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Dynamics and Factors in the Evolution of Landscape Units in the *Casuarina equisetifolia* Strip of the Dakar Region (Great Coast, Senegal)

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Abstract

In 1948, the colonial authorities began to build a strip of filao on Dakar's northern coastline to stem the advance of sand dunes and protect the inter-dune basins (Niayes), the site of important market-garden production. Today, the dynamics of the filao strip in the Dakar region tend to take on significant proportions under the impetus of natural and anthropogenic factors that threaten its sustainability. It is in this context that this study attempts to analyze the relationship between the dynamics of the land-use units of the filao strip and the natural and anthropogenic factors at the origin of its modification. The diachronic study of Landsat Multispectral Scanner System (1978), Thematic Mapper (1990), Enhance Thematic Mapper Plus (2006) and Operational Land Imager (2020) satellite images through the directed pixel-oriented classification method, cartographic information systems and qualitative surveys have been applied. The results based on the analysis of the data obtained show that both natural and anthropogenic factors are at the root of the profound changes observed in the filao strip. They reveal that the average annual progression rates of the open filao strip and the built-up area exceed 100%, and that the closed filao strip classes regressed by −16.2%, the sand dunes by −62.9% and the beach by −18.2% between 1978 and 2020. In short, the study shows that the landscape of the Niayes zone is marked by anthropization, leading to the degradation of the filao strip and natural ecosystems. The shrinking surface area of the increasingly anthropized closed filao strip represents a threat to its future.

Keywords

Niayes, Filao Strip, Dynamics, Landscape Units, North Coast, Dakar

1. Introduction

The Niayes zone runs along the northern coast of Senegal, from Dakar to Saint-Louis. It extends all along the Grande Côte to the heart of the Cape Verde peninsula, covering an area of 8883 km^2 (Fare, 2018).

The Niayes zone stands out for the importance of its biodiversity. It is home to some 419 species, representing almost 20% of Senegal's flora (Flintan et al., 2022). It is Senegal's main vegetable-growing area and offers good conditions for arboriculture (Ba, 2008). The area is home to almost eighty widely distributed woody and sub-woody species. This important floristic resource, marked by the presence of species from the Guinean domain in the Sahelo-Sudanian zone, makes the Niayes a unique ecosystem in Senegal. This ecologically important area is known for its pleasant climate and its role in vegetable production. Its relief, formed by basins between the dunes, coupled with its outcropping water table and rich soils, gives it definite advantages in vegetable production.

However, the Niayes were threatened by the advance of the dunes, which buried the market garden basins. In 1948, in order to preserve market gardening activities, the colonial authorities began building a 180 km strip of filao from Dakar to Saint-Louis. The establishment of this filao plantation has fixed the quickset dunes that buried the market garden basins. This strip is currently undergoing a process of degradation due to the advanced age of certain plantations on the one hand, and human activity on the other. The main cause of filao degradation is due to the intrinsic characteristics of the filao and the physico-chemical characteristics of the environment, notably water deficit, salinity and topography. In addition to the ageing of the filao population, the forest has fallen victim to illegal logging, garbage dumps, sand extraction, land pressure and massive and galloping urbanization (Sow, 2008). The uniqueness of the filao strip along the "Grande Côte" can be seen in a number of ways. In addition to providing an effective physical barrier to slow the advance of sand, the reforested strip has encouraged the return of many farming families who had previously deserted the region (Ndiaye et al., 2012). This strip also serves to protect coastal dwellings and infrastructures in particular from sand dune silting (Sow, 2008). As a result, the dynamics of the landscape units have a negative impact on the environmental and socio-economic sustainability of the filao strip. Today, spatial remote sensing is used to reconstruct the dynamics of natural or artificial environments, or ecosystems in general (Andrieu & Mering, 2008). Spatial remote sensing is currently an essential tool for addressing concerns related to the inventory, monitoring and management of the planet's ecosystems (Solly et al., 2020). Thanks to satellite imagery, it is possible to map vegetation cover, water resources and cropland at a wide range of time and space scales (Solly et al., 2020). Thus, a mastery of land cover dynamics requires an identification and understanding of the mechanisms linked to these dynamics, to better base the analysis on the evolution of the state of the environment (Solly et al., 2020). Faced with this situation, research is being carried out to analyze the management of this green strip. It is within this framework that we have undertaken this study, which is limited to the Niayes of Dakar. The aim of this article is to jointly analyze the dynamics of filao strip occupation units with natural and anthropogenic factors over a 42-year period. To do this, we used Landsat satellite image data combined with field surveys.

2. Presentation of the Study Area

Senegal's Cape Verde peninsula occupies West Africa's most advanced position in the Atlantic Ocean. It lies between 12˚ and 17˚ north latitude and 11˚ and 18˚ west longitude. Senegal is subdivided into several eco-geographical zones, including the Niayes. It is bordered to the south by the Dakar region, to the north by the Saint-Louis region, to the west by the Atlantic Ocean and to the east by national road N˚1. The Niayes area lies between latitudes 14˚ and 16˚ North, and longitudes 16˚ and 17.5˚ West, and occupies the Atlantic fringe of Senegal's long coastline. Thus, our area belongs to both the forest domain (Forest Code) and the public maritime domain (Law N˚6 of July 02, 1976) (Ndao, 2012). Our study area lies within this space, between longitudes 17˚13' and 17˚44' West and latitudes 14˚72' and 14˚89' North. Its surface area is 177.1 Km^2 for a population of 646,827 inhabitants (ANSD, 2013). The area crosses nine communes, from Cambérène to Sangalkam, via Golf sud, Sam Notaire, Ndiarème Limamoulaye, Wakhinane Nimzatt, Yeumbeul Nord, Malika, Tivaoune Peulh and Bambilor (**Figure 1**).

