Original Research Article

Spatial and temporal evolution of the occupation of the water body of Lake Dang in the Sudano-Guinean savannahs of Ngaoundéré, Cameroon

Abstract

Very little information exist on lake environment in Northern Cameroon. The objective of this study is to determine the colonisation plant of Lake Dang using field and remote sensing data from LM, Landsat5, Landsat7 and Landsat8 images, over a 45-year period (1975-2020), spaced 15 years apart (1975; 1990; 2005; 2020). The method of diachronic analysis of satellite data was used and the supervised classification approach based on colour compositions and bands were chosen for class discrimination. The overall accuracies obtained ranged from 96.35 to 89.28%, followed by Kappa indices of 74.43 to 90.18% for the years 1975 and 2020 respectively. The results on the spatio-temporal dynamics of water bodies from 1975 to 2020 show an average annual rate of regression of the water surface of -1.35%/year, i.e. 0.099 km^2/year, in favour of vegetation. The period from 1987 to 2002 shows a more marked evolution, with a rate of plant colonisation of 1.98%/year, i.e. 0.145 km^2/year, compared to the periods from 1975 to 1990 (rate of plant colonisation of 0.85%/year, i.e. 0.062 km^2/year) and 2005-2020 (1.23%/year, i.e. 0.090 km^2/year). Today, 73% (5.376 km^2) of the total surface area (7.365 km^2) of the water body is colonised by vegetation. Moreover, bathymetry shows a maximum depth of 2.70 to 2.80m, which is discriminating for a lake ecosystem in the Sudano-Guinean zone. Consequently, the preliminary results of this study shows that Lake Dang is marked by a strong eutrophication due to anthropic activities caused by agriculture, urbanization and non-rational deforestation which have strongly affected the occupation of the lake banks.

Keywords: Remote sensing, Plant colonisation, Anthropic activities, Lake Dang; Ngaoundéré-Cameroon

Introduction

Climate change and anthropogenic activities are the main pressures leading to the degradation of terrestrial ecosystems, especially fragile aquatic ecosystems such as those in Cameroon. This degradation manifests itself through habitat fragmentation, biodiversity erosion, invasive alien plant species, pollution and declining soil fertility [1;2]. Like most aquatic ecosystems, rich and diverse lake environments with widely recognized key ecosystem functions and services [3; 4; 5] are now also threatened by climate change [6; 7; 8] and human activities [9], mainly agriculture and fishing. In fact, their numbers have been declining sharply at the global level for several decades [10]. The current influence and evolution of lake environments due to anthropogenic activities currently represent a major environmental issue, both in terms of water resources [11] and biodiversity [12] or the atmosphere. The growth of water hyacinths often reaches alarming infestation proportions due to eutrophication, especially in shallow lakes subject to multiple anthropogenic activities. Like most lake environments, Lake Dang, located in the district of Ngaoundéré III, is threatened by anthropogenic activities that lead to environmental, socio-economic and health problems in the locality [13]. Indeed, anthropic activities combined with soil erosion of the banks are currently contributing to silting and the decrease in the depth and surface area of Lake Dang, thus accelerating eutrophication [14]. The physico-chemical quality shows high concentrations of organic matter (9.30 to 10.56 mgO2/L), iron (1.69 to 5.57 mg/L), phosphates (1.73 to 3.09 mg/L), ammonium (1.78 to 2.19 mg/L) and a turbidity of 63.32 to 64.05 NTU [14]. Anthropogenic activities remains the major source of pollutant releases such as heavy metals. farming practices and climate are transforming the shepherds of Lake Dang [13]. However, despite the consistency of the literature, no author reports on the dynamics of the occupation of the water body of Lake Dang. This work proposes to study the spatio-temporal dynamics of the occupation of the water body of Lake of Dang and to apprehend the influence of this occupation on the bathymetry. Thus, the objective is to show the spatio-temporal dynamics of the occupation of the water body and to highlight the bathymetry.

