



Securing Permanent Forests to Combat Climate Change and Enhance Sustainable National and Local Economies in Cameroon

ANNEX 22F

LANDCOVER/LANDUSE CHANGE

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1. INTRODUCTION

Deforestation and forest degradation account for around 10 to 12% of total anthropogenic greenhouse gas (GHG) emissions worldwide and are one cause of climate change (Le Quéré et al., 2015; Hansen et al., 2013).

In the Congo Basin, the deforestation rate increased markedly between 1990 2000 and 2000 2005, from 0.09% to 0.17% respectively (Bozongo, 2019). According to Koyo (2004), this loss of forest is the result, on the one hand, of the unbridled exploitation of its resources, using traditional techniques, to satisfy the needs of both local populations and the international market for raw materials, and, on the other hand, of the inconsistency of the efforts made to ensure the regeneration and conservation of its resources, all against a backdrop of poor governance and increasingly worrying poverty among the population. At this rate, nothing will be left but rainforest by 2050, and forest cover will disappear within the next three centuries (Medjigbodo 2004).

Cameroon's forestry potential is one of the greatest in Central Africa and in the world. The country is located in the Congo Basin, which is the second-largest tropical forest ecosystem after Amazonia. It therefore has a key role to play in international negotiations on climate change. Despite their importance, these forests face several threats that impact their ability to produce goods and services and to effectively combat the effects of climate change (MINFOF, 2019).

Cameroon's permanent forest estate, which is made up of Forest Management Units (FMUs), protected areas, communal forests, and forest reserves, is regularly under threat from a variety of sources, exacerbating their decline in terms of forest cover or woodland area. Communal forests are more vulnerable, with vast areas affected. Deforested areas cover around 193.47 ha, or 50.78% of forest titles belonging to this category (MINFOF, 2019). Similarly, Forest Management Units (FMUs) are also impacted by human activities. These two types of forest titles are subject to timber harvesting operations that regularly create canopy openings and thus cause significant biomass losses. In the case of protected areas and forest reserves, which are fully protected forests, clearings are measuring around 10.87 ha (MINFOF, 2019).

With a view to sustainable management of natural resources and ecosystems, and combating the effects of climate change, the country has made some national and international commitments, through the Ministry of Forests and Fauna (MINFOF) and the Ministry of the Environment, Nature Protection, and Sustainable Development (MINEPDED). These include a commitment to the Voluntary Partnership Agreement/Programme for Forest Law Enforcement, Governance and Trade (VPA/FLEGT), the African Forest Landscape Restoration Initiative (AFR100), and the Reducing Emissions from Deforestation and Forest Degradation, Conservation of Carbon Stocks, Sustainable Forest Management and Enhancing Forest Carbon Stocks (REDD+) process.

Through the African Forest Landscape Restoration Initiative (AFR100) in 2017, the country committed to restoring 12,062,768 hectares of degraded land. This initiative is the pan-African contribution to the "Bonn Challenge", an initiative that aims to restore 350 million hectares of degraded land by 2030. The Restoration Initiative (RI) is a programme funded by the Global Environment Facility (GEF) that brings together three agencies the Food and Agriculture Organization of the United Nations (FAO), the International Union for Conservation of Nature (IUCN), and the United Nations Environment Programme (UNEP) to support the Bonn Challenge and regional initiatives in ten different countries in Asia and Africa by investing in the restoration of degraded land.

This report analyzed the different land uses and land-use changes, as well as the associated sequestration potential, and estimated the greenhouse gas emissions (CO₂) due to the loss of forests in the different zones of the project entitled **"Securing permanent forests to combat climate change and strengthen sustainable national and local economies in Cameroon"**.

2. AIM OF THE STUDY

The objective of this study carried out as part of the feasibility study of the project "Securing permanent forests to combat climate change and strengthen sustainable national and local economies in Cameroon", was mainly to :

- Analyse the different uses and changes in land use in the different landscapes of the project;
- Modelling predictive scenarios of land use change sequenced by 5 years in the baseline scenario over 30 years (BAU)
- Quantifying changes in carbon stocks in the baseline scenario (BAU)

3. GENERAL OVERVIEW OF THE ECOLOGY AND PHYTOGEOGRAPHY OF CAMEROON

Cameroon has often been described as a microcosm of tropical Africa. This image is particularly true when it comes to its vegetation, which offers a compendium of all inter-tropical African vegetation. It contains examples of the continent's main plant formations, from the dense rainforest in the south, through the wooded savannahs of the centre, to the steppes of North Cameroon and the montane forests and grasslands of the West. The major phytogeographical divisions, which correspond to the major climatic zones in terms of both the physiognomy and floristic composition of the vegetation, form three major ecological regions: the Congo-Guinean region in the south, the Sudano Zambézian region in the north, and the montane region associated with the local relief¹.

- Congo Guinean region

The most important vegetation types in this region are :

¹ <https://www.fao.org/3/r4968f/r4968f07.htm>

1) The coastal forest, which extends up to 100 km inland, is an evergreen rainforest occupying the sandy coastal plain at an altitude that rarely exceeds 200 m. Rainfall reaches 4,000 mm on the coast. Characteristic species are *Saccoglottis gabonesis*, *Andira inermis*, *Cynometra hankei*, *Coula edulis*, and *Pycnanthus angolensis*, with *Lophira alata* being exceptionally abundant. This forest is the result of the recolonization of ancient clearings.

2) The Biafran forest lies to the southwest, behind the coastal forest, generally at an altitude of between 200 and 800 m, with rainfall of between 2,000 and 3,000 mm. It is an evergreen rainforest dominated by *Caesalpiniaceae*, the most important genera being *Afzelia*, *Brachystegia*, *Cynometra*, *Didelotia*, *Gilbertiodendron*, *Julbernardia*, *Monopetalanthus* and *Paraberlinia*. It has been subject to intensive human intervention for several decades.

3) The Congolese forest occupies the southern eastern part of the country, in the Dja river basin. It is an evergreen rainforest at medium altitude (200-800 m), with rainfall generally between 1,500 and 2,000 mm and a dry season of up to 3 months. Many of the *Caesalpiniaceae* of the Biafran forest is absent, but it is characterized by the presence of extensive, almost pure stands of *Gilbertiodendron dewevrei*. Other species include *Pericopsis elata*, *Baillonella toxisperma*, *Oddoniodendron micranthum*, and *Afrostryx lepidophyllus*.

4) Semi-deciduous forest is a dense but semi-deciduous forest found at medium altitude immediately to the north of the evergreen rainforests. It is characterized by the abundance of trees belonging to the *Sterculiaceae* and *Ulmaceae* families, many of which have winged seeds that are easily spread by the wind and are dynamic colonizing species. This type of forest is therefore capable of vigorous expansion at the expense of other forest types. To the north, it colonizes the wooded savannah to form vast areas of forest savannah mosaic, while to the south it has formed large pockets in the cocoa-growing areas of the evergreen rainforest, where the semi-deciduous species that make up the forest () provide shade that is favorable to cocoa trees. It includes some high-value peeling and sawing species. Characteristic species include *Triplochiton scleroxylon*, *Mansonia altissima*, *Nesogordonia* sp., *Cola* sp., *Sterculia* sp., *Celtis* sp., *Terminalia superba*, *Entandrophragma cylindricum*, *Piptadeniastrum* sp. and *Parinari excelsa*.

In addition to the four main forest types described above, the Congo Guinean region contains some special edaphic types that are smaller in extent but locally important, such as the mangrove forest along the coast and the swamp forests of the interior.

Between the semi-deciduous forest to the south and the savannahs of the SudanoZambézian region to the north lies an extensive transition zone, sometimes referred to as the Guinea Sudanian savannah. It consists of a mosaic of semi-deciduous forest, mainly concentrated in forest galleries along watercourses, and grassy, wooded or wooded savannah. After the forest has been cleared, the following vegetation succession is found: (1) Grassland with *Pennisetum purpureum* predominating; (2) Grassland with *Imperata cylindrica* predominating; (3) Shrubby savannah with *Annona senegalensis* and

Bridelia ferruginea; (4) Shrubby savannah in which *Terminalia glaucescens* is the most representative species, and which also includes *Annona senegalensis* and *Bridelia ferruginea*, *Albizia spp*, *Crossopteryx febrifuga*, *Hymenocardia sp.* and *Cussonia sp.* From this zone, we gradually move on to the typical Adamaoua savannah of the Sudano Zambezi region.

- Sudano Zambezia region

This region occupies most of the North of the country above the 6th parallel north, with rainfall decreasing progressively as latitude increases. The dry season lasts 6-8 months. The most important vegetation types are as follows, from south to north:

1) The savannah of the Adamaoua plateau lies at an altitude of between 900 and 1,500 metres. It consists of a wooded or treed savannah dominated by *Daniellia oliveri* and *Lophira lanceolata*. *Burkea africana* and *Terminalia spp.* are locally abundant. In the valley bottoms, we find species of the dense semi-deciduous forest, such as *Aubrevillea kerstingii*, *Erythrophloeum suaveolens*, *Chlorophora excelsa*, *Khaya grandifoliola*, *Phyllanthus discoideus*; in the more marshy valleys *Syzygium guineense* var. *guineense* predominates.

2) The savannahs of the Benoué include several types. In the hills immediately to the north of the Adamaoua plateau, the outstanding species are *Uapaca togoensis* and *Anogeissus leiocarpus*, with many species characteristic of the plateau itself. In the upper basin of the Bénoué and its tributaries, *Isobertia doka* and *Monotes kerstingii* predominate. On the Bénoué plain, the typical vegetation is a shrubby savannah dominated by *Terminalia spp.* with other species such as *Dalbergia melanoxylon*, *Diospyros mespiliformis*, *Boswellia sp.* and *Commiphora sp.* In the more marshy parts of the plain, *Borassus aethiopium* predominates.

3) The thorn steppes of the Sahelo-Sudanian zone are found mainly between 10° and 11° latitude North. The predominant species are *Acacia albida*, *Balanites aegyptiaca*, *Acacia seyal*, *Ziziphus sp.*, and *Combretum sp.* In the even drier Sahelo-Saharan zone on the shores of Lake Chad, *Acacia senegalensis* is the only characteristic species.

4) Periodically flooded grasslands cover a vast area south of Lake Chad. Where flooding is only temporary, the dominant species are *Acacia seyal* and *Acacia nilotica*, while where it is more permanent the typical vegetation is treeless grassland.

5) The dry mountains of the Atlantika and Mandara mountains are intensively cultivated, but contain scattered, semi-domesticated trees of *Acacia albida*, *Adansonia digitata*, *Khaya senegalensis*, *Diospyros sp.*, *Tamarindus sp.*, *Ziziphus sp.*

- Mountain region

This region covers a much smaller area than the Congoguinean and Sudano Zambezi regions, and is discontinuous due to the separation between the various mountain ranges. Vegetation types can be classified according to altitude.

1) The submontane forest is a dense evergreen forest between 800 and 2000 m altitude. The only conifer indigenous to Cameroon, *Podocarpus milanjanus*, is found near its upper limit. Tree ferns are a notable feature of the wet valleys.

2) The montane forest is found mainly above 1800 m, and consists of an evergreen forest dominated by shrubs and small trees. At its upper limit, it gives way to "ericaceous thickets". Much of this forest has been cleared for agriculture and grazing.

3) The Afro subalpine zone is found at above 2800 m, and is limited to Mount Cameroon and Mount Oku. The vegetation consists of grassland with shrubs or small trees belonging to the *Vernonia*, *Senecio*, *Alchemilla*, and *Pentaschistis* genera.

4. METHODOLOGY

The various methods used for the analysis of land use changes in this study were based on the REDD+ methodological guidelines of the Carbon Fund for Forest Partnership (FCPF), the 2006 IPCC guidelines on good practice for GHG inventories in the AFAT sector, the guidelines for the REDD+ MNV system in Cameroon and the country's National REDD+ Strategy. These methods were also inspired by the studies carried out in the project's various landscapes in terms of carbon stock assessment. In addition, a general orientation meeting on the different methods used and the results produced, held on 30 June 2022 in Yaoundé, to improve the greenhouse gas assessment statistics (CO₂) in this report.

4.1. PRESENTATION OF PROJECT AREAS

The areas targeted by the project were

- (i) Dja Lobéké landscape (rainforests surrounded by mining operations and large agricultural enterprises rubber, palm, and cocoa plantations, etc.);
- (ii) Bakossi -Bamboutos landscape (traditional agriculture and industrial tea plantations) and ;
- (iii) Waza landscape (Sudano Sahelian) (cotton/rice plantations and large herds of cattle).

The choice of these project areas was based firstly on the implementation sites proposed in the Project Idea Note (PIN), and secondly on a workshop that helped to refine the spatial delimitation of the various project implementation sites. This workshop took place in Mbalmayo with the participation of key players from the Ministry of Forests and Fauna (MINFOF), the Ministry of the Environment, Nature Protection and Sustainable Development (MINEPDED), and certain NGOs and civil society. The selection criteria were essentially permanent forest landscapes under threat from various human activities (agriculture, poaching, livestock farming, logging). Over and above these threats, the presence of permanent forest sustainable management programmes and projects in the targeted landscapes also guided the spatial delimitation of the intervention sites.

Figure 2 shows the project's various impact and intervention zones.



Figure 1 Geographical location of the various project areas

4.2. REMINDER OF THE DEFINITION OF FOREST IN CAMEROON

The REDD+ process, which is a mechanism whereby countries are rewarded for conserving forests and reducing emissions from forests relative to an agreed baseline, the details of which are still being discussed within the United Nations Framework Convention on Climate Change (UNFCCC), combines "reducing emissions from deforestation", "reducing emissions from (forest) degradation", "conservation of forest carbon stocks", "sustainable forest management" and "enhancement of forest carbon stocks".

It is based on the concept of forest as a determining element of its scope. To this end, the United Nations Framework Convention on Climate Change (UNFCCC), as part of the Kyoto Protocol, has defined "forest as an area of at least 0.05 to 1 hectare with tree crown cover (or equivalent stocking level) of more than 10-30% that has the potential to reach a minimum height of 2-5 metres at maturity in place" (UNFCCC, 2002).

Cameroon is one of the countries that have subscribed to and adopted the forest definition of the United Nations Framework Convention on Climate Change (UNFCCC), namely 10% forest cover, a minimum height of 3 meters, and a minimum area of 0.5 hectares (REDD+ National Strategy, 2018). This definition of forest adopted by the country takes into account not only tree and shrub savannahs but also agro forests as being forests because tree and shrub savannahs and agroforestry systems can reach the forest cover threshold chosen by the country (10%) and thus be part of REDD+. For example, Bisseleau et al (2009) have shown that at least some cocoa agroforestry systems in southern Cameroon have a cover of 88%, clearly above the threshold. This implies, for the UNFCCC definition of forest, that all cocoa agroforestry systems in Cameroon have the potential to be forests, and should be included in the REDD+ process. Once a canopy threshold is set, it must be respected consistently. According to the author, most tree production and agroforestry systems meet the minimum requirements for canopy cover and potential tree height. Unpruned coffee trees, for example, can easily reach a height of five metres.

Thus, in the process of identifying the different land use/land cover classes and identifying useful parameters for quantifying the mitigation potential of CO₂ emissions due to deforestation in the project areas, the different land categories presented in Table 1 were used.

Table 1 Different land categories used to classify satellite images according to project landscapes

Categories	Environment ecological	Type	Management mode Operating	Project area
Forest		Dense forest	Communal Forest FMU	Paysag Dja Lobéké

	Guinean-Congolese forest		Community Forest	Bamboutos landscape Bakossi
			Protected areas	
		Open forest	Cultivated land (Perennial crop)	
	Biafran forest		Mosaic of natural vegetation	
		Forest gallery	Firewood	
	Vegetation with tree strata	Wooded savannah	Protected areas	WAZA landscape Bamboutos landscape Bakossi
		Shrubby savannah	Agriculture	
Meadows	Vegetation with herbaceous strata	Grassy savannah	Firewood	WAZA landscape
			Agriculture	
Cultivated land	Crops	Annual crops	Grazing	All the landscapes
			Maize	
			Cassava	
			Macabo	
			Yam	
Other type	No zone Vegetation	Water	Millet/sorghum	All the landscapes
		Establishment	Dam, watercourse	
			Housing, transport	

4.3. SATELLITE IMAGE ANALYSIS

The different satellite image analysis approaches used are presented in stages below .