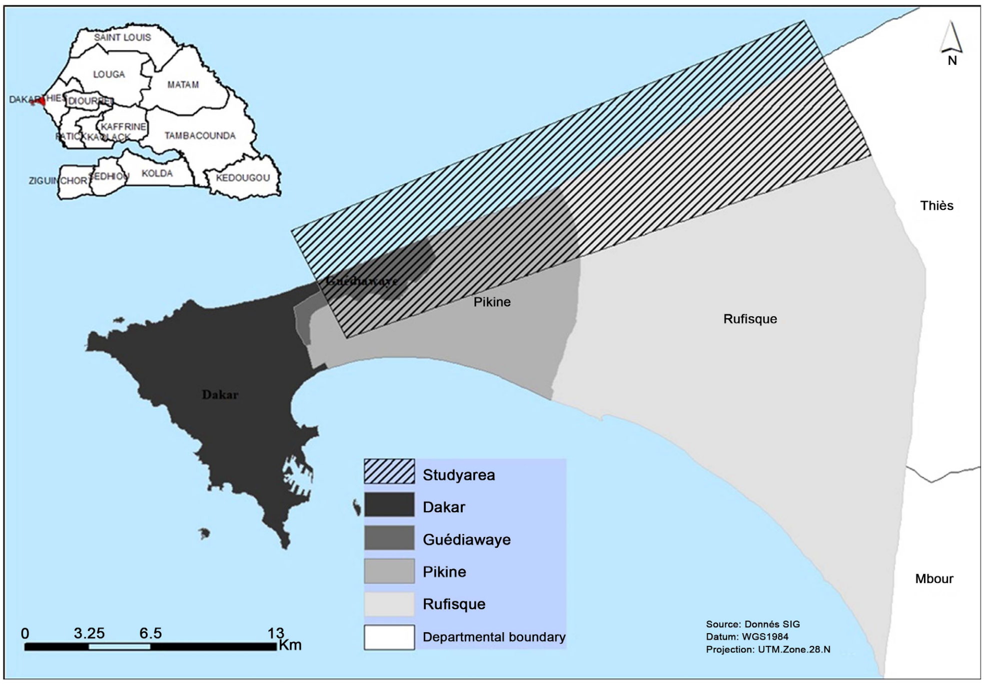

Figure 1. Location map of the study area.

3. Methodology

This study is essentially based on the processing of multispectral satellite images as well as on field observations.

3.1. Data Collection

Landsat satellite images from the Multi Spectral Scanner (MSS) for 1978, Thematic Mapper (TM) for 1990, ETM for 2006 and Operational Land Image (OLI-TIRS) for 2020 have been downloaded free of charge from https://earthexplorer.usgs.gov of the United States of Geological Survey. These data are acquired at the same time in September. This logic keeps the spectral signatures of different landscape units consistent, minimizing the effects of the atmosphere, differences in soil moisture and the difference due to variation in solar angle (Fabre, Briottet, & Lesaignoux, 2015). They are ideal for ecoregion studies as they integrate both biophysical and anthropogenic landscape attributes (Hounto et al., 2019).

Image pre-processing

Satellite image pre-processing is an important step in the study and detection of change using remote sensing. Its aim is to make multidate Landsat images compatible, i.e. images taken on different dates (Jofack, Kouamé, Dibi, & Tankoano, 2016). This operation also produces images that are more faithful to the reality on the ground. Performed in ENVI, it involved applying atmospheric and geometric corrections to Landsat images from 1978, 1990, 2006 and 2020. The images were geometrically corrected for distortions caused by the earth's rotation (Gibson, 2000). USGS (United States Geological Survey) provides Landsat images already orthorectified and corrected to the appropriate coordinate system (Ouatara, 2011). Nevertheless, we have made a further correction to the Landsat images to minimize the root mean square error (RMSE), which is generally below 1/2 pixel. They are then projected in the global WGS 1984, UTM, Zone 28N system. The images were radiometrically corrected. The detection and characterization of landscape evolution using multiple temporal satellite imagery requires atmospheric correction of the image to be used (Ouatara, 2011). These conversions provide a basis for standardized comparison of data in a single scene or between images acquired on different dates or by different captures (Chander et al., 2013). The image DN value was converted to radiance and then to spectral reflectance. The global contrast enhancement technique is applied to all Landsat image bands. This technique involves histogram dilation, by selecting two threshold values, Smin and Smax, which will be assigned to values 0 and 225 respectively when images are displayed on screen (Caloz & Collet, 2001). Several image enhancement and transformation techniques were applied to the extracted study area. These included band combinations, principal component analysis and ratio calculations. This led to the creation of new channels, notably PCA and NDVI. The latter allows changes in vegetation productivity to be used to detect changes in forest cover (Guo, Li, He, Xu, & Jin, 2018). Differences or changes in species types, the presence of disturbed vegetation in an area with a similar vegetation type, or even variations in limatic conditions, and the drivers of change can be reflected through NDVI (Yengoh, Dent, Olsson, Tengberg, & Tucker III, 2015). PCA allows us to synthesize a data set initially expressed by highly correlated variables into a reduced number of new "decorrelated" variables that express the maximum variance in the raw data (Carvalho & Gherardi, 2008).

These were used to obtain the best color compositions, facilitating good spectral discrimination of the major land-use classes.