Materials and methods

Study site

The study took place in the locality of Dang (Figure 1), located 15 km north of the city of Ngaoundéré, capital of the Adamaoua region, on the national road N°1 towards Garoua, in the district commune of Ngaoundéré IIIème. This locality is located at 7°25'29" north latitude, 13°32'54" east longitude, and at 1072m altitude. Its climate is Sudano-Guinean type, mild and cool, with two seasons: a dry season from November/December to March/April, and a rainy season extending over the rest of the year. The average annual rainfall is 1500 mm, with a coefficient of variation of 9.8%. The average annual temperature is 22.5°C and relative humidity 67%. The aridity of the region is due to the influence of the Harmattan (dry wind), which recalls the dry climate of the Sudano-Sahelian savannahs, while its rainfall and thermal amplitudes remindes of the humid climate of the sub-equatorial region. The soils of this locality are of the ferralitic type, reddish-brown in colour, developed on volcanic rocks. The vegetation of this locality is made up of humid savannahs, including wooded and shrubby savannahs, dominated by *Daniellia oliveri* and *Lophira lanceolata*. There are also hydromorphic meadows, which are occasionally flooded and consist of *Hypparhenia rufa*, and forest galleries with *Syzygium guineense* var. *guineense* and *Berlinia grandifolia*. In some parts of the lake, Nymphaeaceae dominate the vegetation, followed by Cyperaceae, Poaceae and Dioscoriaceae [15]. Agricultural activities are very important and remain traditional, and livestock farming is the main economic activity of the region. The locality is irrigated by an important hydrographic network made up of numerous Mayo, whose main rivers are the Bini, Tibaka, Margol [16]. There are also four lakes: Lake Bini, Lake Dang, quarry lakes (Beka Tinguereng and Naboune lakes) and volcanic lakes (Tison and Mbalang lakes). There is a major problem of bank erosion and silting due to deforestation and overexploitation of forest galleries [15].

