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Dynamics of Land Occupation of the Gangan Classified Forest in Guinea

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Abstract

Flora and vegetation are important indicators of the health of a forest ecosystem. The overall objective of this research is to assess the effects of the spatio-temporal dynamics of land use on the flora and woody vegetation of the Gangan classified forest between 1995 and 2024. The main methods used were diachronic land-use mapping and botanical and forest inventories. The results showed that the remaining natural formations are established on land unsuitable for agriculture and grazing. The floristic inventory identified a total of 209 trees and shrubs of 85 woody species and 65 genera divided into 36 families. The average absolute density is 27 individuals/ha. This density decreases with the intensity of the drivers of change in low-altitude areas. In terms of temporal dynamics, seven (07) land cover classes were mapped. The evaluation of the results of the accuracy of the classifications based on the confusion matrices is (86.41% for 1995) and (91.9% for 2024). Comparative analysis of land use in 1995 and 2024 shows an increase of 562.76 ha (6.24%) in the area occupied by wooded savannah and 523.71 ha (5.81%) by built-up areas, and a considerable decrease of 2855.16 ha (31.69%) in the area occupied by shrub/grass savannah. The average annual rates of spatial expansion of the land-use units indicate that built-up areas (10.93%), open forest (3.89%), wooded savannah (1.44%), crops and fallow land (2.62%) and bowal and bare soil (0.03%) have increased in area, while the negative values express the decrease in the area of shrub/herbaceous savannah (−3.41%) and Water (−0.89%).

Subject Areas

Environmental Sciences

Keywords

Dynamics, Woody Vegetation, Classified Forest

1. Introduction

In Africa, as elsewhere, the decline or alteration of wooded areas is becoming a concern, both for local stakeholders and for the scientific community. In West Africa, there has also been the problem of the impact of drought since the end of the 1960s [1]-[3], and that of the relative recovery of rainfall on the state of the vegetation cover. Indeed, the reduction in wooded areas seems linked to climate variability but also to the social, economic and political changes in rural systems that the entire continent has experienced in recent decades [4].

Moreover, at the same time, West African countries are experiencing strong population growth. This increase in population is reflected on the one hand by an expansion of arable land and on the other hand by an expansion of urbanized areas. Consequently, an accentuation of the degradation of natural vegetation is observed [5]. Thus, if vegetation is particularly sensitive to climatic variations, it is also to the dynamics of the anthropogenic component in particular activities linked to agriculture, deforestation and increasing urbanization [6].

The main ecosystems in the West African region are savannahs, tropical forests, and mangroves, not to mention rivers and freshwater lakes. The richness of these ecosystems provides a basis for the survival of indigenous societies [7].

Through environmental observations, underlying economic and social problems are also highlighted. Indeed, due to this climatic variability and population growth, Africa has precarious food security [8].

Information on land use is becoming essential in environmental projects and ecosystem management; this data makes it possible to approach the reality on the ground and understand development issues. To this end, there has been a growing interest in the production of land use data in recent years. These databases have gradually emerged as essential tools for analyzing changes in land cover, its causes and consequences [9].

In the current context of global changes, spatio-temporal changes in land use, especially those of vegetation, have become indicators that allow us to assess the health of terrestrial ecosystems. Thus, vegetation has certainly become the component of terrestrial surfaces most intensively monitored by satellite [10]. The state of flora and vegetation is extremely dynamic and sensitive. Remote sensing is a tool that is now commonly used in environmental monitoring, particularly due to the diversity of existing sensors. It makes it possible to address various issues and at various spatial and temporal scales. Thus, by providing an image of the Earth, satellite images will make it possible to understand changes in plant cover [11]. In our case, images from Landsat sensors are used to set up a diachronic analysis of land use between 1995 and 2024 in our study area. In order to best characterize the dynamics of land use and the transition methods between the different classes from one year to the next, the post-classification method is the simplest to implement [12].

The Gangan classified forest is increasingly experiencing spatio-temporal changes in land use. This forest ecosystem includes both village lands intended for agro-pastoral activities and tourist sites. This part of Mount Gangan has been established as a protected area, notably as a classified forest, by Article 8 of the decree of July 4, 1935. The objectives assigned to this classified forest are the protection of faunal and floral biodiversity as well as the watershed of the Samou River, which feeds the Kalé hydroelectric dam in the sub-prefecture of Samaya and Friguiagbé. But this classified forest is mainly occupied by agro-pastoral and logging activities [13]. The latter also experiences overexploitation of agricultural land and forest resources. In such a context of strong anthropogenic pressures, it is then appropriate to assess the effects of land use on flora and vegetation.

This work aims to characterize land use dynamics in the Gangan Reserved Forest and quantify the impact of anthropogenic pressures on the landscape.

To achieve this, a thorough understanding of land use and its changes over time is necessary for a better understanding of the processes.

The research hypothesis stipulates that land use dynamics induce a disruption of this forest ecosystem.

The materials and methods, results, and discussion constitute the main sections of this article.

2. Materials and Methods

2.1. Presentation of the Study Environment

The prefecture of Kindia is located at an altitude of 458.13 m in the transition region between Lower Guinea and Fouta. It is located between 10˚03 North latitude and 12˚52 West longitude. According to data from the National Institute of Statistics, January 2019, the population of the prefecture of Kindia was 442,984 inhabitants in 2014, 510,624 inhabitants in 2019, and 554,224 inhabitants in 2022. The growth projection shows that the prefecture of Kindia will reach 600,291 inhabitants in 2025. The effect of population growth on forest degradation is associated with the increase in demand for fuelwood. The problem of wood as a source of energy is posed here as a cause of the degradation of natural environments in the Kindia region in general and in the study area in particular, which reflects an urbanization of forest ecosystems, a regression of the plant cover and even a consumption of agricultural land.

