Changes in Land Occupation in the System Oasien of Southeastern Niger, Goudoumaria in Niger

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Abstract: In Niger, the combined effects of variability and climate change, exacerbated by anthropogenic pressure, continue to strongly influence the dynamics of land occupation, particularly in oasis systems. In the department of Goudoumaria, located in the heart of the desert of the Manga oasis system, the spatio-temporal analysis of the landscape shows that, like several other areas in Niger, there are significant changes in landscape evolution. As part of this study, the exploitation of remote sensing products and the use of Geographic Information Systems (GIS) have made it possible to trace the dynamics in progress between 1985 and 2025 and identify the general trend of this. The main objective of this work is to detect changes in land occupation in this study area in the face of climate change and anthropogenic actions. The methodology used is based on the interpretation of Landsat satellite imagery from 1985, 2005 and 2025. The results obtained through land occupation maps, those of changes between two observation dates, and that of prediction until 2045 allow us to say that land occupation is in continuous mutation in the said study area. Thus, between 1985 and 2025, 0.712% of the area occupied by dense tree-shrub steppe remained intact compared to 0.145% % which have undergone transformations into other land occupation units. The agropastoral lands of the valleys and lowlands, the shrubby steppe and rainfed crops and dune fallow, have retained respectively 0.639%, 0.678% and 0.311% of their initial areas while the water bodies have retained 0.995% of their areas without change in other units. The trend of landscape evolution for the 2045 horizon predicts a regression of occupation units such as dense tree-shrub steppe, rainfed crops and dune fallow, areas of silting and water bodies, while the agropastoral lands of the valleys and lowlands, the shrubby steppe and bare or degraded soils will experience an extension of their areas.

Keywords: *Change, Satellite Imagery, Goudoumaria, Oasis System.*

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I. INTRODUCTION

Niger, a Sahelian country, faces problems of desertification and land degradation. These phenomena mainly result from the climate, demographic pressure, and methods of exploiting the environment, which are the determining factors [1]. They have significant negative repercussions on the natural environment. The study of land use dynamics through diachronic analysis is a privileged approach for evaluating the interactions between humans and their environment, as well as for identifying strategies adapted to planned management of natural resources [2], [3]. Indeed, the combination of the impacts of human activities and climatic factors leads to a modification of land use, with harmful consequences on ecosystems, particularly on plant formations [4]; [5]; [6]; [7]; [8], [9]. In this context, the vital needs of the populations, particularly local ones, continue to grow, causing strong pressure on natural resources already weakened by physical factors [10]; [11], [12]. It is therefore judicious to make reliable information on the dynamics of territorial resources available to the various actors involved in decision-making, in order to allow them a better knowledge of the potentialities of their territory and to promote rational planning of management. In achieving these objectives, many methods have been invented and applied with varying levels of effectiveness, including the joint use of Geographic Information Systems (GIS) and remote sensing to understand the evolution of the landscape [13]; ([14]; [15]; [4]; [16]. Indeed, the changes in the Sahelian biophysical environment are notable, and it was imperative to be able to assess their extent in order to provide appropriate responses. Remote sensing and GIS are particularly suitable tools for analyzing and understanding the different changes, especially those related to land use and vegetation cover [17]; [18]. The scientific interest of using remote sensing techniques for the study of ecosystems is no longer to be demonstrated [19]; [20]; [21]. The identification of a coherent and targeted set of variables, as well as harmonized protocols to be used in remote sensing and during field observations, remains a major challenge

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[22]; [23]. The use joint multi-scale remote sensing is a privileged tool for monitoring and understanding the current state as well as the evolution of ecosystems in arid regions at different periods, in order to propose appropriate development schemes [24]; [25]. Located in the heart of the oasis system of southeastern Niger, the department of Goudoumaria has been facing a spatio-temporal change in land use patterns for several decades, which highlights a progressive mutation of the natural landscape. This dynamic is the result of the action of natural factors, amplified by intensive and multifaceted human pressure, thus contributing to the reshaping of territories and their ecological functions. The recurrent droughts of recent decades have profoundly disrupted the environmental balance of eastern Niger [26]. Also, the persistent rainfall deficit would have modified the environmental facies in the region of the Goudoumaria depressions from the beginning of the 1980s with the advent of the second dramatic period of drought (1982-1987) which, in general, led to the disappearance or rarefaction of woody species [27]. Indeed, the study of these changes has made it possible, on the one hand, to assess the dynamics of the different land use units (rainfed crops, human habitats, vegetation, bare soils, etc.) and, on the other hand, to understand the issues related to the sustainable management of these resources.

Thus, the diachronic analysis of the natural environment has made it possible to highlight the trends of past and present environmental changes in the study area, while offering the possibility of predicting the future evolution of natural resources. The objective of this work is to analyze the dynamics of land use in the department of Goudoumaria from satellite images multidate and the use of a Geographic Information System, for the observation periods 1985, 2005 and 2025, in order to evaluate the main trends of their evolution. It is mainly a question of carrying out the diachronic mapping of the land use states of the department for the three reference years, from Landsat 7 and 9 images, in order to trace the evolution of the different units of the landscape. More specifically, the study aims to produce thematic mapping and analyze the changes observed in a context of climate variations and population growth.

II. MATERIALS AND METHODS

➢ *Study Area*

Located in the western part of the Diffa region, the department of Goudoumaria is bordered to the South by the State of Yobe (Federal Republic of Nigeria), to the East by the municipalities of Maïné Soroa and N'Guel Beyli, to the North by the municipality of Tesker and to the West by the municipality of Gouré (Figure 1). It covers an area of 6,915 km2. It has one canton and three (3) Peulh groups, totaling 536 villages including 215 administrative villages and Tribes, and 321 hamlets and camps for a total population estimated at 100,559 inhabitants in 2011 at the General Census of Population and Housing of 2001. In 2022, the population of the department of Goudoumaria is estimated at 138,069 inhabitants [51]. The annual growth rate is 4.7%, for a density of 20 inhabitants/km². The ethnic groups present are mainly Kanouris and Peulhs, in addition to Toubous Azza, Hausas and Tuaregs. The communities are organized in villages, camps bringing together several lineages and tribes. Men represent 49.71% of the population against 50.28% of women. Children of school age represent 23.92% of the population [28].

