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Research Article

Impacts of spatiotemporal land-use change on agricultural land and ecosystem services in the Aga-Foua-Djilas watershed (Senegal), from 1994 to 2023

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Abstract

Strong demographic growth, rapid urbanization and the expansion of agro-industrial investment are contributing to the amplification of land use dynamics. This situation modifies territorial balances and compromises the sustainability of agricultural land and ecosystem services offered to populations. This study of the Aga-Foua-Djilas watershed analyzed the impact of spatiotemporal changes in land use on agricultural land and ecosystem services from 1994 to 2023. Based on Landsat satellite images, a supervised classification using the Maximum Likelihood algorithm was carried out with ENVI 4.7 software. Focus group interviews were conducted with local populations to identify the ecosystem services offered. The six land-use classes identified were agribusiness, built-up areas, water, bare soil, vegetation and agricultural land. Agribusiness, which first appeared in 2013 (478.9 ha), expanded considerably in 2023, encroaching on bare soil, vegetation and farmland. The built-up area increased from 2.2% in 1994 to 8% in 2023, also at the expense of farmland and vegetation. The latter, which dominated until 2002, fell sharply to 21.7% in 2013, but expanded to over 5,800 ha by 2023, reclaiming previously bare soil. Agricultural land increased between 1994 (4,566.3 ha) and 2013 (8,923.9 ha) due to population growth, but decreased in 2023 due to the expansion of agribusiness and urbanization. These changes affect ecosystem services, vital to local communities, including provisioning, supporting and regulating services. However, the reduction in vegetation and agricultural land is diminishing these services, while the population continues to grow. These results underline the vulnerability of the Aga-Foua-Djilas basin and the need to find sustainable solutions for preserving agricultural land and ecosystem services.

1. Introduction

Human and physical environments are strongly impacted by land cover, which is a fundamental variable for regional planning [1]. Today, with the development of remote sensing, which has become an essential tool in environmental management, spatiotemporal monitoring of natural resources has become easier and more controlled [2]. Remote sensing can be used to create databases on the state and evolution of natural resources [3]. Among these resources, agricultural land is the primary production factor for the subsistence of populations, particularly in rural areas, as is the case in the Aga-Foua-Djilas

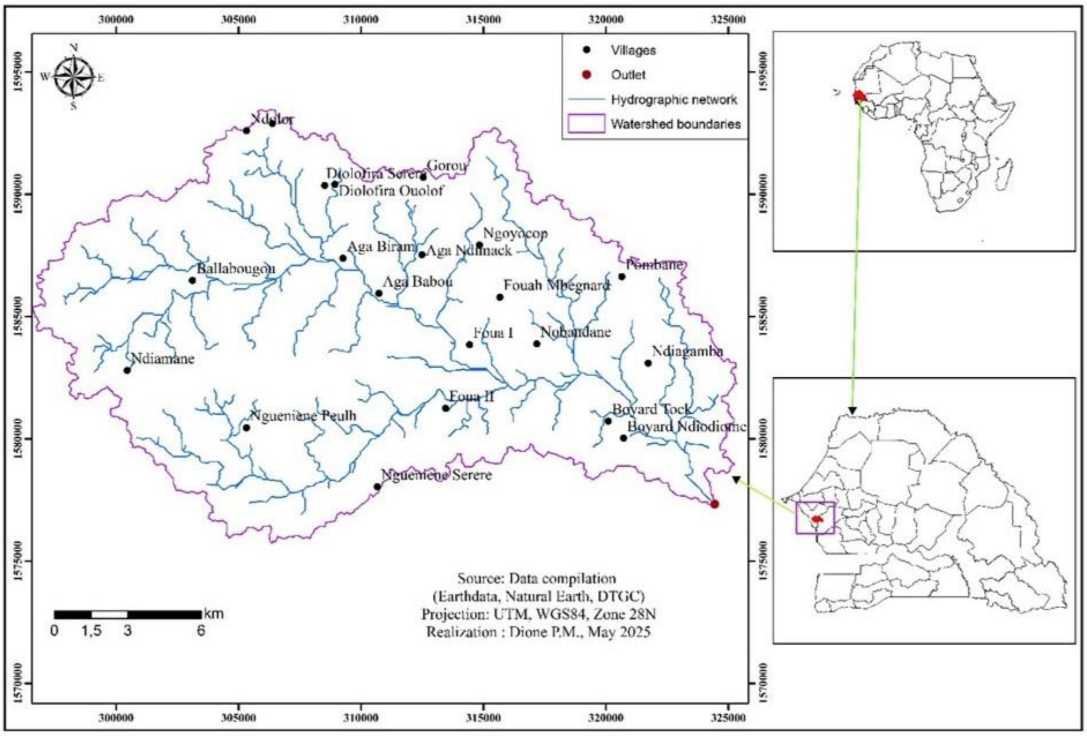

Figure 1. Study areas.

catchment. Land resources contribute to most of the economic and food production of the population [4]. It faces a great deal of competition, particularly old and traditional competition linked to subsistence needs, such as agriculture, livestock farming and forestry. Urbanization with subdivisions being the primary factor in the transformation of farmland into urban areas in Senegal, is also concern [5]. Many agropastoral areas have been transformed into built-up areas or barren land for housing and road infrastructure. Agribusinesses also contribute to the conversion of agricultural land. This has led to a massive transfer of pastoral and family farmland to private investors [6]. In the face of strong demographic growth [7]. The reduction in croplands is a serious threat to food security and the survival of rural populations. As the Aga-Foua-Djilas basin is heavily farmed [7, 8], monitoring changes in land use, environmental change and, above all, farmland, would enable a better assessment of the capacity of the latter to meet ever-increasing food needs. Understanding these changes in land use makes it possible to meet the challenges posed by global change, and to assess the vulnerability, resilience and adaptability of social-environmental systems [9]. Rural development requires the protection of resources that are the basis of people's survival, in order to anticipate the challenges posed by strong demographic growth. The general objective of this study was to analyze the impact of spatiotemporal land use change on agricultural land and ecosystem services in the Aga-Foua-Djilas watershed from 1994 to 2023. The specific objectives of the study were (i) characterize the spatiotemporal evolution of the different land use units from 1994 to 2023, (ii) assess their impact on agricultural land during this period and (iii) the ecosystem services offered.