The Gangan Forest Reserve is located on the Gangan Mountain range, which itself still contains patches of submontane forest near the summit. However, much of this forest has been lost to a now-disused banana plantation; part of the summit has been cleared and is now used by tourists from Kindia as a picnic site. Part of this area has been designated as a classified forest, but unfortunately there has been very little protection on the ground in recent years [14].

The Gangan Reserved Forest is located in a humid tropical climate region, characterized by the alternation of two seasons of unequal duration (rainy season, from May to November). The wettest months are July, August and September with an annual rainfall of 365 mm. The maximum rainfall is generally recorded in August (approximately 505 mm of water). The globally endemic species of Mt Gangan are: *Kindia gangan* (newly described in 2018), *Phyllanthus felicis*, and *Clerodendrum sylvae*. Several other near-endemic species of Mt Gangan are also found there. For example, Pitcairnia feliciana, the only native species of the Bromeliad family in Africa. There are also many rare and endangered species on the sandstone bowes, including *Plectranthus linearifolius* and *Raphionacme caerulea* (See Figure 1).

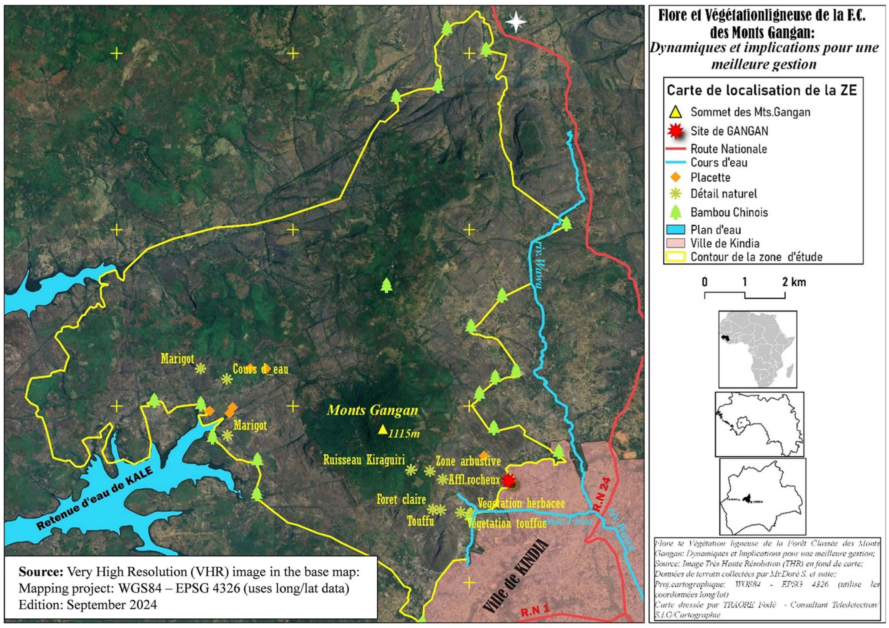

Figure 1. Location map of the study area.

2.2. Methodological Approaches for the Study of Land Occupation Dynamics in the Gangan Classified Forest

To conduct the study, we first consulted the National Directorate of Water and Forests of Kindia and the villagers who farm in the Gangan Forest Reserve. We then targeted villages to gather information by recording the coordinates of local areas and villages.

For various reasons, we chose to address dynamics by focusing primarily on woody plant cover, its changes, and its evolution over time and space. Thus, as recommended in the Geosystem-Territory-Landscape approach, we adopted a "territory-landscape" methodological approach that will allow us to analyze the environment from a human perspective, taking into account the impact of socio-economic organizations on the Gangan Forest Reserve.

To conduct this study, the following data collection, analysis, and processing method was adopted.

2.3. Selection of the Optimal Survey Period

The survey period was carefully chosen to ensure that all species were visible and identifiable. We chose the period from April to July and from October to January for our research due to the climatic conditions in our region.

2.4. Selection of Analysis Variables

We were dealing with several groups of variables, alternating between quantitative or measurable variables and qualitative variables (assessment variables).

2.5. Analysis Variables Relating to the Preparation of the Inventory of the Gangan Classified Forest

The quantitative and qualitative analysis variables relating to the implementation of the inventory of the Gangan classified forest are indicated in Table 1.

Table 1. Analysis variables relating to the state of the Gangan classified forest.

Qualitative variables	Quantitative variables
- Anthropogenic pressures, - Types of land use, - Types of housing in the classified forest, - Number of livestock in the Gangan classified forest, - Quality of forest infrastructure.	- Number of camps in the Gangan Forest Reserve, - Boundary of the Gangan Forest Reserve using GPS on the ground, - Accessible trails within the forest reserve using GPS, - Area of the Gangan Forest Reserve, - Number of herders in the Gangan Forest Reserve.

Analysis variables relating to the spatiotemporal dynamics of the Gangan classified forest

The quantitative and qualitative analysis variables relating to the spatiotemporal dynamics of the Gangan classified forest are indicated in Table 2.

Table 2. Analysis variables relating to the spatiotemporal dynamics of the Gangan classified forest.

Qualitative variables	Quantitative variables
Quality of satellite images of the Gangan Reserved Forest, - GIS data, - Land use class types, - Plant formation types.	- Areas of interest to be verified on the ground using GPS, - Area of land use, - Area of vegetation cover, - Degradation rate of the Gangan classified forest.

2.6. Variables Relating to Management Difficulties in the Gangan Forest Reserve

Management of the Gangan Forest Reserve is characterized by several government initiatives. The government is making efforts to ensure optimal management of the Gangan Forest Reserve. Despite this political will, increasing degradation of the Gangan Forest Reserve is observed. The quantitative and qualitative analysis variables relating to the management difficulties of the Gangan classified forest are indicated in Table 3.

Table 3. Analysis variables relating to the difficulties of managing the Gangan classified forest.

