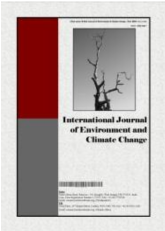

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Spatio-temporal Dynamics of Land use in Lake Ecosystems in the Sudano-Guinean Zone (Adamaoua-Cameroon)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study aims to characterize over 31 years between 1990 and 2021 the spatio-temporal mutations experienced by four lake ecosystems in the Sudano-Guinean zone of Cameroon due to strong anthropic activities caused by the increase of the demography. Landsat satellite images from 1990, 2006 and 2021 were exploited using remote sensing and GIS. The unsupervised classification was used to obtain nine land cover and land use classes (agricultural space, forest gallery, tree savannah, shrub savannah, grassy savannah, bare soil, water surface, hydromorphic zone and housing zone). The dynamics are progressive for the agricultural space (24.40 ha at Lake Bini, 24.38 ha at Lake Dang, and 16.72 ha at Lake Mballang). On the other hand, The dynamics of the plant formations is essentially regressive for the shrubby savannahs (16.21 ha at Lake Bini, 30.56 ha at Lake Dang, 118.13 at Lake Mballang and - 9.67 ha at Lake Ngaoundaba). The water surface area decreased in the lake ecosystems of Bini (0.27 ha) and Mballang (0.04). In contrast, there was an increase in the lake ecosystems of Lake Dang (0.40 ha) and Ngaoundaba (0.21 ha). The factors of this degradation are mainly human (agriculture, overgrazing and galloping demography) and result in the fragmentation of natural habitats to the benefit of cultivated areas

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and purely anthropogenic housing zones. The consequences likely to result from this degradation call on the inhabitants and decision-makers to reduce human activities harmful to the environment and to restore these ecosystems.

Keywords: Lake ecosystems; spatio-temporal mutations; occupation units, land use; vina department; Adamaoua-Cameroon.

1. INTRODUCTION

In the Sahelian country, the combined effects of changing rainfall patterns, population growth and land degradation have led to a deterioration of soil and water resources [1]. Since the 19th century, the Sahel has experienced both droughts and wetter periods [2]. In addition to this natural variability, it is now necessary to take into account the impact of climate change on the rainfall regime. These uncertain factors influencing rainfall have a major impact on the evolution of Sahelian lake systems. Indeed, a large proportion of these lakes are endoreic systems that form reservoirs during the dry season [3]. Their vulnerability to climatic constraints, combined with their great societal importance, makes it essential to understand their hydrological functioning. In the context where ecosystem landscapes have experienced major disturbances due to both natural processes and anthropogenic activities [4]. Lake ecosystems are undergoing many changes related to more intense human activities to meet the socio-economic needs of the populations. This is materialised by the fragmentation of the landscape and the loss of habitats of the flora and fauna of the banks and the hydrosystem.

In Cameroon, the pressure exerted on lake ecosystems by populations in search of new fertile land for market gardening or even off-season crops and fishery resources is at the origin of the transformation and fragmentation of natural habitats. These transformations result in the conversion of natural formations into fields, ranches, effluent outfalls, the erosion of biological diversity and the shortening of the life of lakes [5].

The ecological manifestations resulting from this state of affairs are worrying for the populations that depend directly or indirectly on the natural resources that are being lost. Understanding the succession dynamics of the constituent elements of lake ecosystems is therefore a necessity for sustainable management of natural resources for the benefit of the population's well-being [6]. In addition, degradation and deforestation caused by human activities are at the origin of the emission of a significant amount of carbon. Anthropogenic carbon leads to an increase in greenhouse gas concentration, which can contribute to climate change (Chaplin-Kramer et al. 2015). Quantifying degradation or deforestation processes is therefore a necessity for the implementation of a policy to increase ecosystem carbon stocks in the framework of greenhouse gas emissions induced by forest degradation, destruction and fragmentation. Therefore, remote sensing is an important tool for providing quantitative information over time and space on land use and occupation.

The study of land cover dynamics in time and space, using satellite images and remote sensing techniques, contributes effectively to the sustainable management of natural resources [7].

In Cameroon, studies on land use and land cover have reported degradation of wetlands without specifically highlighting that of lake ecosystems [8,9,10]. Few studies have focused on the dynamics of lake complexes over time, and analysed quantitatively and qualitatively the changes that have occurred within these units. In addition, spatially explicit knowledge of all these parameters is crucial for understanding and modelling a wide variety of Earth system processes and interactions with the environment, including water budgets [11]; carbon or methane exchange rates [12]; sediment trapping (Downing et al. 2008); heat flux and coupled effects of weather and climate; the cycling of pollutants and nutrients [13]; as well as associated ecological processes such as lake productivity [14]; species richness [15]; food chain dynamics [16]; and inland fisheries yields [17] .

Lake ecosystems are dynamic systems that are perpetually subject to natural changes induced by sedimentation, filling with organic matter, or subsidence-drought. Anthropogenic activities, both direct and indirect, such as development activities, pollution, overexploitation, the spread of exotic species and the effects of climate change, are also present. The combined effect of climatic hazards and anthropogenic actions thus profoundly alter the rate of change of lake ecosystems whose existence is now threatened through that of the entities on which they are composed and depend [18-21].

The lake ecosystems of the Sudan-Guinean zone are no exception to this reality. In the past, this area was full of a very important biodiversity, in which several forms of use were counted for the riparian populations. Nowadays, these lakes are subject to an exacerbated threat of its resources because of the strong human pressure on the riparian strips, which endangers these lake ecosystems. At the same time, agricultural practices are becoming more and more intensive through the colonization of new lands for the establishment of market gardening. Faced with this situation, it becomes important to conduct specific studies that will provide a sustainable basis for considering the sustainable management of lake ecosystems in the Sudano-Guinean zone of Cameroon [22,23]. Remote sensing and mapping offer an immense source of data to study the spatial and temporal dynamics of environmental parameters.

The overall objective of this work therefore is to evaluate the Spatio-temporal dynamics of the land use units of the lake complexes (Lake Bini, Lake Dang, Lake Mballang and Lake Ngaoundaba) in the Sudano-Guinean zone (Adamaoua-Cameroon) by coupling remote sensing tools with geographic information systems.

1.1 Data and Methods

1.1.1 Description of the study area

The study is located between 6° and 8° North latitude and between 11° and 15° East longitude, the Adamaoua Cameroon region extends over 63701 km^2. It is bordered to the North by the North region, to the South by the Centre and East regions of Cameroon, to the East by the Central African Republics, to the West by the Federal Republic of Nigeria and to the South-West by the West and NorthWest regions [24]. The climate is Sudano-Guinean, mild and cool, characterised by two seasons, a rainy season (April to October) and a dry season (November to March). The average annual rainfall is 1500mm per year spread over seven months. It is considered the "water tower" of the country because of its highly diversified water network, which originates in the same region and many of the country's rivers have their source there. The investigations took place in the Sudano-Guinean zone (Fig. 1), more precisely in the lake ecosystems of the districts of Ngaoundéré III (Lake Bini and Lake Dang), Nymbaka (Lake Ngaoundaba) and Ngan-ha (Mballang).