2. Materials and methods

2.1. Study area

Administratively, the Aga-Foua-Djilas catchment straddles the communes of Malicounda, Sandiara, Séssène and Nguéniène (Mbour department) and Tattaguine, Loul Séssène and Djilas (Fatick department). Geographically, it extends from 14°15' north latitude to 14°25' north latitude, and from 16°37' west longitude to 16°53' west longitude (Fig. 1). The basin has a surface area of 317.5 km² and a perimeter

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Table 1. Characteristics of the landsat images used.

Sensors	Acquisition date	Bands	Wavelengths in µm	Resolution
Landsat 5				
Sensors	**Acquisition date**	**Bands**	**Wavelengths in µm**	**Resolution**
		Band 1 blue	0,45 - 0,52	
		Band 2 green	0,52 - 0,60	
		Band 3 red	0,63 - 0,69	
		Band 4 Near infrared	0,77 - 0,90	30 m
		Band 5 Short-wave infrared - 1	1,55 - 1,75	
TM	04/04/1994	Band 7 Short-wave infrared - 2	2,09 - 2,35	
Landsat 7				
Sensors	**Acquisition date**	**Bands**	**Wavelengths in µm**	**Resolution**
		Band 1 blue	0,45 - 0,52	
		Band 2 green	0,52 - 0,60	
		Band 3 red	0,63 - 0,69	30 m
		Band 4 Near infrared	0,77 - 0,90	
		Band 5 Short-wave infrared - 1	1,55 - 1,75	
ETM+	18/04/2002	Band 7 Short-wave infrared - 2	2,09 - 2,35	
Landsat 8				
Sensors	**Acquisition date**	**Bands**	**Wavelengths in µm**	**Resolution**
		Band 2 blue	0,452 - 0,512	
		Band 3 green	0,533 - 0,590	
		Band 4 red	0,636 - 0,673	
		Band 5 Near infrared	0,851 - 0,879	30 m
OLI	26/03/2013	Band 6 Short-wave infrared - 1	1,566 - 1,651	
		Band 7 Short-wave infrared - 2	2,107 - 2,294	
		Band 2 blue	0,450 - 0,51	
		Band 3 green	0,53 - 0,59	
		Band 4 red	0,64 - 0,67	30 m
OLI 2	23/02/2023	Band 5 Near infrared	0,85 - 0,88	
		Band 6 Short-wave infrared - 1	1,57 - 1,65	
		Band 7 Short-wave infrared - 2	2,11 - 2,29	

The population in 2023 is estimated (the results of the village census are not yet available).

of 115.7 km. The Aga-Foua-Djilas is a sub-basin of the Sine Saloum and located in the northern and north-western part of the Sine Saloum delta.

2.2. Data used

Landsat imagery was used. This choice is justified by the fact that the data are free and available over a long period. Table 1 shows the characteristics of the images used. The images were acquired during the dry season, particularly between February and April, to highlight the different forms of land cover. Using images in the rainy season (June to September), would have led to confusion about the different forms of land cover, particularly vegetation. During the rainy season, cultivated land can be confused with vegetation, because it is covered by crops at this time.

2.3. Methodology

2.3.1. Image acquisition

The satellite images were downloaded from the https://earthexplorer.usgs.gov/platform. The work was carried out using the QGIS 3.26.3 software interface after installing the Semi-Automatic Classification Plugin extension to perform the following tasks.

Download products: This task enabled us to download all the spectral bands needed to study our theme. These include spectral bands from Landsat images

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from 1994, 2002, 2013 and 2023, covering the catchment area. The choice of year was based on the quality and availability of satellite images. The aim was to obtain a regular ten-year interval. However, given the absence of significant variations between specific target years, years with satellite images of better radiometric quality and less dense cloud cover were selected. The selected years offered more optimal and comparable observation conditions. Methodological quality was given priority over temporal regularity.

Pre-processing satellite images: Pre-processing satellite images enabled us to carry out the operations required before analyzing and extracting information from the images. These included radiometric and geometric correction operations. The radiometric corrections mainly involved converting the data so that they could accurately represent the reflected or emitted radiation measured by the sensor, while the geometric corrections were used to correct geometric distortions due to variations in the Earth-sensor geometry, and the transformation of the data into true coordinates (e.g. latitude and longitude) on the Earth's surface.

2.3.2. Image classification

This was used to identify the land cover units. Using the mid-infrared, near-infrared and red bands, we carried out a supervised classification using the Maximum Likelihood algorithm, in order to identify the land cover classes. This is a classification based on the statistical modeling of classes, where each pixel is assigned to the one with the highest probability of belonging, assuming a Gaussian distribution of spectral signatures [10]. The reliability of this approach relies on the quality of the training samples, which are generally collected via GPS (Global Positioning System) surveys or high-resolution images [11]. Its effectiveness can be enhanced by the integration of spectral indices, such as NDVI (Normalized Difference Vegetation Index) or textural variables, as well as post-processing based on spatial models [12]. However, in the face of spectral overlap between classes, MLC can encounter limitations, which motivates comparisons with other algorithms, such as Random Forest [13]. Performance is typically assessed using a confusion matrix, with overall accuracy rates frequently exceeding 85% [14].