3.2. Supervised Image Classification

Determining and understanding the different thematic classes of mangrove ecosystems on satellite images was made possible by field observations combined with those derived from the high-resolution (50 cm) Pleiade 2015 image and previous work. These observations enabled us to distinguish the different spectral signatures that characterize the study area when defining the training plots. Thus, the land-use units listed are the filao strip (closed and open strip), sand dunes, bare soil, herbaceous carpet, beach, farmland vegetation, dwellings and water surfaces. Based on the spectral characteristics of the land-use types identified, sample plots were selected, visited and validated in the field. This field mission, which coincided with the month in which the 2020 image was taken, enabled us to select training sites that were close enough to reality in the field to offer good supervised image classification. Thus, a supervised classification was applied to the different images. It relies on a priori knowledge of the terrain by the remote sensor, which identifies several areas on the image whose significance it knows (Ndao, 2012). Until recently, maximum likelihood classification was the most commonly used method for supervised classification of remote sensing data (Bhatta, 2008; Kumar et al., 2016). Moreover, this algorithm assumes that the training site statistics for each class follow a Gaussian distribution (Duminili, 2007).

The maximum likelihood classification of Landsat images for the year 2020 was first carried out on the basis of training sites collected during field campaigns, with reference to areas that remained stable between 1978 and 2020. The classification of images from 1990 and 2006 was also carried out.

3.3. Image Classification Validation

This was a very important step, enabling us to accurately confirm the information contained on the map. This verification is used to validate the classification result by calculating a confusion matrix (Antoine, 2014). The 2020 images were used as a reference to validate the classification of land-use units from the 1978, 1990, 2006 and 2020 images. On these images, a maximum number of training zones were sampled in different land-use classes. This enhances the "overall accuracy" of reference image classification (Idrissa et al., 2019). Four hundred and sixty (460) points evenly distributed over all the occupancy units resulting from the classification of the 2020 image were verified during a field campaign. Field validation provided a visual and qualitative assessment of the physiognomic characteristics of the different types of land use. This information on the state of land occupation and use was then used to validate the classification, and then to deduce the issues involved in the spatio-temporal dynamics of the land-use units in the study area. The confusion matrix was used to validate the supervised classification performed. Here are the Kappa tables from 1978 to 2020 (**Tables 1-4**).

Table 1. Confusion matrix of land use units in 1978.

Land use units	Water	Sand dune	Bare ground	Beach	Building	Natural woody vegetation	Closed filao strip	Open filao strip	Herbaceous carpet	Production Accuracy	Omission error
Water	98.54			13.67						95.32	1.46
Sand dune		22.33	0.62		8.88	3.58	5.20	6.31	2.97	17.69	77.67
Bare soil			99.37				5.20	3.60	0.27	85.38	0.63
Beach	1.46			54.54	0.99			0.90		92.76	45.46
Building			0.02		88.67	0.25			2.43	93.75	11.33
Natural woody vegetation		12.62				58.59	22.54	18.02	10.81	80.89	41.41
Closed filao strip		1.94				14.59	60.69		0.27	36.71	39.31
Open filao strip		0.97				2.97	4.62	8.11	0.54	20.45	91.89
Herbaceous carpet		2.91			1.48	20.02	1.73	9.01	82.70	62.83	17.30
User Accuracy	98.54	22.33	99.37	54.54	88.67	58.59	60.69	8.11	82.70		
Commission error	4.68	82.31	14.62	7.24	6.25	19.11	63.29	79.55	37.17		

Table 2. Confusion matrix of land use units in 1990.

Land use units	Water	Sand dune	Bare soil	Beach	Built	Vegetation	Preserved tape		Herbaceous carpet	Production Accuracy	Omission error
Water	93.61			17.26						74.14	6.39
Sand dune		68.85	3.95	13.10		0.52	0.19	26.79		19.09	31.15
Bare soil		4.10	90.88	5.50				0.77		74.94	9.12
Beach	6.39	3.28	0.30	64.09	4.24			0.51		87.84	35.91
Building		5.74	0.30		88.74		0.19	1.02		99.21	11.26
Natural woody vegetation		11.48				96.82	0.57	0.26		98.46	3.18
Closed filao strip						2.60	93.98	10.20		92.82	6.02
Open filao strip		6.56			6.46		5.07	60.46		55.63	39.54
Herbaceous carpet			4.56						100	98.81	00
User Accuracy	93.61	68.85	90.88	64.09	88.74	96.82	93.98	60.46	100		
Commission error	25.86	80.91	25.06	12.16	0.79	1.54	7.18	44.37	1.19		

Table 3. Confusion matrix of land use units in 2006.

Land use units	Water	Sand dune	Bare soil	Beach	Building	Natural woody vegetation	Closed filao strip	Open filao strip	Herbaceous carpet	Production Accuracy	Omission error
Water	99.72				0.58					99.79	0.28
Sand dune		57.55			0.06	15.25	0.94	16.35		16.90	42.45
Bare soil		7.55	99.83		39.29		0.70	3.17	0.37	78.80	0.17
Beach	0.07	1.89		97.45			0.47	1.97		97.57	2.55
Building	0.21	15.09		1.70	60.06				0.09	96.19	39.94
Natural woody vegetation		1.89				70.98	0.82	2.22		97.41	29.02
Closed filao strip				0.61		6.89	80.47	13.97		79.54	19.53
Open filao strip		13.21		0.24		6.72	16.61	62.22		62.03	37.78
Herbaceous carpet		2.83				0.16		0.16	99.54	99.27	0.46
User Accuracy	99.72	57.55	99.83	97.45	60.06	70.98	80.47	62.22	99.54		
Commission error	0.31	83.10	21.20	2.43	3.81	2.59	20.46	37.97	0.73		

Table 4. Confusion matrix of land use units in 2020.

