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Modelling Lake Chad Water Cycle Regime for Sustainable Development

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Abstract
This paper modelled remotely sensed data in GIS environment to examine (open) water cycle regime of Lake Chad for three periods. The findings would be useful to Lake Chad stakeholders (LCBC, member States, Ministries and Parastatals, local communities and Development Agencies) for Lake's management and decision making for conservation and sustainable development. The studyaimed at examining the hydrologic regime using Earth observation data (EOD) for 1986, 1999 and 2003.This was achieved through theprocessing, extraction, computation and comparison of monthly EOD of theperiod/years. This led to determination of monthly Lake Chad hydrologic trend for the three periods. The study usedLandsatimages obtained from UnimaidGEONETCast and Earthexplorer of USGS. The data covered monthly basis of Greater Lake Chad for the three time periodswere: Landsat MSS, TMand ETM+ (1986,1999 and 2003 with spatial resolution of 70, 30 and 28.5m respectively. The study used band ratio technique using bands 4 and 3 for information extraction. The images were sliced and found out that 0.61 was the maximum water value and more than the value indicated other landuses and/or cover.Themonthly estimated lake water extents of Lake Chad and for the period were plotted and trends displayed.The findings revealed that the lake's water regime of 2003 was more than that 1999 and 1986. The monthly trends of the year 2003 were also greater than 1999 and 1986. Therefore, this study reveals that the lake is experiencing an improvement in the surface water area.Though, comparing the lake of 1963 (25,000km^2) and 2003 (2,159km^2), there was a significant decrease of 91%. Therefore, the study recommends the Lake Chad Basin Commission, N'djamena to use climate data and link with these results.

Keywords:* *Lake Chad, hydrologic regime/Lake extent changes, Remote sensing, GIS, Land cover classification.

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I. Introduction

Water resources are fundamental to human health, animals and the natural environment. Water resources include surface water, groundwater, inland water, rivers, lakes, transitional waters, coastal waters and aquifers. In this study the researcher looked at Lake Chad water cycle regime. They are essential component of the hydrological cycle. Monitoring lake dynamics is necessary to allow sustainable management of water resources. In addition, lake surface areas, especially closed lakes, are known for their sensitivity to natural changes and thus may serve as important proxies for regional environmental and global climate fluctuations.

It is important to understand lake water surface and storage changes to be able to assess the influence of climate variation or human activities on water resources. Precise and up to date information on the status and trends of lake surface dynamics is needed to enable the development of effective strategies for sustainable management of lakes and the assessment of environmental change. Water managers cannot manage what they do not know. Therefore, a necessity for accurate spatial and temporal information on water resources continuously is evident for enhanced management. The research is significance to not only water related institutions but also research centres in all the Lake Chad member States. Study on the lake extent and changes would broaden the perspective of the communities, international organizations (FAO, UNDP and UNEP), nongovernmental organizations (NGOs) and the government. The findings provide a useful tool to local stakeholders for decision making in the field of water management, it will help in the adoption of a positive and sustainable approach toward the lake. Positive attitudes as the reduction in the fresh water demand improved and controlled irrigation farming practice, appropriate construction of dams and canals. The Lake Chad Basin Commission (LCBC), Chad Basin Development Authority (CBDA) that are establishments of the government at grass roots may base on this findings in order to formulate strategies and plan to mitigate further shrinking and speed the process of the replenishment project and also to know where and how to go about in their development works.

