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Spatio-Temporal Dynamics of the Noun Floodplain (Cameroon) Using Remote Sensing

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Abstract

In Cameroon, the pressure on wetlands appears to be increasing, leading to desertification and land degradation. This study aims to characterize the spatial and temporal dynamics of land cover in the Noun floodplain in Cameroon using multi-date satellite data. To achieve this, the methodology consisted in using remote sensing and geographical information's systems techniques to identify spatial units and detect changes over a 22-year period (1999 to 2021). The land cover maps were produced from an unsupervised classification with maximum likelihood. The results identified eight classes: herbaceous savannahs with shrubs, forest galleries, fields and plantations, herbaceous tan, young fallows, mineralized and built-up soils, bare soils and surface waters. It appears that in 1999, the landscape was dominated by natural vegetation (72.6%) located from north to south of the Noun plain. However, since 2004, the landscape has been dominated by agricultural areas (56.8%). Natural formations have been progressively reduced in space over time. The evolution of the Noun floodplain landscape reveals that 14.3% of the space has remained stable. These are fields and plantations, young fallows, mineralized soils and surface water. This space has not migrated to other classes. While about 73.9% of the area has moved to higher classes, of which 35.6% to herbaceous tans and 26% to fields and plantations. On the other hand, 72.6% of the area (herbaceous savannahs and forests gallery) has been heavily degraded. These results show that the landscape of the Noun floodplain is marked by a progressive agricultural extension, which would be at the origin of the land degradation. Therefore they alert the different actors in the territory on the level of advanced land degradation and suggest sustainable land management on a local scale.

Keywords

Cameroon, Land Use, Land Degradation, Remote Sensing, Sustainable Land Management

1. Introduction

Since 1970, about 35% of natural wetlands have been lost (CZH, 2021). The global area of wetlands is estimated to be around 1.6 billion hectares (Davidson & Finlayson 2018; FAO, 2021). Indeed, wetlands are threatened by human activities, including agriculture, irrational use of resources, introduction of invasive species, and sedimentation following deforestation upstream of these areas (Blackham & Avent, 2018; Badiane & Edmée, 2018). They are thus undergoing transformations amplified by natural processes linked to climate change and biodiversity loss (Ndiaye et al., 2019).

However, through their various functions, wetlands play a key role in regulating water resources, purification and flood prevention (Leumbe et al., 2015). They also provide various services for climate change mitigation and adaptation (Blackham & Avent, 2018).

Because of their richness, these areas have many social and economic interests (Bérangère, 2022), especially in developing countries (UNCCD, 2022). The future of sustainable food production depends on wetlands in good condition and their wise use.

From a health perspective, wetlands provide a response to current ecological challenges and in relation to dangerous species that cause pandemics (FAO, 2021). Indeed, the degradation of wetlands as a result of agricultural intensification and/or of loss of biodiversity can increase the risks of disease emergence and transmission. Land restoration, therefore, can significantly improve human health and livelihoods, increase food and water security and reduce the risk of future pandemics such as COVID-19 (White & Razgour, 2020; Van Langevelde et al., 2020).

In Cameroon, the pressure on wetlands, which cover nearly 70% of the national territory, is increasing. This is related to the satisfaction of subsistence needs, firewood, grazing, logging and the expansion of development projects. This is how the phenomenon of desertification and land degradation tends to become widespread (MINEPDED, 2017). Yet Cameroon has implemented several initiatives with the support of technical and financial partners on sustainable land use. These initiatives are in harmony with development' vision of the country, which aims to make the country an emerging economy by 2035 in order to improve the living conditions of as many Cameroonians as possible (NDS 2030). However, the reduction of 75% of forest and land degradation due to logging and the halving of the conversion of forests into other forms of land use are among the targets that the country is aiming for regarding land degradation neutrality by 2030.

Currently, in terms of land use, forest has retreated by 619 km^2 and agricultural land has increased by 321 km^2. The surface area of degraded forests and land is estimated at around 12 million hectares, with a general trend towards an increase in the phenomenon due to both natural and anthropogenic factors (MINEPDED, 2017).

Actions in favour of wetlands are widely engaged in the different basins of Cameroon. However, the management strategies for these areas are based on knowledge that is certainly extensive, but still fragmented. There is a serious lack of data on the location of degraded land, on the intensity of degradation and on the way in which farmers address this problem in their land management practices. In order to fill these gaps, this study aims to characterise the spatial units and the extent of degradation in the Noun floodplain. This area has particular economic and social characteristics: it is one of the richest and most productive wetlands in the country. The pastures found there can survive the dry season thanks to residual flood waters, attracting large herds of cattle from nomadic and transhumant herders. However, its potential wealth and productivity are further threatened by water deficit, erosion, terrorism and agricultural over-exploitation. There is a current need for knowledge and management of wetlands that requires the use of well adapted management and monitoring tools (Soro & Alii, 2014; Djagnikpo et al., 2017). The difficulties of access and the complexity of these environments tend to justify the use of remote sensing techniques and geographic information systems.

Thus, the objective of this study is to analyse the dynamics of land use in the Noun floodplain using multi-date satellite images for sustainable land management at the local level, despite the constraints imposed by socio-economic development. Specifically, the aim is to characterise the spatial units of the plain, to detect changes in land cover and use between 1999 and 2021, and finally to propose solutions to limit land degradation. The updated characteristics of the spatial and temporal dynamics of the Noun floodplain make it possible to highlight the spatial interactions and the actors in the environment that must be taken into consideration in sustainable land management strategies. Heavily degraded zones would then be identified and located, which would facilitate the implementation of possible operations. This study also constitutes a reference framework that transcribes the physical identity of the territory. This study also provides politicians, managers and planners with decision-making tools, which are essential for the implementation of an enlightened and sustainable management policy and strategy for these ecologically sensitive areas. Finally, it would enable the various stakeholders, including the local populations, to become aware of the advantages offered by the natural vegetation, the threats and the level of degradation of the land they use, so as to participate effectively in the integrated management of the plain.

This thinking is based on the concepts of land degradation and sustainable land management, which apply to all land uses. This framework allows an understanding of the links between land degradation key factors and theirs variables. The basic assumption is that agricultural activity continues to expand over time.