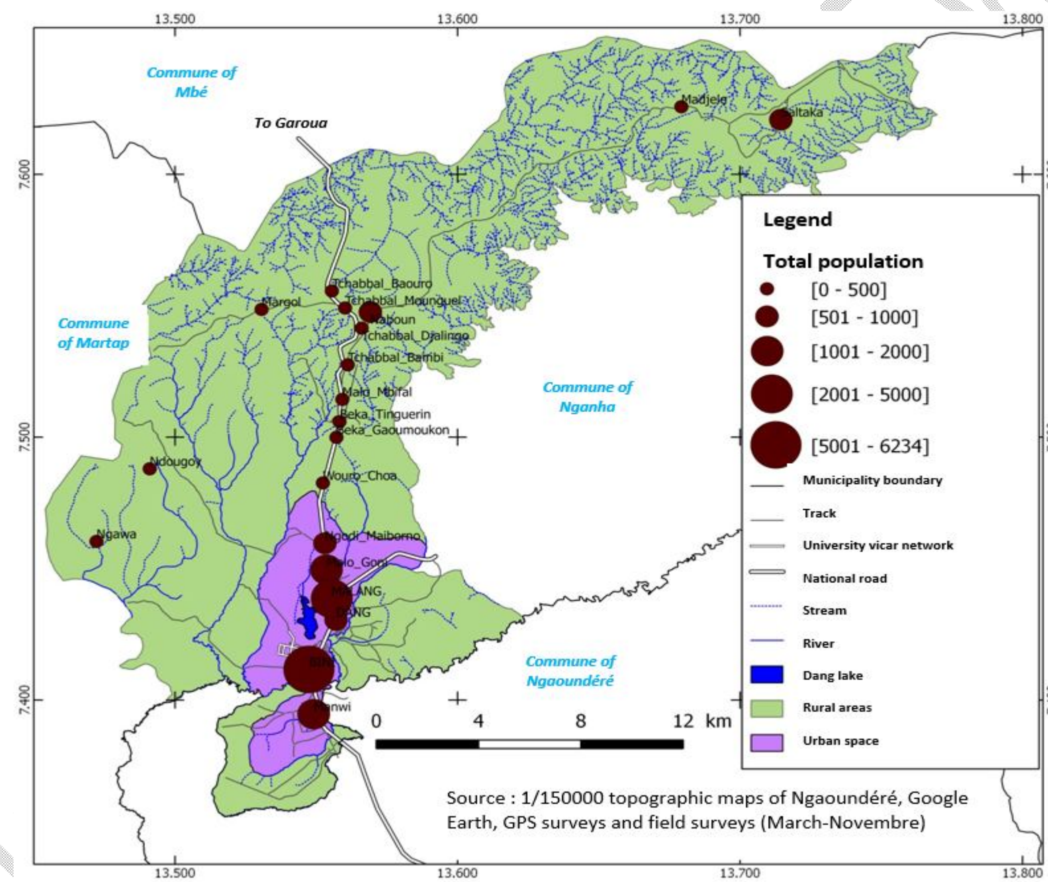

Figure 1: Location Map of the Study Area

II.2.2 Hydrography

Ngaoundere III is watered by an important hydrographic network running through the whole territory, and which is made up of many mayo. The main rivers are the Bini, Tibaka, Margol. We also note the presence of four lakes: Lake Bini, Lake Dang and lakes arising from the quarries of Béka Tinguereng and Naboune and several seasonal ponds. In addition, a long volcanic history has left behind crater lakes in the region, the best known of which are Tison and Mbalang lakes near Ngaoundere. Despite the strategic importance of the water sources of this plateau, there are significant problems of bank erosion and silting due to deforestation and overexploitation of forest galleries [15].

Methodology

Water body dynamics

We used satellite imagery from LM 1975, Landsat5 1990, Landsat7 2005 and Landsat8 respectively for the years 1975, 1990, 2005 and 2020, all with 20m resolution and six bands. The four scenes used are centred on the locality of Dang and have an interval of 15 years. The colour composition resulting from the combination of channels 4-3-7 was chosen for the LM image and the combinations of bands 3-2-1 for ETM+ gave the maximum information. The classification was carried out on Lake Dang and two classes were selected. These are water and vegetation. Then, the supervised classification was used with the help of cartographic data (land use, topography, etc.) at a scale of 1/100 000. It consists in assigning pixels to the nearest samples, according to a so-called Bayesian distance based on the probability that a pixel belongs to a given class [17]. The latter is widely used in supervised classifications and is considered to be the most efficient in the production of thematic maps in the field of land cover [17]. The accuracy of the land cover classification performed, based on data from 1975; 1990; 2005 and 2020, was measured using the confusion matrix and the Kappa index. The Kappa index was used to determine the accuracy of the adopted classification and to validate and estimate the accuracy in the vegetation classification scheme [18]. It is written as follows: K = (Po-Pa) / 1-Pa, where Po is the actual percentage obtained from the classification of land cover elements and Pa is the estimate of the probability of obtaining a correct classification. After analyses and comparisons of the data obtained from each interpreted image, the annual rate of each unit of land cover for the water body is calculated according to the following formula [19]: Annual T = **ViY- ViX/100*P**, where ViY is the value of stratum i for a year Y, ViX is the value of stratum i for a year X and finally P is the length of the observation period between years Y and X, which is 15 years.

Bathymetry

