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Examination of the Spatial Extent of Lake Chad Over Five Time Points

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Abstract

This study examines the spatial extent of Lake Chad over five time points; 1963, 1973, 1987, 1997 and 2001 with a view to providing information on the changes in its size and land cover. The lake is geographically located between latitudes $12^{O}\ 30^{I}\ 00^{II}$ N - $14^{O}\ 00^{I}\ 00^{II}$ N and longitudes$13^{O}\ 00^{I}\ 00^{II}$ E -$15^{O}\ 30^{I}\ 00^{II}$ E, shared among four nations namely: Nigeria, Chad, Niger and Cameroon. Materials for the study are imageries from Modis, Argon and Landsat satellites. Arcview 3.1 and Arcmap 8.1 GIS tools are used to determine the length; width, parameter, area and volume of the lake at each time point, and a land cover change analysis. The results indicate that the lake shrank between 1963 and 1997 but has begun to regain some areas due to the effort of Lake Chad River Basin Authority to recharge the lake. Sand gained a lot in the land cover change analysis carried out which is due largely to the dynamics of the change in size of the lake and an encroachment of the desert. To resuscitate the lake to its past glory, there is the need for a comprehensive conservation treatment for the entire lake.

Introduction

The word “lake” comes from a Greek word meaning hole or pond. However, Hornby (2000) defined lake as a body of water surrounded by land, while Monkhouse and Small (1979) defines a lake as a water-filled hollow in the earth’s surface. Lakes may be found in all parts of the world. Some large bodies of water commonly known as seas are really lakes. These include the Dead Sea, the Sea of Galilee, and the Caspian Sea. Some lakes lie near the highest regions of the earth, and others far below the sea level. Examples are lake Titicaca, in South America 3,812 meters above sea level and the Dead Sea between Israel and Jordan 399 meters below sea level.

The greatest numbers of lakes occur in regions that were once covered by glaciers. In mountainous regions, glaciers carved deep valleys as they traveled. The basins they carved when filled with water, form lakes. In a limestone region, underground water slowly dissolves the limestone rock. This action begins in cracks in the rock and continues until the surface collapses, forming a pit known as a sinkhole. The sinkhole may then be filled with water and become a lake or a pond.

There is a more-or-less complete gradation of size of lake bodies, from the Caspian Sea, with an area of 436,000km^2 (Van der leaden, 1975), to lakes of the smallest size measured in square meter (m^2). The largest lakes are those of tectonic or structural origin, and those associated with major glacial effects (Laurentian Great lakes). Another group of the lakes are also long and deep, but very narrow (glaciated valley lakes, fiord lakes, and the largest man –made reservoirs), and therefore represent rather specialized sedimentary conditions. By far the greatest number of lakes occurs as relatively shallow depressions in the form of ice scour lakes, cirques, oxbow and levee lakes, kettle lakes, wetland lakes, lagoons, and the small man-made lakes.

The form (size and shape) of any existing lake depends not only upon the form of the original basin but upon subsequent tectonic and isostatic movements, and upon the accumulation of infilling materials (or subsequent removal during glaciation’s). Sly (1978), concluded that changes which affect the physical regime of lakes may be separated into four distinct types: One, basin-wide-effects which are caused by climatic change; two, basin-wide-effects which are produced by changes in water level; three, basin-wide-effects which are related to expansion or swallowing, due to natural-accumulation trends; and four, local changes which affect only part of a basin, such as the migration of deltas, formation of spits and bars, or the modification of inflow due to drainage change.

Lakes respond to various forms of physical input, namely, wind, atmospheric heating, river inflow, surface barometric pressure and gravity. The actual response of the lakes to these physical inputs is also a function of other parameters. These include, orientation, size, shape, depth of basin, configuration of the Lake Basin, river discharge, solids content, coriolis force and duration. Among the five physical inputs that the lakes respond to, size contributes more to the actual responses than the other four physical inputs. This shows how important information on size of the lakes is in a scientific study.

