

Socio-Spatial Dynamics of Land in Southwest Niger: The Case of the Commune of Gothèye

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Abstract

In south-west Niger, ecosystems are losing several hectares of their surface area every year due to internally displaced persons and refugees. The commune of Gothèye is not immune to this situation. The aim of this research is to assess the impact of displaced persons and refugees on socio-spatio-temporal dynamics of ecosystems using Landsat images. To achieve this, Landsat TM, Landsat ETM+ and OLI 8 satellite images from September and March were used (2010 to 2024). Operations on Envi 5.3, field validation output and finally mapping on ArcGIS were the steps involved. Discrimination is significant, with kappa coefficients of 0.97, 0.96, 0.86 and 0.85. The results obtained indicate a degradation of natural ecosystems, reflected in a change in landscape structure, with a marked reduction in the quantity and quality of ecosystem goods. Analysis of the evolution of land use showed that 31% of the land remained in its initial state (unchanged), 69% underwent modifications, and 11% was converted to cropland. Over these fourteen years, the study area has undergone changes in land use patterns, which have resulted in a modification of landscape structure, with a marked decline in the quantity and quality of ecosystem services.

Keywords

Dynamics, Ecosystem, Anthropization, Remote Sensing, Displaced Persons

1. Introduction

Climate change and anthropic pressure are the main factors causing landscape

changes not only in urban areas but also in rural communities. In south-western Niger, this anthropic pressure is relatively high, due to an upsurge in insecurity that has plagued the area for the past decade [1]. The area occupies the south-east to south-west corner of the country and borders Burkina Faso and Mali. This insecurity puts a strain on already weak basic social services and has “serious repercussions on fragile livelihoods and people’s ability to provide for themselves” [2]. Persistent insecurity and armed conflict continue to lead to massive population movements in the region, with increasing abandonment of fields for security reasons [3]. Large-scale displacement has a major impact on scarce natural resources, with negative consequences for both ecosystems and ecosystem goods and services [4]. As a result, ecosystems in the vicinity of refugee sites are in a state of advanced degradation. To meet their basic needs, the refugees engage in income-generating activities, including cutting and selling firewood. The latter is a factor in the degradation of the natural environment. Refugees cut down trees to use the wood for food preparation in the household, or to sell it for a few bucks. This rapid process has had a major impact on land use. There is a considerable environmental impact and damage to ecosystems. Controlling the rapid spatial changes brought about by the arrival of displaced people is therefore essential to shed light on the ecological consequences [1].

The analysis of spatial and temporal landscape changes in rural areas is an important clue to reflect the regional development pattern [5], which has always been a hot spot of analysis in the fields of geography, natural resources, and rural planning [6], which can provide important and useful information for sustainable development to make rational decisions [7]. A comprehensive assessment of changes in rural spatial and temporal dynamics will benefit the environmental management and spatial planning of the landscape [8].

In this context, sustainable development will depend, among other things, on the successful management of urban spatial growth, particularly in low-income countries where the most rapid urbanization is expected by 2050, such as those in sub-Saharan Africa [9]. This process also leads to a deterioration in the quality of the urban environment, notably through the removal of original vegetation cover [10]. Yet vegetation elements and formations in rural environments are becoming increasingly important for the provision of ecosystem services [11]. There is an urgent need to understand the spatio-temporal dynamics of landscape anthropization around the settlement sites of displaced persons in the commune of Gothèye, to formulate proposals for mitigating environmental impacts. This quantification of the spatio-temporal dynamics in the commune of Gothèye will be based on landscape ecology analysis tools coupled with digital mapping.

2. Methodology

2.1. Study Area

This study was carried out on the outskirts of the commune of gothéye in south-western Niger (Figure 1). The area is characterized by a Sahelian climate, with a

long dry season (7 to 8 months) alternating with a rainy season. This alternation is reflected in the periods of activity of the natural vegetation, which is active only in the rainy season, with an average annual rainfall of between 400 and 800 mm. Its vegetation is characterized by numerous patches of forest and by a mosaic of crops and plantations of fast-growing species. Watercourses also form distinctive ecosystems.

