FEASIBILITY STUDY FOR THE ANALYSIS OF ANNUAL AND INTER-ANNUAL EVOLUTION (1998 – 2009) OF LAKE CHAD WITH SPOT-VEGETATION IMAGES

Remote sensing SPOT-VEGETATION satellite images for the period of 1998-2009.

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ABSTRACT

The European Commission Joint Research Centre (JRC-IES) and the Universidad de Sevilla (US) have conducted a feasibility study with satellite data to monitor the evolution of environmental conditions in Lake Chad using water surface area and aquatic vegetation as indicators. This study was carried out using a multi-temporal SPOT – VEGETATION satellite image series for the period 1998-2009.

It was proved that in opposition to the strong tendency of the water surface to shrink in the last 50 years, the water surface has reached equilibrium in the last decade with slight and exceptional grown periods probably due to exceptional climatological conditions.

This work could be considered as a preliminary phase for setting up an acquisition and monitoring system to support local and regional African authorities on Water Management.

INTRODUCTION

Sustainable management of water resources is an ever increasing priority for policy authorities, mainly in regions where there is a supply shortage to satisfy the basic needs of its inhabitants. It is therefore necessary to promote methodologies that allow researchers and managers to survey bodies of water that are threatened due to climate change and high human pressures.

Lake Chad is a body of water with very interesting characteristics to be studied. It is located in an arid transition zone, it has a variable shape and size, and its perimeter crisscrosses four countries: Niger, Nigeria, Cameroon and Chad, where the most part of the water surface of the lake is located (see Figure 1). The poor economic level of its inhabitants make them particularly dependent on water resources from the lake for their fishing, agricultural and other associated economical activities.

The European Commission – Joint Research Centre (JRC) – Institute for Environment and Sustainability (IES) and the Universidad de Seville (Romero-Hernandez et al., 2009) have conducted this feasibility study with satellite data to monitor the evolution of water surface area and aquatic vegetation in the Lake Chad as a measure of the environmental conditions. This study was carried out using a multi-temporal series of monthly NDWI and NDVI SPOT VEGETATION satellite images for the period 1998-2009.

There are numerous studies on the use of satellite images for measuring surface water availability and quality with different applications to assess surface, turbidity and depth depending on the sensor features, bodies of water and aquatic vegetation (see Sawaya, et al., 2003; Bustamente et al., 2005).

Figure 1. location of study area

Source: Esri Maps of the World, Landsat and NDVI Images

The great potential of the Remote Sensing technology makes the development of methodology and data collection source a key project for the institutions in charge of managing natural resources, especially in developing countries (Miahle et al., 2008; Combal et al., 2009) because of the reduced cost of information system, reliability of the results and technological sustainability.

METHODOLOGY

This study aims to assess the accuracy of the Remote Sensing image data necessary to undertake the survey of the water surface and aquatic vegetation evolution in Lake Chad for the period between April 1998 and August 2009, with a 10 day synthesis data based on the daily NDVI Maximum Value Composite images. In this first stage of the project, due to the hue amount of images available (~450 two channel images), the data was resampled to two dates per year during the entire period considered: one image from the rainy season (August 11); and, another from the dry season (January 11). The new set of images was composed of 46 images (23 images from the rainy period and 23 from the dry period each image composed of two channels) that were processed and analyzed.

The images used come from the SPOT-VEGETATION satellite, (Normalised Difference Water Index) NDWI and (Normalised Difference Vegetation Index) NDVI, 1 Km^2 spatial resolution. Taking into consideration that the area of study is around ~1250 Km^2, this resolution was considered appropriated.

NDVI images were classified (supervised classification) to differentiate the two categories: bodies of water and aquatic vegetation, defining spectral patterns for each month of the time series. An automated process was then conducted for classifying each 23 image data set of each period. The parallelepiped and minimum distance method was employed. Same process was also applied to the NDWI image dataset (rainy and dry) seasons, gathering results that supported the definition of relevant data.

In certain images of the year there is not a clear defined boundary of the lake water surface and, hence, it was necessary to rely on the results obtained with the NDWI analysis. In such a case, the boundaries of the lake were derived from visual interpretation. The raster format was converted into vectors, so as to facilitate the editing process and calculation of areas and perimeters.

These first results have been compared with those from a recent study conducted with similar methodologies on the same zone (Taiye, 2005).