Land use units	Water	Dune	Bare ground	Beach	Building	Natural woody vegetation	Closed filao strip	Open filao strip	Herbaceous carpet	Production Accuracy	Omission error
Water	100			1.37						99.85	00
Sand dune		50.96	8.93	7.10			2.21	12.14	1.34	67.50	41.04
Bare soil		1.93	91.07	5.46			0.55	0.77	1.34	80.10	8.93
Beach		4.05		86.07	1.14			0.39		90.78	19.93
Building		2.31			97.60		1.10	0.19		98.09	2.40
Natural woody vegetation		15.22			0.76	69.93	6.08	0.77		81.50	30.07
Closed filao strip		1.16			0.51	0.68	61.33	16.96		51.63	38.67
Open filao strip		16.18				14.36	27.07	65.70		60.57	34.30
Herbaceous carpet		0.19				8.95	1.6	3.08	97.32	74.91	2.68
User Accuracy	100	50.96	91.07	86.07	97.60	69.93	61.33	65.70	97.32		
Commission error	0.15	32.45	19.92	9.22	1.91	18.50	48.37	39.43	25.09		

This matrix is obtained by comparing classification data with field verification data (reference data), which must be different from those used for classification. The estimated quality of the classification is indicated by the kappa coefficient, which varies from 0 to 1. Overall, classifications are judged to be excellent, with Kappa values above 0.90 everywhere (see Kappa tables above).

3.4. Calculating the Dynamics of Land-Use Units

This calculation shows the evolution of land-use units between the dates 1978-1990, 1990-2006, 2006-2020 and 1978-2020. So, for understanding the evolution of each land-use unit over time and space, we used a series of ensemblistic transformations (the ensemblistic method of economist Fréderic Poulon). The relationship between the same class at two different dates allows us to extract the <<stable>> areas of <<regression>> and <<progression>> of that class. Thus, to map the transformations that have taken place in the filao strip, we used the equation proposed by: $\Delta U = U2 - U1$.

Let U1 be the set of pixels at date 1, U2 the set of pixels at date 2 and ΔU the variation of one pixel of any land-use unit between dates U1 and U2.

$\Delta U = 0$, reflects steady state (no change);

$\Delta U < 0$, indicates regression (decrease, loss… etc.);

$\Delta U > 0$, reflects progression (extension, gain… etc.).

3.5. Factors in Land Use Dynamics

To identify the factors influencing land-use dynamics, we used a bibliography on the aforementioned area and, above all, field data collected through structured and semi-structured individual interviews with resource persons. These surveys revealed that the main factors are man-made, notably anarchic urbanization, lack of vigorous enforcement of legislation, extraction of sand dunes by carters, cutting of filao stumps and garbage dumps. The natural factors are linked to the intrinsic characteristics of the filao (ageing of the filao with dieback of some of its plants, difficulty of natural regeneration) and to the physico-chemical conditions of the environment, particularly the water deficit from 1968 to 1993, sea spray and topography.

4. Results

The mapping results are shown in **Table 5**. Nine classes were identified according to land use and land cover within the reforestation perimeter. The results highlighted concern the surface areas of the different land-use classes over the 1978-2020 period.

Table 5. Land use dynamics between 1978 and 2020.

Land use units	Area (ha)		Area (ha)		Area (ha)		Area (ha)	
	1978		1990		2006		2020	
	Hectares	%	Hectares	%	Hectares	%	Hectares	%
Closed filao strip	257.5	1.2	379.8	1.8	403.8	1.9	215.9	1
Open filao strip	9.8	0.05	340.5	1.6	428.9	2.1	439.9	2.1
Building	474.5	2.3	1132.5	5.5	1689.7	8.2	2701	13.1
Sand dune	5075.3	24.5	2391.2	11.6	2028.5	9.8	1884.4	9.1

Continued

Water	7271.3	35.2	8499.6	41.1	8477.2	40.1	8461.7	41
Beach	745.2	3.6	441.2	2.13	446.8	2.2	609.7	3
Bare soil	3117.4	15.1	1913.2	9.2	2912.5	14.1	2116.6	10.2
Herbaceous carpet	3060.3	14.8	4209.3	20.3	3384.4	16.4	1836	8.9
Natural woody vegetation	667.3	3.2	1370.8	6.6	907.3	4.4	2413.7	11.7
Total	**20678.3**	**100**	**20678.1**	**100**	**20679.1**	**100**	**20678.9**	**100**

4.1. Analysis of Land Use Unit Dynamics from 1978 to 2020

All ecosystems undergo mutations from one year to the next. But these are exacerbated by natural and man-made changes that can lead to large-scale phenomena that can be irreversible. The evolution of the surface areas occupied by the various biotope units of the filao strip is manifested by an increase, a decrease or a stable state of the portion of the surface area occupied by the biotopes. We have thus identified nine land-use units: Closed filao strip, Open filao strip, Building, Sand dune, Water, Beach, Bare soil, Herbaceous carpet and Natural woody vegetation over a total area of 20,678 ha (Figure 2, Figure 3). Depending on the interest and objectives of the study, we have restricted the nine units into five, namely the closed and open filao strip, the sand and beach dunes and the built-up area (Figure 5).