Lake Chad is a very important study point because it has the following characteristics. One, the size and shape of the lake are constantly fluctuating. It is shared by four nations and finally it is located in an arid region. But more importantly, the lake is one of the least studied when compared with others. The reasons are not far fetched. The absence or lack of basic information is one of the major obstacles. This has subsequently affected the economic potentials and level of utilization of the lake.

The main reason for embarking on this study is to provide information on spatial changes that have occurred in the land cover of the lake, knowing well that findings of this study will assist or prompt other studies on the lake. As a result, the main aim of the study is to determine the changes that have occurred in the land cover of the lake between 1963 and 2001. The period covered by the study is restricted within the time frame because of the data available. The aim of the study is further broken into the following specific objectives. First, to map the land cover of the study area. Secondly, to estimate the changes in the land cover of the lake area over the five time points and finally, the determination of the trends of changes in the land cover

Background of Study Area

Lake Chad is a large lake in the north-central Africa. Most of it lies in Chad, and the rest in Nigeria, Cameroon and Niger. Scientists think the average size of the lake expands and contrasts in 10-year cycles, but its overall size has shrunk for many years. The lakeshore line changes in relation to the quantity of water that rivers pour into it and the rate of water evaporation. The lake is larger in the rainy seasons than in dry seasons and it is seldom deeper than 7m. Many islands rise from the lake's surface, which is covered by a tangle of grasses and weeds (McNutty, 2001).

The lake is geographically located between latitudes $12^{O}\ 30^{I}\ 00^{II}$ N - $14^{O}\ 00^{I}\ 00^{II}$ N and longitudes $13^{O}\ 00^{I}\ 00^{II}$ E -$15^{O}\ 30^{I}\ 00^{II}$ E, at an average height of 200m above mean sea level (Mabogunje, 1971), as illustrated in Figure 1. Its mean depth is about 3m, while different literature over the years put the area of the lake between 10,000 km^2 in the 1960s and 2,500 km^2 during severe drought of the 1970s and 1980s (Ayoade, 1988; Apt *et al*, 1996 and Widdow, 1998). Monkhouse and Small (1979) put the size at 51,800km^2 though they observed that the lake is fluctuating. The lake is supply with water from three major rivers and numerous smaller steams. The major rivers are: Komadugu-Yobe, Chari and Yedseram.

Figure 1: Map of Lake Chad

The climatic conditions of the study area can be divided into two. These are rainy and dry seasons of about five and seven months respectively per year. The rainy season starts in May and ends in September while the dry season starts in October and ends in April. Low temperature is experienced in December-February due to the cold dry harmattan winds blowing from the north east. With clear skies and no rain, the daily range of temperature is large, dropping from 30^{o}c in the day to 13^{o}c at night. In June, rain approaches from the south, often preceded by tornadoes. Yearly maximum temperature and rainfall occur between April-June and July-August respectively. The average annual rainfall and temperature are 864mm and 25.8^{o}c respectively.

The vegetation in the southern part of the lake is Sudan savannah characterized by xeric species, which are mainly short grasses, and medium height trees interspersed with shrubs and herbs. The Sahel savannah zone characterizes the northern part of the lake. It has the same vegetation type with Sudan savannah, however, it differ by been more sparsely distributed. The lake is a fresh water lake on the boundary between the desert and wet tropical Africa. As the climate varies and the green band moves north or south, as a result, the rivers that feed the lake either flood or dry up.

Data Collection Techniques and Analysis

The scope of this study is limited to the use of satellite imageries and maps as source of data for the study. Similarly, the study for now is only focused on the analysis of spatial changes in land cover of the lake. Since the most important parameter for this study is land cover, remote sensing was used as the main method to obtain land cover information. The most widely used remote sensing technique is manual photo interpretation of large-scale aerial photographs in conjunction with the ground-based fieldwork. This method is costly and time consuming when implemented on very large areas (Jackson *et al*, 1977). A second method of obtaining land cover information is by computer-assisted interpretation of satellite imagery. This second approach is better and adopted for the study.