Qualitative variables	Quantitative variables
- Quality of legal texts, - Types of texts, - Education level of the population, - Training level of the Kindia Regional Directorate of Water and Forestry staff, - Staff's ability to adopt new technologies, - Monitoring strategies for the Gangan classified forest.	- Number of texts, - Number of agents responsible for protecting the Gangan classified forest, - Number of means of transport, - Forest conservation budget, - Number of technical equipment, - Number of technological equipment.

2.7. Spatial Dynamics

To understand the spatial dynamics, we first divided the study area into three altitudinal levels according to the relief (**Figure 2**): the altitudinal interval (site I) is the interval between 228.32 m and 500 m altitude, the altitudinal interval (site II) is the interval between 500m and 900m and the terminal altitudinal interval (site III) is the interval from 900m to 1117 m (summit of the area). We then proceeded to analyze the characterization parameters of the flora and woody vegetation for each section taken separately. This allowed us to compare the different altitudinal sites and to deduce the spatial changes. In each altitudinal interval (site), we listed the ecosystem individuals present, the impacts of the population on woody plants and vegetation. This allowed us to detect the role of a factor such as the human "pressure gradient" on the spatial position of the woody plants encountered, the density and diversity of woody species.

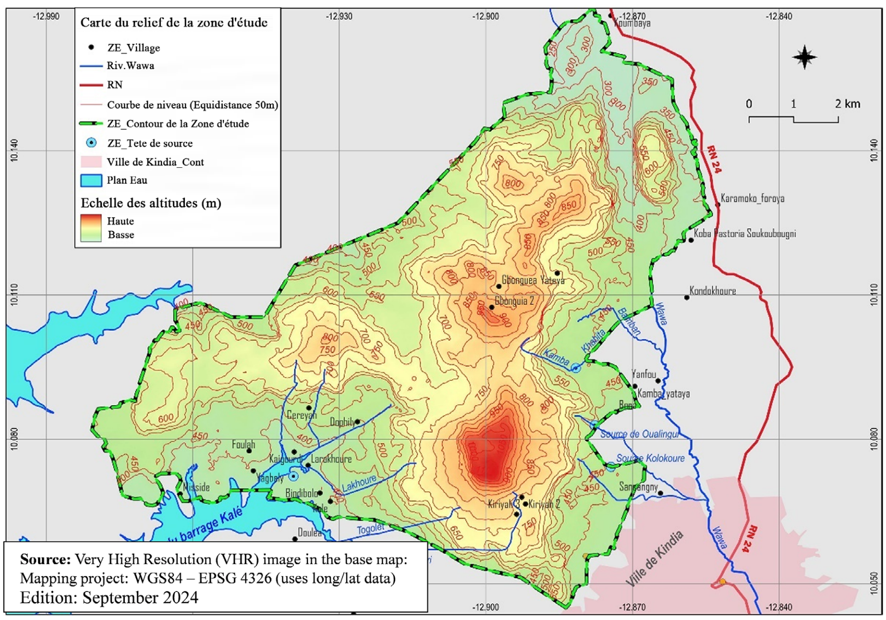

Figure 2. Relief map of the study area.

2.8. Temporal Dynamics

A diachronic analysis was carried out, using satellite images with geomaticians and Geographic Information System (GIS) specialists. We chose to analyze images from the period 1995 and 2024, for several reasons: (i) the need to have data over about thirty years, an acceptable time scale for climate change; (ii) availability and access to Landsat images. Initially, our objective was to acquire, process and analyze images over a period of 30 years from 1995 (30 years being the period we considered sufficient to easily have detectable and significant changes, regardless of the rate and type of change in the vegetation cover).

The data used in this context are multi-source. In fact, in savannah areas, landscapes are highly heterogeneous, and land-use dynamics are far from being understood in space and time. Detailed spatial data such as aerial photographs or satellite images required for this understanding are scarce, often old, and of poor quality. Therefore, the images analyzed are derived from Landsat satellite sensors. We opted to use Landsat images for the following reasons:

- Landsat satellite data are distributed free of charge and without a license for use by their owner, the USGS (US Geological Survey);

- They are among the most suitable for analyzing vegetation cover dynamics [15].

2.9. Sensor Characteristics

Landsat 5 TM (LT05) and Landsat 8 OLI/TIRS Sensors

Monitoring land use dynamics around the Mount Gangan classified forest was carried out using high-resolution Landsat satellite images. The Landsat program provides access to a large body of data available since February 1972, enabling regular monitoring over the past 50 years.

Thanks to this program, we have nearly 50 years of data relating to the observation of Earth's surfaces from space. Furthermore, these images are freely available to the general public through user-friendly portals. The spatial resolution of the images is 30 meters, since the TM sensor was commissioned in 1982, which is already more than sufficient for many applications. These spatial and temporal characteristics allow these images to be used in all possible application areas: land use monitoring, hydrology, glaciology, geology, risk monitoring, etc.

To conduct our study, we worked with images from two Landsat sensors: TM (Thematic Mapper) for 1995 and the OLI/TIRS sensor for 2024; the technical characteristics of these images are summarized in **Table 4**.

In addition, the high spatial resolution of these data (30 m for TM and OLI/TIRS) means that it is possible to characterise landscape features on the ground measuring 900 m^2 [16]. This is sufficient to identify the homogeneous landscape structures specific to our study area. In order to maintain consistency in the spectral response of the different plant cover, the images were all acquired during the dry period (February, March and April). In this way, the greatest spectral differences between landscape elements can be obtained [16], in particular the contrast between 'natural' vegetation systems, whose spectral response will be clearly distinguishable from 'anthropogenic' systems, which will be characterised at this time by a virtual absence of vegetation. Landsat sensors also have good radiometric resolution, enabling the calculation of various vegetation indices, such as NDVI, to improve the spectral identification of vegetation cover. Finally, the use of images acquired during the dry period also provides images with much reduced cloud cover, thereby limiting atmospheric bias [16] [17].