Stage 1: Acquisition of satellite images

In this study, satellite images from the Landsat 45 TM, Landsat 7 ETM, and Landsat 8 OLI sensors for the periods 2000, 2010, and 2021 respectively were used to produce the land cover maps. These images from between November and December were acquired to minimize cloud cover and harmonised the different processing periods. LANDSAT imagery was chosen because of its historical availability in terms of image archives. LANDSAT satellites have been in orbit since 1972 and have been improved over time. In addition, the choice of this space data was based on the REDD+ and IPCC 2006 methodologies, which require images to be taken over a long time (at least 10 years apart) and a resolution of between 30 m and 100 m.

Tables 2, 3, 4, and 5 show the series of satellite images used to map land use in the different landscapes.

Table 2. Satellite image series used in the WAZA country

Sensors	Path	Row	Date of acquisition	Resolution (m)	Sources
20002000					
Landsat 5 TM	184	052	17/11/20002000	30	https://glovis.usgs.gov/
Landsat 5 TM	184	053	17/11/20002000	30	https://glovis.usgs.gov/
Landsat 5 TM	185	052	17/11/20002000	30	https://glovis.usgs.gov/
2010					
Landsat 7 ETM	184	052	30/11/2010	30	https://glovis.usgs.gov/
Landsat 7 ETM	184	053	20/11/2010	30	https://glovis.usgs.gov/
Landsat 7 ETM	185	052	02/12/2010	30	https://glovis.usgs.gov/
2021					
Landsat 8 OLI	184	052	21/11/2021	30	https://glovis.usgs.gov/
Landsat 8 OLI	184	053	21/11/2021	30	https://glovis.usgs.gov/
Landsat 8 OLI	185	052	28/11/2021	30	https://glovis.usgs.gov/

Table 3. Series of satellite images used in the Bakossi -Bamboutos region

Sensors	Path	Row	Date of acquisition	Resolution (m)	Sources
20002000					
Landsat 5 TM	186	056	21/12/2000	30	https://glovis.usgs.gov/
Landsat 5 TM	186	057	29/11/2000	30	https://glovis.usgs.gov/
Landsat 5 TM	187	056	12/12/2000	30	https://glovis.usgs.gov/
2010					
Landsat 7 ETM	186	056	05/12/2010	30	https://glovis.usgs.gov/
Landsat 7 ETM	186	057	05/12/2010	30	https://glovis.usgs.gov/
Landsat 7 ETM	187	056	20/11/2010	30	https://glovis.usgs.gov/
2021					
Landsat 8 OLI	186	056	21/11/2021	30	https://glovis.usgs.gov/
Landsat 8 OLI	186	057	29/12/2021	30	https://glovis.usgs.gov/

Landsat OLI	8	187	056	10/11/2021	30	https://glovis.usgs.gov/
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Table 4. Satellite image series used in the Dja Lobeké country

Sensors	Path	Row	Date of acquisition	Resolution (m)	Sources	
20002000						
Landsat 5 TM	182	058	09/12/2000	30	https://glovis.usgs.gov/	
Landsat 5 TM	182	059	09/12/2000	30	https://glovis.usgs.gov/	
Landsat 5 TM	183	058	01/12/2000	30	https://glovis.usgs.gov/	
Landsat 5 TM	183	059	01/12/2000	30	https://glovis.usgs.gov/	
Landsat 5 TM	184	058	17/12/2000	30	https://glovis.usgs.gov/	
Landsat 5 TM	184	059	17/12/2000	30	https://glovis.usgs.gov/	
2010						
Landsat ETM	7	182	058	06/12/2010	30	https://glovis.usgs.gov/
Landsat ETM	7	182	059	14/12/2010	30	https://glovis.usgs.gov/
Landsat ETM	7	183	058	13/12/2010	30	https://glovis.usgs.gov/
Landsat ETM	7	183	059	10/12/2010		https://glovis.usgs.gov/
Landsat ETM	7	184	058	18/12/2010	30	https://glovis.usgs.gov/
2021						
Landsat OLI	8	182	058	23/12/2021	30	https://glovis.usgs.gov/
Landsat OLI	8	182	059	23/12/2021	30	https://glovis.usgs.gov/
Landsat OLI	8	183	058	28/12/2020	30	https://glovis.usgs.gov/
Landsat OLI	8	184	058	23/12/2020	30	https://glovis.usgs.gov/

Table 5 shows the characteristics of the various Landsat sensors used.

Table 5. Characteristics of the different Landsat sensors used

Characteristics	Landsat 7	Landsat 4 and 5	Landsat 8
Start and end of mission	1999 present	Landsat 4: 1982 1993 Landsat 5: 1984 2013	2013 present
Satellite Status	Mission Completed	Mission Completed	Operational
Mass	816-960 kg	1,938-1,961 kg	2,600 kg
Instruments	ETM: radiometer	MSS and TM: radiometer	OLI and TIRS: radiometer

Spectral bands	B1: 0.45 0.52 μm B2: 0.52 0.60 μm B3: 0.63 0.69 μm B4: 0.77 0.90 μm B5: 1.55 1.75 μm	B1: 0.45 0.5 μm B2: 0.52 0.6 μm B3: 0.63 0.7 μm B4: 0.76 0.9 μm B5: 1.55 1.7 μm B6: 2.08 2.3 μm	B1: 0.43 0.45 μm B2: 0.45 0.51 μm B3: 0.525 0.6 μm B4: 0.63 0.68 μm B5: 0.84 0.88 μm B6: 1.56 1.66 μm B7: 1.36 1.39 μm B8: 2.10 2.30 μm
Thermal infrared	10.40 12.50	10.4 12.5 μm	10.3 11.3 μm 11.5 12.5 μm
Panchromatic	B6: 0.52 - 0.90 μm		B9: 0.5 0.68 μm
Resolution	General: 30 m Panchromatic: 15 m Thermal infrared: 60 m	General: 30 m Thermal infrared :120 m	General: 30 m Panchromatic: 15 m Thermal infrared: 100 m
Imaging technique	Whiskbroom	Whiskbroom	Pushbroom
Orbit	Altitude: 705 km cycle: 16 days time: 10 a.m.	Altitude: 705 km cycle: 16 days time: 9:30 10:00 a.m.	Altitude: 705 km cycle: 16 days time: 10 a.m.

Step 2: Image pre-processing

At this stage, the strips were de-archived and assembled (layer stacking), and radiometric calibration and atmospheric corrections were made to correct for changes in scene illumination, atmospheric and solar conditions, observation geometry, and instrument response using Envi 5.3 software. The image-by-image recording was then carried out for each sensor (TM, ETM+, and OLI).

Stage 3: Identification of land use categories

Land use categories were identified firstly based on the IPCC 2006 recommendations on good practice in the Agriculture, Forestry, and Other Land Use (AFOLU) sector, and then based on a documentary review of national documents from MINEPDEDD, MINFOF, and technical reports from organizations such as CIFORD and GIZ on land use and occupancy in the country's EIAs. Platforms such as Bing Map, Planet, Google Earth, and Maxar were also used to refine the identification of land-use classes. Based on the principles of the IPCC 2006, the guidelines for drawing up MRV in Cameroon, and on the physiognomy of vegetation and the definition of forest in Cameroon, the different land-use categories were established for the project landscapes (Table 1).

Step 4: Image classification

The image classification involved a multi-temporal classification approach using the Envi 5.3 support vector machine (SVM) algorithm. Developed in the 1990s (Boser et al., 1992), support vector machines or wide-margin separators are a set of supervised learning techniques designed to solve discrimination and regression problems. They are based on two main ideas: the notion of maximum margin and the notion of kernel function. SVM fits a linear hyperplane between two classes in a multidimensional feature space by

maximizing the margin between the training samples of the two classes (Foody and Mathur, 2004). The parameter model used was based on training samples of each land use type.

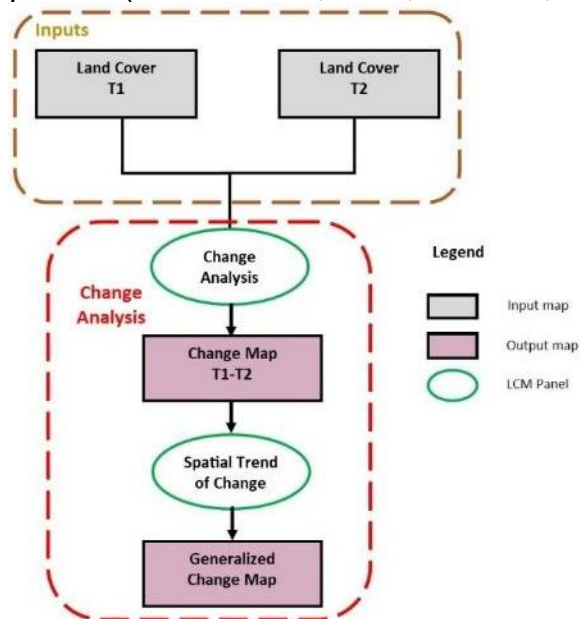
Stage 5: Post-classification and finalization

The post-classification operations involved assessing the accuracy of the classification maps. Pixel confusion matrices were developed. These matrices were used to determine the overall accuracy of the results obtained (total number of correctly classified pixels, Kappa coefficient) and the accuracy of each classified category, including individual accuracy. The classification result was considered acceptable if the total number of correctly classified pixels was greater than 85% (Gao and Skillcorn 1998). The individual accuracies of the categories are of the same order (Anderson et al. 1971), and the Kappa coefficient must be greater than 0.80 (Tso and Mather 2001; Mather 2004). The accuracy of the results was also assessed using the Google Earth and Bing Map platforms, which have a better spatial resolution of around 1.5 m.

Step 6: Detecting changes in land use

The analysis of land use change in this study involved using the Land Change Modeler (LCM) of TerrSet (formerly IDRISI) version 18 software. LCM is a module of TerrSet oriented towards the urgent problem of accelerated land conversion and the very specific analytical needs of biodiversity conservation. In the LCM, the tools for assessing and forecasting changes in land use and their implications are organized around major areas of activity: change analysis, change forecasting, and intervention planning. In addition, the LCM provides support for projects aimed at reducing emissions from deforestation and forest degradation (REDD).

In this analysis, change was assessed between time 1 (2000) and time 2 (2021) of the land cover maps (Figure 5). The changes identified were transitions from one land cover state to another. In addition, annual rates of change were calculated for the different periods (Pontius et al., 2004; Braimoh, 2006).



4.4. CALCULATION OF THE DEFORESTATION RATE

The annual deforestation rate results from the ratio between the deforestation rate over a period and the number of years between the two pivotal years of the period (Menon and Bawa (1997), Ramesh et al. (1997), Narendra Prasad (1998), WRI (1995)). However, the annual deforestation rate cannot be obtained with this simple ratio. Indeed, several publications have recently pointed out that the evolution of forest loss follows the same law as the law of compound interest and have adapted the approach to calculating the rate of deforestation according to this law (FAO, 1995).

Table 6 shows the different formulas for calculating deforestation

Table 6. Approaches to calculating the rate of deforestation

References	Formulas
WRI (1995), Menon and Bawa (1997), Ramesh et al (1997), Narendra Prasad (1998),	$\phi = \frac{1}{t_2 - t_1} \left(A_1 - \frac{A_2}{A_1} \right)$
FAO, 1995	$\phi = 1 - \left(\frac{A_2}{A_1} \right)^{\frac{1}{t_2 - t_1}}$
Vieilledent et al 2013, Grinand et al, 2013	$\phi = 1 - \left(1 - A_1 - \frac{A_2}{A_1} \right)^{\frac{1}{y}}$ y weighted interval
Puyravaud et al 2002	$\phi = -\frac{1}{t_2 - t_1} \ln \left(\frac{A_2}{A_1} \right)$

With :

t1 date of year 1 and t2 date of year 2

ϕ : Annual rate of deforestation between t1 and t2 in [%].

A1: forest area in t1; A2: forest area in t2

Since the various project areas overlap between several Landsat images, the formula proposed by Puyravaud et al 2002 was adopted to calculate the historical deforestation rate in the present study. It is presented in the following relationship:

$$\phi = -\frac{1}{t_2 - t_1} \ln \left(\frac{A_2}{A_1} \right) * 100$$

4.5. MODELLING OF SCENARIOS PREDICTING LAND USE IN PROJECT LANDSCAPES

Over the last 20 years, models such as Markov chain, CA Markov, GEOMOD, and LCM (Land Change Modeler), have been considered efficient and effective for predicting land cover change, as they are coupled to GIS in data analysis, simulation of change probabilities and improvement of predictive results (Eastman, 2006; Pontius and Chen, 2006; Tewolde and Cabral, 2011).

However, it is difficult to compare the performance of these models because of their fundamental differences and their dependence on the research objectives. For example, with the GEOMOD model, the simulation covers only two land cover categories (Silva and Clarke, 2002; Pontius et al., 2001), whereas other models, such as the CA Theoretical and methodological approach to remote sensing and GIS for modelling land cover change, Markov and the LCM can simulate changes in several categories at once (Burstedde et al., 2001; Pontius and Chen, 2006).

The CA Markov model is an improvement on the Markov module which has several advantages over it. Theoretically, this model can simulate changes in several categories at the same time.

The LCM module can be used to assess the accuracy of each stage in the simulation process and to choose the algorithm best suited to the initial objective. It is currently a widely used modelling tool. Still at an experimental stage, it has a lot of potential and can work with neural networks and provide results with an accuracy of over 70% (Islam and Ahmed, 2011). In addition, this model also directly provides as output a predictive map of land use with categories identical to those of the initial map.

As part of the simulation of land use changes in this study, we produced predictive land use maps for several dates with an acceptable overall accuracy. Consequently, we used the Land Change Modeler (LCM) module to predict this change for the next thirty years in each of the project landscapes. On the basis of the historical changes determined from the multi-time series, the land cover maps were integrated to model land cover change using logistic regression (ReLog) or the Multi-Layer Perceptron (PMC) to 2051. The various maps produced were validated in the model by comparing the predictive map with the reference map (2021) (Figure 4).