The main data for this study are imageries from Argon, Landsat and Modis satellites. Figure 2 is imagery from Argon satellite obtained in October 1963. Figure 3 is Modis imagery obtained in October 2001. Figure 4, has four imageries of landsat satellites obtained in 1973, 1987, 1997 and 2001 respectively. All these imageries are available at both soft and hard copy. However, the soft form will be more appropriate for the study. The imageries are downloaded from the internet. Other materials for the study are topographic maps of the area, Geographical Information System (GIS) Arcview 3.1 and Arcview 8.1 version.

The first step was georeferencing of the satellite imageries. This is achieved by identifying points on the imagery whose coordinates on the ground are known. Then a coordinate transformation is carried out to derive coordinate on the imagery. Once, the imagery has a coordinate system related to the ground, points on the imagery are selected whose distance and bearing are then computed. The ratio of the distance on the imagery with distance computed from already existing ground control on topographic map produce the scale of the imagery. In a similar manner, the imagery coordinate system helps to produce orientation (direction) to the imagery.

The second step is taking measurements on the imagery. The required measurements for the study are length, width, perimeter, area and volume. However, only the length, width and perimeter were obtained directly, the others were computed using relevant mathematics formulae. The volume of the lake is estimated based on an average depth of 4m.

The GIS steps started with the opening of a project file and by extension a project view for the analysis. The imagery data was then imported into the project file. Since the structure of the lake is enclosed, a polygon was then selected under the view menu. As a result, the perimeter of each imagery was traced and its area and perimeter determined directly. This process was repeated for each of the imagery. After completing the process, the polygon sub menu was changed to linear, so that maximum length and width of the lake in the imageries could be measured.

The next step was the overlaying of the various polygon traced from the imageries. The map produced was then used to determine the rate and direction of changes in the land cover for the lake. Using various menu in the software, the land cover gain and loss by water to sand, forest, agriculture and etc, were then computed.

Results and Discussion

Table 1, displayed the values of the measured parameters of the study, namely, length, width, perimeter, area and volume. The result shows that the findings are constantly changing over the five time points used for the study. This outcome agrees with existing literature on the lake. However, having a closer look at Table 1 and its representation in graphical form on Figures 4-7, the result reveals that between 1963 and 1997 (four time points) the size of the lake decreases from about 40,000km^2 to 4,837km^2. The size however starts to increase in 1997 from about 4,837km^2 to 7,558 km^2. A similar pattern of fluctuation occurs for the remaining elements of the spatial extent. Although all the elements of the spatial extent have the same pattern when represented graphically, but they have different rates at which they change. For example, the size of the lake

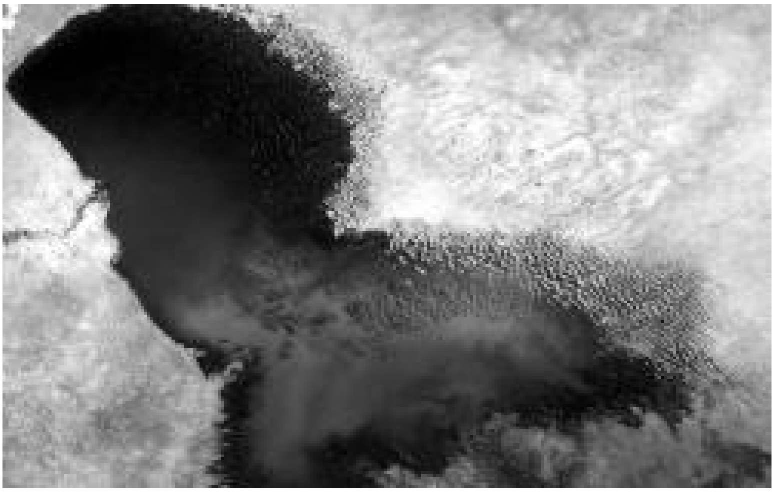

Figure 2: Imagery from Argon satellite obtained in October 1963

Figure 3: Modis imagery obtained in October 2001

from 40,311km^2 in 1963 to 4,837 km^2 in 1997, which revealed that the lake lost about 88% of its size at an annual rate of 1,043.364 km^2. Between 1997 and 2001, the lake gained 2721 km^2, which translated to 56% increase in size at an annual increase of 680 km^2. See Table 3 for further details.