The study is to model the water cycle regime of Lake Chad in order to contribute toward sustainable environmental management. The researcher mapped, analyzed and quantified the historical monthly surface water variation for 1986, 1999 and 2003 as compared to the lake water level/surface variation.Water cycle regime is an important component in the existence of water bodies, which when there is misbalance either more or less has adverse effect on the environment, when not properly monitored will ultimately lead to the loss of livelihood to millions of people, loss of biomass in the water body. There is no doubt that if not properly monitored can turn a prosperous region into poverty and hunger stricken community and more or less like a desert. This study seeks to assess the water cycle regime of Lake Chad. It has been observed that lake hydrologic dynamics is both natural and human induced. It is therefore necessary to detect the rate of changes in this region. Most of the previousresearches are carried out on land-cover and land-use as there are limited studies in the aspect of monitoring the water cycle regime for an extended period of time and making a comparison for sustainable water management, among the previous works are Singh *et al* 2006, 1960s to the 1980s, the area of Lake Chad shrinking (Sarch and Birkett 2000), Coe and Foley (2001) and Birkett (2000) (Campbell 2008) and increased irrigation withdrawals. Also Alfa et al. (2008) studied reduction in size between the periods of study. Li *et al*. (2007) simulated land cover changes had a significant impact on the Lake Chad water balance and the amount of water held in the lake. Gao *et al* 2011 in their research on the causes of the shrinking of Lake Chad found out that over the last 40 years, Lake Chad, once the sixth largest lake in the world, has decreased by more than 90% in area. In this study, Alfa et al. (2008) they concluded that Lake Chad has reduced in size between the periods of study. In 1963 the lake extent was estimated to be 20,900 km^2 which reduced steadily until 2000 when the lake extent was estimated to be 304 km^2 corresponding to about a 95% loss in lake extent.

The purpose of this research was model the water cycle regime of the Lake Chad, this was achieved through collecting satellite Landsat TM and ETM+ data for Lake Chad from available sources; extracted open water surfaces of Lake Chad from the satellite images for three (3) periods (1986, 1999 and 2003);calculated the extent of open water of the Lake Chad for the period;determined the trend of the monthly open water; and compared the extent of the open water.

II. Methodology

2.1 DATA AND MATERIALS

Landsat satellite images for three (3) decades (1986, 1990 and 2003) were used for the study. This data were subdivided based on the satellite periods available which were directly related to the time of their capture. Landsat Multispectral (MSS), Thematic Mapper (TM) and Enhance Thematic Mapper (ETM+) were utilized for this study. The data were on monthly basis of the Greater Lake Chad for the three time periods: Landsat MSS, TM and ETM+ (1986, 1999 and 2003 with spatial resolution of 70, 30 and 30 m respectively. The choice of the period was based on the availability of the satellite images in historical records. The data were sourced from primary and secondary data sources particularly library materials, textbooks journals. Remotely sensed data Landsat images were also downloaded from Earthexplorer of (United States geological survey site) and also from UNIMAID GEONETCast the latter is an archive of the University for Earth Observation Data (EOD) that were accessed by researchers.

2.2 METHOD OF DATA COLLECTION

The instruments used for collating, downloading and extracting data for the research were a computer set (laptop) HP Compaq 2530p, modem and mobile phone with internet access respectively.

2.3METHOD OF DATA PROCESSING

After the data were downloaded, they were imported using ILWIS 3.7 academicfor further analysis in GIS environment. The method used to import and convert the data into ILWIS domain was via Geogateway, a color composite was also created for using band 2, 3 and 4 in other to have a clear distinction colour between water body and other land uses. In addition, the study used band ratio technique using bands 4 and 3 to extract information required for open water. The researcher used sliced technique and found out that 0.61 value was the maximum water representative and more than the value indicated other landuses and/or cover. The monthly estimated lake water extents of Lake Chad and for the period were plotted and trends displayed. This was elaborated in equation i. Then the various pixel values were examined to be either water or others, then computation for ratio band was calculated for band 2 and 4, using the formula:

(BRatio_p185r51_Nov86=lc05_l1tp_185051_19860209_20170713_01_t1_b4/
lc05_l1tp_185051_19860626_20170713_01_t1_b2) eqn i

Which gives a ratio of the two land uses water and others, which was the concern of the study.

A ratio domain was created with 0 as minimum and 10 as the maximum value with precision of 0.01 and the creation of representation for the respective land uses, where upper range 0.61 is represented with blue which is for open water and 10 represented with green for vegetation and other landuses.

The to get the actual surface area for open water, slicing of the image where the ratio of the two (2) bands (2 and 4) were performed, These gave the open water two dimensional surface area which can be viewed from the histogram window and then exported to excel where a monthly table is created for each month from January to December with their value on the next column the figure for water when divided by 1,000,000 to convert the open water surface area in to square kilometer (Km^2). This was further subjected to analysis using graph to have the hydrologic regime trend for the respective decades (1980, 1990 and 2003), and then the mean for the whole three (3) decade is find which is then plot a graph against the mean to compare with the individual decades.

