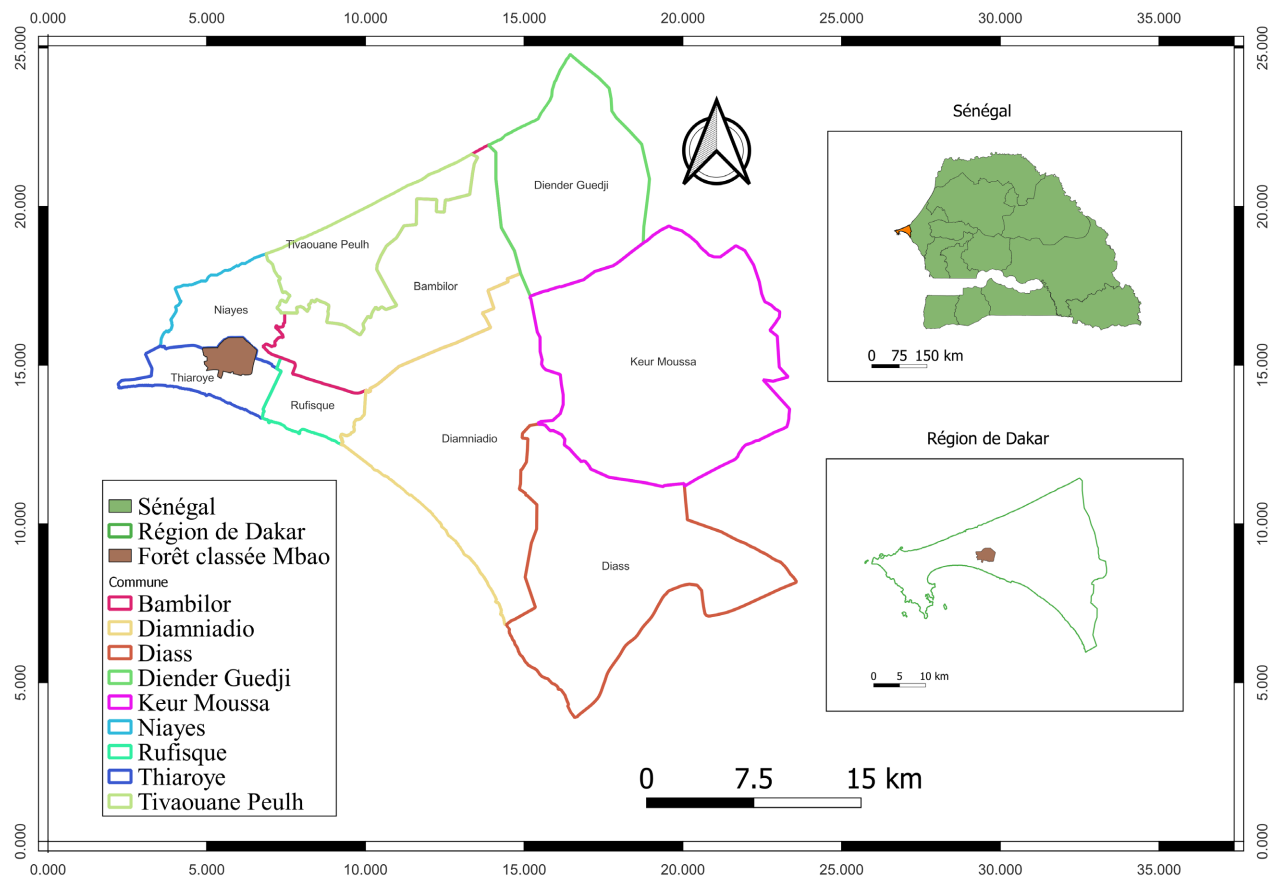


Figure 3. Map of the Mbao classified forest.

The Mbao forest was classified on May 7, 1940, by Decree 979 SE/F. For the conservation and preservation of biodiversity, several species were introduced into the forest between 1940 and 1955: *Eucalyptus camadulensis*, *Prosopis juliflora*,

Anacardium occidentale, etc. [19].

3. Tools, Data, and Software Used

For this study, a combination of tools and software was used to process, analyze, visualize, and interpret geospatial data. These tools, which complement each other in their functionality, enabled the seamless integration of data from different sources (satellites, land registry, and field surveys). Landsat 7 and 8 images were used for the period from 2000 to 2024 to analyze changes in land use in the study areas. Cadastral and land registry data (cadastral map, legal status of plots, types of owners) were essential. They were used to support the analysis of conflict dynamics, facilitating the identification of areas with high potential for land disputes and guiding the conduct of field investigations in a targeted manner. Field data was collected through semi-structured interviews with local populations, neighborhood leaders, traditional representatives, local elected officials, municipal officials, and state technical services (urban planning, water and forestry, hunting and soil conservation, state property services, Land Registry) in order to gather their perceptions, testimonies, and information on changing land uses, land conflicts, changes in agricultural or pastoral practices, and urbanization dynamics. Global Navigation Satellite System (GNSS) measurements were also taken to map areas of land tension, locate new constructions, irregular occupations, transhumance corridors, and fallow plots. These field observations validated the analyses derived from satellite images and established a direct link between spatial data, social practices, and realities on the ground.

These various data were processed using Google Earth Engine (GEE) with customized scripts and QGIS software for image processing, surface statistics calculation (loss of agricultural land, urban expansion), and the establishment of different layers. Field surveys were conducted using the KoboCollect tool.

The images used cover the period from January to May (from 2000 to 2024), covering the dry season in Senegal, in order to reduce the effect of clouds and temporary vegetation cover. A cloud cover index filter (<10%) was applied. In order to identify the main land use classes in the study area, supervised classification was implemented with the following classes: urban areas, agricultural land, water bodies, and bare soil.

4. Results and Discussion

Field surveys identified key areas for understanding land dynamics, namely:

- **Perceptions of rapid urbanization:** Interviews highlighted the diversity of views among respondents—some see urbanization as a driver of development, while others are concerned about its effects on agricultural land, habitats, and social balance.
- **Land access practices:** Discussions documented forms of land acquisition (inheritance, formal or informal purchase, state allocation), conflicts related to land use, and the coexistence of customary practices and modern mechanisms.