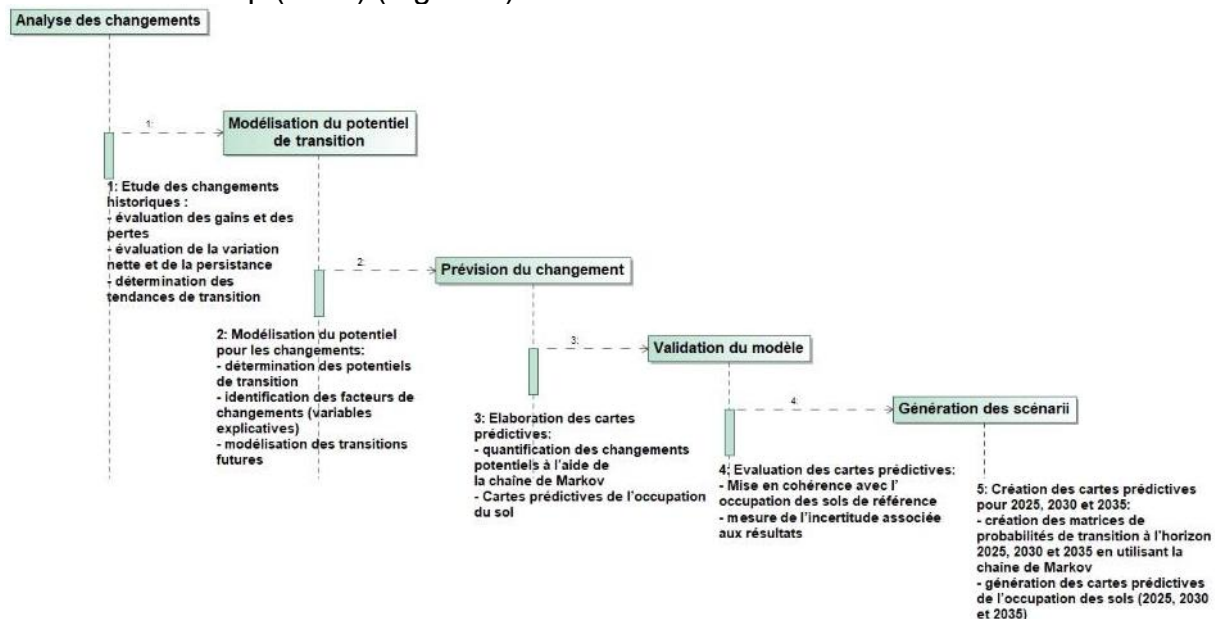


Figure 3 Scenario for predicting land use change using the LCM (Source: Tanougong, 2019)

In order to spatialise the potential predictive changes in the different landscapes of the project, two biophysical explanatory variables were selected for the development of a predictive map of the evolution of land use: distance to the road network, and distance to towns and villages. To this end, an Euclidean distance was applied to these variables to obtain the spatial distribution of their influence on the forests. The changes identified in each pair of images were considered as independent transition submodels linking the observed mutations with explanatory variables. These were selected based on their explanatory potential and assessed using the CramerV coefficient. This compares each explanatory variable with the categories of the 2000/2000 and 2021 maps.

Figures 5, 6, and 7 show the spatial distribution of the different explanatory variables used (roads and localities). The proximity of roads and towns could explain the high pressure on natural resources. The areas with high values are those that will have the least impact in terms of change because the explanatory variables are not present in these areas.

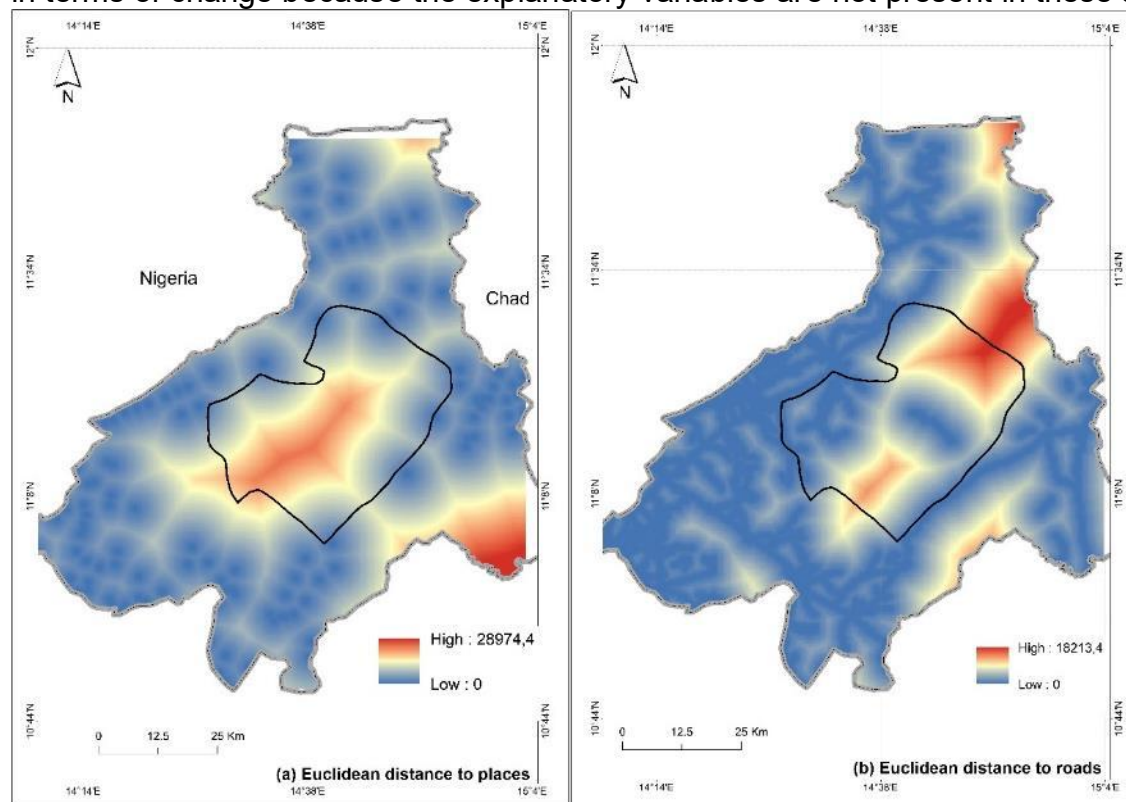


Figure 4 Variables used to predict changes in land cover in the Waza landscape

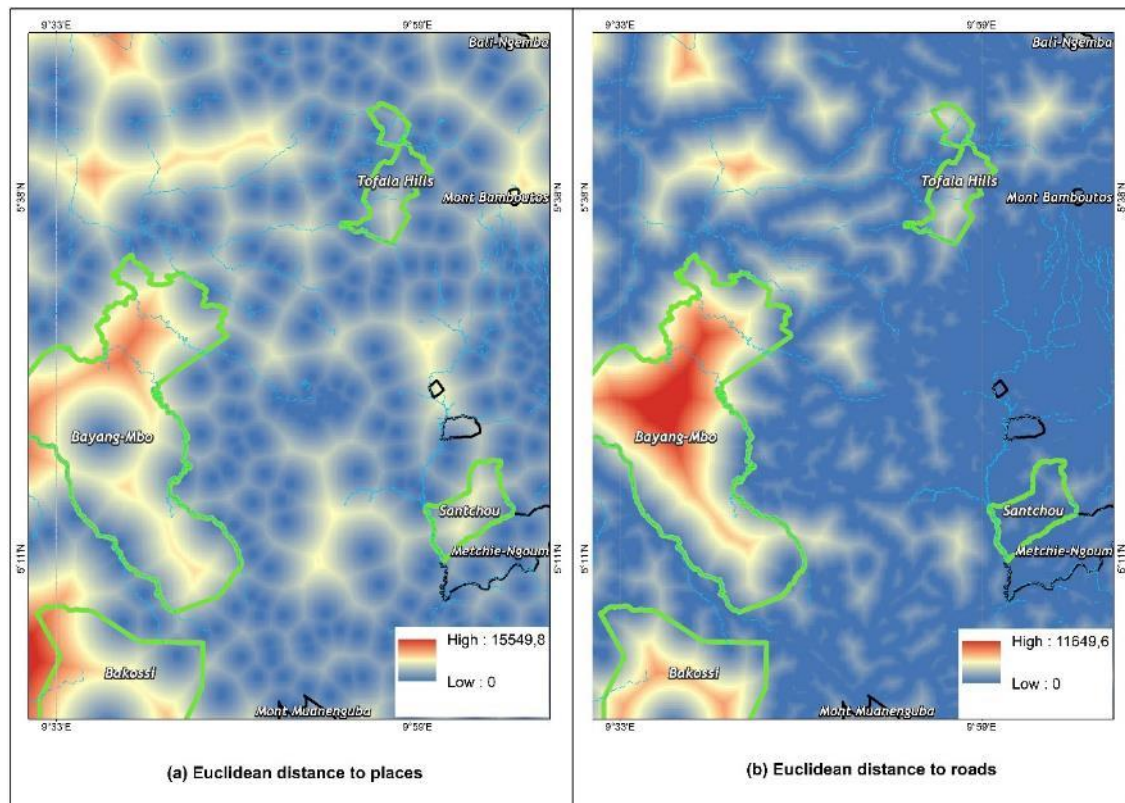


Figure 5 Variables used to predict changes in land cover in the Bamboutos landscape Bakossi

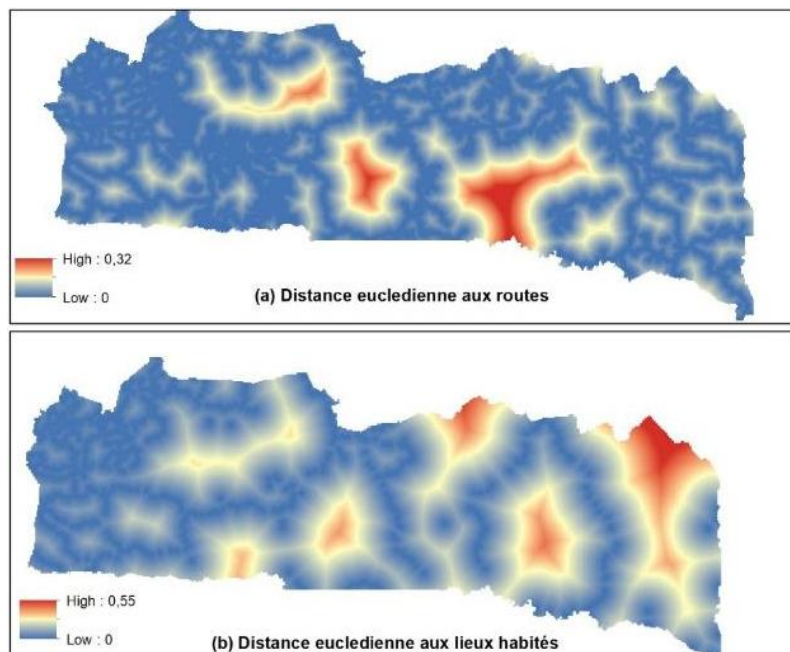


Figure 6 Variables used to predict changes in land cover in the Dja Lobeke landscape

4.6. CALCULATION OF CO₂

The calculation of greenhouse gas (GHG) emissions linked to land use change is based on the level of carbon balance in each vegetation type. CO emissions₂ (or CO sequestration₂) are calculated as the difference between the carbon content of the final vegetation type and the initial vegetation type. For example, for deforestation due to the expansion of cultivated land, as the carbon content of cultivated land is assumed to be zero, emissions will be equal to the carbon content of the forest in the biomass above and below ground in a given spatial unit.

In this study, we did not take into account the carbon in the litter and dead wood, but rather that in the trees (epigeous and hypogeous) and in the soil, due to the lack of data on the various carbon pools in the project areas. Furthermore, the only gas included in this report is carbon dioxide (CO₂). Non-CO₂ gases associated with fire were not taken into account, due to the lack of data on slash-and-burn agriculture.

Emissions for this study were calculated on the basis of IPCC good practice guidelines (IPCC, 2003) and greenhouse gas inventories (IPCC, 2006). Historical land use change data was used (2000 to 2021). The equation below was used to calculate emissions due to deforestation.

$$\Delta C_{CONVERSION} = \sum_j EF_j \times \Delta A_j$$

Where:

A represents the area affected by deforestation and **EF** represents the emissions factor or the quantity of gas lost per unit area.

The deforested area corresponds to activity data, i.e. the destruction or conversion of forests to other types of land use (crops, urbanisation, etc.). For each period of satellite image analysis, these activity data were first obtained by image cross-referencing (2000-2021), and then the areas of lost forest resulting from the cross-referencing were evaluated in ha.

To deduce the emission factor (EF), we have used the work of numerous researchers who have assessed the carbon stocks in different landscapes, and we have deducted the average.

The IPCC guidelines provided different methodologies for estimating changes in carbon stocks. The gains-losses method was used in this study. This method is a process-based approach, which estimates the net balance of additions to and removals from a carbon stock. Gains can be attributed to growth (increase in biomass) and the transfer of carbon from another pool (for example, transfer of carbon from the living biomass carbon pool to the dead organic matter pool due to harvesting or natural disturbances). Gains are always marked with a positive sign (+). Losses can be attributed to carbon transfers from one pool to another or to emissions due to decomposition, harvesting, burning, etc. are always marked with a negative sign (-).

The following formula was used to calculate the land remaining in the same land use category;

ÉQUATION 2.7
VARIATIONS ANNUELLES DES STOCKS DE CARBONE DE LA BIOMASSE DES TERRES RESTANT DANS LA
MEME CATEGORIE D'AFFECTATION DES TERRES (METHODE GAINS-PERTES)

$$\Delta C_B = \Delta C_G - \Delta C_P$$

CG represents the annual increase in biomass carbon stocks due to the increase in biomass on land remaining in the same land use categories.

CP represents the annual reduction in carbon stocks due to biomass losses on land remaining in the same land use categories

CG is obtained by applying the following formula;

$$\Delta C_G = \sum_{i,j} (S_{i,j} \bullet C_{ce-TOTALE_{i,j}} \bullet FC_{i,j})$$

Where

$$C_{ce-TOTALE} = \sum \{C_{ce} \bullet (1 + Tx)\}$$

Tx, Cce, and FC values are provided by default by the IPCC when not available for the country.

Cp is obtained by applying the following formula;

$$\Delta C_P = P_{\text{extraction-de-bois}} + P_{\text{bois-de-chauffage}} + P_{\text{perturbations}}$$

Or

$$P_{\text{extraction-de-bois}} = \{R \bullet FECB_E \bullet (1 + Tx) \bullet FC\}$$

$$P_{\text{bois-de-chauffage}} = [\{FG_{\text{arbres}} \bullet FECB_E \bullet (1 + Tx)\} + FG_{\text{parties}} \bullet D] \bullet FC$$

$$P_{\text{perturbation}} = \{S_{\text{perturbation}} \bullet B_W \bullet (1 + Tx) \bullet FC \bullet fp\}$$

$P_{\text{extraction de wood}}$ represents the annual loss of carbon in the biomass due to the extraction of wood

$P_{\text{bois de}}$ represents the annual loss of carbon in the biomass due to the extraction of firewood.

$P_{\text{perturbation}}$ represents the annual loss of carbon in the biomass due to disturbance.

The following formula was used to calculate land converted to other land uses:



Annual change in biomass carbon stock of land converted to other land-use categories = annual increase in biomass carbon stock due to growth of land converted to other land-use categories + initial change in biomass carbon stock of land converted to other land-use categories - annual decrease in biomass carbon stock due to losses associated with harvesting, fuelwood collection, and disturbance on land converted to other land-use categories. The EF values for each formula are contained in the various tables in volume 4 of the 2006 guidelines.

4.6.1. ESTIMATED EMISSIONS IN THE WAZA LANDSCAPE

In the Waza area of Far North Cameroon, there were almost no studies that have estimated or assessed carbon stocks. However, according to measurements by Kodji et al (2021) in 5 villages (Gawar, Minawao, Sabongari, Windé, and Zamay) south of Mokolo Minawao, in the Far North region of Cameroon, in the Mayo Tsanaga Department to be precise, carbon stocks in woodlands vary between 0.38 and 0.65 tC/ha. Ibrahima and Fanta (2008) also estimate carbon stocks in the tree and shrub facies of the Guinean Soudano savannahs at between 0.66 and 48.1 tC/ha. Based on the results of these studies, by calculating the average of the variations in carbon stocks measured by these authors, we have used the value of 12.44 tC/ha as the carbon stock for woodland formations. Given that one tonne of carbon corresponds to 3.67 tonnes of CO₂ (Katembera et al., 2015), the EF is therefore 45.67 tonnes of CO₂ emitted per hectare.

Table 7 shows the different carbon stocks used to calculate emissions.