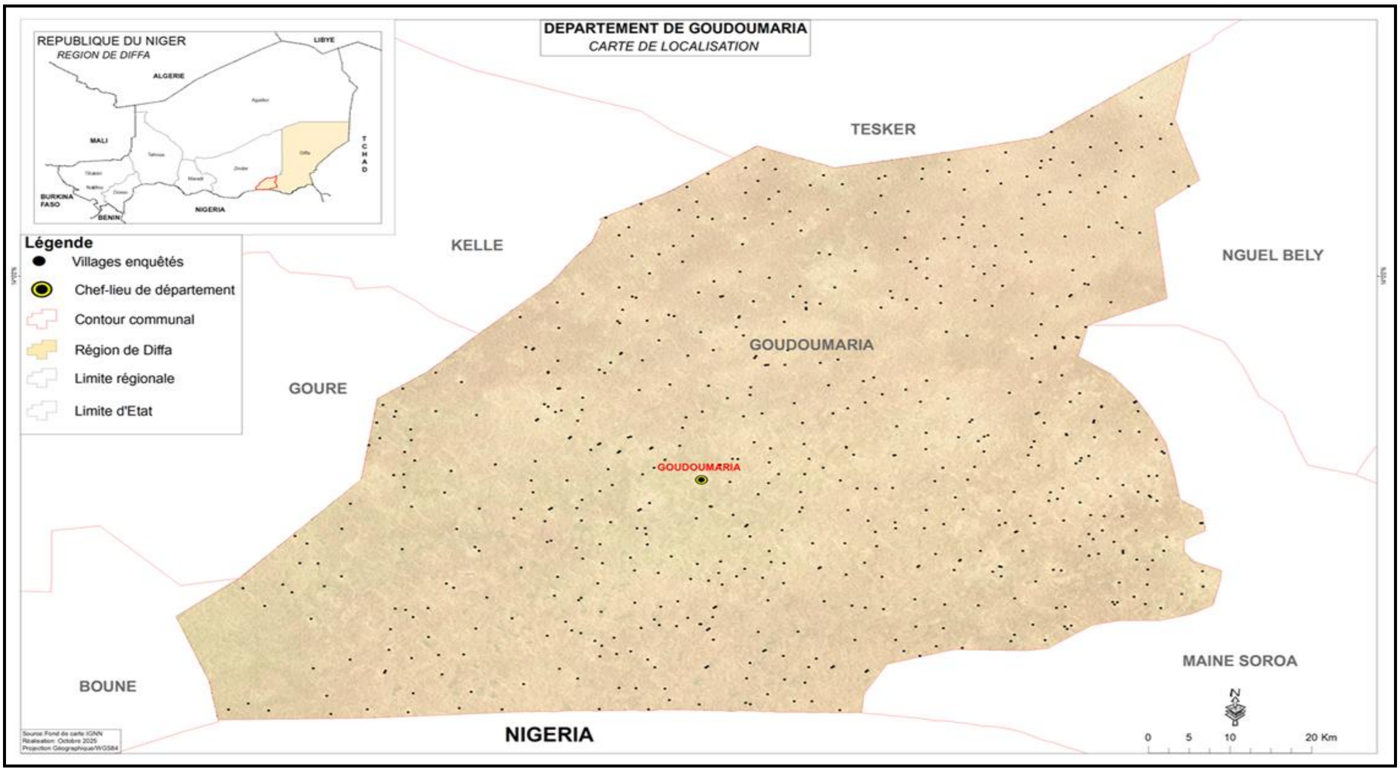

Fig 1 Location Map of the Study Area

➢ *Material*

The equipment used in this study consists of a GPS receiver, intended for recording geographical coordinates in the field, as well as image processing and Geographic Information Systems (GIS) software such as ArcGIS 10.8 and QGIS 3.X. Statistical analysis and graphing tools, including the Excel spreadsheet, were also used.

➢ *Basic Data*

Monitoring the evolution of the landscape by analyzing land use in the department of Goudoumaria is based on the analysis of four (04) data sources: the georeferenced layers of administrative boundaries and localities of Niger produced by the IGNN, the topographic map at 1/200,000 of 1964 (Sheet ND-32-XII), climatic data as well as field surveys. The images used come from different Landsat sensors: Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Operational Land Imager (OLI). Table 1 gives the characteristics of Landsat images used.

Table 1 Characteristics of Landsat Images Used.

Image	Spatial resolution	Sensor	Acquisition date	Path& Row
Landsat 5 TM		TM	June1985	187/050
Landsat 7 ETM+	30 m	ETM+	June2005	
Landsat 9 OIL -2		OIL-2& TIRS-2	June2025	

Source: USGS/Earth Explorer, 2025 Adapted

➢ *Methodology Used*

The methodology adopted to detect spatio-temporal changes in land use in the study area is based on diachronic analysis using remote sensing data, mapping by supervised classification, and the use of Geographic Information System (GIS) techniques.

➢ *Image Preprocessing*

Initially, the image scenes were identified and acquired at different dates via the Landsat grid (Path and Row), then downloaded from the USGS EarthExplorer website. As for the preprocessing itself, it includes all the operations aimed at making the images readable and superimposable with other data sources. This includes geometric corrections (to ensure superposition with other reference cartographic documents) and radiometric corrections (intended to improve radiometric quality and correct artifact effects). This process also includes image mosaicking and extraction of the study area. This last operation was not necessary because a single scene covers the study area.

➢ *Image Processing and Analysis*

False-color composites were created from band combinations 5-4-3 (Landsat 5 TM and Landsat 7 ETM+) and 6-5-4 (Landsat 9 OLI-2). The objective of these compositions is to obtain a visual synthesis rich in information, favoring a better discrimination of the different land use units. In addition, the visual interpretation of the images, which aims to establish a relationship between the images and field observations, has made it possible to identify the different land use classes, based on knowledge of the field and in reference to the Land Use Nomenclature of Niger (NOT). These aspects guided the choice for supervised classification using the "Maximum likelihood" algorithm. This calculates a multidimensional probability function to determine the probability of each pixel belonging to one of the categories corresponding to the spectral signatures [30]. Thus, based on the training sites previously defined and which correspond to the different classes retained in this work, the image was classified in order to produce the provisional thematic mapping. To validate the accuracy of this classification through the confusion matrix, indices (overall accuracy, Kappa coefficient, excess and deficit errors, user accuracy and producer accuracy) were used to verify and evaluate the number of pixels correctly classified and those that are not. Field missions made it possible to collect control points using a receiver GPS in order to correct the classification. After integrating the field data and correcting the classification, a majority spatial filter (Majority Filter) was applied to smooth out any isolated pixels isolated, before vectorizing the classified images and creating the final thematic maps with the ArcGIS 10.8. © software.

➢ *Detection of Land Use Changes*

In order to highlight the changes that have occurred between two periods, the vectorized maps of 1985, 2005 and 2025 were crossed. These changes are understood through the evolution in time and space of land use classes towards a stage of degradation, improvement or more or less stable equilibrium, reflecting all spatiotemporal variabilities [31]. This dynamic makes it possible to synthesize changes in land cover classes that occurred in the same landscape at different periods [31]. As part of this work, change detection between two dates was performed with the MOLUSCE (Modules for Land Use Change Evaluation) plugin of QGIS using the classified images, from 1985 to 2005 and from 2005 to 2025. In addition, this extension made it possible to calculate the transition matrix, to simulate future landscape evolutions (land cover change predictions) and to determine the Kappa coefficient. The latter is a statistical indicator measuring the agreement between the predicted classification and reality (ground truth or validation image). The results of image processing are exported in shapefiles format and attribute data in Excel format for the various analyses.

The Overall Rate (TG) of land cover change was calculated using the equation proposed by the Food and Agriculture Organization of the United Nations (FAO) of 1996. Thus, the rate corresponding to the dynamics of each land cover unit is calculated according to the formula of [1].

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Tg = (S2-S1) /S1x100 [1]

Where:

Tg: Overall growth rate;

S_1: the area of a class of surface unit at the date t_1;

S_2: the area of the same class of surface unit at date t_2.

The data from the results of the calculation of the rate of change of land cover will be preceded by minus **(-)** or plus to express respectively either a regressive or a progressive dynamic [32].

The annual rate of change (T) between consecutive dates is calculated according to the following formula of Oloukoi et al., 2007 [8].

$$T = \frac{(\ln S_{i+1} - \ln S_i)}{t \times \ln e} \times 100$$

Where:

Si = Area of the occupation class at the date i;

Si+1 = Area of the occupation class at the following date;

t = Number of years separating the dates of observation Si and Si+1;

ln =natural logarithm and, e = 2.71828 (approximate value of e of Leonard EULER).

This formula measures the average annual rate of change of an area or variable between two given dates [8].

➢ *Transition Matrix*

It makes it possible to highlight the different transformations undergone by land cover units between two dates t1 and t2. It describes in a condensed way the changes in state of the elements of a system during a given period [33], whose cells contain the value of a variable having passed from an initial class a to a final class b during the period from t1 to t2 [34]. She is made up of X rows and Y columns. The number of rows in the matrix indicates the number of classes of land cover at time t0; the number Y of columns of the matrix is the number of classes of land cover converted at time t1 and the diagonal contain the areas of the vegetable's formations remained unchanged.

The transformations therefore take place from rows to columns [35]. As part of this study, the transition matrix is obtained from the intersection of the classified images from 1985, 2005 and 2025, thanks to the MOLUSCE plugin from QGIS and their processing with the Excel spreadsheet after export. Figure 2 presents the conceptual diagram for data processing and analysis.

