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Geospatial Assessments of the Shrinking Lake Chad

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Abstract

In this paper, the rapid rate of the shrinking Lake Chad in the four host countries, that is, Cameroon, Chad, Niger and Nigeria was assessed and analyzed with the use of Remotely Sensed data and Geographical Information System techniques. Satellite images of 1973, 1979, 1986, 1999, 2005, 2011 and 2017 of Lake Chad were acquired, processed and classified into three main landcover classes: open water, swamp and "others" (the "others" include all other landcover types that are neither water nor swamps). 1963 Lake coverage of the lake was acquired and digitized as the base map. The portion of the Lake in each of the four riparian countries, comprising Cameroon, Chad, Niger and Nigeria were also digitized and the three classified landcover types were clipped to each of the riparian countries. The calculate module of the ArcGIS software was used to calculate the area covered by each of the landcover types within the lake as well as in each of the riparian countries. The results show that open water that occupied a total area of 24,596.66 km^2 in 1963, reduced drastically to just 2,264.30km^2 (9.21%) and 4,498.32km^2 (18.29%) in 1979 and 1986 respectively. Though, open water increased in 1999, but since then, the lake water has been decreasing with only 1316.73km^2 (5.35%) in 2017. It was also revealed that open water generally reduced in size in all the four riparian countries. Between 1979 and 1986, the four countries recorded very low open water; the same period when open water completely disappeared in Niger. Though, the size of open water in Cameroon was not as large as those of Nigeria and Chad, but open water in Cameroon was discovered to be more stable than in the other countries. It was recommended that the riparian countries as well as the entire world should step up their efforts in controlling the rapid disappearing lake as well as sustainable utilization of the lake, so as to maintain conducive environment for the benefits of the lake water to man.

Keywords: Geospatial; Lake Chad; GIS; Satellite Images; Shrinking.

Introduction

For several decades now, the rapid shrinking of Lake Chad has become a subject of concern not only to the countries which benefit directly from the lake, or Africa where the lake is located, but also among the water resource managers, hydrologists, agriculturalists, ecologists and other relevant establishments or agencies. However, the four countries, that is, Cameroon, Chad, Niger and Cameroon in which the lake is situated, no doubt, feel the impact of the disappearing lake than any other beneficiary or non-beneficiary countries. It is no longer news that the lake is shrinking at alarming rate as numerous researchers have testified. For instance, Eric et al (2006) reported that over the past decades, the lake has experienced series of devastating drought, has shrunk dramatically over the last 40 years and within the last century, the lake that was as large as 25,000km^2, is now as small as one tenth of that size. Hassan (2012) also reported that the lake has shrunk considerably since the 1960s when it had an area of more than 26,000km^2, making its surface the fourth largest in Africa. Sow (2017) stated that between 1963 and 2013, the lake lost 90 percent of its water mass, shrinking from 25,000km^2 to 2,500km^2 and that the reduction in the size of the lake has threatened the resources and livelihoods of the 50 million residents in that region. However, Stacke (2017) singled out the only benefit of the shrinking Lake that the lake's disappearance has brought one gift, the mineral deposit of natron that is left behind as the water evaporates; collecting and trading this mineral provided income for its miners - until their trade routes became impassable (by insurgents).

Many factors have been attributed to the shrinking Lake. For instance, Stacke (2017) opined that drought, desertification, deforestation, and resource mismanagement in addition to climate change have contributed to its drastic reduction in size by almost 90 percent in the last 60 years. Okonkwo *et al.*, (2015) reported that in the early 1970s, the Atlantic Multidecadal Oscillation (AMO) was in its so-called "cold phase," meaning that oceanic and atmospheric circulation patterns shifted in such a way that the

Sahel received less rain. The researchers also found that the effect was strong enough to override short-lived, mild recoveries in lake levels during La Niña phases of El-Nino Southern Oscillation (ENSO), which typically bring wetter conditions. A transition to a strong El Niño in 1982–1983 only added to the dryness.

Wade (2015) noted that many Lakes all over the world are receding due to the effect of global warming. He reported that global warming is a phenomenon that is implicitly tied to all areas of the globe, and the desiccation of lakes is a trend that is not confined to Africa. According to him, the Dead Sea (a misnomer) has shrunk at an incredible rate due to heightened evaporation levels, and the local governments have planned to pump in ocean water in an attempt to replenish the hyper saline lake. Poyang Lake in China has receded so much so that a 400-year old stone bridge has surfaced along the dried-up shores. Recently Lake Chad was confronted by another serious disaster; Boko Haram insurgency. Ben (2017) reported that in recent years, the Lake Chad region has become the setting of the world's most complex humanitarian disaster, devastated by converging scourges of climate change, violent extremism, food insecurity, population explosion, disease, poverty, weak statehood, and corruption. Sow (2017) observed that another challenge in the region is the threat posed by the Boko Haram insurgency. He concluded that there are 2.8 million refugees in the Lake Chad region, and estimates state that there are 9.2 million people in need of humanitarian assistance in the region.

Numerous authors have highlighted the importance of Lake Chad to the general environment of its location: GIWA (2004) stated that the Lake is very important to the communities living in the region; it serves as the political barrier between the neighbouring countries of Cameroon, Chad, Niger and Nigeria. AEO (2002) also stated that the lake is an important source of potable water in a drought prone region and a source of employment for a variety of professions and its fisheries resource is particularly significant to the rural populations, which was supported by (Neiland and Béné 2003) that the seasonal fluctuations provide excellent feeding grounds for fish through the exposing and submerging of the lake shore. SAP (2008) commented that the lake serves as a critical, strategic area for global biodiversity, being home to 120 species of fish as well as supporting 372 bird species. In the report of Isiorho et al. (1996), the recessional lake waters also provide very fertile agricultural and pasture land which has been capitalized upon during lake retreats as fertility is then restored during periods of lake expansion, while Isiorho et al. (2000) noted that a significant amount of water is stored beneath Lake Chad and is very important for the recharge of the groundwater system which may be available for future use and that the Kanem Lakes (northeast of Lake Chad) contain the blue-green algae *Arthrospira*, which is sundried by the local Kanembu tribe to make the cake Dihé. The land area immediately around the lake serves as an important grazing area for livestock while the lake fishery, an important source of protein for local populations, is under threat.

In spite all these numerous uses and importance of the Lake to the inhabitants as well to the entire environment, the alarming rate of the Lake's shrinkage, has put the existence of the lake under threat. This is because, if the Lake continues to disappear at its current shrinking rate, then, very soon, Lake Chad might become a "once upon a time lake" which would have great negative effects on man, flora and fauna and the general environment of the Lake area. Many researchers (GIWA 2004, Eric *et al.,* 2006, Ediang et al 2009, Jason 2015, Olapeju *et al.,* 2017), have expressed the adverse impacts of the shrinking lake on the people and the environment. Hence, there is the need to assess the shrinking lake not just within the Lake alone but also among the riparian counties. Therefore, the objectives of this paper are:

(i) to assess the rate of the disappearing Lake from 1963 to 2017 – a period of 55 years using GIS techniques
(ii) to assess the rate at which Lake water in each of the riparian countries is disappearing.

It is hoped that the outcome of these paper would assist each of the riparian countries in assessing the level of the shrinking lake water for policy and decision making towards sustainable utilization of the lake and introduction and enforcement of programs that may help in the lake recovery and stabilization

The Study Area

Lake Chad is located between latitudes 12˚ 22' and 13˚ 45′ N and longitudes 13˚ 05' and 15˚ 35′ E (Fig. 1).The lake is bounded in the north by Chad Republic, east by Cameroon, south by Nigeria and in the northwest by Niger Republic.