The Adamaoua Region belongs to the ecological zone known as the Guinean high savannah [25]. It is considered the country's "water tower" because of its highly diversified water system, which originates in the same region. The climate in this region is Sudano-Guinean, mild and cool, characterized by two seasons: a rainy season (April to October) and a dry season (November to March) [26]. The average annual rainfall is 1479 mm, with a coefficient of variation of 9.8% [27]. Temperature extremes range from 5 to 7 °C for the minima, and from 30 to 35 °C for the maxima [28]. Resulting from the emergence of the old crystalline basement, Adamaoua is covered in places by basaltic rocks. There are also wet valleys covered with rocky outcrops and basaltic cones. The characteristic vegetation of the Adamaoua Plateau is a shrub or tree savanna with *Daniellia oliveri* (Fabaceae) and *Lophira lanceolata* (Ochnaceae) (Letouzey, 1968). The most common woody species present include *Annona senegalensis*, *Croton macrostachyus*, *Entada africana*, *Hymenocardia acida*, *Psorospermum febrifugum* and *Terminalia macroptera* [29]. Natural resources are developed mainly through agriculture, cattle breeding, beekeeping and fishing [30].

1.2 Plan Metric Data

The data used in the study of land cover dynamics here is essentially satellite images, all captured at the beginning of the dry season. Indeed, the very low cloud cover of the dry season allows the satellite sensor to have good views [31]. Therefore, Landsat_5 from February 1990, Landsat_7 from February 2006 and Landsat_8 from February 2021, all with a resolution of 30m, was uploaded to the website http://earthexplorer.usgs.gov in GEOTIFF format. Topographic maps and base maps from the National Institute of Cartography was also used in this study. A GARMIN GPS (Global Positioning System) was used to locate the position of the various field control points. In addition to these planimetric data, some data (density, sown areas, pedology, etc.) were collected during a light survey of the populations to better profile the analysis of the dynamics of land use [32].

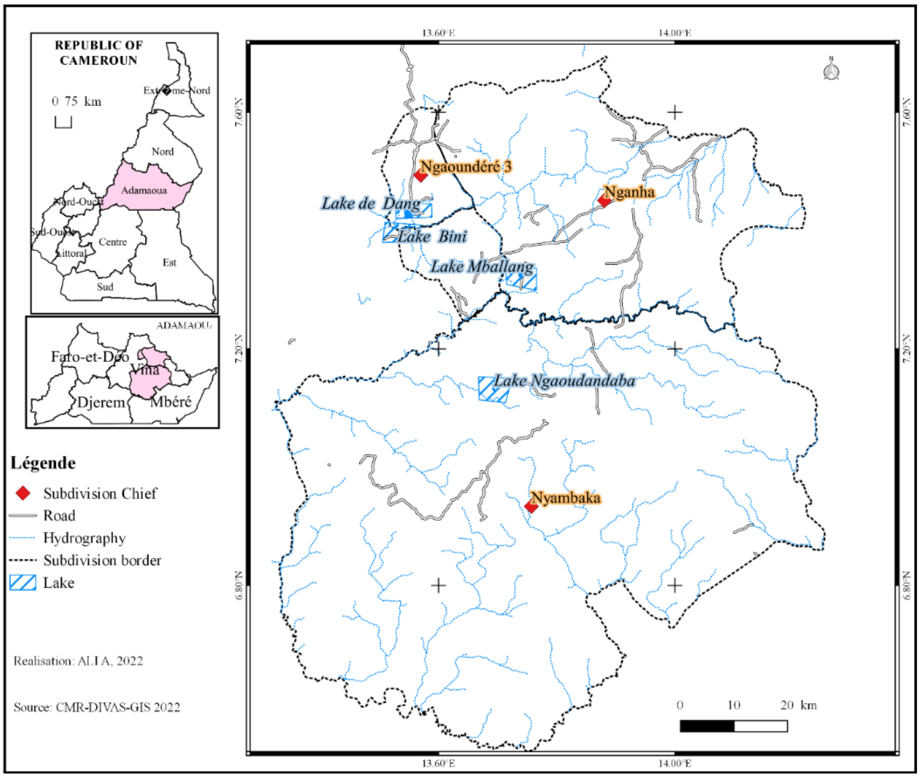

Fig. 1. Location map of the lake ecosystems

2. METHODS

After downloading these images (1990; 2006 and 2021) with less than 10% cloud cover, we imported them into Envi 4.5. It is in this software that the supervised classification operations took place. Thus we applied the supervised classification algorithm to the maximum likelihood parameter. Beforehand, it was necessary to import the shapefile vector layer of the boundary of the different lake ecosystems to create the metadata on which a coloured composition was applied to create the mask. The creation of the mask was essential since it allows one to delimit only the area in which want to work on. Once the mask has been created, it must be applied to the metadata and then a coloured composition must be made to leave only the area to be studied. Here the radiometric bands that can provide one with information on land use and land cover units were overlaid by additive synthesis of primary colours [32]. Thus, the bands were combined through a false colour composition with the combination of bands 2, 3 and 4 for the ETM+ image and 3, 4 and 5 for the OLI-TIR image. This operation, therefore consisted in making a false colour composition in RGB (Red-Green-Blue). To facilitate the overlay of images for diachronic analysis, the 1990, 2006 and 2021 images were co-registered using the image-to-image coregistration method, which ensures a good alignment of the pixels of the different images. The land use points were painted in different colours characteristic of the land uses.

The study area was cut to the part of the image corresponding to the area of interest from the polygon representing the boundaries of the Boroughs. The supervised classification method according to the maximum likelihood algorithm was used. The classification established and the colours used to represent each land use category were adapted from the Corine Land Cover (CLC) nomenclature. The accuracy and Kappa index were used to validate the classifications. The land cover maps produced provided the basic data for the analysis and quantification of the landscape. The areas of the different land-use categories were calculated and diagrams were drawn to assess the speed and intensity of change. Both descriptive and diachronic approaches were used for the analysis.

Quantum GIS 2.14 (Geographic Information System) was used to design the maps and calculate the areas of each land use class via the "*groupstats*" extension, which can be downloaded directly from the list of Qgis extensions. The following landscape indices were calculated to assess the observed dynamics:

2.1 Kappa Coefficient or Index

The coefficient or Kappa index, which corresponds to the ratio of the number of well-ranked pixels to the total number of pixels surveyed, was retained as it better indicates the agreement between the predicted models and reality (Tilahun et al. 2015). It was expressed as:

K= (Po-Pa) / 1-Pa

With Po = actual percentage of land cover elements classified, Pa = estimate of the probability of obtaining a correct classification.

2.2 Normalized Differential Vegetation Index (NDVI)

This is the most widely used vegetation index and is calculated from the visible and nearinfrared light reflected by the vegetation. Healthy vegetation absorbs most of the visible light that reaches it and reflects most of the near infrared light [33]. It was calculated using this formula:

NDVI = (NIR - Red) / (NIR + Red)

Knowing that NIR is the Near Infrared band, represented by band 4 in Landsat 5TM and 7ETM+ images and band 5 in Landsat 8 OLI/TIRS images; Red is the Red Band, represented by band 3 in Landsat 5TM and 7ETM+ images and band 4 in Landsat 8OLI/TIRS images. Knowing that NDVI values are theoretically between -1 and +1, negative values correspond to non-vegetated surfaces such as snow, water or clouds. For bare soil, the NDVI has values close to 0. Vegetation formations have positive NDVI values, generally between 0.1 and 0.7, with the highest values corresponding to the densest cover. The NDVI index offers one with the possibility to analyse the change in vegetation cover during the study years [33].