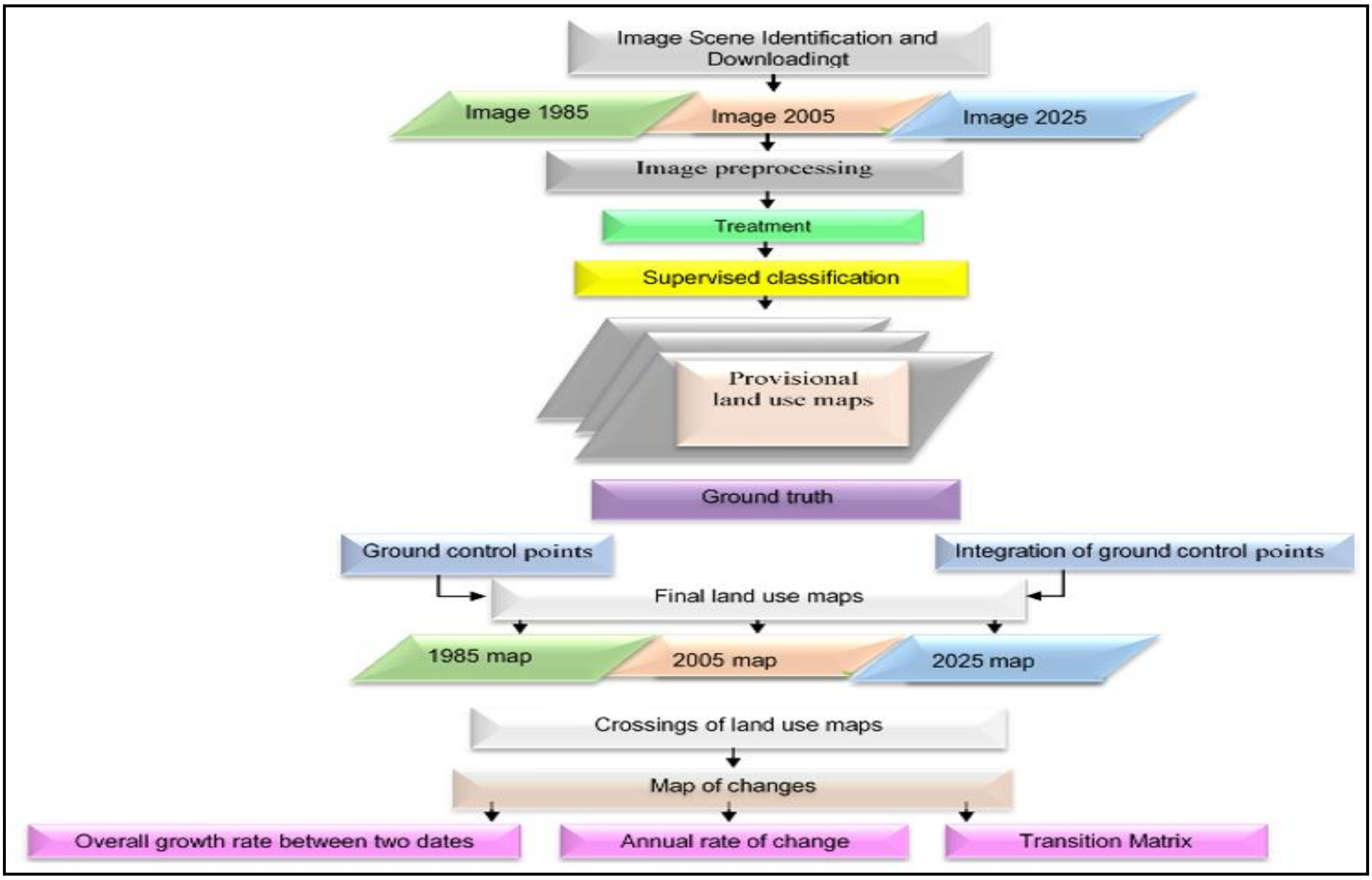

Fig 2 Conceptual Diagram for Data Processing and Analysis

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III. RESULTS

➢ *Climate Evolution*

The analysis of rainfall data recorded at the Goudoumaria station between 1952 and 2024 (Figure 3) reveals a first wet phase extending from 1952 to 1965, marked however by a deficit year in 1957. This period is followed by a first dry phase from 1967 to 1973, during which the years 1974 and 1975 are distinguished by a relative return to more humid conditions. A second dry phase, which extends from 1976 to 1993, followed by a surplus year in 1994. The third dry phase extends from 1994 to 2004. Since 2005, we have observed a return to a more humid period, punctuated however by a few deficit years (2008, 2009, 2014), marking a slight humid alternation. This alternation of dry and wet periods would have influenced changes in land use, particularly plant resources.

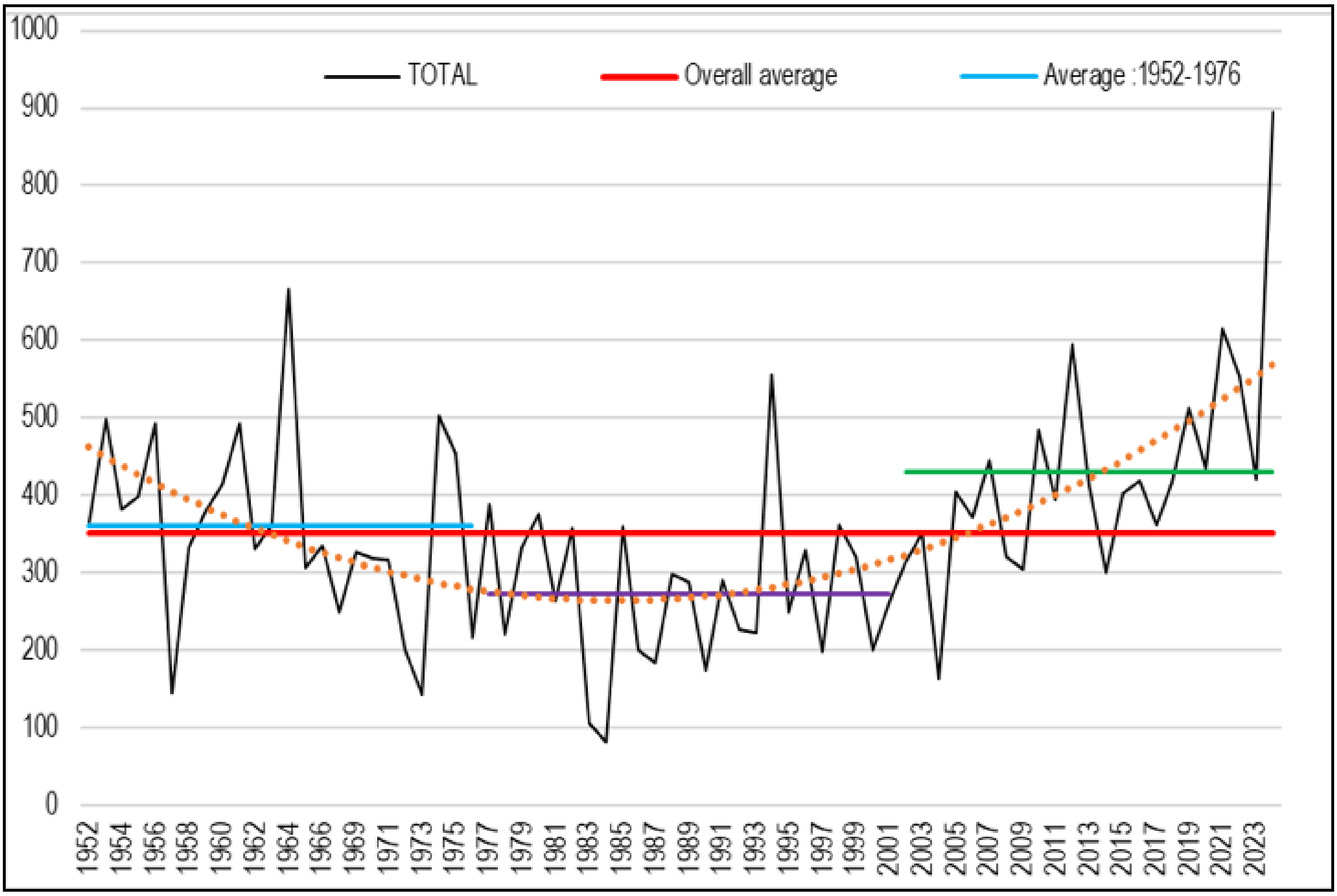

Fig 3 Evolution of Rainfall at the Goudoumaria Station over the Period 1952-2024.
Source: National Directorate of Meteorology and NASA POWER Data Access Viewer

➢ *Accuracy of Satellite Image Classifications and Mapping Results*

Table 2 presents the results relating to the accuracy of the classifications of the 1985, 2005 and 2025 images which resulted in the land use maps for the reference years. The classifications thus obtained prove to be globally excellent and reliable. This reliability is confirmed by the overall field accuracies resulting from the field validations, carried out using Ground Control Points (GCP), comparing the classes of the provisional land use map of 2025 to the reality observed in the ground.

