SPACIO-TEMPORAL DYNAMIC OF THE VEGETATION AND DEGRADATION FACTORS OF THE VEGETATION COVER AROUND LAGDO LAKE, NORTH CAMEROON

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ABSTRACT

Lagdo lake with an area of 586 km^2 is a dam lake located in the North Region of Cameroon. It is under the influence of silting and siltation. These phenomena are becoming more and more widespread to the point where the hydroelectric dam is now threatened for the production of electrical energy. The objective of this study is to map the dynamics of land use between 1973, 2000 and 2020 and to determine the factors that affect the vegetation cover around Lagdo Lake. The methodology adopted consisted of identifying land cover units and determining the factors that are responsible for land cover degradation. Landsat images from 1973, 2000 and 2020 and survey data from 416 farmers in the area were used. The results show that the study area has undergone an advanced spatial and temporal change over the period 1973-2020. This change reveals that the average annual regression rates for vegetation formations are -3.21% and respectively -0.88% and -2.33% for tree and shrub savannahs. On the other hand, an increase was observed in anthropogenic formations such as mosaics of bare soil and farms (43.41%), and buildings (0.52%). From 1973 to 2020, anthropogenic formations (buildings and mosaics of bare soil and farms) have progressed to the detriment of natural formations (shrubby savannahs and tree savannahs). These natural formation paned from -37040.5 ha between 1973-2000 to -439284.5 ha between 2000-2020 to the benefit of built-up areas and mosaics of bare soil and farms. The mutation of this vegetation is due to anthropic pressures linked to agricultural activities (20±11.24%), fishing (9.5±3.29%), pastoral activities (8.65±9.51%), vegetation slash and burn (17±8.8%), poorly controlled urbanisation (5.1±5.78%) and demographic pressure (17±8.23%). However, agriculture remains the main factor for the degradation of vegetation cover. Considering the accelerated rate of the degradation of the vegetation cover of the said lake, the energy production of the Lagdo dam would cease in the future years.

Key words: Vegetation dynamic, lake silting, Lagdo, North Cameroon.

INTRODUCTION

Wetlands are among the most productive natural environments in the world (Akognongbe *et al*., 2014). They are areas where water is the main element that controls the natural environment, animal and plant life (Azonhoume, 1979). These ecosystems provide very important and varied economic services, such as: water supply, fisheries, agriculture, timber production, energy resources, wildlife, navigation and tourism activities. These ecosystems also play major ecological roles: firstly, they host a very high level of biodiversity, and secondly, they also play a particular role as ecological corridors by allowing the circulation of animal and plant species (Dufour and Piégay, 2006). The case of Lagdo Lake is a particularity. Being part of the important hydrographic network, that Cameroon has, Lagdo Lake is a dam lake located in the North Cameroon Region and its covering an area is of 586 km^2 (PNDP, 2015). It is adjoined by a hydroelectric power plant allowing for electricity generation, improved navigability, agricultural and fisheries development among others (Ngatcha *et al.*, 2002). Fed by a network of watercourses (mayo) dominated by the Benue and its major tributaries (Mayo-Sina, Mayo-Godi, Mayo-Ray and Mayo-Mbay), this environment is characterised by various plant communities, including a herbaceous stratum, a shrub stratum and a tree stratum (Banoun and Souina, 2009). This bank vegetation, also known as riparian vegetation, ensures multiple, varied and complementary functions which not only contribute to the good condition of the watercourse, but also provide multiple services to human society (Koulinski, 2014). Among these functions, these are cited: bank stabilisation, flood mitigation, water quality improvement and biodiversity refuge (NEF, 2018). Despite their undeniable interest in the good state of aquatic environments and their role in the territory's green and blue fabric, this vegetation is subject to various pressures that lead to its destruction. In the same vein, Galea *et al.* (1993) reported that deforestation indirectly increases the peak flow of floods, thus contributing to the irreversible destruction of the habitat (Varana and Maire, 2008) with the direct consequence of soil erosion, sediment production (Rey *et al*., 2004), and the silting up of the shallows; and the banks of Lagdo Lake are not on the fringe of the aforementioned deforestation phenomenon. Indeed, the activities perceived during the last decade around this lake testify the anthropic pressures on this environment and on its vegetation cover. This situation, qualified as bad or average, gives an image characterised by a forest corridor sometimes reduced to a row of trees, a disturbed regeneration (Ousseina *et al*., 2015) to the benefit of an increasingly fragile and ephemeral ecosystem at this lake (Banoun and Souina, 2009). In fact, because of its silting up due to soil degradation, since 2014 Lagdo lake has experienced a decrease in its water retention capacity, thus leading to a reduction in its surface area and water depth. Because of its silting up, the Lagdo hydroelectric dam is experiencing a water deficit causing power cuts in the Far North Region of Cameroon. For this reason, the issue of vegetation dynamics around the lake is of paramount importance. However, in Cameroon, and particularly in its Sudano-Sahelian part, most of the studies carried out on vegetation dynamics concern the management of protected areas (national parks, reserves, ZIC) (Tabopda and Fotsing, 2010; Djiongo *et al*., 2020). But those dealing with the vegetation dynamics of these wetlands are rarely highlighted. To fill this gap, the present study was initiated with the objective of mapping the dynamics of land use between 1973, 2000 and 2020 and to determine the factors of vegetation cover degradation around Lagdo Lake.