2. Methodology

2.1. Presentation of the Study Area

The study was carried out in the Noun floodplain located in the Noun department in Cameroon. The study area is located between latitude 05˚40'24" North and longitude 010˚28'41" West and covers an area of about 7687 km^2 (Figure 1) in the West Cameroon Region. The department comprises nine (09) municipalities (Bangourain, Foumban, Kouoptamo, Koutaba, Magba, Malantouen and Massangam. Njimom). It is bordered to the east by the municipalitie of Massangam, to the west by those of Bafoussam 1st and 2nd, to the north by the municipalitie of Koutaba, and to the south by the Department of Nde (PCD, 2014). It lies at an average altitude of between 1100 and 1300m. Its relief is made up in places of isolated hillocks and residual hills. The slopes are gentle (generally between 0 and 20%).

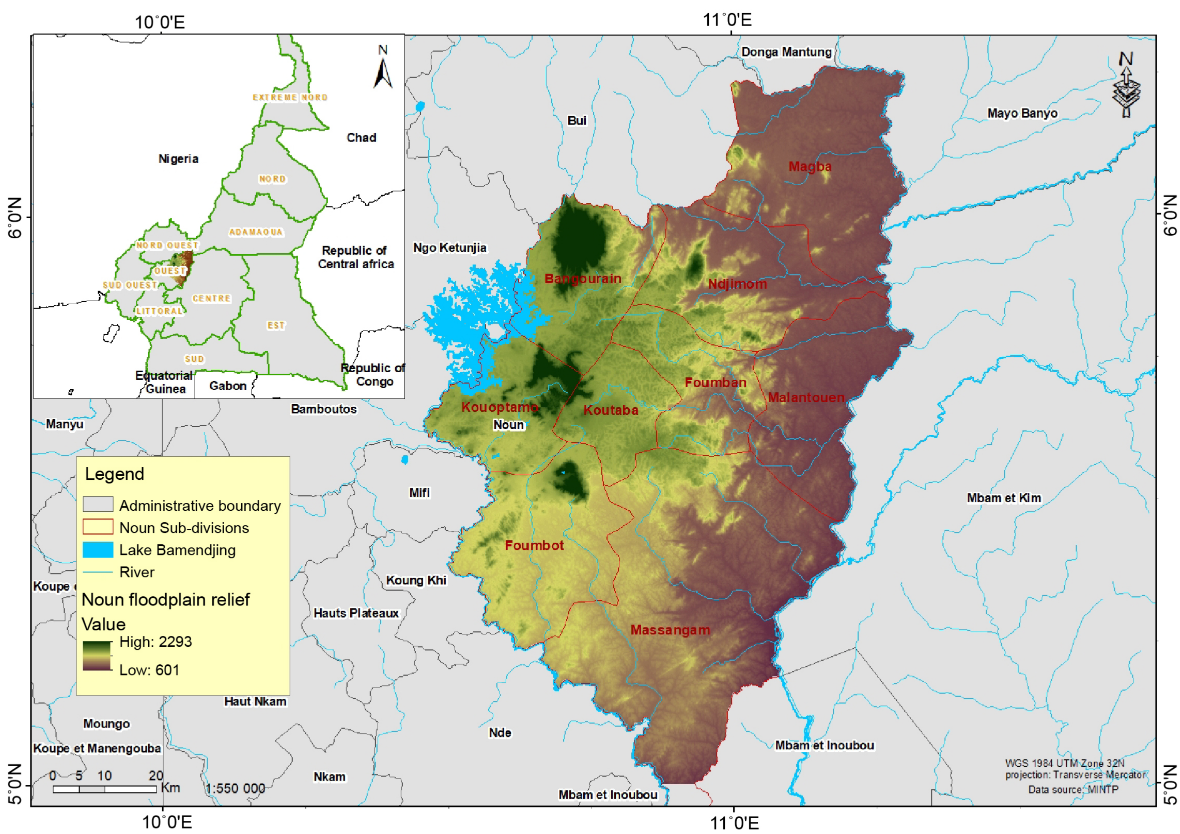

Figure 1. Location of the study area (Noun Department).

The Noun floodplain is subject to a tropical Sudanese-Guinean climate characterised by a rainy season from mid-march to mid-november and a dry season from mid-november to mid-march marked by very high evapotranspiration. The average rainfall varies between 2500 and 5000 mm per year with minimum and maximum in November and July respectively. The average annual temperature is around 21˚C. The soils are mostly of volcanic origin and are black in colour with a high agronomic value. On the whole, there are andosols, hydromorphic soils located in the lowlands and shallow acidified soils.

The Noun plain is mainly fed by the river Noun and some tributaries. There are also lakes at the top of Mount Mbapit and some small water points in the lowlands. The vegetation of the Noun plain is characterised by the predominance of mixed woody (tree and shrub) and herbaceous plant formations. The woody cover is clear (not closed) and dominated by savannahs with variable local physiognomy. Gallery forests are found along the watercourses. The fauna is not very rich and diverse. This is due to the pressure of human activities (fields and housing). The population of the Noun department is estimated at around 455,083 inhabitants of various origins (Bamoun, Bamileke, Haoussa, foulbés, bororos, natives and allogenes, ...) who practice agriculture (coffee, potatoes, plantain banana, tomato, ...), livestock farming, fishing, trade, handicraft and tourism.

2.2. Material and Methods

In order to assess the evolution of land use in the Noun floodplain, a two-stage approach was adopted: characterisation of the spatial units of the plain and detection of changes in land use between 1999 and 2021. The characterisation of the spatial units of the plain was approached by mapping with the help of satellite images, which offer a particular vision of the land surface, adapted to the understanding of large areas and the interpretation of sometimes complex landscapes. Remote sensing techniques have made it possible to assess land cover and to develop diachronic analyses using digital processing (El Hage et al., 2019).

Choice of satellite images: The Noun floodplain was isolated from Landsat 7 images of the years 1999, 2004, 2010, 2014 and 2021 of the ETM+ (Enhanced Thematic Mapper Plus) sensor with a resolution of 30 m, due to their availability and accessibility. The choice was made to use images from the same period, in particular the month of november, in order to better appreciate the interannual changes in land use (Foody, 2002).