Table 7 Carbon stocks used to estimate emissions in the Waza landscape

Category	Change in carbon stock (tC/ha)	Sources
Forest	0.38 à 0.65 Average = 0.51	Paul Kodji, Tchobsala , Ibrahima Adamou. (2021). Impacts of refugees on the specific contribution and carbon stock of herbaceous plants in the Minawao savannah (Cameroon). https://doi.org/10.35759/JABs.164.5
	0,66 à 48,1 Average = 24.38	Adamou IBRAHIMA and Chimène ABIB FANTA. (2008). Estimation of carbon stock in tree and shrub facies in savannahs. Soudano from Ngaoundéré, Cameroon. Cameroon Journal Of Experimental Biology 2008 Vol.04, N° 01. http://cajeb.ifrance.com

4.6.2. ESTIMATED EMISSIONS IN THE BAKOSSI LANDSCAPE BAMBOUTOS

In the Bakossi-Bamboutos landscape, several studies have estimated the carbon stock in forests (Cuni and Sullivan (2021), Frederic et al. (2018) and Temgoua et al., (2020)) and in agroforestry systems (Fogaing et al., (2021) and Tsewoue et al., (2021)). By averaging the variations in carbon stocks identified in the literature, we used the value of 160.30 tC/ha for forests and 64.58 tC/ha for crops/plantations as the carbon stock. Given that one tonne of carbon corresponds to 3.67 tonnes of CO₂ (Katembera et al., 2015), the EF is then 588.30 tonnes of CO₂ emitted per hectare for forests and 237.02 tonnes of CO₂ emitted per hectare for crops.

Table 8 shows the different carbon stocks used to calculate emissions.

Table 8 Carbon stocks used to estimate emissions

Category	Change in carbon stock (tC/ha)	Sources
Forest	137,1 à 164,2 Average = 150.65	Cuni Sanchez, A., Sullivan, M.J.P., Platts, P.J. et al. (2021) High aboveground carbon stock of African tropical montane forests. <i>Nature</i> 596, 536-542 (2021). https://doi.org/10.1038/s41586-021-03728-4
	298.08 à 114.36 Average = 206.22	Frederic C. Lounang Tchatchouang, Cedric Chimi Djomo, Vice Clothex Tajeukem, Paul Djibrillia, Joseph Youta Happei (2021). Diversity, Structure, and Carbon Stocks from Three Pools in the Kouoghap Sacred Forest, Hedgerows and Eucalyptus Plantations in the Batoufam Locality (West Cameroon). <i>Applied Ecology and Environmental Sciences</i> . Vol. 6, No. 4, 2018, pp 160 169. http://pubs.sciepub.com/aees/6/4/7
	235.88 à 12.15 Average = 124.04	Temgoua, L. F., Etchike, A. B. D., Marie Solefack, C. M., Tumenta, P., & Nkwelle, J. (2020). Woody species diversity conservation and carbon sequestration potential of coffee agroforestry systems in the Western Region of Cameroon. <i>Journal of Horticulture and Forestry</i> , 12(2), 35 48.
Plantation	59.82 à 29.66 Average = 44.74	Fogaing J.R., Ndonmou E.C., Kuete Fogang M., Avana Tiencheu M.L., & Tsalefac M.4. (2021). Carbon storage potential of agroforests on the eastern slopes of the Bamboutos Mountains in the Western Highlands of Cameroon. <i>Revue scientifique et</i>

		technique foret et environnement du bassin du congo, 16, 36-49. https://doi.org/10.5281/zenodo.4699504
	144.1 à 27.76 Average = 84.43	Tsewoue, M. R., Avana Tientcheu, M. L., & Boyah, J. K. (2021). Structure and carbon stock of canarium schweinfurthii (engl) (burseraceae) in coffee based agroforestry systems of the bamboutos, west cameroon. International Journal of Research GRANTHAALAYAH, 9(10), 173-186. https://doi.org/10.29121/granthaalayah.v9.i10.2021.4306

4.6.3. ESTIMATED EMISSIONS IN THE DJA LOBÉKÉ LANDSCAPE

Several studies have estimated carbon stock variations in the Dja Lobéké landscape (Tabue et al. 2018, Suspense, 2019, Zapfack et al. 2013, Temgoua et al, 2018). By averaging the changes in carbon stocks based on the results of these studies, we used 194.61 tC/ha as the carbon stock for forests and 78.36 tC/ha for crops/plantations. Given that one tonne of carbon corresponds to 3.67 tonnes of CO₂ (Katembera et al., 2015), the EF is then 714.22 tonnes of CO₂ emitted per hectare for forests and 287.58 tonnes of CO₂ emitted per hectare for crops.

Table 9 shows the different carbon stocks used to calculate emissions.

Table 9 Carbon stocks used to estimate emissions

Category	Change in carbon stock (tC/ha)	Sources
Forest	58.6 à 238.9 Average = 178.05	Tabue et al (2018). Diversity, structure, and carbon storage potential of the Dja Wildlife Reserve vegetation cover
	80 à 430 Average = 295	Suspense Averti Ifo and Stoffenne Binsangou (2019). Spatial variability of aboveground biomass carbon stock from urban to dense tropical forest in five localities in the Republic of Congo.
	65.27 à 123.76 Average = 127.15	Zapfack et al (2013). Deforestation and Carbon Stocks in the Surroundings of Lobéké National Park (Cameroon) in the Congo Basin.

	55.48 à 250.12 Average = 180.54	Temgoua et al (2018). Spatial and temporal dynamic of land cover/land use and carbon stocks in Eastern Cameroon: a case study of the teaching and research forest of the University of Dschang.
	46.4 à 338.3 Average = 192.35	Bocko et al (2017). Quantifying Carbon Stocks in Three Key Carbon Pools in Central Africa: The Case of the Likouala Swamp Forest (Northern Congo).
Plantation	17.31 à 60.22 Average = 47.42	Zapfack et al (2013). Deforestation and Carbon Stocks in the Surroundings of Lobéké National Park (Cameroon) in the Congo Basin.
	38.27 à 142.08 Average = 109.31	Temgoua et al (2018). Woody Diversity and Carbon Stock of Cocoa-based Agroforestry Systems in East Cameroon.

5. RESULTS OF THE STUDY

Land cover is a relevant indicator of a combination of human activities that societies deploy in space and to which land cover reacts with a certain inertia and natural factors (Paegelow M., 2014). Changes in land cover are calculated by comparative analyses of information layers at different dates. This section of the report presents the land cover dynamics as well as the mitigation potential of emissions from deforestation in the different landscapes of the project.

5.1. WAZA LANDSCAPE

The WAZA landscape in the Soudano Sahelian zone of Cameroon is an ecosystem with multiple potentials that contribute to the economic and social development of the local populations. Because of all its potential, the landscape is highly prized and subject to multiple pressures and threats that jeopardize the permanent forest estate. The section below describes the land typology and land-use dynamics in the WAZA landscape.

5.1.1. ASSESSMENT OF THE ACCURACY OF LAND USE MAPS IN THE WAZA LANDSCAPE

The accuracy of the 2000, 2010, and 2021 images was based on sampling plots (ROIs) of the different land use categories. The pixels of the land use classification for each date are listed in table 10. Table 1 shows that out of 42443 pixels tested, 38290 correlate perfectly with the reference data. The overall accuracy is 87.85% and the Kappa coefficient is 0.82.

Table 10 Calculation of uncertainty errors

Occupancy class	Commission error (pixel)	Omission error (pixel)
Humid grassland savannah	1501/26487	1149/26135
Built up area	1659/2914	1447/2702
Cropland	709/5029	1638/5958
Grassland	0/1480	28/1508
Forest	37/1289	0/1252
Water surface	482/4041	847/4406

5.1.2. LAND USE IN THE WAZA LANDSCAPE IN 2000

In 2000, the Waza landscape was largely occupied by wet grassy savannahs (271,124.37 hectares), i.e. 41.66% of the landscape. This wetland, which lies along the border with Chad, was classified as a RAMSAR site in 2012. Forests cover 247,541.58 hectares of the landscape or 38.04% of spatial occupancy. Grassland savannahs (72,502.29 hectares) account for 11.14% of land use. Cultivated areas or agricultural plantations, located in the southern western part of the landscape (Figure 3), occupy 56,001.06 hectares, or 8.61% of the land area. Other land uses included water areas and inhabited areas, which accounted for 0.45% and 0.10% of the landscape area respectively. Table 11 shows the land use statistics for the WAZA landscape in 2000.

Table 11: Land use statistics for the Waza landscape in 2000

Landcover	Area (2000)	%
Humid grassland savannah	271 124,37	41,66
Built up area	630,99	0,10
Cropland	56 001,06	8,61
Grassland	72 502,29	11,14
Forest	247 541,58	38,04
Water surface	2 956,05	0,45
Total	650 756,34	100

Figure 7 shows the spatial distribution of the different land use categories in the WAZA landscape in 2000.

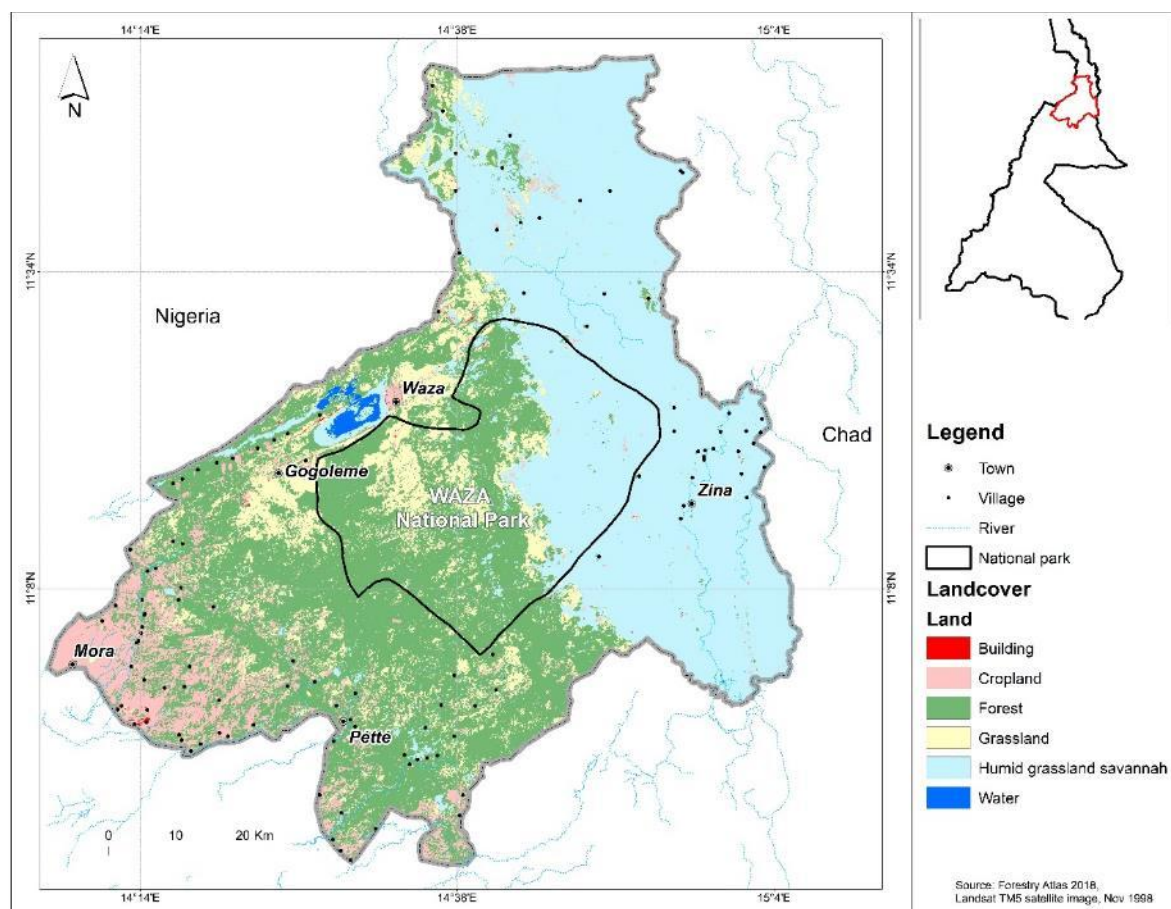


Figure 7: Land cover map of Waza landscape in 2000

5.1.3. LAND USE IN THE WAZA LANDSCAPE IN 2010

In 2010, the physiognomy of the Waza landscape was still dominated, on the one hand, by wet grassy savannahs and, on the other, by forests (Figure 9). Wet grassy savannah occupied 41.17% of the landscape, or 267,907.86 hectares. Forest covered almost the entire landscape with a proportion of 23.64% (153,855.09 hectares). Cultivated land accounted for 18.42% or 119,866.77 hectares of the landscape. The other land use categories, such as inhabited areas, grassy savannahs, and water areas, represented 0.16%, 16.14%, and 0.47% respectively of the spatial occupancy of the landscape in 2010 (Table 12).

Table 12: Land use statistics for the Waza landscape in 2010

Landcover	Area (2010)	%
Humid grassland savannah	267907.86	41.17
Built up area	1039.95	0.16
Cropland	119866.77	18.42
Grassland	105056.37	16.14
Forest	153855.09	23.64
Water surface	3030.3	0.47

Total	650 756.34	100.00
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The spatialisation of land use in the Waza landscape in 2010 is shown in the figure below

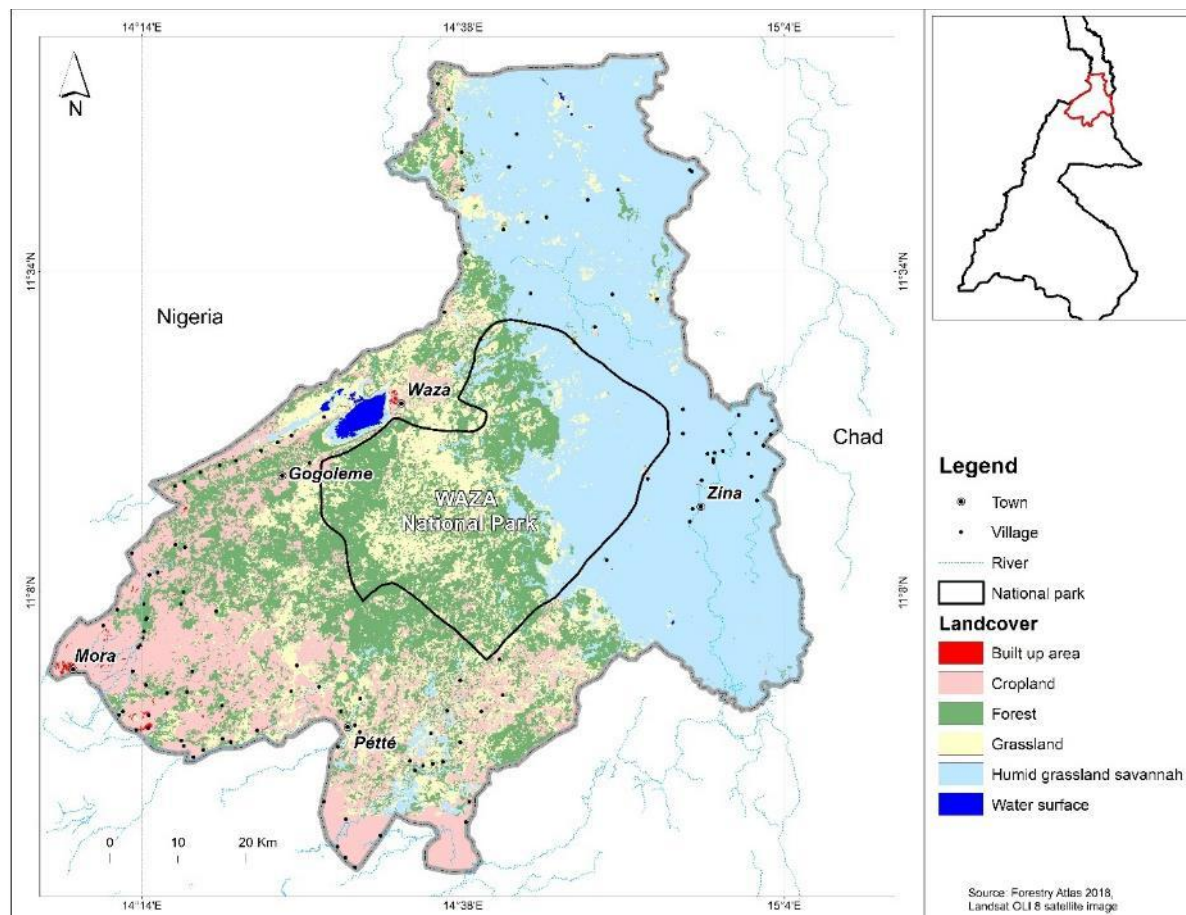


Figure 8: Land cover map of Waza landscape in 2010

5.1.4. LAND USE IN THE WAZA LANDSCAPE IN 2021

In 2021, the Waza landscape is mainly made up of wet grassy savannahs and cultivated areas. Wet grassy savannahs occupy 236 204.55 hectares, or 36.30% of the landscape, compared with 32.27% (210 025.08 hectares) for cultivated land (millet/sorghum). Grassland savannah accounted for 107,414.73 hectares, or 16.51%, compared with 0.73% for residential areas (4,755.69 hectares), 13.65% for forests (88,811.28 hectares), and 0.54% for water bodies (3,545.01 hectares) (Table 13).