MATERIAL AND METHODS

Geographical location of the Lagdo Council

Lagdo Council is located at 09°03'440.4" North, and 13°39'335.5" East (PCDL, 2015). It is located at a distance of 65 Km from Garoua, North Region. It covers an area of 2250 Km² and is bounded (Banoun and Souina, 2009): to the North by the Councils of Ngong and Bibémi; to the South by the Councils of Tchollíré and Poli; to the East by the Councils of Rey Bouba and Bibémi and to the West by the Council of Ngong (Figure 1).

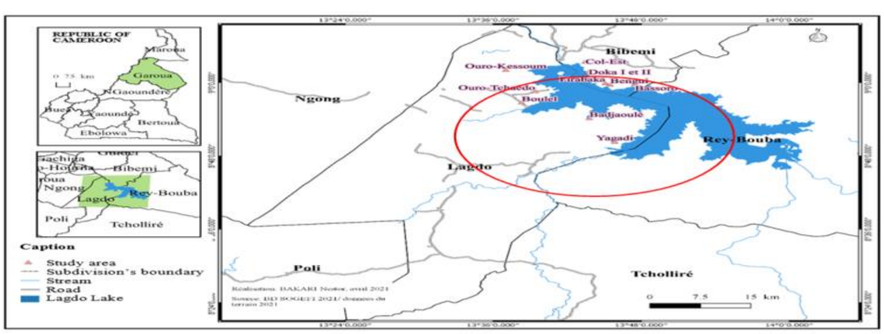


Figure 1. Location map of the study area

The climate is tropical of the Sudano-Sahelian type, characterised by two seasons: a dry season that runs from November to March and a rainy season that begins in April and ends in October (Ngatcha *et al*., 2002; Djoufack, 2011). The average annual rainfall that hovers around 950 mm of water would be accumulated in 55 days of rainfall most often (DAADER, 2015). Temperatures are high with an average of 32.2°C with average maxima reaching 39°C in April (DAADER, 2015).

Mapping data used and methodology. For the mapping of land use dynamics, ENVI software was used to produce three land use maps based on satellite images from 1973 and 2020. The images chosen were obtained at the same period of each year in order to reduce problems related to differences in solar angles, ecological change in vegetation and differences in soil moisture (Mamane *et al*., 2018). Everything started by identifying the area in the region of interest on Google Earth Explorer. Then uploading to explorer based on the date of 1973, 2000 and 2020 landsat image type 7, 4, 8. These images were imported into ENVI. Once imported, the colour composition of the study area was made. In this composition there was identification of the false colour composition (joining of band 6, 5 and 3) infrared and the true colour composition (joining of band 4, 3 and 2). Finally, a coloured composition (false colour) was used to obtain the best visualisation of the objects in the image (Sarr, 2009). After this phase, the clipping (creation of the masks) was carried out successfully. Thus, the import of the vector file was accompanied by the setting up of RI (region of interest) by assigning colours according to fingerprints and the RI is exported by doing the classification. Hence the formula: pre-processing of satellite images + digital image classification + post-classification processing and validation of results is used. The 1973, 2000 and 2020 land use maps around Lagdo Lake were also produced. The following landscape unit indices were calculated to assess the observed dynamics:

