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# Vegetation dynamics and anthropogenic activities following the space management policies of Azagny National Park, southern Côte d'Ivoire

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## Abstract

Azagny National Park, with 21,850 hectares, is home to rich and varied biodiversity in very diverse habitats. This site has been subject to strong anthropogenic pressure which has disrupted its integrity. The present study is therefore initiated to analyse the dynamics of vegetation in the Azagny National Park area between 1987 and 2023. Landsat images from 1987, 2002 and 2023 served as the basis for this study. These images were coupled with field missions in order to determine the dynamics and history of anthropogenic activities, then land use maps were produced. This diachronic study shows that the Azagny National Park has experienced an improvement in its floristic cover, in connection with the decline in anthropogenic activities. Areas that were previously cultivated are transformed into falls. Some fallow land is converted to degraded forest, and degraded forest areas are converted to non-degraded forest. Overall, this is a positive development in the reconstitution of the plant cover. However, in the rural areas adjoining the park, the expansion of cash crops such as rubber and palm plantations is developing at the expense of the protected area. The importance of the functional management of particular ecosystems and the preservation of biodiversity invites the manager to raise awareness among local populations for ecological awareness. This will allow the practice of ecological agriculture guaranteeing the sustainable management of natural ecosystems.

**Keywords:** Environmental Management; Riparian Measures; Parks and Reserves; Remote Sensing; Vegetation

## 1. Introduction

In Ivory Coast, deforestation and the loss of natural habitats have become a national concern. The economic and social development of this country was based on agriculture that paid little attention to environmental conservation [1-4]. It is an extensive, anarchic, not very rational agriculture, which compensates for its weaknesses by the permanent conquest of new lands [5]. This results in deforestation exacerbated by abusive exploitation of forest resources without concern for natural regeneration, practiced by a rapidly growing population in perpetual search of arable land [6]. The regression of plant cover and the problems linked to the conservation of biodiversity in Côte d'Ivoire have already been documented [7-9]. The abusive exploitation of natural ecosystems has caused the fragmentation of the Ivorian forest into small units which still continue to be attacked by operators [10].

Faced with this situation, Côte d'Ivoire has put in place an institutional framework, legal and financial means for the conservation and sustainable use of biological diversity [11]. Protected areas are created with management programs involving local populations [12]. Among these protected areas is the Azagny National Park, which is an area of approximately 21,850 hectares. This space is home to floral and faunal potential. Despite the importance of the Azagny

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National Park, it is subject to strong anthropogenic pressures, particularly in its northern and western part. This degradation of the park led the forestry administration to declassify part of the park and subsequently establish a buffer zone. The local populations were authorized to freely practice their agricultural activities without creating new plantations. The Azagny National Park thus sees its surface area reduced to approximately 19,400 hectares. In 1986 the State decided to effectively implement the policy of eviction of populations within the buffer zone at the level of the Azagny National Park. The populations will leave in successive waves until 2002. Since 2002, there are no longer any infiltrated populations installed inside the park.

However, sustainable management of the park after eviction requires riparian measures as well as ecological monitoring of the park. These different aspects are poorly documented and do not present the levels of knowledge on the state of development of the contiguous rural area. Thus, with the aim of meeting the needs for riparian measures as well as ecological monitoring of the park, this work set itself the objectives of characterizing and analyzing the dynamics of the vegetation of the Azagny National Park area.

## 2. Material and methods

### 2.1. Study site

Azagny National Park is located between 5°09' and 5°30' North latitude and between 4°47' and 4°57' West longitude (Figure 1). From a Partial Wildlife Reserve in 1960, Azagny became a National Park in 1981 [13]. The development of agro-industrial activities encourages strong migration of populations from the Center of the country and non-natives from northern border countries. These populations also enter the park to establish plantations. It is subject to a subequatorial climate and the average annual rainfall is 1650 mm with an average annual temperature of 26 °C and an average relative humidity of approximately 85% [14]. The entire Azagny National Park is located in the rain-producing sector of the Guinean domain, characterized by dense evergreen humid forest. The vegetation of the Azagny National Park is characterized by a mosaic of very different plant formations, such as coastal savannahs, swamp formations, thickets, dense evergreen forests, secondary forests, coastal forests, mangrove forests and abandoned plantations [15]. On the outskirts, we observe the presence of oil palm plantations and rubber crops.