Pre-processing: The pre-processing consisted of removing impurities from the Landsat images. The cloud cover had to be less than 10%. Indeed, the images provided by the USGS server are level 1 products which present defects due to the presence of streaks at the edges of the image resulting in a loss of more than 22% of the scene. These black lines in the images are the result of a mechanical failure (on 31 May 2003) of the optical system ETM+ Scan Line Corrector (SLC), which was used to restore parallelism to the scanned images distorted by the satellite's advance (Tang et al., 2013). In order to remove the black lines from the failure, the 'fill no data' tool of the GDal extension of the QGiS 3.18 software was used. Once completed, atmospheric and reflectance corrections were performed.

Spatial analysis: The 3-2-1 and 4-3-2 combinations of spectral bands allowed the prior identification of the land use units to be mapped, which were grouped into 4 categories. The ground truth helped to recognise and define the landscape features of the study area. The reference classes were selected from the satellite image and validated by GPS point surveys (Solly et al., 2020). In order to better discriminate the different spectral signatures of the colour compositions, a Principal Component Analysis (PCA) was initially applied to perform band combinations to increase the separation between the different clusters, thus improving the quality of the classification (Lagabrielle et al., 2007). An unsupervised classification by the K-Means clustering algorithm using the SNAP software of the Sentinel platform (Astri, 2017) was then performed. The number of clusters was arbitrarily set to 20. The spectral classes were then named according to the predominance of a land cover based on visual analysis, and then grouped into a common legend determined from the results obtained. This classification was inspired by the LCCS (Land Cover Classification System) nomenclature proposed by the FAO.

Quantification of change: Several statistical indicators were used to quantify the change in land cover classes: the global change rate (Tg) and the transition matrix. Indeed, to measure the growth of macroeconomic aggregates between two given periods (Soro, 2014), the overall rate of change (Tg) of land cover class areas was determined according to the equation proposed by FAO (1996): $Tg = (S_2 - S_1) \times 100/S_1$. With S_1 as the area of a land unit class at date t_1; S_2 the area of the same land unit class at date t_2. The variable considered here is the area (S), positive values indicate an increase in the area of the class during the period analysed and negative values indicate a loss of area between two dates. Values close to zero indicate that the class remains relatively stable between two dates (Kpedenou et al., 2016; Mama et al., 2013).

Transition matrix: In order to assess the different forms of conversion undergone by the land use units between two dates t_1 and t_2, the transition matrix (Schlaepfer, 2002) was determined to describe the changes that occurred. It is obtained by crossing the land cover maps of 1999 and 2021, made possible by the Semi-automatic Classification Plugging (SCP) tool of Qgis 3.8.

Confusion matrix: The accuracy of the classifications was assessed through the automatic calculation of a confusion matrix (Foody, 2002). Using the Qgis SCP tool, the classification results were compared with a set of GPS reference points collected in the field. Two classifications validation indices, namely the overall accuracy (proportion of well classified pixels, calculated as a percentage) and the Kappa index (ratio between well classified pixels and the total number of pixels surveyed) were determined (Skupinski et al., 2009).

3. Results

3.1. Characterisation of the Spatial Units of the Noun Floodplain between 1999 and 2021

Spatial analysis of Landsat 1998 satellite imagery has enabled the precise mapping of the different land cover units of the Noun floodplain. Discrimination was made between artificial areas and different vegetation formations. This grouping favoured the spatial precision of the classes, by broadening their semantic scope. Land use maps were produced after unsupervised classifications of Landsat images from 1999, 2004, 2010, 2014 and 2021. In total, eight (08) land cover classes were mapped for each year as shown in Figure 2.

Table 1 summarises the land use conditions whereas Figure 3 describes the percentages of the different classes of land cover in the Noun floodplain between 1999 and 2021.

Overall, if the landscape was dominated by natural vegetation (72.6%), represented by the forest gallery and the herbaceous savannah, located from the north to the south of the Noun plain in 1999, since 2004, it is the agricultural