- **Local environmental preservation strategies:** Some local actors mentioned reforestation initiatives, community monitoring, and awareness-raising about the protection of natural areas, despite the limited resources available.
- **Governance and institutional coordination issues:** Interviews highlighted communication failures between state and local structures, as well as overlapping legal texts and jurisdictions, which often lead to ambiguity or deadlock.

Satellite imagery was also used to produce various thematic maps for the periods 2000, 2015, and 2024.

- **Diamniadio urban center**

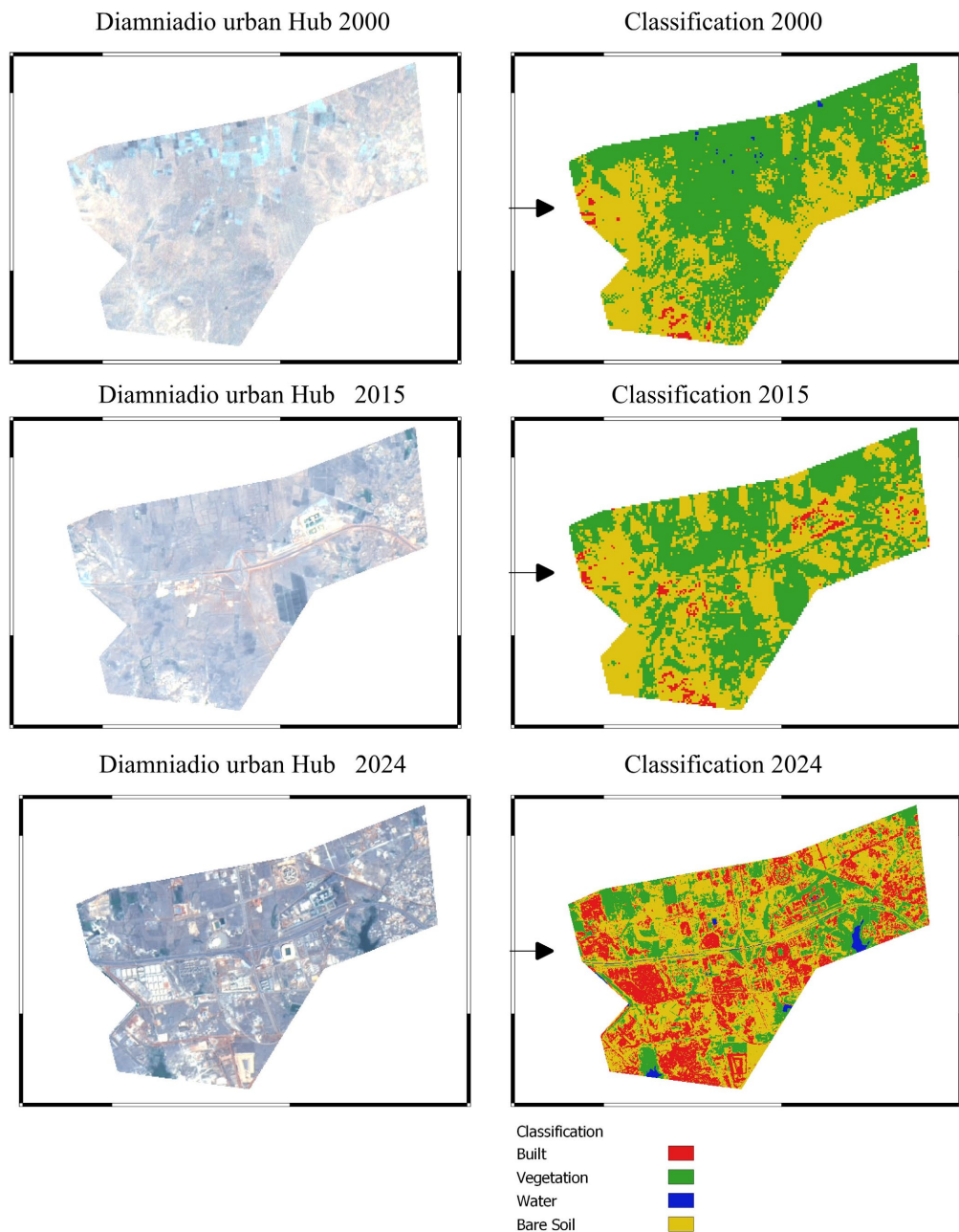


Figure 4. Changes in land use in the Diamniadio urban center.