The color composition carried out in the RGB channels enabled us to identify the following spatial feature classes: Agribusiness, Buildings, Water, Bare Soil, Farmland Vegetation. The software used to analyze and extract information from the images was Envi 4.7. However, there are Tannes classes at the basin outlet. These are associated with bare soil. As the reflectance obtained after the color composition between the two units was similar, the Maximum Likelihood algorithm could not differentiate between the two units. As a result, in the upstream zone, tannin units were identified, even though they corresponded to Bare Soils. To avoid any confusion, especially as the Tannes units are not as large, the class was associated with Bare Soils.

Google Earth and Google Maps were used to validate the classification. This enabled us to obtain more information about the area and check it whenever necessary.

After classification, post-classification operations were performed on the results to further refine the classification results to prepare the cartographic output.

2.3.3. Cartographic editing of data and detection of changes in land use

ArcMap 10.8 software was used for statistical calculations of the areas of land cover classes and their proportions. It was also used for the layout and formatting of maps.

ArcMap 10.8 also detects changes in land use and produces change matrices using the Arctoolbox extension. The study was carried out in two stages:

- Changes in land use were first identified using the Union function in the Analysis Tools' Overly. Each land cover unit was assigned a code. To observe the changes, we first entered the first year, which is the reference year. It was compared with the second year to observe the changes in land use. The layout of the codes assigned to each unit provides a clearer picture. Some units remain stable in certain areas, while others lose land to others. If we have the same code (e.g. 1.1), this

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Table 2. Land use class statistics between 1994 and 2023.

Years	1994	2002	2013	2023
Classes	Surface area (in ha)	Surface area (in ha)	Surface area (in ha)	Surface area (in ha)
Agribusiness			478,9	817,3
Building	684,4	763,1	2068	2528,7
Water		323,3	976,99	288,9
Bare floors	4796,3	5036,6	12415,3	10474,4
Agricultural land	4566,3	6821,9	8923,9	4940,3
Vegetation	21693,4	18795,6	6877,3	12690,8

means that the agrobusiness of that code is allocated, is stable and has not changed since its allocation. If we have two different digits (e.g. 6,5), two situations arise: one land use unit is declining to the benefit of another. The first number is 6, which corresponds to vegetation, indicates a decline in vegetation in favor of farmland, which has the code 5. In other words, farmland occupied areas that were colonized by vegetation in the previous year.

- The change matrices were then determined using Arctoolbox's Spatial Analyst Tools extension, using the Tabulate Area function in the Zonal section. A statistical table of losses and gains for the different land use units was then drawn up.

2.3.4. Valuation of ecosystem services

In order to assess the ecosystem services provided by the basin's resources, focus group interviews were conducted with local communities between October and December 2023. They focused on the activities carried out in different land-use classes, the functions of lowland wetlands and the impact of climate change on the ecosystem services provided by vegetation.

In the villages of the watershed, settlements are grouped into hamlets. Interviews were conducted by the hamlet. Heads of households, as the people in charge of production units, were targeted. They ranged in age from 30 to over 65 years. The hamlets ranged from 5 to 7 per village, and 2 were randomly selected from each.

3. Results

3.1. Changes in land use units

The land-use units in the Aga-Foua-Djilas catchment had different proportions and variable trends from 1994 to 2023. Their statistics are shown in Table 2 and Fig. 2. Fig. 3 shows their spatial distribution.

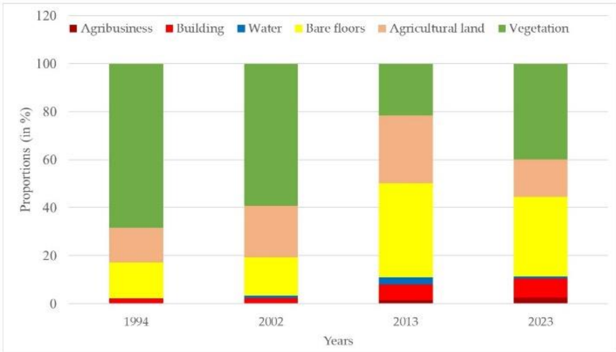

Figure 2. Proportions of land use units from 1994 to 2023.

1994:

During this year, built-up areas, bare soil and agricultural land were the only land-use classes present. Agricultural land is rainfed cropland farmed by families from June to September, which corresponds to the rainy season in Senegal. In the dry season, they are left to graze. Vegetation (consisting of trees and shrubs), with a surface area of 21693.4 ha or 68.3%, dominated the basin. It was more prevalent in the west around the villages of Nguénième Peul, Ballabougou and Ndiémane. It was followed by bare soil and farmland, which covered 15.1% and 14.4% of the surface area of the basin respectively. Built-up areas accounted for only 2.2% of the area, and were found in larger villages such as Nguénième (to the south), Boyard and Ndiagamba (to the east).