Table 4. Technical characteristics of the images.

Sensor	Spectral band used	Spectral resolution (µm)	Spatial resolution (m)	Acquisition date
Landsat 5 TM (LT05)	1	0.45 - 0.52 (Bleu)	30	1995 05 04
	2	0.52 - 0.60 (Vert)	30	
	3	0.63 - 0.69 (Rouge)	30	
	4	0.76 - 0.90 (PIR)	30	
	5	1.55 - 1.1.75 (MIR 1)	30	
	7	2.08 - 2.35 (MIR2)	30	
Landsat 8 OLI/TIRS	2 (OLI)	0.45 - 0.51 (Bleu)	30	2024 04 17
	3 (OLI)	0.53 - 0.59 (Vert)	30	
	4 (OLI)	0.64 - 0.67 (Rouge)	30	
	5 (OLI)	0.85 - 0.88 (PIR)	30	
	6 (OLI)	1.57 - 1.67 (MIR1)	30	
	7 (OLI)	2.11 - 2.29 (MIR2)	30	

These images have the advantage of being freely available on the Internet (http://glovis.usgs.gov/).

2.10. Google Earth© Images

Google Earth Pro images were used for the diachronic mapping of land cover for the most recent dates. The Google Earth© satellite images were used to identify the different types of vegetation cover and to match their spectral response on the 1995 Landsat satellite images.

2.11. Field Mission

2.11.1. Taking Field Points

The Gangan classified forest is characterized by fairly heterogeneous landscapes with gradual transitions through mosaics. Detecting different land use categories from satellite images alone remains difficult, which is why it is necessary to rely on field data [18]. The field mission was carried out from April 5 to October 20, 2024. Its aim was to recognize and define the landscape elements of the study area and to carry out surveys of GPS points representative of each land use class previously defined by the nomenclature. The data thus collected helped to understand the satellite data, then ground truth points for the validation of the most recent classification (2024). The points were collected in circular plots with a radius of

25m. In total, nearly a hundred GPS points were collected and stored in format. GPX (default projection system WGS84). Then, for a certain number of points considered representative, an Excel spreadsheet was created to allow the correspondence with the land use class concerned and the name of the point as recorded in the GPS.

2.11.2. Definition of Land Cover Classes

The land use of the Gangan classified forest is very heterogeneous and the transition between the different classes is often done in the form of a progressive gradient depending on the density of the cover and the size of the individuals. If many classes can be discriminated, we have chosen to work here on seven (7) main classes to implement the classification. Some of them have been grouped by preliminary analyses. Indeed, the more detailed the initial typology, the more difficult it is to discriminate between the classes. Thus, according to [6], the use of 4 to 7 land use classes is often sufficient to set up a cartographic analysis on this type of landscape.

2.11.3. Processing GPS Points

The GPS points taken in the field are in GPX format and it will be difficult to use them, particularly if they are to be used as control points in the field. In addition, the files were not organised in a consistent way, with redundant points in many cases. Nor was there any correspondence between the Excel file describing the points and the GPS points file. The geographical coordinates of the points were not known, or at least they had not been transcribed in a specific file.

Before using the points from the field mission, the files were cleaned and reformatted. The aim was to obtain an Excel file in which the entire field mission was presented and which could be used subsequently. This file should take the following form (see **Table 5**).

Table 5. Excel file of the field mission.

Date: Village or location	Latitude	Longitude	Altitude	N˚Point	N˚Photo	Descript/Observat

After processing the Excel file in .CSV format (delimited text), the result is a layer of points in .shp format, a standard format used by the majority of GIS and image processing software, whose attribute table contains the land use class. This layer can then be used to validate the classifications. As the projection system associated with Landsat images is WGS 84, the layer has also been indexed in this same system.

2.12. Colour Composition of Landsat TM Images from 1995 and 2024

For the purposes of this study, the colour composition used to determine land cover units was based on standard false colour. For the 1995 and 2024 Landsat images, the near-infrared, red and green (432) bands of the sensor were combined with the red, green and blue display plane of the screen, respectively. For the Landsat 08 images, the 543 bands were combined and, for good visual interpretation, the contrast of the images obtained was improved by histogram equalisation. This made it possible to clearly distinguish very dense forest formations from sparse formations and highly degraded areas from bare ground.

The digital image classification process involved choosing the colour compositions, defining the legend or filling in the ROI (Regions Of Interest), selecting the training plot samples, describing and filling in the various classes and choosing the classification algorithm.

Colour compositions were obtained by assigning the near-infrared (0.76 - 0.90 µm), red (0.63 - 0.69 µm) and green (0.52 - 0.60 µm) bands to the three primary colours (red, green and blue), in that order. Visual interpretation of the images after colour composition enabled us to identify types of occupation and therefore to delimit the training zones. The delineation of these training zones was reinforced by the network of GPS data collected in the field.

Knowledge of the study area guided the choice in favour of supervised classification, which consists of applying the same treatment to each pixel, independently of neighbouring pixels. The Minimum Distance algorithm was chosen for image classification. This method calculates the probability of a pixel belonging to a given class rather than another. Pixels will be assigned to the class for which the probability is highest.

2.13. Post-Classification Processing and Validation of Results

Once the classification had been completed, processing was carried out to refine and evaluate the accuracy and validate the results.

The first process involved passing the classified image through a 3 × 3 majority filter (isolated pixels are transformed into majority neighbouring pixels in a 3x3 square around the pixel under consideration. The classification is simplified and isolated pixels are removed.