III. Results

3.1 Presentation of Findings

In analysis, results were broken down or simplified into its constituent parts in forms of line graph or charts for the purpose of discussion and interpretation. Figure 3.1 shows the results obtained for Lake Chad 12 months water cycle regime starting from January through December 1986. It shows that the open water surface area in January 1986 is relatively higher which stood at over 2,000 $km^{2,}$ and later drop to less than 500 km^2 in February, again rises above 1,500km^2 in the month of March and drop to less than 500km^2 from April which continues through to September and rises above 1,000km^2 and again rises above 1,500km^2 in the month of October and receded a little below 1,500km^2 in November and rises close to 2,000km^2 in December. Overall the month of January marked the highest peak with 2,073km^2 coverage and the lowest was in February with 279km^2. It is obvious the rapid change of the lake which was as a result of high rate of evaporation and drop in the amount of rainfall received in the areas that drain into the lake and the lake area itself, also it is responsive to little changes in the environment and it was during this year one of the drought that struck the Sudano-sahelian region occurred, as observed by Sambo, (2017).

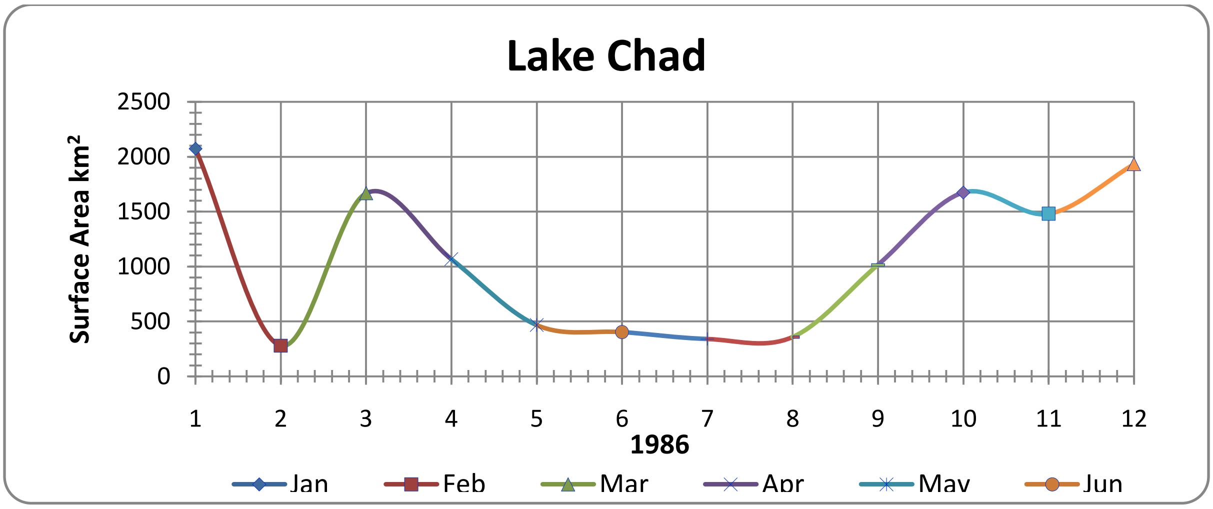

Fig 3.1: Lake Chad Open Surface Water Trends 1986

The result obtained from the Figure 3.1 (1999) looks similar to that of Figure 3.2, but with slight different. During this period the lake's surface area is experiencing improvement and is surging relative to the 1986, though it started with less than 1,500 km^2 in the month of January, gradually raised in February slightly more than 1,500 km^2, and begins to drop in March to less than 1,500km^2, continue dropping to less than 1,000km^2 in April, June, July, August and began to rise again more than 1,000km^2. The Lake improved to rise more than 1,500km^2 and dropped to less than 1,500km^2 in November. This fluctuated again to less than 1,500km^2 and steadily began in the month of October with 1,607 km^2 and the lowest was recorded in the month of July with 616 km^2. Therefore, highest surface area coverage was witnessed in January for this period.