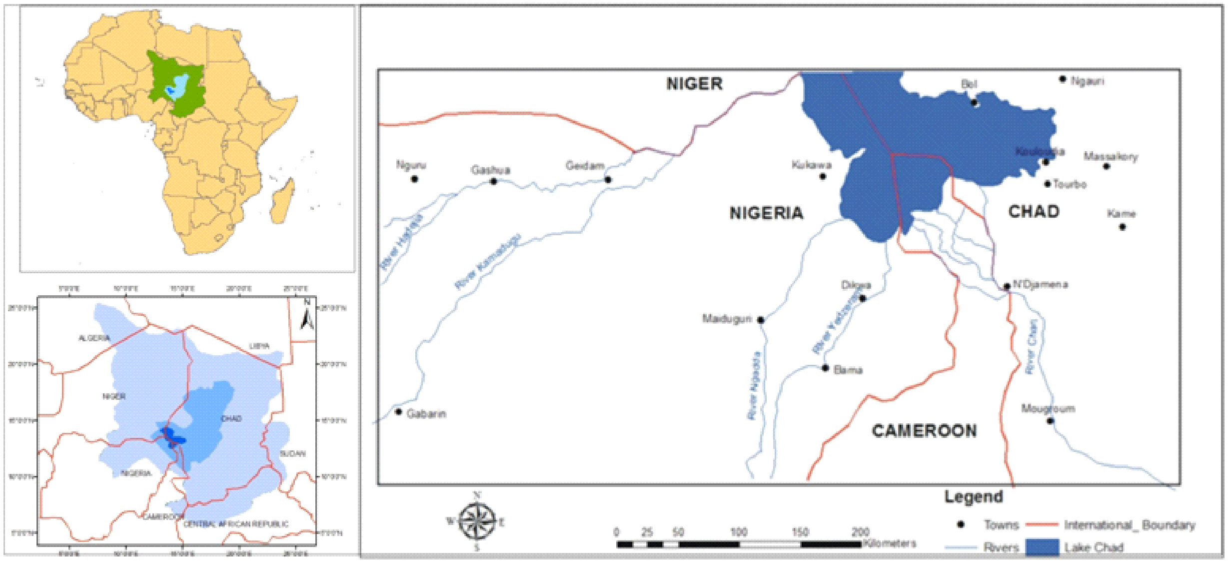


Figure 1: The Study Area

According to Hassan (2012) the name Chad is a local word meaning “large expanse of water”, in other words, a lake. Lake Chad is remnant of a former inland sea palaeolake Mega Chad. At its largest, sometime before 5000 BC, lake Mega-Chad was the largest of four Saharan palaeolakes, and is estimated to have covered an area of 400,000km^2, larger than the today’s Caspian Sea. The Chari River, fed by its tributary, the Lagone provides over 90% of Lake Chad’s water, with a small amount coming from the Yobe River in Nigeria/Niger. Over half of the lake’s area is taken up by its many small islands (including Bogomerom archipelago) reed bed and mud banks, and a belt of swampland across the middle, divides the northern and southern halves while the shorelines are largely composed of marshes. Because the lake is shallow with 10.5m at its deepest, its area is particularly sensitive to small changes in average depth, and consequently, it also shows seasonal fluctuations in size of about 1m every year. Lake Chad has no apparent outlet, but its waters percolate into the Soro and Bodele depressions. The climate is dry most of the year, with occasional rains from June to December. SAP (2008) also reported that the lake itself has a maximum surface area of approximately 25,000km^2, and has distinct morphological pools that become fully visible at a water surface elevation of about 279 meters.

There are four countries that share borders with the Lake: Nigeria, Niger, Chad and Cameroon (Figs. 1). It is these four countries that are referred to as the riparian countries in this paper. Eric et al (2006) asserted that when the four riparian countries gained independence in 1960s, there was a great surge for cooperation and the then political leaders turned their attention to the development of the Lake Chad area. It was realized that the area formed one ecological unit, and that development activities in one country would affect the other countries. The initiative was taken by Chad in 1962 and a convention and statue (The Fort Lamy Convention) were formally drawn and signed by the four countries on 22nd May, 1964, establishing the Lake Chad Basin Commission to coordinate the development and promote Cooperation in Lake Chad and its drainage basin (Jauro,1994). Sudan also has since been admitted in 2000.

Materials and Methods

In a study like this, multi-date satellite images are needed for the monitoring of the shrinking Lake. Seven satellite images captured between 1973 and 2017 (having made the area coverage of the Lake in 1963 as the base for the study resulting to a period of 55 years) were obtained, processed and analyzed to derive the changes in the area covered by the lake within the 55 years (Table 1).

Table 1: The satellite data and sources of each of the images that were used for this study

Images	Dates of Acquisition	Sources
Map	1963	NASA Goddard Space Center (http//www.gstc.nasa.gov/gstc/earth/environ/lakechad/chad.htm
Landsat MSS	3^{rd} Jan.1973	NASA Goddard Space Center (http//www.gstc.nasa.gov/gstc/earth/environ/lakechad/chad.htm
Landsat MSS	1979 (undated)	NASA Earth Observatory images by Jesse Allen, provided by the U.S. Geological Survey. In Kathryn Hansen (2017)
Landsat MSS	11^{th} Jan.1986	NASA Goddard Space Center (http//www.gstc.nasa.gov/gstc/earth/environ/lakechad/chad.htm
Landsat TM	13^{th}. Nov.1999	NASA Goddard Space Center (http//www.gstc.nasa.gov/gstc/earth/environ/lakechad/chad.htm
Landsat ETM+	11^{th}.Oct..2005	NASA Goddard Space Center (http//www.gstc.nasa.gov/gstc/earth/environ/lakechad/chad.htm
Landsat ETM+	9^{th} Oct. 2011	NASA Goddard Space Center (http//www.gstc.nasa.gov/gstc/earth/environ/lakechad/chad.htm
Landsat 8	2017 (undated)	Lake Chad (1963-2017) • Map • PopulationData.net - MapsRoom . *https://mapsroom.com/pin/551/*

Image acquisition was the greatest challenge in this study as Lake Chad covers several scenes and the possibility of getting the same year in all the scenes was difficult if not impossible which necessitated the reliance on existing images for the study. Except the 1979 and 2017 images that the days and months are not known, other images were acquired between January and November which fall in the same climatic zone on the Lake. Though the specific dates of 1979 and 2017 images were not known, the generated results conforms to similar studies, hence, considered acceptable for the study.

All the images were resampled to the 2017 image, while the 1963 image which was considered as the base map was digitized as polygon in ArcGIS software. The 1963 polygon was used to extract the lake area from the other six images (1973, 1979, 1986, 1999, 2011 and 2017). The essence of the resampling of all the images into one (2017 image) and using the extracted polygon of the 1963 base map was to ensure uniformity in the shape and sizes of the lake so that each of the seven maps will have the same characteristics in terms of rows, columns, pixel numbers among others. This activity will enable image overlay and equal area when they are calculated.