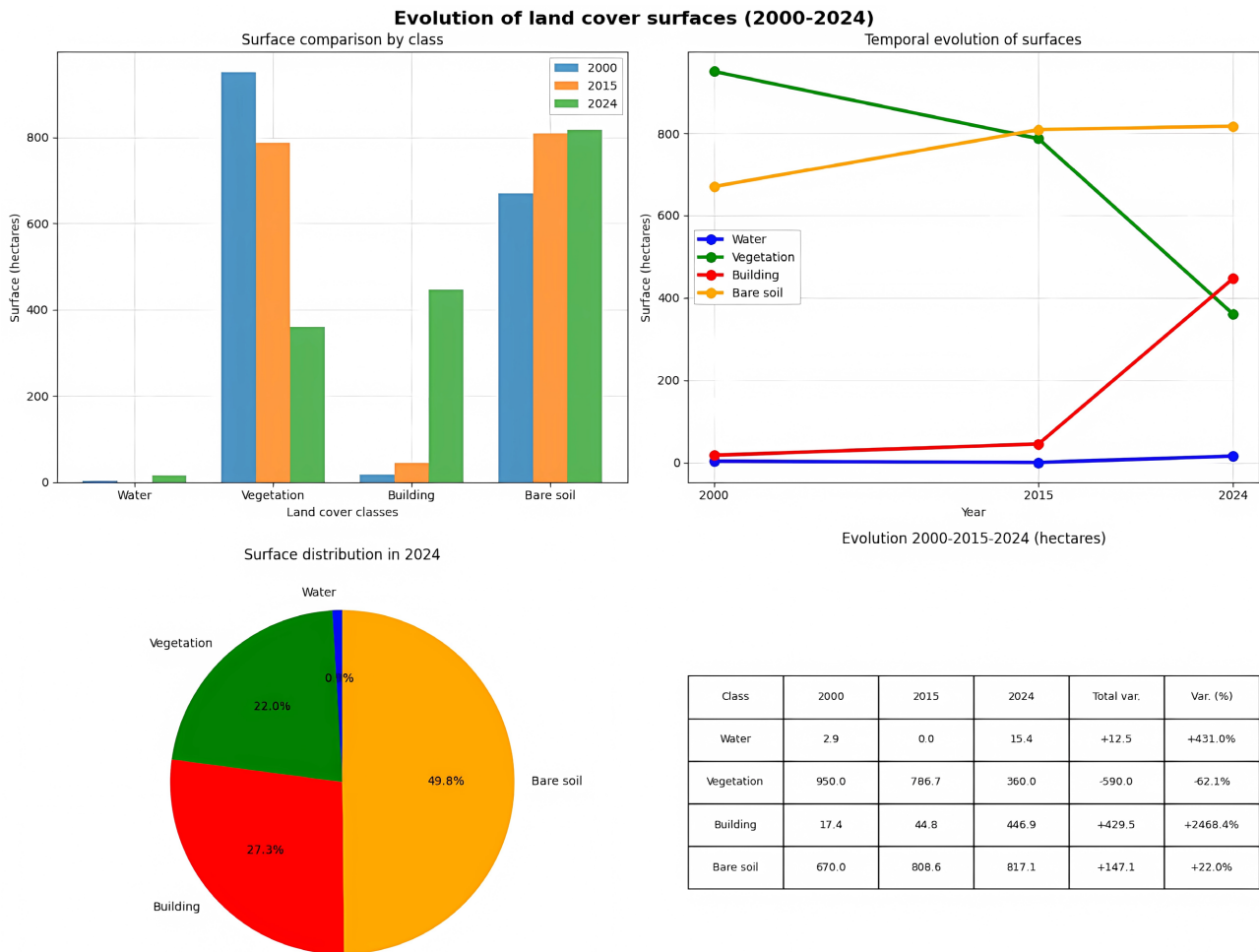


Figure 5. Evolution of land area by land use class in the Diamniadio urban center (2000-2024).

In 2000, the Diamniadio urban center was characterized by a predominance of bare land and vegetation, reflecting a still sparsely urbanized territory. In 2015, urban development was evident, with a significant increase in buildings, particularly in the central and southern areas. There was also accelerated land clearing between 2000 and 2015. This trend became more pronounced in 2024, with much more dominant urbanization, leading to a sharp decline in vegetated areas (Figure 4). The appearance of water areas can be explained by the emergence of artificial retention basins and depressions or lowlands accentuated by the artificialization of the area, leading to changes in the relief (Figure 5).

In 2000, Diamniadio had 950.0 ha of vegetation cover, which was reduced to 786.7 ha in 2015 and then to 360.8 ha in 2024 (Figure 5). This gradual decline represents an overall decrease of -589.1 ha, or -62.0% in 24 years. The built-up area increased from 17.4 ha in 2000 to 44.8 ha in 2015, then to 446.9 ha in 2024. This represents a total increase of +2472.8% in 24 years. This situation can be attributed to several factors:

- The gradual disappearance of farmland and wasteland in favor of housing and infrastructure;

- The lack of active reforestation or conservation policies in the face of urban expansion;
 - Accelerated artificialization linked to the ambition to make Diamniadio a structuring development hub;
 - The establishment of large public infrastructure projects;
 - Residential urbanization driven by the state and private actors;
 - Planned development that is sometimes only partially or haphazardly implemented.
- **Tivaouane Peulh**