Native and non-native villages have sprung up because of migratory movements to the area. The main activity of the local population is agriculture. In addition to farming, artisanal and industrial logging, charcoal-making, transport, livestock breeding and trading are some of the activities in which the people of this area engage.

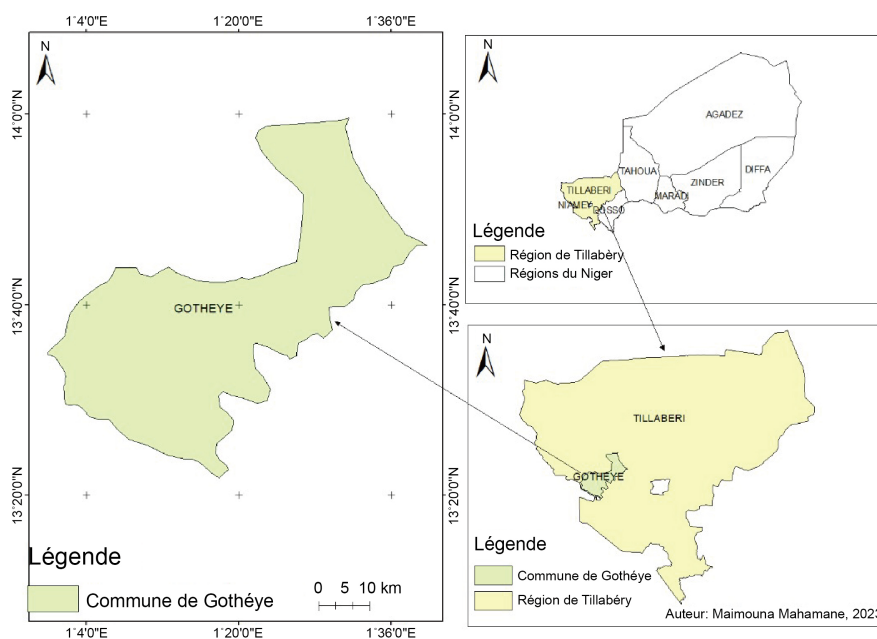


Figure 1. Map of Gothéye.

2.2. Data Collection

The essential data used are images. Satellite images taken during the dry season were selected to facilitate the discrimination of land-use units. Bands 4, 5 and 3 of Landsat 7 and 8, respectively, were used to discriminate between the various land-use units concerned (**Table 1**).

Table 1. Detail of data sources used for analysis of LULC in the study.

Satellite	Sensor	Resolution (m)	Path/row	Season	Multispectral
Landsat 5	TM	30 × 30	128/47, 128/48	Dry	1 - 5 and 7
Landsat 7	ETM+	30 × 30	128/47, 128/48	Dry	1 - 7 and 8
Landsat 8	OLI-TIRS	30 × 30	128/47, 128/48	Dry	1 - 8 and 9

Note: TM stands for Thematic Mapper, and OLI stands for Operation Land Imager. Source: <http://earthexplorer.usgs.gov/>.

Google Earth Pro software was used to facilitate the discrimination and visual interpretation of land-use units in the images.

2.3. Satellite Image Processing

The post-processing results comparison method [12] was used to determine the dynamics and rate of change by occupancy class over the study period.

For pre-processing, all images had already been radiometrically and geometrically corrected by the supplier, in the UTM-31 WGS-84 North datum. To homogenize pixel size at 6 m resolution, resampling was applied prior to image acquisition. These operations were carried out to increase image legibility, facilitate interpretation and enable images from the same region to be stitched together [13]. Image extraction and mosaic (or assemblage) tools were applied.

Visual interpretation was carried out using the photo-interpretation approach to images under QGIS remote sensing software. To facilitate extractions and the homogeneous stratification of land-use units, a false color composition combining channel 3 for infrared, channel 2 for red and channel 1 for green, with the Red, Green and Blue display system, was applied. The color composition and control points of the terrain and the Google Earth image background were used as a basis for interpreting the 2010 images. Occupancy unit limitation was facilitated by the spectral signature of the main land objects (color, tone, structure, texture, shape and location). The 2015 images were then interpreted using the 2010 image and the Google Earth archive image background from 2010. Images for 2020 and 2024 were interpreted on the basis of those for 2010 and the Google Earth archive image background for 2010.