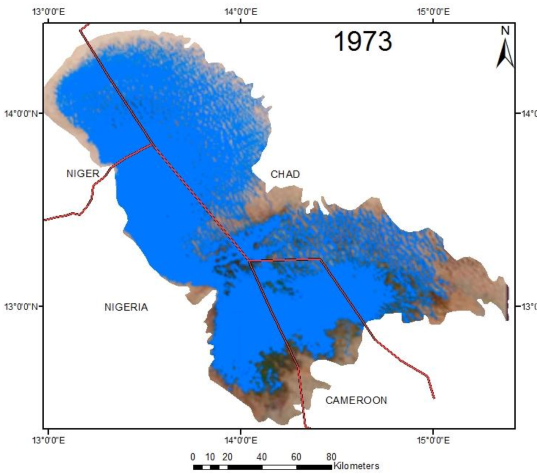
After the resampling and extraction of the seven images, classification of images was carried out. The landcover types of interest for this study are: open water and swamps since the interest is the availability or otherwise of water and swamps which are indicators for wetlands. All other landuse and landcover types such as sparse grassland, dry lands, bare surfaces among others were classified as “others”. Therefore, water, swamps and others were the three classes that were obtained from the image classifications. Other than image extraction, image filtering which is an important pre-processing activity was also carried out. The 3 by 3 filter was applied for the filtering which clearly revealed the edges of the various features represented by digital numbers (DN) in the image.

The main processing task in this study is image classification. In classifying the images, supervised classification techniques was adopted. Various training sites were selected based on the spectral characteristics of the image. Regions with same or very similar characteristics were grouped together as a class and each class is assigned a value which is known as pixel value. This procedure was followed to classify all the seven images (1963 consists of only water body which has already been digitized as base map) into the three desired landcover of open water, swamps and “others”. All the images were reclassified, assigning pixel numbers 1, 2, and 3 to water, swamps and “others” respectively to all images. Accuracy assessment was the only post processing that was done in this paper. The accuracy ranged from 81% to 94% which was accepted as appropriate to this study. The boundary (polyline) of the four riparian countries was digitized and overlain on the 1963 base map. The portion of each country within the Lake was then digitized as polygon. The three landcover types was clipped one after the other to the polygon of each country so that the three classified landcover types in each country were clearly extracted (through clipping) and calculated using ArcGIS software.

Results and Discussion

Trends of the Shrinking Lake Chad (1963-2017)

The extracted images as well as corresponding classified image of each of the six years (1963 not classified) is presented in Fig. 2a – n.