2002:

Although vegetation was still dominant in the basin in 2002, covering 59.2% of its area (18,795.6 ha), it declined by 13.4%. In contrast to the vegetation, agricultural land increased considerably, covering

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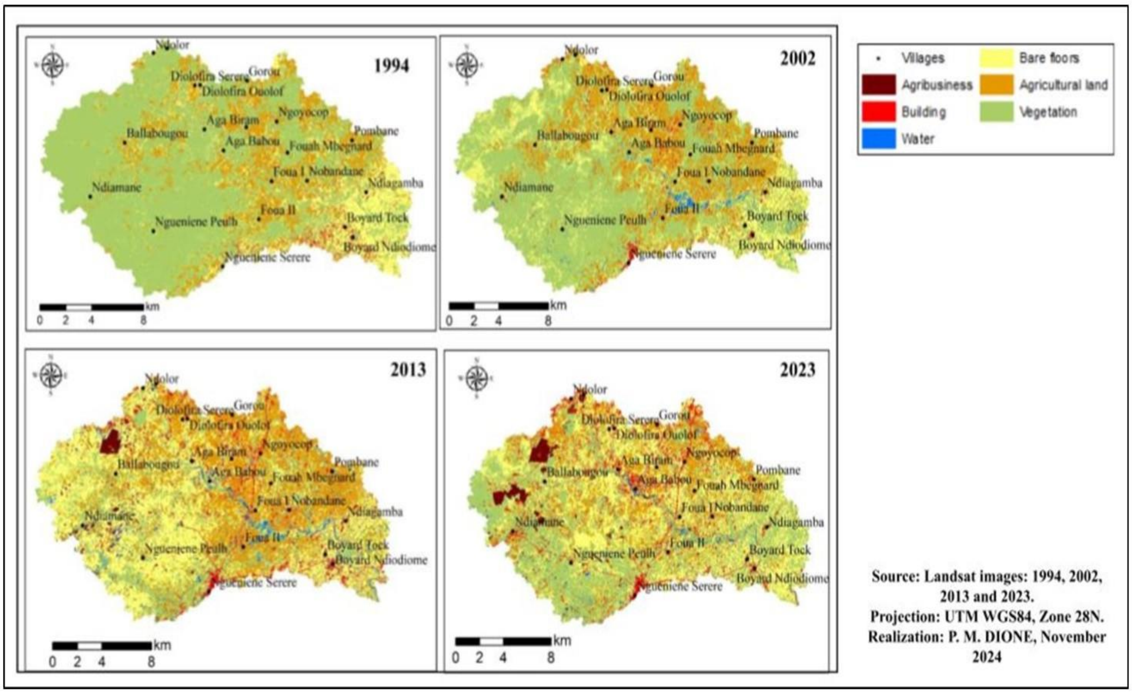

Figure 3. Land use classes in 1994, 2002, 2013 and 2023.

21.5% of the basin. It increased from 4,566.3 ha in 1994 to 6,821.9 ha in 2002, a growth rate of 49.4% (Table 3).

Table 3. Rate of change in land cover from 2002 to 2023.

Years	2002	2013	2023
Agribusiness			70,7
Building	11,5	171,0	22,3
Water		202,2	-70,4
Bare floors	5,0	146,5	-15,6
Agricultural land	49,4	30,8	-44,6
Vegetation	-13,4	-63,4	84,5

They expanded mainly in the centre, north and north-east, at a time when vegetation still dominated the west. Both built-up areas (2.4% of the basin) (still concentrated in the larger villages) and bare ground (15.9% of the basin) saw a slight increase of 11.5%, although their proportions remained relatively unchanged. The year 2002 was marked by the appearance of the water class, found along the main watercourse, but especially in the large depression between the villages of Foua 1 (south-west) and 2 (north-east) (Fig. 4).

2013:

It is marked by the development of a new activity, agribusiness, practiced over an area of 478.9 ha (1.5% of the basin) and in the West and North-West zones. These farms are mainly run by foreign, and national, private promoters [15]. One foreign promoter was the private Spanish company PRODUMEL, which operated in the vicinity of the villages of Ballabougou and Ndiémane. It was active in the cultivation of melons. There was also Beer Sheba, a company owned by a Frenchman and based between the west of Diolofira Sérère and the south of Ndolor. It operates in the field of agroforestry. As for the nationals, there was a national company Agence Nationale d'Insertion et de Développement Agricole (ANIDA) based south of Aga Babou, whose activities revolved around agropastoral and fodder farming. Other national but private promoters were also active in the basin. These agricultural promoters were based mainly in pastoral zone, rainfed cropland and some market garden areas [6]. Agribusiness is mainly carried out during the dry season. The differentiation of this facies from that of agricultural land is facilitated by the choice of satellite images (between February and April). In the dry season, the tillage marks of family farmland were still visible in the images, especially with the color composition combining the mid-infrared, near-

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	1994					
	Classes	Building	Bare floors	Agricultural land	Vegetation	Total
2002	Building	46,7	160,8	160,8	415,1	783,5
	Water	4,5	72,4	74,4	175,4	326,7
	Bare floors	198,5	1342,9	433,7	3076,7	5051,8
	Agricultural land	172,4	988,0	1811,2	3838,6	6810,2
	Vegetation	280,4	2253,0	2100,2	14142,1	18775,8
	Total	702,6	4817,1	4580,4	21647,9	31748,0

	2002						
	Classes	Building	Water	Bare floors	Agricultural land	Vegetation	Total
2013	Agrobusiness	34,7	25,1	96,5	7,5	308,6	472,4
	Building	297,0	2,0	340,7	450,8	974,0	2064,5
	Water	47,2	88,5	101,5	51,8	665,9	954,9
	Bare floors	115,6	21,6	2888,2	1264,5	8134,0	12423,9
	Agricultural land	119,6	9,5	1138,3	4320,0	3366,2	8953,7
	Vegetation	169,4	179,9	486,5	715,7	5327,2	6878,6
	Total	783,5	326,7	5051,8	6810,2	18775,8	31748,0