Table 2 Validation Index of the Classifications of the Department of Goudoumaria in 1985, 2005 and 2025

Validation index	**1985**	**2005**	**2025**
Kappa coefficient	0,89	0,95	0.97
User precision (%)	82,35%	85%	87,5%
Overall precision (%)	96,91%	97,51 %	98,68%

➢ *Analysis of Land Use Change*

The land use mapping results for the department of Goudoumaria are given in figures 4, 5, 6 and 7. Overall, there is a regression of plant resources, in particular shrubby steppe, while agricultural areas located on dunes, in valleys and lowlands, as well as bare or degraded soils, are increasing in area.

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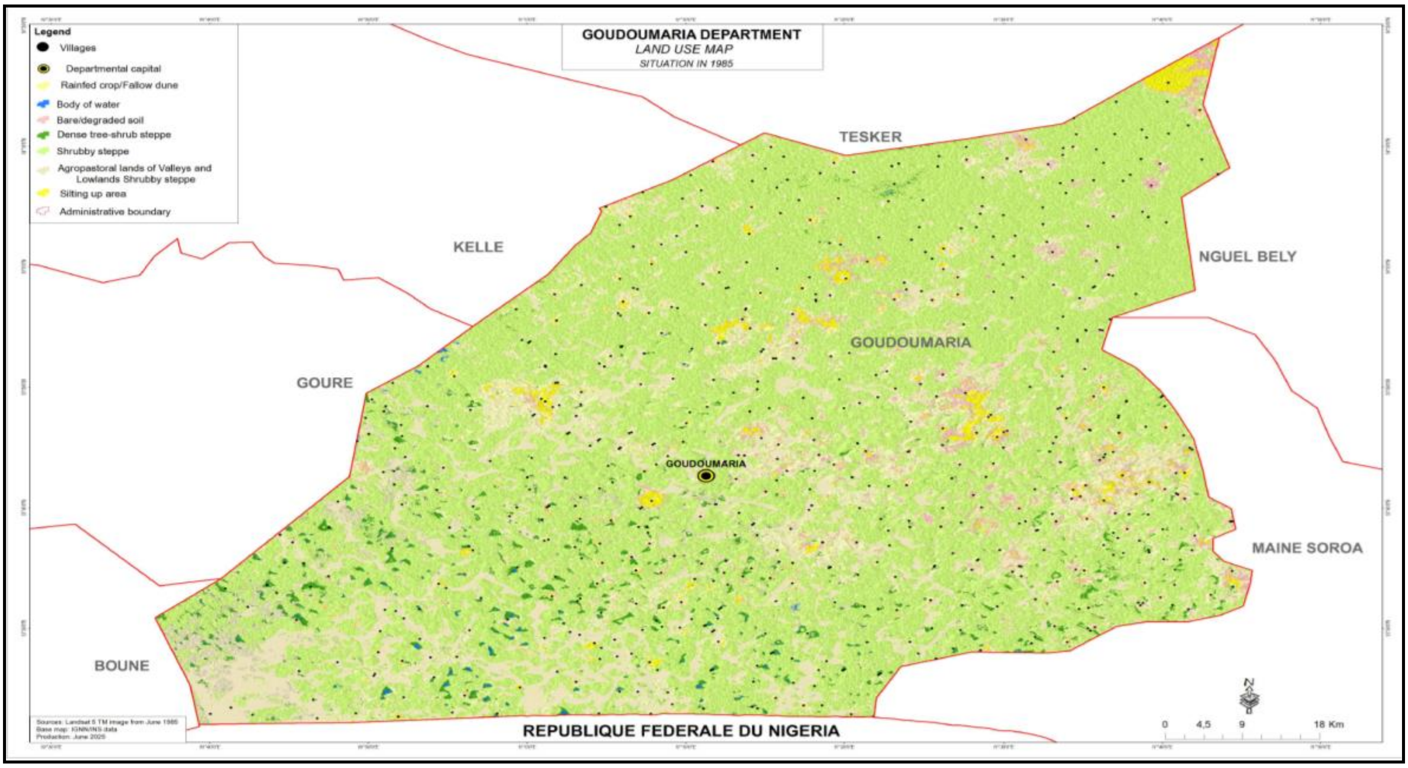

Fig 4 Land use Study Map of the Department of Goudoumaria in 1985

In 1985, shrubby steppe and dense tree-shrub steppe occupied 565,931.88 ha and 20,562.21 ha respectively, i.e., 72.15% and 2.63% of the total area of the study area. Rainfed dune crop areas represented 132,724.98 ha, or 16.94%. Bare or degraded soils covered 22,657.41 ha, corresponding to 2.89%. Sanding areas and bodies of water occupied 15,599.79 ha (1.99%) and 1,476.81ha (0.19%) respectively. Finally, the agropastoral lands of the valleys and lowlands, they presented 357.87 ha, or 3.11% of the total area.

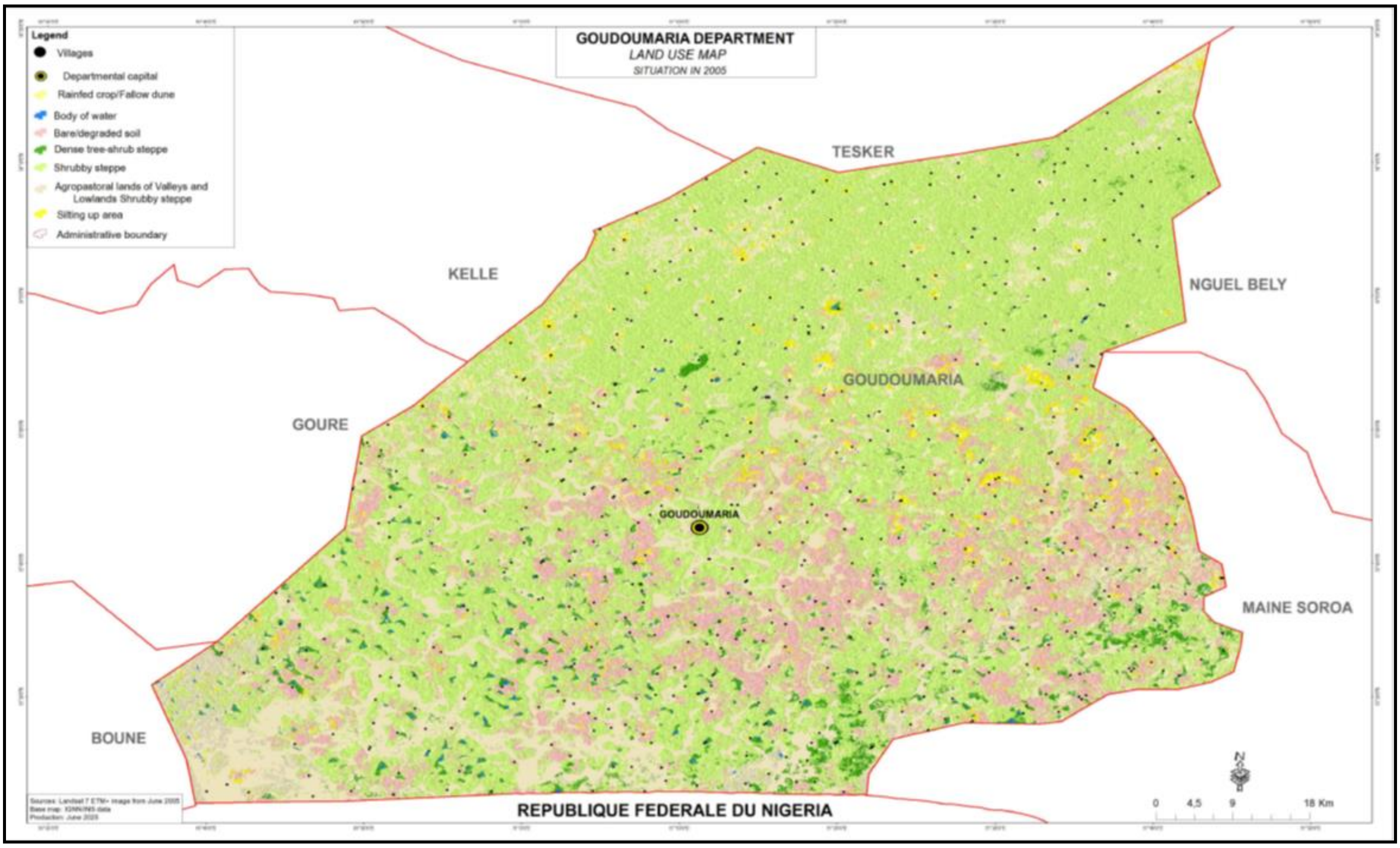

Fig 5 Land Use Study Map of the Department of Goudoumaria in 2005

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The analysis of the 2005 land use map reveals that rainfed crops occupied 131,686.92 ha, or 16.81% of the total area of the study area. The dense tree-shrub steppe and the shrub steppe represented 37,471.14 ha (4.78%) and 425,689.2 ha (54.34%) respectively. The agropastoral lands of the valleys and lowlands covered 45,486.45 ha, while the bodies of water extended over 2,091.51 ha. Finally, the areas of silting reached 3.37% of the total area of the study area, or 2,643,372 ha against 114,452.01 ha (14.61%) for bare or degraded soils.