From the data process, the following parameters were obtained for each image and period: geometric area, perimeter and distribution of the lake's water surface and aquatic vegetation for the 11 years of the period considered in this study (1998-2009). For the rainy season, a new flooding area category was devised. This category was not identified for the dry season (see Tables 1 and 2)

RESULTS

Table 1. NDVI and NDWI analysis results for the month of January (Dry Season).

JANUARY – DRY SEASON					
	WATER SURFACE		AQUATIC VEGETATION		
YEAR	Surface (Km2)	Perimeter (Km)	Surface (Km2)	Perimeter (Km)	TOTAL AREA
1999	1155,6325	183,8542	12177,7524	1159,7492	13333,3849
2000	1338,8295	279,2574	11840,086	1226,9037	13178,9155
2001	1432,1222	279,6152	10497,4156	1420,7441	11929,5378
2002	1502,3196	499,9352	9446,0687	1422,7024	10948,3883
2003	1632,9192	419,7158	7517,6168	1515,1718	9150,536
2004	1442,5134	358,083	9850,5622	1550,4841	11293,0756
2005	1718,1407	469626	8485,041	1963,0661	10203,1817
2006	1621,2859	510,5329	9388,698	1621,2859	11009,9839
2007	1680,6227	566,9557	7687,8433	1776,6851	9368,466
2008	1582,5849	479,7068	10290,6571	2019,953	11873,242
2009	1628,3974	550,0519	9260,4674	1914,8035	10888,8648

Table 2. NDVI and NDWI analysis results for the month of August (Rainy Season).

AUGUST – RAINY SEASON							
YEAR	WATER SURFACE		AQUATIC VEGETATION		AREA DE INUNDACIÓN		TOTAL AREA
	Surface (Km2)	Perimeter (Km)	Surface (Km2)	Perimeter (Km)	Surface (Km2)	Perimeter (Km)	
1998	1516,866	215,7888	9965,847	1839,437	511,856	344,5046	11994,570
1999	1605,875	264,6427	19583,72	1694,726	2091,400	499,471	23280,999
2000	1670,720	349,3356	11455,46	1689,755	4579,918	349,3356	17706,102
2001	1712,979	307,6758	13634,15	1752,712	4692,967	641,4179	20040,098
2002	1647,517	322,7001	13416,84	1820,649	4961,743	691,1884	20026,108
2003	1782,026	364,2826	13804,00	1717,624	2393,835	573,5515	17979,864
2004	1702,047	404,0045	12042,27	1676,232	3517,898	705,2519	17262,220
2005	1836,342	367,3471	14899,62	1951,940	1883,090	614,8048	18619,061
2006	1986,628	428,8414	13112,99	1851,673	1417,761	415,9954	16517,388
2007	1859,510	346,8156	16471,09	1471,121	1508,552	370,8768	19839,158
2008	1836,554	366,9683	14519,37	2021,803	1547,109	621,2725	17903,033
2009	1872,721	396,3028	14520,67	1981,631	1686,438	567,9504	18079,836

The results of this study were compared to those conducted for the identification of Lake Chad's evolution and dynamics carried out with similar techniques by (Taiye, 2005) even though the two studies only coincide in one year (2001). Taiye, 2005 study was conducted specifically for 1963, 1973, 1987, 1997 and 2001, using Landsat TM images with a 30 m spatial resolution. Results differ in the coinciding year in approximately 3.000 km^2, although it is not specified if the value is the total area of the lake or only the surface water area, but for the dimension, it is believed to be the first.

Contrary to the study by the *Department of Geography of the Nigerian Defense Academy,* official figures produced by the UN Food and Agriculture Organization (FAO), report a lake's surface for 2001 no bigger than 1.500 Km^2. This data is consistent with the results obtained in the present analysis, considering that in the 2001 summer, the water surface was 1.432 Km^2.

The differences between the studies considered here are probably due to the spatial resolution of the images or even the differences between the acquisition dates. Effectively, as it has been shown in this analysis, the lake's dimension, specially the aquatic vegetation, varies considerably between the rainy and dry seasons (around 10%).

Table 1-2 show that the aquatic vegetation during the month of January, 1999, was approximately 12.200 km^2, while during August of the same year the vegetation increased to 19.600 km^2 (40%). However, during the year 2000, aquatic vegetation remained almost in the same values 11.500 Km^2 in January and August. There are also considerable variations between the same dates of different years. For instance, aquatic vegetation in August, 1998 (rainy season), was close to 10.000 km^2 and on that date in 1999 the aquatic vegetation area rose to almost 20.000 km^2 (50%).