The study also reveals interesting changes that occurred in the land cover within the study period. Table 2 and Figure 8 show that water, which used to be the predominant land cover of the lake in 1963 has lost its position to mainly vegetation, sand and other land cover types such as houses, roads and rocks. In 1963, water has a staggering 98% with sand and vegetation sharing the remaining 2%. However, by 1997, the percent cover for water has dropped to 11.76%. The land cover lost by water was gained by sand and vegetation. The land cover size of sand increased from 1.30% in 1963 to 18.47% in 1997 while vegetation increased from 0.70% to 69.77% for the same period. Just as the size of the lake reversed from shrinking in 1997, so also the land cover for water. Between 1997 and 2001 the water cover has increased to 18.38%, gaining mainly from the lost in vegetation cover.

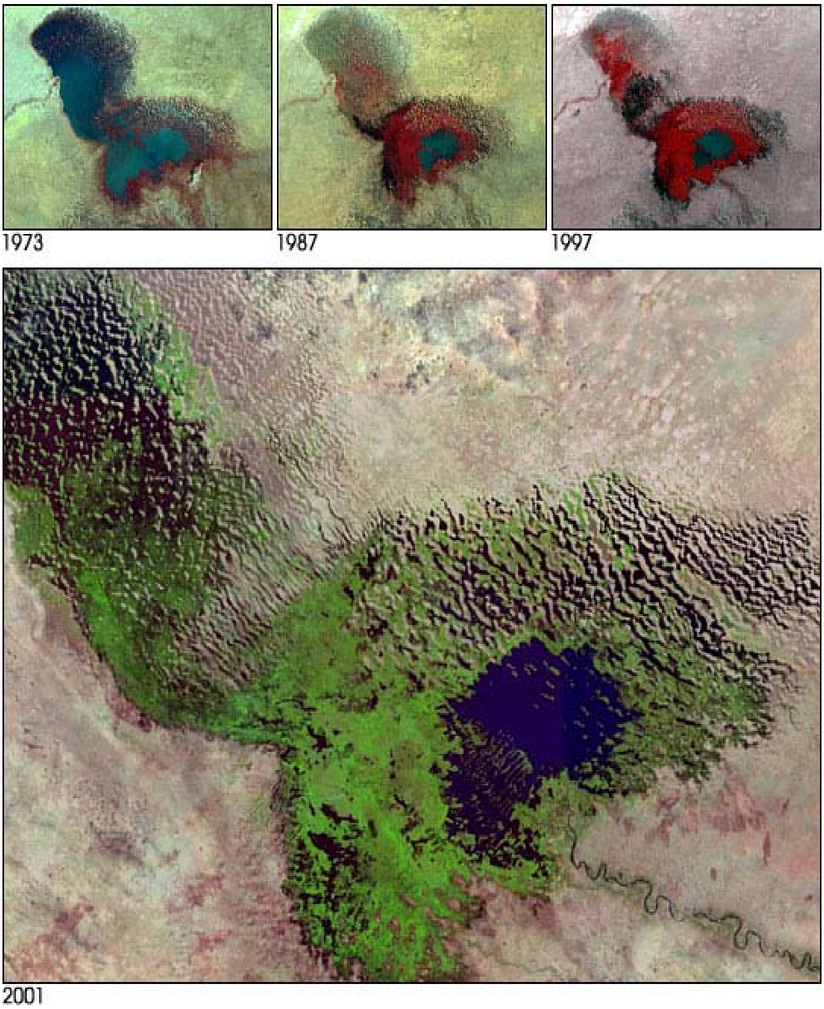

Figure 4: Imageries of Landsat satellites obtained in 1973, 1987, 1997 and 2001

Table 1: Spatial extent of the lake over the five time points

Year/ Item	Length (km)	Width (km)	Perimeter (km)	Area (km^2)	Volume (km^3)
1963	250.159	271.870	806.236	40,311.805	201.560
1973	244.280	254.319	755.854	26,874.537	134.373
1987	56.887	80.311	234.241	5,374.907	26.875
1997	53.541	80.311	200.778	4,837.417	24.187
2001	83.658	93.670	301.167	7,558.500	37.793