The areas to be checked were identified on the images using their geographical coordinates recorded in the GPS (13 points). The integrated coordinates were used, after verification of non-accurate elements, to make corrections updating the toponymy [9]. This verification operation only concerns the interpretation of the 2015 images. For this purpose, a sample of 13 points collected in the various land-use units were used to assess overall accuracy and calculate the Kappa coefficient following the completion of the confusion matrix. This field test was carried out between November and December 2019. The 2010 and 2015 images were validated on the basis of Google Earth archive images. To refine the interpretation of the images, the observations and suggestions of the local population and resource persons were taken into account.

2.4. Analysis of Land Use Dynamics

Spatial changes were analyzed by cross-referencing the land-use maps in pairs. This cross-tabulation was used to obtain the transition matrix for the periods 1995-2005 and 2005-2015, using the ArcGIS Analysis Tools module. Comparison of the land-use maps for four years (2010, 2015, 2020 and 2024) revealed changes in terms of gain, loss or stability for each land-use unit.

The rate of change (T_v) used by [14] was used to assess the evolution of land-

use units.

$$Tv (\%) = (S2/S1) \times 100\%$$

where S1 is the area of the land-use unit in year 1 and S2 is the area of the land-use unit in year 2.

When Tv (%) is negative, this means a regression of the land-use unit from year 1 to year 2; otherwise, a positive rate implies an increase in the land-use unit from year 1 to year 2; and if the rate is zero, this means stability of the land-use unit from year 1 to year 2.

3. Results

3.1. Validation of Classifications and Mapping Results

Digitization of the topographic maps and interpretation of the Landsat images resulted in land cover maps for the years 2010, 2015, 2020 and 2024. The overall accuracy obtained is 96%, with a Kappa coefficient of 0.96 for the 2020 image, and 97% for the 2024 image, with a Kappa index of 0.97 (**Table 2**). These values mean that over 95% of the pixels in both images have been correctly classified in accordance with the ground-truth data. Overall, the values of the various supervised classification accuracy indicators obtained for the different images reflect, on the one hand, the good quality of the samples and, on the other hand, the good correspondence between the classification result and the spatial reality contained in the images. Six land-use classes were identified on the three images selected. These include: agrosystems, grazing areas, steppes, barren soil, rivers and streams.

Table 2. Overall accuracy and Kappa coefficient values of supervised classifications of Landsat images around Gothèye 2010, 2015, 2020 and 2024 based on the maximum likelihood algorithm.

Images	Overall accuracy	Kappa coefficient
2010	0.84	0.85
2015	0.87	0.86
2020	0.96	0.96
2024	0.97	0.97

3.2. Analysis of Land Use Evolution

The evaluation of land use evolution highlights the changes that have taken place between the different periods: 2020-2015, 2015-2020, 2020-2024 (**Figure 2**). The average annual rate of spatial expansion, the transition matrix and the rate of change have been calculated on the basis of the surface areas of these units. There has been a marked increase in fallow field complexes, to the detriment mainly of gallery forests.

The various land-use units in the reserve have changed overall between 2010 and 2024. The transition matrices, revealing the changes in land-use units in the commune of Gothèye between 2020-2015, 2015-2020, 2020-2024, are presented in **Table 2**.