Fig, 2a. !973 Extracted Image of Lake Chad

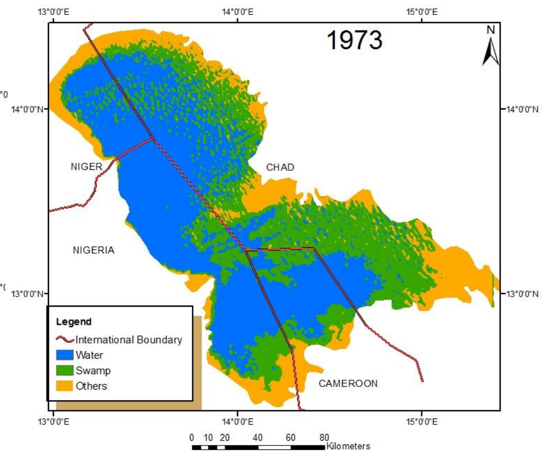


Fig. 2b. !973 Classified Image of Lake Chad

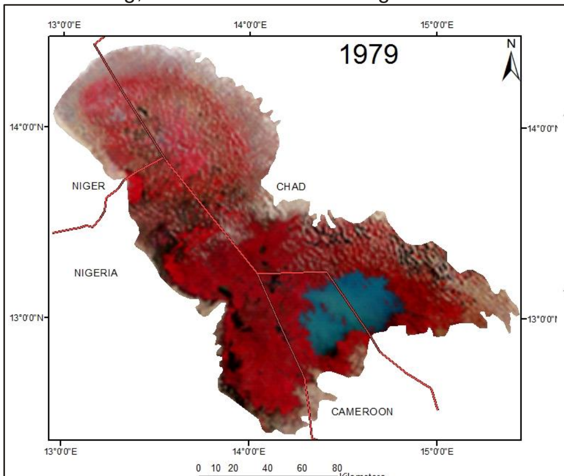


Fig.2c. !979 Extracted Image of Lake Chad

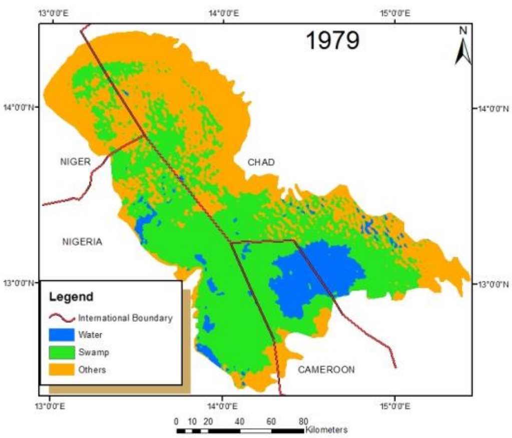


Fig. 2d. !979 Classified Image of Lake Chad

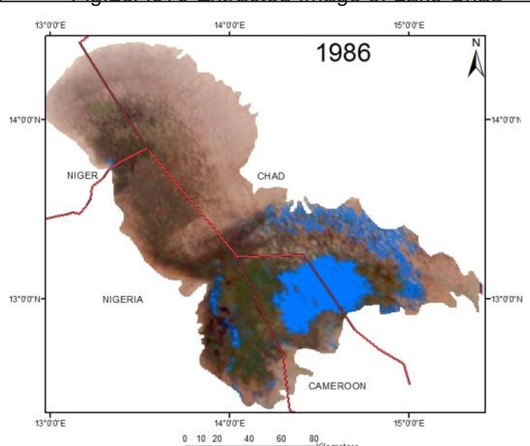


Fig. 2e. !986 Extracted Image of Lake Chad

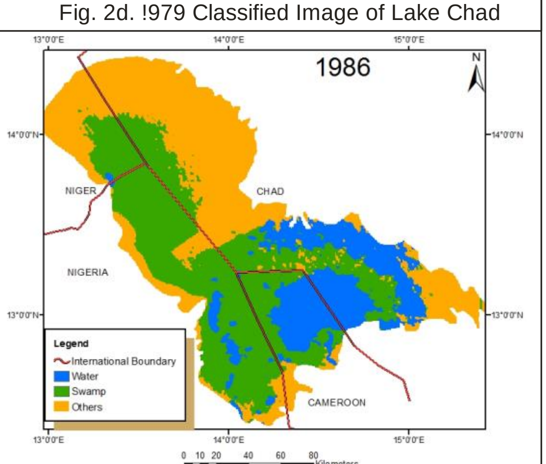


Fig. 2f. !986 Classified Image of Lake Chad

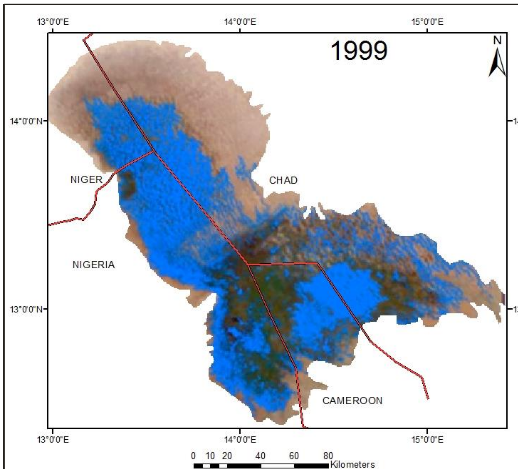


Fig. 2g. 1999 Extracted Image of Lake Chad

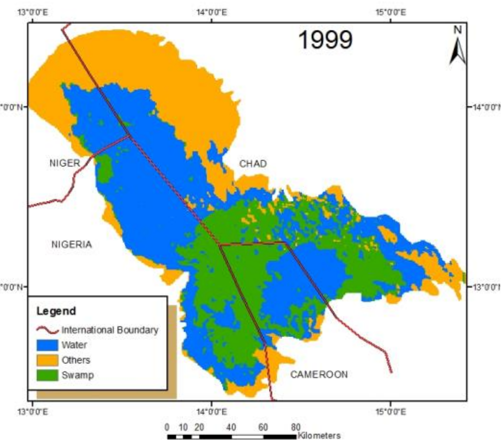


Fig. 2h.1999 Classified Image of Lake Chad

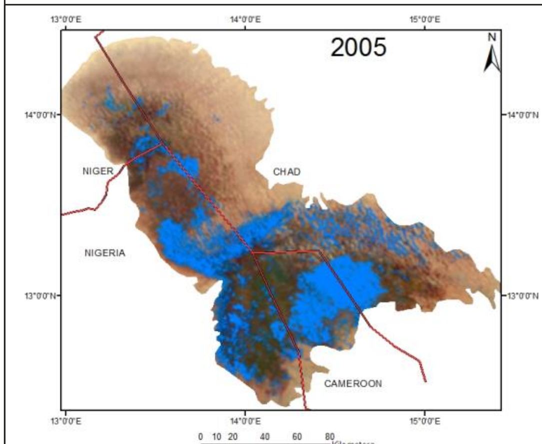


Fig.2i. 2005 Extracted Image of Lake Chad

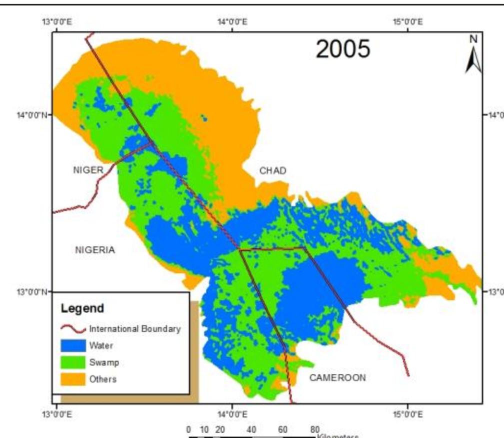


Fig. 2j. 2005 Classified Image of Lake Chad

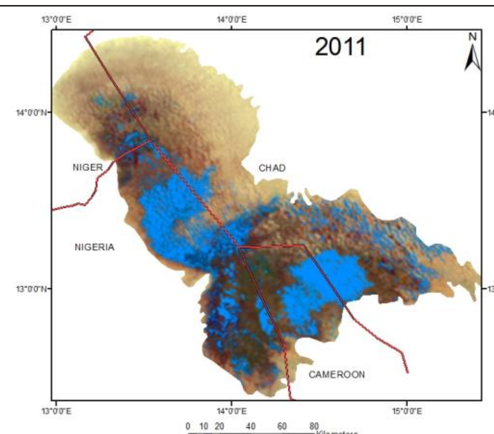


Fig. 2k 2011 Extracted Image of Lake Chad

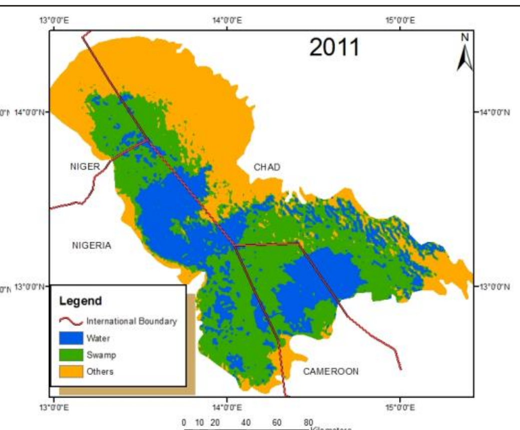


Fig. 2l. 2011 Classified Image of Lake Chad

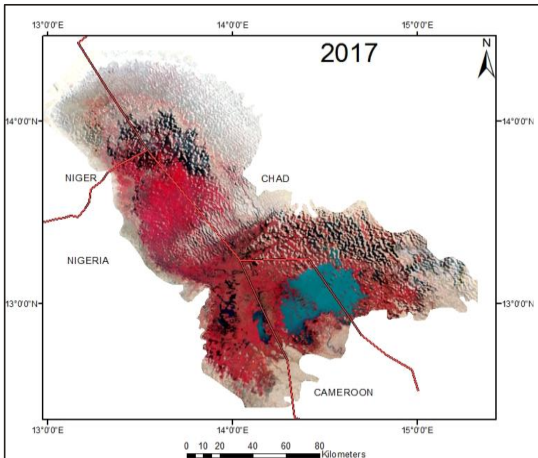


Fig. 2m. 2017 Extracted Image of Lake Chad

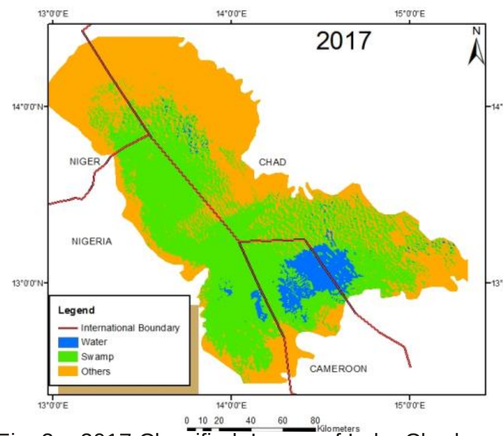


Fig. 2n. 2017 Classified Image of Lake Chad

The result of the area calculation of each of the three landcover types (water, swamps and others) within the lake area is shown in Table 2. The total values of each year in Table.2 were obtained by adding the values of each of the land cover type in each year.

Table 2: Results of the calculated landcovers from the classified images

LANDCOVER	**1963 AREA/%**	**1973 AREA/%**	**1979 AREA/%**	**1986 AREA/%**	**1999 AREA/%**	**2005 AREA/%**	**2011 AREA/%**	**2017 AREA/%**
LAKE	24596.66 (100%)	11389.61 (46.31%)	2264.30 (9.21%)	4498.32 (18.29%)	10700.33 (43.50%)	7681.22 (31.23%)	6084.37 (24.74%)	1316.73 (5.35%)
SWAMPS	-	8310.80 (33.79%)	11570.47 (47.05%)	9990.23 (40.62%)	6137.03 (24.95%)	8806.10 (35.80%)	9590.33 (38.99%)	11373.62 (46.24%)
OTHERS	-	4896..25 (19.91%)	10761.89 (43.75%)	10108.11 (41.10%)	7759.3 (31.55%)	8109.34 (32.97%)	8921.96 (36.27%)	11906.31 (48.41%)
TOTAL	**24596.66**	**24596.66**	**24596.66**	**24596.66**	**24596.66**	**24596.66**	**24596.66**	**24596.66**