Rate of change (rate of change and average annual rates of spatial expansion). The annual rate of change (Tv) and the annual average rate of spatial expansion (T) of the land cover categories between the years 1973, 2000 and 2020 are calculated respectively through the equation proposed by FAO (1995) and which is very frequently used (Kpedenou *et al*., 2016; Brun *et al*., 2018; Tsewoue *et al*., 2020), and that of Bernier (1992).

$$\mathbf{Tv\ (\%)} = \frac{\mathbf{S2 - S1}}{\mathbf{S1}} \times \mathbf{100}$$

With S_1 the land area of a land-use category at date t_1; S_2 the landarea of the same land-use category at date t_2, with 2 > 1.
Tv > 0: indicates the progression of the land use class;
Tv < 0: indicates the regression of the land-use class;
Tv = 0: indicates stability of the land cover class.

$$\mathbf{T} = \frac{\mathbf{lnS2 - lnS1}}{\mathbf{(t2 - t1) \times lne}} \times \mathbf{100}$$

S1 and S2 the area of a landscape unit at date t1 and t2 respectively; t2 - t1 the number of years of evolution; ln the natural logarithm; e the base of the natural logarithm (e = 2.71828).

Method and technique of data collection

Explanatory determinants of the degradation of the vegetation cover around Lagdo Lake

Bibliographical approach to the identification of explanatory factors. This approach is based on documentary research in documentation centres and university libraries (Ngaoundéré), MEADEN, DAADER Lagdo, DAEPIA Lagdo, CF Lagdo, Lagdo Council and online (on the internet). It gave an idea of the different determinants or factors that could explain the degradation of vegetation cover in Sudano-Sahelian wetlands in general and in Northern Cameroon in particular.

Participatory approach to the identification of explanatory determinants. A total of ten (10) villages (Yagadi, Badjaoulé, Boulel, Ouro-Tchaido, Ouro-kessoum, Cole-Est, Doka I and II, Firabaka, Bengui and Bassoro) constituted the object of the study. Indeed, discussions were held with the various actors supposedly involved in the changes in vegetation cover around Lagdo Lake. These were mainly loggers, farmers, herders and fishermen, and other resource persons (CARDER staff, water and forestry officers and community development officers) who were selected according to their responsibility in the agricultural, livestock, fish farming and water and forestry sectors.

Sampling. In order to ensure better participation of all social strata in each village, the gender approach was used by interviewing women separately and the second group of participants was men. This positive discrimination is also justified by the fact that it is the women who are mainly responsible for gathering forest products (leaves, fruit, wood, roots) in order to satisfy the family's vital needs and create additional income. In order to have a good perspective over time, the proportion of elderly people will be high (Mamadou, 2006) while taking into account the seniority in the site. The determination of the sample size per camp (village) was based on the number of agricultural, grazing, timber and fishing households around Lagdo Lake. For this purpose, the sample size was determined by the probabilistic method of Schwartz (1995) which is expressed by the formula:

$$X = \frac{Z\alpha^2 \times P(1-P)}{i^2}$$

X = the sample size; Zα = the reduced deviation corresponding to a 95% sampling rate. This value is 1,96; P = n/N with P = proportion of farm households in the two Councils considered with n = total number of farm households in the sampled villages and N = total number of households in the two Councils; i = desired precision equal to 5%.

RESULTS AND DISCUSSION

Mapping. The landscape around the lake in 1973, 2000 and 2020 was occupied by various land use units. In total, six (06) land use categories were mapped in figure 2. These are: built-up areas (white colour), mosaics of bare soil and farms (purple colour), tree savannahs (dark green colour), shrubby savannahs (light green colour), happy savannahs (yellow colour) and water surfaces (blue colour). The areas of these different land use classes are summarised in table 1.