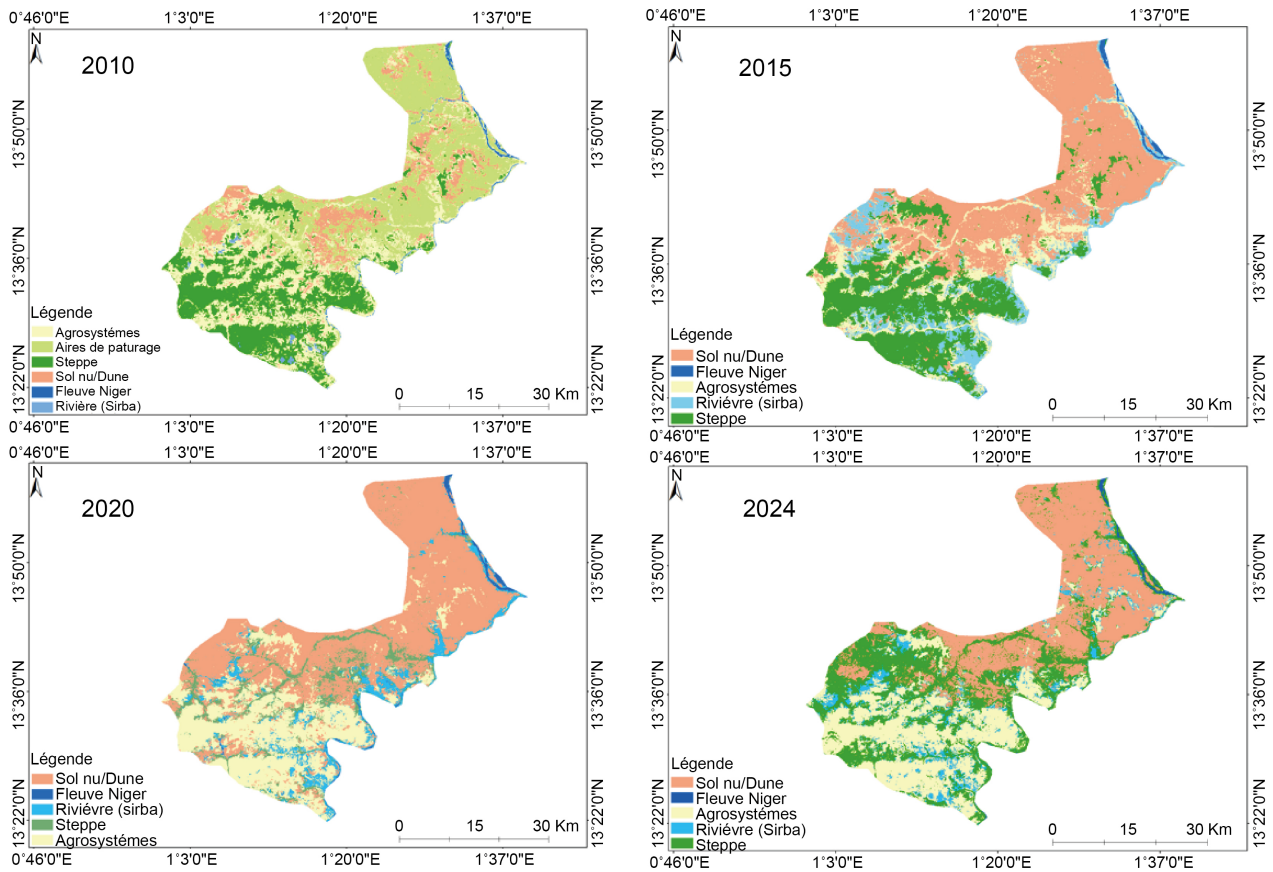


Figure 2. Gothèye land-use maps 2010, 2015, 2020 and 2024.

Confusion matrix 2010

Classes	A	B	C	D	E	F
A	15,334	0	7	0	1	6
B	0	770	0	0	0	3
C	0	0	862	0	0	0
D	9	0	0	2852	0	0
E	79	9	0	0	3767	249
F	0	0	0	4	314	4124

Legend: A) Bare soil, B) Niger River, C) River (Sirba), D) Mosaic of fallow fields, E) Forest gallery F) Grazing areas.

Confusion matrix 2015

Classes	A	B	C	D	E
A	19,259	0	0	0	0
B	0	998	0	0	0

Continued

C	10	0	260	0	0
D	1	0	0	5778	0
E	5	0	0	0	975

Legend: A) Bare soil, B) Niger River, C) River (Sirba), D) Mosaic of fallow fields, E) Forest gallery F) Grazing areas.