2.3 Typology of Changes (∆)

The typology of changes was characterised based on the nomenclature described by FAO (2011). To do so, a subtraction was performed between the digital values of the two images so that the change detection consisted in identifying the change of codes for the homologous vectors (∆i). After the land use maps of 1990; 2006 and 2021 were drawn up, a two-by-two comparative analysis (1990-2006; 1990-2006 and 1990-2021) was made. The analysis of the evolution of the different land use units was done using the following formula.

∆ = Sit- St1

Sit is for the area of land occupation by a unit at an initial date, whereas St1 is for the area of land occupation of the same unit at a given date and ∆ the variation of this inter-periodic area. If: ∆ = 0, then there is stability (S); ∆ => 0, then there is progressive evolution (P); ∆ =< 0, then there is regression (R).

2.4 Average Annual Rates of Spatial Expansion

The areas of land use and land cover units between the two dates were used to calculate the annual expansion rate according to the following formula from Bernier (1992):

$$T = (lns_1 - lns_0) / lne\ (t_1 - t_0) * 100$$

S0 and S1 represent the areas of a landscape unit at date t0 and t1 respectively; ln is the natural logarithm, and e represents the base of the natural logarithm (e = 2.71828). This rate expresses the annual proportion of change in each unit of land cover and land use.

2.5 Conversion Rate

To quantify the change between the two dates, the conversion rate of each discriminated land-use class was calculated. The conversion rate measures the degree of conversion of a given unit into other landscape units between two dates t0 and t1 . It is obtained from the transition matrix [34], according to the formula:

$$Tc = (S_{it} - S_{is}) / S_{it} * 100$$

Sit: Area of the landscape unit at the initial date t; Sis : Area of the same unit remaining stable at date t1

2.6 Speed of Change of Land Use Categories

To know the rate IN change of in the identified land use categories, the following formula was used:

$$\Delta s = St_1 - Sit / t_1 - t_i$$

Where: Δs= Rate of change (extension or regression in ha/year); **Sit** = Area occupied by the occupation category considered in year 1 (ha); **St1** = Area occupied by the occupation category considered in year 2 (ha); ti = year 1; t1 = year 2.

3. RESULTS

3.1 Discriminated Units

Table 1 presents the quality evaluation indices of the classified images. It can be observed that the overall statistical accuracies of the classified images were between 90.23% and 97.14% with kappa indices ranging from 86.93% to 95.65%. These indices were, respectively better in increasing chronological order. The lake ecosystems of lake Dang, Bini, Mballang and Ngaoundaba recorded the best overall accuracy and Kappa indices respectively.

3.2 Spatial Distribution of Land use and Land Cover Units in 1990, 2006 and 2021

Figures 2, 3, 4 and 5 show the different land use changes in the four Lake ecosystems between 1990 and 2021. It is apparent that nine common land-use unit classes have been discriminated in the Lake ecosystems of Mballng (Fig. 4) and Dang (Fig. 3). These are agricultural space, forest gallery, tree savannah, shrub savannah, grassy savannah, bare soil, water surface, hydromorphic zone, and housing area. On the other hand, the Lake Bini ecosystem (Fig. 2) has eight land use and occupancy unit classes, including agricultural space, forest gallery, tree savannah, shrub savannah, bare soil, water surface, hydromorphic zone and housing area. The Ngaoundaba lake ecosystem (Fig. 5) presents the same land use and occupancy unit classes as the Bini lake ecosystem (Fig. 2), except for the agricultural area.

Table 1. Quality assessment scores for classified image

	Lake Ecosystems	Overall accuracy (%)	Kappa (%)
1990	Lake Bini	96,78	95,30
	Lake Dang	97,14	95,65
	Lake Mballang	95,27	93,81
	Lake Ngaoundaba	93,52	92,09
2006	Lake Bini	96,11	94,64
	Lake Dang	97,05	95,56
	Lake Mballang	92,53	91,11
	Lake Ngaoundaba	90,23	88,85
2021	Lake Bini	95,84	94,37
	Lake Dang	96,47	94,99
	Lake Mballang	94,31	92,86
	Lake Ngaoundaba	92,64	91,22

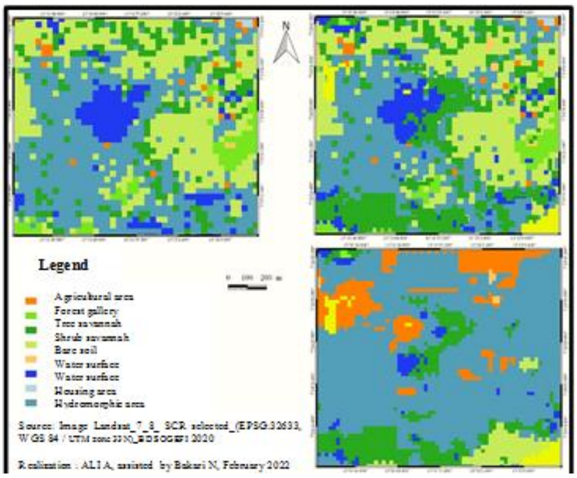

Fig. 2. Spatial distribution of land use units in the Lake Bini ecosystem between 1990 and 2021

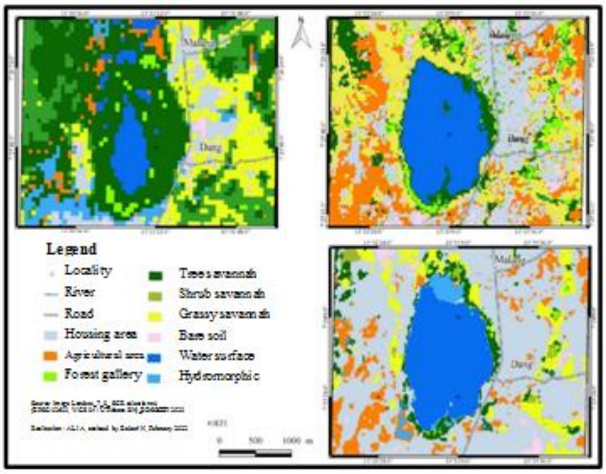

Fig. 3. Spatial distribution of land use units in the Lake Dang ecosystem between 1990 and 2021

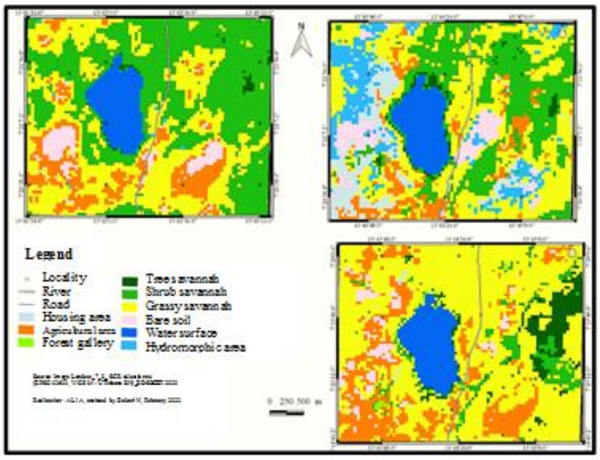

Fig. 4. Spatial distribution of land use units in the Lake Mballang ecosystem between 1990 and 2021