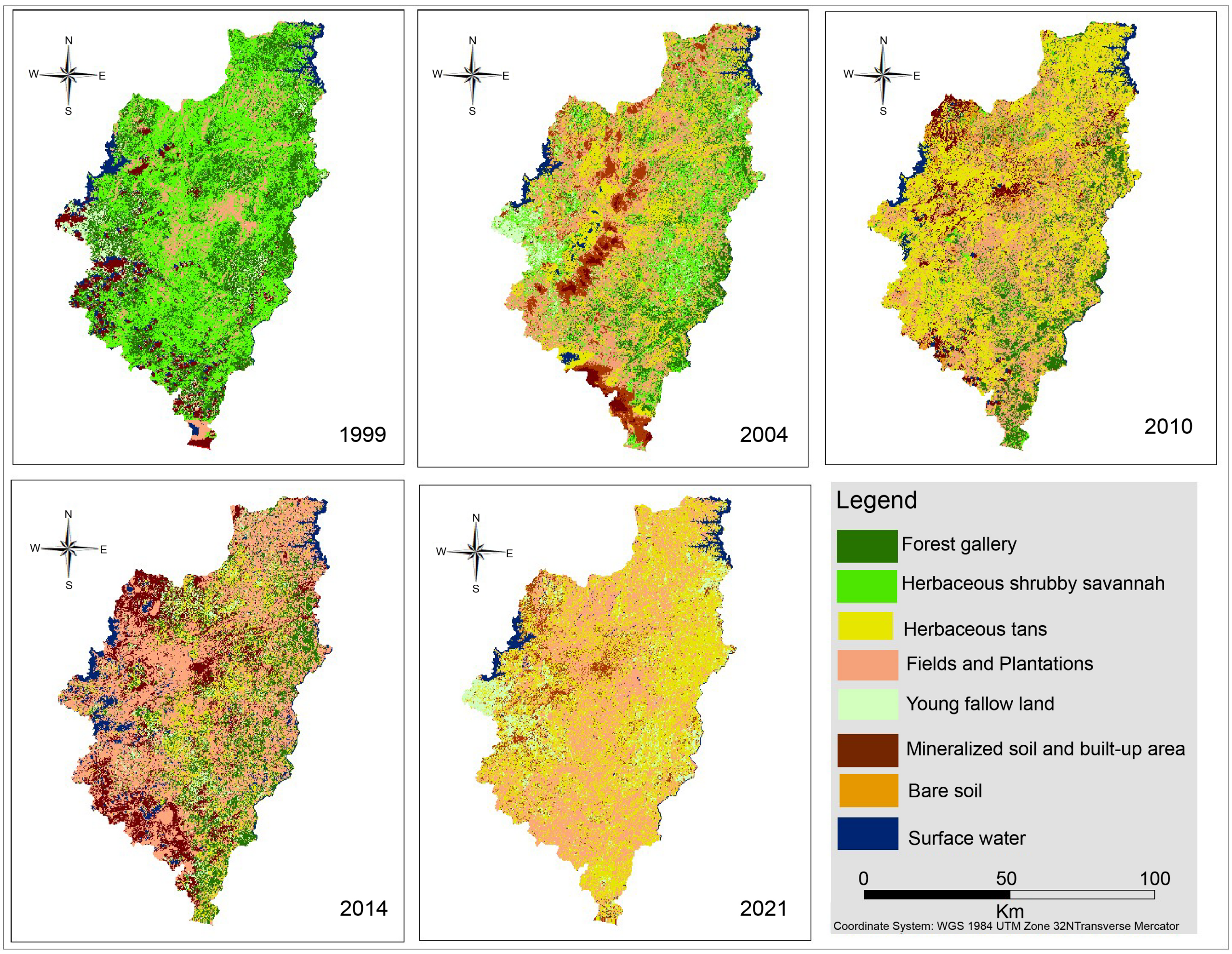

Figure 2. Map of land use evolution between the years 1999, 2004, 2010, 2014, 2021.

Table 1. Statistics of land cover classes between 1999 and 2021.

Land cover classes	Years									
	1999		2004		2010		2014		2021	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Gallery forest	217562.35	28.5	102592.77	13.4	97696.9	12.8	123860.24	16.2	0	0
Herbaceous shrubby savannah	336666.33	44.1	123753.93	16.2	20327.64	2.9	0	0	0	0
Herbaceous tans	0	0	159414.01	20.9	320978.06	42	93386.75	12.2	329581.7	43.1
Fields and plantations	100051.44	13.1	234809.78	30.7	225571.8	29.6	305118.63	40	286679.03	37.5
Young fallow land	32846.1	4.3	40077.07	5.2	0	0	50148.65	6.6	76235.23	10
Mineralized soil and built-up area	40621.42	5.3	82310.15	10.8	45034.8	6	143721.28	18.8	50922.34	6.7
Bare soil	0	0	0	0	26456.5	3.4	**0**	**0**	0	0
Surface water	36041.8	4.7	20848.51	2.8	25256.6	3.3	47566.32	6.2	20376.05	2.7
Total	**763789.44**	**100**	**763806.22**	**100**	**763801.72**	**100**	**763801.87**	**100**	**763794.35**	**100**

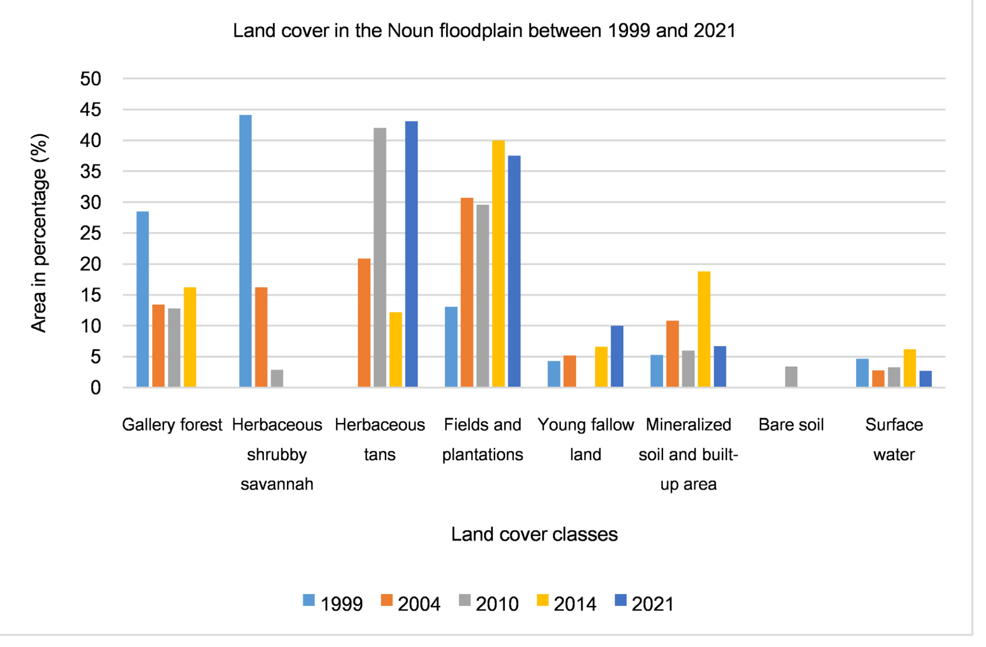

Figure 3. Description of Land cover in the Noun floodplain between 1999 and 2021.

zones (herbaceous savannah, field and plantation, young fallow land) that dominate the landscape. In fact, agricultural areas have gradually moved from the interior of the plain in 2004 (56.8%) to its borders in 2021, occupying 90.6% of the department's surface area. Natural formations have been gradually reduced in space and time. The class of mineralized soils and built-up has increased slightly between 1999 and 2014, from 5.3% to 18.8% respectively. As for the class represented by surface water, it lost about half of its surface area between 1999 and 2021.

3.2. Detection of Land Use Changes between 1999 and 2021

The evolution of land cover and land use between 1999 and 2021 in the Noun floodplain is presented in Table 2, which specifies the different land cover classes and their resulting rates of change in area.

The statistics from the mapping analysis indicate a significant and progressive loss of the area of natural vegetation zones, namely herbaceous shrub savannah and gallery forests between 1999 and 2021, reaching −100% in 2021. Similarly, fields and plantations class have decreased from 134.68% between 1999 and 2004 to −6.04% between 2014 and 2021. However, there was a slight loss of herbaceous tans between 2010 and 2014 (−70.9%), followed by a significant growth around the year 2021 (252.92%). As for water surfaces, they first increased between 2004 and 2014 respectively with rates of 21.14% and 88.33%, before decreasing significantly between 2014 and 2021 to around −57.16%.