The bathymetry was carried out using an *in-situ* depth record at 50 m intervals using a graduated stick and following the longitudinal axes from the north shore to the south shore and from the east shore to the west shore [15]. This operation was then repeated along the diagonal axes from the northwest shore to the southeast shore and from the southwest shore to the northeast shore. During this operation, the coordinates of all these points were meticulously noted and then recorded in the Argis software.

Results

Evaluation of the accuracy of the classification

Table 1 presents the confusion matrix of the classification of the four LM, Landsat5, Landsat7 and Landsat8 images. The analysis shows that two classes of water body occupancy have been identified: water and vegetation. The four images show good overall accuracy for the entire study area. At the level of different years and classes, the accuracy is variable. From all the four images (1975, 1990, 2005 and 2020), water has higher accuracies than vegetation. The image for the year 1975 has the highest confusion for vegetation, 27.67%, compared to confusion values for images from other years, which are 15.38%; 13.88%; and 12% for images from the years 1990, 2005 and 2020 respectively. These decreasing percentages of confusion in the chronological order of the images may be due to the earliness and dispersed nature of the vegetation that abounds in the water body.

Table 1: Confusion matrix for Landsat TM and ETM+ image classification

Class	**1975**		**1990**		**2005**		**2020**	
	Water	**Vegetation**	**Water**	**Vegetation**	**Water**	**Vegetation**	**Water**	**Vegetation**
Water (%)	76,53	27,67	88,47	15,38	90,82	13,88	91,36	12
Vegetation (%)	23,47	72,33	11,53	84,62	9,18	86,12	8,64	88
Total (%)	100	100	100	100	100	100	100	100
Kappa (K)	74,43		86,54		88,47		90 ,18	
Overall accuracy	96,35		92,14		89,94		89,28	

Dynamics of the occupation of Lake Dang

The various maps drawn up cover the whole of Lake Dang and make it possible to apprehend the evolution of the water body of this ecosystem over the last forty-five years (1975 to 2020) at intervals of 15 years. It can be seen that in the space of 45 years, the changes in the occupation of the water body are quite clear and are reflected in a qualitative and quantitative way by the changes in the geographical space and by the decrease in its surface area. A review of Figure 2 and the associated maps (Figures 3, 4, 5 and 6) provides a good indication of the overall occupancy of the water body over time. For example, the lake is being colonized by vegetation at the expense of water. This colonization increased from 12% in 1975 to 73% in 2020, i.e. 61% of the water body invaded by vegetation. The surface area of the vegetation cover has been multiplied by more than five times in the space of 45 years.