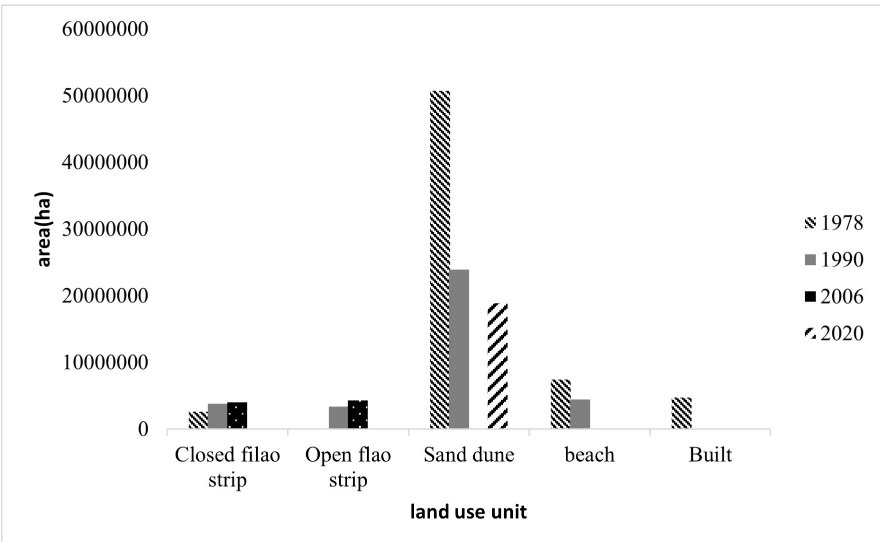

Figure 2. Evolution of land use units between 1978 and 2020 on the coast north of Dakar.

4.2. Analysis of Closed Filao Strip Dynamics

The evolution of the closed filao strip is characterized, on the one hand, by an extension between the periods 1978-1990 and 1990-2006 and, on the other hand, by a retreat between 2006 and 2020. The area expanded by 47.5% (122 ha) between 1978 and 1990, and by 6% (24 ha) between 1990 and 2006. This increase can be

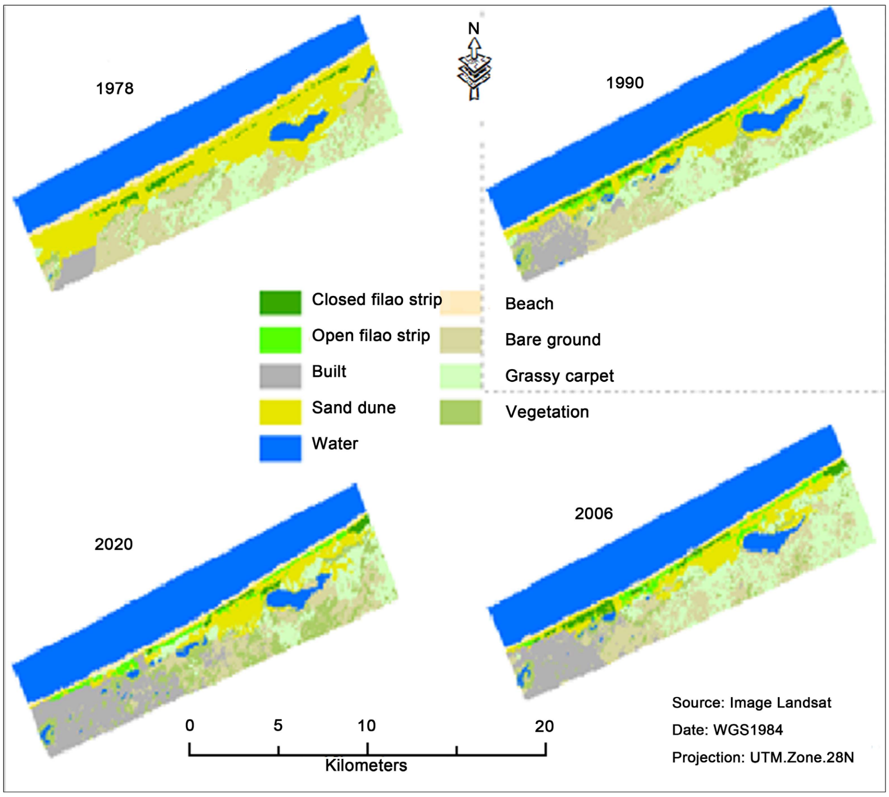

Figure 3. Dynamics of land use from 1978 to 2020.

explained by the reforestation activities undertaken by the forestry service in 1981 on new areas with the "PL 480" project financed by USAID and which continued until 1986 in the south of the Great Coast, as well as the Conservation des terroirs du Littoral (CTL) activities begun in 1988 and financed by the Canadian International Development Agency (CIDA). However, the trend is downward by 46.5% (187.9 ha) due to human activities such as urbanization, lack of vigorous enforcement of legislation, illegal filao logging and others.