The analysis from the annual and inter-annual dynamics are described for the landcover elements considered in this study (bodies of water, aquatic vegetation and flooding areas). Figures clearly depict the evolution during the period surveyed and in the seasons (rainy and dry).

From the results obtained, it can be affirmed that even though the lake's water surface has been diminishing dramatically during the last 50 years, during the time span of this study, the water surface of the lake increased 1.5% annually, with a similar trend during the rainy and dry seasons. See Graph 1.

During the rainy season the water surface area does not increase substantially, but flooding zones appear as small bodies of water over the sand dunes as shown in Figure 2. a-b.

Figure 2.a. Dunes in Lake Chad with water surfaces

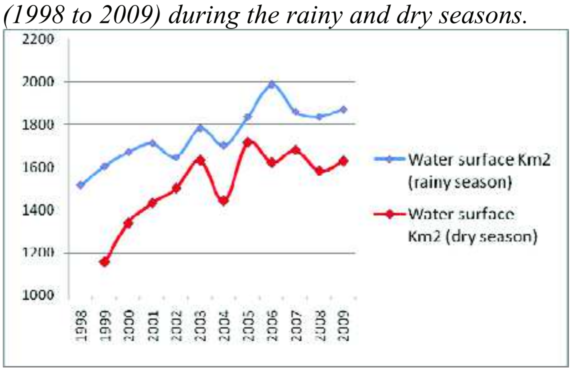
These areas are identified in the northern side of the lake in the period of 1999 and 2000, and to a lesser extent, from August 2003, but the increase has shifted to the eastern side. From 2006 and until August, 2009, the area has remained almost constant with a slight increase.

Figure 2.b. Dunes in Lake Chad with water surfaces

Source: Rocío Pacheco in Ambientum.com

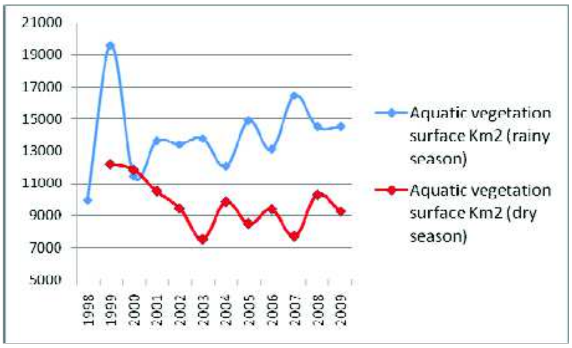
Even though the water surface area is greater in the rainy season than in the dry season (Graph 1), the inter-annual dynamics maintains a water surface rise and fall trend similar for each year, except for the year 2006. In 2006, compared to the year before, the body of water reduced its size area during the dry season, whereas in augments significantly in the rainy season, more in fact than the other years reviewed. This was probably due to an exceptional climatological year that is to be confirmed.

Graph 1. Evolution of the Water surface area in km² (1998 to 2009) during the rainy and dry seasons.

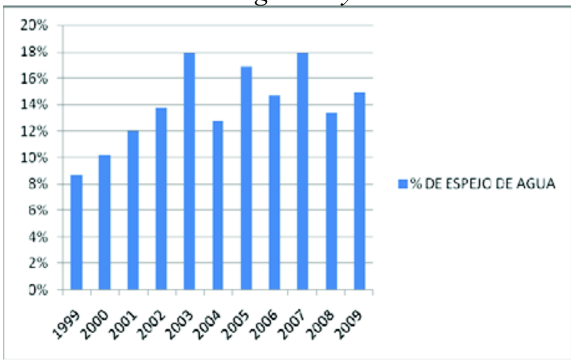


The water surface area, that three decades ago covered the body of water, is today 20% of the lake's total area in the dry season (See Graph 3) and 35% in the rainy season (See Graph 4). This is mainly due to the big flooding zones that as shown in Graph 4, are accumulation of small bodies of water covering zones without vegetation.