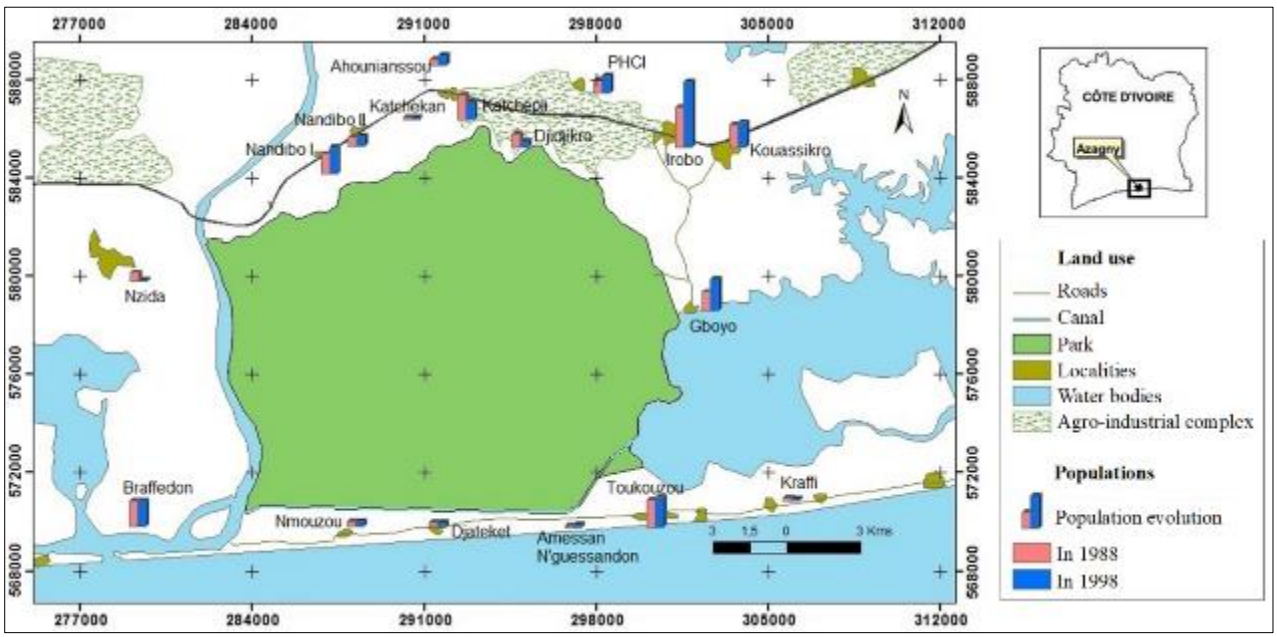


**Figure 1** Location of the Azagny National Park with some data from surrounding populations**.**

### 2.2. Data gathering

A Landsat 4 TM image from December 22, 1987 was downloaded and used to mark the start of the eviction process, then a Landsat 7 ETM image from December 31, 2002 to characterize the end of this eviction. The OLI image from April 21, 2023 made it possible to perceive the situation on the ground at the time of the study. All these images belong to scene 96-056 and were obtained from the link https://earthexplorer.usgs.gov/ . These images completely cover the Azagny National Park and the rural area adjoining the park.

Field surveys were carried out between December 2022 and December 2023 among local populations. The information collected was supplemented with bibliographic data on the Azagny National Park. This includes the history of the park, the movements and activities of populations around and within the park, and data on the flora and fauna of the park.

### 2.3. Data analysis

The study area was extracted from a vector file of the park. Then, a five-kilometer buffer zone was cut around the park to present the pressures linked to anthropogenic activities. Finally, the classifications were made separately between the park and the surrounding area to prevent too many classes from creating significant confusion. Atmospheric and radiometric corrections were made, then the geographic coordinates of the maps converted to UTM Zone 30N. An unsupervised classification was carried out from the 2023 image, then a field mission made it possible to validate the classification obtained. Comparisons were made with the classifications of images from 2002 and 1987. This technique made it possible to recognize types of vegetation or land cover on the images from 2002 and 1987 based on observations from the 2023 image.

However, not all spectral signatures could be identified by this technique. The identification of spectral signatures was completed with the assistance of the local population, park management agents, and then forest guides. These resource people made it possible to trace the history of anthropogenic activities in the area of the Azagny National Park. Sites of old plantations and camps inside the park were visited and the years of abandonment were documented. This information was supplemented by previous work on park mapping [16, 17].

The study of vegetation units preferentially requires the use of radiometric bands B5 in the mid-infrared, B4 in the near-infrared and B3 in the red [18]. Band 3 corresponds to the characteristic wavelength of chlorophyll absorption of green vegetation. It is one of the most important radiometric bands in the study of vegetation [19, 20]. Band 4 is sensitive to the quantity of biomass contained in the vegetation. It is therefore useful for identifying the different types of vegetation and for highlighting the radiometric differences between bare soils and agricultural areas, then between land and water areas [21]. Radiometric band 5 is sensitive to the quantity of water contained in plants. A colorful composition of strips 5-4-3 was made in red, green, blue for the creation of each card.

The different forms of land use were distinguished on the basis of image classes. Then, spaces of interest within the park as well as in the peripheral area were visited. These are primarily easily accessible sites such as trails, paths, near camps or roads. For the classification of images, the maximum likelihood algorithm was chosen because it is a powerful method in producing land cover maps [19, 21, 22]. It is used by many authors in vegetation studies in Côte d'Ivoire [18, 23-26]. Then, a 3X3 median filter was applied to the different images to homogenize the classes by eliminating isolated pixels.

Subsequently, a field investigation was carried out in order to recognize the different land uses following the different dates. Training areas were then identified for maximum likelihood classification. The field survey for the classification of the 2023 image thus made it possible to identify the spectral signatures of the different plant formations in the study area. These are the forms of vegetation inside the park, then the land uses around the park. For the classification of images from 2002 and 1987, in addition to spectral signatures, survey data made it possible to recognize image classes.

The validation of the classification was done based on the regions of interest identified in the field. These are natural formations, old plantation or cultivation sites. The classifications were verified with control plots other than those used for training. To evaluate the dynamics of the vegetation during the period of eviction, an estimation of the different surface areas of the land use types was necessary. Diachronic analyzes of changes were carried out with the vector of changes between 1987 and 2002, then, with the vector of changes between 1987 and 2023. Indeed, the study of diachronic evolution from satellite images consists of establishing a procedure for identifying the evolution of surface states at different dates [27, 28]. These analyzes make it possible to study the development of vegetation and to monitor dynamic phenomena such as deforestation and forest dieback [18]. The variations in radiometry between the different dates make it possible to assess the state of evolution of the plant cover [28, 29].