	Classes	Agrobussines	Building	Water	Bare floors	Agricultural land	Vegetation	Total
2023	Agrobussines	227,7	25,1	40,2	279,9	38,7	187,5	799,1
	Building	30,7	790,0	124,1	625,7	513,6	465,9	2550,0
	Water	10,1	36,2	72,9	60,8	12,1	108,6	300,5
	Bare floors	15,1	420,6	114,6	5171,9	3855,2	893,6	10470,9
	Agricultural land	27,6	179,4	53,8	1328,8	2867,1	467,9	4924,6
	Vegetation	161,3	613,1	549,3	4956,8	1667,0	4755,3	12702,8
	Total	472,4	2064,5	954,9	12423,9	8953,7	6878,6	31748,0

(green)	Earnings
(red)	Losses
(blue)	Unchanged

Figure 4. Land use change matrices

infrared and red bands. This same composition reveals the healthy vegetation (crops) of agribusiness at this time of year. In addition, knowledge of the terrain and the Google Earth and Google Map platforms enabled us to verify and validate the classifications. Furthermore, agribusiness land is fenced, unlike family farmland, which is open field. This development of agribusiness was at the root of numerous conflicts between herders' associations, the Nguéniène municipal council and the promoters who enjoy its trust [15]. The encroachment on pastoral areas considerably compromises the development of livestock farming and forces pastoralists to migrate.

Built-up areas (2,068 ha), water (976.99 ha), bare soil (1,415.3 ha) and farmland (8,923.9 ha) were continued to grow, accounted for 6.5%, 3.1%, 39.1% and 28.1%, respectively of the surface area of the basin, with respective growth rates of 171.0%, 202.2%, 146.5% and 30.8%. Bare land is becoming increasingly important, followed by farmland. Vegetation cover, which has been declining since 1994, has experienced a further decrease in surface area of 63.4%, but it remains fairly significant, accounting for 21.7%.

2023:

It's a year of nuances, as most land-use units did not maintain the same dynamics. Agribusiness was gaining ground, increased to 817.3 ha, a proportion of 2.6% with a growth rate of 70.7%. The same dynamic was maintained by the built-up area, which occupied 8% of the territory (2,528.7 ha), even the growth rate was (22.3%), compared to the previous period (2002-2013). This dynamic growth in the built-up area reflects urban development, especially in Nguéniène, and an increase in infrastructure, particularly in roads. On the other hand, the water, bare soil, and agricultural land classes have experienced declines of 70.4%, 15.6%, and 44.6%, respectively. These classes, whose surface areas have been steadily increasing since 2002, have lost considerable space to other units. Water lose observed 688.09 ha, bare soil 1940.9 ha and agricultural land 3983.6 ha. For the first time since 1994, the area covered by vegetation, rising from 6,877.3 ha in 2013 to 1,690.8 ha in 2023, i.e. 40% of the basin area. The considerable increase in the space of 10 years (84.5%) can be explained by several factors, including the retreat of bare soil, the reforestation of halophilic species in the Boyard valley by local people,

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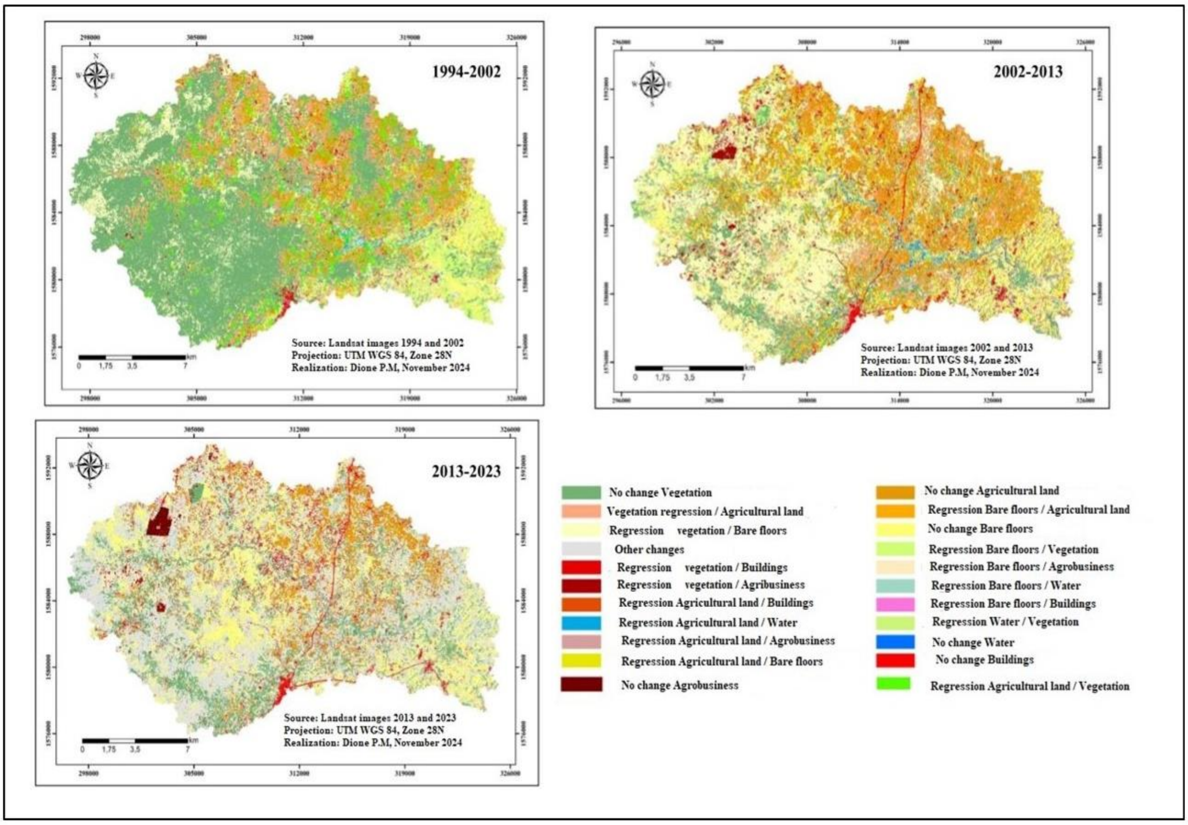