As regards mineralized soils and built area, they have globally fallen from a change rate of 102.62% between 1999 and 2004 to −64.56% between 2014 and 2021. The most dramatic increases are in the field and plantation, young fallow, bare soil and herbaceous tans classes with change rates of over 100% between 1999 and 2021 (Figure 4). Overall, the results of the area regressions are consistent with the change rates obtained.

The transition matrix is presented in Table 3. It reveals the changes in land cover and land use classes in the Noun floodplain between 1999 and 2021. The transition matrix (Table 3) shows that all transition rates are positive, which means that all transformations are in the same direction. Some are medium (16.5%; 19.1%; 21.2%) and others low (0.1%; 0.2%; 0.3%). Of the 28.5% of the area occupied by gallery forests in 1999, 0% remains unchanged in 2021.

This indicates that in 2021 there would be no more gallery forests in the Noun plain.

However, 16.5% has been transformed into herbaceous tans, 4.8% into fields and plantations, 4.3% into young fallows, against 2.9% into mineralized soils and buildings. The herbaceous shrubby savannah has evolved in the same direction

Table 2. Change rate (Tg in %) between 1999 and 2021.

Land cover classes	1999~2004	2004~2010	2010~2014	2014~2021
Gallery forest	−52.84	−4.77	26.78	−100
Herbaceous shrubby savannah	−63.24	−83.57	−100	0
Herbaceous tans	15941401	101.34	−70.90	252.92
Fields and plantations	134.68	−3.93	35.26	−6.04
Young fallow land	22.01	−100	5014865	52.01
Mineralized soil and built-up area	102.62	−45.28	219.13	−64.56
Bare soil	0	2645650	−100	0
Surface water	−42.15	21.14	88.33	−57.16

Table 3. Transition matrix of land cover classes between 1999 and 2021.

2021 / 1999	Gallery forest	Herbaceous shrubby savannah	Herbaceous tans	Fields and plantations	Young fallow land	Mineralized soil and built-up area	Bare soil	Surface water	Total
Gallery forest	0	0	16.5	4.8	4.3	2.9	0	0	**28.5**
Herbaceous shrubby savannah	0	0	19.1	21.2	1.8	2	0	0	**44.1**
Herbaceous tans	0	0	0	0	0	0	0	0	**0**
Fields and plantations	0	0	3.5	**8.8**	0.5	0.3	0	0.3	**13.1**
Young fallow land	0	0	1.4	0.1	**2.3**	0.5	0	0	**4.3**
Mineralized soil and built-up area	0	0	1.9	1.6	0.8	**0.8**	0	0	**5.3**
Bare soil	0	0	0	0	0	0	0	0	**0**
Surface water	0	0	0.8	1	0.3	0.2	0	**2.4**	**4.7**
Total	**0**	**0**	**43.1**	**37.5**	**10**	**6.7**	**0**	**2.7**	**100**

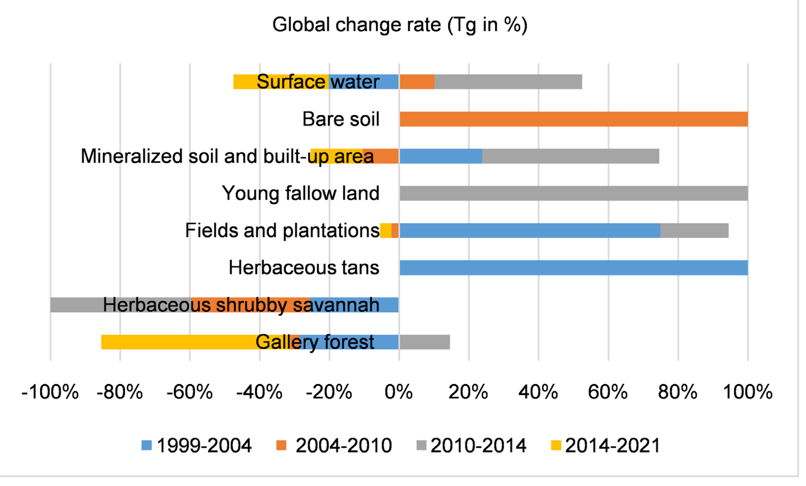

Figure 4. Summary of changes (Tg in %) of the different land cover classes between 1999 and 2021.

with respectively 19.1%, 21.2%, 1.8% and 2%. The natural vegetation zones would have disappeared completely, which is confirmed by the statistics of the land cover classes. This trajectory of regression is also perceptible at the level of fields and plantations, young fallow land, and even at the level of mineralised soil and surface water.

Yet, 8.8% of fields and plantations, 2.4% of surface water, 2.3% of young fallow land and 0.8% of mineralised soils and buildings remained stable between 1999 and 2021. This means that 14.3% of spatial units remained stable. Overall, this is a conversion of land cover classes to classes of another category. On the other hand, 67.7% of the area (herbaceous savannahs and forest galleries) have undergone a strong degradation in favour of the agricultural zones.

4. Discussion

4.1. The Noun Floodplain: An Environment with Diverse Spatial Units

The results of the confusion matrix indicate an accuracy level of 90% for the 1999 Landsat image and 95% for the 2021 Landsat image. This reveals that the changes observed on the images do indeed correspond to variations in land cover and land use in the Noun floodplain over the period 1999 to 2021. In addition, the values of the Kappa index, which are 0.49% (1999) and 0.54% (2021), are statistically acceptable and explain the quality of the classification performed. Indeed, a Kappa index of 0.3% is acceptable for Landis and Koch (1977). However, Pontius (2000) considers that a Kappa value higher than 0.50 is good and exploitable. Nevertheless, these average values could be explained by the high intensity and variability of land use, by the cloud cover of the area and by the high temporal dynamic of these changes. Moreover, the recent spatial data (2021) represent only a non-exhaustive sample of the ground reality. This study confirms the possibility offered by space remote sensing to observe the Earth's surface continuously. It thus contributes to a database on the Noun floodplain, which provides informations on the state of local ecosystems and their evolution (Diédhiou et al., 2020).