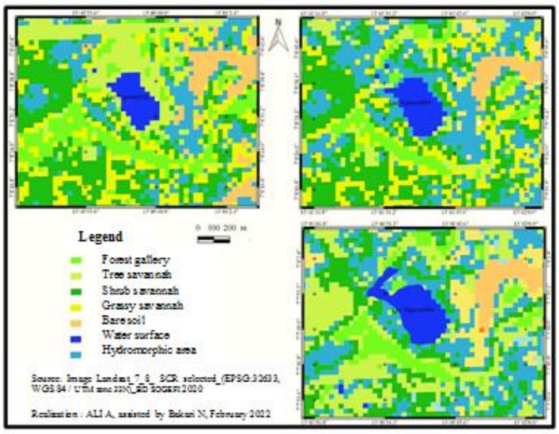

Fig. 5. Spatial distribution of land use units in the Lake Ngaoundaba ecosystem between 1990 and 2021

3.3 Estimation of the Normalized Differential Vegetation Index (NDVI)

The NDVI maps (Figs. 6-8) show a difference between the different years. The recorded values of the NDVI of Lake ecosystems varied from 0 to 0.214; from 0 to 0.214; from -0.116 to 0.326 and from -0.06 to 0.282 respectively for the Lake ecosystems of Bini (Fig. 6), Dang (Fig. 7), Mballang (Fig. 8) and Ngaoundaba (Fig. 9). The low NDVI values were recorded at the level of the water bodies of the different lakes while the maximum values were recorded at the level of the riparian strips.

3.4 Dynamics of Land use and Land Cover Units

Fig. 10 shows the different land use units of the Lake Bini ecosystem. Examination of this figure shows that in 1990, the shrub savannah (26.43%) followed by the hydromorphic zone (25.68 %) and tree savannah (1629%) recorded the largest areas compared to the habitation area (0.26 %). In 2006, the hydromorphic zone (44.13%) was followed by the agricultural area (29.28 %) and the shrub savannah came in the first place to the detriment of the forest gallery (0.98%), which was the least represented. In contrast, in 2021, the agricultural area (41.05 ha) was followed by the hydromorphic zone (29.30%) and the residential area (10.11%). The forest gallery (0.85%) was the land use unit with the smallest surface area in 2021.

For the Lake Dang ecosystem (Fig. 11), it can be observed that in 1990 the grassy savannah (40.23%) followed by the shrub savannah (21.29%) and the water area (9.65%) occupied more surface area compared to the residential area (0.59) which occupied the least surface area. In 2006, the grassy savannah (40.23%) followed by the residential area (21.09%) and the agricultural area (14.93%) occupies more surface area than the forest gallery (1.24%), which is poorly represented. On the other hand, in 2021 the residential area (27.75%), and the agricultural area (22.70%) followed by the grassy savannah occupied more land to the detriment of the forest gallery (0.47%) which remained the least represented.

In 1990, the Lake Mballang ecosystem (Fig. 12) shows a higher extent of land use units of the shrub savannah type (33.05%) followed by the grassy savannah (30.05%) and the agricultural area (17.27%). The smallest area was noted in the hydromorphic zone (0.08%). The land use units in 2006 were dominated by grassy savannah (32.51 ha) followed by shrub savannah (32.05%) and agricultural area (16.57%). The forest gallery (0.64%) had the smallest area. In 2021, the grassy savannah (56.49%) was followed by the agricultural area (21.65%) and the water area (11.89%). The hydromorphic zone (0.13%) had the smallest area.

The most important land use unit at Lake Ngaoundaba (Fig. 13) in 1990 was the shrub savannah (22.50%) followed by the tree savannah (21.53%) and the hydromorphic zone (16.31%). In 2006, the grassy savannah (21.17%) followed by the shrub savannah (20.12%) and the tree savannah (19.37%) occupied the largest areas respectively. In 2021, the hydromorphic zone (28.13%) was followed by shrub savannah (19.04%) and tree savannah (19.37%). In addition, the water surface occupied the smallest areas for the years 1990, 2006 and 2021, i.e. 2.35%; 3.50% and 3.93% respectively.

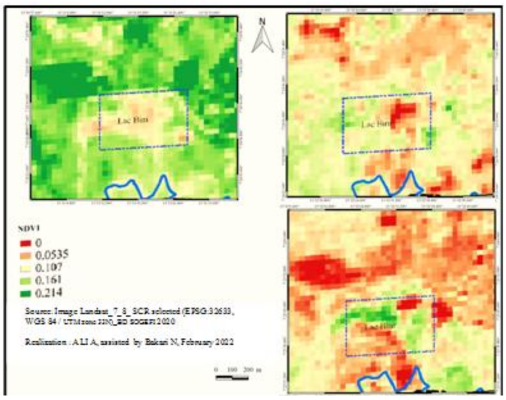

Fig. 6. Normalized differential vegetation index of the Lake Bini ecosystem between 1990 and 2021

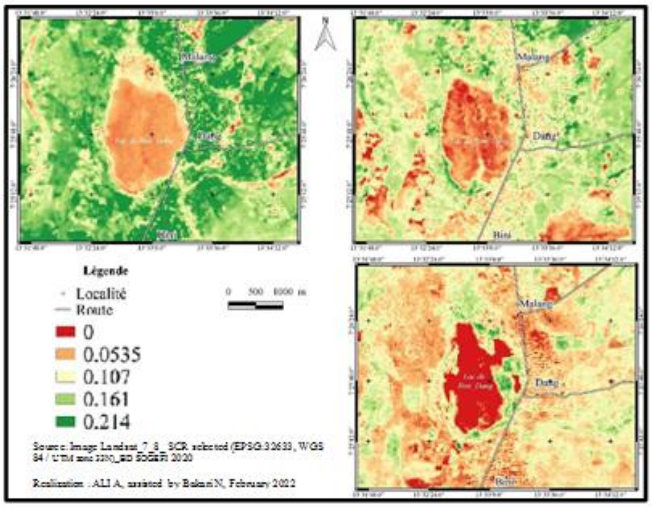

Fig. 7. Normalized differential vegetation index of the Lake Dang lake ecosystem between 1990 and 2021

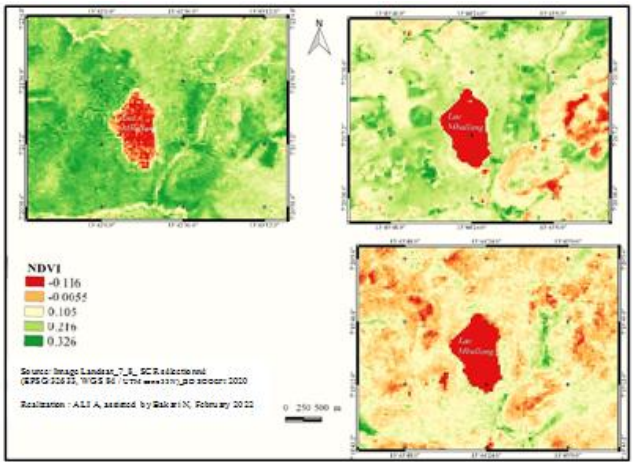

Fig. 8. Normalized differential vegetation index of the Lake Mballang ecosystem between 1990 and 2021