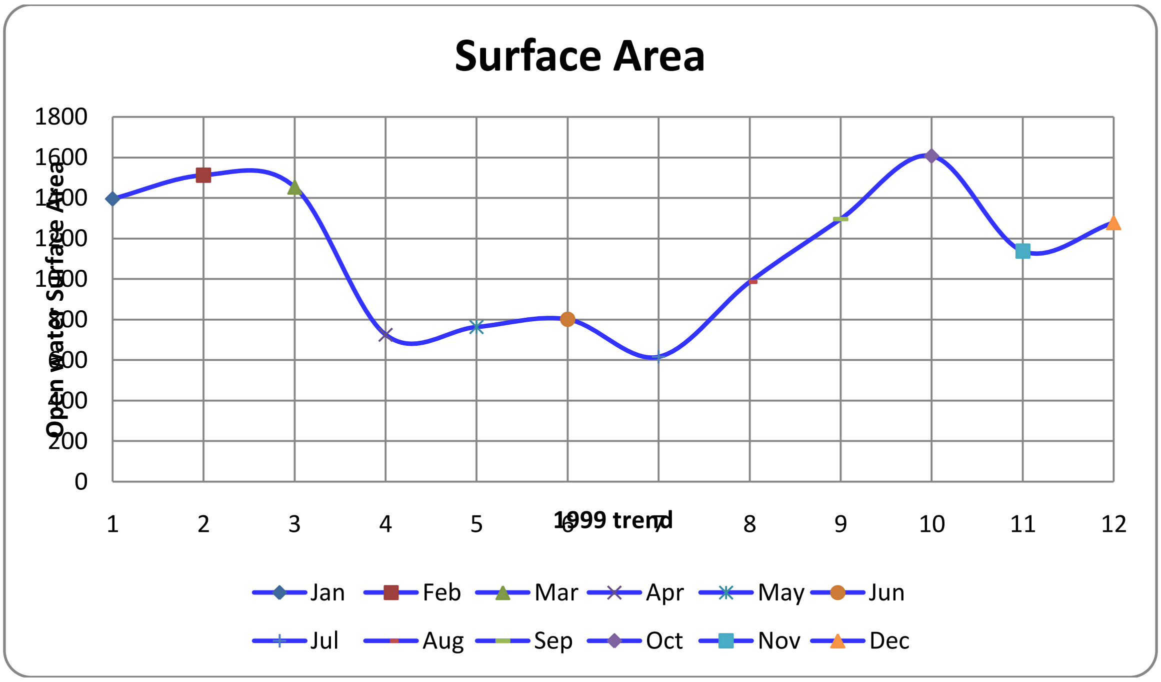

Fig 3.2: Lake Chad Open Surface Water Trends of 1999

Figure 3.3 shows result obtained from the same area as Figures 3.1 and 3.2 but in different year (2003). Generally during this period the lake's surface area was experiencing improvement and was surging relative to the 1986, though it starts with less than 2,000 km^2 in the month of January, gradually raised to 2,000km^2 in February. It receded by 500 km^2 in March (1,500km^2) and continued to just less than 1,000km^2 in April as shown in Figure 4.3. From April, it continued to rise until to slightly more than 2,000km^2 in the month of May. The Lake started to recede to less than 1,000km^2 in June and to about 500 km^2 in the month of July, but as the rainy season began, the lake's volume it raised from 543km^2 in July to above 1,000km^2 in August, which dropped to about 500km^2 in September and then continued to rise again to about 1,000km^2 in October and above 1,500km^2 in the month of November and finally it steadily begins to drop from November to December. Therefore, the highest surface area coverage was in the month of February with 2,159km^2, which is different to that of 1999 and 1986 and the lowest was recorded in the month of September with 511km^2. This shows there is significant increase compared to the 1986 which has four (4) months of successive surface area of less than 500km^2.