Table 13: Land use statistics for the Waza landscape in 2021

Landcover	Area (2021)	%
Humid grassland savannah	236204.55	36.30
Built up area	4755.69	0.73
Cropland	210025.08	32.27

Grassland	107414.73	16.51
Forest	88811.28	13.65
Water surface	3545.01	0.54
Total	650756.34	100

The spatial distribution of the different land use categories in the WAZA landscape in 2021 is shown in Figure 9.

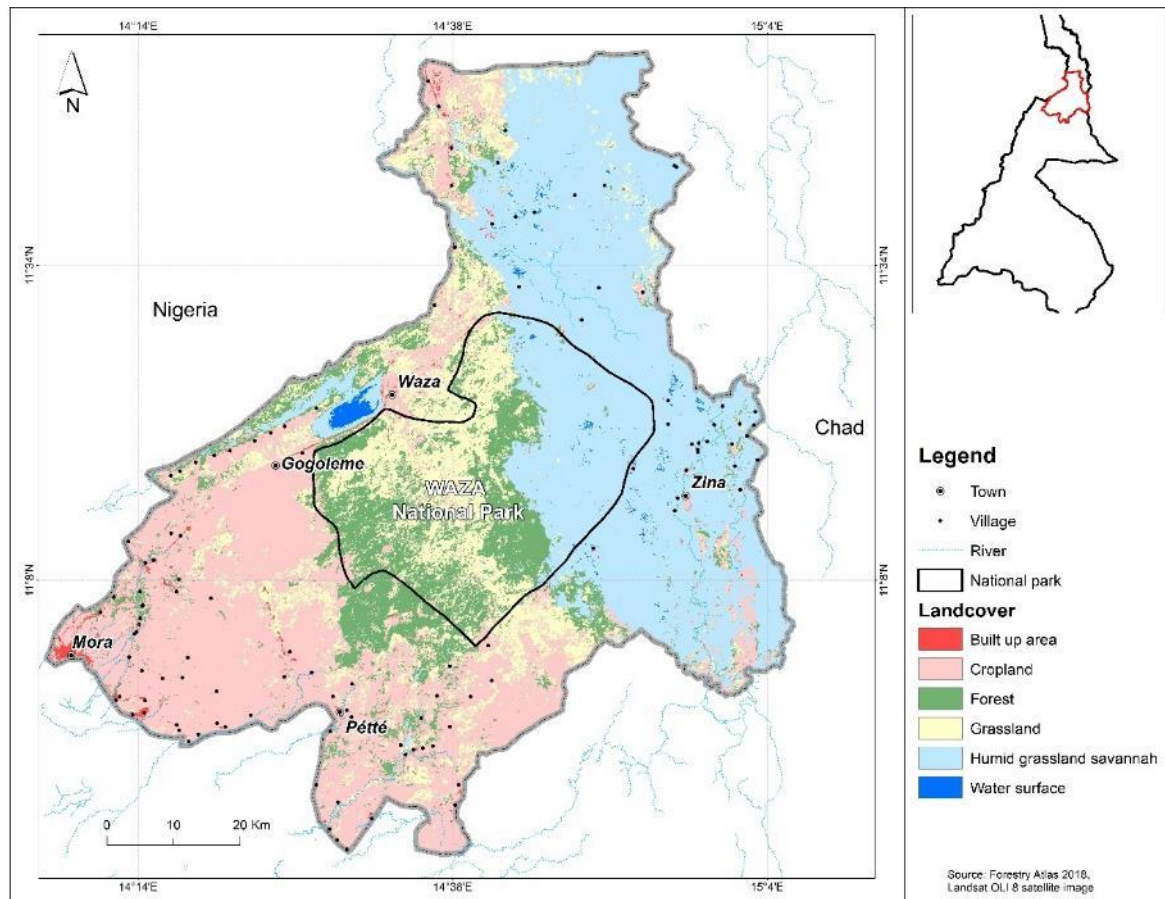


Figure 9: Land cover map of Waza landscape in 2021

5.1.5. LAND USE CHANGE IN THE WAZA LANDSCAPE BETWEEN 2000 AND 2010

Table 14 shows the land cover transition matrix between 2000 and 2010. The diagonals of each matrix indicate the proportion of land use classes that showed persistence between 2000 and 2010. The off-diagonal entries represent land uses that showed transitions from one class to other classes over the study period. Between 2000 and 2010, the most spectacular category of land use in terms of change was cultivated land, which increased significantly at a relatively high rate, accounting for almost 18.37% of land consumption. This increase is taking place at the expense of forest land, particularly in the southeast west sectors. The socio-economic surveys carried out in January 2022 in the Waza landscape identified agriculture as the driving force behind the conversion of forest land. In addition, the most persistent classes are wet grassy savannahs and water bodies.

Table 14: Area in ha of land use change in the Waza landscape between 2000 and 2010

Landcover		2010						
		Humid grassland savannah	Built up area	Cropland	Grassland	Forest	Water surface	Total
2000	Humid grassland savannah	247642.11	64.98	2590.11	13900.23	6002.46	913.14	271113.03
	Built up area	0.9	630.99	0.6	0.82	0	0	633.31
	Cropland	2192.4	719.19	37571.4	6365.7	9133.02	9	55990.71
	Grassland	3850.2	63.45	16580.97	23930.1	28071.9	1.71	72498.33
	Forest	13581.63	103.86	62775.99	60412.14	110569.68	79.47	247522.77
	Water surface	568.71	42.59	24.12	322.38	13.41	2026.98	2998.19
	Total	267835.95	1625.06	119543.19	104931.37	153790.47	3030.3	650756.34
	%	41.16	0.25	18.37	16.12	23.63	0.47	100

Table 15 shows the changes in the various land use categories between 2000 and 2010. The land use class that has grown the most is cultivated land, which has increased from 56 001.06 hectares in 2000 to 119 866.77 hectares in 2021, an increase of 63 865.71 hectares, corresponding to an annual rate of change of 6.34%. This extension of cultivated land is explained by the galloping demographic explosion observed since the 2005 census. Residential areas have also seen spectacular growth. They rose from 630.99 hectares in 2000 to 1,039.95 hectares in 2010, an increase of 408.96 hectares, corresponding to an annual rate of change of 4.16%. Forests, however, have declined dramatically. They fell from 247 541.58 hectares in 2000 to 153 855.09 hectares in 2010, a loss of 93 686.49 hectares, corresponding to an annual rate of change of 3.96%. Grassland savannah increased from 72 502.29 hectares in 2000 to 105 056.37 hectares in 2010, an increase of 32 554.08 hectares, for an annual rate of change of 3.09%. Wet savannah is more or less stable, with an annual rate of change of 0.10%.

Table 15: Change in surface area for the various categories between 2000 and 2010

Landcover	Area (2000)	Area (2010)	Surface variation	Rates
Humid grassland savannah	271124.37	267907.86	3216.51	0.10
Built up area	630.99	1039.95	408.96	4.16
Cropland	56001.06	119866.77	63865.71	6.34
Grassland	72502.29	105056.37	32554.08	3.09
Forest	247541.58	153855.09	93686.49	3.96
Water surface	2956.05	3030.3	74.25	0.21

Total	650756.34	650756.34		
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The figure below shows the spatial distribution of deforestation hotspots between 2000 and 2010. During this period, 136,953.09 hectares of forest land were converted to non-forest land.

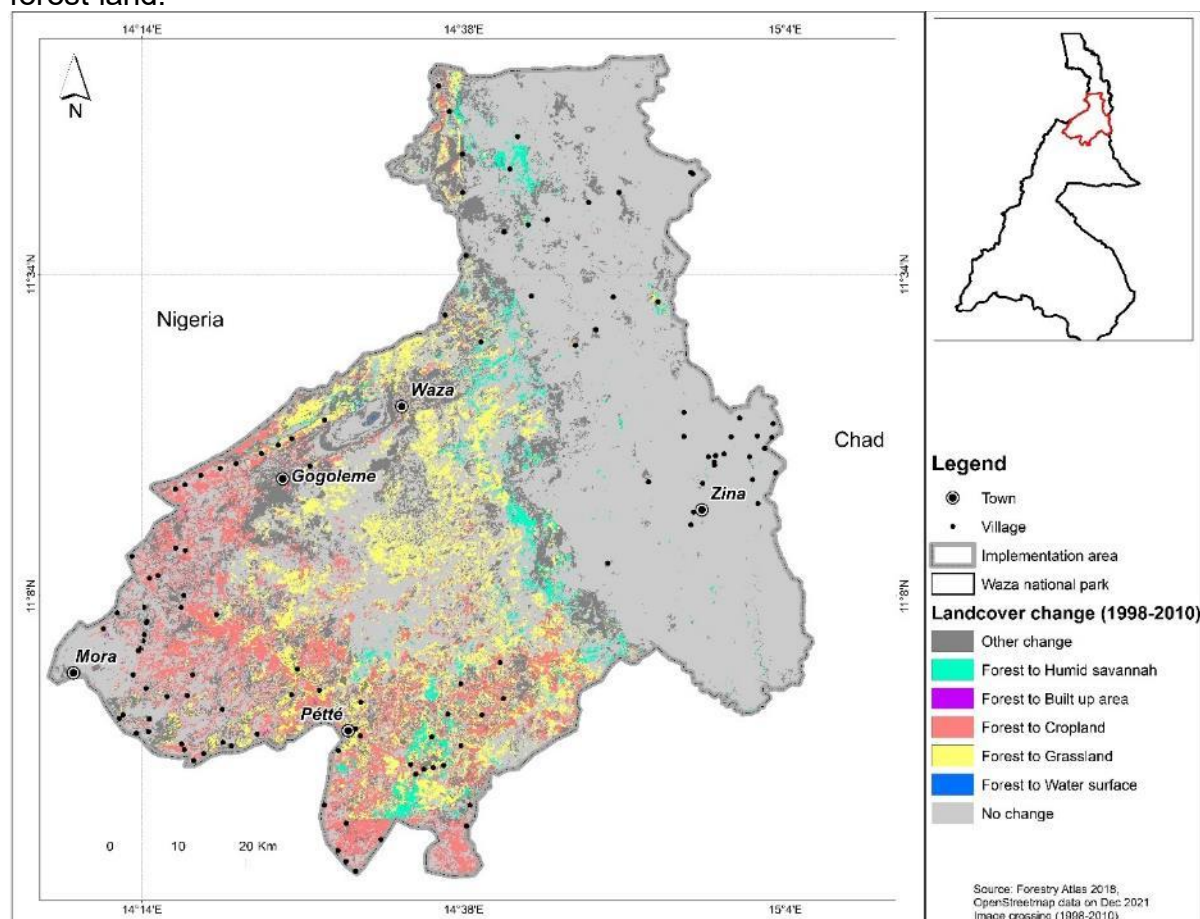


Figure 10: Conversion of woodland to other land categories in the Waza landscape between 2000 and 2010

5.1.6. LAND USE CHANGE IN THE WAZA LANDSCAPE BETWEEN 2010 AND 2021

The statistics in Table 16, derived from the cross-tabulation of the 2010 and 2021 land-use maps, show that three categories have persisted overall: grassy savannahs, water areas, and wetlands, which have undergone some minor changes. Buildings, cultivated areas, and forests show significant gains in surface area, with rates ranging from 5 ha/year to more than 13 ha/year across the Waza landscape as a whole (Table 16).

There has been a significant increase in the area under cultivation, at a relatively high rate, which alone accounts for almost 32% of land consumption (Table 16). This increase is taking place at the expense of forest land, particularly in the southeast west sectors and away from inhabited areas. The area surrounding the WNP is the main zone affected by this change in land use (Figure 11).

Table 16: Cross-tabulation of land use in 2010 (horizontal) and 2021 (vertical)

2021									
Landcover		Humid grassland savannah	Built up area	Cropland	Grassland	Forest	Water surface	Total	%
2010	Humid grassland savannah	220741.65	270.45	17082.63	15102.99	12899.61	1765.62	267862.95	41.16
	Built up area	0.43	1029.57	9.95	0	0	0	1039.95	0.16
	Cropland	772.2	2640.69	94794.48	14713.74	6939.81	5.85	119866.77	18.42
	Grassland	10652.67	651.69	40575.51	33221.52	19932.66	22.32	105056.37	16.14
	Forest	2767.05	661.23	57131.1	44276.49	49013.46	5.76	153855.09	23.64
	Water surface	1257.3	44.91	2.16	19.53	5.85	1745.46	3075.21	0.47
	Total	236191.3	5298.54	209595.83	107334.27	88791.39	3545.01	650756.34	100
	%	36.29	0.81	32.21	16.49	13.64	0.54	100	

The evolution of the different categories of land use shows significant changes. This is the case for crops for example which have increased from 119866.77 hectares in 2010 to 210025.08 hectares in 2021 an increase of 90158.31 hectares corresponding to an annual rate of change of 5.10%. This expansion of cultivated land can be explained by the galloping demographic explosion coupled with the migration of certain populations who find refuge on the outskirts of the WNP. Forests however have declined dramatically. They have fallen from 153855.09 hectares in 2010 to 88811.28 hectares in 2021 a loss of 65043.81 hectares corresponding to an annual rate of change of 5%. Grassland savannahs increased from 105056.37 ha in 2010 to 107414.73 ha in 2021 an increase of 2358.36 ha for an annual rate of change of 0.20%. Wet savannahs have declined by around 31703.31 ha (1.14%). They have fallen from 267907.86 ha in 2010 to 236204.55 ha in 2021. Residential areas have practically doubled from 1039.95 ha in 2010 to 4755.69 ha in 2021 an increase of 3715.74 ha for an annual rate of change of 13.82%. This increase in surface area is justified by the proliferation of new villages the main cause of which is the growing insecurity in the Waza landscape.

Table 17 Change in surface area for the various categories between 2010 and 2021

Landcover	Area (2010)	Area (2021)	Surface variation	Rate (%)
Humid grassland savannah	267907.86	236204.55	31703.31	1.14
Built up area	1039.95	4755.69	3715.74	13.82
Cropland	119866.77	210025.08	90158.31	5.10
Grassland	105056.37	107414.73	2358.36	0.20
Forest	153855.09	88811.28	65043.81	5
Water surface	3030.3	3545.01	514.71	1.43
Total	650756.34	650756.34		

Data from the cross-referencing of classified satellite images (2010-2021) has made it possible to spatialise hotspot areas in the WAZA landscape between 2010 and 2021. These deforestation hotspots are located in the southern western eastern and northern western parts of the landscape (Figure 13) and result in the conversion of forests into cultivated areas, grassy savannahs, and inhabited areas. During this period, 104,841.63 hectares of forest disappeared. The villages or localities that contributed to this loss of forest cover could be Mora, Gogolema, Lougouma, Waza, Petté, Dieguéré, and Andirni, as they are in the major deforestation hotspots.