Finally, the accuracy of the classifications was assessed using a confusion matrix [19]. To this end, the results of the classifications were compared with a set of GPS readings collected in the field. Two classification validation indices were then determined, namely overall accuracy (proportion of well-classified pixels, calculated as a percentage) and the Kappa index (ratio of well-classified pixels to the total number of pixels surveyed) [20].

2.14. Evolution of Land Cover

The spatio-temporal evolution of each land cover class was evaluated using a series of set transformations [21]. The relationship between the same class at two different dates was used to extract the 'stable', 'regressing' and 'progressing' areas of the said class. S_1 is taken to represent the area occupied by the land use classes on date 1, and S_2 is the area occupied by these same classes on date 2.

2.15. Quantifying Change

In order to quantify the changes in land cover classes, several statistical indicators were calculated: rates of change and the transition matrix.

2.14. Calculation of Rates of Change

The rates of change (annual rate of change and overall rate of change) in the areas of the land cover classes between 1986 and 2015 were determined respectively using the equation proposed by [22] (1) and that of [23] (2), which is commonly used to measure the growth of macroeconomic aggregates between two given periods [24]-[26].

$$Tg = \frac{S_2 - S_1}{S_1} \times 100$$

where S_1 is the surface area of a surface unit class at date t_1; S_2 is the surface area of the same surface unit class at date t_2.

$$Tc = \frac{\ln S_2 - \ln S_1}{(T_2 - T_1) \times \ln e} \times 100$$

with S_1 the area of a unit area class at date t_1; S_2 the area of the same unit area class at date t_2; ln the natural logarithm; e the base of natural logarithms (e = 2.71828). Positive values represent an increase in the surface area of the class over the period analysed, while negative values indicate a loss in the surface area of a class between the two dates. Values close to zero express the relative stability of the class over the two periods.

2.15. Transition Matrix

This matrix provides a condensed description [27] of the various forms of conversion undergone by land-use units between two dates t_1 and t_2, and describes the changes that have occurred. It is obtained by cross-referencing the 1995 and 2024 land use maps, made possible by the 'Intersect polygons' algorithm of the Geoprocessing extension in ArcGIS 10.0.

2.16. Map Layout in ArcMap

The map layout took into account the various map elements. These include the map frame, the legend, the graphic scale, the geographic North, the source of the Landsat base image and the UTM map coordinate system. After this layout operation, the perimeter and area of each land use unit were calculated. This work enabled various calculations to be made relating to a number of spatial structure indices and the evaluation of average annual rates of spatial expansion.

3. Results

3.1. Assessment of Classification Accuracy and Mapping Results

The results of the evaluation of the accuracy of the classifications based on the confusion matrices are (86.41% for the 1995 classification) and (91.9% for 2024); the Errors (of Omission and of Commission) and the Accuracies (of Production and of Use) respectively for 1995 and 2024 (**Table 6** and **Table 7**), indicate that the classification is of good quality [27].

Table 6. Confusion matrices for classifications of 1995 Landsat 8 images.

Characteristic	Buildings	FoCl	SArbo	Sarbu	CuJa	BoSoN	Eau	TOTAL	EC	PU
Buildings	**8**	0	0	0	5	4	0	17	53	47
FoCl	0	**7**	6	0	0	0	0	13	46	54
SArbo	0	0	**39**	3	0	0	0	42	7	93
Sarbu	0	0	2	**71**	0	0	1	74	4	96
CuJa	0	0	0	1	**54**	13	1	69	22	78
BoSoN	0	0	0	0	11	**124**	3	138	10	90
Eau	0	0	0	0	0	0	**15**	15	0	100
TOTAL	8	7	47	75	70	141	20	**368**		
EO	0	0	17	5	23	12	25			
PP	100	100	83	95	77	87	75			

Legend: FoCl: Open Forest, SArbo: Wooded savannah, Sarbu: Shrubby savannah, CuJa: Crop and fallow, BoSoN: Bowal and bare soil. EO: Omission error, EC: Commission error, PP: Production accuracy, EO: Omission error, PU: Use accuracy.

In 1995, the high values of Precision of Use Classes (PU) at the level of the different land use classes (see Table 6), Water (100%); Sarbu (96%); SArbo (93%); BoSoN (90%); CuJa (78%); FoCl (54%) and Bâtis (47%) and those of Precision of Production (PP) of these same classes: Bâtis (100%); FoCl (100%); Sarbu (95%); BoSoN (87%); SArbo (83%); CuJa (77%); and Water (75%).

Table 6 shows that a large proportion of the land use classes were well identified.

Table 7. Confusion matrix for the classification of satellite image LC08_2002053_20240417.

Characteristic	Buildings	FoCl	SArbo	Sarbu	CuJa	BoSoN	Eau	TOTAL	EC	PU
Buildings	**13**	0	0	0	0	0	0	13	0	100%
FoCl	0	**138**	1	0	0	0	0	139	0.007	99.3%
SArbo	0	18	**9**	0	0	0	0	27	0.67	33.33%
Sarbu	4	0	0	**17**	1	0	0	22	0.23	77.3%
CuJa	1	0	0	0	**7**	0	0	8	0.125	87.5%
BoSoN	0	0	0	0	0	**68**	0	68	0	100%
Eau	0	0	0	0	0	0	**32**	32	0	100%
TOTAL	18	156	10	17	8	68	32	**309**		
EO	0.28	0.11	0.1	0	0.125	0	0			
PP	72.22%	88.5%	90%	100%	87.5%	100%	100%			

In 2024, the high values of Accuracy of Use of Classes (PUC) at the level of the different land use classes (see Table 7), Buildings (100%); BoSoN (100%); Water (100%); FoCl (99.3%); CuJa (87.5%); Sarbu (77.3%); SArbo (33.33%) and those of Production Precision (PP) of these same classes: BoSoN (100%); Water (100%); Sarbu (100%); SArbo (90%); FoCl (88.5%); CuJa (87.5%) and Bâtis (72.22%) also indicate that the majority of classes were well allocated in the appropriate classes.