## 3. Results

### 3.1. Anthropogenic activities in the Azagny area

In 1987, there were already oil palm plantations with a processing unit. There were also coffee and cocoa plantations. Annual crops were sparsely grown and intended for domestic consumption. There were also forest relics in hydromorphic spaces. At the end of the eviction in 2002, there was a significant reduction in forest areas around the park. Agro-industrial cultivation areas have increased. These crops are made up of industrial plots of oil palm trees,

peasant plantations of cocoa and coffee trees. Observations carried out in 2023 show a significant regression in agro-industrial cultivation areas. Coffee and cocoa plantations have been abandoned. Annual crop areas and crop and fallow mosaics have increased.

### 3.2. Evolutionary trend in land use in 2023, in 2002 and in 1987

Classification performance has improved over time, with overall map accuracies increasing from 80.54% in 1987 to 84.74% in 2002 and 89.35% in 2023. The associated Kappa coefficients have also improved, passing from 0.81 in 1987 to 0.85 in 2002 and to 0.88 in 2023. However, despite these improvements, persistent confusions were observed between swamp forests, flooded forests and savannah-inclusive swamp forests across the board. maps of the different dates (Tables I, II and III). The various analyzes carried out indicate that forest formations constitute the majority of the park's vegetation. The general ecosystem of the park presents spaces that are temporarily or permanently flooded. Within degraded areas, we find fallow areas, old plantations which are still the subject of clandestine exploitation.

Thus, in 1987 (Figure 2), swampy areas covered 6389.25 hectares, or 29.2% of the interior landscape of the park, while degraded or secondary forests occupied 6058.23 hectares, equivalent to 27.7% of the park's interior landscape. area. In comparison, bare soil and cleared areas together accounted for an area of 599.31 hectares, or only 2.7% of the total area. However, in rural areas, agro-industrial crops and flooded forests were predominant, covering 9988.49 hectares (34.5%) and 9544.38 hectares (33%) respectively.

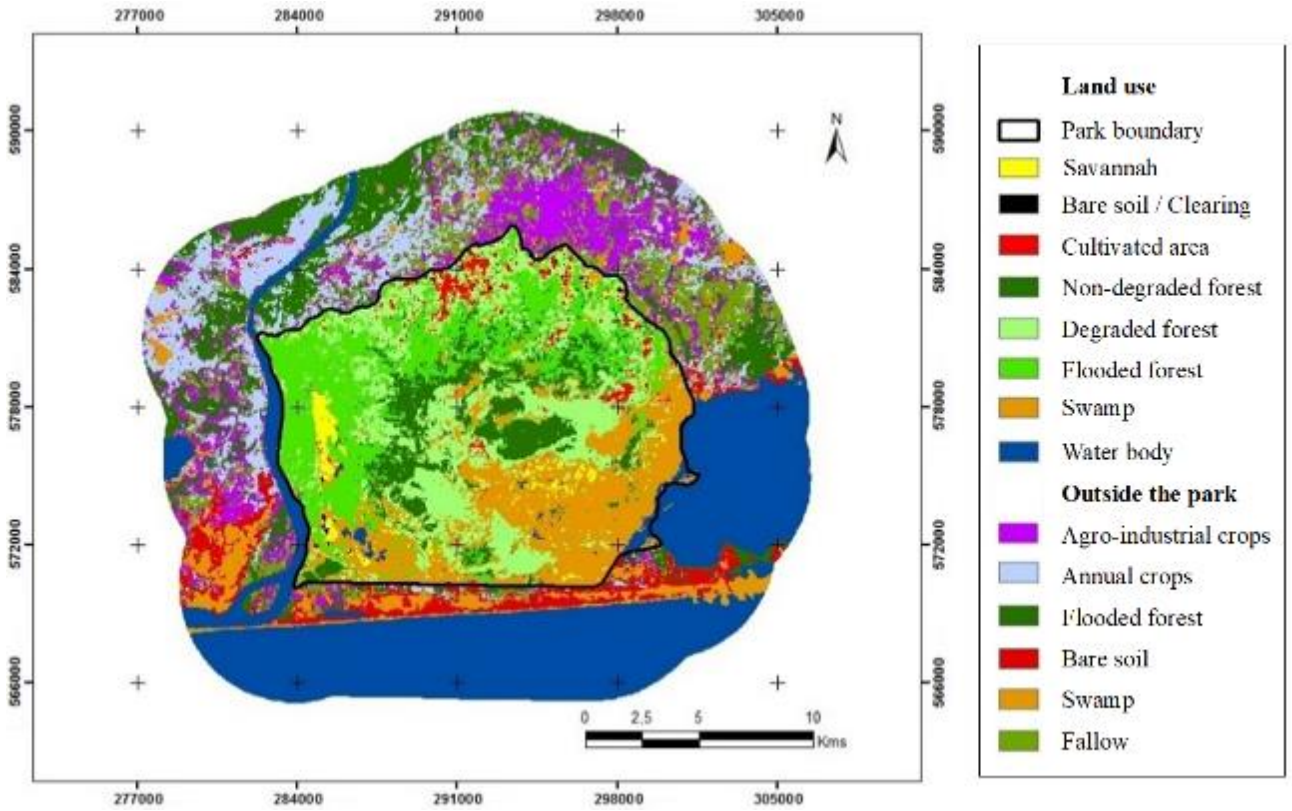


**Figure 2** Land use of the Azagny National Park area in 1987

In 2002 (Figure 3), once again, degraded or secondary forests and swampy areas predominated in the park, covering 5178.95 hectares (23.7%) and 4907.34 hectares (22.5%) respectively as this is shown in Figure 4. On the other hand, in the unprotected or buffer zone, it was the mosaics of crops/fallows and agro-industrial crops that shaped the landscape, with areas of 11,341.9 hectares (39.2%). and 7956.6 hectares (27.5%).