Confusion matrix 2020

Classes	A	B	C	D	E
A	1530	1	0	0	25
B	0	811	0	0	0
C	0	4	117	13	18
D	8	0	0	24,105	7
E	0	0	0	2	17,113

Legend: A) Bare soil, B) Niger River, C) River (Sirba), D) Mosaic of fallow fields, E) Forest gallery F) Grazing areas.

Confusion matrix 2020

Classes	A	B	C	D	E
A	1199	33	7	142	146
B	0	621	0	0	0
C	9	26	165	11	309
D	3	0	0	24,471	3
E	31	2	0	1	27,166

Legend: A) Bare soil, B) Niger River, C) River (Sirba), D) Mosaic of fallow fields, E) Forest gallery F) Grazing areas.

4. Discussion

According to the results, during the past three decades, Gothèye county has undergone large changes in land use types. Between 2010 and 2024, analysis of land use change showed that 31% of land remained in its initial state (unchanged), 69% underwent modifications, and 11% was converted to cropland. Dominance values within fallow land increased from 21.41% to 8.76%. This suggests that the largest patch of this class has been fragmented, indicating abandonment due to threats from non-state armed groups. Over the period 2010-2024, the fractal dimension values for the pasture and gallery forest classes decreased from 1.37 to 1.16 and from 1.8 to 1.27 respectively. This decrease indicates a trend towards regularity in the shape of patches in these natural classes, reflecting the impact of human activity in the study area. The decline in fallow and grazing land cover in the landscape

between 2010 and 2024 reflects their exploitation by displaced people, resulting in their degradation due to their provisioning services.

The growth in cultivated areas is accompanied by a strong fragmentation of the landscape, an increase in the number of field patches and a regression of forest formations. The results obtained in the Kompienga watershed in eastern Burkina Faso confirm this trend towards landscape anthropization. Reduced vegetation cover leads to the disappearance of natural wildlife habitats and accelerates climate change, with alternating droughts and floods, as well as soil erosion and declining soil fertility, thus compromising food security. These results corroborate those found in other regions of Africa [14] [15]. The factors behind this dynamic are man-made. Rapid population growth has led to an increase in primary needs, notably housing and food. These needs will drive populations to conquer new living spaces and arable land to meet these important needs. Agricultural practices and the large-scale extraction of natural resources are also a major factor in the degradation of plant cover. Human activities profoundly alter the natural geographical environment, with land use being a primary form of this influence, directly leading to alterations of the land surface. The results of this diachronic analysis show that soil degradation in the commune of Gothèye is a complex process, involving the action of nature, particularly drought, and that of displaced people. [15] [16] estimate that, over the last 60 years, the sub-region has lost more than 70% of its original forest cover. What remains today is highly fragmented, restricting habitat to isolated blocks, and dozens of unique species of flora and fauna are in danger of extinction. There is therefore a real urgency to reverse this trend. Indeed, ecosystem dynamics are closely linked to climatic disturbances and anthropogenic causes. This observation calls for a new vision, that of making investments to recover these degraded ecosystems [17] [18]. Studies on the driving mechanism of land use change at the global scale indicated that 60% of land use change can be caused by human economic and social development activities, and 40% of land use change was associated with climate change [19] [20]. As a result, with the purpose of formulating scientific, reasonable, and sustainable land use policies, it becomes vital to investigate land use transition at the micro-scale.

5. Conclusion

To conclude, this study deciphered the dynamics of land use changes in response to natural environmental and human activities. The results of this study highlight the negative impact of the displaced on ecosystems. Ecosystems have been systematically destroyed to meet the needs of displaced populations for goods and services. This suggests that the displaced have contributed significantly to the disturbance and dynamics of the landscape. Generally speaking, the study area has undergone a major transformation, mainly due to anthropogenic disturbance and demographic pressure. Although the disturbance of human activities and the change in natural factors jointly influence the land use type and its spatial distribution, their contributions are different. Faced to this situation, particular attention

needs to be paid to internal displacement phenomena in order to minimize induced impacts. This must be done in the interests of environmental conservation. If inaction persists, we may well see the collapse of our systems, whether natural (ecosystems) or human.

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Conflicts of Interest

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

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