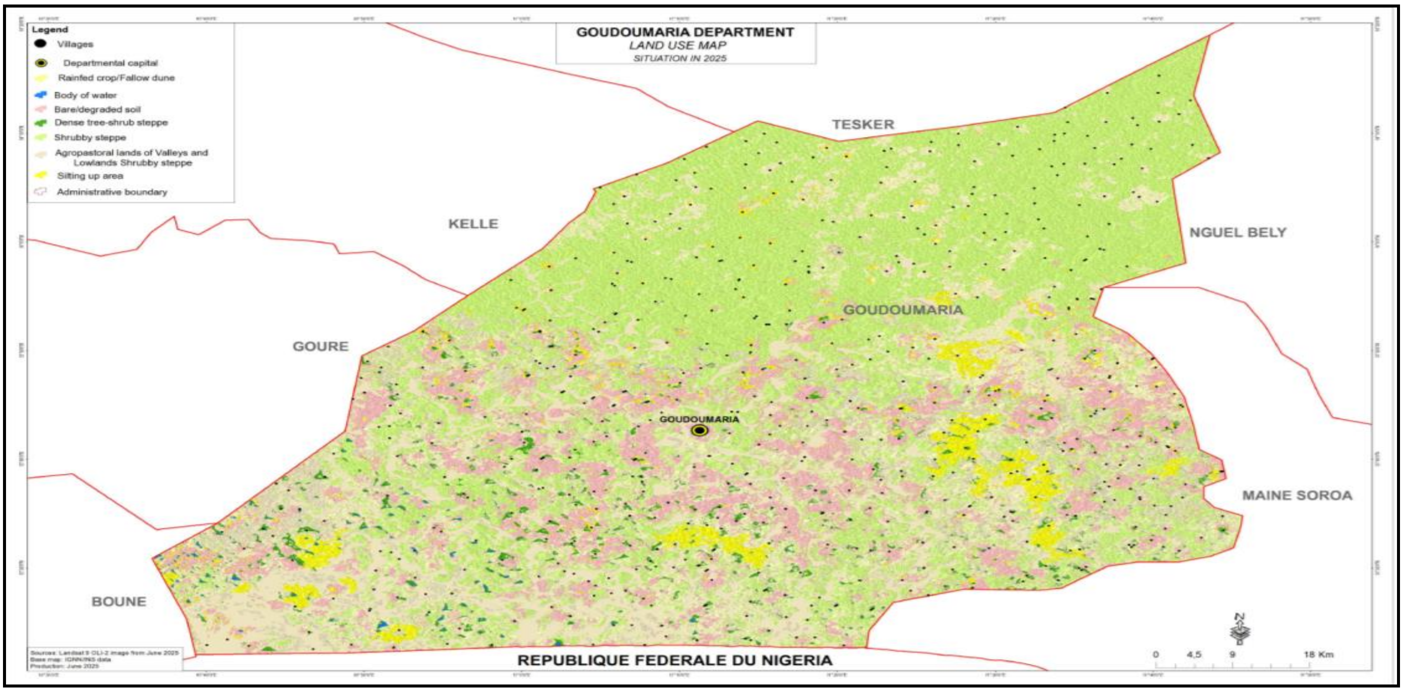

Fig 6 Land Use Study Map of the Department of Goudoumaria in 2025

In 2025, the landscape of the Goudoumaria department is characterized by a regression of the areas occupied by the shrub steppe, which represent only 33.88% against 72.25% in 1985. On the other hand, we observe an expansion of the areas dedicated to rainfed dune crops and bare or degraded soils, covering respectively 239,597.73 ha (30.59%) and 133,621.02 ha (17.06%). The areas of silting, for their part, recorded a slight decrease, with an area of 14,065.47 ha (1.80%).

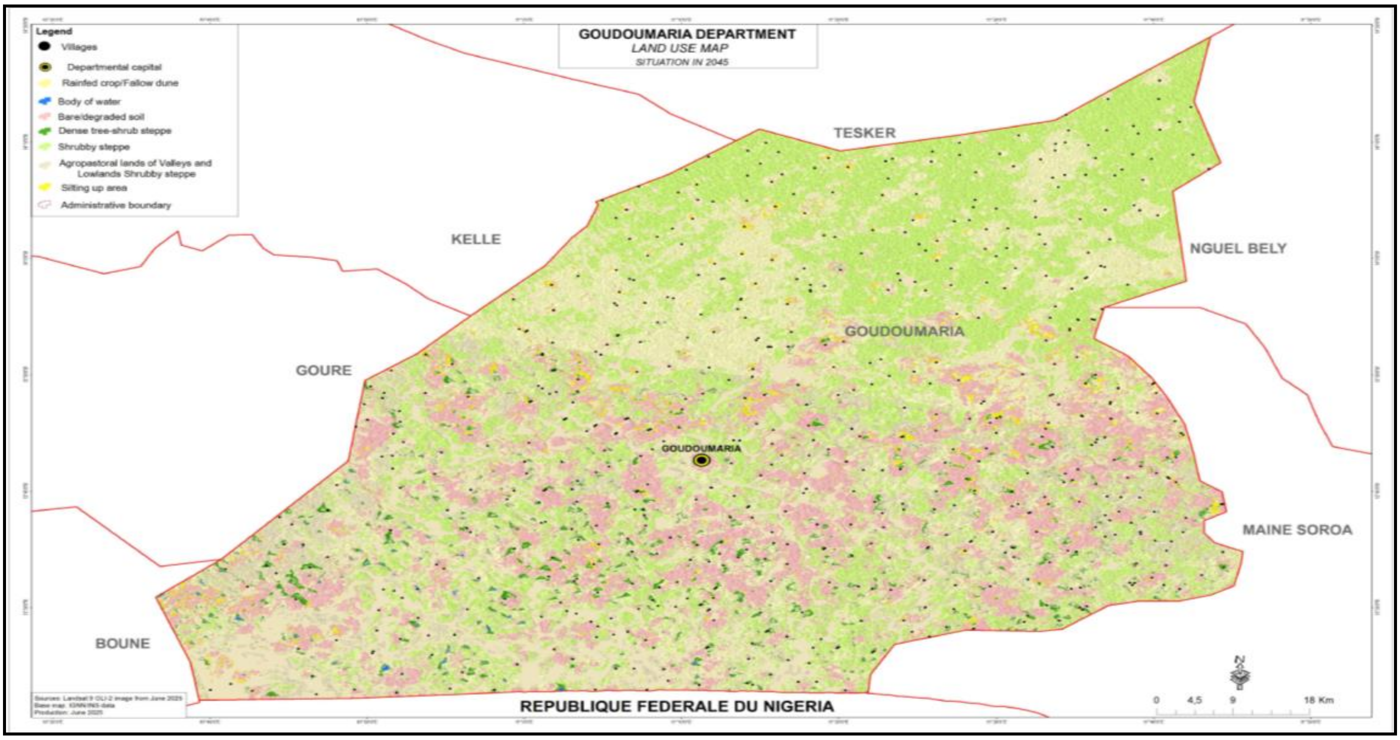

Fig 7 Predictive Land Use Study Map of the Department of Goudoumaria in 2045

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In 2045, the landscape of the department will be marked by a slight regression of plant formations, notably the dense tree-shrub steppe (-0.299%). A trend similar will be observed for certain units such as rainfed crops and fallow dunes (-2.726%), areas of silting up (-0.138%) as well as bodies of water (-0.066%). On the other hand, the agropastoral lands of the valleys and lowlands, the shrubby steppe and the bare or degraded soils will experience an extension of their areas, reflecting a notable progression of these units in the landscape. Changes in land use from 1985 to 2025.