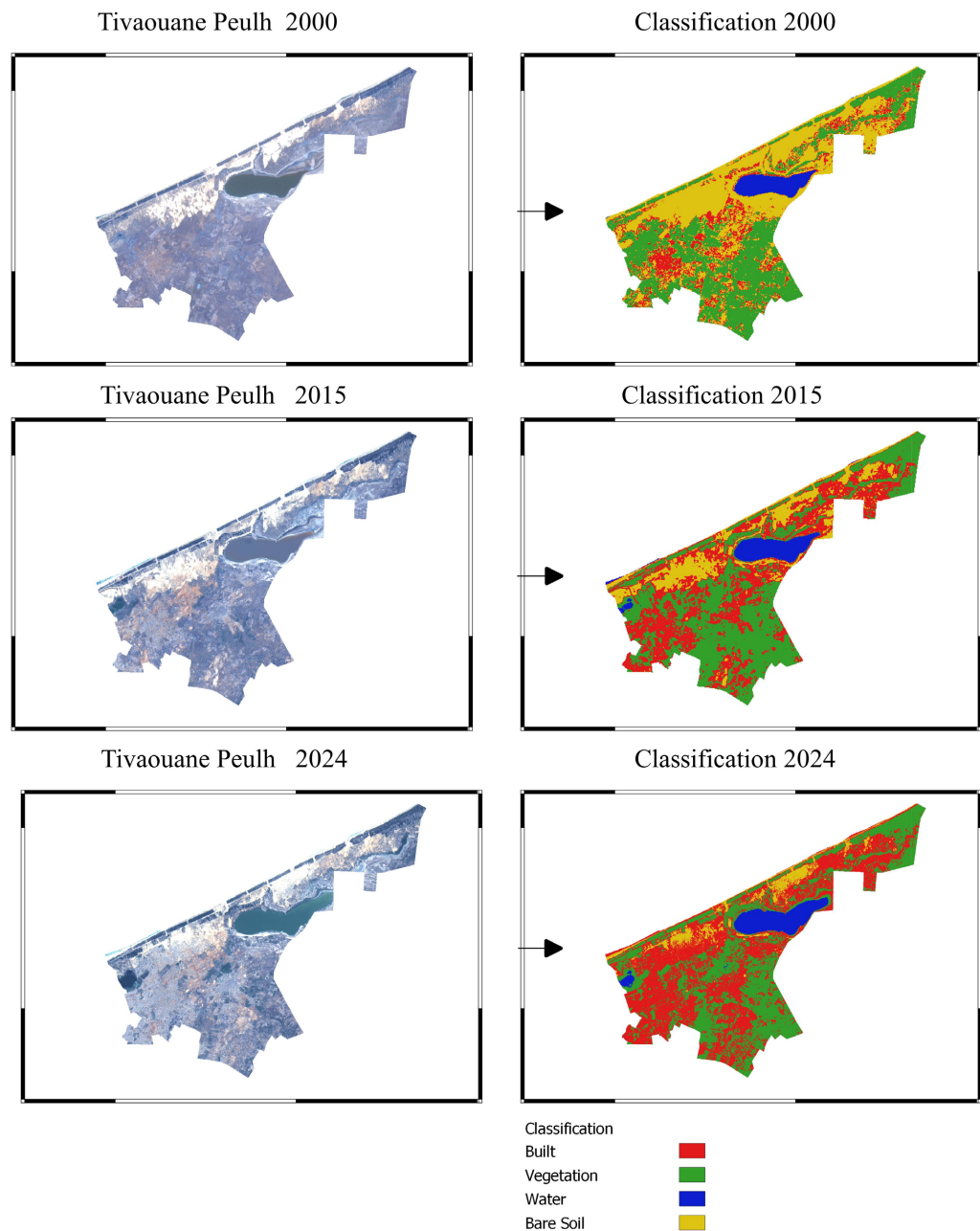


Figure 6. Changes in land use in the Tivaouane Peulh area.

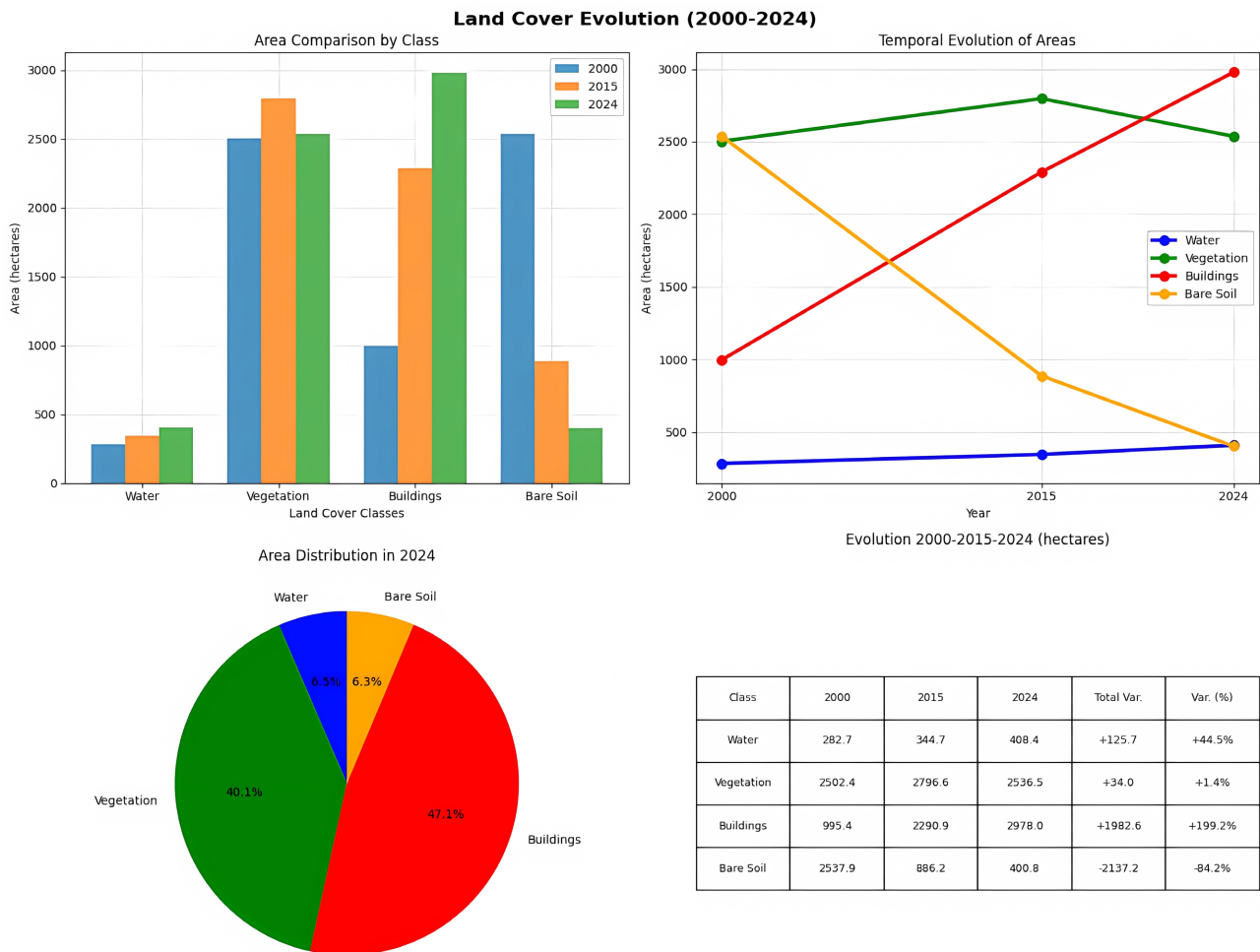


Figure 7. Changes in land use in the Tivaouane Peulh area from 2000 to 2024.

In 2000, the Tivaouane Peulh area was predominantly rural, characterized by natural vegetation and bare soil, with very limited infrastructure (Figure 6 and Figure 7). By 2015, the establishment of new infrastructure and transport links had become noticeable, driving urban growth mainly concentrated along major roads. In 2024, there was marked urbanization, particularly in the northern and central parts, leading to a significant decline in green areas in favor of buildings. Wetlands remain but are showing signs of decline due to increasing land pressure, which can be explained by the housing shortage in Dakar and the high cost of renting buildings.

Compared to Diamnadio, here we see much slower land clearing and urbanization taking place on bare ground (disappearance of bare ground in favor of buildings), resulting in uncontrolled urbanization and urban sprawl.