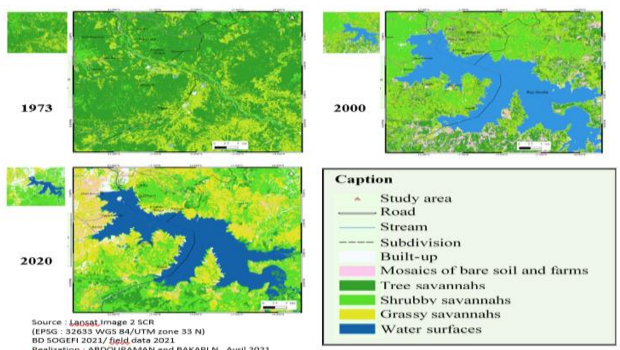


Figure 2. Land use maps for 1973, 2000 and 2020

Land use dynamics around Lagdo Lake

Analysis of the states of land use around the lake in 1973, 2000 and 2020

The analysis of figure 2 and table 1 enables to apprehend that the physiognomy around the lake in 1973 was considerably dominated by the wooded savannahs which cover 618506.69 ha corresponding to a proportion of 67.86%, followed by the grassy savannahs which covered 157972.44 ha (17.33%) and the wooded savannahs of 111021.29 ha (12.18%). Of the remaining 23951.44 ha (2.62%) of the other land use categories, water surfaces covered only 109.30 ha or 0.01%. In 2000, shrubby savannahs dominated the area around the lake with 520496.44 ha, i.e. 57.11% of the total area. Next in terms of surface area were tree savannahs with 171991.04 ha (18.87%), grassy savannahs with 110444.78 ha (12.12%), water surfaces with 62337.03 ha (6.84%), mosaics of bare soil and farms with 4332.23 ha (4.82%), and finally built-up areas with 2250.34 ha (0.24%). In 2020, land use is largely dominated by grassy savannahs and mosaics of bare soil and farms, which cover 325647.79 ha (35.73%) and 281397.39 ha (30.87%) respectively. The surprising progression of grassy savannahs, especially built-up areas and mosaics of bare soil and farms observed during these two (02) periods (1973-2000 and 2000-2020) to the detriment of natural formations can be explained by the progressive dynamics of the population and the new needs in terms of provision of space for agro-pastoral, fishing and energy activities (essentially firewood, service wood, timber and coal). Indeed, all these activities increase the degradation of the vegetation cover observed in recent years around the lake. This analysis is supported by Jiagho (2018) who showed that current trends in land and vegetation cover degradation in the Sudano-Sahelian zone of Cameroon are largely linked to the expansion of subsistence activities (agriculture and energy) and are therefore strongly correlated with demographic patterns.

Table 1. Land areas in hectares and percentage of land use units

Land use units	Land area in 1973		Land area in 2000		Land area in 2020	
	ha	%	ha	%	ha	%
TS	618506.69	67.86	17199.04	18.87	106674.94	11.70
SS	111021.29	12.18	520496.44	57.11	146528.04	16.07
GH	157972.44	17.33	110444.78	12.12	325647.79	35.73
MBSF	22952.41	2.52	43932.23	4.82	281397.39	30.87
BA	889.73	0.09	2250.34	0.24	2982.57	0.33
WS	109.30	0.01	62337.03	6.84	48221.13	5.29
Total	911451.86	100	911451.86	100	911451.86	100

TS: Tree Savannahs; SS: Shrub Savannahs; GS: Grass Savannahs; MBSF: Mosaics of bare soil and farms; BA: Built-up areas; WS: Water surfaces.

Variation in rates of change of land use units around the lake from 1973, 2000 and 2020. Table 2 presents the rates of change by land use units and time period. The analysis of this table shows that shrub savannahs have mostly regressed during both periods, with a higher rate of regression during the 1973-2000 period than during the 2000-2020 period. In fact, these plant formations regressed annually by -0.23% during the period 1973-2000 and by -2.33% during the period 2000-2020. The same situation is also observed in the tree savannahs. The water surfaces increased by 56932.96% (evolution rate) during the period 1973-2000 and an alarming regression during the period 2000-2020 with an annual decrease rate of -0.47%. However, at the level of grassy savannahs the annual rate of regression is lower during the period 1973-2000 (-0.49%) than during the period 2000-2020 (1.99%). Bare soil and farm mosaics are the only formations that have gradually increased from 1973 to 2020 with an annual expansion rate of 0.88% in 1973-2000 and 3.41% in 2000-2020. While the built-up area grew more strongly in the 1973-2000 period (1.26%) than in the 2000-2020 period. This trend is consistent with the findings of Ruelland *et al.* (2010), who observed an increase in the agricultural area in the Sudano-Sahelian zone of Mali. This dynamic is the consequence of a strong mutation of the areas of natural formation in pasture and cultivation of different speculations such as: maize, rice, groundnut, cowpea, millet, sesame and cotton without forgetting the market gardening on both sides of the lake.