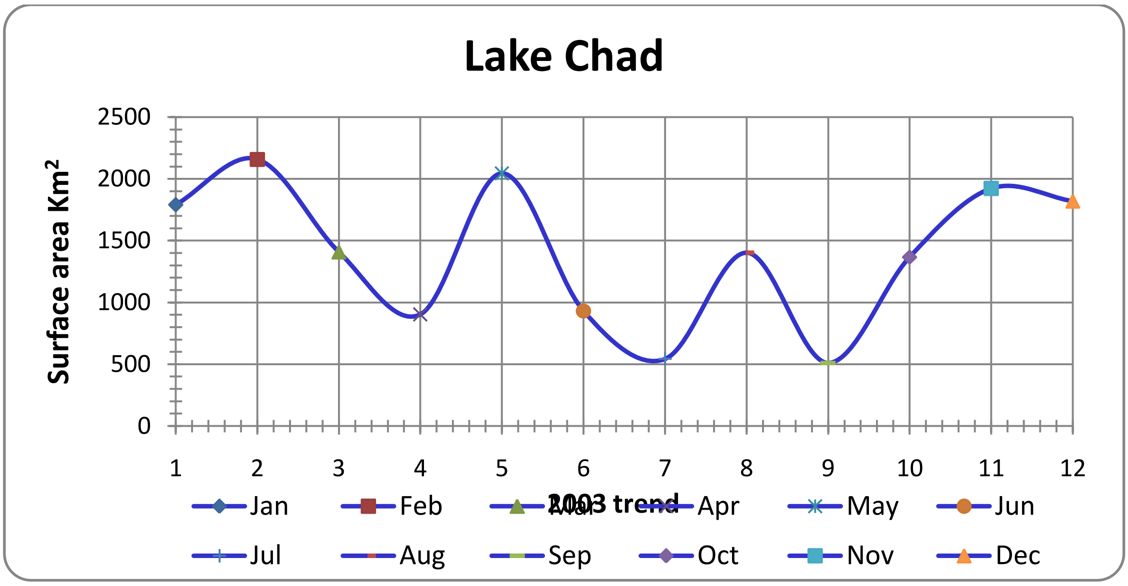

Fig:3.3: Lake Chad Open Surface Water Trends of 2003

Figures 3.1 and 3.2 showed the results of the surface water and trends of the Lake for different years. By comparison, they are ascertained that the open surface water trend in 2003 is more recharged than that of 1986 even though the level of change was insignificant.

Figure 3.4 shows the mean open surface water trend of the Lake Chad for the reference periods which were 1986, 1999 and 2003. The beginning of the month shows a significant coverage which has an area of more than 1,500km^2, where it started to drop towards the month of February to less than 1,500km^2 and slowly surged towards March recording more than 1,500km^2 in March and again receded to less than 1,000 km^2 in the month of April, May, June, July, August and September. The Lake then improved to more than 1,500km^2 in the month of October, November and December. This was because Chari inflow comes around this period.

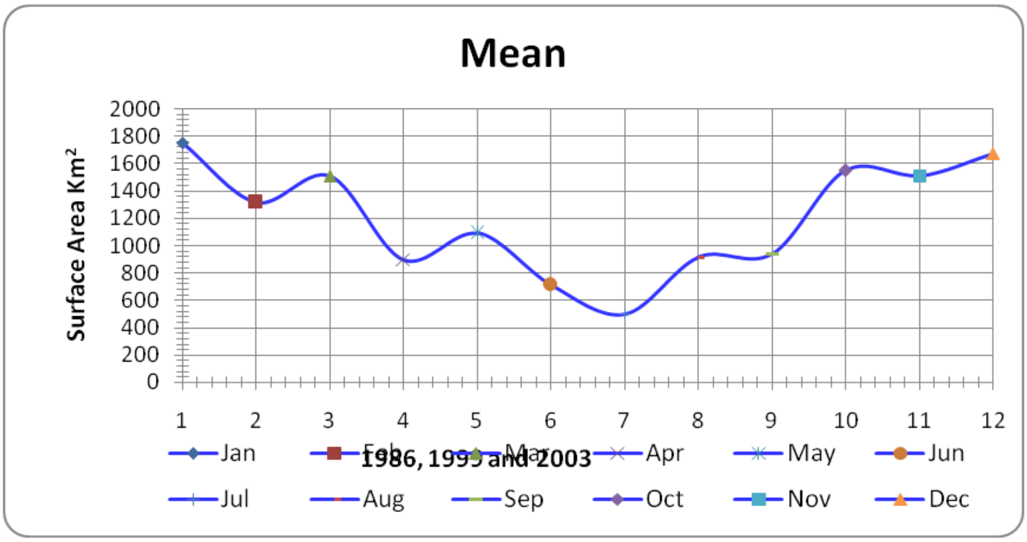

Fig 3.4: Lake Chad Open Surface Water Trends mean for 1986, 1999 and 2003

Figure 3.5 shows a comparism result between the mean of the three study periods and the 1986 results. They show that the January 1986 surface area was greater than the mean which stood above 2,000km^2 while the mean was less than 2,000km^2 in January. In Febuary it was less than the mean where with about 500km^2, while the mean was greater than 1,000km^2. In March it was more than the mean which was more than 1,500km^2 while the mean was a little above 1,500km^2. while in April its still greater than the mean surface area, this trend changes from May, June, July, August where it dropped againt the mean by less than 500km^2 and began to rise more than the mean between September and October. This dropped againt the mean in November and then rises again in December at a surface area greater than the mean. The Figure 4.5 shows that in 1986 the lake area has 4 months of less than 500km^2 against the mean.