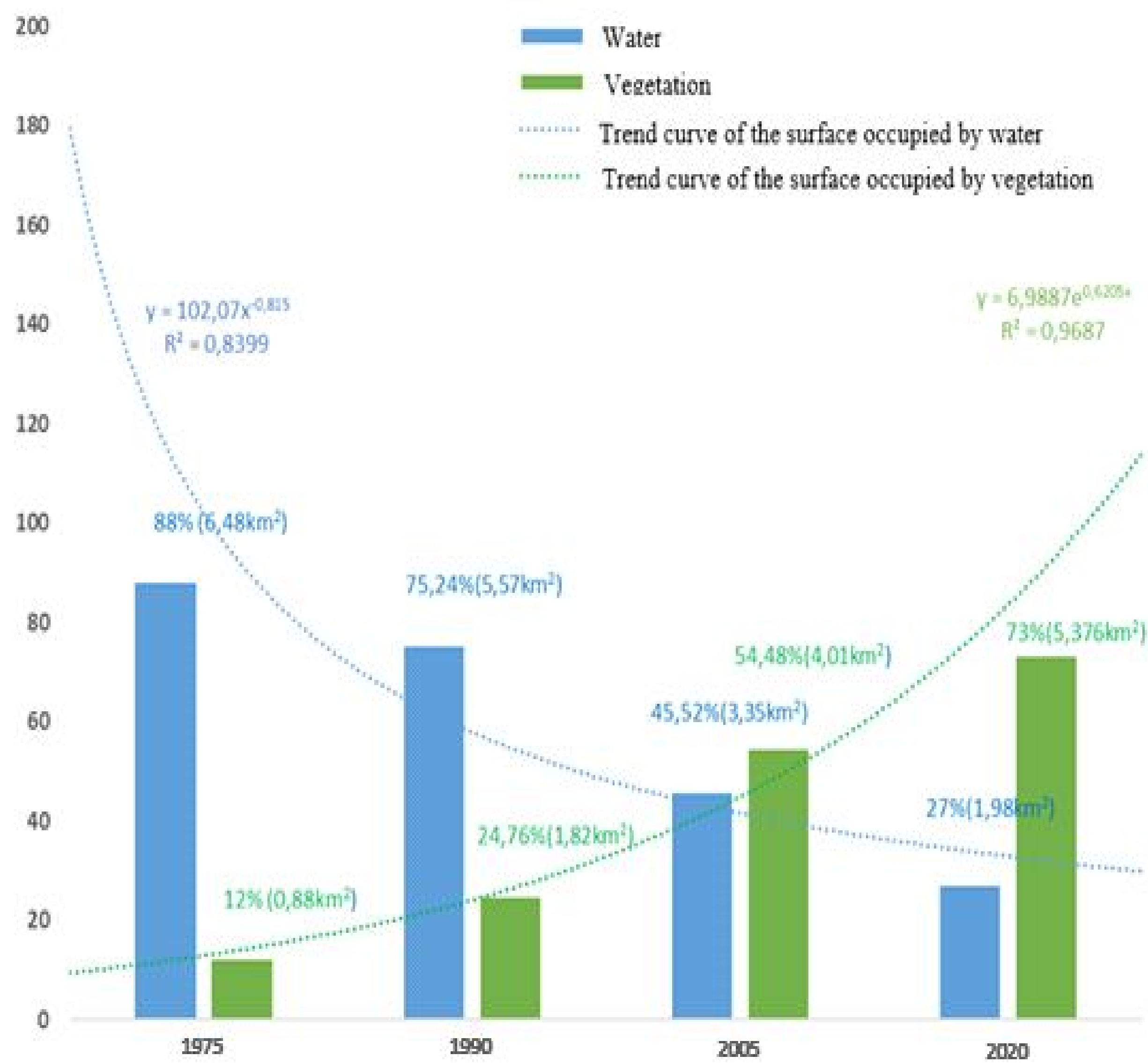

Figure 2: Occupancy of the water body

According to the sequence of 15-year intervals, it can be seen that the second period (1990-2005) shows more pronounced lake dynamics leading to a balance in the areas occupied by water and plants (Figures 2 and 5). This period is preceded by the period (1975-1990) of domination of the water body to the detriment of vegetation (Figures 2, 3 and 4), i.e. 75.24% for the water against 24.76% for vegetation and followed by the period (2005-2020) of lake invasion by (Figures 2 and 6) vegetation, i.e. 54.48% for vegetation against 45.52% for the water body.