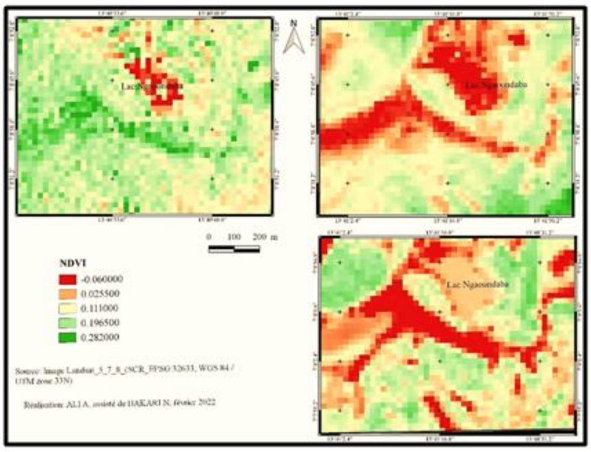

Fig. 9. Normalized differential vegetation index of the Lake Ngaoundaba ecosystem between 1990 and 2021

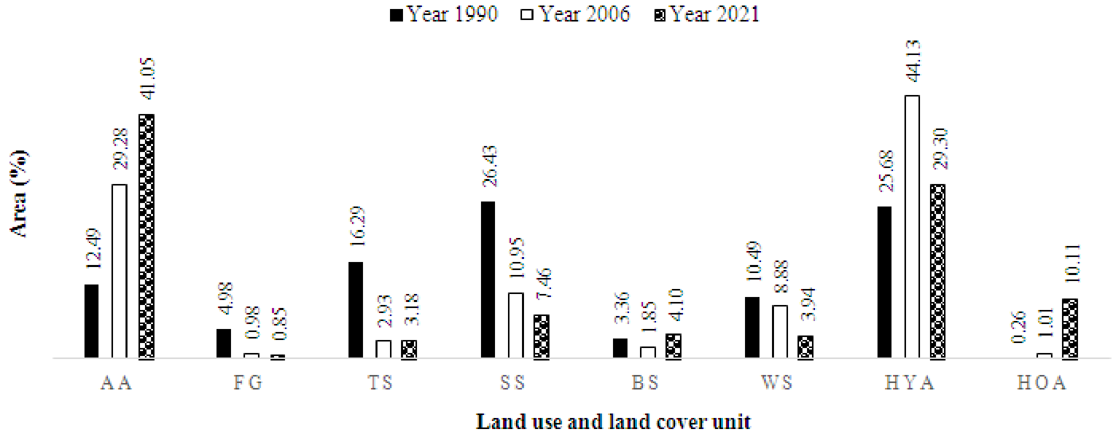

Fig. 10. Areas of different land use units in the Bini lake ecosystem
AA: Agricultural area, FG: Forest gallery, TS: Tree savannah, SS: Shrub savannah, GS: Grassy savannah, BS: Bare soil, WS: Water surface, HYA: Hydromorphic area, HOA: Housing area

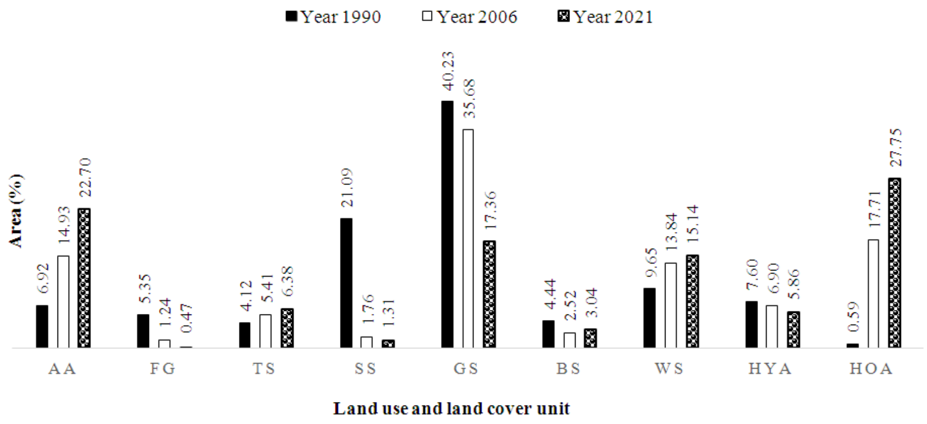

Fig. 11. Areas of different land use units in the Lake Dang ecosystem
AA: Agricultural area, FG: Forest gallery, TS: Tree savannah, SS: Shrub savannah, GS: Grassy savannah, BS: Bare soil, WS: Water surface, HyA: Hydromorphic area, HoA: Housing area

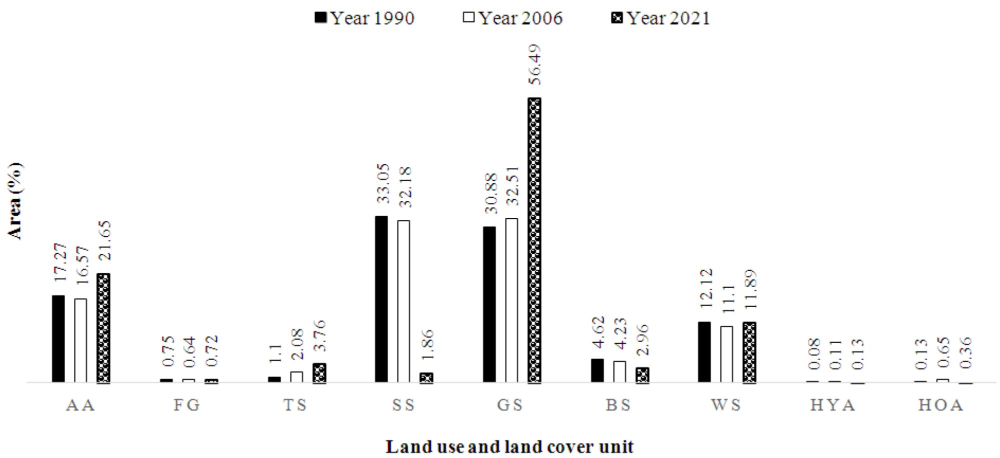

Fig. 12. Areas of the different land-use units in the Mballang lake ecosystem
AA: Agricultural area, FG: Forest gallery, TS: Tree savannah, SS: Shrub savannah, GS: Grassy savannah, BS: Bare soil, WS: Water surface, HyA: Hydromorphic area, HoA: Housing area