Table 2: Changes in land cover of the lake

Year/ land cover	Water (%)	Sand (%)	Vegetation & others (%)	Total (%)
1963	98.00	1.30	0.70	100
1973	65.33	2.39	32.28	100
1987	13.07	10.58	76.35	100
1997	11.76	18.47	69.77	100
2001	18.38	26.20	55.42	100

Table 3: Rates of change in the size of the lake

Year/ Item	Area (km^2)	% Change	Cumulative % Change	Annual gain or lost (km^2)	Cumulative average gain /lost (km^2)
1963	40,311.805	-	-	-	-
1973	26,874.537	-33.3	-33.3	-1,343.727	-1,343.727
1987	5,374.907	-80.0	-87.0	-1,536.688	-1,455.704
1997	4,837.417	-10.0	-88.0	-53.749	-1,043.364
2001	7,558.500	+56.25	-81.25	+680.271	-861.929

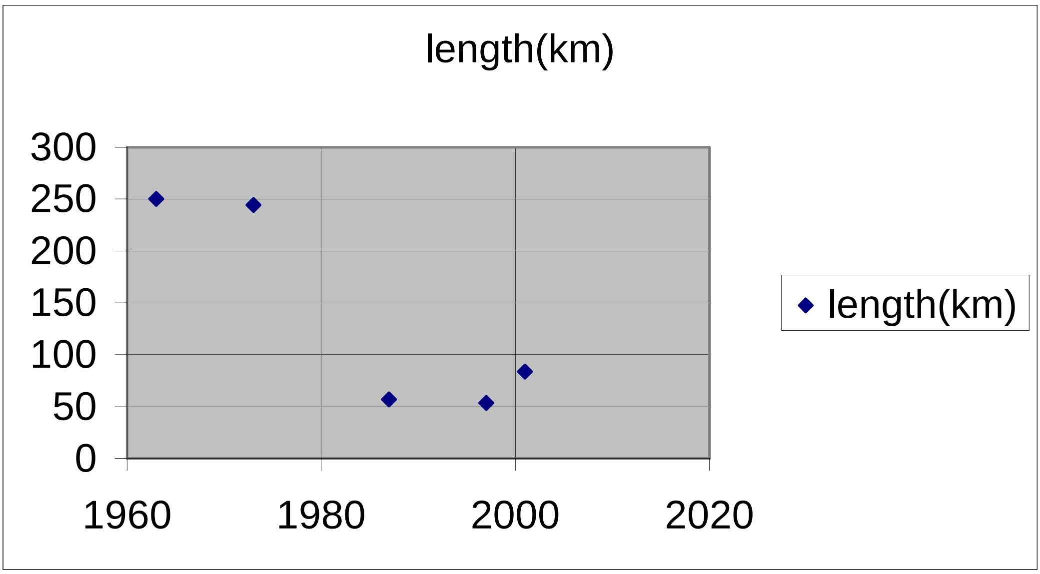

Figure 5: Changes in the length of the lake

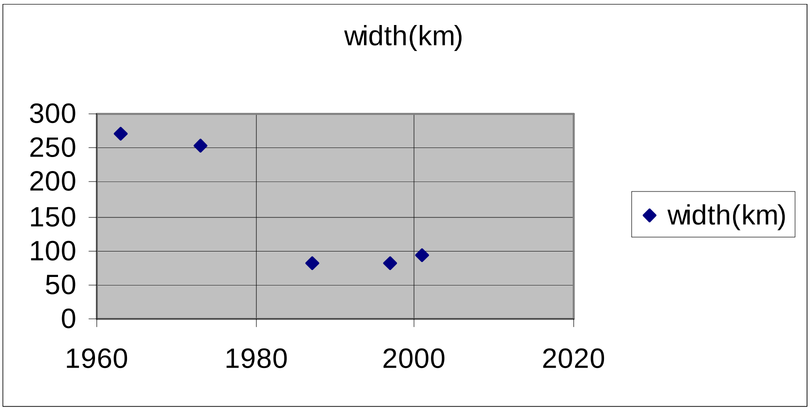

Figure 6: Changes in the width of the lake

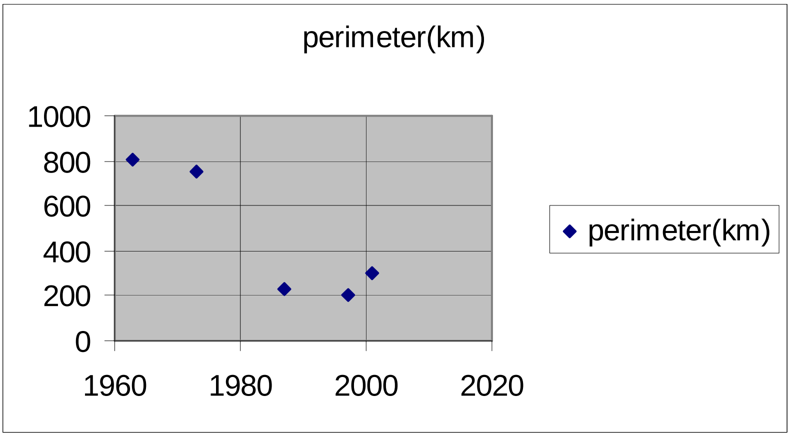

Figure 7: Changes in the perimeter of the lake

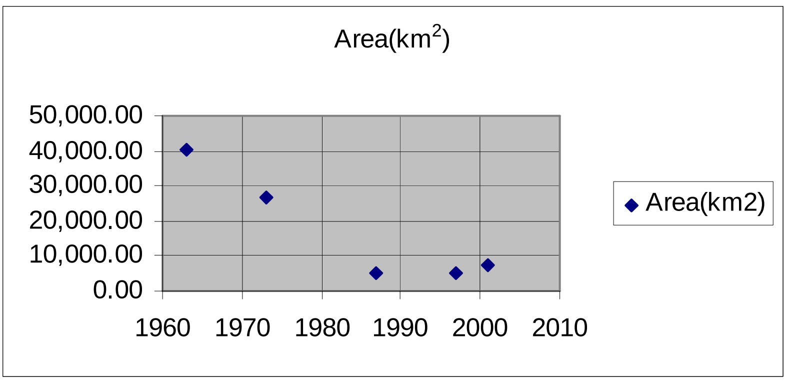

Figure 8: Changes in the area of the lake

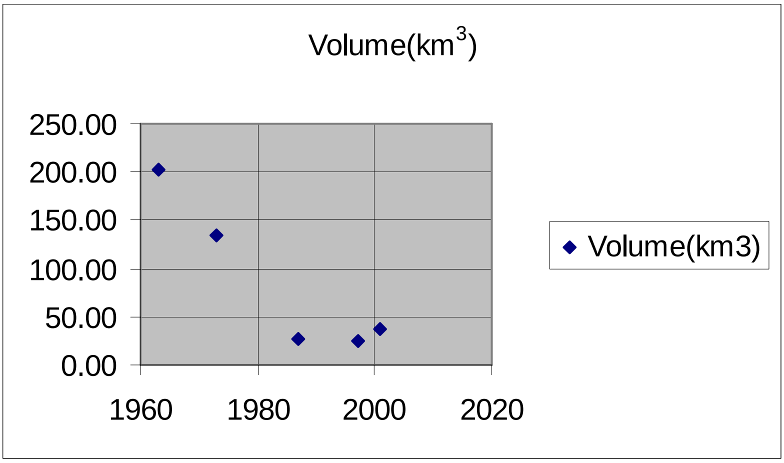

Figure 9: Changes in the volume of the lake

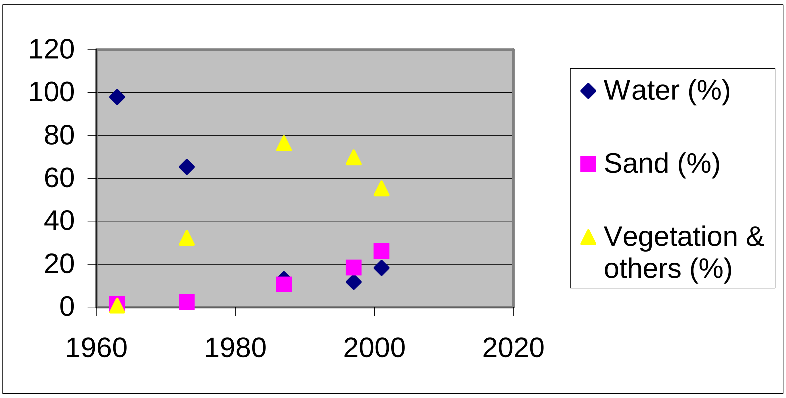

Figure 10: Changes in the land cover of the lake

Another interesting finding is that the land cover for sand has been increasing steadily. This can be attributed to two factors, which were noticed during the image interpretation. One, encroachment of the desert from the northern part of the lake, two, eventual loss of vegetation gain from the lost of water cover to sand in other parts of the lake. Therefore, there seems to be a relationship between the dynamics of the spatial extent of the lake and its land cover.