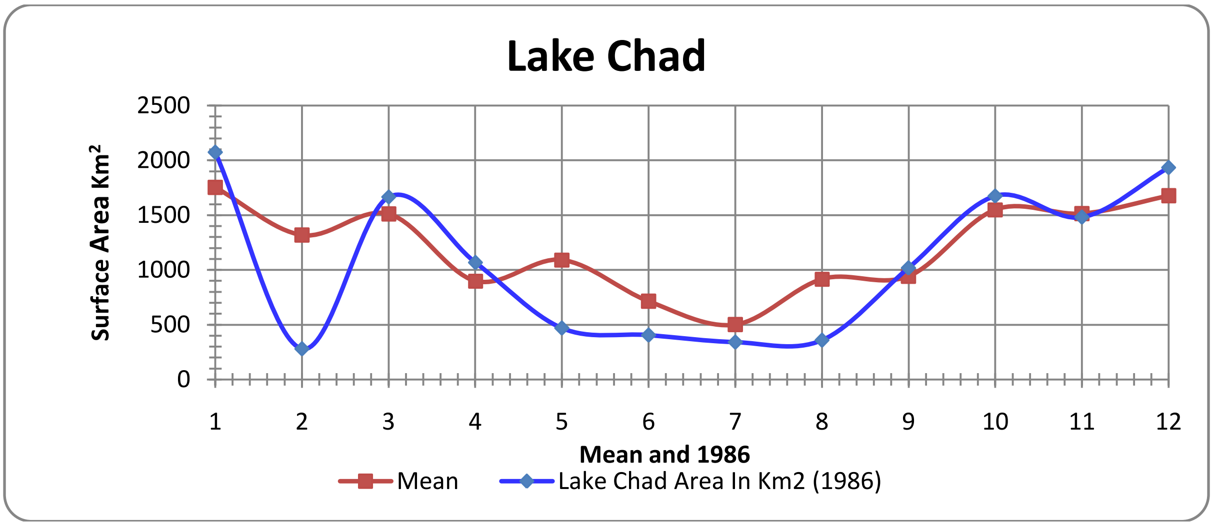

Fig:3.5 Mean open surface area trend and 1986

Figure 3.6 shows a comparism results between the mean and the 1999 results. Which shows that the January 1999 surface area was less than the mean which stood below 1,500km^2 while the mean greater with area above 1,500km^2, in Febuary it is increased to above 1,500 km^2 but here greater than the mean, in March, April, and May that was less than 1,000km^2 which shown to be less than the mean for the three months. Howeber, it was greater than the mean in June, July August, September and October before dropping againt the mean in November. The later increased in December as shown in Figure 4.6 for 1999. The lake area had maintained to less than 500km^2 and that it has six month that are greater than the mean and and six months less than the mean.