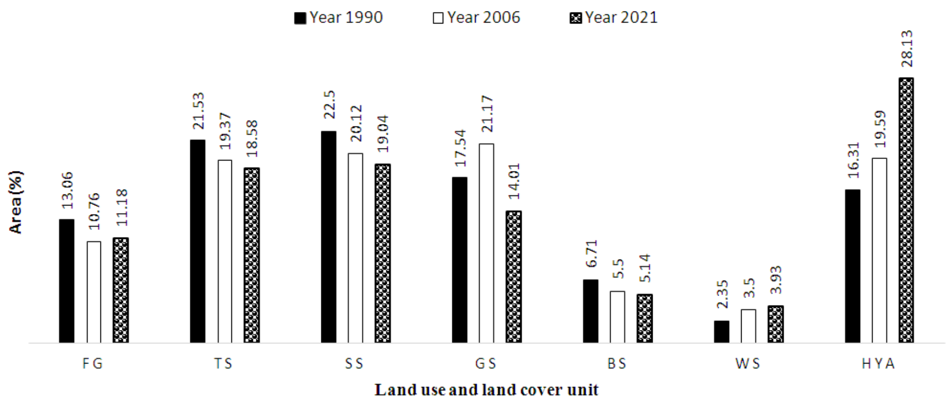

Fig. 13. Areas of the different land use units of Lake Ngaoundaba ecosystem

AA: Agricultural area, FG: Forest gallery, TS: Tree savannah, SS: Shrub savannah, GS: Grassy savannah, BS: Bare soil, WS: Water surface, HyA: Hydromorphic area, HoA: Housing area

3.5 Typology of the Dynamics of Change from 1990 to 2021

Table 2 shows the diachronic analysis of the typology of the land use units of the Lake ecosystems of Lake Bini, Lake Dang, Lake Mballang and Lake Ngaoundaba from 2021 to 1990; from 2021 to 2006 and 2006 to 1990.The analysis of this table 2 shows that the Lake Bini, the agricultural space, the bare soil and the hydromorphic zone have evolved progressively to the detriment of the forest gallery, the tree savannah, the shrub savannah and the water surface, which have gone into decline.

However, in the Dang lake ecosystem, the agricultural space, the tree savannah, the water surface and the housing area have progressively gone to the detriment of the forest gallery, the shrub savannah, the grassy savannah and the hydromorphic area. However, in the Mballang lake ecosystem, the agricultural area, the shrub savannah, the grassy savannah and the hydromorphic zone have progressively increased at the expense of the shrub savannah and the soil. On the other hand, in the Mballang lake ecosystem, the forest gallery and the water surface described a progressive dynamic exclusively during the periods 2021 to 2006 and regressive from 2006 to 1990. On the other hand, the Ngaoundaba lake ecosystem shows that the water surface and the hydromorphic zone record a progressive dynamic to the detriment of the tree and shrub savannah and the bare soil which are regressive. On the other hand, the forest gallery showed a progressive dynamic during the period 2021 to 2006.

3.6 Conversion and Expansion Rates of Occupancy Units

Table 3 presents the rate of conversion and expansion of land use units of the studied lake ecosystems during the periods 2021 to 1990; 2021 to 2006 and 2006 to 1990.

The rate of conversion and expansion at the Lake Bini ecosystem was highest at in settlement area followed by the agricultural area and bare ground. However, the rate of conversion and expansion wass lowest during the period 2021 to 1990 at the gallery forest unit followed by the shrub and tree savannah. The rate of conversion and expansion of land use units in the Lake Dang ecosystem on the other hand showeds that during the periods 2021 to 1990; 2021 to 2006 and 2006 to 1990, the rate of conversion and expansion was highest in the settlement area followed by the agricultural area. These rates were lower in the forest gallery unit followed by the tree and shrub savannah.

The rate of conversion and expansion of land use units in the Lake Mballang ecosystem showeds that during the periods 2021 to 1990; 2021 to 2006 and 2006 to 1990, the rate of conversion and expansion was the highest in the shrub savannah, the habitation area. In contrast, these rates were lower in the shrub savannah and bare ground units. The rate of conversion and expansion of the land use units of the Ngaoundaba lake ecosystem showeds that during the periods 2021 to 1990; 2021 to 2006 and 2006 to 1990, the rate of conversion and expansion was highest in the hydromorphic zone and the water surface. However, these rates were lower in the bare soil unit followed by the grassy savannah.

Table 2. Change in the area of land use units of the lake ecosystems studied

	Land use unit	Evolution 2021-1990 (Ha)		Superficie 2021-2006 (Ha)		Superficie 2006-1990 (Ha)	
Lake Bini	Agricultural space	24.40	Progressive	10.06	Progressive	14.34	Progressive
	Foresty gallery	-3.53	Regressive	-0.11	Regressive	-3.42	Regressive
	Wooded savannah	-11.20	Regressive	0.22	Progressive	-11.42	Regressive
	Shrubby savannah	-16.21	Regressive	-2.98	Regressive	-13.22	Regressive
	Bare ground	0.63	Progressive	1.92	Progressive	1.29	Progressive
	Water surface	-5.60	Regressive	-4.22	Regressive	-1.38	Regressive
	Hydromorphic zone	3.09	Progressive	-12.67	Regressive	15.75	Progressive
	Residential area	8.42	Progressive	7.78	Progressive	0.65	Progressive
	Agricultural space	24.38	Progressive	12.00	Progressive	12.38	Progressive
Lake Dang	Foresty gallery	-7.53	Regressive	-1.19	Regressive	-6.34	Regressive
	Wooded savannah	3.49	Progressive	1.5	Progressive	1.99	Progressive
	Shrubby savannah	-30.56	Regressive	-0.7	Regressive	-29.86	Regressive
	Grassland savannah	-35.34	Regressive	-28.31	Regressive	-7.03	Regressive
	Bare ground	-2.17	Regressive	0.8	Progressive	-2.97	Regressive
	Water body	8.48	Progressive	2	Progressive	6.48	Progressive
	Hydromorphic zone	-2.70	Régressive	-1.60	Regressive	-1.09	Regressive
	Residential area	41.95	Progressive	15.51	Progressive	26.44	Progressive
Lake Mballang	Agricultural space	16.72	Progressive	19.41	Progressive	-2.68	Regressive
	Foresty gallery	-0.12	Regressive	0.31	Progressive	-0.43	Regressive
	Wooded savannah	10.17	Progressive	6.42	Progressive	3.75	Progressive
	Shrubby savannah	-118.13	Regressive	-114.80	Régressive	-3.33	Regressive
	Grassland savannah	97.78	Progressive	91.55	Progressive	6.23	Progressive
	Bare ground	-6.62	Regressive	-4.84	Regressive	-1.78	Regressive
	Water surface	-0.88	Regressive	3.01	Progressive	-3.89	Regressive
	Hydromorphic zone	0.21	Progressive	0.09	Progressive	0.12	Progressive
	Residential area	0.87	Progressive	-1.13	Regressive	2.00	Progressive
Lake Ngaoundaba	Foresty gallery	-5.24	Regressive	1.18	Progressive	-6.42	Regressive
	Wooded savannah	-8.25	Regressive	-2.19	Regressive	-6.05	Regressive
	Shrubby savannah	-9.67	Regressive	-3.01	Regressive	-6.65	Regressive
	Grassland savannah	-9.86	Regressive	-20	Regressive	10.14	Progressive
	Bare ground	-4.38	Regressive	-1.03	Regressive	-3.35	Regressive
	Water surface	4.40	Progressive	1.21	Progressive	3.19	Progressive
	Hydromorphic zone	33.00	Progressive	23.84	Progressive	9.15	Progressive

Table 3. Conversion and expansion rates of land use and land cover units in the Bini lake ecosystem