Source: Calculated from the classified images

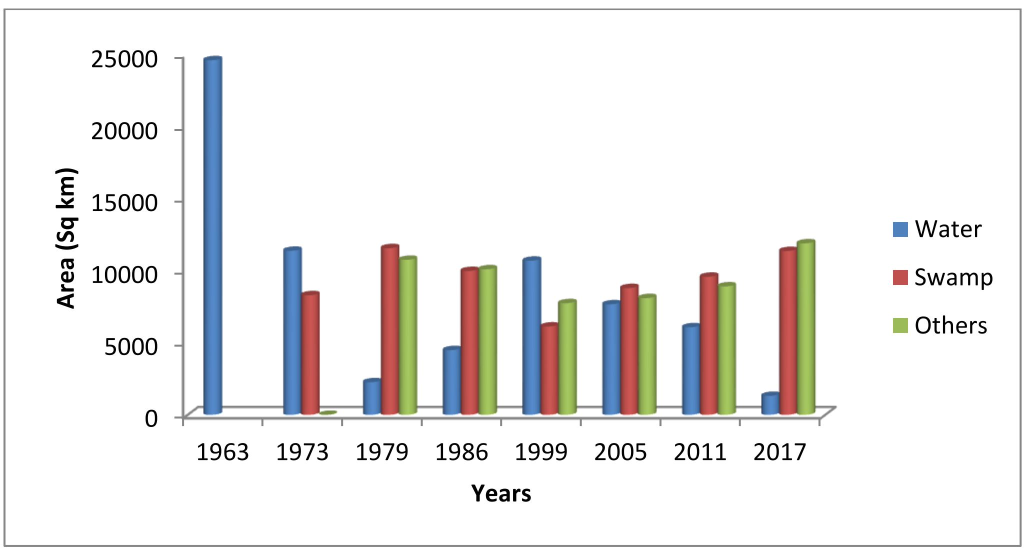


Figure 3: Area (km^2) of landcover of Lake Chad from 1963 – 2017

Table 2 and Fig. 3 revealed that in 1963, the entire lake area which covered 24,596.66 km^2, was filled with water, that is, no swamp or any other landcover type occupied any part of the lake except water. This finding is similar to previous reports on the lake size in 1963. For instance, Eric et al (2006) estimated the Lake size of the Lake in 1963 as 25,000 km^2, while Hassan (2012) reported 26,000 km^2 as the estimated size. Between 1963and 1973, the size of the water in the Lake decreased drastically from 100% to 46.31%. In the report of Lakepedia (2017), it was stated that when the lake was large, it is said to have had a surface area of 24,000 km^2. Table 2 and Fig. 3 also shows that the worst period of the shrinking lake was between 1973 and 1979 when water in the lake covered only 9.21% of the total land area, while "others" landcover types which principally include drylands increased from 19.91% in 1973 to 43.75% in 1979. Therefore, it can be concluded that the water in the Lake dropped drastically between 1973 and 1979. Though there was a slight increase in water in the lake between 1979 and 1986, but the increase is very minimal and water in the lake was still restricted to the southern basin (Fig.3f).

The fall of the lake water between 1973 and 1986, has also been reported by Lakepedia (2017) that the lake went from its normal size to small proportions in less than two years (between 1973 and 1975) which falls within the period of 1973 to 1979 in this study. Lakepedia (2017) concluded that the dramatic shrinking is the result of poor human management, improperly designed and used dams, overgrazing, irresponsible irrigation, deforestation, and a dry climate.

On dry climate, it was widely reported that there was a serious drought within this time of drastic reduction in the lake water (1973 – 1986). For instance, Ediang et al (2009) reported that according to Nichola (1980) in Goni, (2002) from the historical record there are records of droughts from 1680 – 1690, 1730 – 1760 and 1820 – 1840 in addition to the recent drought during the 1970s which was similar to the report of GIWA (2004) that the Lake Chad Basin has a history of drought episodes and for 40 years (1974-2004) there have been series of severe drought events. From the middle of the 1960s, rainfall started to drop intermittently but relentlessly until the big drought of 1972-1974. There was then a second occurrence of drought in 1983 to 1984. The effect of the droughts in 70s and that of the 1983-1984 in the Lake area reflected on the rapid fall of the size of the water in the lake in the 70s as well as early and mid-80s (Table.1).

Hansen (2017), observed that for more than a decade, severe droughts plagued the African Sahel, which resulted into the reduction in size of Lake Chad. She used satellite images to show the lake in 1973, 1976, and 1979; a time of great transition and decline in the lake extent. She concluded that:

- ♦ Around 1973, the lake was in a phase called "Normal Lake Chad"; a single body of water with an archipelago on the north side of the southern basin, with little vegetation around the lake at this stage.

- ♦ By 1976, the lake had transitioned to "Small Lake Chad." It had separated into two areas: the northern basin and the southern basin, divided by a shallow sill called the Great Barrier. In years when there was not enough inflow to spill over the barrier, the northern lobe stayed relatively dry, with increases in vegetation as permanent or seasonal marshes.

- ♦ Throughout the 1970s, water disappeared from the northern basin. Since then, water has come and gone from the northern lobe depending on the year and season. But the two lobes have never reconnected into a single lake.

- ♦ By the 1980s, the lake area reached a low of just 300 square kilometers (down from 22,000). The 1987 Landsat image shows the northern lobe drying out completely. Scientists proposed a new name for this driest phase of Lake Chad: "Dry Small Lake Chad". In this phase, the northern lobe stays dry for the entire year—a phenomenon that happened several times in the 1980s. The northern lobe was completely dry for at least a few months almost every year from the mid-1970s to late 1990s.

The four observations above were confirmed in this study. For instance, the 1973 classified image in Fig 2b revealed that the lake water extended from the north to the south. The small vegetation around the Lake reflected in Table 2 which shows that swamp (which is home of vegetation) in the Lake area in 1973 covered only 33.79% of the entire lake the lowest except that of the 1999 throughout the study period. Fig. 2d shows the clear separation of the lake water into north and south basins, while the Great Barrier was clearly conspicuous. Swamp in this period increased from 33.79% to 47.09%. The total disappearance of water in the northern basin was noticed in the 1979 and 1986 images in Figs 2d and 2f. The total disappearance of open water in the northern basin was noticed in the 1986 Landsat image.

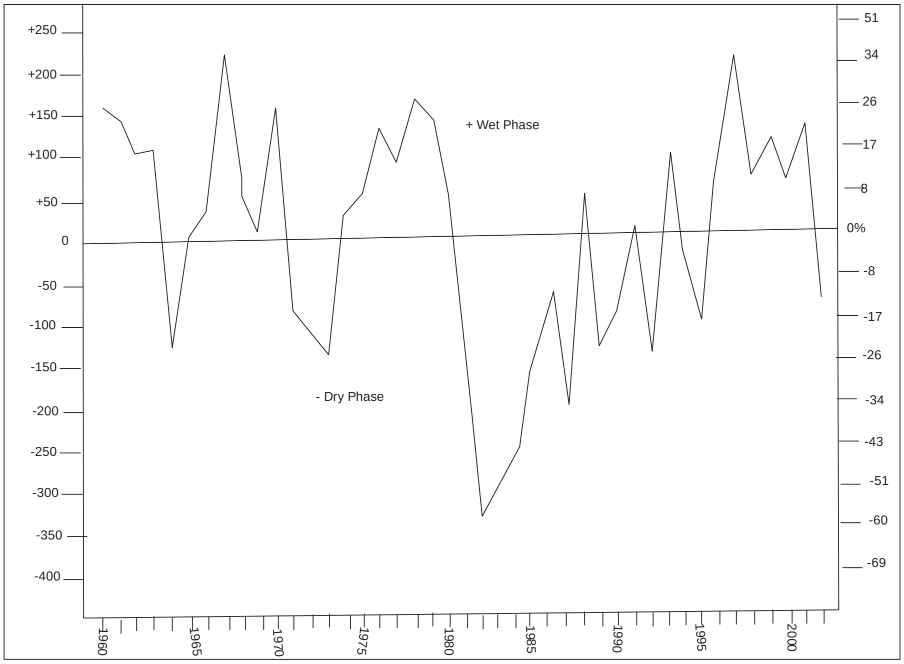
Another school of thought for the cause of the drastic fall in the area occupied by water between 1973 and 1986 was that of Okonkwo *et al.,* (2015) who opined that the late 1960s through the early 1970s marked a turning point in the response of Sahel rainfall to two of Earth's climate cycles—the Atlantic Multi-decadal Oscillation (AMO) and the El Niño Southern Oscillation (ENSO). These large-scale changes in atmospheric circulation affect precipitation in the Sahel. He concluded that in the early 1970s, the AMO was in its so-called "cold phase," meaning that oceanic and atmospheric circulation patterns shifted in such a way that the Sahel received less rain. He noted that the effect was strong enough to override short-lived, mild recoveries in lake levels during La Niña phases of ENSO, which typically bring wetter conditions. A transition to a strong El Niño in 1982–1983 only added to the dryness.