3.2. Mapping after Classification

Figure 3 and Figure 4 show the maps obtained after supervised classification of Landsat images from 1995 and 2024.

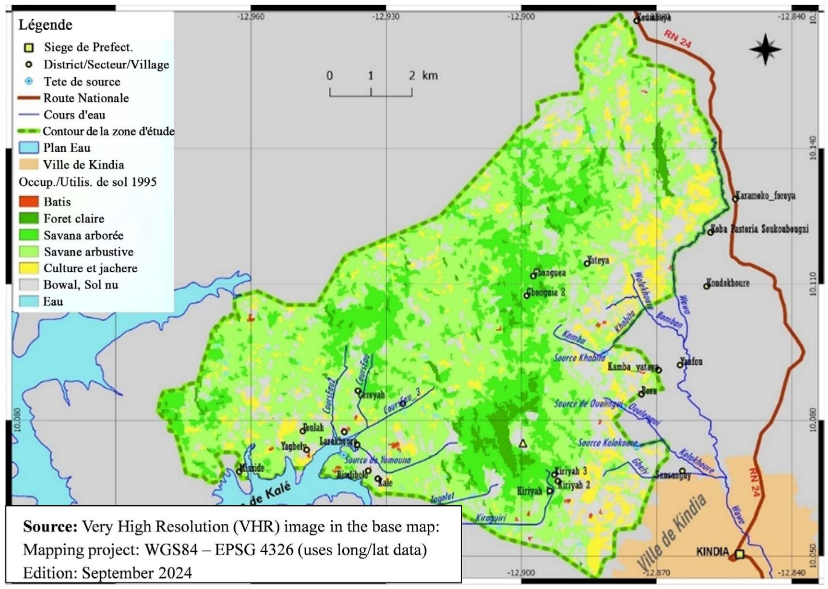

Figure 3. Land use in the Gangan classified forest in 1995.

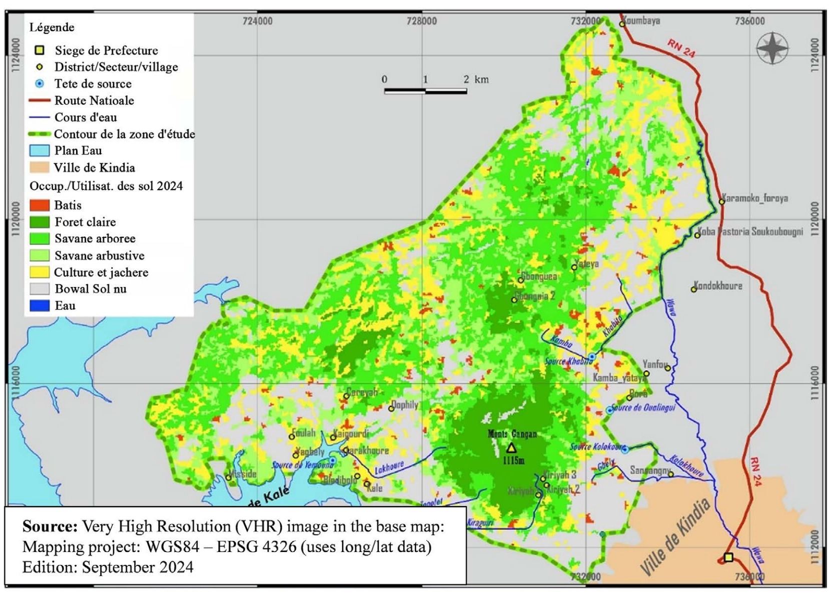

Figure 4. Land use in Gangan classified forest in 2024.

The land cover maps for 1995 (Figure 3) and 2024 (Figure 4) are derived from the vectorisation of classified images. They illustrate spatially and quantitatively the major changes that have occurred in the Gangan classified forest over the period 1995 to 2024 at the level of the different land-use units.

3.3. Land Use Dynamics

A total of seven (07) land-use classes were mapped. These classes include: open forest, savannah (all types of savannah and other low formations), cultivated and fallow areas (plantations and agroforests), built-up areas, bowal and bare soil, and water bodies.

Analysis of Land Use Conditions in 1995 and 2024

Land use conditions in 1995 and 2024 are summarised in Figure 5 and Figure 6 below.

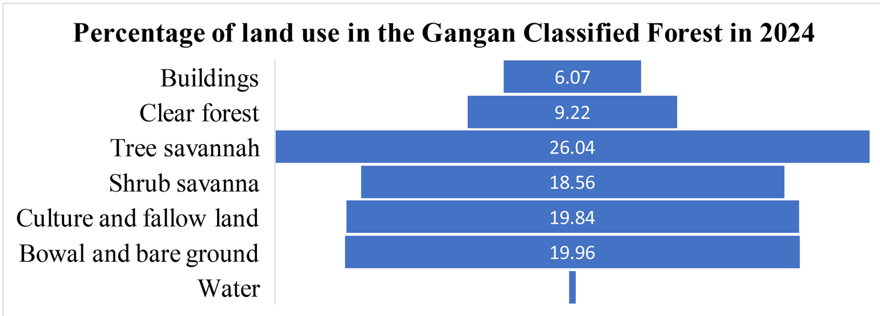

Figure 5. Percentage of land use in the Gangan classified forest in 1995.

Figure 5 shows that in 1995, shrub/grassland savannah predominated by just over 50% of the total area of the Gangan classified forest, followed by bowal and bare soil (19.76%), wooded savannah (17.15%), and cultivation and fallow (9.2%).