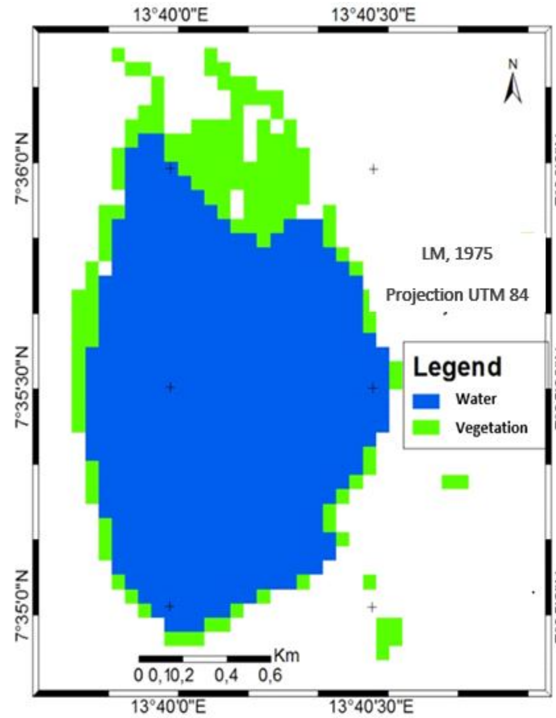

Figure 3: Image of the 1975 Supervised Classification

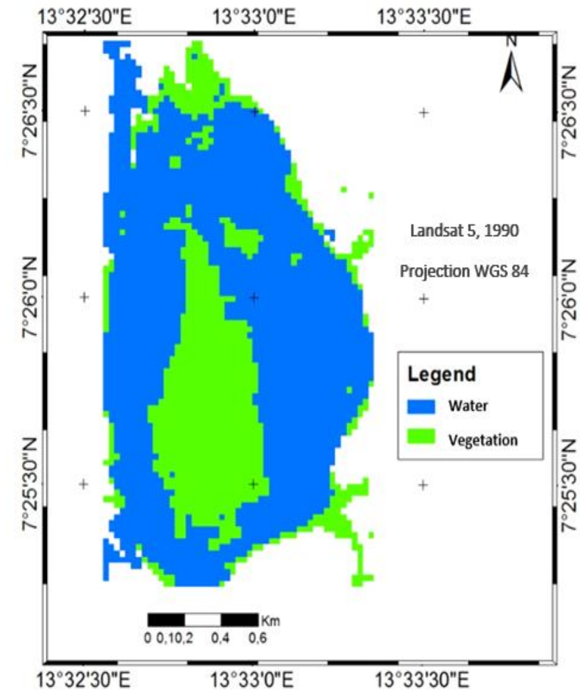

Figure 4: Image of 1990 Supervised Classification

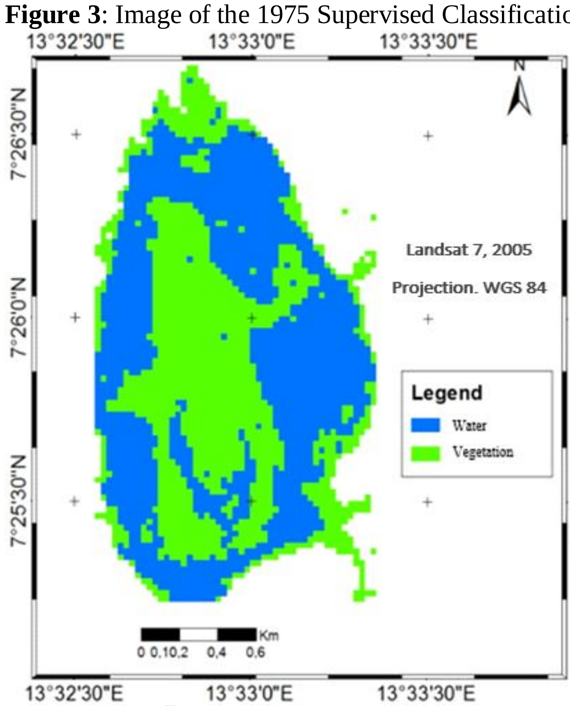

Figure 5: Image of the 2005 Supervised Classification

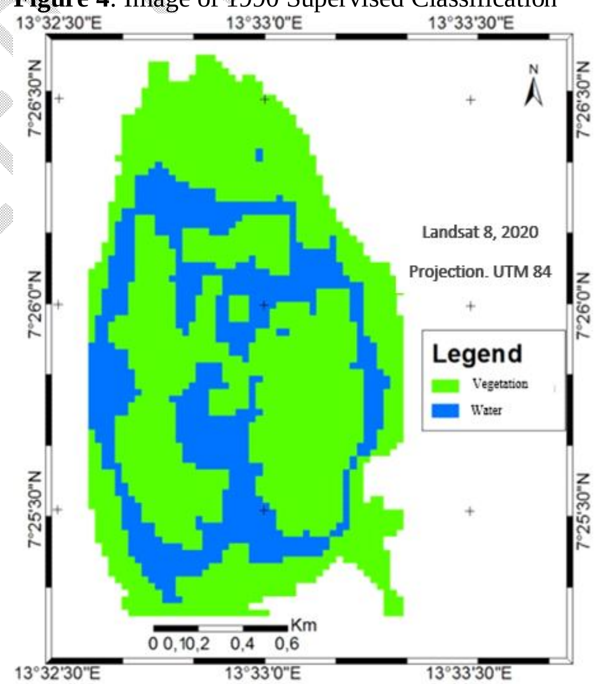

Figure 6: Image of the supervised classification of 2020

The dynamics of the water body of Lake Dang present an antagonism within the two classes of water surface and vegetation (Figure 7). The rate of vegetation colonization of the lake is positive and is determined by the following trend equation: $Y_1 = -0.94x2 + 3.95x - 2.16$, while the rate of decrease of the open water body is negative and is determined by the following trend equation: $Y_2 = 0.94x2 - 3.95x + 2.16$. The dynamics of the water body of Lake Dang is antagonistic within the two classes of water surface and vegetation (Figure 7). The second 15-year period (1990-2005) is the period of equilibrium between the invasion of the lake by vegetation and the regression of the unoccupied water surface, where the speed of this colonization of the lake reaches its optimum and that of the decrease of the open water surface reaches its minimum, i.e. 1.98 and -1.98%/year for vegetation and water respectively. This period is preceded by the period (1975-1990) when the velocities of the vegetation and water dynamics are minima, i.e. 0.85%/year and -0.85%/year respectively. It is followed by the period (2005-2020) where this speed is intermediate, i.e. 1.23 and -1.23%/year.