There was a high increase of Lake water between 1986 and 1999. The size of water in the Lake not only increased twice its size in 1986 (Table 2), but major parts of the lake that were hitherto dried (especially in the northern basin) were filled with water (Fig. 2h). The increase in the lake water area in 1999 over that of 1986 could be attributed to variation in annual rainfall as commented by L'Hôte *et al.*, (2002) that the 1990s was less dry than the 1970s and 1980s and there were wet years in 1994 and 1999. This finding was confirmed by Hansen (2017) that in 1999, some water filled northern Lake Chad year-round again, which according to Okonkwo *et al.,* (2015) a transition of the AMO from a cold (dry) phase to a warmer (wet) phase has played a role. They however, concluded that the recovery has been slow, and lake levels are still below the 1900–2010 mean and far below levels of the 1960s.

The continuous reduction of the Lake as from 2005 till 2017 could be a cumulative effect of regional and global climate change, desertification, poor water management practices and other human activities. For instance, Wade (2015) noted that global warming has contributed to the disappearance of not only Lake Chad, but to other Lakes in the world. He reported that Global warming is a phenomenon that is implicitly tied to all areas of the globe, and the desiccation of lakes is a trend that is not confined to Africa. The Dead Sea (a misnomer) has shrunk at an incredible rate due to heightened evaporation levels, and the local governments have planned to pump in ocean water in an attempt to replenish the hyper-saline lake. Poyang Lake in China has receded so much so that a 400-year old stone bridge has surfaced along the dried-up shores. These are just a handful of lakes that are at risk of disappearing due to global warming.

Another common reason for the lake reduction is the increased water diversion due to the construction of many dams in the hydrologically active sector of the Basin used to supply water for mainly irrigated cultivation which according to Oyebande (2001), stores all the water from the Tiga and Challawa Gorge dams, and releasing too little for downstream users. This has led to the recent pro-active opposition from the down-steam States of Yobe and Borno to the construction of the Kafin Zaki Dam on the Jama'are River (IUCN 2003), while GIWA (2004) noted that the largest upstream irrigation scheme at present is the Kano River Irrigation Project (KRIP), fed by the Tiga Dam completed in 1974, which has an active storage capacity of 1 400 million m^3.

Rainfall variability has been a clear evidence of drought resulting into rapid shrinking of the Lake as seen from rainfall variation of Maiduguri between 1960 and 2006 in Bukar *et al.,* (2009).



Source: Modified from Bukar et al., (2009)

Figure 4: Rainfall trends in Maiduguri from 1960 – 2002

There is a strong relationship between Fig.3 and Table 2. For instance, 1963 in Fig. 4 falls in a dry phase which was said to have marked the beginning of the Lake shrinkage (Hassan 2012). The 1973 period did not only fall in a dry phase but also fell in a period where there had been persistent droughts since 1970 – a period of four years (Fig.4), hence the drastic reduction of the Lake water to just 46.31% within a period of ten years, that is 1963-1973 (Table 2). The 1986 lake condition can be said to be the worst period with only 18.29% of the lake covered by water, which could be attributed to the consistent drought since 1980 (Fig. 4). There was a great improvement in the size of water in the Lake between 1986 and 1999 as revealed in Table.2. The improvement could be connected to the fact that the period fell in wet phase that began from 1995 (Fig. 4). Though, the rainfall variation in Fig. 4 did not extend beyond 2002, but the graph shows a downward trend of rainfall from 1997 and even entered dry phase in 2001. Therefore, it can be concluded that rainfall variability has great impact on the rate of shrinking of Lake Chad.

Lastly, the topography of the lake which has not been mentioned by many authors also has its little role in water retention within the Lake. The topography of the lake is represented in Figs 5a and 5b. While Fig.5a shows the DEM, that is, the elevation of the lake which ranged from 274m to 307m above the sea level. The lowest part of the lake with elevation ranging from 274m to 279m was found in Chad, Niger and Nigeria. Ordinarily, it is this part of the Lake that supposes to have more water than the other parts of the Lake. However, following the droughts in the 70s, water in this part of the lake dried up, and replenishing the region became very difficult because of the following reasons: the Great Barrier which separates this region from the southern part disallows water from flowing back into the region. Secondly Fig. 5b revealed that the lake is drifting towards the south east, making the region to depend on rainfall and inflow from other streams for survival. Furthermore, underground leakage of water could also be considered as reported by Rashid and Shaofeng (2018) that even though only a small percentage of the water leaks underground, it is also accompanied by heavy salt flows, escaping through underground passageways. Lastly, the lake's main inflow is the Chari River, which provides more than 90% of the lake's water, coming in from the Southern part, together with another contributor, Logone stream (Rashid and Shaofeng, 2018) while the main inflow from the north is the Kamadougu Yobe which has been dammed in so many places at the upstream. Hence, the northern part of the lake is bound to disappear before any other parts of the Lake.

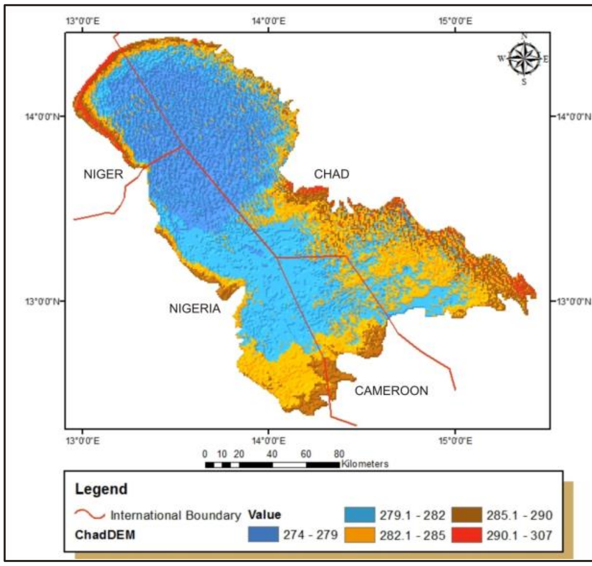


Fig. 5a. DEM of Lake Chad

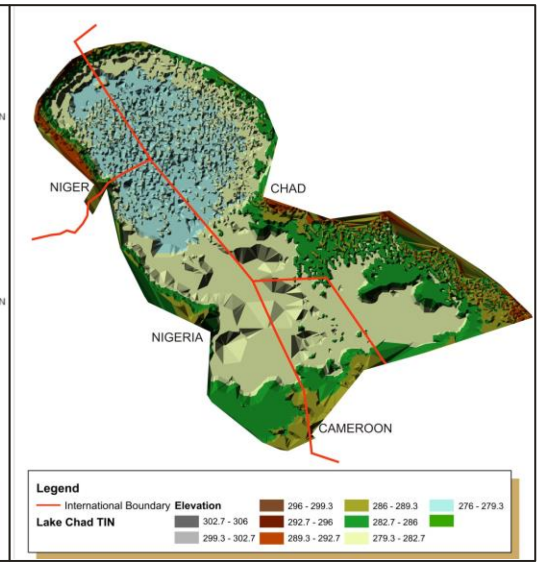


Fig. 5b. TIN map of Lake Chad

Figure 5b: The TIN map of the Lake. The advantage of a TIN map over DEM is that it shows areas of depressions. For instance, Fig 5b revealed the depressed parts of the lake and if compared to Figs 2, the retention of water was more within the depressions than the other areas within the Lake.