	Land use units	Conversion rate			Expansion rate		
		2021-1990	2021-2006	2006-1990	2021-1990	2021-2006	2006-1990
Lake Bini	Agricultural space	227.98	40.23	133.89	3.83	2.25	5.31
	Foresty gallery	-82.92	-13.33	-80.29	-5.70	-0.95	-10.15
	Wooded savannah	-80.38	8.80	-81.97	-5.25	0.56	-10.71
	Shrubby savannah	-71.78	-31.89	-58.57	-4.08	-2.56	-5.51
	Bare ground	36.03	146.84	-44.89	0.99	6.02	-3.72
	Water surface	-62.00	-55.38	-14.83	-3.12	-5.38	-1.00
	Hydromorphic zone	33.49	-22.99	73.34	0.93	-1.74	3.44
	Residential area	3863.30	900.00	296.33	11.87	15.35	8.61
Lake Dang	Agricultural space	227.98	52.02	115.75	3.83	2.79	4.81
	Foresty gallery	-91.19	-62.10	-76.74	-7.84	-6.47	-9.12
	Wooded savannah	54.85	11.28	39.15	1.41	0.71	2.06
	Shrubby savannah	-93.80	-25.74	-91.65	-8.97	-1.98	-15.52
	Grassland savannah	-56.86	-51.36	-11.31	-2.71	-4.80	-0.75
	Bare ground	-31.49	21.45	-43.59	-1.22	1.30	-3.58
	Water surface	56.94	9.35	43.52	1.45	0.60	2.26
	Hydromorphic zone	-22.92	-15.05	-9.26	-0.84	-1.09	-0.61
	Residential area	4559.13	56.68	2873.59	12.39	2.99	21.20
Lake Mballang	Agricultural space	25.37	41.90	-11.65	0.73	2.33	-0.77
	Foresty gallery	-4.10	12.56	-14.80	-0.13	0.79	-1.00
	Wooded savannah	242.08	80.72	89.29	3.97	3.95	3.99
	Shrubby savannah	-94.37	-94.22	-2.64	-9.28	-19.00	-0.17
	Grassland savannah	82.95	73.78	5.28	1.95	3.68	0.32
	Bare ground	-35.88	-29.98	-8.42	-1.43	-2.38	-0.55
	Water surface	-1.89	7.10	-8.40	-0.06	0.46	-0.55
	Hydromorphic zone	70.00	-90.59	1706.67	1.71	-15.76	18.09
	Residential area	178.13	-45.48	410.17	3.30	-4.04	10.18
Lake Ngaoundaba	Foresty gallery	-14.38	3.94	-17.62	-0.50	0.26	-1.21
	Wooded savannah	-13.72	-4.38	-9.77	-0.48	-0.30	-0.64
	Shrubby savannah	-15.39	-5.30	-10.66	-0.54	-0.36	-0.70
	Grassland savannah	-20.13	-33.84	20.72	-0.73	-2.75	1.18
	Bare ground	-23.82	-7.19	-17.92	-0.88	-0.50	-1.23
	Water surface	51.90	2.20	48.63	1.35	0.15	2.48
	Zone hydromorphe	72.47	43.61	20.10	1.76	2.41	1.14

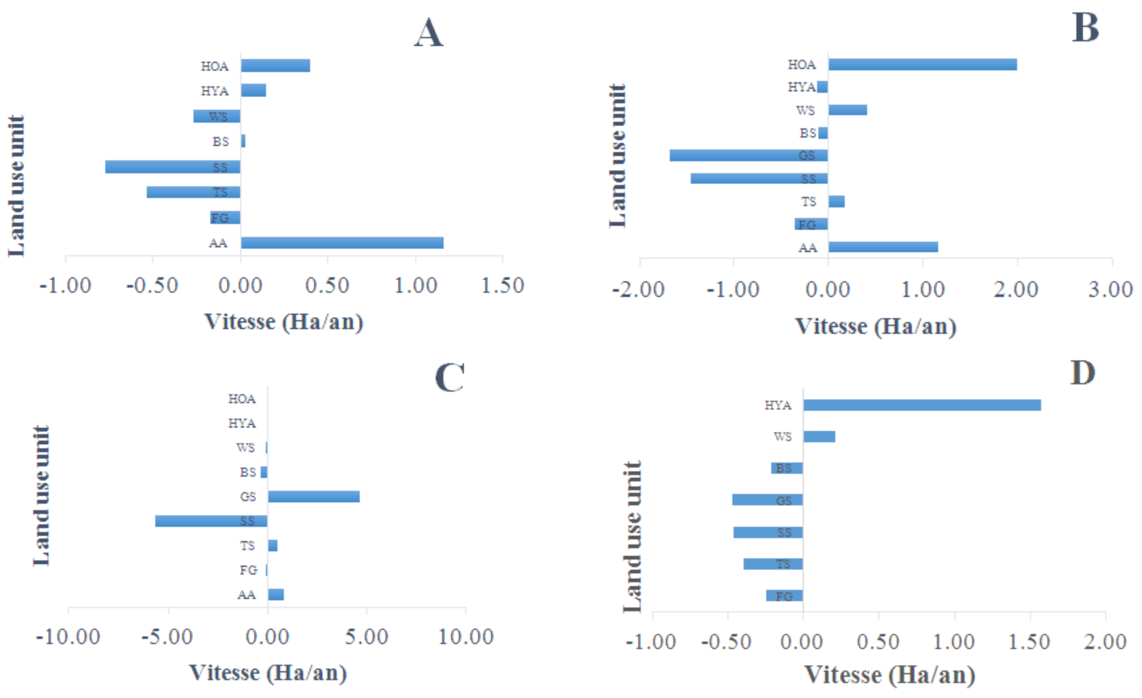

Fig. 14. Rate of change of land use units in the lake ecosystems of Bini (A) Dang (B) Mballang (C) and Ngaoundaba (D)

AA: Agricultural area, FG: Forest gallery, TS: Tree savannah, SS: Shrub savannah, GS: Grassy savannah, BS: Bare soil, WS: Water surface, HyA: Hydromorphic area, HoA: Housing area

3.7 Extent of Change in Land Use Units

Fig. 14 shows the extent of change in the land use units of the Lake ecosystems of Lake Bini (Fig. 14 A) Lake Dang (Fig. 14 B) Lake Mballang (Fig. 14 C) and Lake Ngaoundaba (Fig. 14 D) from 1990 to 2021.

In the Lake Bini ecosystem, all land use units experienced significant change, both positive and negative. The agricultural area (1.16 Ha/year) followed by the residential area (0.40 Ha/year) experienced the highest acceleration. On the other hand, the lowest acceleration between 1990 and 2021 is observed in the forest gallery (0.17 Ha/year) followed by bare soil (0.03 Ha/year).

In the Lake Dang ecosystem, the residential area (2.00 Ha/year) followed by the agricultural area (1.16 Ha/year) recorded the highest rates of change. On the other hand, the slowest rates of change were in the bare soil (-0.13 Ha/year) and the hydromorphic area (-0.10 Ha/year).

For the Lake Mballang ecosystem, the grassy savannah (4.66 Ha/year) followed by the agricultural area (0.80 Ha/year) showed the highest rates of change. However, the lowest velocities were noted in the forest gallery (-0.01 Ha/year) and the water surface (-0.04 Ha/year) respectively.