Figure 5. Changes in land use from 1994 to 2023.

and the development of arboriculture along the river. Many market gardeners were grown trees as well as vegetables. Analysis of these data revealed complex trends in land use over time. This highlights the importance of monitoring and understanding changes in the catchment environment for more effective and sustainable spatial planning and rational use of resources.

3.2. Change in land use

The landscape of the Aga-Foua-Djilas catchment underwent dynamic land use changes between 1994 and 2023. Maps of land-use units, cross-referenced in pairs, were used to identify and geolocate:

- Fixed units that did not change, i.e. those that remained stable between the two dates;
- Units that have regressed in favor of others. These are conversions, which are the passage from one land use unit to another [2].

The matrix of changes determined from these cross-tabulations, was used to produce statistics showing the areas retained and those lost.

Fig. 5 shows the various changes in the basin space and time. Table 4 shows the gains and losses for each unit.

Between 1994 and 2002, vegetation suffered the greatest loss of all land cover units. Conversions were mainly to bare soil and agricultural lands. The extension of the latter took place mainly on agricultural land and soils, with more than 3,000 ha in each unit. The built-up area also extended over vegetation (415 ha), farmland (160.8 ha) and bare soil (160.8 ha).

From 2002 to 2013, the conversion of vegetation into other units was also much higher. The conversion to agricultural land (3,366.2 ha) and built-up area (974 ha) can be explained by strong demographic growth, which is accompanied by high demand for agricultural land and housing. In addition to the conversion of vegetation to farmland, 1138.3 ha of bare land were converted into cropland. The new agri-business unit has established itself mainly on vegetation and bare soil.

For the first time since 1994, more farmland was lost than gained. Conversions were to agri-business (38.7

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Table 4. Ecosystem services provided by the basin's resources.

Basin resources	Ecosystem services
	Horticultural and market garden production
Agribusiness	Agroforestry
	Fodder crops
Building	Accommodation,
	Socio-economic infrastructure
	Under-rain and irrigated crops (market gardening, rice growing)
	Climate control
	Domestic use (washing clothes and dishes)
Water	Livestock watering
	Fishing
	Climate control
	Pastures
	Sand for construction
Bare floors	Potential support for vegetation
	Land suitable for farming
	Groundwater recharge through infiltration
	Forestry (food, use of dead wood for cooking, construction for housing, manufacture of tools for economic activities)
	Pharmacopoeia
	Combating soil erosion
Vegetation	Carbon storage
	Production of oxygen
	Climate control
	Animal shelters offering food
	Food production
Agricultural land	Soil conservation,
	Vain pastures
	Sand for construction

ha), buildings (513.6 ha), water (12.1 ha), bare soil (3,855.2 ha) and vegetation (1,667 ha). In return, they extended more on bare soil (1328.8 ha) and vegetation. Unlike farmland, vegetation gained space, especially on farmland (1,667 ha) and bare soil (893.6 ha). Agribusiness also continues to expand, mainly on vegetation (187.5 ha), bare soil (279.9 ha), water (40.2 ha) and farmland (38.7 ha).

3.3. Changes in agricultural land in the catchment area

As agriculture is the main livelihood activity of the basin's populations, it is vital to analyze its development in order to improve the management of agricultural land and spatial planning prospects in the short, medium and long terms. This has facilitated decision-making, particularly in terms of food security, especially the availability or non-availability of agricultural land can have a considerable impact on the availability of local food resources.

Between 1994 and 2013, the area of farmland and its proportion of the total basin area increased considerably (Fig. 6). The area increased from 4,566.3 ha in 1994 to 8,923.9 ha in 2013, almost doubling (increasing by 4,357.6 ha) within 20 years. In contrast, agricultural land has declined drastically over the past 10 years. From 8923.9 ha in 2013, the basin's farmers found themselves with just 4940.3 ha in 2023, a decrease of 3983.6 ha. The area of farmland in 2023 was only 374 ha larger than that in 1994.