Assessments of the Lake shrinkage in each riparian country

The rate of shrinkage of Lake Chad in each of the riparian countries: Chad, Cameroon, Niger and Nigeria were assessed in this section. The result of the calculation of the area coverage of each landcover classes is also presented in Table 3.

Table 3 revealed that open water is generally reducing in size in all the four riparian countries. The period between 1979 and 1986 was also seen as the period when the four countries recorded very low open water, with Niger recording zero, the rate of disappearance of the lake water differs from one country to another. While the figures in Table 3 are necessary especially for reference sake, Figs 6a -6d are graphs showing the disappearance of open water in each of the riparian countries. Figs 6a –d revealed that though, the size of open water in Cameroon was not as large as those of Nigeria and Chad, but open water in Cameroon was discovered to be more stable than in the other countries as shown in Fig. 6a. It is the only country that as at 2017, open water of the lake within the country covers more than 500km^2 when other countries recorded close to zero. Fig. 6a-d also revealed that Niger was worst hit by the lake shrinkage because since 1973 open water of the lake within the country did not reach 1000 km^2 and year 2017 recorded only 3.89km^2 of open water. Between 1986 and 2011, Nigeria had the highest land covered by water within the Lake, but in 2017 the size of the open water was less than 100km^2.

Table 3: Rate of shrinking Lake Chad in each of the riparian countries

	1963 AREA (km^2)	***1973 AREA (km^2)***	***1979 AREA (km^2)***	***1986 AREA (km^2)***	***1999 AREA (km^2)***	***2005 AREA (km^2)***	***2011 AREA (km^2)***	***2017 AREA (km^2)***
CAMEROUN								
LAKE	2806.13 ***(100%)***	1513.46 *(53.93%)*	930.47 (33.16%)	1281.42 *(45.67%)*	1218.13 *(43.41%)*	1555.66 *(55.44%)*	1078.50 *(38.43%)*	724.87 (25.83%)
SWAMPS	-	879.69 *(31.35%)*	1505.69 (53.66%)	1205.61 *(42.96%)*	1304.24 *(46.48%)*	1122.61 (40.01%)	1485.05 (52.92%)	1493.48 (53.22%)
OTHERS	-	412.98 *(14.72%)*	369.97 (13.18%)	319.10 *(11.37%)*	283.76 *(10.11%)*	127.86 (4.56%)	242.58 (8.65%)	587.78 (20.95%)
TOTAL		***2806.13***	***2806.13***	***2806.13***	***2806.13***	***2806.13***	***2806.13***	***2806.13***
CHAD								
LAKE	12791.81 ***(100%)***	4049.45 *(31.66%)*	964.85 (7.54%)	2800.40 *(21.89%)*	4653.48 *(36.38%)*	2801.01 *(21.90%)*	2113.32 *(16.52%)*	493.83 (3.86%)
SWAMPS	-	5678.95 *(44.40%)*	4408.12 (34.46%)	2850.75 *(22.29%)*	2596.23 *(20.30%)*	3260.53 (25.49%)	4012.55 (31.37%)	4397.74 (34.38%)
OTHERS	-	3063.41 *(23.95%)*	7418.84 (58.00%)	7140.66 *(55.82%)*	5542.1 (43.33%)	6730.27 (52.61%)	6665.94 (52.11%)	7900.24 (61.76%)
TOTAL		***12791.81***	***12791.81***	***12791.81***	***12791.81***	***12791.81***	***12791.81***	***12791.81***
NIGER								
LAKE	2335.26 ***(100%)***	1421.01 *(60.85%)*	0 (0%)	22.41 *(0.96%)*	913.27 (39.11%)	284.17 (12.17%)	130.08 (5.57%)	3.89 (0.17%)
SWAMPS	-	320.50 *(13.72%)*	593.51 (25.42%)	888.67 *(38.05%)*	69.69 (2.98%)	1162.43 (49.78%)	843.65 (36.13%)	475.17 (20.35%)
OTHERS	-	593.75 *(25.43%)*	1741.75 (74.58%)	1424.18 *(60.99%)*	1352.3 (57.91%)	888.66 (38.08%)	1361.53 (58.36%)	1856.2 (79.49%)
TOTAL		***2335.26***	***2335.26***	***2335.26***	***2335.26***	***2335.26***	***2335.26***	***2335.26***
NIGERIA								
LAKE	6663.46 ***(100%)***	4405.69 *(66.12%)*	368.98 (5.54%)	394.09 *(5.91%)*	3915.45 *(58.76%)*	3040.38 *(45.63%)*	2762.47 *(41.46%)*	94.14 (1.41%)
SWAMPS	-	1431.66 *(21.49%)*	5063.15 (75.99%)	5045.20 *(75.71%)*	2166.87 *(32.52%)*	3260.53 *(48.93%)*	3249.08 *(48.76%)*	5007.23 (75.14%)
OTHERS	-	826.11 *(12.40%)*	1231.33 (18.48%)	1224.17 *(18.37%)*	581.14 *(8.72%)*	362.55 *(5.44%)*	651.91 *(9.78%)*	1562.09 (23.44%)
TOTAL		***6663.46***	***6663.46***	***6663.46***	***6663.46***	***6663.46***	***6663.46***	***6663.46***
G/TOTAL	**24596.66**	**24596.66**	**24596.66**	**24596.66**	**24596.66**	**24596.66**	**24596.66**	***24596.66***

The recent loss of lake water in Chad, Niger and Nigeria could be attributed to some human activities around the lake in conjunction with the effects of the natural factors such as climate change and desertification (Hansen 2017). Assessing the effect of irrigation, Coe and Foley (2010) reported that a 30 per cent decrease took place in the lake between 1966 and 1975 and irrigation accounted for five per cent of that decrease, with drier conditions accounting for the rest. They concluded that irrigation demands increased four folds between 1983 and 1994, accounting for 50 per cent of the additional decrease in the size of the lake. Baga Polder Project which was established for irrigation purposes around the lake in Nigeria is a good example of irrigation program in and around the lake. However, Wood and Yapi (2004) on the project, reported that the Baga Polder Project, had a goal of irrigating 20 000 ha to produce 26 000 tons of wheat, 28 000 tons of maize and 14 000 tons of groundnuts annually. However, by 1996 only 1 000 ha were under irrigation and now the project concentrates on farming the receding lake waters. The original polder that was constructed for irrigation purposes is now several kilometers from the lake shore.