➢ *Changes in Land Use from 1985 to 2025*

The results of the spatio-temporal analysis of land use units show an irregular evolution (sawtooth) of the areas occupied by the dense tree-shrub steppe unit, the share of which increased from 2.63% in 1985 to 4.78% in 2005, before regressing to 2.41% in 2025. A similar trend is observed for the rainfed crops and fallow dunes unit, which presents a comparable evolution, although marked by different statistical values. the rainfed crops and fallow dunes unit which has experienced an almost comparable evolution, although marked by different statistical values. On the other hand, the surfaces occupied by bare or degraded soils as well as by the lands agropastoral lands of the valleys and lowlands show a notable progression over the same period. Bare or degraded soils thus increased from 2.89% in 1985 to 17.06% in 2025, while agropastoral lands increased to reach 3.11% and 14.13% respectively of the total area of the study area. Detailed statistics of this evolution are presented in table 3, while figure 8 graphically illustrates the dynamics of each land use unit for the three-reference period (1985,2005; and 2025).

Table 3 Statistics of Land Use Units of the Department of Goudoumaria in 1985, 2005, 2025 and Predictive for 2045

Units	1985		2005		2025		2045	
	Area (Ha)	Pourcentage	Area (Ha)	Pourcentage	Area (Ha)	Pourcentage	Area (Ha)	Pourcentage
DT-SS	20562.21	2.63	37471.14	4.78	18843.93	2.41	36815.4203	2.106
APLV/LSS	24357.87	3.11	45486.45	5.81	110645.64	14.13	49315.45866	15.753
SS	565931.88	72.25	42568920	54.34	265360.95	33.88	424151.5455	34.179
RC/FD	132724.98	16.94	131686.92	16.81	239597.73	30.59	119876.5725	27.861
SUA	15599.79	1.99	2643372.00	3.37	14065.47	1.80	32507.38356	1.658
BW	1476.81	0.19	2091.51	0.27	1176.21	0.15	1017.407825	0.084
B/DS	22657.41	2.89	114452.01	14.61	133621.02	17.06	119627.1617	18.359

- Note. Dense Tree-Shrub Steppe (DT-SS), Agropastoral Lands of Valleys and Lowlands Shrubby Steppe (APLV/LSS), Shrubby Steppe (SS), Rainfed Crop/Fallow Dune (RC/FD), Silting Up Area (SUA), Bodies of Water (BW), Bare/Degraded Soil (B/DS).

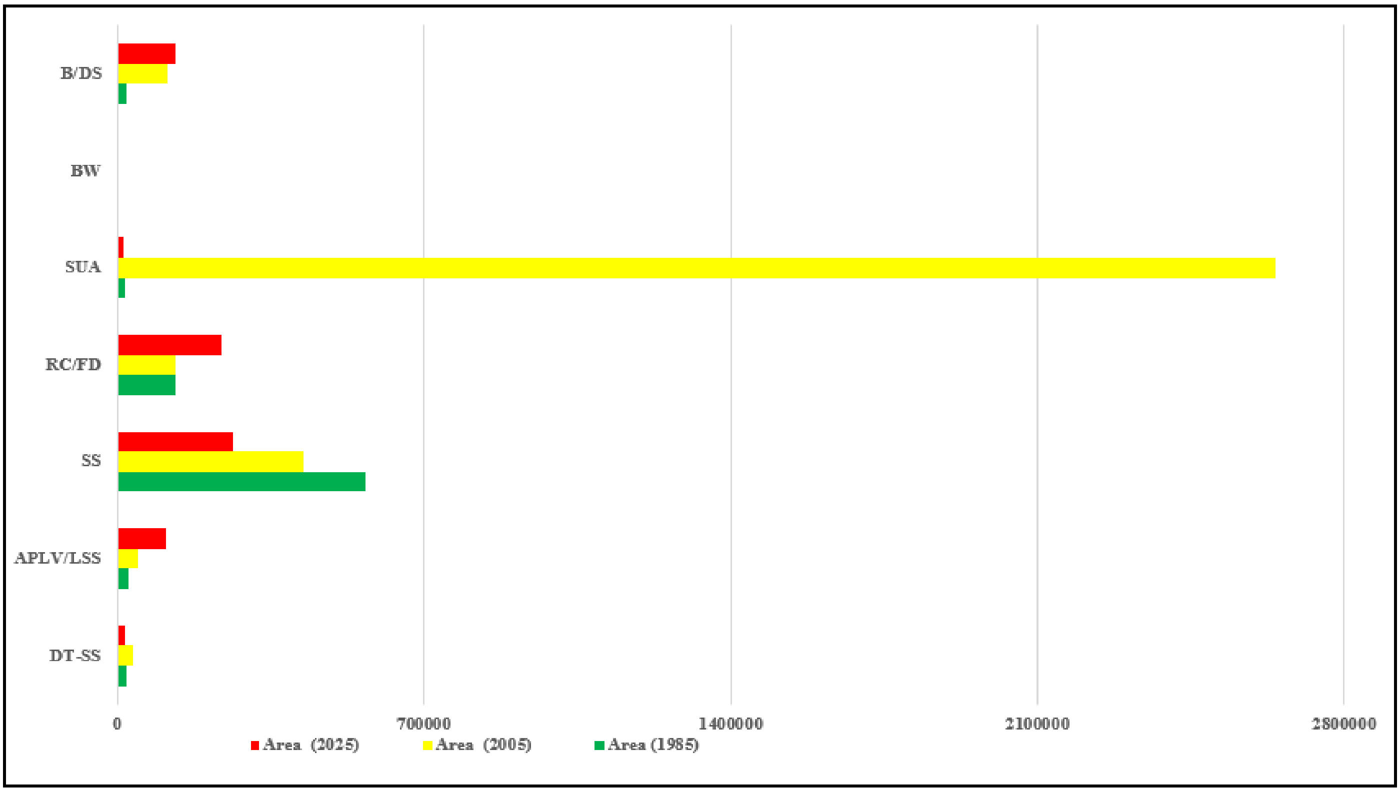

Fig 8 Evolution of Land Occupation Units of the Goudoumaria Department in 1985, 2005 and 2025

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- Note. Dense Tree-Shrub Steppe (DT-SS), Agropastoral

Lands of Valleys and Lowlands Shrubby Steppe (APLV/LSS), Shrubby Steppe (SS), Rainfed Crop/Fallow

Dune (RC/FD), Silting Up Area (SUA), Bodies of Water (BW), Bare/Degraded Soil (B/DS).

> *The Overall Rate of Evolution of Land Occupation Units from 1985 to 2025*

The rate of spatio-temporal evolution of land occupation units (table 4) shows a marked regression of plant resources, particularly dense tree-shrub steppe, which records a rate of variation of -0.219%. On the other hand, the shrub steppe shows an evolution of 38.372%, while remaining the unit most affected by regression. The same trend is observed for bodies of water and areas of silting with respective regressions of -0,038 %. And -0.196%. This latter decrease is partly explained by dune fixation operations and land restoration currently underway in the department. On the other hand, the other units have recorded a significant increase, with rates ranging from 11,016% for the lands agropastoral valleys and lowlands, used for both agricultural and pastoral activities. 13,644%, while bare or degraded soil has experienced an increase of 14,166 %.

Table 4 Rate of Evolution of Land Occupation Classes in the Goudoumaria Department

Land occupation units	1985-2005	2005-2025	1985-2025	Nature	2025-2045	Nature
DT-SS	2,158	-2,378	-0.219	Regression	-0,299	Regression
APLV/LSS	2,697	8,318	11.0157	Progression	1,627	Progression
SS	-17,903	-20,468	-38.371	Regression	0,301	Progression
RC/FD	-0,132	13,776	13.643	Progression	-2,726	Regression
SUA	1,383	-1,578	-0.195	Regression	-0,138	Regression
BW	0,078	-0,116	-0.038	Regression	-0,066	Regression
B/DS	11,718	2,447	14.165	Progression	1,300	Progression

> *The Changes that Occurred from 1985 to 2025*

Figure 9 shows the annual rates of evolution of land occupation classes in the department of Goudoumaria between 1985 and 2025. The analysis of this (Figure 9) shows that between 1985 and 2025, some landscape units have experienced a regression, particularly dense tree-shrub steppe, shrub steppe, silting areas and bodies of water whose values are negative (less than zero). Conversely, units with positive values (greater than zero) show an increase. These include agropastoral lands of valleys and lowlands, rainfed crops and dune fallows, as well as bare or degraded soils. This regression or progression reflects a variation in areas, expressed respectively in decrease or extension of the different units of occupation of the lands.