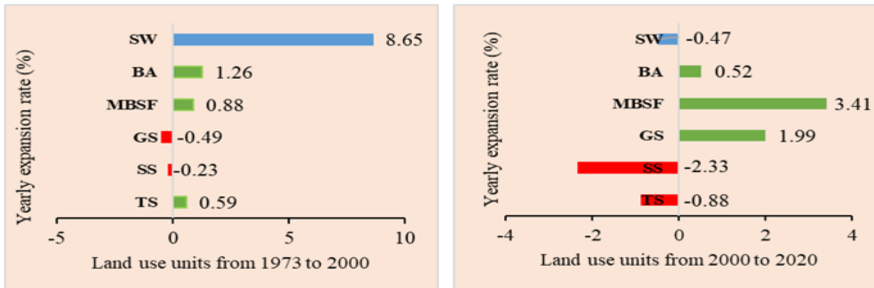
Table 2. Rate of change of tenure units between 1973-2000 and 2000-2020

Land use units	Land area 1973	Land area 2000	Land area 2020	Evolution rate (1973-2000)	Evolution rate (2000-2020)	yearly expansion rate (1973-2000)	Yearly expansion rate (2000-2020)
	ha	ha	ha	%	%	%	%
TS	111021.29	171991.04	106674.94	54.92	-37.98	0.59	-0.88
SS	618506.69	520496.44	146528.04	-15.85	-71.85	-0.23	-2.33
GS	157972.44	110444.78	325647.79	-30.09	194.85	-0.49	1.99
MBSF	22952.41	43932.23	281397.39	91.40	540.53	0.88	3.41
BA	889.73	2250.34	2982.57	152.92	32.54	1.26	0.52
WS	109.30	62337.03	48221.13	56932.96	-22.64	8.65	-0.47
Total	**911451.86**	**911451.86**	**911451.86**				

TS: Tree Savannahs; SS: Shrub Savannahs; GS: Grass Savannahs; MBSF: Mosaics of bare soil and farms; BA: Built-up areas; WS: Water surfaces.

Impacts of land use change on the silting of Lagdo Lake

From the analysis of the results of the comparison between the evolution of the vegetation formations (shrub savannahs and tree savannahs) and that of the water surfaces, it results a particularly high correlation between the silting of the lake and the degradation of the cover around the said lake. In fact, shrub savannahs and water surfaces experienced an increase during the period 1973-2000 with an annual expansion rate of 0.59% and 8.65% respectively, whereas they underwent an unprecedented regression with an annual expansion rate of -0.88 and -0.47 respectively between the period 2000 and 2020 (Figure 3). Physiognomically, parts of the wetland that were covered by vegetation in 1973 are in 2020 covered by buildings and mosaics of bare soil and farms. As a result, the sandy outcrops that are linked to the degradation of the vegetation cover are easily observed by a layer of sand at the edges and in some places of the lake in recent years. In view of these results, a possible explanation for this phenomenon could be that the water flowing between the furrows of the newly cultivated fields at the edge of the lake picks up the sand and deposits it in the lake. In addition to this failure, logging is a source of silting of the lake because the need for wood for energy causes land clearing that exceeds regeneration and reforestation, without forgetting the installations of fishing camps around the lake. These results corroborate the conclusions of a large part of the field observations and survey data which establish a link between the regressive dynamics of the vegetation around the lake and the silting up of the lake. In short, one of the most important factors affecting the depth and surface area of the lake is land use. As a result, the banks of the lake are subject to strong surface erosion, which promotes sedimentation and silting of the lake (Figure 4). This observation may support the hypothesis that the riparian forest not only plays an anti-erosion role, but also a sediment trap role by which it limits the filling and silting of the deep parts of the water bodies (Roche International, 2000b).



TS: Tree Savannahs; SS: Shrub Savannahs; GS: Grass Savannahs; MBSF: Mosaics of bare soil and farms; BA: Built-up areas; WS: Water surfaces.