- Mbao classified forest

In 2000, the Mbao classified forest was characterized by dense vegetation and wetlands, while built-up areas remained marginal. In 2015, urbanization was evident, with the gradual expansion of residential and industrial areas, particularly visible in red on the map. In 2024, urbanization has intensified significantly: build-

ings cover a large part of the area, with bare ground having receded, while water bodies have increased slightly, possibly reflecting the emergence of artificial wetlands or hydraulic developments linked to urbanization. This reflects a profound transformation of natural environments under pressure from human activities.

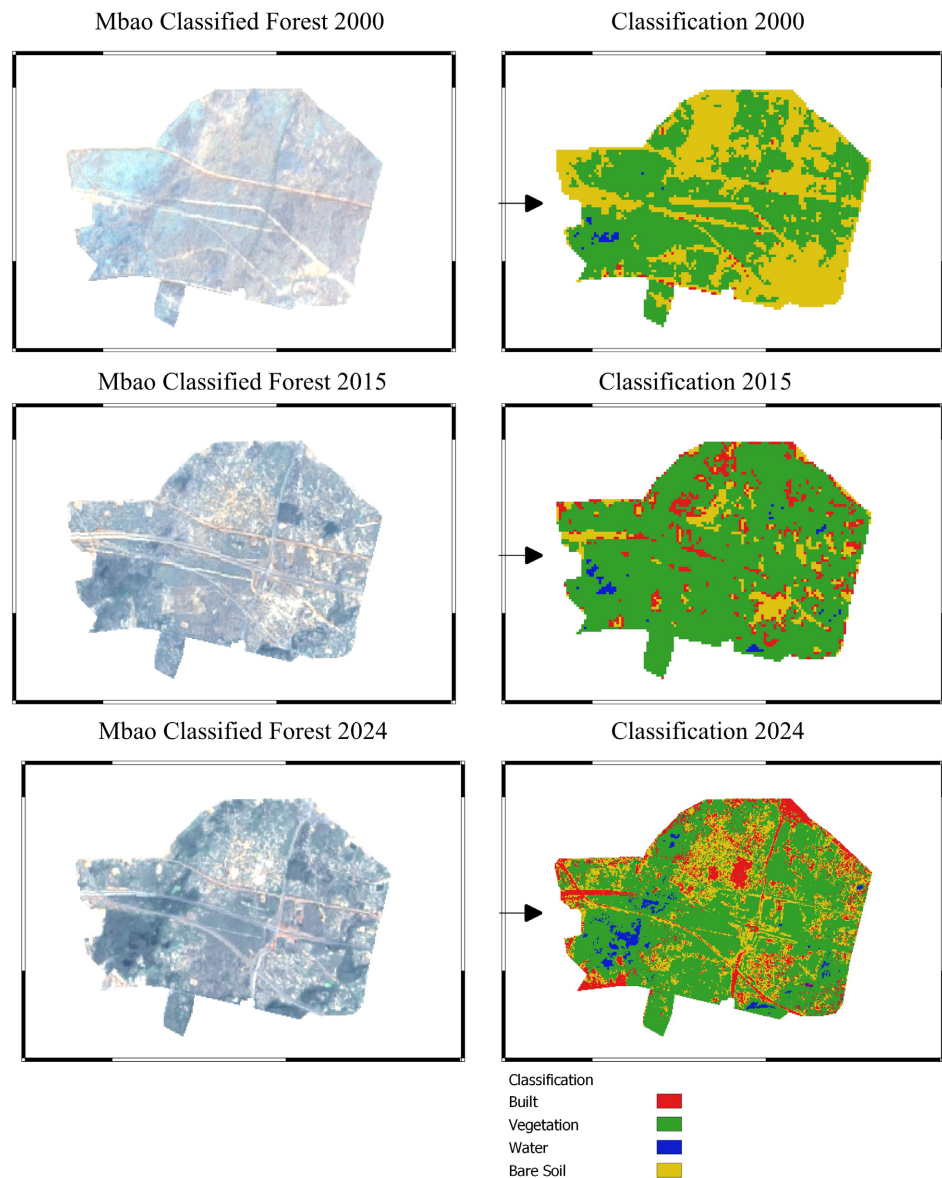


Figure 8. Changes in land use in the Mbao classified forest.

In 2000, the forest had a vegetation cover of 407.2 ha. This area increased to 595.9 ha in 2015, before falling back to 467.2 ha in 2024, representing a net loss of 128.7 ha since 2015, a decrease of 21.6% from its peak, and an increase of 14.7% compared to 2000 (**Figure 8** and **Figure 9**). Although this site benefits from protected status established by the classification decree of October 23, 1940, and reinforced by the Senegalese Forest Code (Law No. 98-03 of January 8, 1998), anthropogenic pressures are evident and growing. The protection mechanisms in

place, such as the ban on land clearing, monitoring by the Water and Forestry Department, and administrative sanctions, seem to be struggling to adapt to current socio-economic and land ownership realities, particularly demographic pressure and increased demand for housing around Dakar.