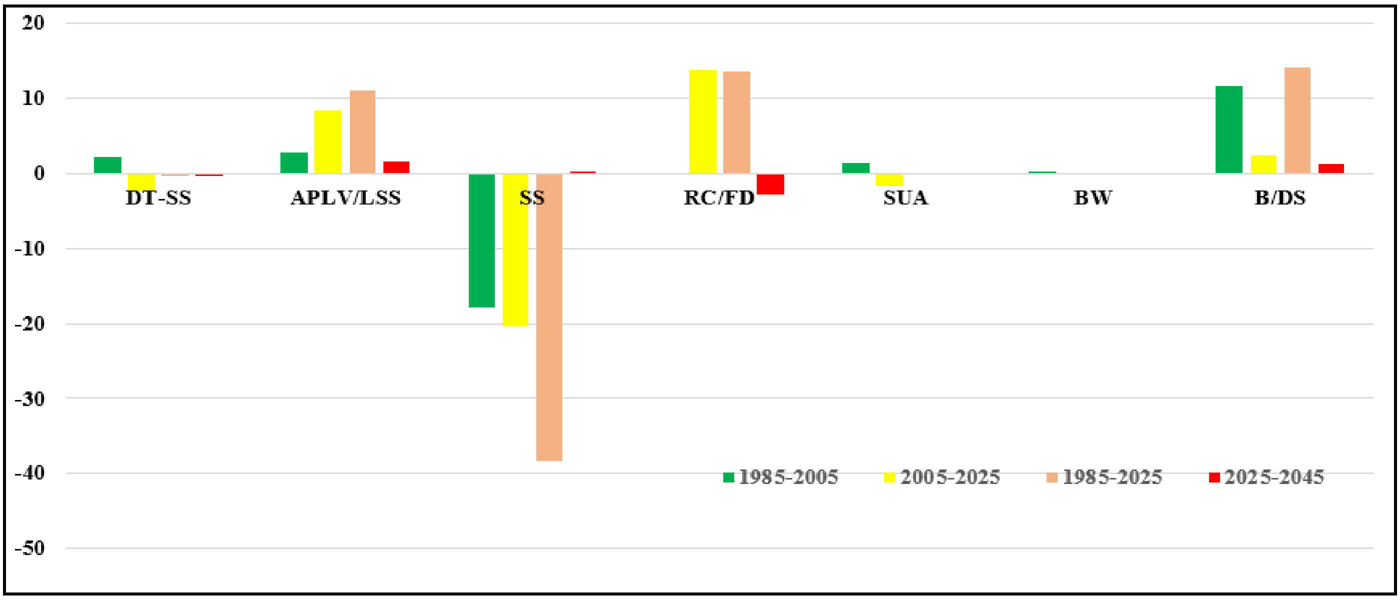

Fig 9 Annual Rates of Change in Land Use Classes in the Department of Goudoumaria Between 1985 and 2025.

> *Transition Matrices from 1985 to 2025*

The transition matrices, illustrating the changes in land use units in the department of Goudoumaria for the periods 1985-2005, 2005-2025, 985-2025, as well as the projection to the horizon 2025-2045 are presented in Tables 5, 6, 7 and 8. These matrices indicate for each pair of years the values expressed as a percentage of the transformations observed.

Between 1985 and 2005, change have been observed within certain land use units. Thus, 0.975% of the areas occupied by dense tree-shrub steppe have been transformed into other units, including 0.037% into rainfed dune cultivation areas and 0.032% into shrub steppe, while only 0.712% of this unit remained stable. Similarly, the agropastoral lands of valleys and lowlands have undergone

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modifications, with 0.360% of their initial area converted into other units, compared to 0.639% conserved. The rainfed crops and dune fallows unit has also undergone notable transformations: 0.311% of its area has been maintained, while 0.689% has been converted into other forms of land use. Among the other changes observed, there are those of the shrub steppe, of which 0.322% of the area has evolved towards others, including bare or degraded soils (0,125%) and areas affected by desertification (0.016%).

➢ *Transition Matrices from 2005 to 2025*

Between 2005 and 2025, the most significant changes concern the dense tree-shrub steppe, which has retained only 0.647% of its original area. Significant transformations are also observed in the rainfed crops and dune fallows unit, of which 0.338% have been transformed into other units, compared to 0.426% for shrub steppe and 0.303% for agropastoral lands of valleys and lowlands. On the other hand, some units have better resisted changes. The areas of silting, rainfed crops and dune fallows, bodies of water and bare or degraded soils have respectively retained 0.359%, 0.662% and 0.756% of their areas.

Between 1985 and 2025, only 0.712% of the area occupied by the dense tree-shrub steppe in 1985 remained intact, compared to 0.145%% which were converted into other land use units. The agropastoral lands of valleys and lowlands, the shrub steppe and the rainfed crops and dune fallows have, for their part, retained 0.639%, 0.678% and 0.311% of their initial areas respectively. However, these units have also undergone changes, estimated at 0.232% for the first, 0.494% for the second and 0.491% for the third. The areas of silting and bare and degraded soils have undergone mutations towards other units respectively at a rate of 0.86% and 0.54%. On the other hand, bodies of water have shown relative stability, retaining 0.995% of their initial area without notable change.

Between 2025 and 2045, slight regression of plant formations is expected, notably at the level of the dense tree-shrub steppe (-0.299%). A similar trend will be observed for rainfed crops and dune fallows (-2.726%), areas of silting (-0.138%) and bodies of water (-0.066%). However, some units should experience an increase in terms of area occupied, notably the agropastoral lands of valleys and lowlands (+1.627%), the shrub steppe (+0,301 %) and bare or degraded soils (+1,303%). This progression, particularly marked for the agropastoral lands of the valleys and lowlands, is explained by their spatial extension linked to the retreat of the populations towards the valley and lowland areas more favorable to agropastoral activities, to the detriment of the dune lands less conducive to these uses. Conversely, the regression of the rainfed crops unit and dune fallow reflects this progressive shift of human activities towards more productive areas better adapted to local conditions.

Table 5 Transition Matrix in Percentage (%) of Land Use Units Between 1985 and 2005

1985-2005	DT-SS	APLV/LSS	SS	RC/FD	SUA	BW	B/DS	Total
DT-SS	0,712	0,000	0,116	0,140	0,001	0,000	0,006	0,975
APLV/LSS	0,086	0,639	0,262		0,002	0,000	0,011	1,000
SS	0,032	0,000	0,678	0,148	0,016	0,000	0,125	1,000
RC/FD	0,037		0,355	0,311	0,067	0,000	0,229	1,000
SUA	0,008	0,000	0,231	0,176	0,272	0,000	0,314	1,000
BW	0,000	0,678	0,000	0,678	0,000	0,995	0,005	1,000
B/DS	0,011	0,000	0,260	0,171	0,187	0,000	0,396	1,025
Total	0,887	0,639	1,901	0,947	0,546	0,995	1,086	7,000

* Note. Dense Tree-Shrub Steppe (DT-SS), Agropastoral Lands of Valleys and Lowlands Shrubby Steppe (APLV/LSS), Shrubby Steppe (SS), Rainfed Crop/Fallow Dune (RC/FD), Silting Up Area (SUA), Bodies of Water (BW), Bare/Degraded Soil (B/DS).