The development of agricultural land poses a serious problem in terms of access to resources and food security in the basin, where the population grown continuously. This strong demographic growth is

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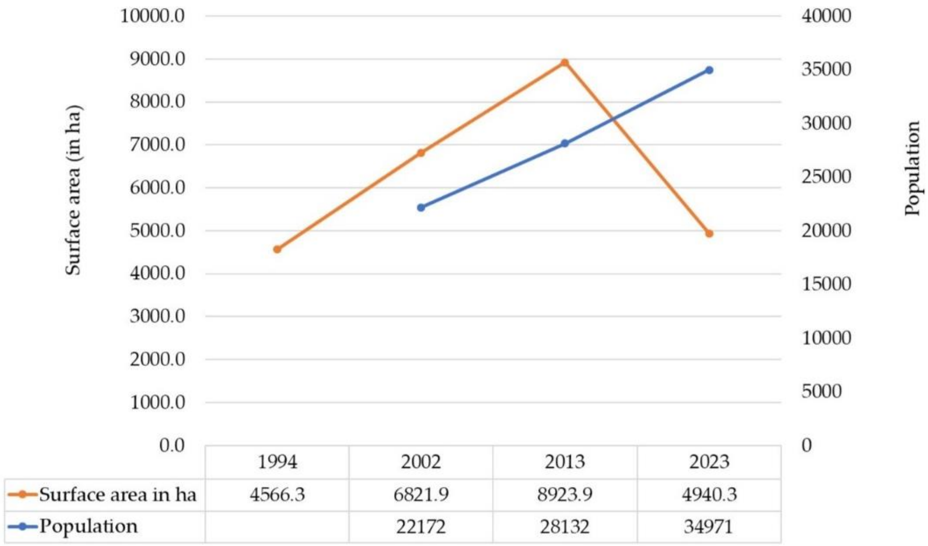

Figure 6: Changes in the area of agricultural land (1994 to 2023) and population (2002 to 2023).

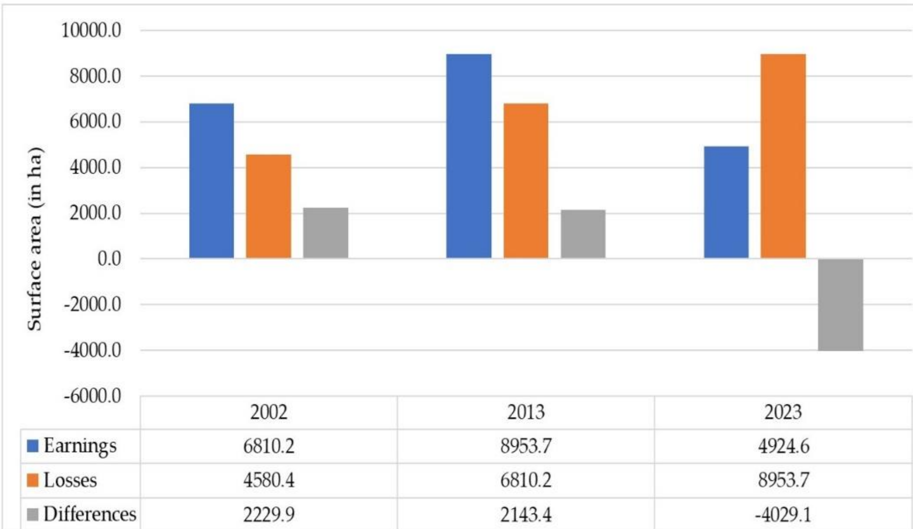

Figure 7. Gains and losses of agricultural land between 2002 and 2023.

accompanied by a growing demand for farmland. 99% of the basin's population practice agriculture as their main subsistence activity, and 81% of them believe that there is not enough land to grow crops.

Between the 2002 and 2013 censuses, the population of the basin rose from 22172 to 28132, an annual growth rate of 2.2% (interviews with local people). The results of the latest census in 2023 showed a general increase in Senegal's population. As these results were not available at the village level at the time, the population of the basin in 2023 is estimated at 34971 (https://resultats.ansd.sn). This shows that at the same time as the population is increasing, the "agricultural land" resource is decreasing, which is a worrying situation in a rural agropastoral environment.

Fig. 7 shows the gains and losses in agricultural land use. The gains are made up of newly cultivated land and land converted to agricultural use. Losses are lands that have been downgraded from agricultural status or lost.

In terms of land use change, agricultural land expanded more on other units than it converted to others between 1994 and 2013. It was not until 2023 that they lost as much area as they gained in the other units (Fig. 7).

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3.4. Ecosystem services in the catchment area

The different land-use classes identified in the Aga-Foua-Djilas catchment attest to its wealth of natural resources. These play a fundamental role in the survival of the local population, and are highly prized. These are in fact, the ecosystem services of the basin. Table 4 highlights the different resources and ecosystem services they provide.

3.5. Functions of the catchment's lowlands

The lowlands are wetlands which in the basin, are filled with water for a large part of the year (from July to December, or even May for the large lowlands where retention basins are built). They have a number of functions, as shown in Table 5.

Table 5. Functions of wetlands in the basin.

Functions	Services
Economic values	Market gardening
	Grazing
	Rice
	Fishing
Cultural values	Support for totem poles and protective genies
	Ritual sites
Social values	Domestic use (washing clothes and dishes)
	Swimming
	Hunting
	Leisure
	Walks
Biological functions	Biodiversity reservoirs
	Carbon storage
	Climate control

3.6. Impacts of climate change on the ecosystem services provided by vegetation in the basin

The Aga-Foua-Djilas basin is mainly agricultural and is vulnerable to climate change. Local people have noted the impact of climate hazards on the basin's water supply, regulation and vegetation support services. It is as follows:

Supply services: Reduced access to food and dead wood due to the retreat of plant formations as a result of drought and abusive tree felling, scarcity of traditional medicines due to the disappearance of certain species, and disappearance of animal species.

For regulation services: A reduction in the amount of carbon storage, and an increase in microclimate temperatures.

For support services: Erosion of soil exposed to wind and rain.