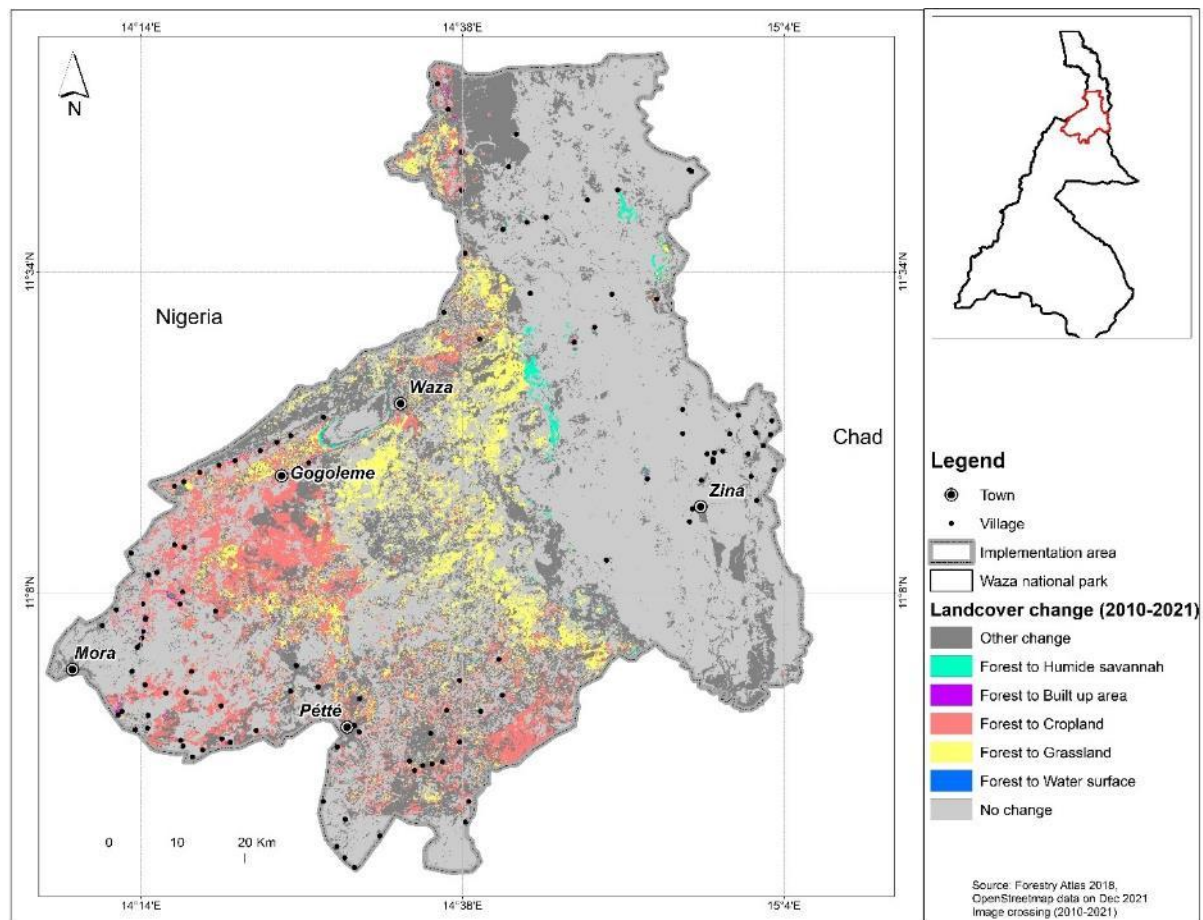


Figure 11: Conversion of woodland to other land types in the Waza landscape between 2010 and 2021

5.2. BAKOSSI-BAMBOUTOS LANDSCAPE

The Bakossi-Bamboutos landscape is covered by high-altitude dense evergreen rainforest, dominated by *Allophylus bullatus* (Sapindaceae), *Bambusa spp.* (Poaceae), *Bersama abyssinica* (Melianthaceae), *Bridelia speciosa* (Euphorbiaceae), *Clausena anisata* (Rutaceae) and *Ficus spp.* (Moraceae). Most of these forests are located at altitudes of between 200 and 800 m, with rainfall ranging from 2 000 to 3 000 mm. These forests have been subject to intensive human intervention for several decades. The landscape also abounds in tree/shrub savannahs made up of plant species such as

Entadua. and *Combretum sp.*, and grasslands made up largely of *sporobolus a.* species and expanses of *Kikuyu* grass.

5.2.1. ASSESSMENT OF THE ACCURACY OF LAND-USE MAPS IN THE BAKOSSI-BAMBOUTOS LANDSCAPE

Depending on the dates, three confusion matrices were produced to assess the intrinsic quality of the classifications in the Bakossi-Bamboutos landscape. These matrices were used to calculate the percentage error of omission, the average percentage of correctly classified pixels, and the Kappa coefficient (Cohen et al., 1960, Caloz et al., 2001 cited by Masimo, 2015). Using these confusion matrices, we found that the Kappa coefficient was 0.81 between the years 1990 and 2010 and slightly higher in 2018. The accuracy measure or MPCC (Mean Correctly Classified Pixels) is between 80% and 87% for the three periods.

5.2.2. LAND USE IN THE BAKOSSI-BAMBOUTOS LANDSCAPE IN 2000

Table 19 shows the statistics by land cover type in the Bakossi-Bamboutos landscape in 2000. During this period, forests predominated, accounting for 574 148.79 hectares, or 81.51% of the landscape area. The cultivated savannah grassland mosaic is estimated at 97 615.89 hectares (13.86%), while cultivated areas account for 2 8173.6 hectares (4%). Built-up areas and water areas occupy 0.53% (3 762.63 hectares) and 0.10% (711.81 hectares) of the area respectively.

Table 18: Land use statistics for the Baboutos Bakossi landscape in 2000

Category	Area (ha)	%
Forest	574148.79	81.51
Mosaic crops and Grassland	97615.89	13.86
Cropland	28173.6	4.00
Built up area	3762.63	0.53
Water surface	711.81	0.10
Total	704412.72	100

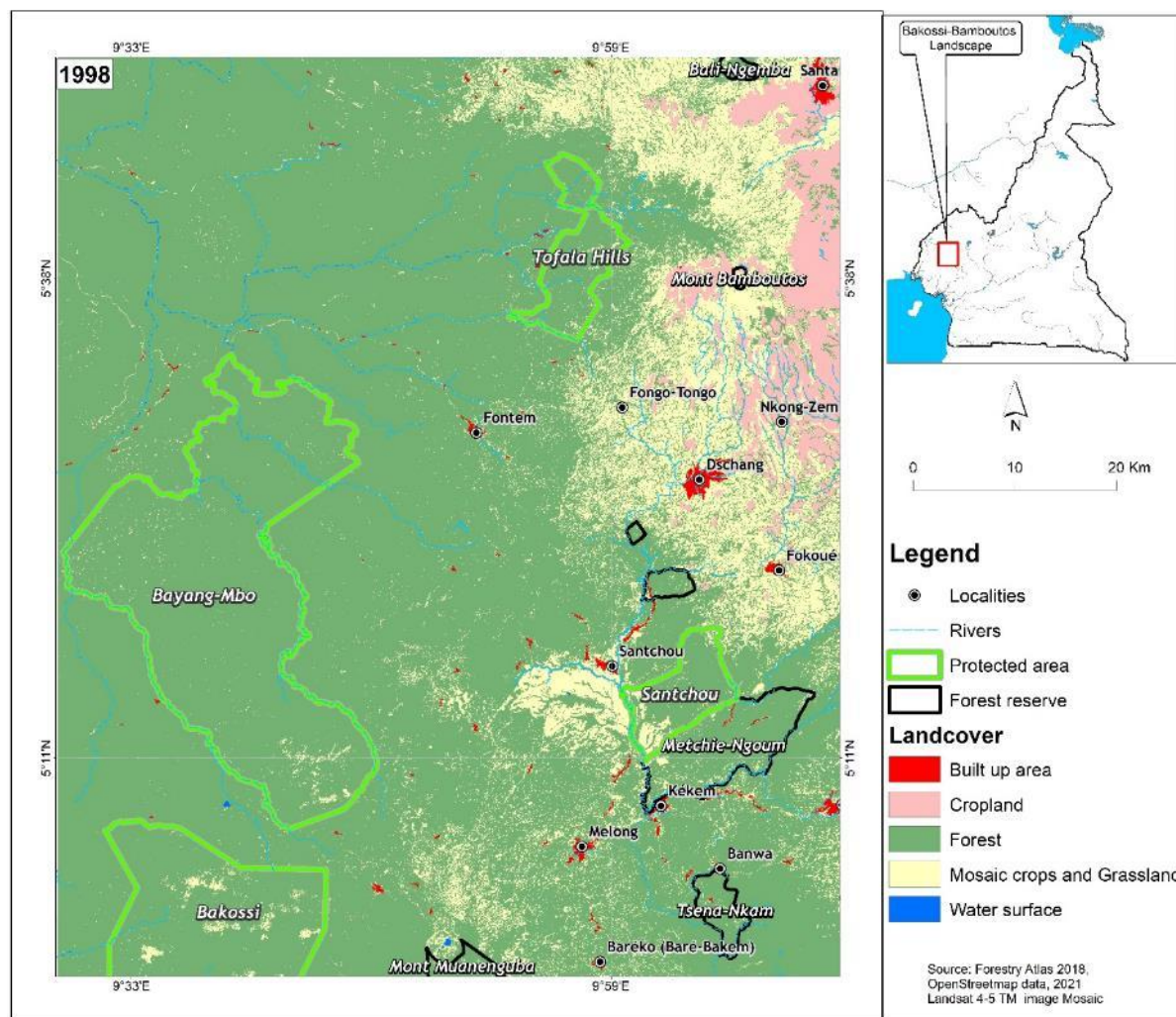


Figure 12: Land use in the Bakossi-Bamboutos landscape in 2000

5.2.3. LAND USE IN THE BAKOSSI-BAMBOUTOS LANDSCAPE IN 2010

The Bakossi-Bamboutos landscape in 2010 is still largely occupied by forests, which account for 571 720.68 hectares, corresponding to 81.16% of the landscape's spatial occupancy. These are still followed by crop mosaics grassy savannahs, which occupy 99 220.77 hectares, or 14.09%. Cultivated areas account for 28 315.35 hectares (4.02%). Other types of land use, such as residential areas and water areas, cover 0.55% (3 850.74 ha) and 0.19% (1 305.18 ha) respectively.

Table 19: Land use statistics for the Baboutos Bakossi landscape in 2010

Category	Area	%
Forest	571720.68	81.16
Mosaic crops and Grassland	99220.77	14.09
Cropland	28315.35	4.02
Built up area	3850.74	0.55

Water surface	1305.18	0.19
Total	704412.72	100

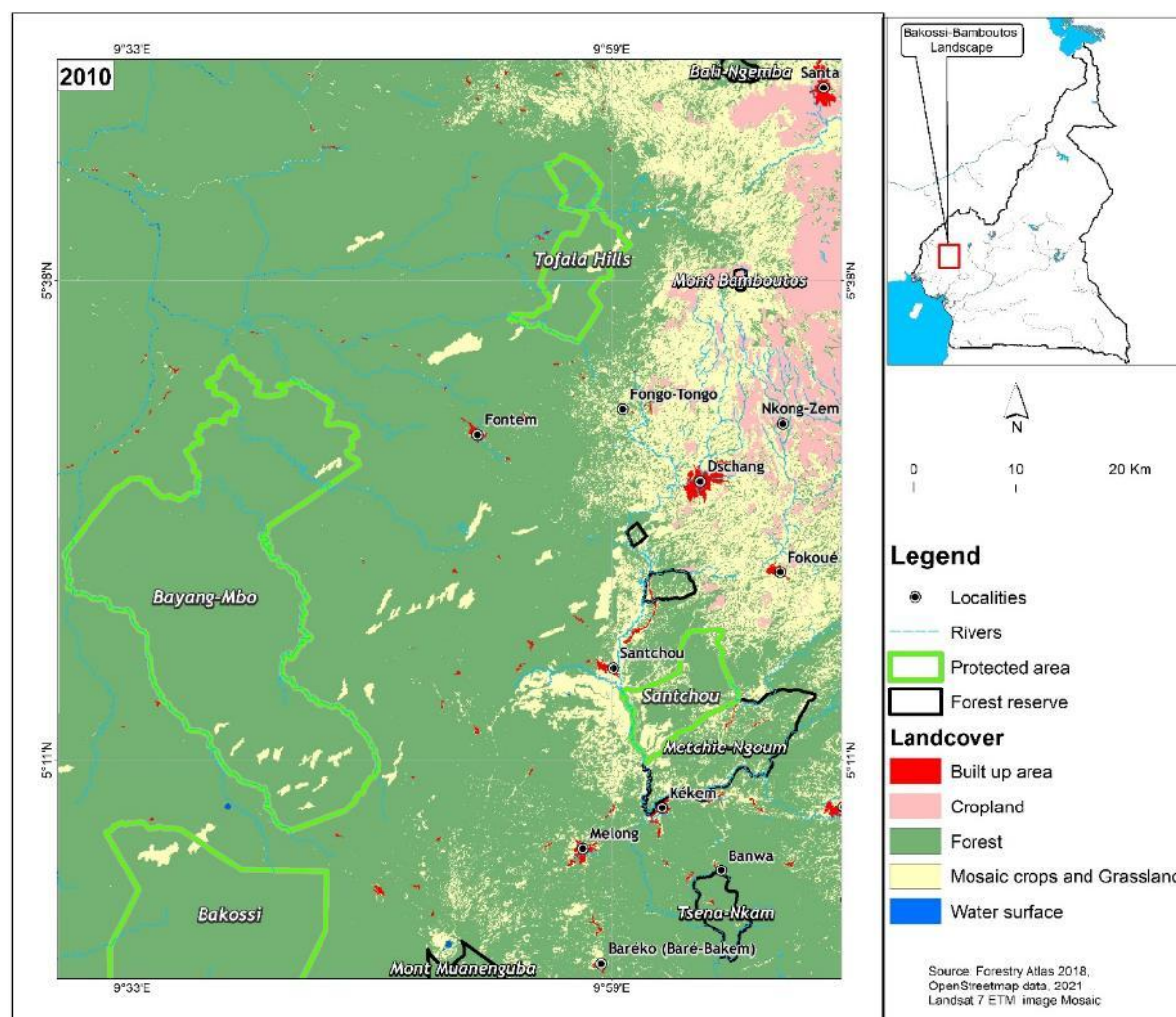


Figure 13: Land use in the Bakossi-Bamboutos landscape in 2010

5.2.4. LAND USE IN THE BAKOSSI-BAMBOUTOS LANDSCAPE IN 2021

In 2021, forests in the Bakossi-Bamboutos landscape will occupy 79.37% (5,9073.69 ha), compared with 13.22% (9,3097.98 ha) for cultivated mosaics savannah grasslands. Cultivated areas occupy 6.49%, representing 45726.31 hectares of the landscape. Other types of land use such as residential areas and water areas cover 0.82% (5806.26 ha) and 0.10% (708.48 ha) respectively.