**Table 1** Confusion matrix of the 1987 image

| Classes | Savannah | Bare soil / Clearings | Cultivated areas | Non-degraded forests | Degraded forests | Flooded forests | Swamps | Bodies of water | Total |
|---|---|---|---|---|---|---|---|---|---|
| Savannah | 78.13 | 5.88 | 0.00 | 0.00 | 0.00 | 0.00 | 43.59 | 0.00 | 3.55 |
| Bare soil / Clearings | 0.00 | 94.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.32 |
| Cultivated areas | 0.00 | 0.00 | 70.21 | 0.00 | 5.37 | 0.00 | 0.00 | 0.00 | 7.02 |
| Non-degraded forests | 0.00 | 0.00 | 0.00 | 100.00 | 0.10 | 5.66 | 0.00 | 0.00 | 2.56 |
| Degraded forests | 0.00 | 0.00 | 6.38 | 0.00 | 94.52 | 1.89 | 0.00 | 0.00 | 75.95 |
| Flooded forests | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 43.40 | 0.00 | 0.00 | 1.90 |
| Swamps | 21.88 | 0.00 | 23.40 | 0.00 | 0.00 | 49.06 | 56.41 | 7.41 | 5.62 |
| Bodies of water | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 92.59 | 2.07 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Overall accuracy: 80.54%; Kappa index: 0.81; Cells in gray color represent the number of well-placed pixels of a type of land use

**Table 2** Confusion matrix of the 2002 image

| Classes | Savannah | Bare ground / Clearing | Fallow | Non-degraded forests | Degraded forests | Flooded forests | Swamps | Water places | Totals |
|---|---|---|---|---|---|---|---|---|---|
| Savannah | 77.78 | 27.03 | 0.00 | 0.00 | 0.00 | 0.00 | 13.73 | 0.00 | 1.63 |
| Bare ground / Clearing | 0.00 | 72.97 | 1.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.90 |
| Fallow | 0.00 | 0.00 | 92.31 | 0.00 | 1.92 | 0.00 | 0.00 | 0.00 | 4.62 |
| Non-degraded forests | 0.00 | 0.00 | 0.00 | 86.18 | 2.98 | 35.85 | 1.96 | 0.00 | 11.68 |
| Degraded forests | 2.78 | 0.00 | 5.77 | 0.00 | 94.91 | 0.00 | 0.00 | 0.00 | 67.46 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Flooded forests | 0.00 | 0.00 | 0.00 | 13.82 | 0.00 | 64.15 | 27.45 | 0.00 | 4.42 |
| Swamps | 19.44 | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 56.86 | 2.56 | 3.13 |
| Bodies of water | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 97.44 | 5.16 |
| Totals | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Overall accuracy: 84.74%; Kappa index: 0.85; Cells in gray color represent the number of well-placed pixels of a type of land use

**Table 3** Confusion matrix of the 2023 image

| **Classes** | **Savannah** | **Swamps** | **Bare ground / Clearing** | **Degraded forests** | **Swamp forests** | **Non-degraded forests** | **Bodies of water** | **Totals** |
|---|---|---|---|---|---|---|---|---|
| Savannah | 96.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.81 |
| Swamps | 0.00 | 96.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.41 |
| Bare ground / Clearing | 3.85 | 0.00 | 100 | 0.00 | 0.00 | 0.00 | 0.00 | 1.68 |
| Degraded forests | 0.00 | 2.04 | 0.00 | 99.50 | 0.25 | 25.76 | 0.00 | 22.03 |
| Swamp forests | 0.00 | 0.00 | 0.00 | 0.00 | 74.88 | 0.91 | 0.00 | 23.17 |
| Non-degraded forests | 0.00 | 1.53 | 0.00 | 0.50 | 24.88 | 73.33 | 0.00 | 26.37 |
| Bodies of water | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100 | 8.54 |
| Totals | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Overall accuracy: 89.35%; Kappa index: 0.88; Cells in gray color represent the number of well-placed pixels of a type of land use