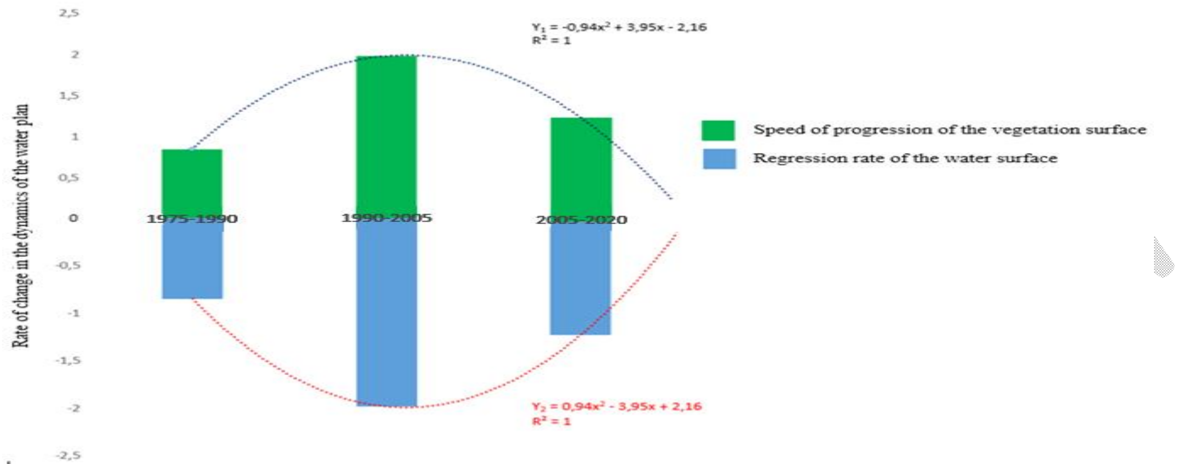

Figure 7: Evaluation of the dynamics on the occupation of the water body

Bathymetry of Lake Dang

The depth of Lake Dang varies according to the density of the colour of the dots (Figure 8). In general, the center of the lake is deeper than the peripheries. The deepest point is about 2.80m and is located a little further north of the center. However, the southern part of the lake is shallower (0.50 to 0.60 m) and more muddy. It is followed by the western part of the lake.

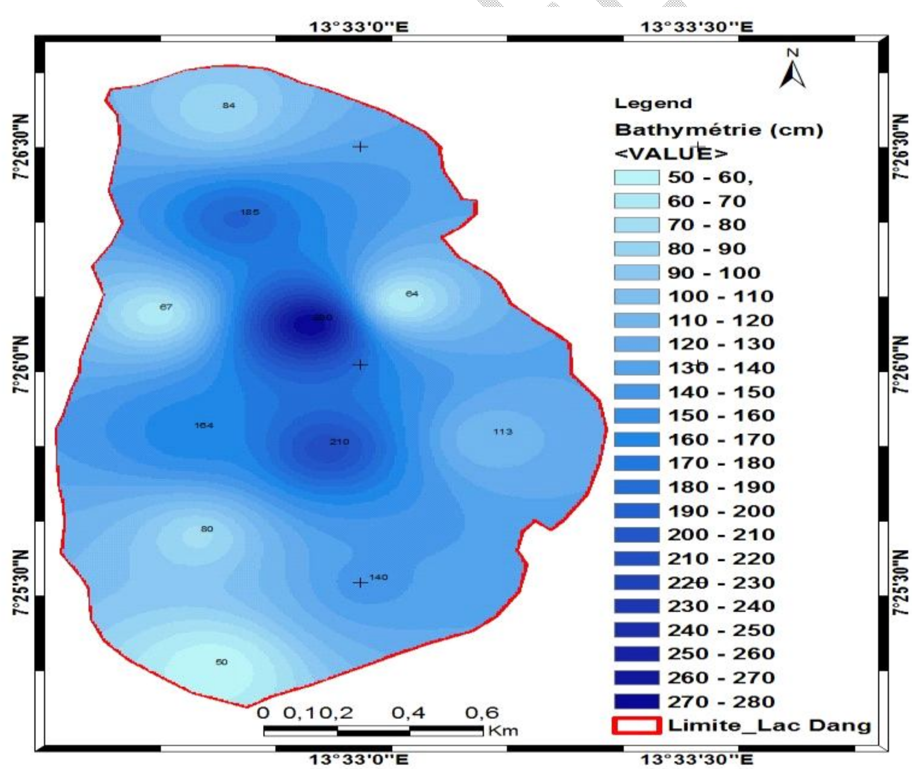

Figure 8: Bathymetry of Lake Dang

Discussion

The classification of water body occupancy resulting from the analysis of LM, Landsat5, Landsat7 and Landsat8 images gave an overall accuracy of 96.35%; 92.14%; 89.94% and 89.28% respectively, followed by Kappa indices of 74.43%, 86.54%; 88.47% and 90.18% respectively for the years 1975, 1990, 2005 and 2020. Since these Kappa index values are above 50%, it can be concluded that the results of this analysis are statistically good and usable [19]. Therefore, the present classification with two classes is acceptable and allows to assess the trend of changes in water body occupancy over a 45-year period. On the other hand, the water classes for the various years show some errors of confusion with respect to the water class. The difficulty in visually discriminating these classes may be due to spectral signatures of the chlorophyll in the water. This explains why some parts of the water surface are confused with vegetation. Apart from the 27.67% confusion between water and vegetation in the 1975 LM image, no other error exceeds 16%. These errors are therefore acceptable as long as none of these errors is greater than 70%, which is the limit value [19]. In all, the values of the different precision indicators of the supervised classification analysed for the different images reflect, on one hand, the good quality of the samples and, on the other hand, the good correspondence between the result of the classification and the spatial reality contained in these images. The analysis of the dynamics of the occupation of the water body between 1975 and 2020 shows that the water surface is significantly receding, compared to that occupied by vegetation, which is clearly increasing. tt of market gardening types has developed at an accelerated pace over the years through intense and artisanal irrigation [14], which uses large areas of land. In addition, the university campus set up in 1982 near the lake discharges a large part of its waste into the lake by drainage.