For the Lake Ngaoundaba ecosystem, the hydromorphic zone (1.57 Ha/year) followed by the water surface (0.21 Ha/year) recorded the highest velocities. The lowest velocities were recorded in the bare soil (-0.21 Ha/year) and the forest gallery (-0.25 Ha/year) respectively.

4. DISCUSSION

Spatio-temporal dynamics can be seen as a process of permanent occupation of a territory by various land use and occupation units in space and time [35]. Diachronic analysis based on spot satellite images from 1990, 2006 and 2021 has enabled the study to assess the evolution of the various landscape units for thirty-one years. The overall statistical accuracy of the classified images ranges from 90.23 to 97.14% with kappa indices varying from 86.93 to 95.65%. In the present study, the Kappa index was above 50% and the lowest value was 88%. In the study of land cover, when the Kappa index evaluated in the classification operations is between 50 and 75%, the adopted classification is valid and the results can be used judiciously (Pontius, 2000). The different evaluation results of the images classified by the supervised classification method were therefore validated and could be explained by the ability of the sensors to generate good images during low cloud cover. These results could be explained by the ability of these environments to allow several elements to coexist within the ecosystem that they constitute. These results were closer to 98.86% with kappa indices varying from 85.65 to 97.35% on the spatiotemporal dynamics of land cover in three protected areas in Burkina Faso. They are also similar to those of Ganame, [36] who reported overall statistical accuracies of classified images ranging from 88.90% to 98.86% with kappa indices varying from 85.65 to 97.35% on the spatiotemporal dynamics of land cover in three protected areas in Burkina Faso.

The fairly large number of land use and occupancy unit classes in the four Lake ecosystems (9 classes in Mballang, 9 classes in Lake Dang, 8 classes in Lake Bini and 7 classes in Lake Ngaoundaba) shows a diversity in the lake ecosystem landscape. These units are not always well differentiated, probably because of the close spectral responses of these natural and particularly woody plant formations. These challenges have been encountered by several authors and even in other countries [37,38]. These challenges could be related to the homogeneous plots when choosing training sites. However, despite these challenges, the results obtained remain exploitable. Similar results, which discriminate a maximum of 9 land use and occupation unit classes on the banks of the Gbaga Lagoon in West Africa, were also reported by Ahehehinnou et al. [39].

The estimation of NDVI from the maps of spatiotemporal dynamics revealed a regression of the vegetation of lake ecosystems. The recorded NDVI values of the lake ecosystems varied from 0 to 0.214; from 0 to 0.214; from -0.116 to 0.326 and from -0.06 to 0.282 respectively for the lake ecosystems of Lake Bini, Lake Dang, Lake Mballang and Lake Ngaoundaba. The larger NDVI differences at Lake Mballang (-0.116 to 0.326) and Lake Ngaoundaba (-0.06 to 0.282) ecosystems could be explained by the variation in vegetation density and edaphic parameters across these ecosystems. Mackey et al. (2012) revealed that vegetation could significantly reduce the temperature if NDVI exceeded 0.35. In the study, the results showed a strong decrease in vegetation over time. Consequently, the reduction of vegetation cover increases the soil surface temperatures of lake ecosystems.

The evolution of land use and land cover units showed changes in the area of land use units in general and in vegetation cover in the years 1990, 2006 and 2021. In general, in 1990 the savannahs (shrub savannah, tree savannah and grass savannah) were the most extensive units. In 2006 and 2021, agricultural space, housing area, bare soil and hydromorphic area were gaining ground to the detriment of savannah and forest gallery. These results could be explained by the growth in demography and the increase in poverty, which leads respectively to the extension of agricultural areas and the search for habitable areas with low land value. The expansion of these units had encroached on areas previously occupied by natural formations such as savannahs and gallery forests. These results confirm the findings of Gauze et al. [40] on the Characterisation of land use dynamics and morphology of the Aby Lagoon in the Ehotile Islands National Park area; South-East of Côte d'Ivoire, Bamba et al. [41] on Influence of anthropogenic actions on the Spatio-temporal dynamics of land use in the Bas-Congo province (D.R. Congo).

Spatial and temporal dynamics are expressed in terms of regression, stability or progression of land-use units, hence the notion of typology. The typology of the dynamics of change from 1990 to 2021 shows that the agricultural space, the housing area, bare soil and the hydromorphic zone describe a progressive dynamic to the detriment of the forest gallery, the wooded savannah, the shrubby savannah and the water surface which have gone into regression. These results would be the result of strong pressures on the resources of the banks of the studied lake ecosystems for the satisfaction of different needs. The wetlands as a space with a high potential for life have favoured the immigration and settlement of people from dry areas for grazing, watering animals and fishing. This situation leads to the uncontrolled occupation of lake ecosystems by people who largely encroach on the riparian vegetation, which provides enormous ecosystem services. These results are similar to those of Tente [42] whoworked in the forest of Eastern Cameroon and showed that other types of vegetation formation areprogressing while others are regressing. This also confirms well the results of Mama et al [43], Tente [42], Orékan (2007) and Arouna (2012) concerning the regression of dense vegetation formations infavour of agricultural spaces.

The rate of conversion and expansion of the land use units of the lake ecosystems studied shows in general that during the periods from 2021 to 1990, the rate of conversion and expansion is higher in the residential area followed by the agricultural area. This clear difference in the rate of conversion and expansion of the land use units of the four lake ecosystems studied could be explained by the fact that anthropogenic action was more likely to be directed towards agriculture and urbanisation, while neglecting the environmental aspect. Agriculture is the main source of deforestation. Similar results have also been observed in several other localities in Cameroon [44], (Temgoua et al. 2018b).

In general, the acceleration of the dynamics over the last 31 years has revealed progressive degradation in the grassy savannah, the residential area, the agricultural area and the hydromorphic area. These degradations have been at the expense of the shrub savannah, the tree savannah and the forest gallery. These plant formations have been degraded at a considerable rate. The causes of the degradation of the vegetation cover are anthropogenic and can also be climatic when the ecological zone does not benefit from the minimum rainfall that should allow the spontaneous reconstitution of plant formations, which is increasingly observed with climate change (Adjonou et al. 2010). In addition, agricultural activities are the major causes of vegetation degradation [8,44-46]. However, this regression of shrubby savannahs, trees and forest galleries would be accompanied by the loss of biodiversity and land degradation.

5. CONCLUSION AND RECOMMENDATIONS

The study of the spatiotemporal dynamics of land use in four lake complexes in the Sudano-Guinean zone showed that the natural plant formations (shrubby savannah, trees and forest gallery) had undergone a strong regressive dynamic to the benefit of anthropogenic formations (the residential area and the agricultural space). The regression of these vegetation formations on the banks was due to several factors, the most important of which were population growth, the extension of cultivated areas and logging. This destruction of plant the cover leads to an imbalance in the natural resource cycle, soil degradation and, above all, the loss of ecosystem services and biodiversity. These results call on the various actors or decision-makers in charge of wetland management to consider management and restoration methods. This makes clear the urgent need to establish integrated and participatory management strategies at both local and regional levels to preserve and control lake ecosystems more effectively. They also contribute to a better knowledge of the predictions on the evolution of these ecosystems expected from different socio-economic scenarios and to ensure resilience.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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