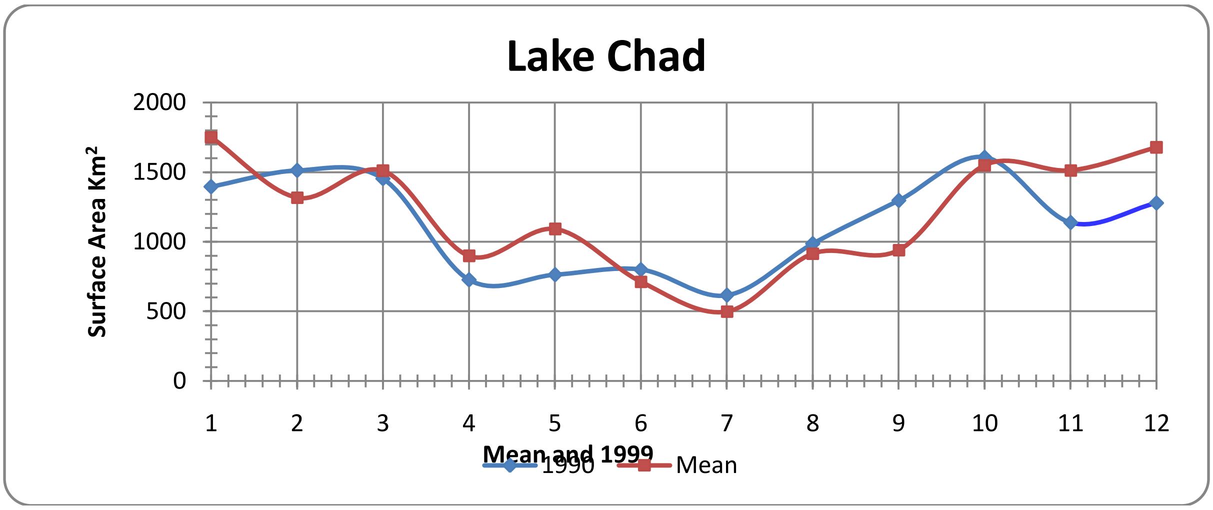

Fig:3.6: Comparision of the Mean Open Surface Water Area and 1999 Trend

Figure 3.7 also shows a comparism between the mean and the 2003 results. It shows that the January was slightly higher than the mean but both were having surface area greater than 1,500km^2. In Febuary the difference was much higher than that of January (2,000km^2), the trend changes starting March (1,409km^2) with just less than the mean (1,509km^2), and it raised more than the mean even though it has an area of less than 1,000km^2. In May the water almost doubled the mean surface area by having greater than 2,000km^2, this was maintained through June, July and August with less than 1,000km^2 except August where it had more than 1,000km^2. The Lake water dropped against the mean in September and October, and then finally raised against the mean in both November and December with areas more than 1,500km^2. Comparative to the mean it had nine months greater than the mean.

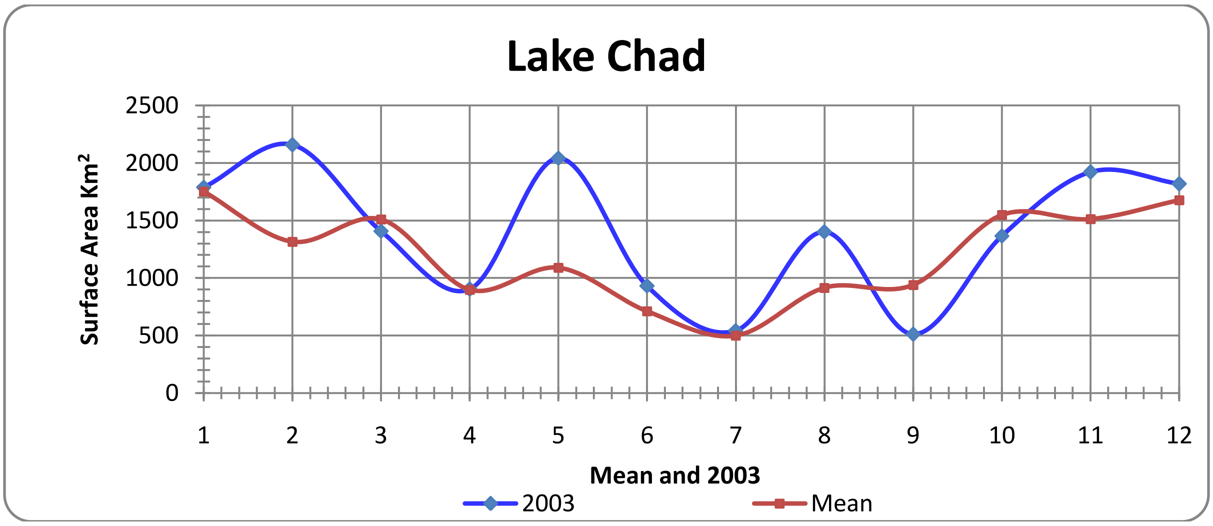

Fig:3.7: Comparision of the Mean Open Surface Water Area and 2003

Figure 3.8 also shows a comparism between the mean and the 1986, 1999 and 2003 results. It shows that the 1986 result is mostly less than the mean in the months of febuary, may, june, july and august when it begine to rise. 2003 in most o the months stands above the mean as in the months of Febuary, May, June, August and November.