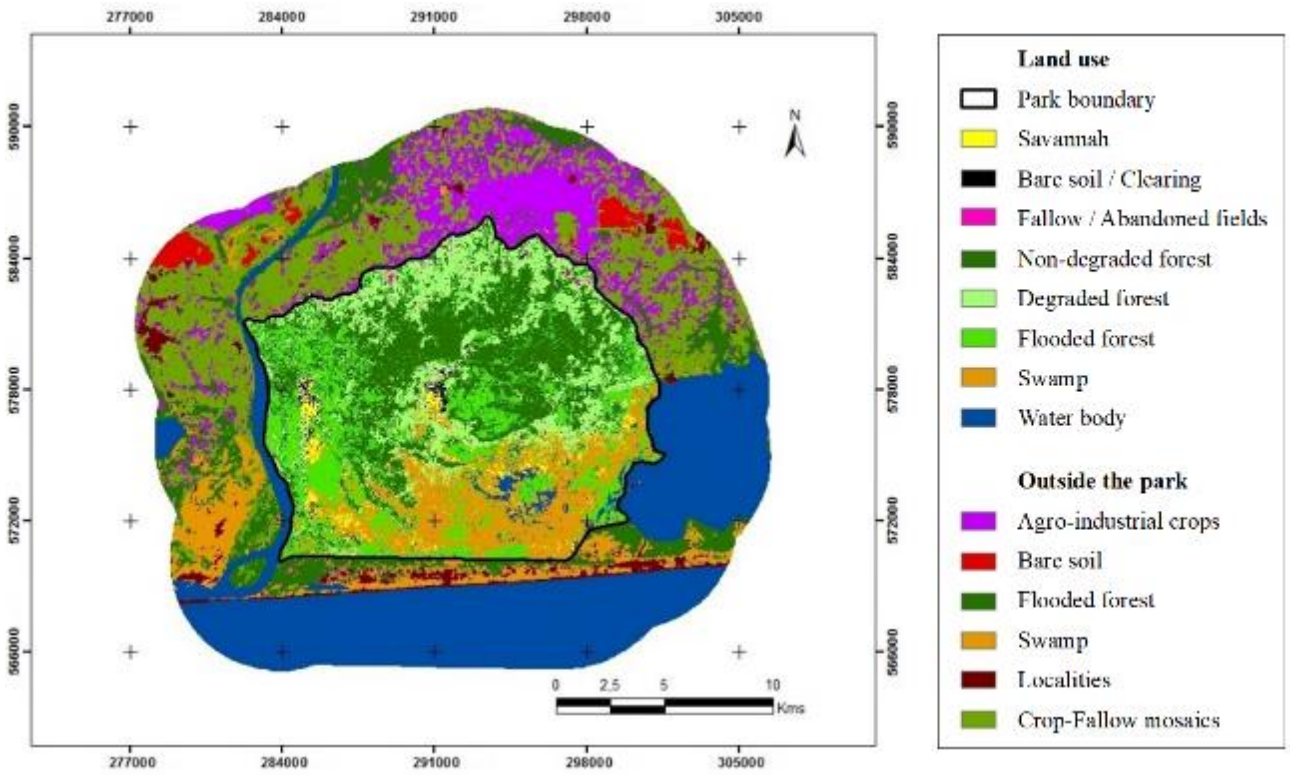


**Figure 3** Land use of the Azagny National Park area in 2002

In 2023 (Figure 4), degraded or secondary forests and areas with temporary and permanent flooding predominate within the PNA, covering respectively 6567.56 hectares (30.1%) and 5385.32 hectares with a percentage of 24 .6% (Figure 5). On the other hand, in the rural area located 5 km around the park, agro-industrial crops, annual crops and crop/fallow mosaics are widely represented, with respective areas of 8557.3 hectares (29. 6%), 6334.89 hectares (21.9%) and 5895.2 hectares (20.4%).