Table 20: Land use statistics for the Baboutos Bakossi landscape in 2021

Category	Area (ha)	%
Forest	559073.69	79.37
Mosaic crops and Grassland	93097.98	13.22

Cropland	45726.31	6.49
Built up area	5806.26	0.82
Water surface	708.48	0.10
Total	704412.72	100

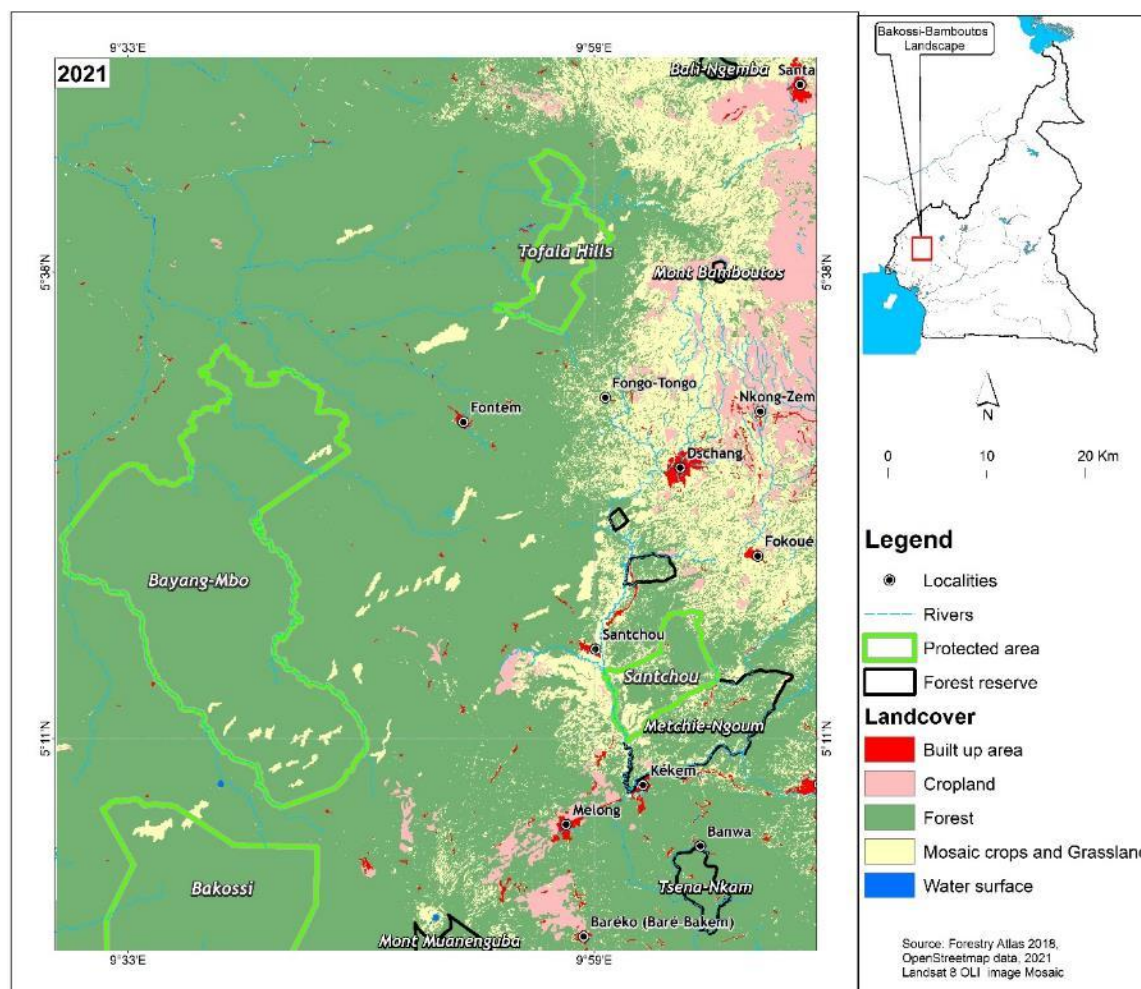


Figure 14: Land use in the Bakossi-Bamboutos landscape in 2021

5.2.5. LAND USE CHANGE IN THE BAKOSSI-BAMBOUTOS MOUNTAINS LANDSCAPE BETWEEN 2000 AND 2010

The statistics in Table 22, derived from the cross-tabulation of the 2000 and 2010 land use maps, show the changes in land use for the different types of land cover. The table shows almost 30 884.62 hectares of woodland converted to a mosaic of crops savannah grassland, 1346.5 hectares of crops, 302.94 hectares of built-up areas, and 300.33 hectares of water areas. In addition to forest conversions, there were also almost 3 335.36 hectares of crop grassland savannah mosaic converted to the forest and 1 130.4 hectares

of cropland converted to forest. Over this period, the different land-use classes generally persisted.

Table 21: Cross-tabulation of land use in 2000 (horizontal) and 2010 (vertical)

2010								
Landcover classes		Forest	Mosaic crops and grassland	Cropland	Built up area	Water surface	Total	%
2000	Forest	539322.21	30884.62	1346.5	302.94	300.33	572156.6	81.22
	Mosaic crops and grassland	32535.36	64061.01	2353.95	238.41	32.04	99220.77	14.09
	Cropland	1130.4	1316.745	25809.795	58.23	0.18	28315.35	4.02
	Built up area	0.82	0.95	0.53	3411.08	1.44	3414.82	0.48
	Water surface	891	35.82	0.27	0.27	377.82	1305.18	0.19
	Total	573879.79	96299.145	29511.045	4010.93	711.81	704412.72	100
	%	81.47	13.67	4.19	0.57	0.10	100	

However, the state of land use between 2000 and 2010 nevertheless shows an increase in the cultivation of mosaic savannah grassland and cultivated land. These increased by 1,604.88 hectares respectively, for an annual rate of change of 0.15%, and 141.75 hectares for an annual change of 0.05%/year. The main contributor is the forest class, which reduced its area by around 2428.11 hectares, corresponding to an annual rate of change of 0.04% (Table 23).

Table 22: Change in surface area for the various categories between 2000 and 2010

Landcover	Area (2000)	Area (2010)	Change in surface area	Rate (%)
Forest	574148.79	571720.68	2428.11	0.04
Mosaic crops and grassland	97615.89	99220.77	1604.88	0.15
Cropland	28173.6	28315.35	141.75	0.05
Built up area	3762.63	3850.74	88.11	0.21
Water surface	711.81	1305.18	593.37	5.51

Total	704412.72	704412.72		
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5.2.6. LAND USE CHANGE IN THE BAKOSSI-BAMBOUTOS MOUNTAINS LANDSCAPE BETWEEN 2010 AND 2021

The cross-tabulation matrix shows that the most significant transition between 2010 and 2021 in the Bakossi-Bamboutos landscape was the conversion of forested areas into cultivated land, which represents almost 27210.35 hectares of the landscape. The percentage of land occupied by forest fell from 81.51% (574184.79 hectares) in 2010 to 79.31% (558 644.2 hectares) in 2021.

Table 23: Cross-tabulation of land use in 2010 (horizontal) and 2021 (vertical)

		2021						
Landcover classes		Forest	Mosaic crops and grassland	Cropland	Built up area	Water surface	Total	%
2010	Forest	546426.7	11646.09	15564.26	507.69	40.05	574184.79	81.51
	Mosaic crops and grassland	11735.46	80123.83	4558.5	1421.55	39.87	97879.21	13.90
	Cropland	422.37	1303.38	26032.86	414.63	0.36	28173.6	4.00
	Built up area	0	0.47	0	3462.03	0.81	3463.31	0.49
	Water surface	59.67	24.21	0.18	0.36	627.39	711.81	0.10
	Total	558644.2	93097.98	46155.8	5806.26	708.48	704412.72	100
	%	79.31	13.22	6.55	0.82	0.10	100	

During the period from 2010 to 2021, forests and the savannah grassland mosaic experienced the greatest losses, with reductions of 12,646.99 hectares (0.20% per year) and 6,122.79 hectares (0.58% per year) of total land cover, respectively. In contrast, cultivated land saw the most significant gain, increasing by 4.36% of land cover, which corresponds to 17,410.96 hectares over this period (Table 25). The major localities contributing to forest loss between 2010 and 2021 include Dschang, Mbouda, Nkong Zem, Santa, Fontem, Melong, Santchou, and Fongo Tongo.

Table 24: Change in surface area for the various categories between 2010 and 2021

Landcover	Area (2010)	Area (2021)	Change in surface area	Rate (%)
Forest	571720.68	559073.69	12646.99	0.20
Mosaic crops and grssaland	99220.77	93097.98	6122.79	0.58
Cropland	28315.35	45726.31	17410.96	4.36
Built up area	3850.74	5806.26	1955.52	3.73
Water surface	1305.18	708.48	596.70	5.55
Total	704412.72	704412.72		

5.3. DJA LANDSCAPE LOBÉKÉ

The Dja Lobéké landscape was covered by low-altitude dense rainforest. Plant formations are dominated by Ulmaceae, Sterculiaceae (Ayous, Kola, etc.), and Meliaceae (Sapelli, Sipo, Kossipo, etc.). The most threatened plant species are *Autranella congoensis*, *Pericopsis alata*, *Diospyroscassiflora*, *Swartzia fistuloides*, *Khaya spp.* and *Entadrophragma spp.*

The land cover is made up of dense, high-density wet evergreen forests, dense, low-density wet evergreen forests, dense wet evergreen forests with a high density of forest gaps, dense wet forests with a low density of forest gaps, old secondary forests with a high density, temporarily flooded swamps, raphial swamps, crops, and housing areas.

5.3.1. ASSESSING THE ACCURACY OF LAND-USE MAPS IN THE DJA LANDSCAPE LOBEKE

Depending on the dates, three confusion matrices were produced to assess the intrinsic quality of the classifications. These matrices were used to calculate the percentage error of omission, the average percentage of correctly classified pixels, and the Kappa coefficient (Cohen et al., 1960, Caloz et al., 2001 cited by Masimo, 2015). Confusion matrices were produced to signify class separation performance for 2000, 2010, and 2021, with an overall accuracy of 94.0%, 89.1%, and 92.7% and Kappa values of 0.91, 0.85, and 0.93 respectively.

5.3.2. LAND USE IN THE DJA LOBEKE LANDSCAPE IN 2000

Table 27 and Figure 16 highlight the statistics and spatial distribution of land use in the Dja Lobéké landscape in 2000. During this period, this landscape was mainly covered by forest, i.e. 6,413,488.35 hectares (98.11%). Arable land occupied 96,737.80 hectares (1.48%) of the area. Residential areas and bodies of water occupied 7,757.68 hectares (0.12%) and 19,246.66 hectares (0.29%) respectively.

Table 25: Land use statistics for the Dja Lobéké landscape in 2000

Landcover	Area (ha)	%
Forest	6 413 488.35	98.11
Built up area	7 757.68	0.12

Cropland	96 737.80	1.48
Water surface	19 246.66	0.29
Total	6 537 230.49	100

Figure 15 Distribution of land use classes in the Ngoyla landscape Lobéké in 2000

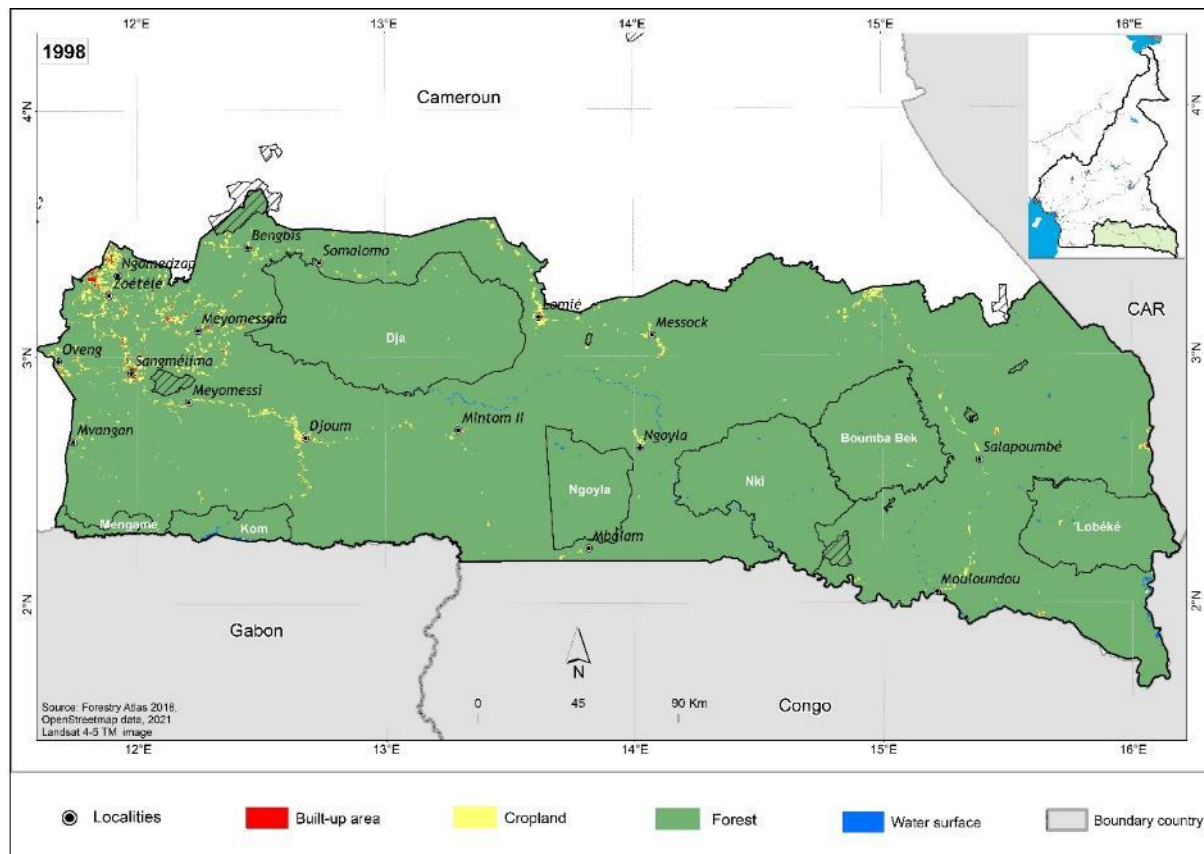


Figure 16: Land use in the Ngoyla landscape Lobéké in 2000

5.3.3. LAND USE IN THE DJA LOBEKE LANDSCAPE IN 2010

In 2010, forests in the Dja Lobéké landscape accounted for 97.97%, or 6 404 769.29 hectares. Crops occupy 103 952.91 hectares (1.59%). Residential areas and bodies of water occupy 9042.62 hectares (0.14%) and 19 465.67 hectares (0.30%) respectively.