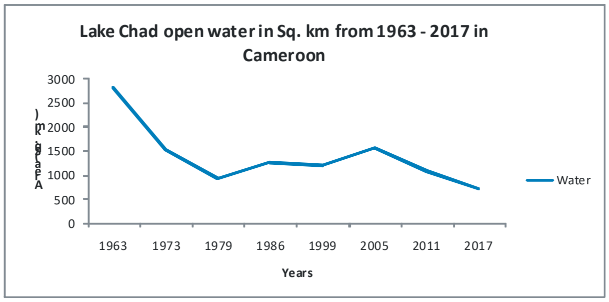


Fig. 6a. Lake Chad open Water in Cameroon

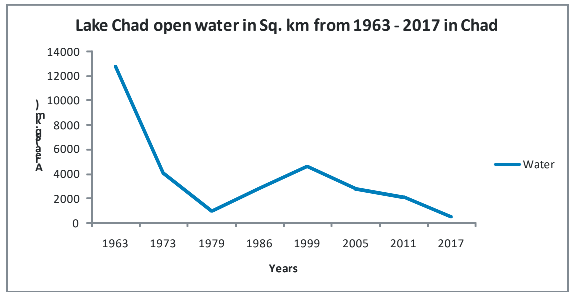


Fig. 6b. Lake Chad open Water in Chad

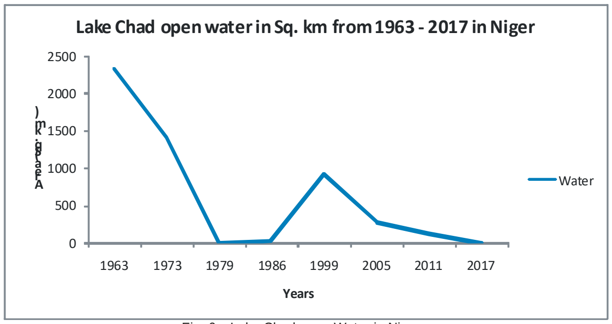


Fig. 6c. Lake Chad open Water in Niger

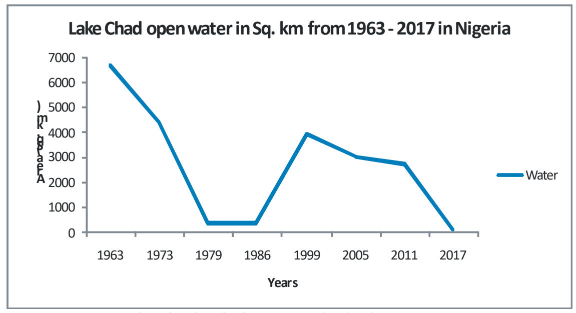


Fig. 6d. Lake Chad open Water in Nigeria

Groundwater draw-downs of several tens of meters have been reported in the Maiduguri area of Nigeria due to the over-pumping of water (Isiorho *et al.*, 2000), The droughts of the 1980s triggered the mass drilling of 537 wash boreholes between 1985 and 1989 (CBDA 1990 in Isiorho *et al.*, 2000). This free flow of water is very inefficient and results in vast amounts of water being lost due to the high rates of evaporation in the region (Isiorho *et al.*, 2000). Water points at Ala near Marte (Nigeria) monitored on a routine basis by the Lake Chad Basin Commission, have shown a sharp decline of about 4.5 m within a period of one year attributable to the general decline in the artesian pressure within the Basin.

Another major factor for the rapid shrinking of the Lake is the construction of dams on the upstream as Neiland & Béné (2003) reported that during the 1970s and early 1980s around 20 reservoir dams were built on the Hadejia river system, which negatively affected the hydrology of the Yobe River, the only inflowing river into Lake Chad's northern pool. The dams control about 80% of the total run-off of the Hadejia River. The River used to supply large amounts of water to the Lake but has now been reduced to an insignificant flow of 1% since the construction of the dams and pre-drought years,

The existence of more water in the Lake within Cameroon than in other countries might not only be due to the aforementioned factors or the geographical location of the country following the drifting lake towards the south-eastern part where the Cameroon is lucky to have been located, but also due to some stabilizing programs that are being carried out by the country. For instance, Wood and Yapi (2004) reported that Cameroon has been doing so much to stabilize the Lake with several projects among which is Maroua project (Fig 6). The location of the project is Maroua, Northern Cameroon, with a population of about 100,000 people, a mean annual rainfall of about 700 mm/year and an altitude of about 300 m above sea level. The pre-project survey estimated that some 13% of the total land area of the Maroua region was degraded due mainly to mechanized cotton mono-cropping by hundreds of local farmers with fertilizer inputs supplied by the cotton industry (SODECOTON). Other causes were shifting cultivation; overgrazing; over-harvesting of fuel wood; uncontrolled forest fires, and high population pressure.

Source: Wood and Yapi (2004)

Figure 7: Reclamation of the degraded land around Lake Chad in Cameroon

Assessment of area coverage of open Lake Water (1963-2007)

The area coverage of the lake water in each of the four riparian countries from 1963 to 2007 – a period of forty nine years is presented in Table 2. The table revealed that the lake water has long left the shores of Niger and Nigeria, while little portion of 2.0% and 2.02% are still remaining in Cameroon and Chad Republics respectively. According to GIWA (2004) receding waters during the 1970s caused Lake Chad to separate into two pools with the “Great Barrier” between them. Since the 1970s the northern pool has only held some temporary waters, and has consequently impeded access for Nigeria and Niger to the open waters of the Lake. No wonder the two countries (Niger and Nigeria which are located in the northern part of the Lake) were the first casualties of the Lake’s water loss. Nicholson (1988) in Le Barbé & Lebel (1997) asserted that recent scientific research by Coe and Foley’s climatic data analysis (2001) have demonstrated that rainfall events in particular have reduced and in turn led to drought and increasing desertification especially in the northern part of the Lake. Desertification in the arid northern regions of the basin will continue to cause a southward migration towards the Lake and the southern river basins, and consequently increase the pressure placed on these habitats. The most obvious indicator of declining freshwater availability has been the dramatic decrease in the surface area and volume of Lake Chad.

Conclusion

It is evidenced from this paper that Lake Chad is seriously disappearing in all the four riparian countries of the Lake. It is also revealed from the study that as at 2017, only small proportions of the Lake exists in Niger and Nigeria. The existence of little water in Cameroon and Chad seem to be a matter of time as the lake that is drifting south-east wards may soon seize to be in existence in any of the four countries. The causes of the rapid shrinking of the Lake has long been a debate among various authors, while some attribute the disappearance to human activities, others strongly believed it to be more of natural than human factors. However, the issue now is not “why”, but what can be done to revive and stabilize the Lake and make the water of the lake areas that have been lost to other landcover types, return. The concerned are aware of the need for the urgent revitalization of the lake and efforts are now being made to unit as an entity to save the Lake. Recently, specifically on February 28, 2018, the leaders of Nigeria, Niger, Chad, Cameroon, the Central African Republic and Gabon, joined by experts and political stakeholders on February 28, 2018, concluded an international conference in Abuja, Nigeria on saving Lake Chad from drying up. The International Conference on Lake Chad was organized by Nigeria and the Lake Chad Basin Commission with the support of the United Nations Educational, Scientific and Cultural Organization, UNESCO. The theme was "Saving Lake Chad to revive the basin's ecosystem for sustainable livelihoods, security and development." to implement *Transqua*, a massive project to refill Lake Chad with water from River Congo by dredging canals. The unity of all the concerned countries to put their resources, technology, ideas, expertize and influence from the external world is the only way forward to save the lake as it will very difficult for the countries to achieve this individually.

Recommendations

The climatic conditions of the lake area should be closely monitored and programs/projects that will minimize the effects of climate change on the environment should be put in place. For instance, previous plans of revitalizing the lake such as the 1960s plan of diversion of the river Ubangi into Lake

Chad, the 1980s and 1990s proposed inter-basin water transfer schemes by Nigerians Engineers and Italian *Bonifica Transaqua* Scheme which was also proposed by the Lake Chad Basin Commission (LCBC) in March 2008 and which was committed by the Heads of State of the LCBC member countries in April 2008 when the LCBC advertised a request for proposals for a world Bank-funded feasibility study (Hassan 2012), should all be revisited and step-up the efforts to achieving the goals.

Human activities such as damming of upstream rivers, irrigation projects especially in the northern part, which may have negative effects on the Lake should be seriously controlled.

All the concerned countries should urgently pull their resources together to save the lake from being "once upon a time" Lake.

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