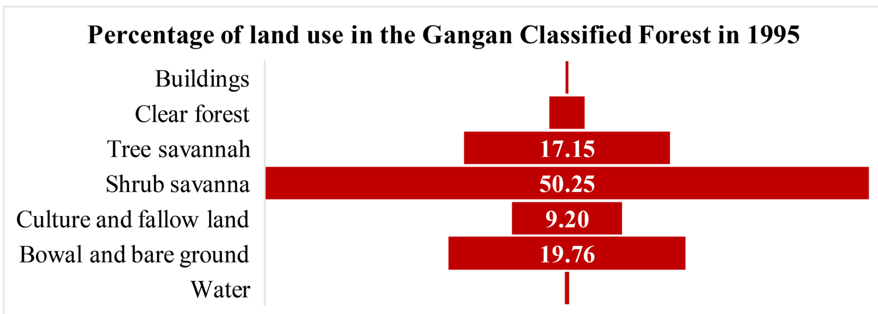

Figure 6. Percentage of land use in the Gangan classified forest in 2024.

Figure 6 shows that in 2024, wooded savannah occupies 26.04% of the total area of the Gangan classified forest, followed by bowal and bare soil (19.96%), cultivation and fallow (19.84%), shrub/grassland savannah (18.56%) and open forest (9.22%).

In the comparative analysis between land use in 1995 and land use in 2024, we note an increase in the areas occupied by wooded savannah and buildings, and a considerable decrease of 1846.8 ha in the area occupied by shrub/grassland savannah; This explains why forest conservation officers in the Kindia region have taken protective measures for the protected area, even though the population is still growing and has occupied eight times more built-up area than in 1995.

In conclusion, the increase in built-up area and the decrease in water surface area allow us to state that "deforestation is the consequence of the increase in the population that lives off the area's forest resources, and these two factors go hand in hand with the decrease in water surface area."

3.4. Average Annual Spatial Expansion Rates (T)

The average annual spatial expansion rate expresses the proportion of each land-use unit that changes annually. Based on the surface area of the land-use units, this rate was calculated using Bernier's (1992) formula:

$$T = \left[\left(\ln S_2 - \ln S_1\right) / \left(\left(t_2 - t_1\right) \times \ln e\right)\right] \times 100$$

S_1 and S_2: Area of a landscape unit at date t_1 and t_2 respectively; $t_2 - t_1$: Number of years of evolution; ln: Natural logarithm; e: Base of the natural logarithm (e = 2.71828).

Changes between 1995 and 2024: Areas and Average Annual Spatial Expansion Rates of Land Use Units

Table 8 shows the areas and average annual spatial expansion rates of land use units in the Gangan Reserved Forest between 1995 and 2024.

Table 8. Areas and average annual spatial expansion rates of land use units (1995-2024).

Land occupation units	Years		Average annual rate of spatial expansion (T) in (%)
	1995 (t1)	2024 (t2)	
	Area (S1) (ha)	Area (S2) (ha)	
Buildings	23.04	546.75	10.93
Clear forest	268.74	831.15	3.89
Tree savannah	1545.3	2346.39	1.44
Shrub/grass savannah	4527.54	1672.38	−3.41
Cultivation and fallow	829.08	1787.85	2.62
Bowal and bare ground	1780.74	1797.93	0.03
Water	35.37	27.36	−0.89
TOTAL	9009.81	9009.81	

The results in Table 8 reflect the annual average rates of spatial expansion of land use units in the study area. Overall, the positive values of the rate indicate that the buildings (10.93%), the clear forest (3.89%), the tree savannah (1.44%), the crops and fallows (2.62%) and bowal and bare soil (0.03%) have experienced an increase in areas, while the negative values express the decrease in the areas of the shrub/grass savannah (−3.41%) and Water (−0.89%), see **Figure 7**.

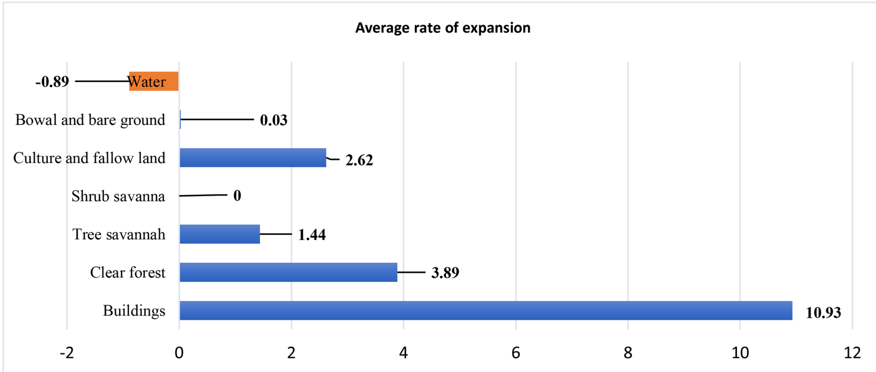

Figure 7. Average annual rate of spatial expansion (T in %).

In this **Figure 7**, we notice that the class of Bowal and bare soil has not undergone a big change because on the surface of bowal, no income-generating activity can be carried out as on the ground covered with vegetation, while the class of Built has considerably increased. This is explained by the fact that the population found in the classified forest of Gangan is increasing exponentially either by birth or by the incessant arrival of new people of various origins and for various reasons, which follows the construction of villages, hamlets and camps.