Although half of the Noun floodplain (67.7%) appears to be degraded, it remains an environment composed of several spatial units represented by the eight classes selected in this study. It has a rugged relief that is difficult to access. The accuracy of land use mapping in this environment remains a challenge, due to the spectral similarities in the main spatial units as stated by Jofack et al., (2016) in a study conducted in the western region in which the Noun plain is located. In fact, it was difficult to dissociate within the lowlands the different spatial units represented by fields (for vegetable crops) and plantations (for field crops), mineralized soils and buildings. This justifies the grouping of these classes in the same cluster. To overcome this impasse it is necessary to integrate and use complementary methods and tools (Hosni, 2002). The use of a battery of methods and tools also has the advantage of producing more accurate land cover maps that best reflect the reality on the ground. In reality, the detection of different land cover categories from satellite images alone is difficult and therefore reliance on field data is necessary (El Hage et al., 2019).

4.2. Natural Vegetation: A Covetousness for Agricultural Activity

Globally, the agricultural zone appears to be the main transformation of the Noun floodplain landscape. This indicates that human activity is the main cause of land degradation in this area. Indeed, traditional agricultural production methods are mostly rudimentary and often destructive of natural resources. This is the case even in conditions of low land use. This decrease in the area of natural vegetation to the benefit of agriculture is confirmed by the 2016 Global Forest Watch data, which indicates a loss of total area of 2.7% in the Western region to which the Noun floodplain belongs. This regression of natural vegetation converted to agricultural area has been observed in the western region of Cameroon (Tsewoue et al., 2020; Solefack et al., 2018; Temgoua et al., 2018) and in West Africa (Julien et al., 2014; Kpedenou et al., 2016). The results also reveal the intensity and high variability of land use in the Noun floodplain (coffee, plantain, potatoes, tomatoes, watermelons, etc.). However, field reconnaissance can explain the total absence of natural vegetation units in the cartographic classification, but also allows us to observe a more or less rapid regeneration of natural vegetation, scattered throughout the vast agricultural areas. The analysis of the change maps shows a significant progression of the artificialized unit and a regression of the natural unit in favour of agricultural units. The rate of natural vegetation goes from 72.6% in 1999 to −100% in 2021. This regression of natural formations indicates a degradation of the environment linked to the development of socio-economic activities (cultivation on bushes, exploitation of timber and firewood) in a context of demographic pressure. According to the National Institute of Statistics of Cameroon, the population of the Noun department increased from 293,725 inhabitants in 1987 to 45,5083 inhabitants in 2005. This population is estimated to be over one million in 2020. It is clear that demography is increasing over time. However, the area that hosts this dynamic population is not increasing, hence the strong pressures on the land. Indeed, Atta et al, 2010 have blamed population growth and certain modes of exploitation as being responsible for land degradation resulting in the disruption of ecological balances. This situation is frequent in sub-Saharan Africa where high population densities and the crisis of agricultural space lead populations to seek new land (Abotchi, 2002; Munyemba & Bogaert, 2014). The Anglophone crisis that has been in the north-west region of Cameroon since 2016 by forcing population's movement could accentuate land degradation in the Noun plain As displaced populations seek land to settle and feed themselves. The conversion of the natural environment into an agricultural area suggests an improvement in the agricultural production system (Julien et al., 2014).

In addition to human activities, there is the climatic factor that could explain this regressive dynamics of natural vegetation formations in the Noun floodplain. The effects of drought in savannah environments are often observed through variations in woody cover, which are highly indicative of climate change at the local scale (Dewitte et al., 2012). The reduction of the water surface by half between 2014 and 2021 justifies the observation of the progressive scarcity of rainfall in the area, leading to an increase in irrigation and the intensification of cultivation on the tan, which are areas conducive to the regeneration of the natural vegetation.

4.3. Trend in Land Degradation and Prospects for Sustainable Land Management

The preliminary results of this study indicate that population pressure will continue, the environment will become increasingly degraded, and access to cropland will become more difficult, particularly due to conflict and land degradation (Ndam, 2021). Similarly, current natural resource management and use practices threaten the health and survival of many species, including humans (UNCCD, 2022). Decision-makers and managers, including local populations, should be made aware of the level of degradation of the environment in which they live and of the interactions between different spatial units. The trend of land degradation can be reversed by adopting development (land) policies that take into account the ecosystem services provided by wetlands while creating opportunities that improve livelihoods and prepare for future challenges. This study provides specific informations on the Noun floodplain in terms of the amount of degraded land. This allows for the application of specific land restoration measures, which are in line with the country's land degradation neutrality (LDN) objectives. Wetlands, which have been the focus of attention of managers and decision-makers from an early stage, are protected through different mechanisms such as Nature Parks, Nature Reserves, Regional Botanical Gardens. However, there are a large number of wetlands described as “ordinary” that have not yet been inventoried (Sébastien et al., 2019). The knowledge and quantification of the spatial units of the Noun floodplain would contribute to promoting these “ordinary” environments in order to draw the attention of decision-makers, managers and local populations to their level of degradation.

Furthermore, the data obtained from this study provide guidelines for the elaboration of municipalities development plans (MDP) and land use plans (LUP), documents that translate spatial, physical and environmental development based on available natural resources. Indeed, the degradation of wetlands caused by agricultural intensification and urbanisation has contributed not only to a reduction in fauna and flora but also to an increase in water pollution and in the frequency of low water and flooding (Acreman & Holden, 2013). The inventory, delimitation, characterisation and monitoring of these environments have therefore emerged as priority elements of European and regional action programmes aimed at recovering water quality and biodiversity (Gramond, 2014). To reduce the conversion of natural vegetation areas into other forms of occupation, coherence should be ensured between agricultural development plans and strategies to limit deforestation and/or degradation through municipalities development plans (MDPs) and land use plans (LUPs), at the local level. While adopting sustainable land management practices in agro-sylvo-pastoral activities. These sustainable land management practices include integrated management of crops (trees), livestock, soils, water, nutrients, biodiversity, diseases and pests with the aim of optimising the provision of a range of ecosystem services (Cornell et al., 2016). Furthermore, it should be recognised that investing in large-scale land restoration would help fight against desertification, soil erosion and declining agricultural production. This is a gain for the environment (UNCCD, 2022).