The findings of this study in terms of the actual size of the lake over the five time points did not agree with some literature. For instance, Gresswell and Huxley (1965) put the size at 15,000km^2, Ayoade (1988), said that the size to fluctuated between 13,000 km^2 to 26,000 km^2, and averaged its size to be 16,317 km^2. Apt *et al* (1996) claimed that the lake had shrunk from 24,500 km^2 in 1966 to 2,125 km^2 in 1992. These are far estimates from the findings of this study. In a similar manner, Ayoade 1988 estimated that the maximum width and length of the lake were 144km and 1000km respectively. This reveals that the maximum length of the lake fluctuated between 53.541km in 1997 and 250.159km in 1963, while its maximum width decreased to 80.311km in 1987 and 1997 from 271.890km in 1963.

This study does not attempt to rubbish existing claims because the sources and credibility of data for the study may differ, likewise, the methods and date (time of study). For instance, the study of Apt *et al* (1996) where the primary data for the study were aerial photographs collected in 1966 and 1992 (two time points and different observing platform) should not be expected to produce the same result with this study. Finally this study has shown that the monitoring of the changes in the size of the lake and its land cover dynamics can provide some information on the drought and desertification frequency in the region. This can be particularly achieved by constantly monitoring the land cover loss from vegetation and water to sand. A graphical plot of data of such loss or gain in land cover will reveal the rate and trend of drought and desertification in the region. Also the findings of this study can provide basis for computing the volume of economic loss in terms of resources and potential investment on the lake due to drastic changes in its spatial extent over the years.

Conclusion

Based on the results of this study, the usefulness of the integration of remote sensing and geographic information systems techniques have been demonstrated once again in environmental studies. This study was undertaken to ascertain the spatial extent and the land cover changes of lake Chad. The findings are very revealing. The result shows how the values of various elements of the spatial extent keep changing over the five time points. The study also reveals how the land cover of the lake has changed with its pattern. More importantly, the study reveals that some of the effort to recharge the lake may pay off if sustained.

The values arrived at in this study are different from existing values in the literature, which is actually expected due to differences in source of primary data and date of data collection. The results as provide a lot of detailed information on the lake spatial extent. Information on the maximum length and width of the lake provides information on how the geometrical dimension of the lake changes. In a similar manner, information on perimeter, area and volume shows that the lake was initially shrinking however it has started to expand again.

In summary, this study will like to suggest that the current effort to recharge the lake should be sustained so that it can recover its former size and land cover. Two, the approach of using remote sensing and geographic information systems techniques to monitor the environment can be used to map other environmental parameters and examine how healthy they are and provide basis for any intervention.

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