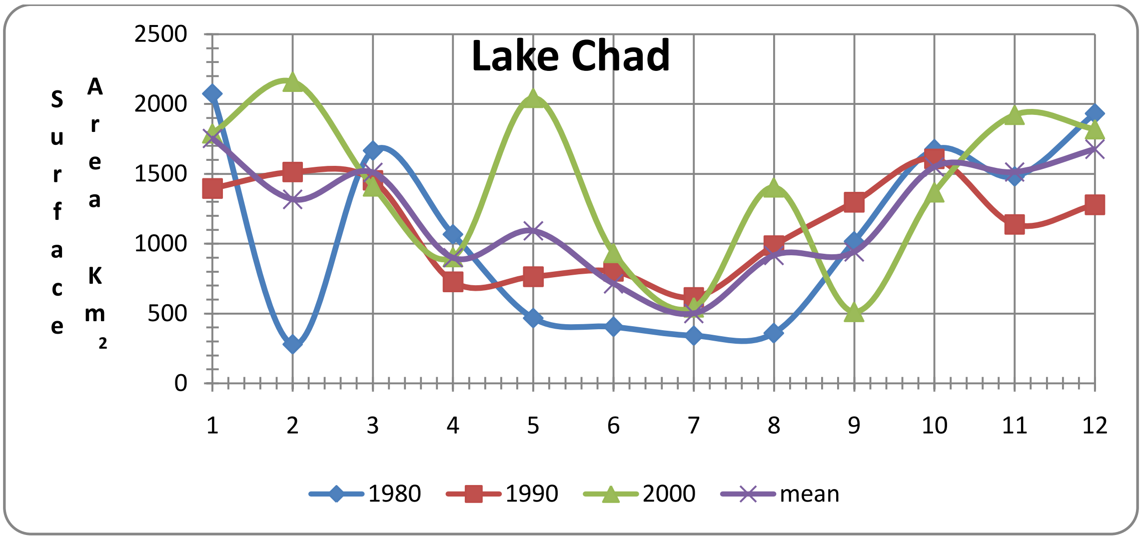

Fig:3.8: Comparision of the Mean Open Surface Water Area and 1986, 1999 and 2003.

IV. Discussions

The study area is located in one of the Sudano-Sahelialn region of the world. The research shows that the Lake Open surface area decline was more prevalent in the 1986 as shown to be in both human and naturally induced, and it is obvious that one of the severe drought of 1986 occurred during this period of this study. Result from this area in 1986 shows great deal of decline which coincides with (Isiorho and Njock-Libii, 1996) stated that during the last forty years regional precipitation has been reportedly low and there have been notable droughts between 1968-1974 and 1983-1985. (Coe and Foley, 2001; and Sambo, 2017) showed that Lake Chad has shrunk over the past 35 years. Also with Singh *et al* 2006, finding shows that from the 1960s to the 1980s, the area of Lake Chad shrank from 22,000 km^2 to about 300 km^2 which has imposed a significant social–economic impact in the region (Sarch and Birkett 2000). Studies by Coe and Foley (2001) and Birkett (2000) have suggested that the shrinking was due to persistent droughts (Campbell 2008) and increased irrigation withdrawals. Also Alfa et al. (2008) concluded that Lake Chad has reduced in size between the periods of study. In 1963 the lake extent was estimated to be over 20,900 km^2 which reduced steadily until 2000 when the lake extent was estimated to be 304 km^2 about a 95% loss in lake extent.The 2003 trend has some little resurge which has luxuriant open water surface and it has not dropped below 500km^2, however, due to the activities of man and environmental factors, results from 2003 which can be attributed to the more precipitation received even though the evaporation in the area is high and the abstraction of its feeder river for the construction of dams and improper irrigation. This also is in agreement with the findings of Oluwafemi (2005) where he discovered that there is an increase in lake area between 1997 and 2001. It can be seen that the effect of anthropogenic land use changes on the closed drainage basins is significant with respect to the lake extent for both of these examples (i.e., Li et al. (2007) in Lake Chad and Shibuo et al. (2007) in the Aral Sea.

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