Table 6 Transition Matrix in Percentage (%) of Land Use Units Between 2005 and 2025

2005-2025	DT-SS	DT-SS	DT-SS	DT-SS	DT-SS	DT-SS	DT-SS	Total
DT-SS	0,647	0,000	0,204	0,143	0,002	0,000	0,004	1,000
APLV/LSS	0,061	0,694	0,169	0,000	0,006	0,000	0,066	0,997
SS	0,002	0,000	0,574	0,356	0,002	0,000	0,066	1,000
RC/FD	0,021	0,000	0,253	0,662	0,017	0,000	0,047	1,000
SUA	0,012	0,000	0,029	0,134	0,359	0,000	0,466	1,000
BW	0,000	0,000	0,000	0,000	0,000	0,998	0,002	1,000
B/DS	0,004	0,000	0,069	0,157	0,016	0,000	0,756	1,002
Total	0,747	0,694	1,299	1,452	0,401	0,998	1,408	7,000

Table 7 Transition Matrix in Percentage (%) of Land Use Units Between 1985 and 2025

_1985-2025	DT-SS	DT-SS	DT-SS	DT-SS	DT-SS	DT-SS	DT-SS	Total
DT-SS	0,855	0,000	0,057	0,076	0,002	0,000	0,010	1,000
APLV/LSS	0,066	0,768	0,086	0,000	0,010	0,000	0,070	1,000
SS	0,008	0,000	0,506	0,324	0,011	0,000	0,152	1,000

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RC/FD	0,018	0,000	0,209	0,510	0,033	0,000	0,229	1,001
SUA	0,012	0,000	0,205	0,230	0,139	0,000	0,415	1,000
BW	0,000	0,000	0,000	0,000	0,000	0,997	0,002	0,999
B/DS	0,012	0,000	0,217	0,240	0,075	0,000	0,455	0,999
Total	0,971	0,768	1,281	1,380	0,269	0,998	1,333	7,000

Table 8 Transition Matrix in Percentage (%) of Land Use Units Between 2025 and 2045

2025-2045	**DT-SS**	**DT-SS**	**DT-SS**	**DT-SS**	**DT-SS**	**DT-SS**	**DT-SS**	**Total**
DT-SS	0,994	0,000	0,000	0,006	0,000	0,000	0,000	1,000
APLV/LSS	0,000	0,999	0,000	0,000	0,000	0,000	0,000	0,999
SS	0,000	0,000	0,980	0,016	0,000	0,000	0,004	1,000
RC/FD	0,000	0,000	0,068	0,897	0,001	0,000	0,034	1,000
SUA	0,000	0,000	0,000	0,020	0,900	0,000	0,079	1,000
BW	0,000	0,000	0,000	0,000	0,000	1,000	0,259	1,259
B/DS	0,000	0,000	0,000	0,003	0,000	0,000	0,739	0,742
Total	0,994	0,999	1,049	0,942	0,901	1,000	1,115	7,000

IV. DISCUSSION

➢ *Dense Tree-Shrub Steppe and Shrub Steppe*

The dense tree-shrub steppe, which occupied 2.63% of the department's area, or 20,562.21 ha in 1985, recorded a regression of 0.22%, to cover only 2.41% of the total area in 2025, i.e., an area of 18,843.93 ha. For its part, the shrub steppe experienced a much more marked decline, falling from 72.25% in 1985 to 33.88% in 2025, a decrease of 38.37% of its initial area. This trend towards the regression of plant formations highlighted in the present study has also been observed by other authors who have worked on land use changes. This is particularly the case in the work of [9], on the spatiotemporal dynamics of land use in the commune of Simiri (Niger), which revealed a sharp decrease in vegetation, from 493,528 ha to 886 ha between 1973 and 2020. Other authors have also confirmed this trend towards the decline, or even the progressive disappearance, of plant formations [36]; [37]; [38]; [39]. For example, a study carried out by [40] in Benin on the Mékrou Classified Forest highlighted a regression of plant formations, from 70.53% in 1992 to 39.33% in 2012, a decrease of 31.2% in the space of twenty (20) years. For their part, [39] showed that the shrub savanna in the commune of Allada (Benin) experienced a marked decline, falling from 11.47% in 1990 to a complete disappearance in 2014. The results obtained by [41] in the Tamou Total Wildlife Reserve (Niger), by [42] in the Gouré department (East Niger), by [43] and [16] in the communes of Gabi and Gothèye (Niger), as well as those of [34] in South-East Togo and [44] in the Bam province (Burkina Faso), all confirm a generalized decrease in plant formations in their respective study areas. Regarding the shrub steppe, a progressive evolution is expected by 2045 with an estimated increase of 0.30% compared to its situation in 2025. These results corroborate those of [45], who observed an improvement in vegetation cover of 66.8% between 2001 and 2013 in south-eastern Burkina Faso. Other studies conducted in the Sahel in general, and in Niger in particular, also confirm the trends observed in the present study [46], [47]; [48] ; [49] ; [50].

➢ *Rainfed Crops/Dune Fallow and Agropastoral Lands of Valleys and Lowlands*

The areas occupied by rainfed crops and bodies of water represented 16.94% and 3.11% respectively of the total area of the study area in 1985 against 30.59% and 14.13% in 2025. The extension of these land use units has been at the expense of other formations, notably the dense tree-shrub steppe and the shrub steppe. This expansion is linked to the conquest of new, more suitable agricultural land, favored by the demographic growth of the department, whose population increased from 100,559 inhabitants in 2011 to 138,069 inhabitants in 2022 [51]. Several studies have highlighted the impact of demographic growth on the expansion of cultivated areas [52]; [53]; [54]; [55]; [56]; [37]. Indeed, the areas of rainfed crops have increased by 106,872.75 ha in forty (40) years, from 132,724.98 ha in 1985 to 239,597.73 ha in 2025. Similarly, the agropastoral lands of the valleys and lowlands have increased by 86,287.77 ha over the same period. This expansion of areas is partly explained by the availability of land resources and demographic growth, which encourage rural populations to seek new, more suitable land for agropastoral activities. This translates into a growing interest in the lands of the valleys and lowlands, considered more favorable to these practices.

➢ *Bodies of Water*

The areas occupied by bodies of water represented 0.19% of the total area of the study area in 1985, compared to 0.27% in 2005, then 0.15% in 2025. This fluctuating evolution is closely linked to the rainfall variability that characterizes the area, as illustrated by the rainfall evolution curve of the department. The results of the present study corroborate those of [16], who observed between 1984 and 2017 a regression of bodies water of -23.16% in Gothèye and -11.67% in Torodi in Niger.

Similarly, [54] highlighted a decrease in surface water from 9.92% in 1987 to 0.98% in 2013, a decrease of -8.94%. Conversely, other authors such as [57] and [38] have reported in their work an increase in the areas occupied by bodies of water.

➢ *Bare or Degraded Soils and Areas of Sand Accumulation*

In the department of Goudoumaria, bare or degraded soils and areas of sand accumulation have experienced contrasting dynamics over time. Thus, the areas occupied by bare or degraded soils increased from 2.89% of the total area of the study area in 1985 to 17.06% in 2025, an increase of 14,175% over forty (40) years, and a predictive increase of

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1.30% for the period 2025-2045. In contrast, areas of sand accumulation have experienced a fluctuating evolution, going from 1.99% in 1985 to 3.37% in 2005, then to 1.80% in 2025 with a predictive regression of -0,13% the horizon 2045. Several factors can explain these dynamics, including the effects of climate change and its corollaries, as well as anthropogenic actions. The latter include both negative practices (deforestation, agricultural practices, etc.) and positive actions (biomechanical dune fixation operations, restoration of degraded ecosystems, etc.). According to [58], the reduction of vegetation cover exposes the land more to the main erosive agents, including wind and runoff water, in a Sahelian context marked by high rainfall variability and soils consisting of an eolian sandy deposits. Other studies confirm this trend, including that of [38], which reports an increase in bare soils in the northern part of the Dallol Bosso in Niger, while [59] and [61] observe similar results in other regions of the country. In the Gouré region, [60] have also highlighted the increased dynamics of sand accumulation in the depressions. Similarly, [9] notes a regression of vegetation cover between 1973 and 2020, and at the same time an increase in bare soil areas in the commune of Tondikiwindi in Niger. Data from the Departmental Directorate of the Environment and the Fight Against Desertification (DDE/LCD) of Goudoumaria on the achievements of dune fixation between 2012 and 2025 are estimated at 14,355.35 ha in thirteen years (13). This could partly explain the regression of active dunes and degraded soils in the study area.

V. CONCLUSION

The diachronic study of the evolution of land use status of the department of Goudoumaria, based on the use of remote sensing products and the use of Geographic Information Systems (GIS) techniques, made it possible to understand the changes that occurred between 1985 and 2025. The results obtained show that the study area has undergone a degradation of its ecosystem, which is reflected in a significant regression of plant formations, in particular dense tree-shrub steppes, and shrub steppes. However, we observe the extension of certain land use units (rainfed crops and dune fallow, agropastoral lands of valleys and lowlands, bare or degraded soil). Other units such as areas of sand accumulation have evolved in a sawtooth pattern, with an increase in area between 1985 and 2005, then a regression of their areas between 2005 and 2025.

Overall, this study has highlighted the major transformations that have occurred within the different land use units, as well as predicting the evolution of the landscape by 2045.

The results indicate a regression of certain occupation units such as the steppe dense tree-shrub, rainfed crops and dune fallows, areas of sand accumulation and bodies of water, while other units should experience an extension of their areas.

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