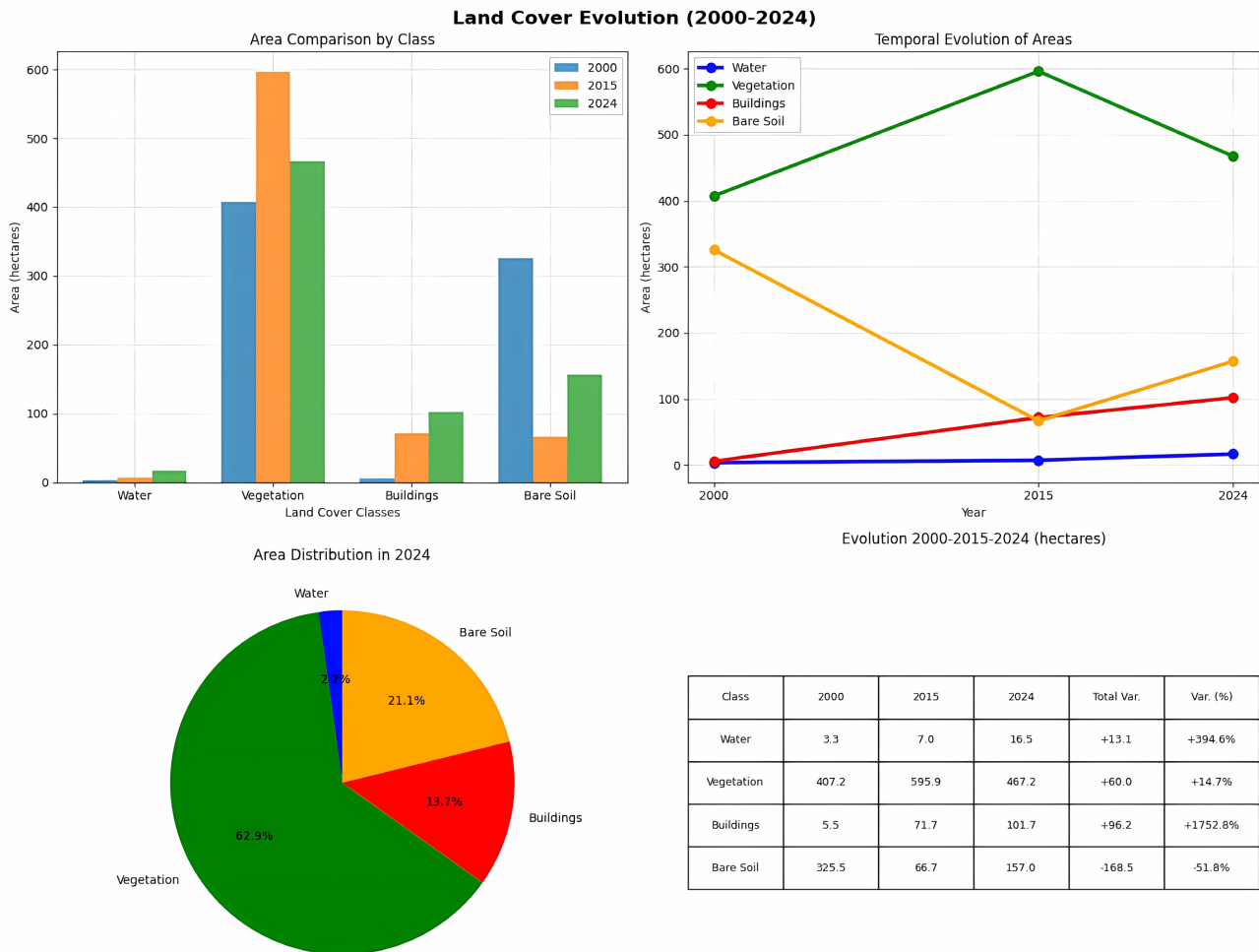


Figure 9. Changes in land use in the Mbao classified forest from 2000 to 2024.

These three case studies reveal that the rapid urbanization east of Dakar is a complex and multifaceted phenomenon. Whether planned (Diamniadio), disorderly (Tivaouane Peulh), or threatening to protected areas (Mbao), it systematically results in a reduction in agricultural and forest land (Figures 4-9). It revealed intense change due to rapid urbanization and land pressure. The results illustrate a significant decrease in agricultural and forest land, coupled with the development of urban infrastructure, leading to land use conflicts and serious environmental concerns.

- **Diamniadio:** The new urban hub was intended to relieve congestion in Dakar. This led to the large-scale transformation of agricultural land into urban centers. Expropriation and compensation policies caused significant social unrest, exposing failures in land governance.

- **Mbao Classified Forest:** Although the forest is still protected, it continues to face human (illegal occupation, construction) and environmental (soil degradation, invasive species) pressures. Shrub harvesting or reforestation activities are less than the disturbances caused.
- **Tivaouane Peulh:** The lack of rigorous spatial planning has led to uncontrolled urbanization, characterized by informal settlements, the rapid disappearance of agricultural land, and increasing conflicts over land use. Testimonies gathered in the field highlight the perception of opaque and unfair land governance. As one resident reports: “Many families have lost their fields without really understanding how the land was allocated. We hear about social housing projects, but no one shows us the official documents”.

A customary representative adds: “Decisions often come from above, without consultation with local communities. This creates tensions, especially when the boundaries between village land and reserved areas are not clearly defined”. These accounts illustrate how institutional opacity and weak participatory planning fuel frustration and exacerbate social tensions.

Managing the future of these territories will certainly require an integrated approach combining rigorous planning, effective land tenure security, and active ecosystem protection, taking into account local specificities.

5. Projected Scenarios

To better understand future trends in these land use dynamics and the possible transformations that may occur in the areas studied, prospective modeling was carried out using the CA-Markov method. This method combines Cellular Automata (CA) to simulate local spatial dynamics and Markov chains to estimate the probabilities of transition between different land use classes based on satellite images from previous years. This approach makes it possible to project future land use changes based on trends observed in the past.

The choice of the CA-Markov model is justified by its ability to integrate both the temporal and spatial dimensions of land use change, while taking into account neighborhood interactions, which are essential in the processes of urbanization and landscape fragmentation. Other modeling approaches, such as models based on Logistic Regression (LR), use explanatory variables (slope, distance to roads, etc.) to determine the probability of transition for each class of pixels. These require extensive collection and preparation of spatial factors (explanatory variables), which can be time-consuming. They are less effective for large areas. etc.) to determine the transition probability for each pixel class, require extensive collection and preparation of spatial factors (explanatory variables), which can be time-consuming, are less effective for large areas or for simulating the pure neighborhood effect, and CLUE-S (Conversion of Land Use and its Effects at Small regional extent) models, combined statistical probabilities and LULC transition demands with spatial allocation rules to satisfy demand. Although highly effective, they are more complex to configure and require more socio-economic and institutional data

to define “demand” in land use classes. Although these alternative models (such as Logistic Regression or CLUE-S) offer specific advantages, they often require more socio-economic data or complex parameters that need to be calibrated. In African contexts, access to such data is generally limited.