4.3. Analysis of Open Filao Strip Dynamics

The natural degradation factors of the open filao strip are ageing, rainfall deficit and sea spray (Figure 4). Its dynamics are marked by an upward trend between 1978-2020. Indeed, the increase in the area of open filao strip is estimated at 94.4% (330.6 ha) between 1978-1990, 26% (88.2 ha) between 1990-2006 and 2.6% (11.2 ha) between 2006-2020. The main cause of the degradation of these filaos is due to the intrinsic characteristics of the filao on the one hand (difficulty of natural regeneration, dieback of certain plants) and on the other hand to the physicochemical characteristics of the environment, notably water deficit, salinity and topography. From 1968 to 1993, rainfall fell by 20 to 25%, coinciding with the long Sahelian drought, during which annual rainfall trends in Dakar were irregular, especially in the 1978-1987 decade. These deficits are bound to have a negative impact on groundwater recharge and, by the same token, on the filaos trees, which cannot withstand a severe drop in the water table (below 3 m). Physiography also seems to have an influence on the decline of filao plantations: trees behave differently depending on whether they are located on depressions, ridges, slopes or flat land. Low mortality classes are more represented on depressions, while high mortality classes are represented on flat terrain. On ridges, mortality is higher the closer the observations are to the ocean.

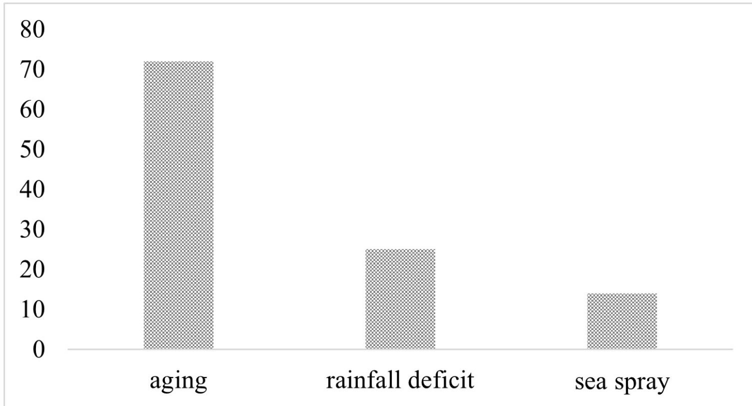

Figure 4. Natural factors of degradation of open casuarina strip.

In addition, the extension of the open filao strip is particularly dependent on anthropogenic factors (rampant and anarchic urbanization, lack of vigorous enforcement of legislation, sand extraction, illegal filao cutting and garbage dumps) which permanently shrink its surface area (**Figure 5**).

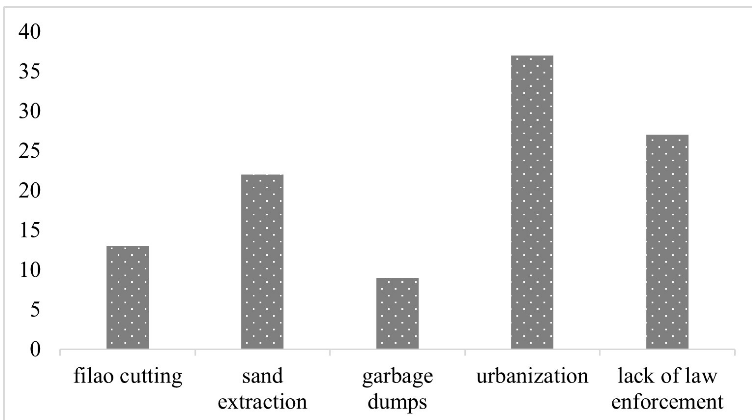

Figure 5. Anthropogenic factors of degradation of the casuarina strip.

Similarly, this regressive evolution of the open filao strip is also linked to the excessive downgrading in this strip. Thus, with decree N˚1738 of September 11, 2018. Union of Magistrates of Senegal has been granted a 4-hectare plot of land to build an administrative building in the municipality in Wakhinane Nimzatt, a 12-hectare plot of land within the reforestation perimeter was declassified for the construction of Muslim (8 ha) and Christian (4 ha) cemeteries. The cooperation of land registry agents has also been granted a 5-hectare plot of land on May 20, 2021, as has the tax union, which has been granted a 4-hectare area at Golf Sud, 4 ha at Wakhinane and 6 ha at Gadaye, without the site being declassified. Two weeks later, decree no. 2021-701 of June 4, 2021 declassified the 150.58-hectare zone as part of the Guédiawaye department's detailed urban development plan. In the department of Pikine, 23 ha 99a 95ca were declassified by the municipality of Yeumbeul Nord, 37 ha for the resettlement of people affected by the VDN3 and Bus Rapid Transit (BRT0) and 45 ha for the Layenne family. Not far from the Gadaye traffic circle, 9 ha have been declassified and dedicated to a contractor for the construction of an Demba Ka company (EDK) station, not forgetting the 8 ha warehouse of a major Chinese construction subsidiary, China Road and Bridge Corporation (CRBC). It is in charge of the Bus Rapid Transit (BRT) project. According to our investigations, its current location will host a station for this government project. Abusive cutting of filao trees reveals the pressure on these stands (**Figure 6**).

Figure 6. Cut casuarina strains.

4.4. Analysis of the Dynamics of Sand Dunes

Sand dune dynamics show a downward trend from 1978 to 2020. Indeed, the reduction in sand dune area is estimated at 112.2% (2684.1 ha) between 1978-1990, 17.8% (362.7 ha) between 1990-2006 and 7.1% (144.1 ha) between 2006-2020. This downward trend is closely linked to sand dune extraction at the Yoff-Cambérène quarry (1945) and the Mbeubeuss quarry (1985), but above all by carters who continue to extract sand at night and discreetly (**Figure 7**).

Figure 7. Extraction from the sand quarry in the casuarina strip of Guédiawaye.