Table 26: Land use statistics for the Dja Lobéké landscape in 2010

Landcover	Area (ha)	%
Forest	6 404 769.29	97.97
Built up area	9042.62	0.14
Cropland	103 952.91	1.59
Water surface	19 465.67	0.30
Total	6 537 230.49	100

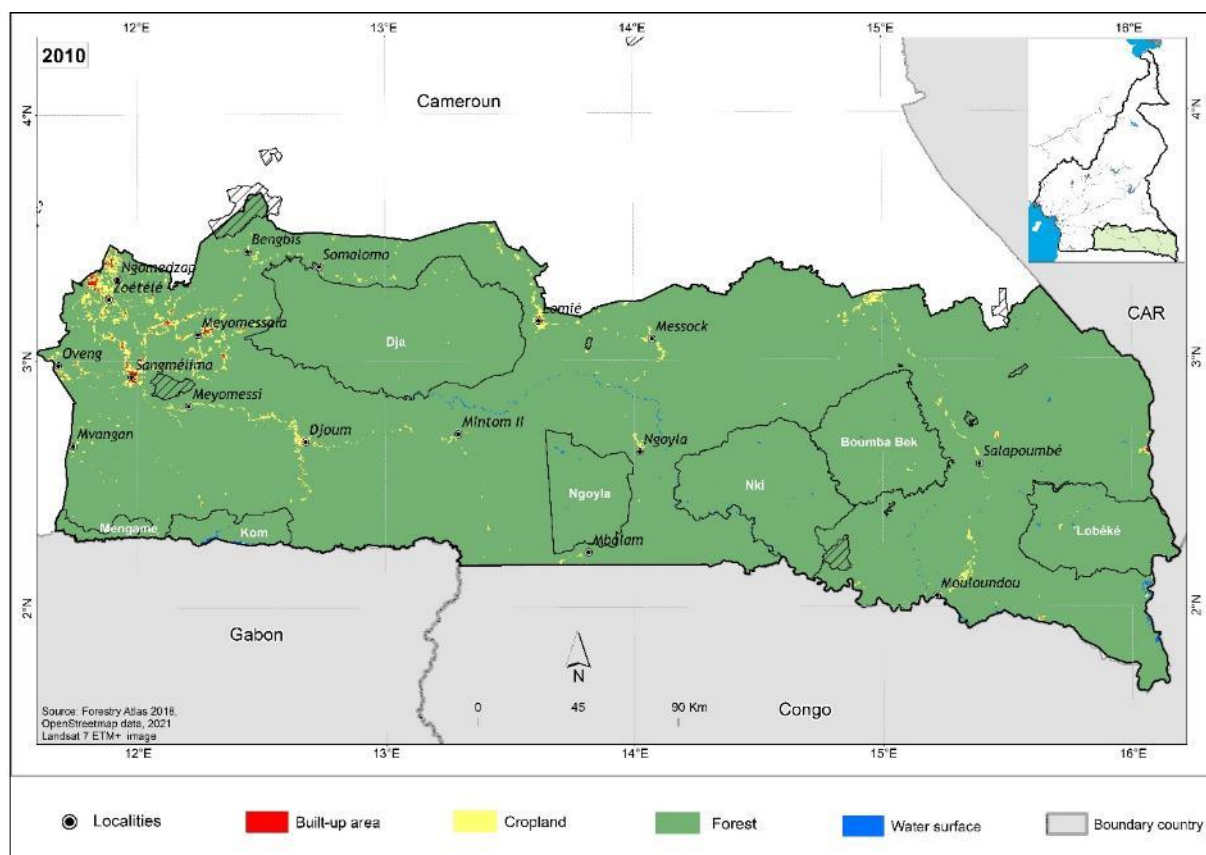


Figure 17: Land use in the Dja Lobéké landscape in 2010

5.3.4. LAND USE IN THE DJA LOBEKE LANDSCAPE IN 2021

In 2021, the dense forests of the Dja Lobéké landscape alone will account for 97.64% (6 383 247.68 hectares), compared with 1.92% (125 484.05 hectares) of cropland. Other types of land use, such as inhabited areas and bodies of water, account for 0.14% (9 156.92 hectares) and 0.30% (19 341.85 hectares) respectively. Figure 18 and Table 29 show the statistics and spatial distribution of land use in the Dja et Lobéké landscape in 2021.

Table 27: Land use statistics for the Dja Lobéké landscape in 2021

Landcover	Area (ha)	%
Forest	6 383 247.68	97,64
Built up area	9 156.92	0,14
Cropland	125 484.05	1,92
Water surface	19 341.85	0,30
Total	6 537 230.49	100

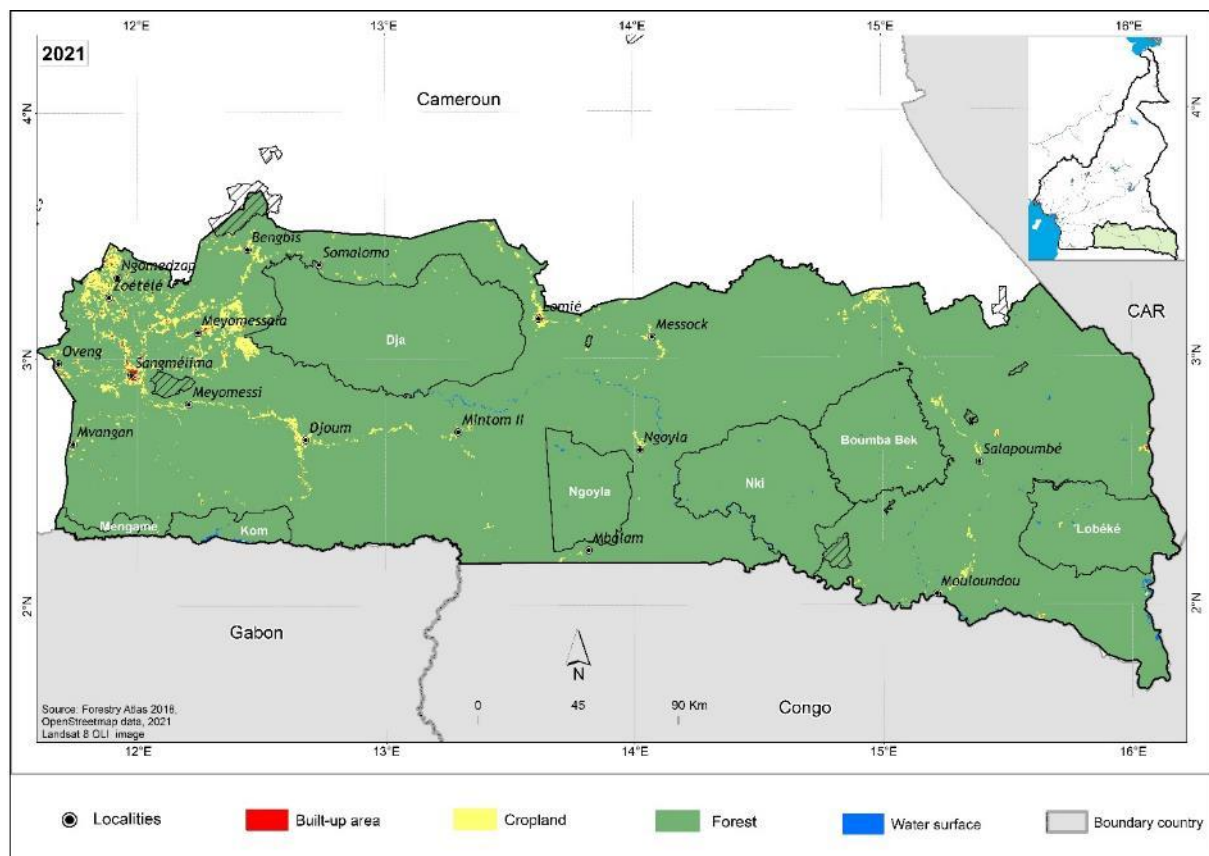


Figure 18: Land use in the Ngoyla Lobéké landscape in 2021

5.3.5. CHANGES IN LAND USE IN THE DJA LOBÉKÉ LANDSCAPE BETWEEN 2000 AND 2010

Table 30 shows the land cover transition matrix between 2000 and 2010. The diagonals of each matrix indicate the proportion of land use classes that showed persistence between 2000 and 2010. The off-diagonal entries represent land uses that showed transitions from one class to other classes over the study period. In 2000, cultivated land occupied 1.48% of the landscape, extending around roads and between forest concessions, protected areas, and community forests. This increased from 96,737.80 hectares in 2000 to 103,952.91 hectares in 2010, an increase of 7,215.12 hectares between the two periods. Forests are the main contributors to the expansion of new farmland (15,743.81 hectares). The decline in woodland is attributed to agricultural expansion and the extension of inhabited areas. The socio-economic surveys carried out in the landscape in January 2022 identified agriculture as the main driver of forest land conversion.

Table 28: Area in ha of land use change in the Dja Lobéké landscape between 2000 and 2010

Land use class	Forest	Built up area	Cropland	Water	Total
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Forest	6 395 974,08	1 684,80	15 743,81	85,67	6 413 488,36
Built up area	0	7 472,12	0	0	7 472,12
Cropland	8 795,21	285.56	87 923.55	19.04	97 023.36
Water surface	0	0	0	19 246.66	19 246.66
Total	6 404 769.29	9 442.48	103 667.36	19 351.37	6 537 230.50
%	97.97	0.14	1.59	0.30	

Figure 19 shows the main deforestation hotspots in the Dja Lobéké landscape between 2000 and 2010. These areas are located more in the northern-western part of the landscape.

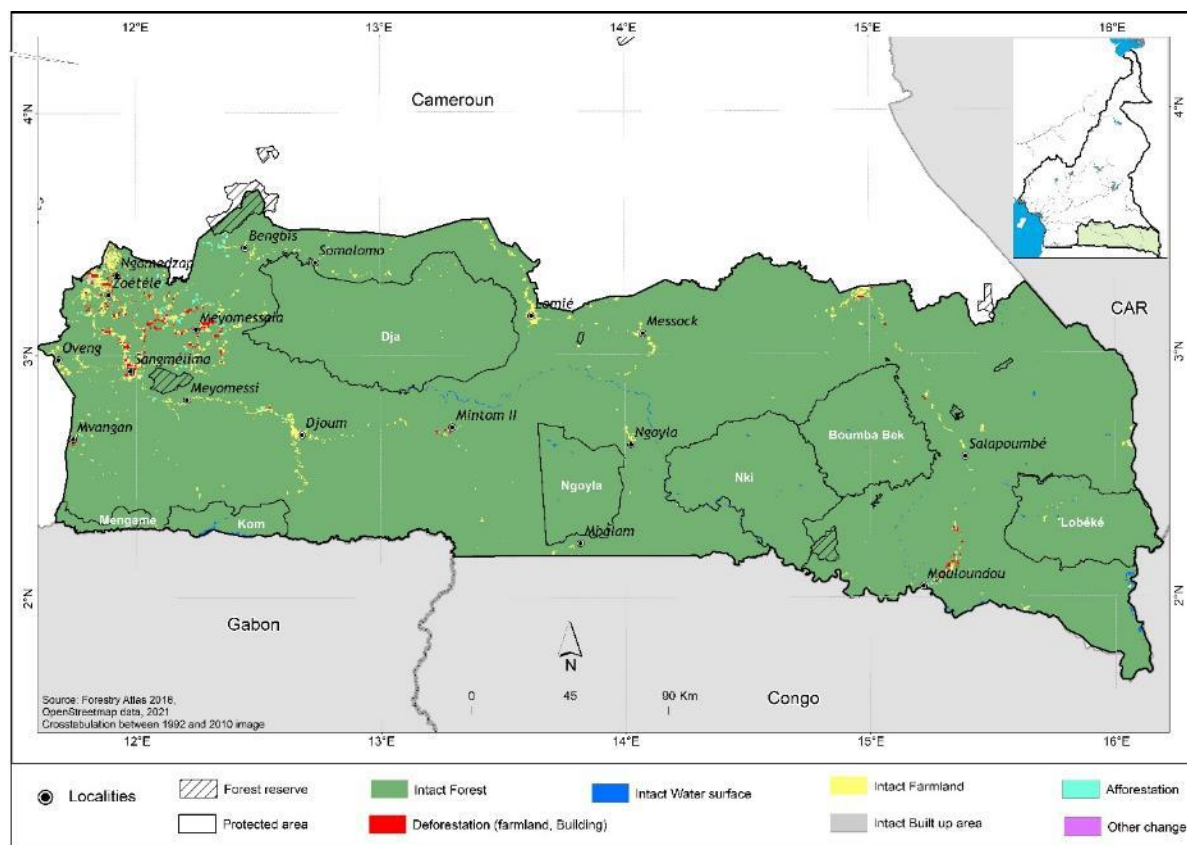


Figure 19: Conversion of forest to other land categories in the Dja Lobéké landscape between 2000 and 2010

5.3.6. CHANGES IN LAND USE IN THE DJA LOBÉKÉ LANDSCAPE BETWEEN 2010 AND 2021

Over the period from 2010 to 2021, cultivated land continued to expand, reaching 1.92% of the landscape. Forest remains the main contributor (25 709.81 hectares) to the newly added cultivated land. These significant increases in cultivated land have contributed to varying degrees of deforestation, coupled with rapid population growth.

Table 29: Areas in ha of land use change in the Dja Lobéké landscape between 2010 and 2021

Land class	use Forest	Built up area	Cropland	Water	Total
Forest	6 379 088.03	152.30	25 709.81	0	6 404 950.14
Built up area	0.00	8 890.40	0	0	8 890.40
Cropland	4 159.64	85.67	99 793.27	0	104 038.58
Water surface	0	0	9.52	19 341.85	19 351.37
Total	6 383 247.67	9 128.36	125 512.60	19 341.85	6 537 230.48
%	97.64	0.14	1.92	0.30	

Figure 20 illustrates the main deforestation hotspots in the Dja Lobéké landscape between 2010 and 2021. These areas are located more in the northern western part of the landscape and mainly concern the localities of Sangmélina, Méyomessala, and Djoum.

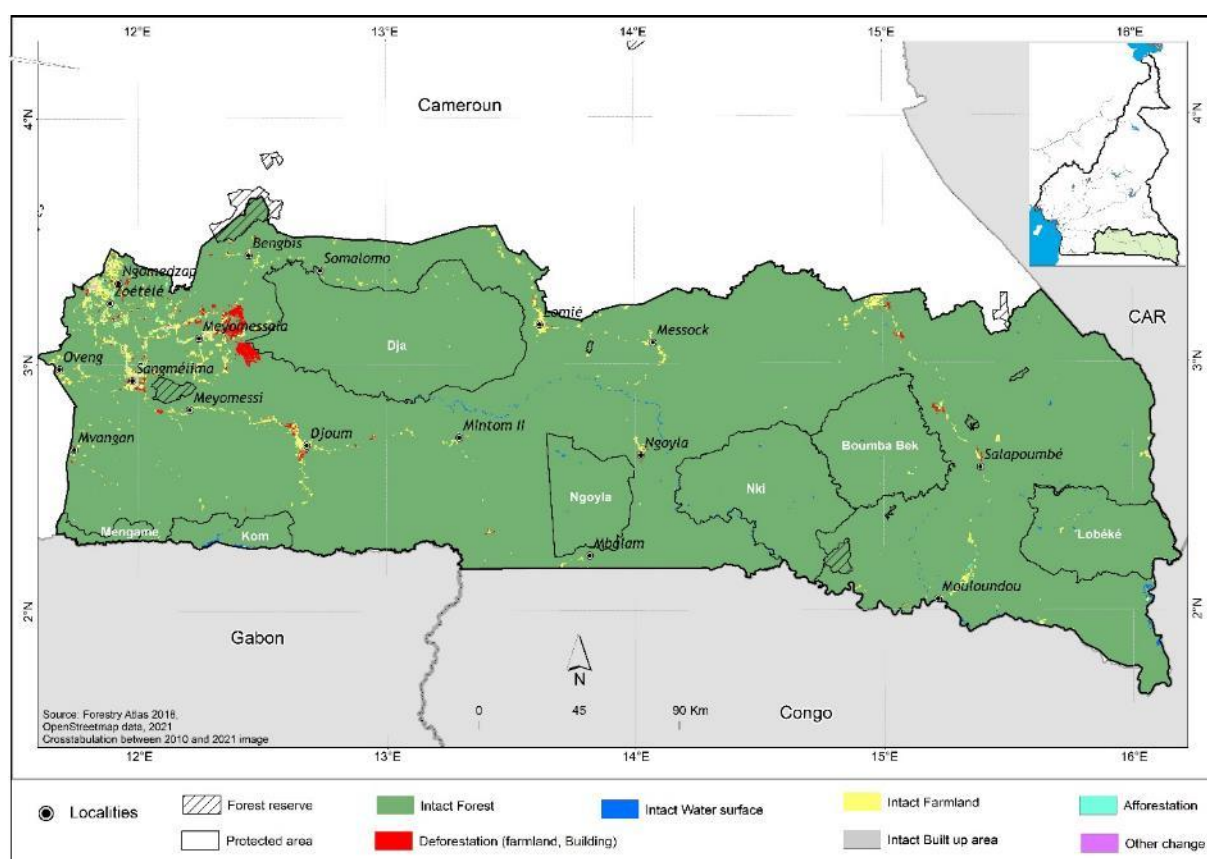


Figure 20: Conversion of forest to other land categories in the Dja Lobéké landscape between 2010 and 2021

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