In comparison, the CA-Markov model offers a robust compromise between simplicity, accuracy, and interpretability, allowing for accurate reproduction of spatial trends observed from the available satellite data alone. It is therefore particularly well suited to the objectives of this study, which focuses on the spatial projection of urbanization and agricultural and forest land degradation dynamics in the Dakar region.

Analysis of the transition matrices generated by the model highlights the most likely urban development scenarios, the dominant transformations between classes (e.g., conversion of vegetation to built-up areas or transformation of bare land to urbanized areas), and areas at risk, particularly those threatened by the disappearance of agricultural land, degradation of vegetation cover, or increasing pressure on sensitive ecosystems such as wetlands and forests.

The historical probabilities from the Markov matrix were then combined with these suitability maps to produce conditional probability maps, which were used as inputs for the cellular automaton module. The model was calibrated using retrospective validation (simulation 2000 → 2015) and fine-tuning of parameters (neighborhood type, weights assigned to variables, stochastic component). However, it should be noted that the models obtained could be improved by incorporating additional variables (accurate demographic forecasts, medium-term urban development projects, private investments not yet made official, accurate climate and hydrological data).

- **Diamniadio urban center**

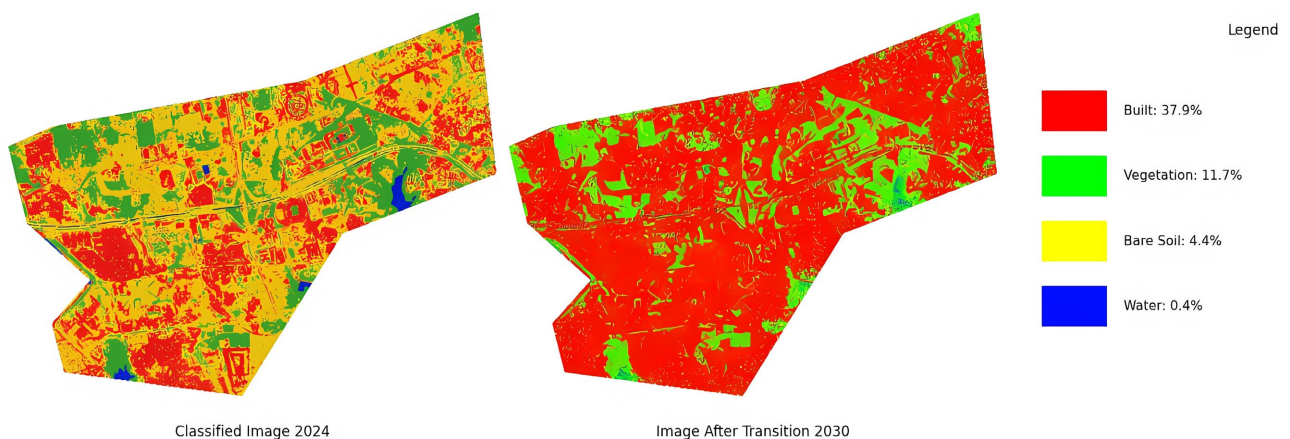


Figure 10. Projection of urban expansion in the Diamniadio urban center by 2030.

The transition matrix reveals a high degree of stability in built-up areas (98% retention), but also a significant conversion of vegetation (23.2%) and bare soil (30.6%) to built-up areas. Bare land is the most unstable class (only 48.8% retention), with notable transitions to buildings (30.6%) and vegetation (20.1%). This

suggests that open spaces that have not yet been built on are at high risk of disappearing, giving way to an increasingly dense urban fabric. This scenario reflects relatively rapid and controlled urbanization, typical of an area undergoing transformation into a new city (Figure 10).

- Tivaouane Peulh

The urbanization dynamic is even more pronounced in this area, with 58.4% of bare land expected to be converted into built-up areas, which is a very high transition rate (Figure 11). Similarly, 29.6% of vegetation is likely to be converted into built-up areas. These figures indicate that urban sprawl is likely to accelerate significantly in this municipality, to the detriment of natural spaces. Water remains a very stable class (96.2%), reflecting the permanence of existing ponds or wetlands, but their small size would limit their long-term ecological role.

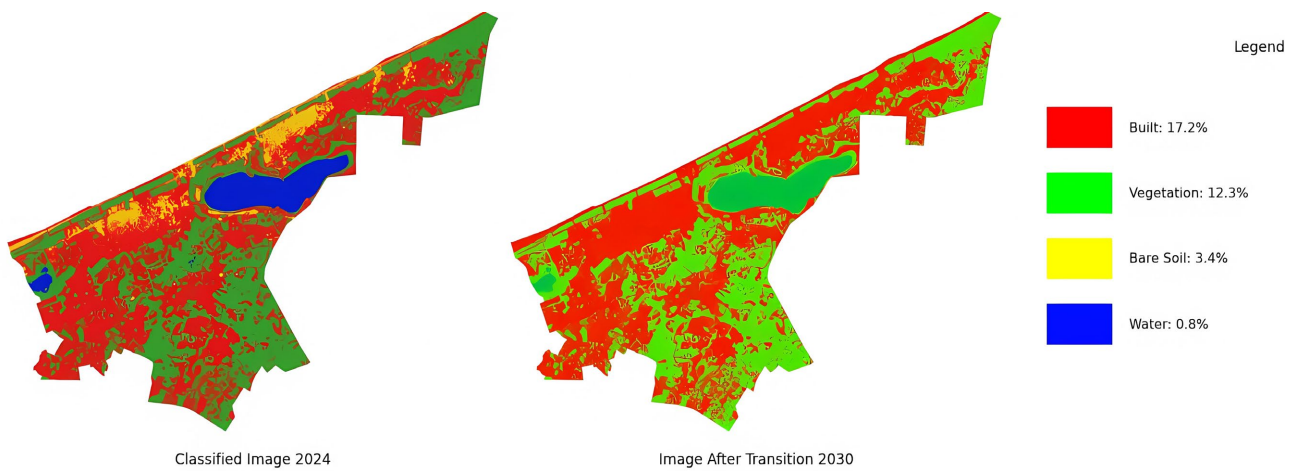


Figure 11. Projected urban expansion of the Tivaouane Peulh area by 2030.