4.5. Beach Dynamics Analysis

The evolution of the beach is characterized, on the one hand, by a decrease between the period 1978-1990 and, on the other hand, by an extension between the periods 1990-2006 and 2006 and 2020. In fact, the decline was 68.9% (304.1 ha) between 1978-1990, while the increase was 1.29% (5.7 ha) between 1990-2006 and 36.4% (162.9 ha) between 2006-2020. This decline from 1978 to 1990 is linked in particular to the extraction of beach sand and sand dunes at Yoff-Cambérène (1945) and Mbeubeuss (1985). In fact, 1978 statistics from the Regional Mining Department show 200 truck movements per day, loaded with an average of 5 to 6 m^3, i.e. an estimated borrowing of over 1000 m^3/day. An estimate of the volume of sand borrowed from the new Yoff quarry on January 10, 1980, showed that over 375,000 m^3 had been extracted in 10 months. This decline is also due to anthropogenic activities that aggravate the sediment deficit on beaches, such as sand dune extraction and beach construction. At Mbeubeuss, 305,150 m^3 of sand was extracted in 1996, 328,330 m^3 in 1997 and 234,510 m^3 in 1998. However, the upward trend is closely linked to the measures taken by the authorities to regulate activities on the coast, through the application of the Mining Code and the Forestry Code. Law n˚98/03 of January 08 1998 and decree n˚98/164 of February 20 1998 clearly regulate mining, including sand extraction. It is the application of this law that has made it possible to curb the abusive exploitation of sea sand in unsuitable locations, and also the fact that people are using less and less beach sand for their constructions.

4.6. Building Dynamics Analysis

Between 1990 and 2020, the built-up area underwent uncontrolled expansion. It was 50% (557.2 ha) between 1990-2006 and 59.9% (1011.3 ha) between 2006-2020. This increase is due to the galloping urbanization that began in the 1970s and has been taking on worrying proportions since 1990. After an initial test phase with Hamo 4, 5 and 6 in 1986, this phenomenon became more pronounced in the 1990s, when a number of companies and institutions decided to house their employees there. As a result, SONES, SENELEC, SOFRACO, DOUANES, COMICO, Supreme Courst, Presidence, housing estates for municipal employees, Cité Air Afrique, Cité Gadaye 2005 and "Lotissements Baba Thiam" 2003 were built. Construction, particularly along the coastline, is causing the filao strip to narrow. This phenomenon is most visible between Golf Sud and Yeumbeul Nord, where the width of the strip, which was 200 m at the start of planting, is now only around 20 m. The trend is for it to become thinner as developers encroach on the reforestation and restoration perimeter for construction purposes (**Figure 8**). Similarly, infrastructures have been built on the reforestation perimeter, such as the sludge treatment plant at Tivaoune Peulh, the VDN3 road and the Chinese company CRBC, not to mention the human settlements on the living dunes near Lac Rose. Paradoxically, the increase in building activity is leading to a reduction in the surface area of this green cordon, which is in danger of disappearing under the helpless gaze of the local population.

Figure 8. Housing estates in Yeumbeul Nord.