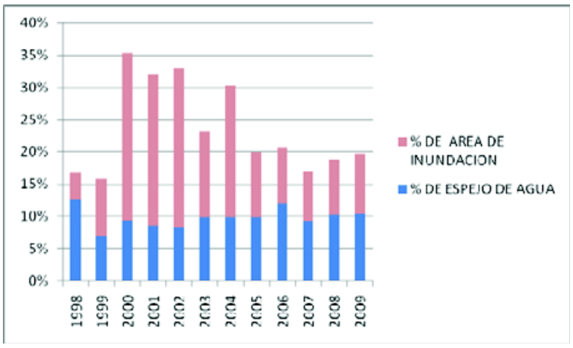
Graph 2. Evolution of the Aquatic vegetation area in km² (1998 to 2009) during the rainy and dry seasons.



Graph 3. Water surface area as percentage of total lake's area during the dry season



Graph 4 Water surface area and flooding zones as percentage of total lake's area during the dry season



CONCLUSIONS

This feasibility study clearly showed how Remote Sensing data and Geographical Information Systems can be combined at minor costs (images, standard statistical tools and computer systems) to monitor Lake's Chad water surface and aquatic vegetation multi-temporal evolutions. SPOT-VEGETATION data can be downloaded from the online VEGETATION for free.

This paper presents the last ten years evolution of the lake Chad water surface, as opposed to the dramatic reduction seen in the last 50 years (see Figure 3). In the period considered, the area has not varied much and has actually slowly recovered in some cases (1200 Km^2 in 1999 to 1600 Km2 starting in 2006, and to 1700 Km^2 in 2007, gaining some more area in certain dates of the study. This study is to be further complemented by a thorough analysis of the entire temporal series (450 images) in order to characterize with more precision inter and intra-annual variations.

This plausible recovery of the Lake may be due to: 1) management efforts in the lake basin are beginning to show results; 2) better management of water resources by cropland and irrigated land around the lake; and, 3) this period corresponds to a shift in regional-local precipitation in the last years.

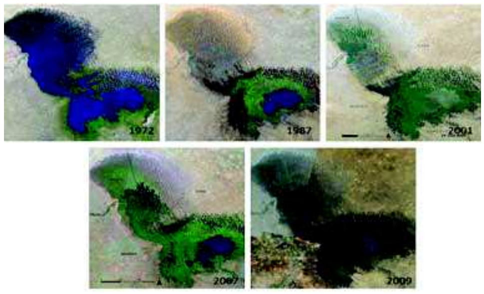
In 2001, the only coinciding year of study with the work by (Taiye, O.A., 2005), the lake's total area is 11.929,5378 Km^2. This difference is significant and may be due to several factors: first, the spatial resolution in the two works may vary; the Nigerian Department of Geography had some detailed scale information sources, such as topographical maps and direct knowledge of the work area; or it may be because of the acquisition date of the Landsat images. The acquisition dates were not specified in the study and could perfectly explain the differences with this current analysis.

It has been clearly shown that the lake's surface dimension strongly varies during the year. It can even change from one month to the next. And finally, the lake's perimeter is difficult to be determined from the NDVI images because of the vegetation spectral response (high water content aquatic vegetation is identified thanks to its high reflectance values). These high values may be high in some perimeter sectors of the lake where crops are located, especially in the rainy season.

Even though the difficulty to determine the lake's perimeter can be a source of ambiguity, the water surface can be clearly identified using the NDVI and NDWI images. Flooded areas and areas without vegetation can be easily discriminated.

Since there were not found other bibliographic references about the body of water for the period considered to compare and validate the study, this methodology will permit permanent monitoring of the lake's water surface and aquatic vegetation, due to the high temporal resolution (one synthesis image every ten days). This establishes precise variations in the water surface and in the evolution of aquatic vegetation, needed for the management of the lake and its resources.

Figure 3 Evolution of the water surface from 1972 to 2009



Perspectives

Wetlands in the arid zones represent an important proportion of these ecosystems in the world. Therefore, the environmental impacts they may suffer as a result of anthropogenic pressure and Climate Change, make them very vulnerable, particularly in river deltas where water may be diverted and dammed, as it is the case in this lake.

The sustainability depends on water arriving from its tributaries. So, it is important also to include them in future analysis studies, because water sources from tributaries have to be managed in a sustainable way along their course, otherwise wetlands downstream are bound to disappear.

It is necessary to continue research on monitoring methodologies that allow bettering understanding the evolution of this body of water and its tributaries.

These ecosystems are vital for the survival of thousands of people and animals, and are also of great environmental value for their natural and economic resources in a context of Climate Change.

Acknowlwdgements

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