- Mbao classified forest

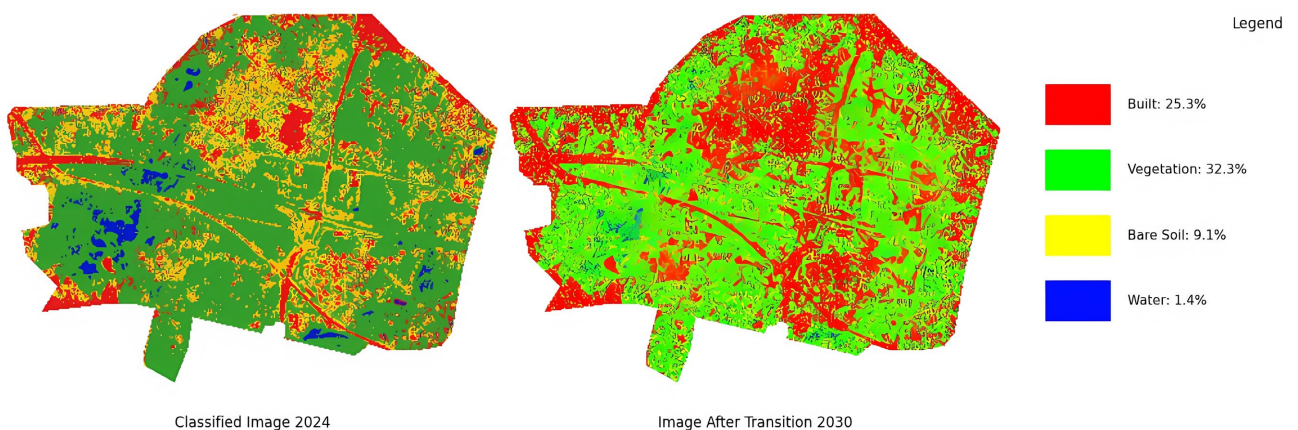


Figure 12. Projected urban expansion in the Mbao classified forest by 2030.

Although the built environment is relatively stable (87.4%) in this area, the vegetation is facing worrying changes: around 31% of the vegetation is expected to

become bare or built-up land. In addition, water areas are undergoing a transformation into vegetation, a sign of invasion by species such as cattail and more intensive agriculture. These dynamics reflect strong pressure on the classified forest, accompanied by diffuse urbanization and disorganized development around retention basins (Figure 12).

6. Proposed Strategies for Protecting Agricultural Land and Classified Forests

When unregulated, urban growth leads to rapid land artificialization, significant loss of agricultural land, and increased pressure on classified forests. In a context such as Senegal, where arable land is limited and forests play a crucial ecological role (local climate regulation, biodiversity conservation, water reservoirs), the protection of these areas becomes a long-term strategic requirement. To this end, several levers for action can be mobilized at different levels.

- **Strengthening the legal status of agricultural land and classified forests**

Current legal protection mechanisms are often undermined by private land interests, political pressures, or a lack of effective implementation. It is therefore recommended to:

- **Sanctuarize strategic agricultural areas** in urban planning documents by integrating them into exclusive agricultural use zones (ZAE) that cannot be built on unless an exceptional exemption is approved by decree;
- **Actualiser update forest classifications** with the support of remote sensing and GIS monitoring tools to enhance traceability and prevent arbitrary declassifications for speculative purposes;
- **Create Special Protection Zones (SPZs)** around classified sensitive forests, such as the Mbao Forest, with a regulated and monitored security perimeter;
- **Promote the inclusion of classified forests in the national natural heritage**, giving them additional protection and a more rigorous management framework.

- **Land security for agricultural producers**

Rural farmers often find themselves in a precarious land tenure situation, particularly in peri-urban areas, which makes them vulnerable to land subdivision and expropriation. To remedy this:

- **The issuance of simplified** and secure land use titles (occupancy certificates, usage titles) to farmers who have been living on national land for several generations should be accelerated, based on Law No. 64-46 and ongoing reforms;
- **Protected Agricultural Zones (ZAPs)** can be established around large urban areas to ensure the availability of land for local food production;
- **The creation of agricultural land cooperatives** would enable producers to pool land management and strengthen their bargaining power in relation to urban projects.

- **Promotion of urban and peri-urban agriculture**

Urban agriculture is an innovative response to the challenges of food security,

local employment, and environmental sustainability. With this in mind:

- It is necessary to integrate agricultural spaces into urban planning documents (master plans, territorial coherence plans), particularly in the form of agroecological corridors crossing the city or green belts, and the development of a green network under the responsibility of cities (decentralization);
- The promotion of multifunctional urban farms (production, training, organic waste recycling) in landfill areas or areas with low building potential can restore productive value to certain brownfield sites;
- Community gardens, attached to schools or social centers, can strengthen ecological awareness and social cohesion around sustainable food.

- **Participatory and integrated management of classified forests**

Classified forests should no longer be managed solely by the state: an inclusive approach involving local communities is needed. This approach is based on:

- The development of participatory forest management plans, incorporating activities such as agroforestry, local ecotourism, or low-impact forestry;
- The development of village monitoring committees trained in the use of mobile tools (smartphones, GPS, drones) to detect illegal activities (logging, illegal occupation, fires);
- The introduction of Payments for Environmental Services (PESs) to compensate communities for conservation efforts;
- Combining forest management with reforestation projects of high social value, particularly with native, edible, or medicinal species.

7. Conclusions

This study examined the crucial issue of sustainable management of agricultural land and classified forests in the face of rapid urbanization in Senegal, using remote sensing and Geographic Information Systems (GISs). Through an in-depth analysis of land use dynamics in strategic areas such as the urban centers of Diamniadio and Tivaouane Peulh, the Mbao classified forest, and the shores of Lac Rose, it has been demonstrated that uncontrolled urban expansion poses a real threat to land resources and natural ecosystems.

In short, this work demonstrates that geomatics tools, when properly integrated into decision-making processes and accompanied by land reforms, can play a key role in regulating urban expansion and preserving natural resources.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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