4. Discussion

4.1. Factors of Land Occupation Dynamics

The assessment of the land use dynamics of the Gangan classified forest from 1995 to 2024 revealed a regression of natural formations in favor of fields and fallow land and buildings. Deforestation and degradation of its resources are occurring in this classified forest, which deserves special attention. According to [14], the practices of activities such as subsistence farming, livestock farming, uncontrolled urbanization of the area, market gardening, charcoal production, excessive logging, slash-and-burn cultivation, fire for grazing and hunting are indicated to explain the degradation of natural formations in the Gangan classified forest. Beyond considering these activities as the drivers of deforestation and degradation of the vegetation cover, it is important to ask the reasons that can explain the practice of these activities in the classified forest of Gangan, which was nevertheless established as a classified forest by the colonial administration by article 8 of the decree of July 4, 1935, the date of reservation, and August 22, 1942, the date of classification. At that time, the local populations were involved in this operation. With the population explosion and its corollaries of increased need for arable land associated with the ban on access to classified forests without the means to enforce it, the path of free access to the lands of this classified forest was opened. The appropriation of this classified forest by the State and the exclusion of local populations, often carried out in the name of the general interest, allowed devastating practices within this classified forest. The State, through the forestry administration, exercises almost no more surveillance control or development activities in the Gangan classified forest. The Gangan classified forest then became the scene of several human activities. The "tragedy of the commons" was gradually established, symbolizing the degradation of the environment following the competing use of a resource by several users, each seeking to make the most of it.

4.2. Land Use Dynamics

The diachronic analysis of land use made it possible to understand the overall dynamics observed within the different land use classes of the Gangan classified forest for the years 1995 and 2024. The results of this dynamic show the major trends in overall development. In 1995, the landscape of the Gangan classified forest was dominated by the formation of shrub/grass savannah with (50.25%), Bowal and bare soil (19.76%), wooded savannah (17.15%), crops and fallow land (9.20%), open forest (2.98%), water (0.39%) and buildings (0.25%) while in 2024, the land use of this area was dominated by wooded savannah (26.04%) followed by bowale and bare soil (19.95%), crops and fallow land (19.84%), shrub/grass savannah (18.56%), open forest (9.22%), buildings (6.06%) and water (0.3%).

The comparative analysis of the two reference years shows a considerable increase in favor of the wooded savannah (26.04%), which dominates land use in 2024, but also the open forest, which is gradually gaining space (9.22%) compared to 1995. We noted that the space occupied by buildings is increasing enormously (6.07%), which follows the expansion of land use by crops and fallow land (19.84%) to the point of meeting the socio-economic needs of the population. The area occupied by bowal and bare soil (19.94%) has increased due to trampling of the thin layer of soil by livestock farmers and their herds and erosion that occurs during heavy rains after drought. The activities of farmers and livestock farmers have a negative impact on the plant cover of the Gangan Classified Forest.

4.3. Average Annual Spatial Expansion Rates between 1995 and 2024

These represent the average annual spatial expansion rates of the land use units in this classified forest. Overall, positive values indicate that built-up areas (10.93%), open forest (3.89%), wooded savannah (1.44%), crops and fallow land (2.62%), and bowal and bare soil (0.03%) have increased in area, while negative values indicate a decrease in the area of shrub/grassland savannah (−3.41%) and water (−0.89%).

4.4. Variability of Vegetation Structure along the Altitudinal Gradient

Vegetation structure and its variability are indicators of ecosystem functioning and condition [28]. The pattern of structural composition and distribution of forest plant communities with altitude has been shown to depend on the ecological characteristics of the vegetation [29]-[33]. In this study, it was observed that the variability of vegetation structure is a function of the altitudinal gradient. Land use in the Gangan classified forest in 2024 shows that the degradation of the plant cover is particularly accentuated at low and medium altitudes (site I: between 228.32 m and 500m and II: between 500 m and 900 m) occupied by wooded savannah, bowale and bare ground. Compared to site III (between 900 m and 1117 m), which is little impacted by human activities, this area has a more or less dense and contiguous canopy (the branches and foliage forming the crown of the trees fit together to provide extensive but not continuous shade).

5. Conclusions

Land cover mapping in the Gangan Reserved Forest between 1995 and 2024 made it possible to analyse land cover changes that occurred during this period. The approach based on geospatial technologies (GIS, mapping, etc.) made it possible to detect and quantify changes in different land cover units (built-up areas, open forests, wooded savannahs, shrub/grassland savannahs, crops and fallow land, bowal and bare soils, and water) over time and space.

Thus, in 1995, the high Class Use Accuracy (CUA) values for the different land cover classes were: Water (100%); Sarbu (96%); SArbo (93%); BoSoN (90%); CuJa (78%); FoCl (54%) and Frames (47%) and those of Production Precision (PP) of these same classes: Frames (100%); FoCl (100%); Sarbu (95%); BoSoN (87%); SArbo (83%); CuJa (77%); and Water (75%).

Compared to the year 2024, the high values of Accuracy of Use of Classes (PU) at the level of the different land use classes are Built (100%); BoSoN (100%); Water (100%); FoCl (99.3%); CuJa (87.5%); Sarbu (77.3%); SArbo (33.33%) and those of Precision of Production (PP) of these same classes: BoSoN (100%); Water (100%); Sarbu (100%); SArbo (90%); FoCl (88.5%); CuJa (87.5%) and Built (72.22%) also indicate that the majority of classes have been well allocated in the appropriate classes.

According to the analysis of the transition matrix for the study period 1995-2024, the reduction in water and shrub savannah areas was to the benefit of bare soil formations and grassy areas around the Kale hydroelectric dam reservoir and crops and fallow land.

Also, during this period, the average annual rates of spatial expansion T of land use units indicate that buildings (10.93%), open forest (3.89%), wooded savannah (1.44%), crops and fallow land (2.62%) and bowal and bare soil (0.03%) have experienced an increase in areas, while the negative values express the decrease in the areas of shrub/grass savannah (−3.41%) and water (−0.89%).

These analysed results show that this situation of differential conversion of land use units (plant formations) would be the consequence of non-compliance with the principles of safeguarding natural resources by local populations in this classified forest. This situation therefore deserves particular attention from the local populations through awareness sessions and from the political authorities for rigorous application of the laws on the rational management of the Gangan classified forest, for its sustainable preservation.

Conflicts of Interest

The authors declare no conflicts of interest.

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