Figure 3. Summary of the conversion of plant formations between 1973 and 2020

Moreover, even the study of the evaluation of the sedimentation of Lagdo Lake and determination of the frequency of cleaning (MEADEN, 2004) showed a clear tendency for the bottom of the said lake to rise: + 1.97 m in 20 years, which corresponds to a rate of silting up of the order of 10 cm. year -1. However, the degradation of the vegetation cover around Lagdo Lake is mainly due to socio-economic (anthropic) factors, figure 4.

Figure 4. Sand layer of the May-Zamba bank.

Local perception of the factors causing the degradation of the vegetation cover around Lagdo Lake

Table 2 shows the factors that are causing the degradation of the vegetation cover around Lagdo Lake. The analysis of variation indicates a significant difference (P<0.05) between the factors of vegetation cover degradation. The analysis of this table shows that in all the villages surveyed, agriculture is the main source of income around the lake. Given the size of the population, which is increasing overnight, cultivation requires the advancement of the agricultural front. This activity (20±11.24%) is one of the main causes of the degradation of the vegetation cover and the reduction of the lake area (Figure 5A). The second most important cause is fishing activity (17.25±10.03%), followed by wood cutting (17±8.80%) (Figure 5B) and demographic pressure (17±8.23%). Other factors such as livestock (pastoralism and transhumance) (9.50±3.29%), Vegetation slash and burn (8.65±9.51%) and poorly controlled urbanisation (5.10±5.78%) come last. However, the potential of these factors varies from one village to another. These results are in agreement with those acquired by MEADEN (2024) which places in first place agriculture as the main factor of deforestation around this lake because of its quest for space leading to the sacrifice of natural formations. For example, Badahoui *et al.* (2010) on the degradation of Lake Ahémé in Benin have shown in their work that the main factors of degradation of the banks of the lake are essentially the agricultural practice and the deforestation of the banks.

Table 3. Percentage of respondents (%) according to the factors of vegetation cover degradation around Lagdo Lake

Degradation factors	Eastern villages to the Lake					Western villages to the Lake					Average/satandard deviation
	Bas	Ben	Fir	Dok	C-Es	Yag	Bad	Bou	O-Tc	O-Ke	
Livestock	2.50	5	2.50	5	0	15	21.50	7.50	0	27.50	9.50±3.29^{b}
Fishing	10	12.50	7.50	10	5	7,5	15	12.50	5	10	17.25±10.03^{c}
Vegetation fires	15	17.50	20	25	27.50	5	0	20	25	15	8.65±9.51^{b}
Wood cutting	25	15	25	30	22.50	2,5	27.50	5	12.50	7.50	17±8.23^{c}
Agriculture	22.50	25	7.50	12.50	17.50	32,5	0	37.50	25	20	20±11.24^{c}
Urbanisation	2.50	5	0	0	5	10	18.50	2.50	0	7.50	5.10±5.78a^{b}
Demography	20	15	32.50	15	15	22,5	5	12.50	25	7.50	17±8.23^{c}
P											0

Figures with the same letter (a) are not significantly different at the 5% threshold; Bas: Bassoro; Ben: Bengui; Fir: Firabaka; Dok: Doka I and II; C-Es: Col-Est; Yag: Yagadi; Bad: Badjaoulé; Bou: Boulel; O-Tc: Ouro-Tchaïdo; O-Ke: Ouro-Kessoum.

Figure 5A. Cleared farms next to the lake in Bengui camp.

Figure 5B. Fuelwood in a transport car in Djippordé.

CONCLUSION

The study area has undergone advanced spatio-temporal change over the period from 1973 to 2020. Vegetation cover degradation is more insistent during the period 2000-2020 than the period 1973-2000. This spatio-temporal dynamics of the landscape around Lagdo Lake can be explained mostly by anthropogenic activities as well. The modification of this vegetation is due to anthropic pressures linked to agricultural activities, fishing, pastoralism, the practice of bush fires and poorly controlled urbanisation. The knowledge of this dynamics allows to predict the future and to propose forms of development and sustainable territorial management not only of the lake, but also its surroundings and its natural resources for the well-being of the population of the great north in general and that of Lagdo in particular.

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