5. Discussion

The evolution of land use in the filao strip of the Dakar region is marked by increased degradation in favor of built-up areas, which are taking on worrying proportions. As early as 1978, the filao strip and sand dunes were the dominant land-use classes, whereas in 2020, the filao strip has declined in area in favor of built-up areas. This could be explained by human pressure due to strong demographic growth and rampant, poorly planned urbanization. The results of this study concur with several works including those of (Dibi, N'Guessan, Wajda, & Affian, 2008) in the Marahoué National Park in Côte d'Ivoire, (Bamba, 2010) in the Province Orientale and Bas Congo in the Democratic Republic of the Congo, (Marega et al., 2021) in Gabon in Akanda and Mayumba National Park, (Alohou, Ouinsavi, & Sokpon, 2016) and (Mama, Bamba, Sinsin, Bogaert, & De Cannière, 2014) respectively in the classified forest-sacred forest block in southern Benin and in the Sudano-Guinean zone of Benin. (Ndao, 2012) in the Niayes area of Dakar obtained similar results. The same is true of (Kyale Koy et al., 2019) in the Yangambi Biosphere Reserve in the Democratic Republic of Congo. In these areas, the evolution of vegetation cover and the changes observed are often linked to human pressure, both rural and urban, in the form of population growth and agricultural activities. In most West African countries, agricultural activities and urbanization are often the cause of changes to natural landscapes, leading to the fragmentation of savannahs, open forests, wetlands and dense forests (Ariori & Ozer, 2005). In Senegal, agricultural land has gained ground on the wooded savannahs and open forests of central and southern Senegal (Tappan, Sall, Wood, & Cushing, 2004). In our study area, the dynamics of building are at the heart of deforestation. In fact, the extension of the 430 ha open filao strip is dependent on anthropogenic factors that are permanently shrinking its surface area. On the other hand, the 1568.5 ha increase in built-up area is attributable to the poorly controlled urbanization that began in the 1970s. Indeed, 50 years ago, Dakar was a triangular peninsula surrounded by swamps and vegetation, which earned it the name "Cape Verde". Natural vegetation used to dominate the surrounding area, whereas today it's built-up areas that dominate, and this has been the case since the great drought the Sahel experienced in the 1970s. Drought, deteriorating terms of trade, liberalization and the opening up of the domestic market as part of structural adjustment policies all contributed to the weakening of producers, who could no longer face up to international competition. In fact, the only recourse for these social strata, especially the younger ones, was the rural exodus to the capital, especially to the Pikine-Guédiawaye suburbs. To cope with this migratory flow and the displacements from Dakar, neighborhoods such as Limamoulaye 1973, Fith Math 1976 and Golf-Sud 1979 were created, as was the construction of certain neighborhoods on the Cambérène dunes. After an initial test phase with Hamo 4, 5 and 6 in 1986, this phenomenon gained momentum in the 1990s when a number of companies and institutions decided to house their employees there. This is how SONES, SENELEC, SOFRACO, DOUANES, COMICO, Cours Suprême, Présidence, housing estates for municipal employees, Cité Air Afrique, Cité Gadaye 2005 and "Lotissements Baba Thiam" 2003 came into being (Diop, 2004). Buildings, particularly along the coastline, have contributed to the narrowing of the strip of filao. This phenomenon is most visible between Golf Sud and Yeumbeul Nord, where the width of the strip, which was 200 m at the start of planting, is now only around 20 meters. The thinning trend is the result of developers encroaching on the reforestation perimeter for construction purposes. Infrastructure has also been built on the reforestation perimeter, including the sludge treatment plant at Tivaoune Peulh, the VDN3 road and the Chinese company CRBC, not to mention the human settlements on the sand dunes near Lac Rose. The increase in building activity is leading to a reduction in the surface area of this green belt, which is in danger of disappearing under the helpless gaze of the local population. In addition to human activities, natural factors also seem to play a role in the degradation of the filao strip. Thus, the increase in the area of open filao strip is also due to the intrinsic characteristics of filao on the one hand (difficulty of natural regeneration) and on the other hand to the physico-chemical characteristics of the environment, notably water deficit, salinity and topography. Indeed, rainfall variability over the last three decades in Africa's western and central sub-regions has shown a downward trend in rainfall since the 1970s and 1980s (Batchi Mav, Ngouala Mabonzo, & Massouangui Kifouala, 2023). This corroborates the reality of rainfall in Dakar, where we record a 33.5% decrease, equivalent to a fall of 189.3 mm since the 1970s compared with the 1921-1969 average of 565.3 mm (Ndiaye et al., 2024). However, with a few exceptions, the years prior to 1970 saw rainfall in excess of 500 mm. It was from this date onwards that extreme climatic phenomena, especially very high rainfall deficits (Descroix et al., 2015) began, before becoming more pronounced thereafter. These deficits undoubtedly have a negative impact on groundwater recharge and, at the same time, on filaos trees, which cannot withstand a severe drop in the water table (below 3 m). Similarly, although filao is a species that thrives in salty conditions (proximity to the sea, spray), experiments carried out to assess the germination capacity of seeds subjected to salt stress have shown that the germination capacity of filao seeds falls with increasing salt content and is cancelled out at a concentration of 15 g/l NaCl (Tamba, 2004). Physiography also seems to have an influence on the decline of filao plantations: trees behave differently depending on whether they are located on depressions, ridges, slopes or flat land. Low mortality classes are more represented on depressions, while high mortality classes are represented on flat terrain. On ridges, mortality is higher the closer the observations are to the Atlantic Ocean. These results are in line with those of (Seck, 2015) as well as Sow, 2008 who states that in the Dakar filao strip, the major management constraints are rather anthropogenic. They range from unbridled land pressure to abusive cutting of filao trees and extraction of sea sand, which ultimately has a negative impact on filaos. Between 1955 and 2003, the strip shrank from 3876 ha to 1823 ha, a reduction of 53%. This degradation is more pronounced between Golf Sud and Malika, where human densities and land pressure are very high. These results also concur with those of (Massaoudou et al., 2015) who, in their work on the characterization of woody stands in Faidherbia albida parks in central Niger, link these types of losses to man's action on his environment, and the (FAO, 2011), which elsewhere estimates the decline in forest cover at 3.7% in Niger.

6. Conclusion

A joint analysis of the dynamics and factors of land use in the filao strip showed significant changes in the landscape units between 1978 and 2020, due to the ageing of the filaos, the difficulty of regeneration, the physico-chemical conditions of the environment, uncontrolled urbanization, weak enforcement of legislation, sand dune extraction, garbage dumps and filao cutting. Generally speaking, there is a downward trend in the closed filao strip, the open filao strip and the sand dunes, and vice versa for the beach and built-up area classes. Thus, in the space of 42 years (1978-2020), almost the entire surface area of the filao strip in Guédiawaye and Pikine has been replaced by built-up areas where only traces of filao can be seen. In Cambérène (Dakar Department), the filao strip has completely disappeared, while in the Rufisque Department, degradation is less advanced. Added to this are the climatic constraints of the area, in particular the Sahelian drought that began in 1968, resulting in low groundwater recharge and salinization of the land. These water stresses, combined with the senescence of certain filaos, are responsible for the decline of many filao trees. Added to these factors is the State's lax application of the legislation (environmental, forestry and mining codes) governing Senegal's coastline. Real estate developers encroach on the reforestation perimeter with complete freedom, as they hold authorizations from the relevant departments, carters continue to extract sand day and night, and local residents dump their garbage as if they were in Mbeubeuss. At this rate, this strip of filao is in danger of disappearing forever, with disastrous consequences such as the silting up of market gardening basins, habitats and infrastructures, not to mention the 17,500 market gardeners who risk sinking into unbearable insecurity and anguish.

Following the many problems identified in our study, we propose a few recommendations for better sustainable management of the reforestation area. This involves increasing the number of forest rangers and equipping them with the means to move around the different forest sectors to better monitor the strip. We also see an urgent need to set up forestry brigades within the filao strip, with forestry officers on permanent guard duty, to apply vigorously the legislation governing the filao strip and to coordinate the various interventions in the filao strip.

Conflicts of Interest

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

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