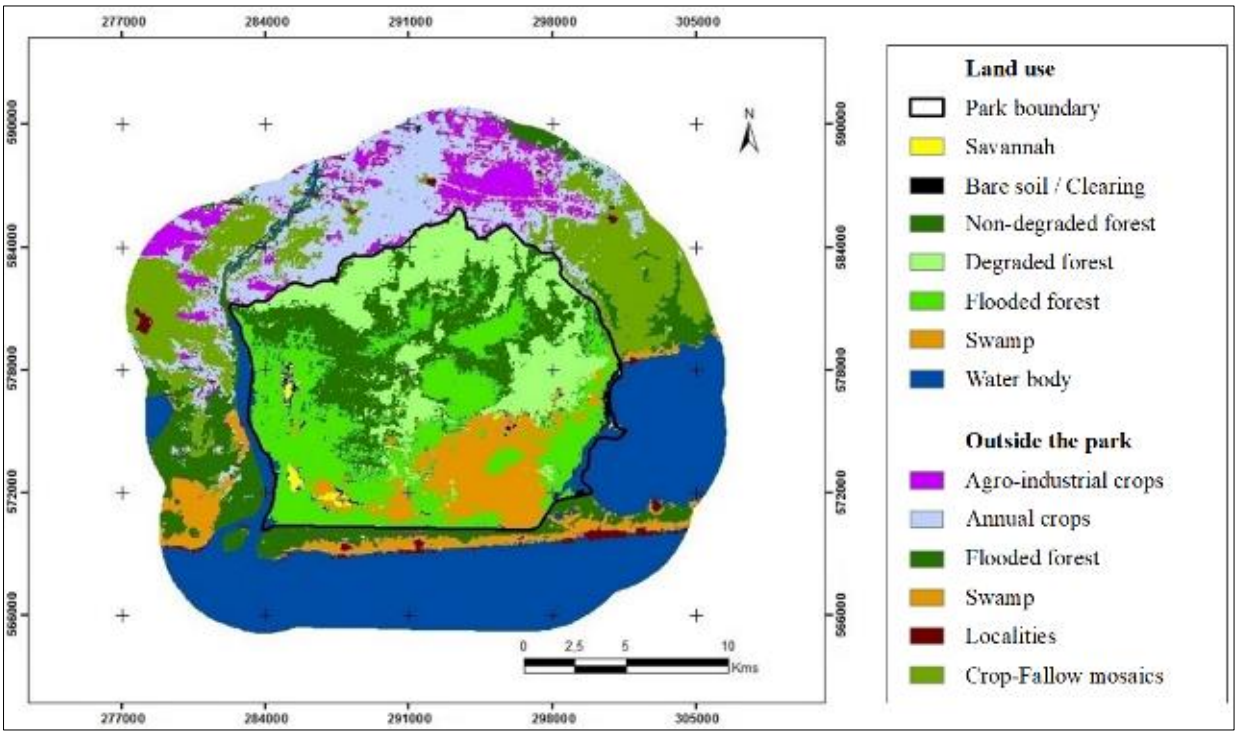


**Figure 4** Land use of the Azagny National Park area in 2023

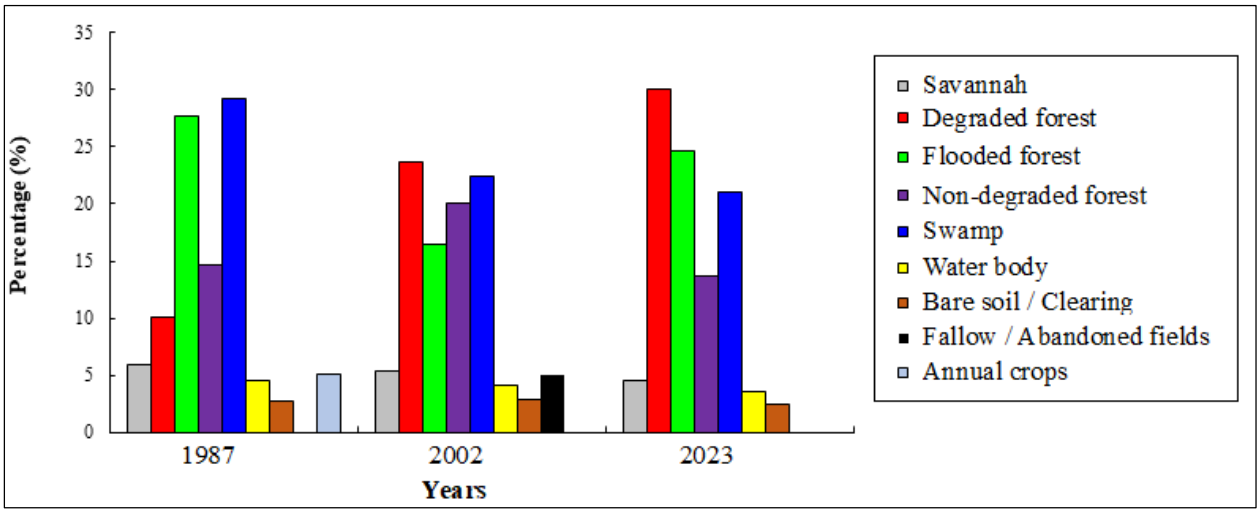


**Figure 5** Evolution of land use types over the years

### 3.3. Dynamics of land use between 1987 and 2002

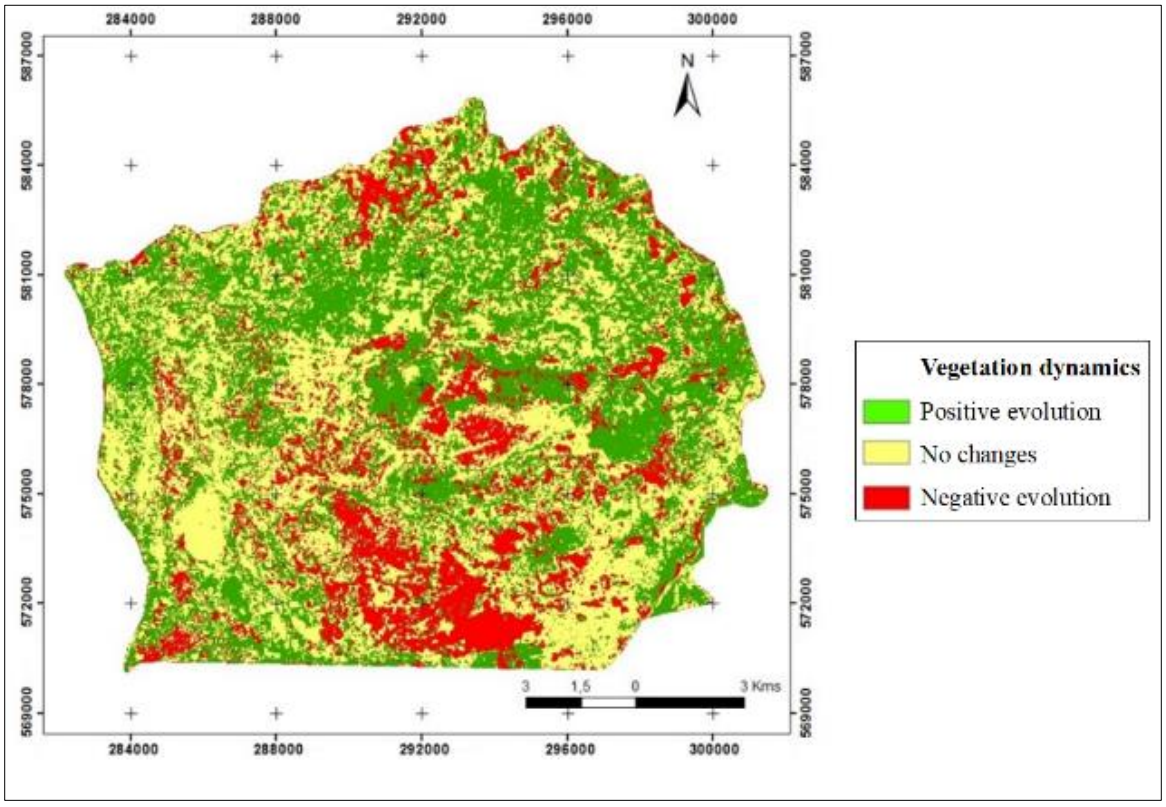


**Figure 6** Changes in vegetation structure during the period 1987 to 2002

The first period analyzed is that of the period from 1987 to 2002. The analysis of the vector of change shows that 41.86% of the Azagny park has experienced positive development (increase in forest). We observe a negative evolution, that is to say a decrease in the forest on an area representing 21.37%. On 32.76% of the park's surface area, the vegetation has not undergone any notable transformation (Figure 6). The regression of plant cover in certain areas of the park is linked to particular environmental conditions and the influence of anthropogenic activities. Among the changes linked to environmental conditions, a variation in the surface area of water bodies was observed. In 1987, the flooded areas represented 1.58%, or 350 hectares. In 2002, this surface area was estimated at 2.07% of the park, or 459 hectares of bodies of water. During periods of flooding in hydromorphic areas, the plant cover decreases while the bodies of water become more important. We also observe a negative evolution of the plant cover in less humid areas. These are spaces