5. Conclusion

Remote sensing and geographical information systems have effectively identified spatial units and detected land use changes in the Noun floodplain over a period of about 22 years (1999-2021). The study shows that the Noun floodplain is a contrasted environment, composed of several dynamic spatial units. The extension of the agricultural zone with damages on natural plant formations is due to the galloping demography and unsustainable agricultural practices. This is likely to degrade the land of the plain. This situation would be aggravated by climate change and the security crisis on the western border of the plain. The trend would be the progressive regression of natural areas and the advanced degradation of the land and its impacts on soil productivity, water quality, and the survival and well-being of species living in the environment. Decision-makers can help to slow down, halt or even reverse the trend by making wise use of existing wetlands, restoring wetlands that have been degraded, developing sources of funding for wetland conservation and raising awareness of the benefits of wetlands. However, new scientific developments based on artificial intelligence, such as Deep Learning, could provide decision-makers and land managers with modern and efficient tools for enlightened decision-making for a better monitoring of the natural resources of the Noun plain.

Similarly, the analysis of the determinants of agricultural expansion, the analysis of its interactions with other human activities, or the conflicts concerning the use and appropriation of land are other research fields to explore.

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Conflicts of Interest

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

References

Abotchi, T. (2002). Agricultural Colonisation and Rural Dynamics in Togo: The Case of the Northern Mono Plain. *Revue du C.A.M.E.S. Sciences Sociales et Humaines. Series B, 4,* 97-108.

Acreman, M., & Holden, J. (2013). How Wetlands Affect Floods. *Wetlands, 33,* 773-786. https://doi.org/10.1007/s13157-013-0473-2

Astri, P. (2017). *SNAP Wookbook. Earth Observation for Sustainable Development.* http://www.eo4sd-eastern.eu/sites/default/files/publications/snap_workbook_english.pdf

Atta, S., Achard, F., & Ould Mohamedou, S. O. M. (2010). Recent Evolution of Population, Land Use and Floristic Diversity in an Agricultural Area of Southwestern Niger. *Science & Nature, 7,* 119-129. https://doi.org/10.4314/scinat.v7i2.59948

Badiane, S. D., & Edmée, M. (2018). *Urban Wetlands with a Double Face in Dakar: Opportunity or Threat? The Irste Review* (5 p.). Sciences Eaux & Territoires-hors série article n° 51-2018. http://www.set-revue.fr/

Bérangère, A. (2022). *Dp-Plan National Milieux Humides 2022-2026* (18 p.). French Ministry of Ecological Transition. https://www.ecologie.gouv.fr

Blackham, G. V., & Avent, T. D. (2018). *National Guide to Sustainable Wetland Management* (83 p.). Wildfowl & Wetlands Trust.

Cornell, A., Weier, J., Stewart, N., Spurgeon, J., Etter, H., Thomas, R., Favretto, N., Chilombo, A., van Duivenbooden, N., van Beek, C., & de Ponti, T. (2016). *The Economics of Land Degradation Initiative: Report for the Private Sector. Sustainable Land Management—A Business Opportunity* (60 p.). GIZ. https://www.eld-initiative.org

CZH (2021). *Convention on Wetlands. Global Wetland Outlook: Special Edition 2021* (56 p.). Secretariat of the Convention on Wetlands.

Davidson, N. C., & Finlayson, C. M. (2018). Extent, Regional Distribution and Changes in Area of Different Classes of Wetland. *Marine and Freshwater Research, 69,* 1525-1533. https://doi.org/10.1071/MF17377

Dewitte, O. et al. (2012). Satellite Remote Sensing for Soil Mapping in Africa. *Progress in Physical Geography, 36,* 514-538. https://doi.org/10.1177/0309133312446981

Diédhiou, I., Mering, C., Oumar, S., & Sané, T. (2020). Remote Sensing Mapping of Land Cover and Land Use Change. *EchoGeo,* 54 p. http://journals.openedition.org/echogeo/20510

Djagnikpo, K. et al. (2017). *Land Use Analysis for the Monitoring of Landscape Evolution of the Ouatchi Territory in Southeast Togo between 1958 and 2015 Kpedenou Cahiers du cerleshs numero 55 octobre 2017* (pp. 203-227).

El Hage, H. H., Ardillier-Carras, F., & Charbel, L. (2019). Land Use Changes in the West Beqaa (Lebanon): The Role of Anthropogenic Actions. *Cahiers Agricultures, 28,* 10. https://doi.org/10.1051/cagri/2019010

FAO (1996). *AFRICOVER Land Cover Classification Scheme* (26 p). Working Paper for the Dakar Meeting of the AFRICOVER International Working Group on Land Cover Classification and Map Legend. https://www.fao.org/home/en/

FAO (2021). *The State of the World's Land and Water Resources for Food and Agriculture-Systems on the Brink. Synthesis Report 2021.* Rome.

Foody, G. M. (2002). Status of Land Cover Classification Accuracy Assessment. *Remote Sensing of Environment, 80,* 185-201. https://doi.org/10.1016/S0034-4257(01)00295-4

Gramond, D. (2014). Requalifying Continental Wetlands: Logics and Paradoxes. *Geocarrefour, 88,* 247-256. https://doi.org/10.3917/geoc.884.0247

Hosni, G. (2002). *Utilisation des réseaux de neurones pour la cartographie des zones humides à partir d'une série temporelle d'images RADARSAT 1* (p. 230). Thèse de doctorat de l'Université du Québec.

Jofack Sokeng, V.-C., Kouamé, F. K., Dibi, N. H., Tankoano, B., Akpa, Y. L., & Ngounou, N. B. (2016). Land Cover Mapping of the West Cameroon Highlands by Neural Networks Applied to a Landsat 8 OLI Image. *International Journal of Innovation and Scientific Research, 23,* 443-454.

Julien, A., Mama, A., Toko, I., Kindomihou, V., & Sinsin, B. (2014). Land Use Dynamics in the W National Park and Its Periphery in Northwest Benin. *International Journal of Biological and Chemical Sciences, 8,* 2608-2625. http://ajol.info/index.php/ijbcs https://doi.org/10.4314/ijbcs.v8i6.22

Kpedenou, K. D. et al. (2016). Quantification of Land Use Changes in the Prefecture of Yoto (Southeast Togo) Using Landsat Satellite Imagery. *Revue des Sciences de l'Environnement, Laboratoire de Recherches Biogéographiques et d'Etudes Environnementales (Université de Lomé), 31,* 137-156.

