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


Claudia Patricia Romero Hernández¹, Cesar Carmona Moreno², Belén Pedregal Mateos³

(1) Institute of Environmental Studies, Universidad Nacional de Colombia, Calle 44 número 45-67 Bloque 2 Unidad Camilo Torres, Bogotá cpromero@unal.edu.co

(2) European Commission, Joint Research Centre, Institute for Environment and Sustainability, 1, via Fermi, 21020-Ispra (Italia). cesar.carmona-moreno@jrc.it

(3) Department of Human Geography, Universidad de Sevilla, C/ María de Padilla s/n, 41004 Sevilla, bpedregal@us.es; bernalmm@us.es

Keywords: Remote sensing, water bodies monitoring, Lake Chad, water surfaces, aquatic vegetation.

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).
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 Km² spatial resolution. Taking into consideration that the area of study is around ~1250 Km², 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).

<table>
<thead>
<tr>
<th>YEAR</th>
<th>WATER SURFACE</th>
<th>AQUATIC VEGETATION</th>
<th>TOTAL AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface (Km²)</td>
<td>Surface (Km²)</td>
<td>Perimeter (Km)</td>
</tr>
<tr>
<td>1999</td>
<td>1155.6325</td>
<td>12177.7524</td>
<td>1159.7492</td>
</tr>
<tr>
<td>2000</td>
<td>1338.8295</td>
<td>11840.0848</td>
<td>1226.9037</td>
</tr>
<tr>
<td>2001</td>
<td>1432.1222</td>
<td>10497.4150</td>
<td>1420.7441</td>
</tr>
<tr>
<td>2002</td>
<td>1502.3196</td>
<td>9446.0687</td>
<td>1422.7024</td>
</tr>
<tr>
<td>2003</td>
<td>1632.9192</td>
<td>7517.6148</td>
<td>1515.1718</td>
</tr>
<tr>
<td>2004</td>
<td>1442.5134</td>
<td>980.5622</td>
<td>1550.4841</td>
</tr>
<tr>
<td>2005</td>
<td>1718.1407</td>
<td>8485.941</td>
<td>1963.0661</td>
</tr>
<tr>
<td>2006</td>
<td>1621.2859</td>
<td>9388.698</td>
<td>1621.2859</td>
</tr>
<tr>
<td>2007</td>
<td>1680.6227</td>
<td>7687.8433</td>
<td>1776.6851</td>
</tr>
<tr>
<td>2008</td>
<td>1582.5849</td>
<td>10290.687</td>
<td>2019.953</td>
</tr>
<tr>
<td>2009</td>
<td>1628.3974</td>
<td>9266.4674</td>
<td>1914.8035</td>
</tr>
</tbody>
</table>
Table 2. NDVI and NDWI analysis results for the month of August (Rainy Season).

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Surface (Km²)</th>
<th>Perimeter (Km)</th>
<th>Surface (Km²)</th>
<th>Perimeter (Km)</th>
<th>Surface (Km²)</th>
<th>Perimeter (Km)</th>
<th>Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>1516.866</td>
<td>215.788</td>
<td>4965.847</td>
<td>1829.437</td>
<td>511.856</td>
<td>344.5046</td>
<td>11994.570</td>
</tr>
<tr>
<td>1999</td>
<td>1605.875</td>
<td>264.642</td>
<td>10583.72</td>
<td>1694.726</td>
<td>2001.400</td>
<td>499.471</td>
<td>23240.999</td>
</tr>
<tr>
<td>2000</td>
<td>1670.720</td>
<td>234.1356</td>
<td>11455.46</td>
<td>1689.755</td>
<td>4879.918</td>
<td>340.3556</td>
<td>17706.102</td>
</tr>
<tr>
<td>2001</td>
<td>1712.979</td>
<td>307.675</td>
<td>15634.11</td>
<td>1752.712</td>
<td>4602.967</td>
<td>661.4179</td>
<td>20040.098</td>
</tr>
<tr>
<td>2002</td>
<td>1617.017</td>
<td>232.7001</td>
<td>15416.84</td>
<td>1820.649</td>
<td>4961.743</td>
<td>661.1804</td>
<td>20026.108</td>
</tr>
<tr>
<td>2003</td>
<td>1782.026</td>
<td>364.2826</td>
<td>14596.08</td>
<td>1717.624</td>
<td>2305.835</td>
<td>575.5015</td>
<td>17979.864</td>
</tr>
<tr>
<td>2004</td>
<td>1702.047</td>
<td>404.0045</td>
<td>12042.27</td>
<td>1676.232</td>
<td>3517.896</td>
<td>705.2519</td>
<td>17262.220</td>
</tr>
<tr>
<td>2005</td>
<td>1836.342</td>
<td>367.3471</td>
<td>14899.02</td>
<td>1951.940</td>
<td>1883.000</td>
<td>614.8084</td>
<td>18619.061</td>
</tr>
<tr>
<td>2006</td>
<td>1986.628</td>
<td>428.6414</td>
<td>11312.09</td>
<td>1851.673</td>
<td>1437.761</td>
<td>615.9054</td>
<td>16917.381</td>
</tr>
<tr>
<td>2007</td>
<td>1859.510</td>
<td>346.4156</td>
<td>1671.09</td>
<td>1471.121</td>
<td>1508.552</td>
<td>370.6728</td>
<td>18839.178</td>
</tr>
<tr>
<td>2008</td>
<td>1836.358</td>
<td>366.9683</td>
<td>14519.37</td>
<td>2021.803</td>
<td>1547.109</td>
<td>621.2725</td>
<td>17903.031</td>
</tr>
</tbody>
</table>

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 km², 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.

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.
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 km$^2$ (1998 to 2009) during the rainy and dry seasons.

Graph 2. Evolution of the Aquatic vegetation area in km$^2$ (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 Km$^2$ 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.
Acknowledgements

The pilot project on Lake Chad has been financed by JRC-IES: AIDCO - Knowledge Management: A test for managing Remote Sensing Products. Feasibility Study for Water and Vegetation spatial-temporal change monitoring.


References


Williams, D. (2009): “Climate Change and Lake Chad” National Environmental Education Foundation and the American Meteorological Society


Menjón, M. “El lago que desaparece” La catástrofe ecológica del Lago Chad