occupied by savannahs in 1987 which are classified as bare soils or clearings. Indeed, it is therefore appropriate to note a drop in plant cover in these areas. Bare soils or clearings have seen an increase. These areas, estimated at 96 hectares in 1987, increased to 298 hectares in 2002. This decline in plant cover is linked to anthropogenic activities. Some poachers in search of game set fire to the savannah to attract large ruminants in search of fresh grass. This practice continues to be widely used. We also observe that certain areas continued to be the subject of new clearings within the park during the eviction period.

### 3.4. Dynamics of land use between 1987 and 2023

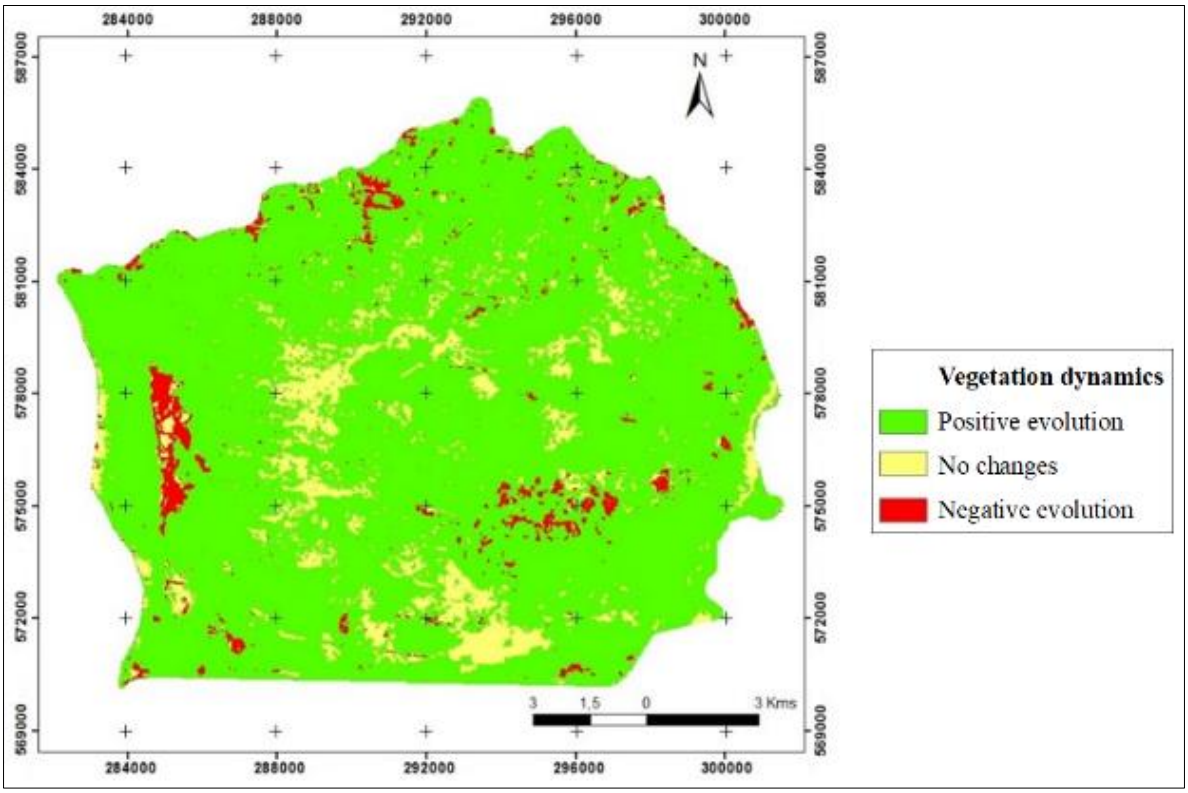


**Figure 7** Changes in vegetation structure during the period 1987 to 2023.

The second period analyzed is that going from 1987 to 2023. We observe at this level that 85.6% of the park is experiencing positive development. On 10.2% of the park, there are no substantial changes to the plant cover. Finally, 4.19% of the park's surface area is experiencing regression in the structure of the vegetation (Figure 7). The areas which have experienced a negative evolution are mainly concentrated in the South and Center of the park and sparsely in the Northern parts. These are hydromorphic environments and savannahs. The areas which have experienced positive development are mainly found in the North, East and West parts of the park. These are forest formations that have been anthropized.