4. Discussion

Mapping the evolution of land use in the Aga-Foua-Djilas catchment, particularly monitoring the evolution of agricultural land and analyzing the ecosystem services offered, is essential for decision-making on environmental management and the livelihoods of local populations. The use of Landsat satellite imagery provided an overview of the spatiotemporal evolution of the different classes identified, namely agribusiness, built-up areas, water, bare soil, farmland and vegetation. Interviews with local communities helped to identify the various services provided by the basin's resources.

In the space of just 30 years (29 years), different land use situations have been noted in the basin. Of all the classes identified, only the built-up area showed a steady upward trend. From less than 700 ha in 1994, this class increased to more than 2,500 ha by 2023. Agribusiness, which appeared in 2013, has seen its surface area almost doubled in the past 10 years. It increased from 478.9 ha in 2013 to 817.3 ha in 2023, an increase of 338.4 ha. In addition to changing the agricultural landscape, this new activity is causing multiple conflicts over land ownership, especially as it extends onto rainfed and pastoral farmlands. It also encourages the development of fenced fields [15], adjoining open field landscapes characterized by the absence of fences [6]. The development of farmland and vegetation exhibited irregular patterns. From 1994 to 2013, farmland increased before declining in 2023, whereas vegetation declined. Vegetation shrank from 1994 to 2013, before increasing in 2023. In addition, owing to the maps of changes in land use, the conversions with the losses and gains in surface area recorded by each unit and the stabilities, i.e. the classes whose cover has not changed from one year to the next, are identified.

This study, which is the first of its kind to be carried out in the Aga-Foua-Djilas basin, has some limitations

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related to classification errors. If, in a classification, the value of the kappa index is greater than 0.50, the results are considered good and usable [16, 17]. Nevertheless, confusion errors are noted.

At the basin outlet, the classification algorithm could not distinguish between the reflectance of tannins and that of bare soil. Therefore, the tans were included in the bare soil class. This part of the basin was affected by tans [18, 19]. The change matrices between 2013 and 2023 show a decline in built-up areas in favor of agribusiness and vegetation. In the first case, this was probably due to the reflectance of the pixels of the two units, which could not be distinguished by the classification algorithm. The areas where agribusinesses are expanding are mainly rain-fed croplands and pastoral areas that stand out from the dwelling. In the second case, vegetation grows around the dwellings. As the spatial resolution of the images was 30 m, dwellings with areas no larger than 900m² (30m x 30 m) are dominated by vegetation, which has a higher reflectance. However, these classification errors can be corrected by finer resolution images combined with site visits.

Agricultural land, the main resource for the survival of the basin's population, declined considerably in 2023. Analysis of this situation reveals that the most serious threats to the conversion of farmland are the development of agribusiness and built-up areas. Land-use planning with proper regulation of agribusiness practices and control of residential sprawl should be a priority for local authorities, especially in the context of environmental change and strong demographic growth in the region.

5. Conclusions

The supervised classification using the Maximum Likelihood algorithm carried out in this study, one of the objectives of which was to analyze the dynamics of land use change and the evolution of agricultural land in the Aga-Foua-Djilas basin from 1994 to 2023, made it possible to identify the different land use units and their long-term trends. Agribusiness, built-up areas, water, bare soil and farmland are the different units occupying the basin area.

The agri-business class appeared in 2013 and covered 478.9 ha in that year. In 2023, it increased considerably, gaining ground on bare soil, vegetation and farmland. Inhabited areas and areas with infrastructure, particularly roads, increased from 2.2% (684.4 ha) of the surface area of the basin in 1994 to 08% (2528.7 ha) in 2023. This expansion has mainly occurred in agricultural land and vegetation. These last two classes showed contrasting trends. Vegetation covered more than half of the basin in 1994 (68.3%) and 2002 (59.2%), although it declined in the intervening years. In 2013, however, it lost considerable ground, with a proportion of 21.7% (6,877.3 ha). In 2023, however, it covered more than 5,800 ha, previously occupied mainly by bare soil (4,956.8 ha). In contrast, agricultural land increased from 4,566.3 ha in 1994, when it represented 14.4% of the surface area of the basin, to 6,821.9 ha in 2002, and then to 8,923.9 ha in 2013. This increase, mainly due to strong demographic growth, which-led to an increase in the need for farmland, and curbed in 2023 by the development of agribusiness and the same demographic growth due to the increase in housing.

Another objective of this study was to analyze ecosystem services. Interviews with local people revealed various services. These include provisioning, supporting, and regulating services. Supply services include food production through agribusiness, farmland and vegetation. The degradation of the latter as a result of climate change and overexploitation exposes soils to water and wind erosion. This decline in vegetation and farmland when the population is steadily increasing. It is a wake-up call to the development players are working in the basin to put in place sustainable solutions, especially as the basin which is highly agricultural and vulnerable to the impacts of climate change.

These results highlight the need to preserve agricultural land and ecosystem services in the watershed. To this end, stakeholders must consider integrated watershed planning to control the expansion of agribusiness and built-up areas, and establish a participatory governance system for land resources. They must also promote sustainable agricultural practices and develop spatiotemporal

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land-use monitoring systems using GIS tools and remote sensing techniques.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Conceptualization, P.M.D.; methodology, P.M.D., M.S.; software, P.M.D., M.S.; validation, M.S., C.F.; formal analysis, P.M.D.; writing-preparation of the original draft, P.M.D.; writing-revision and editing, P.M.D., C.F., M. S.; supervision, C.F.

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Availability of data and materials

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Conflicts of interest

The authors declare no conflict of interest.

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