Lagabrielle, E., Metzger, P., Martignac, C., Lortic, B., & Durieux, L. (2007). Land Use Dynamics in Reunion Island (1989-2002). *Mappemonde, 86,* 1-23. https://mappemonde-archive.mgm.fr/num14/articles/art0

Landis, R. J., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics, 33,* 159-174. https://doi.org/10.2307/2529310

Leumbe, L. O., Bitom, D., Mamdem, L., Tiki, D., & Ibrahim, A. (2015). Mapping Flood Risk Areas in the Sudano-Sahelian Zone: The Case of Maga and Its Surroundings in the Far North Region of Cameroon. *Africa Science, 11,* 45-61. https://www.afriquescience.info/

Mama, A., Sinsin, B., De Canniere, C., & Bogaert, J. (2013): Anthropisation and Dynamisation of Landscapes in the Sudanian Zone in Northern Benin. *Tropicultura, 31,* 78-88.

MINEPDED (2017). *Final Report of the Process of Defining National Voluntary NDT Targets* (51 p.).

Munyemba, K. F., & Bogaert, J. (2014). Anthropisation and Land Use Dynamics in the Lubumbashi Region from 1956 to 2009. *E-revue UNILU, 1,* 3-23.

Ndam, I. (2021). Contribution to the Analysis of Land Tenure Insecurity in the Agricultural Pioneer Fronts of the Bamoun Country Margins. *African Journal on Land Policy and Geospatial Sciences, 4,* 179-195.

Ndiaye, I., Diop, M., Ba, A., & Ba, B. (2019). *The Economic Effects of Progressive Land Degradation in Mbar Diop* (42 p.). A Report by the ELD Initiative under the Project "Reversing Land Degradation in Africa through Large-Scale Adoption of Agroforestry. https://www.eld-initiative.org

PCD (2014). *Plan Communal Development Foumbot.* https://fdocuments.fr/document/plan-communal-de-developpement-de-foumbot-plan-communal-de-developpement-de-foumbot

Pontius Jr., R. G. (2000). Quantification Error versus Location Error in Comparison of Categorical Maps. *Photogrammetric Engineering and Remote Sensing, 66,* 1011-1016.

Schlaepfer, R. (2002). *Analysis of Landscape Dynamics. Fiche d'enseignement 4.2, Laboratoire de Gestion des Ecosystèmes, Ecole Polytechnique de Lausanne, Switzerland* (10 p.).

Sébastien, R., Bernard, C., & Laurence, H.-M. (2019). Mapping Wetlands by Remote Sensing: A Multi-Scalar Approach for Environmental Planification. *Cybergeo: European Journal of Geography [Online], Cartography, Imagery, GIS, 89,* Paper 885. http://journals.openedition.org/cybergeo/31606

Skupinski, G., Binhtran, D., & Weber, C. (2009). Multi-Date Spot Satellite Images and Spatial Metrics in the Study of Urban and Suburban Change: The Case of the Lower Bruche Valley (Bas-Rhin, France). *Cybergeo: European Journal of Geography [Online], Systems, Modelling, Geostatistics, 35,* Article 439. http://cybergeo.revues.org/21995

SND (2020). *Cameroon National Development Strategy 2030.* https://minepat.gov.cm/

Solefack, M. C., Njouonkou, A. L., Temgoua, L. F., Djouda, R., Zangmene, J. B., & Ntoupka, M. (2018). Land-Use/Land-Cover Change and Anthropogenic Causes Around Koup Matapit Gallery Forest, West-Cameroon. *Journal of Geography and Geology, 10,* 201-219. https://doi.org/10.5539/jgg.v10n2p56

Solly, B., Dieye, E. H. B., & Sy, O. (2020). Remote Sensing Mapping of Land Use and Land Cover Changes in Upper Casamance, Senegal, 1987-2018. *American Journal of Remote Sensing, 8,* 35-49. https://doi.org/10.11648/j.ajrs.20200802.11

Soro, G., & Alii (2014). Contribution of Remote Sensing to the Mapping of Spatio-Temporal Evolution of Land Use Dynamics in the Lakes Region (Central Ivory Coast). *Afrique Science, 10,* 146-160.

Tang, Y., Atkinson, P.-M., Wardrop, N.-A., & Zhang, J. (2013). Multiple-Point Geostatistical Simulation for Post-Processing a Remotely Sensed Land Cover Classification. *Spatial Statistics, 5,* 69-84. https://doi.org/10.1016/j.spasta.2013.04.005

Temgoua, L. F., Ajonina, G., & Woyu, H. B. (2018). Land Use and Land Cover Change Analysis in Ajei Upland Waterched Community Forest, North West Region, Cameroon. *Journal of Geoscience and Environment Protection, 6,* 83-99. https://doi.org/10.4236/gep.2018.69007

Tsewoue, M. R., Tchamba, M., Avana, M. L., & Tanougong, A. D. (2020). Spatio-Temporal Dynamics of Land Use in the Moungo, Littoral Region, Cameroon: Influence on the Expansion of Banana-Based Agroforestry Systems. *International Journal of Biological and Chemical Sciences, 14,* 486-500. http://www.ifgdg.org https://doi.org/10.4314/ijbcs.v14i2.15

UNCCD (2022). *Global Land Outlook. Summary for Policy Makers* (2nd ed., 24 p.). United Nations Convention to Combat Desertification. https://www.unccd.int

Van Langevelde, F., Rivera Mendoza, H. R., Matson, K. D., Esser, H. J., de Boer, W. F., & Schindler, S. (2020). *The Link between Biodiversity Loss and the Increasing Spread of Zoontoic Diseases*. European Parliament.

White, R. J., & Razgour, O. (2020). Emerging Zoontotic Diseases Originating in Mammals: A Systematic Review of Effects of Anthropogenic Land-Use Change. *Mammal Review, 50,* 336-352. https://doi.org/10.1111/mam.12201