## 4. Discussion

### 4.1. Distinction of land use classes

The obtained Kappa indices indicate that there is substantial agreement between the maps and the ground truth. However, some confusions observed between the image classes are linked to the particular environmental conditions of the park as well as to anthropogenic activities. A first type of confusion concerns hydromorphic and sparsely wooded environments. In dry periods, some swamps dry out and present a morphology and photosynthetic activity similar to savannahs. Areas of flooded forests are difficult to distinguish from swamps to the extent that these areas have similar levels of afforestation.

The Landsat images used have resolutions of 30 meters, this does not make it possible to clearly discriminate certain formations such as small plantations which remain incorporated into certain ecosystems. To resolve these difficulties, it is possible to use multispectral images such as ASTER or hyperspectral images of the Hyperion type which have many

more bands. The Azagny National Park is a permanently wetland and the use of Radar or drone images will allow good discrimination of spaces despite environmental conditions. Such observations are similar from Abrou et al. (2017) during their work carried out in the Forêt des Marais Tanoé-Ehy (FMTE) located in the south-east of Côte d'Ivoire. These authors assert that the low resolution of Landsat images does not make it easy to distinguish certain plant formations.

### 4.2. Evolution and relevance of human pressures in the PNA space

The results of this study show a positive evolution from non-degraded forest towards degraded areas and fallow crops inside the park and a sharp reduction in forest islands in the rural area. This state of affairs could be explained by the fact that during the process of eviction of populations inside the park, the abandoned plantations were converted into fallow land. Also, the absence of any activities inside the park following the evictions also allowed the reforestation of degraded areas into non-degraded areas. However, the displaced populations resettled around the PNA to set up new plantations, resulting in the reduction of some forests. These remarks are not consistent with those observed by Konan [30]in the area of the Azagny National Park. For this author, the work carried out in the park presents a general trend towards deforestation during the period from 1975 to 2000. Indeed, this is a period marked by anthropogenic pressures on the Azagny National Park. An increase in the local population with a boom in agro-industrial production marked by the creation of new plantations. However, the start of the eviction process marks the resumption of vegetation in the Azagny area.

Indeed, the process of forest retreat and recovery is also highlighted in various scientific works. Thus, for the dense humid forest of the Bertoua region in Cameroon, calculations carried out on Landsat TM images show an annual deforestation rate of 0.5% [31]. For the same region, the analysis of aerial photographs coupled with Landsat TM images reveals a dynamic of plant cover characterized by a slow progression of the forest at the expense of the adjacent savannah [32].

The discrimination of anthropogenic activities inside the Azagny National Park was made on the basis of exchanges with the populations. This procedure is inspired by the reticulate space model [33]. According to this model, in forest areas, populations organize themselves through a punctuation of places, reflecting sites of memory (location of ancient villages, ritualized places, historical sites) and production (agriculture, hunting, gathering, training dominant plants, grazing areas). This approach makes it possible to design a more faithful form of restitution, both diachronic and synchronic, of the organization in space and time of anthropogenic activities. The work of Diallo, Bamba [24]on the combined effects of climate and anthropogenic pressures on the evolutionary dynamics of the vegetation of a protected area in Mali also used the same principle.

For Jha, Goparaju [34], forest fragmentation due to anthropogenic activities leads to losses of biodiversity in forest habitats. Certain plant species are therefore directly threatened with disappearance from anthropized spaces. These are often specific species whose presence and survival is linked to the stability of the environment. The Azagny National Park contains numerous biotopes which have been disrupted by the actions of man. It is therefore possible that changes in vegetation types have also led to modifications in the floristic compositions of these environments.

Historical administrative data on the populations living inside the park and the different inhabited sites in the park have not been found. This situation does not make it possible to establish a good correlation between anthropogenic pressures and the degradation of the plant cover. However, the policy of creating a so-called “buffer” zone in which peasant activities would be controlled did not produce convincing results during the eviction process. The populations continued to create new agricultural plots when they just had to harvest the already existing plantations. It is therefore appropriate to take into account the perceptions and habits of local populations in protected area management policies.

## 5. Conclusion

The development of agro-industrial activities has led to strong growth in the population around the Azagny National Park. Part of this population settled inside the park to carry out agricultural activities. The natural environments of the park were disturbed or replaced by fields. The policy of eviction allowed the flora to reconstitute itself. Overall, note that within the park, non-degraded forests have taken precedence over degraded forests and flooded forests. Formerly cultivated areas and certain still persistent crops become fallow. On the other hand, in the immediate rural environment, the areas of cash crops such as oil palm, rubber cultivation and cocoa are increasing to the detriment of the forest lungs. To deal with this situation which prevails in the PNA space, it is necessary to better understand the different modifications in the structure of the flora of the environments encountered, in particular the epiphytic flora which remains sensitive to variations in the environment. It is also necessary to establish a good estimate of the cartography

and the degree of anthropization, which will highlight the correlation between the density of human presence and its influence on the environments.

## Compliance with ethical standards

*Disclosure of conflict of interest*

The authors of this article declare that there is no conflict of interest.

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