The average annual rates of change for water and vegetation, calculated after 45 years, are -1.35% and +1.35% for water and vegetation respectively. However, it is during the period from 1990 to 2005 that the rates of colonisation of the water body by vegetation and the decrease in the open water surface are highest in absolute value. This acceleration in the rate of vegetation colonization during this period (1990 to 2005) is partly due to climate variability and population growth, which has led to a rapid increase in urbanization and anthropogenic activities around the lake, such as agriculture, over-exploitation of shoreline timber and the discharge of wastewater, solid soil materials, etc. [21; 22]. This has led to the acceleration of the eutrophication process of Lake Dang. The reduction of the open water body seems to be related to the climatic variability that manifested itself directly in the area of irrigable land. Indeed, this lake initially covered an estimated surface area of 7365 km2 with a drainage coefficient of 3.00. The lake is now a large open water body. The regression of the open water surface area by about 61% (4492.65 km) would be attributable to the strong evaporation that takes place on the surface conquered by plants [23].

The deepest point of Dang Lake is about 2.80m and is located a little further north of the center. On the other hand, the shallowest and most muddy part is located south of the lake. These results differ from those of Daïwe and Ngounou Ngatcha, who observed 2006 a maximum depth of about 2.50 m for this lake. This can be explained by the fact that the latter only took into account the median axes, yet the phenomenon of silting and eutrophication continues to occur in places and in an uneven manner. The magnitude of the physiochemical parameter was not addressed in this study. However, bathymetry was carried out and it shows a strong anthropisation due to silting and degradation of the water retention capacity within the basin. Indeed, changes in bathymetry affecting both plant and animal populations in a given basin, whether anthropogenic or natural in origin [24; 15]. In this case, the lake develops a low retention capacity as a result of its reduced depth. As a result, surface runoff is important and water erosion phenomena will tend to develop. A similar evolution has been observed in the figure watershed in northern Côte d'Ivoire. Consequently, the degradation of lake ecosystems has a more or less direct influence on the relationship between the ecosystem and economic services generated. Anthropic activities significantly and visibly impair the physiochemical qualities of surface waters [26]. The degradation of freshwater reservoirs directly influences the socio-economic activities around and within the site [25]. There is general evidence that the silting and shrinking of Lake Chad has considerable negative impacts on the social and economic activities of more than 20 million people, as bathymetry affects the nature of the biodiversity that can populate a lake and the activities that can be carried out there.

Conclusion

Freshwater lakes are rich and diverse environments with multiple functions and values that are now widely recognized and deserve protection. Although their delimitation is now operational, the evaluation of their spatio-temporal dynamics has only been carried out on a minority of them, thus hindering their management. The method of supervised classification has made it possible to discriminate between two classes of occupation of Lake Dang, namely water and vegetation. The overall accuracies obtained vary from 88.47% in 1986 to 90.46% in 2005. The

Kappa index of the confusion matrix is 85.84% for 1990 and 88% for 2005. The maps drawn up for the last forty-five years have made it possible to identify a spatio-temporal evolution on the occupation of the open water of the lake under study. This evolution shows an average annual rate of regression of the water surface of 1.35%/year (or a speed of 0.099 km2/year) in favour of that of plant colonization, which is 1.35%/year (or a speed of 0.099 km2/year). The period from 1990 to 2005 is the one where plant colonization of the open water body experienced a maximum acceleration, with a rate of 1.98%/year or a speed of 0.145km2/year, compared to the periods from 2005-2020 (plant colonization rate of 1.23%/year, i.e. a speed of 0.090km^2/year) and from 1975-1990 (plant colonization rate of 0.85%/year, i.e. a speed of 0.062km^2/year). Finally, the maximum depth of the lake varies between 2.70 and 2.80 m and remains low. The evolution of the open water body and the depth of Lake Dang are the direct consequences of the climatic variability and indirect consequences of the demographic growth of the locality of Dang, in particular the establishment of the University of Ngaoundere since 1982 has led to an increase in the population of Dang by more than 10 times. This study also shows the importance of remote sensing in the study of the dynamics of lake ecosystems and finally to set up a sustainable management plan for these ecosystems, especially those of fragile areas such as that of the locality of Dang Cameroon.

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